University of Southern Queensland

Faculty of Health, Engineering and Sciences

The development of a Light Weight Composite Conveyor Belt Idler Roller

A dissertation submitted by

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ENG4111 Research Project Part I

ENG4112 Research Project Part II

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Abstract

High incidence of injuries caused by the manual handling of heavy idler rollers is a major concern for the Australian mining industry. Consequently, major mining industry stakeholders called for the development of light weight idler rollers. As a result this project was designed to develop a light weight idler roller using pultruded continuous glass fibre, vinyl ester composite circular hollow section.

Current literature on the subject highlighted the need for non-ferrous light weight idler rollers but offers no real solution. A rigorous test regime, including physical static and dynamic testing in conjunction with finite element analysis, was used to analyse a designed light weight composite prototype idler roller.

The main empirical finding of the project was the possibility of producing shaftless lightweight composite idler rollers for use in the mining industry. The conceptual shaftless composite rollers are estimated to be 40-60% lighter than traditional steel rollers. The light weight of the concept idler roller, combined with the possibility of manufacturing idler rollers that are dimensionally suitable for mining, addressed the concerns of the Australian mining industry and answered the call to develop a light weight conveyor belt idler roller.

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Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

BARNARD JANSE VAN RENSBURG

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Signature

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Date

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This thesis was produced using Microsoft Word 2010

Barnard Janse van Rensburg

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Nomenclature and acronyms

ATM	Accelerated Testing Method
ASTM	American Society for Testing and Materials
BMA	BHP Billiton Mitsubishi Alliance
BMG	Bearing Man Group
CFT	Composite Fibre Technologies
CHS	Circular Hollow Section
CIDECT	Dévelopement et l'Etude de la Construction Tubulaire
CII	Conveyor Innovations International
CMW	Coal Mine Worker
DNRM	Department of Natural Resources and Mines
EPDM	Ethylene Propylene Diene Monomer
FEA	Finite Element Analyses
FEM	Finite Element Method
FRP	Fibre Reinforced Plastic
GOAF	Ground Opposite Advancing Facing
HDPE	High Density Polyethylene
ISO	International Standard Organisation
JSEA	Job Safety and Environmental Analysis
KWHSSA	Key Work Health and Safety Statistics, Australia
LTI	Lost Time Injury
MIG	Metal Inert Gas
Mt	Million tonnes
MW	MegaWatts
OH&S	Occupational Health and Safety
OHS	Occupational Health and Safety

PDF	Portable Document Format
PPE	Personal Protective Equipment
PU	Polyurethane
PVC	Polyvinyl Chloride
RHS	Rectangular Hollow Section
RPM	Revolutions per Minute
SHS	Square Hollow Section
SWA	Safe Work Australia
TPH	Tonnes per Hour
UHMW-PE	Ultra-High-Molecular-Weight Polyethylene
WCFT	Wagners Composite Fibre Technologies
WHS	Workplace Health and Safety
WI	Work Instruction

Chapter 1

Introduction

The purpose of this chapter is to describe the project background, contextualise the industry from where this proposition originates, outline the project's direction and highlight the research objectives of the project. This brief but comprehensive introduction is given to provide the reader with the basic information that applies to the author's thesis, and to add a basic circumstantial framework to the author's work.

1.1 Project topic

The development of a light weight composite conveyor belt idler roller for use in the mining industry

The primary purpose of this project was to investigate the prospect of a light weight conveyor belt idler roller constructed from pultruded continuous glass fibre, vinyl ester composite as produced by Wagners Composite Fibre Technologies (CFT).

1.2 Project background

A large contributor to the Australian economy is the processing of the abundance of natural mineral resources such as iron ore, nickel, gold, uranium and coal. Mining is a significant primary industry in Australia and can be defined as the act or process of extracting minerals by means of excavation or creating subterranean extraction passages.

1.2.1 Queensland coal mining operations

The Queensland Department of Natural Resources and Mines (2012) released a paper stating that 'Queensland has a rich endowment of high quality coal resources, with more than 34 billion tonnes (raw coal in-situ) having been identified by drilling operations. They have identified resources of coking coal which amount to approximately 8.7 billion tonnes, of which about 4 billion tonnes are suitable for open cut mining'.

The annual coal production of 180 million tonnes (Mt) is mined by 43 open cut mines producing 154 Mt and 13 underground mines adding a further 26 Mt (Queensland Department of Natural Resources and Mines 2012). The Queensland coal industry exports approximately 116 million tonnes of metallurgical grade coal and 46 million tonnes of thermal coal per annum (Queensland Department of Natural Resources and Mines 2012).

Open cut mines are more common within Australia due to the operating costs of open cut mines being cheaper than underground mining. However, over half of the identified resources are suitable for underground mining. Therefore, an increase in the number of underground mines is expected.

1.2.1.1 Open cut mining

Open cut mining, also known as open pit or opencast mining, primarily mine by excavating from the surface. Rock covering the coal seam, the overburden, is blasted and removed by draglines, shovels and dump trucks. Open cut mines can reach depths exceeding 100m with modern equipment and technologies. Figure 1-1 illustrates a typical opencast mining pit.

Figure 1-1: BMA Goonyella Riverside open cut mine

1.2.1.2 Underground mining - Longwall mining

According to the Australian Department of Resources, Energy and Tourism geoscience division (2012) underground mining in Australia is usually performed by either the bord and pillar or longwall method.

In bord and pillar mining, coal is extracted through a series of parallel tunnels. Bords, cut at right angles by another tunnel series called cut-throughs, leave blocks of coal, known as pillars (Geoscience Australia 2012). In comparison, longwall techniques result in higher productivity and coal recovery rates due to the total extraction of larger blocks of coal whilst also allowing the mine roof to collapse behind the working face (Geoscience Australia, 2012). Longwall mines are created by driving two parallel underground roadways, known as headings, over 300m or more part, into the coal seam from the main travel road. The length of the block is determined by the individual mine requirements and geological conditions. The two headings are connected by a perpendicular heading called the installation road, as illustrated in Figure 1-2.

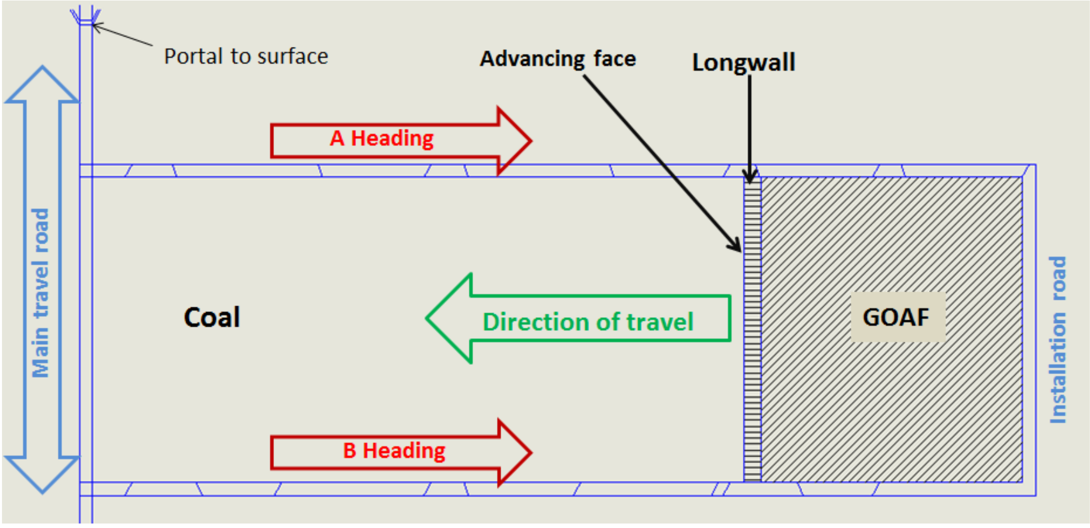

Figure 1-2: Simple longwall mine plan

A wall of hydraulic chocks is used to keep the roof from collapsing while a shearer is used to dig into the advancing face, as seen in Figure 1-3 (Joy Global 2012).

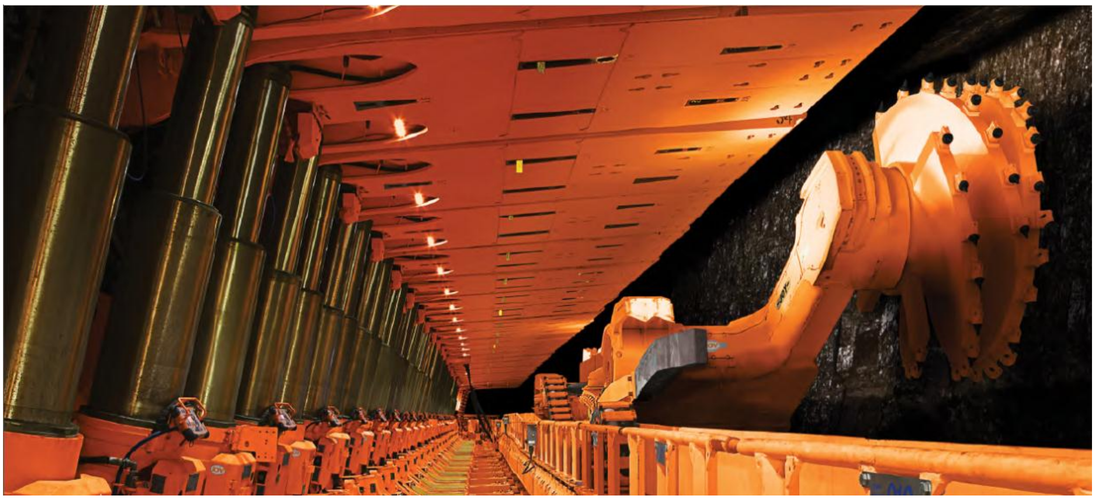

Figure 1-3: Longwall shearer and chocks assembly (Joy Global 2012)

As the shearer advances the chocks follow in a snakelike pattern and the roof is allowed to collapse behind the chocks. The collapsed material is known as '*ground opposite advancing face*' more commonly referred to as GOAF.

As the longwall advances towards the main travel road, service lines such as water, electricity and the conveyor belts need to be shortened because the distance between longwall and the travel road diminishes.

1.2.2 Bulk material handling

Bulk material handling is the engineering field that predominantly deals with moving large amounts of dry material from one location to another, often from the mine site to a processing plant or from a processing facility to a transport mode such as ships or trains.

Today's practises can be traced back through history. An early example of bulk material handling is a shaduf, used by ancient Egyptians to irrigate cultivations with water from the Nile River. Peterson (2006) explains that early modern bulk material handling started in the late 1700s, where human powered bucket conveyors or lifts we use to stack ships with primary produce. In 1804 the first steam powered conveyor was commissioned in a bakery as a time saving device, using cloth and leather as belting material (Todd 2008).

The first mining conveyor was invented in 1905 by Irish-born engineer and inventor, Richard Sutcliffe (Todd 2008). It was also the world's first underground conveyor and the conveyor belt revolutionised the mining industry forever. The belt was made with cotton and rubber panels. Bulk material handling became very popular during World War II with the development of synthetic materials for belting (Peterson 2006), mainly due to the scarcity of natural materials such as cotton.

Today, bulk material handling systems incorporate a variety of machines such as screw conveyors or augers, stackers, reclaimers, rail cars, bucket elevators and the most common, troughed belt conveyors (McGuire 2009).

1.2.3 Conveyors

The Australian resource sector uses a large variety of high-capacity conveyors, with some systems boasting a 4 MW drive configuration with conveyor lengths in excess of 9 km and a rating of 5000 Tonnes per Hour (TPH) (ACE 2011). The basic definition of a conveyor belt is a system that contains two or more pulleys with the continuous loop of material, called the conveyor belt, supported by structural members that hold the pulleys in place, called conveyor structure (McGuire 2009).

Belting materials vary significantly depending on the application. Some of the materials commonly used includes cotton, canvas, Ethylene Propylene Diene Monomer (EPDM), leather, neoprene, nylon, polyester, polyurethane (PU), urethane, Polyvinyl Chloride (PVC), rubber, silicone and steel (Peterson 2006).

1.2.3.1 Conveyor belt anatomy

Figure 1-4 illustrates the basic conveyor components. The head pulley, more commonly known as the drive head, is responsible for driving the conveyor. The drive head uses friction to drive the conveyor belt and sufficient friction is generated by tensioning the belt with take up weights.

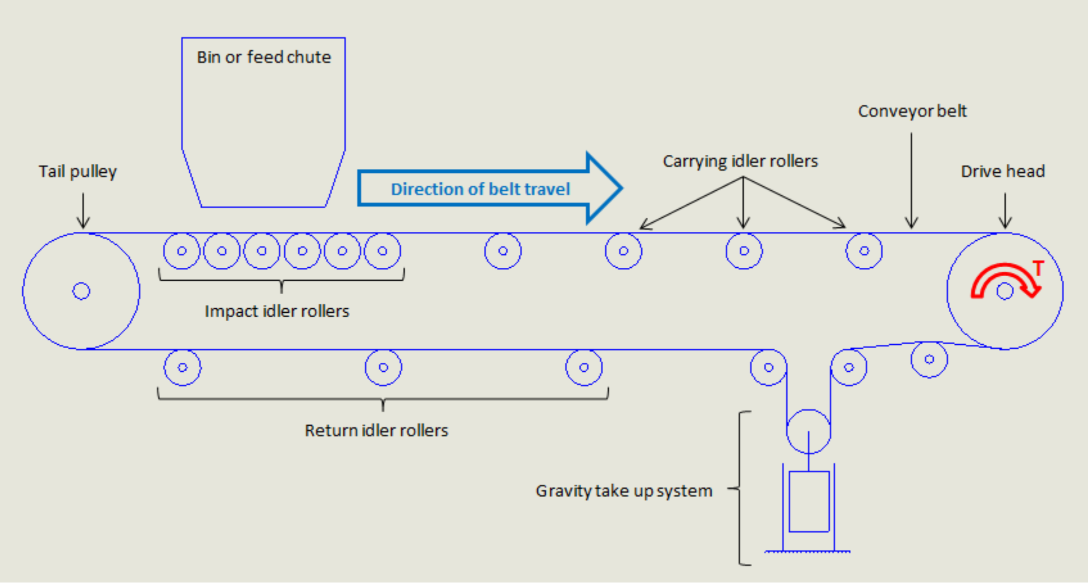

Figure 1-4: Conveyor Anatomy

Generally rollers between the drive head and tail pulley are known as idler rollers, with sub categorisation. The rollers directly below the feed chute (load point) are known as impact rollers. Impact rollers perform a very specific task with high intensity workloads.

Weight carrying rollers are known as carrying idlers or simply idler rollers. Rollers that support the belt on the reverse travel direction are known as returned idlers. Carrying idlers and returned idlers are the same rollers; however, the idler spacing is much larger for the return idlers as the load is only the weight of the belt itself. This project focused on the development of light weight composite carrying and return idler rollers.

1.3 Justification

This project emerged as a result of a call from Queensland mining giant, BHP Mitsubishi Alliance (BMA), to the conveyor industry. BMA was interested in finding a way of reducing the high number of manual handling related injuries that occur as a result of constructing, maintaining and disassembling conveyor systems.

The problem with traditional steel idler rollers, particularly with large gauge belts, is that individual rollers can weigh in excess of 20 kg. The various arrangements of conveyor structure and idler roller fixings can exacerbate this problem exponentially. Figure 1-5 and Figure 1-6 show two extreme examples of particularly challenging circumstances that would be encountered during construction, maintenance and disassembly of these conveyors.

Figure 1-5: Stacker tower

Figure 1-6: Underground conveyor

Conveyor stackers often tower hundreds of metres above the ground. The location and sheer height of these towers often mean that the conveyor is only accessible by the stairways and walkways constructed alongside the conveyor system. Therefore rollers must be manually handled by workers to their positions on the conveyor structure. This task often results in having to face obstacles such as steep ramps, stairs and gates.

Underground conveyor structures are often hung from the roof and due to a lack of space in the underground passages, they do not allow for any mechanical help. Therefore, people have to carry the rollers to their positions as well as manoeuvre the rollers into their individual fixtures. Structures often hang above head height and ladders are used to reach these overhead structures. This poses two significant problems: one, the person installing the roller has to carry the large heavy roller up the ladder and two, manoeuvring the roller often requires awkward body positions to be undertaken whilst on a ladder while the roller is placed in position. Figure 1-7 is an example of a suspended roller assembly.

Figure 1-7: Suspended roller assembly (Sandvik 2008)

This assembly is widely used in BMA Broadmeadow, Crinum and many other Australian underground coal mines and is used in conjunction with longwall operations. Over and above the normal challenges faced by underground conveyor structure, this suspended roller assembly arrangement is the worst, with assemblies weighing over 60 kg. The need for suspended arrangement idlers is justified by the nature of longwall operations where the conveyors structure needs to be removed very swiftly as the longwall advances. Therefore a more suitable system must be developed to help overcome the challenges posed by these circumstances.

1.3.1 Hierarchy of control

Justifying the project using engineering hierarchy of control according to ISO 9001 – Quality systems:

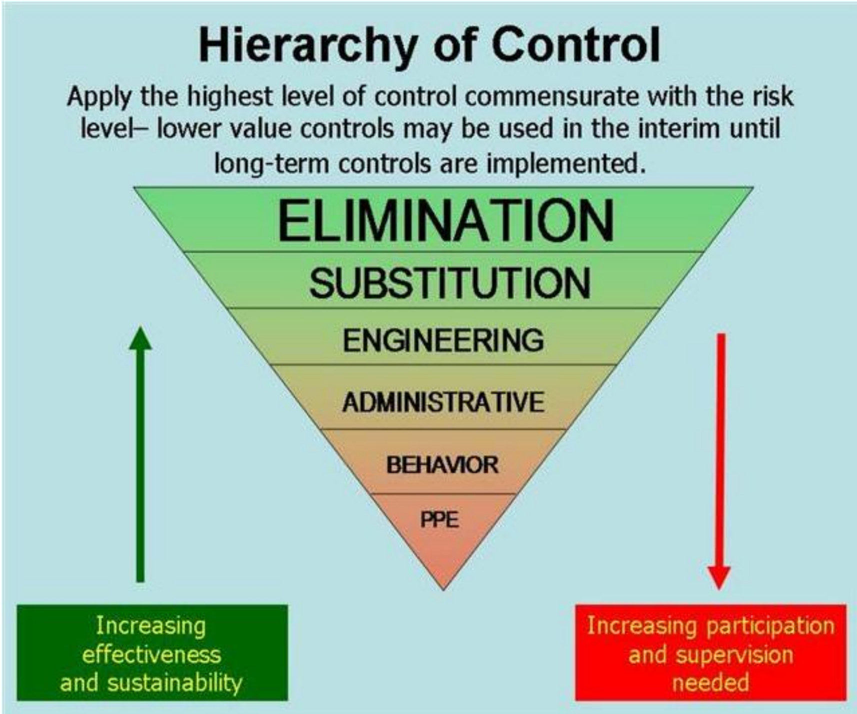

Figure 1-8: Hierarchy of control (Quality Systems Toolbox 2013)

The top three control strategies (elimination, substitution and engineering) are known as engineering controls and should be implemented, where possible, because they are less subject to human failure (Quality Systems Toolbox, 2013).

- Elimination is the best control measure; however, elimination is not possible in the coal industry especially underground mining. The coal must be transported from the mine to the mode of transport.
- Substituting conveyors with trucks is possible. This would be a very expensive change and the increased vehicular traffic may introduce new risks of significant magnitude.
- Engineering control can be introduced by making changes to the equipment to reduce the hazards. This is a suitable control. Engineering new rollers with a significant reduction in weight can substantially reduce the hazard of manual handling injuries.

1.3.2 Conclusion

The issues discussed in the previous section highlight the need for an alternative roller that will ensure safer working conditions for workers interacting with conveyers. This project was primarily concerned with the development of a light weight composite material roller that will fulfil these requirements.

1.4 Composite materials

A composite material is created when two or more distinct materials, that do not merge, combine to create a superior and unique material with properties resulting from the combination of their individual attributes (Johnson 2013).

Johnson (2013) suggests that by combining mud and straw, the ancient Egyptians produced their own primitive composites that they used to create strong buildings. The success of the conqueror Genghis Khan, during the 1200s, can be attributed to the military dominance given by the powerful and accurate composite Mongolian bows, which were constructed using bamboo, sinew and animal horn.

However, modern composites owes its origins to salesperson Owens Corning that originally developed fibre reinforced polymers for use as insulation material in 1935 (Strong 1995). The anisotropic nature of the fibrous material was soon discovered and the development of structural products followed shortly.

Composite materials have proven to be the prime choice in extreme performance applications, such as the aerospace and nautical industries, as well as high corrosion environments. Attributed to the benefits of high strength to low weight ratio, extreme corrosion resistance and long service life, composite materials' acceptance by engineers has greatly increased in recent years.

1.5 Wagners Composite Fibre Technologies

Wagners CFT fabricates structural grade composite sections, both Rectangular Hollow Section (RHS) and Circular Hollow Section (CHS), using continuous glass fibre and vinyl ester resin in a pultrusion process. Wagners CFT is a world leader in research and development. They design and implement Fibre Reinforced Plastic (FRP) solution for specialty applications reaching into areas such as marine infrastructure, road infrastructure, timber bridge rehabilitation, pedestrian infrastructure and electrical industry solutions.

Wagners CFT has pioneered the use of structural composite materials to manufacture the world's first composite road bridge in a public road network. Wagners strive to be world leaders in structural applications of composites and has a strong focus on research and product development with respect to new FRP products. The underlying support to new product research sets the scene for Wagners CFT's involvement in the development of light weight composite conveyor belt idler rollers.

All Wagners CFT sections are pultruded continuous glass fibre, vinyl ester composites. This poses a significant challenge with regards to idler roller design. Traditional idler rollers are moulded or die cast with sections included for bearing houses. Continuously pultruded sections do not have this capability as the process only produces the CHS. The design must incorporate bearing housing location and method of attachment.

1.6 Project Aims and Objectives

The deliverables of this project have been carefully composed to fulfil the requirements of ENG4111/4112, and because it is an industry based project, also the objectives of Wagners CFT. The research aims and objectives are an extension of the project specification that can be found in appendix A.

This project endeavours to investigate the prospect of developing a light weight composite conveyor belt idler roller for use in the mining industry constructed from pultruded glass fibre vinyl ester composite as produced by Wagners CFT.

The project objectives are to:

- Research and investigate current idler rollers technologies used in conveyor belts
- Define Wagners CFT CHS composite and determine required section properties
- Review literature pertaining to composite's performance in fatigue
- Investigate issues with conveyor belt systems in the Australian mining industry with particular interest in conveyor belt system related injuries during installation, maintenance and decommissioning through case studies and Workplace Health and Safety statistics
- Define problem and need for research
- Develop methodology for the development of a light weight composite idler roller
- Conceptually design possible idler rollers and choose prototype design. Substantiate prototype design by recognised mechanical engineering methods
- Build prototype

- Evaluate design. This will be achieved by mechanical laboratory static and fatigue testing, mathematical calculations and Finite Element Analysis
- Analyse results from various tests and determine suitability of belt idler rollers shell constructed from pultruded glass fibre vinyl ester composite
- Conceptualise final design
- Make recommendations and suggest further studies.

1.7 Concluding remarks

This chapter introduced the project topic and defined project aims and objectives. The introduction described the industry and project background. A comprehensive literature review was conducted to highlight specific background information and develop technical knowledge required to proceed with the construction of a methodology.

Chapter 2

Literature Review

A review of appropriate literature pertaining to modern conveyors systems including current non-ferrous idler rollers, composite materials and Occupational Health and Safety (OHS) is presented and discussed in this chapter.

2.1 Conveyors

The most common material handling conveyor in use today is the belt conveyor (McGuire 2009). Belt conveyors are the least expensive powered conveyor (ACE 2011) with the capability and capacity to carry almost all raw materials from grain to iron ore (ACE 2011). Belt conveyors generally carry materials over long distances and use anywhere from one to ten drive stations depending on the length (McGuire 2009). For the purpose of this project, literature with respect to current conveyor technologies, including the common ferrous idler rollers and roller design methodologies, was reviewed.

2.1.1 Current conveyor technologies

There is a heavy reliance on conveyor technology to increase productivity across the entire mining industry. McGuire (2009) describes the broad spectrum of possible conveyor options that include table top chain conveyors, static and powered conveyors. According to McGuire (2009), the belt conveyor is the world's most versatile and widely used conveyor and has experienced some drastic developments and specialisations over the last decade. Belt conveyors may come in a variety of configurations such as flat belt, curved belt, cleated belt, troughed belt, as shown in Figure 2-1, and pipe conveyor, depicted in Figure 2-2 (McGuire 2009). All variations of configurations require idler rollers to carry the load and give the belt the required shape. The following illustrations shows a simple conveyor type such as troughed conveyors, Figure 2-1,and a complex conveyor type such as a pipe conveyor, Figure 2-2.

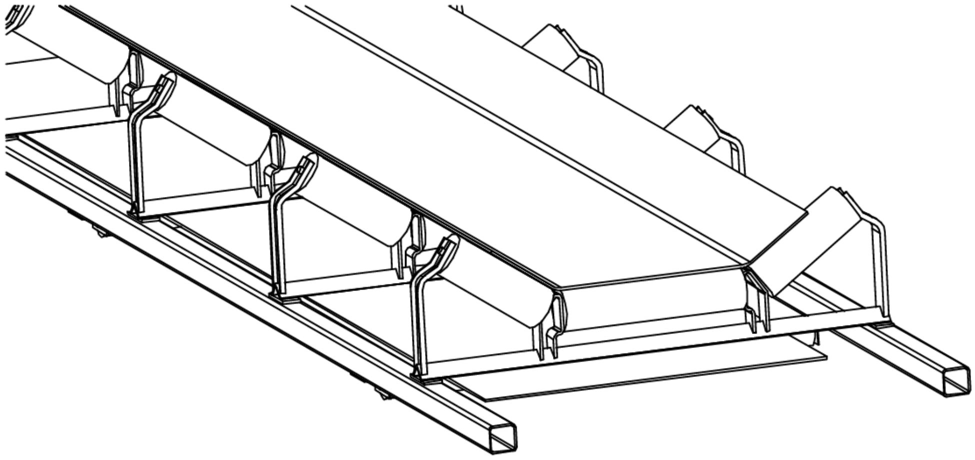

Figure 2-1: Simplified troughed belt conveyor (McGuire 2009, p. 63)

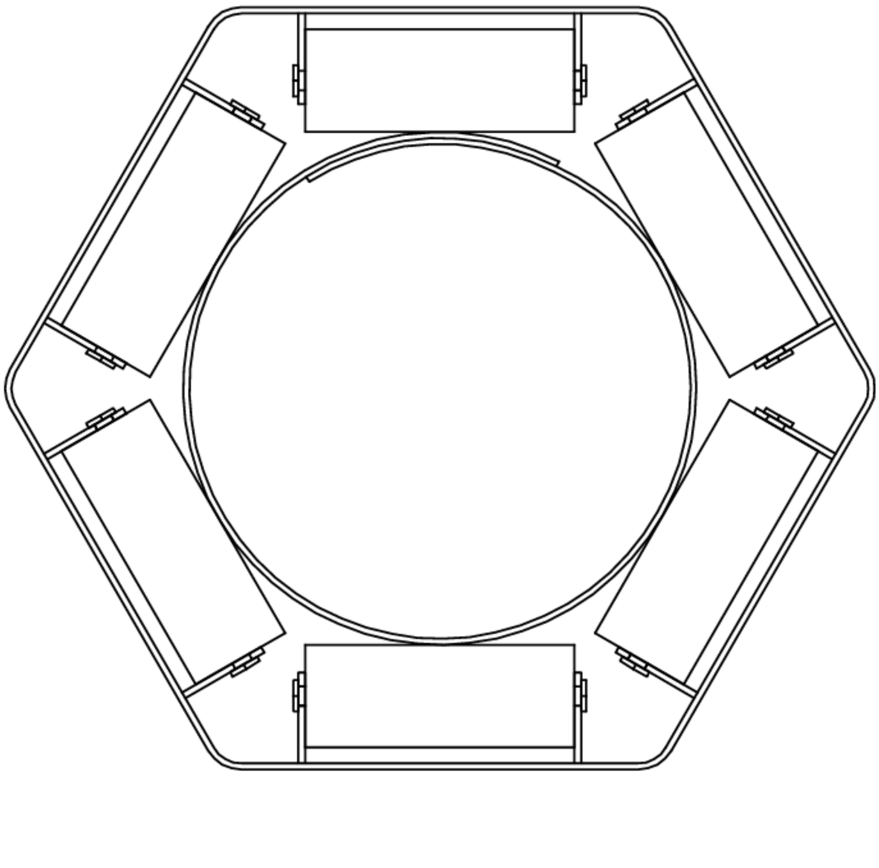

Figure 2-2: Pipe conveyor (McGuire 2009, p. 66)

Technological changes over the past few decades have allowed conveyors to be driven by many different methods. The most common drive types are drive heads and tripper drives (ACE 2011) as shown in Figure 2-4 and Figure 2-5 respectively or a combination of both as shown in Figure 2-3.

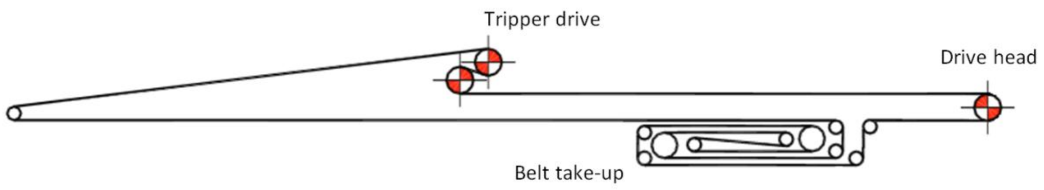

Figure 2-3: Simplified belt conveyor system

Figure 2-4: Belt conveyor drive head (Nordstrong 2013)

Figure 2-5: Tripper station at BMA Broadmeadow Mine

Other modern drive systems include belt-driven live roller, lineshaft and motorised rollers. These systems rely on the rollers to support and transport the payload (McGuire 2009).

The selection criteria and selection process for installation of belt conveyors is a very intricate procedure that deals with a complex interweaving of conveyor system capacities, technological options and specified objectives. Major conveyor belt supply companies, such as Dunlop, Rulmeca and Sandvik, produce large documents, called design manuals, with the purpose of assisting engineers to select the most appropriate option for their requirements. The design manuals guide engineers step by step through all of the design considerations that should be assessed. All of the manuals contain a section that deals with idler roller selection. This is discussed in more detail in roller design methodology (Section 2.1.3).

All belt conveyors require rollers to support the load, guide the belt and provide the belt shape regardless of the configuration. The number of idler rollers required by each conveyor depends on a multitude of different criteria such as length of conveyor, material characteristics, required capacity, belt speed and terrain (Dunlop 2004).

2.1.2 Idler roller technologies

As the conveyor industry technology develops, idler technology must develop to keep up with modern design requirements and standards. While the belt conveyor is the most common bulk material handling conveyor in use today (McGuire 2009), all belt conveyors require idler rollers to support the payload between the drive head and tail pulley. Idlers can be reviewed with many general factors like noise emission, vibration, material composition, corrosion resistance, performance, size, speed reliability, weight and many others.

The purpose of this project is to develop a light weight composite roller. Therefore the idler technologies was reviewed under sub sections of ferrous and non-ferrous with a strong emphasis on weight, performance and construction with minimal consideration given to cost. The following factors was used as a guide of characteristics to be considered:

- Shell/roller body
- End cap/end plate/bearing housing
- Bearing
- Seals
- Shaft/spindle

The roller shell is the heaviest part of the idler (Haines, 2007; McGuire, 2009) closely followed by the shaft. The rollers reviewed as part of this project were a selection of commercially available rollers and the review of these is focused specifically on comparing shell and shaft design.

2.1.2.1 Ferrous Idler roller technologies

2.1.2.1.1 Rex Idlers

Rexnord (Rex) manufacture a press-fit disc and groove end plate combination complimented with a labyrinth-seal protected tapered roller bearing assembly to promote excellent idler and belt life. The shell is fabricated with steel and welded to the endplate under the rounded lip as shown in Figure 2-6. The rounded lip and hidden weld bead result in minimal belt wear. The end plate serves as the bearing housing and has uniform wall thickness to reduce vibration. Rex rollers feature either a factory sealed “sealed for life” assembly or a regreasable configuration. All rollers are fitted with tapered roller bearings that provide extra load carrying capacity. Factory sealed bearings are used in low to medium duty operational situations where no maintenance is needed. Regreasable bearings are used in environments containing water and high likelihood of contamination. Periodical regreasing flushes bearings and seals of contaminants extending roller life. The unique assembly allows for a rear “G” seal and a labyrinth seal at the exposed surface. Rex rollers utilise solid steel shaft with drilled grease plumbing and external grease nipples. Rex utilises steel for most idlers with a non-standard range of ceramic, urethane and rubber discs for specialised applications. The Rex system is durable and capable of handling heavy duty applications. This is very costly to manufacture and the rollers are heavy.

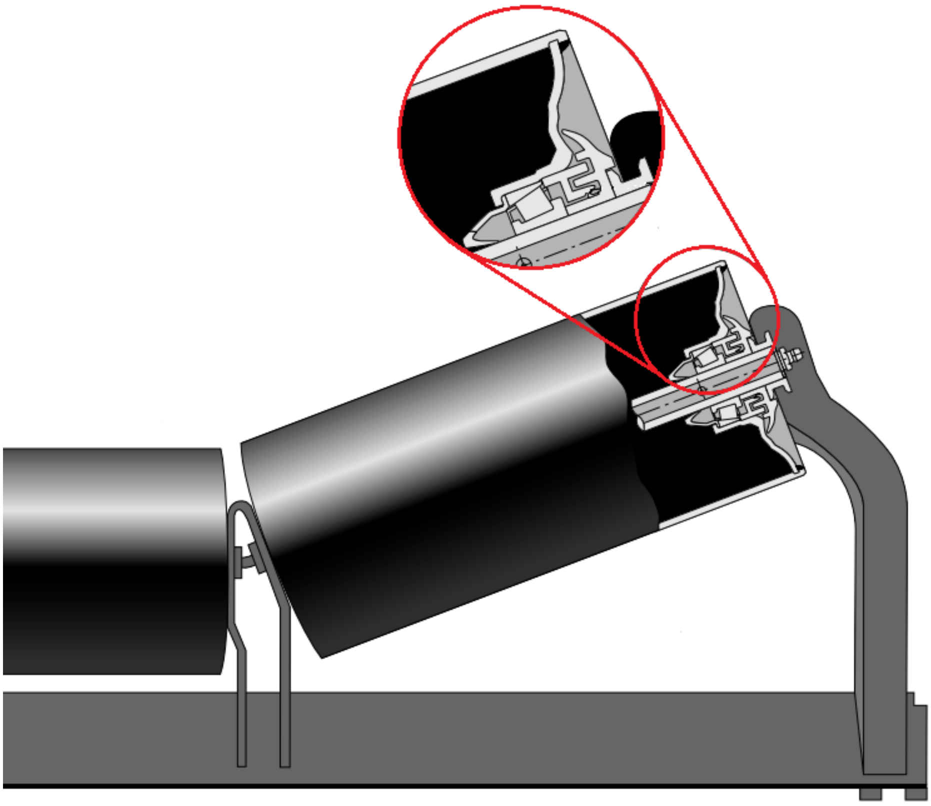

Figure 2-6: Rex Roller (Rexnord Corporation 2013)

2.1.2.1.2 RKM Roller Company PTY LTD

RKM Roller Company mass produces standard high performing rollers for mine and port structures. The roller body is rolled from electric-resistance-weld ERW 200 -350 tube utilising plain steel. The end housing grooves are precision machined to ensure eccentricity. The end housing discs are pressed into the required shape and welded into place with an autonomous welder, placing a 3 mm fillet bead at the junction. All rollers are fitted with single row deep groove ball bearings with C3 internal clearance. The bearings are factory greased for life with Lithium based grease. Starting from the inside, the various protective elements are:

- a rear seal fitted to protect the bearing from mill scaling and any inherent contaminate,
- a triple labyrinth female seal,
- a triple labyrinth male seal,
- a dust trapping steel cover,
- a rubber lip seal to prevent the entry of liquid, and
- an anticorrosive shield pressed onto the shaft.

The shaft consists of solid cold drawn mild steel round bar that is machined to seat components. RKM rollers, as seen in Figure 2-7, are cheap and suit most general purpose applications but the steel construction is heavy.

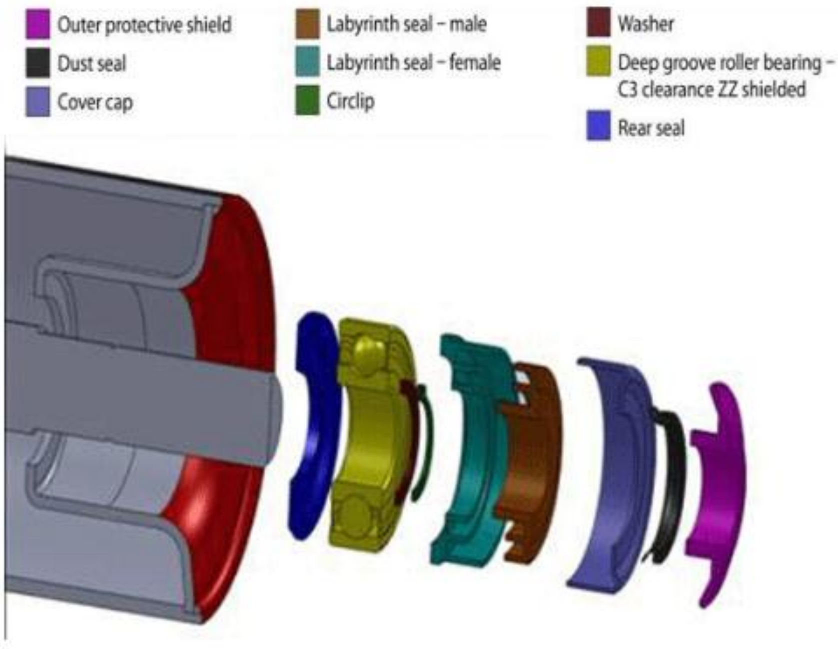

Figure 2-7: RMK idler roller exploded (RMK 2012)

2.1.2.1.3 StrongFlex

The China based company StrongFlex, produces carrying idler rollers. These rollers are manufactured from steel called RollKing and plastic rollers, sold as StrongFlex High Density Polyethylene (HDPE) and Ultra-High-Molecular-Weight Polyethylene UHMW-PE roller (described in section 2.1.2.2.2). The rollers are produced with steel shells equipped with groove pressed end caps. The deep groove ball, double sealed bearings with C3 clearance are seated in the steel end caps with a firm press fit. The bearings are lubricated with lithium soap type grease, protected by a simple labyrinth to deflect moisture and dust. StrongFlex rollers are manufactured with a solid shaft and can be painted to any colour required. StrongFlex rollers are very cheap and Data from alibaba.com (2013) indicates that these rollers are heavy and not as reliable as the more renowned idlers on the market. Figure 2-8 shows Rollking completed idlers and the idler shipping crates.

Figure 2-8: RollKing ilders and idlers ready for transport (StrongFlex 2011)

2.1.2.1.4 Fenner Dunlop

Fenner Dunlop Engineered Conveyor Solutions is part of the global engineering giant, Fenner Dunlop Group. Fenner Dunlop Engineered Conveyor Solutions Australia is an Australian based conveyor servicer, supplier and installer. Fenner Dunlop designs, manufactures and supplies two types of idlers, steel and polyurethane (PU) (see section 2.1.2.2.3). The steel roller shells are manufactured form tube that are free from flats and weld seams. The bearing housing is made from drawn and cold rolled sheet and kept in place by a full Metal Inert Gas (MIG) weld. Sealed deep groove single row ball bearings are used to support the roller assembly onto the machined solid metal shaft. Fenner Dunlop boasts a self-cleaning seal that uses centripetal force to clean itself, as well as practical vibration-less rollers with minimal noise generation. All rollers have smoothed over edges to protect the belt. The idler rollers are produced to the highest standards and Fenner Dunlop is a true industry leader in idler design. The steel version of the roller has substantial weight and the exploded idler roller arrangement can be seen in Figure 2-9.

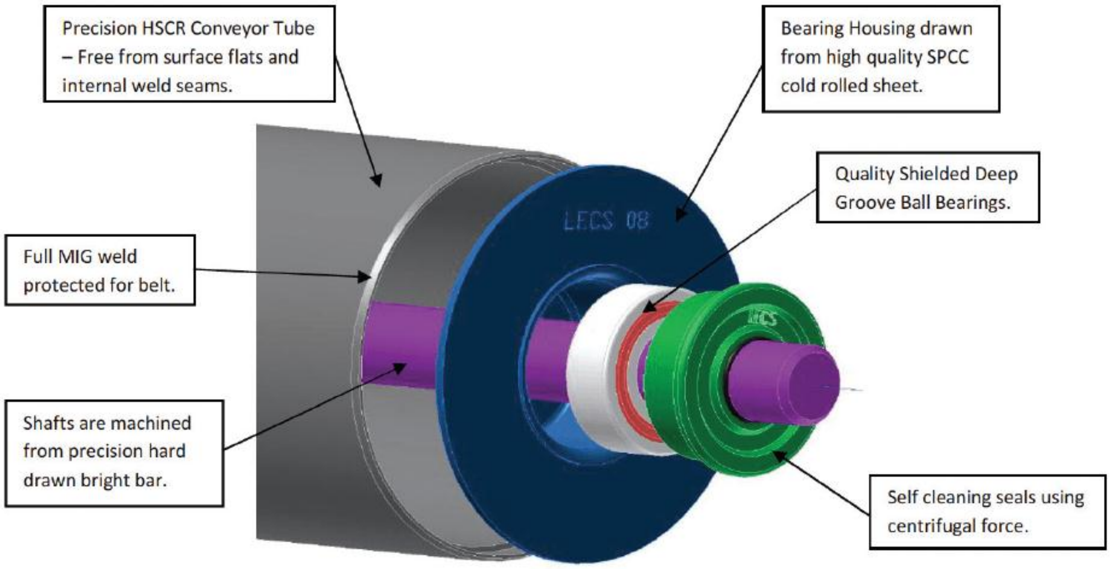

Figure 2-9: Fenner Dunlop idler (Fenner Dunlop 2013)

2.1.2.1.5 Sandvik Mining

Sandvik Mining is a world leader and global supplier of equipment, tools, services and technical solutions for the mining industry. Sandvik Mining produces a wide range of traditional ferrous and non-ferrous rollers for a variety of applications. The ferrous roller types include steel, impact, formed, low noise and unit handling idlers, with aluminium and HDPE moulded end cap rollers listed as non-ferrous. The range of ferrous rollers differ greatly in construction, manufacturing methods and operation speed, however steel is used to manufacture the roller bodies. Various processes such as tube-and-weld, hot formed and turning are used to achieve different outcomes such as economic construction, heavy duty and low noise. The rollers use specifically designed endplates to house the bearings and transfer the loads to the shaft. A selection of single row ball bearing configurations can be selected to optimise reliability, maintenance requirements and cost. Bearings may be sealed-for-life or regreasable. The bearing is protected by a dust cap with splash protection and a multiple plastic labyrinth. Sandvik offers a solid steel shaft configuration for medium to heavy duty applications and hollow shafts for light to medium duty applications and return idlers. Rollers are coated with a 60µm powder coating for superior anti-corrosion performance. The range of Sandvik rollers are very well built with a reputation for reliability and a long operational life with low maintenance. The idler arrangement can be seen in the exploded illustration in Figure 2-10.The price for reliability and rugged construction is extra weight as Sandvik rollers are among the heaviest rollers in the conveyor industry.

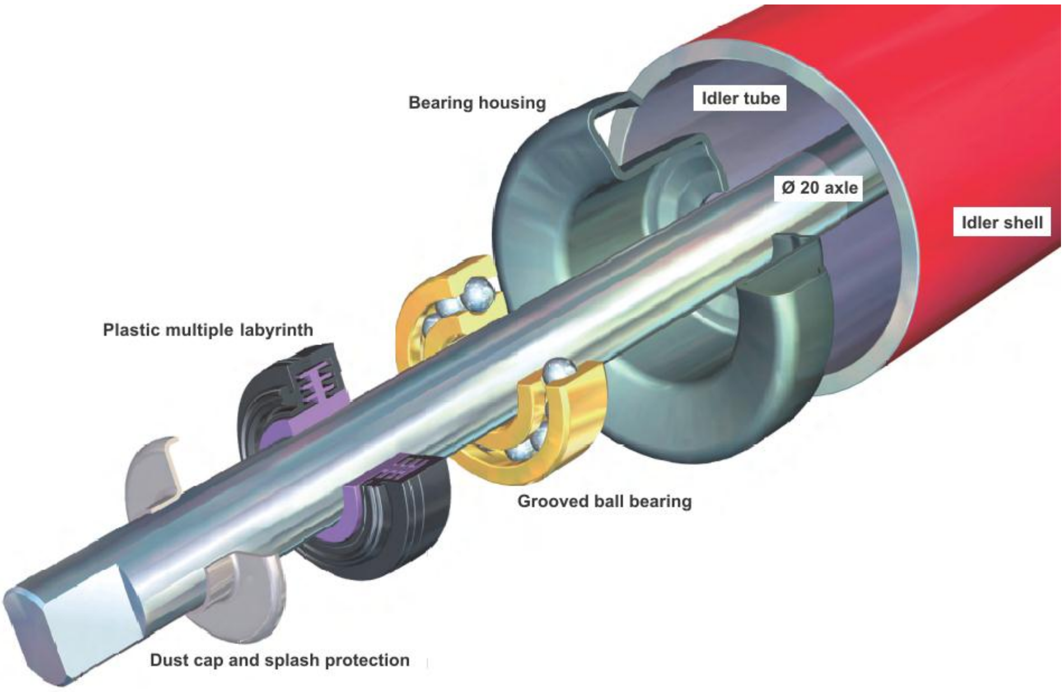

Figure 2-10: Sandvik idler arrangement (Sandvik 2011)

2.1.2.1.6 Bearing Man Group Belting

Bearing Man Group Belting is a subdivision of Bearing Man Group (BMG), a South-African company, which primarily deals with conveyor supply, technical advice and service. BMG Belting developed a distinctive conveyor idler system that utilises steel three-idler-roller 35° trough load carrying configuration with flat HDPE return idlers as depicted in Figure 2-11.

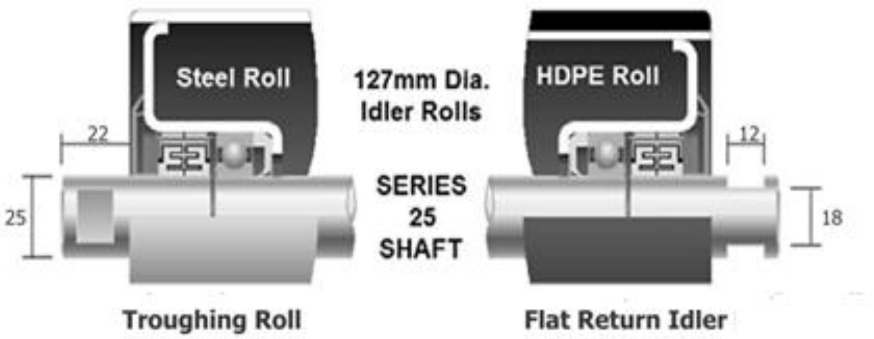

Figure 2-11: BMG Belting system (BMG Belting 2010)

The endplates are pressed into position with a weld to keep the roller supported and sealed. The edge of the shell is rounded to avoid unnecessary belt wear and belt tearing. The HDPE roller has the same steel endplate glued into place with special steel-bonding resin. Precision ball bearings are sealed at the front and rear to ensure the sealed-for-life bearings perform for the life of the roller. The front seal is a labyrinth with a complex path to inhibit the entry of debris. A cover is used as a primary defence barrier to deter moisture and dust. The shaft is made from solid steel for both the steel and HDPE shell variations. BMG Belting uses standard idler rollers in an efficient manner to produce a very effective conveyor system with low rolling resistance and maintenance. Figure 2-12 shows the top layer of a packed steel idler roller pallet in storage.

Figure 2-12: BMG Belting idlers (BMG Belting 2010)

2.1.2.1.7 Rulmeca

Rulmeca, founded in 1962, is a globally recognised specialist in bulk handling and unit handling under the materials handling umbrella. With its three product brands, Rulmeca, Precismeca and Melco, Rulmeca Group is the world's largest supplier of idlers and motorised pulleys for conveyors in the quarry and mining industries. Rulmeca produces three steel roller series, MSV, PSV and PSV-FHD as well as aluminium anti-corrosive idlers and thermoplastic idlers (discussed in section 2.1.2.2.4). All of the steel idlers shells, end plates and bearing seats are fabricated from a singular circular tube formed by cold rolling and heated pressing (shaping) process. The single row, deep groove bearings are protected on both sides by seals as shown in Figure 2-13. Rulmeca only uses radial ball race type bearings of the series: 6204, 6205, 6305, 6206, 6306 and 6308 with internal C3 tolerance. The simple single lip internal seal protects the bearing from internal moisture build up and rust particles, whilst the external greased labyrinth seal protects the bearing from foreign material ingress. Further out from the labyrinth, a wiper seal protects the bearing from moister and larger particles are deflected by a stone guard. This is the most effective and advanced seal system in the idler industry. The spindle is made from hard high carbon steel with a h6 or g6 fit.

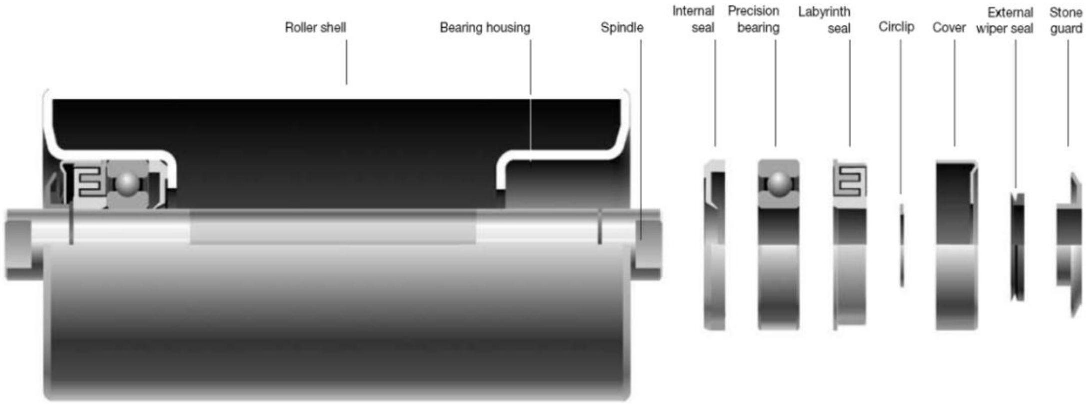

Figure 2-13: Rulmeca PSV idler exploded view (Rulmeca 2012)

Rulmeca PSV idlers are the world most commonly used roller for both its reliability in operation and economical cost. These rollers are produced with a goal of long service life and no material is spared, making these rollers very heavy. The non-ferrous rollers consider weight and therefore, are much lighter. A cut-away view of the packed Rulmeca PSV idler roller can be seen in Figure 2-14.

Figure 2-14: Rulmeca PSV idler cut away (Rulmeca 2012)

2.1.2.1.8 Conveyor Innovations International

Tamec Services, rebranded in 2013 as Conveyor Innovations International (CII), is a broad based engineering company that services the Australian mining industry. CII armed with a vision to be the product and service provider of choice, committed to innovative design and production of 21st century products within its respective mining field. CII prides itself on the revolutionary shaftless OneFits idler roller as shown in Figure 2-15. Shaftless OneFits offers a range of three shell types, namely: black steel, anti-corrosive Vitresteel and carbon fibre. The black steel rollers are manufactured from 250-350 MPa steel and will suit most low demand applications. The anti-corrosive Vitresteel tubes are composed of proprietary fused ferric metals, claiming to be twice as strong as black steel. The Vitresteel idlers are used in high demand applications, such as ports and mines that require good surface finishing on the rollers to assist good belt tracking, reduced friction for long belts and low belt wear. The experimental carbon fibre rollers are in the developmental stage for underground mining usage for ergonomic reasons. The bearings are housed in a very unique tightly packed unit that can withstand large moments. This housing also serves as the endplate for the roller. The rollers utilise double row tapered roller bearings with a back-to-back arrangement that can withstand large moments and provide very low rolling friction. The bearings are sealed by a press fit plate that attaches to the bearing housing and locates the bearing. OneFits does not have a central shaft and therefore the body is the main structural member. The shaftless design allows for a light roller, however the steel shelled rollers are heavy and the carbon fibre roller is not commercially available at this time. Figure 2-16 shows OneFits rollers with a bearing housing laid on the ground in front of the rollers.

Figure 2-15: Shaftless OneFits half cut view (CII 2013)

Figure 2-16: Shaftless OneFits idler with bearing housing (CII 2013)

2.1.2.1.9 Ferrous idler remarks

The shell or body of most ferrous rollers are manufactured from mild steel tube. CII developed a purpose-specific alloy to use in the shaftless idler design, Vitresteel, to create a light and strong roller. Certain manufacturers turn the body to ensure eccentricity and close tolerances. All rollers are rounded at the ends to ensure no sharp exposed edges will cut belts. A significant amount of manufacturers MIG weld the turned end caps into place using a groove to position the plate. A few companies press the end caps. Only one company (Rulmeca) uses a singular CHS construction that is hot and cold worked into shape. The CII idler has a uniquely designed bearing housing that is a tightly packed unit that can withstand large moments. This housing also serves as the end cap. With the exception of Rex Roller's single row tapered roller bearing and CCI's double row tapered roller bearings, all remaining idlers contain radial single row deep groove ball bearings with a C3 internal clearance. Bearings can be factory sealed or regreasable depending on the application. Low to medium duty bearings are normally factory sealed-for-life whilst medium to heavy duty applications require regreasable bearings. An added benefit of regreasble bearings is the fact that the bearings and seals get flushed with as clean grease replaces the old soiled grease. Labyrinth seals are standard for most idlers with the exception of proprietary self-cleaning seals by Fenner Dunlop. Commonly solid mild steel shafts or spindles are used to support the rollers. These shafts are machined and often plumbed with grease lines. Particular manufacturers utilise hollow shafts on the return non-payload carrying idlers. Some heavy duty idlers can use high carbon steels for added strength. CII OneFits are currently the only shaftless rollers commercially available.

2.1.2.2 Non-ferrous Idler roller technologies

2.1.2.2.1 Glide seal idler roller

Glide seal rollers are aluminuim skinned idlers that employ a polymeric end bearing housing as shown in Figure 2-17. Aluminium metal provides corrosion resistance only matched by exotic metals such as titanium and complex alloys. The aluminium shell can reduce the weight of the shell by up to 50% when compared to standard steel roller. The polymeric bearing housing is highly resistant to degradation from weather and stresses with an additional benefit of insulating and absorbing noise generated through vibration in either the shaft or the aluminium shell.

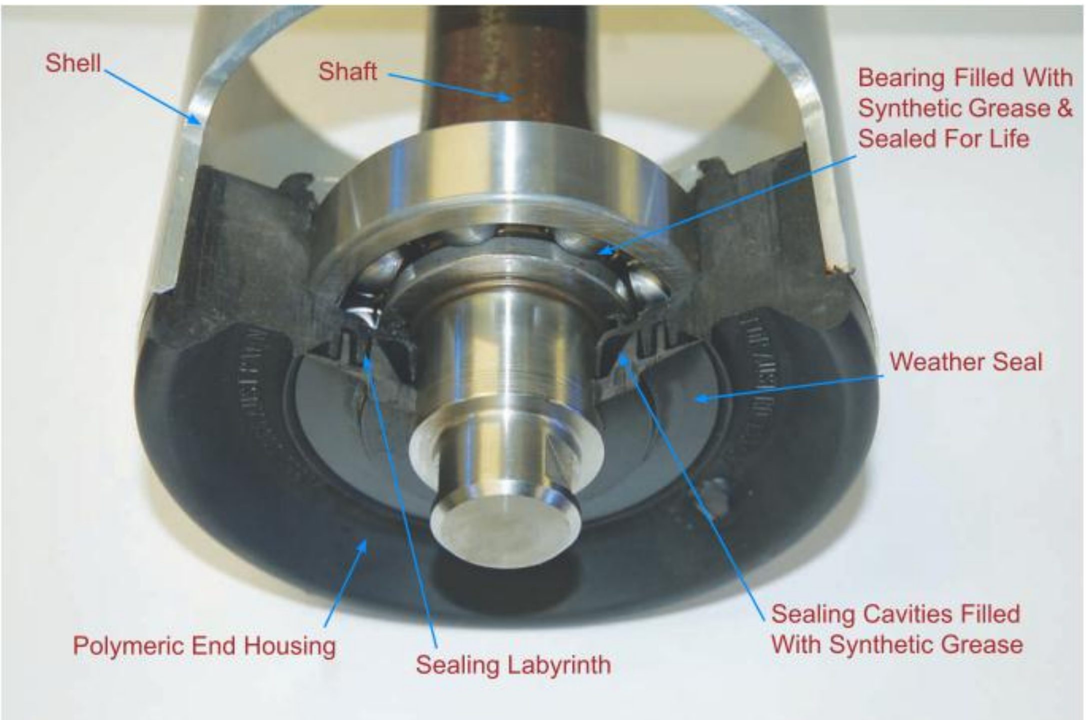

Figure 2-17: Glide seal roller (Glide seal 2009)

The Glide seal roller uses ball bearings that are grease filled and sealed for life. The bearings are protected from the elements by an inbuilt labyrinth. The shaft is made from high carbon steel to withstand the operational stresses of an idler roller. The light weight version of the idlers, used in belt return applications, features a hollow central shaft design. Glide seal rollers are currently installed on ship-loader equipment around Australian ports. The benefits of the light weight shell and polymeric bearing housing gives Glide seal rollers a very light setup, however, aluminium metals are not permitted on most surface mines and contraband in underground mines.

2.1.2.2.2 StrongFlex HDPE and UHMW-PE rollers

The China based company StrongFlex also produces two plastic rollers, HDPE and UHMW-PE. UHMW-PE is a thermoplastic polymer known for having extremely long mer chains usually between 2 and 6 μ (Huang et al. 2013). The longer chains transfer the load much more effectively resulting in a very tough, high impact resistance material (Huang et al. 2013). StrongFlex does not readily disclose their proprietary information regarding these two rollers. The only available specifications are the use of labyrinth seals and solid shafts.

2.1.2.2.3 Fenner Dunlop

Fenner Dunlop produces a polyurethane (PU) idler that is starting to trend within Australia especially with informed decision makers. PU is a thermoset polymer composed of organic units and carbamate (urethane) chained together (Ionescu 2005). The patented PU shells are made in a range of sizes and wall thicknesses: Ø102mm x 12mm, Ø127mm x 12mm and Ø152mm x 17mm. The PU idler has a distinctively designed endplate and bearing housing that claims to increase bearing life by absorbing shock loads. This arrangement, as shown in Figure 2-18, combined with sealed single row bearings, produces a low friction and highly efficient idler, unsurpassed by any other non-ferrous roller currently available.

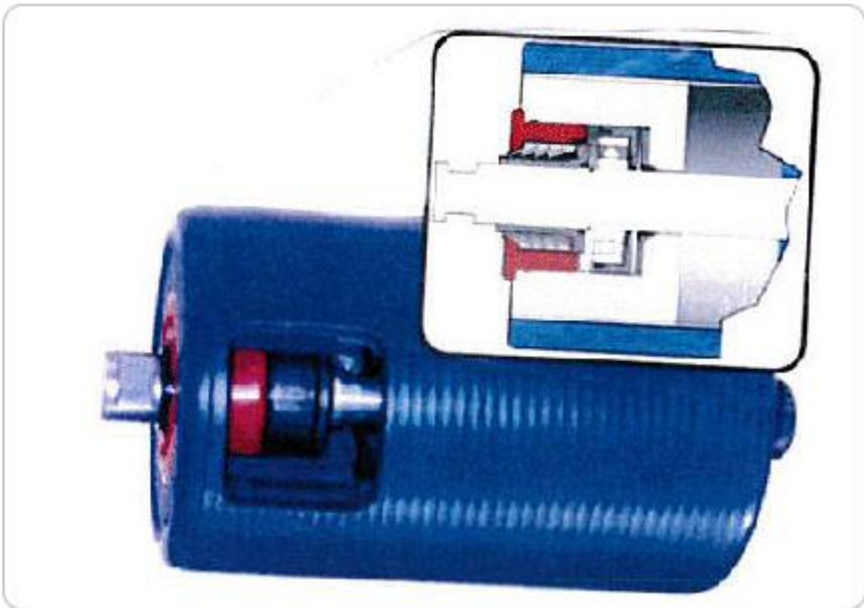

Figure 2-18: Fenner Dunlop Polyurethane idler (2013)

The seal is a four-rake press fit seal as based on Figure 2-18. (This is only an educated deduction as the arrangement is confidential). The PU idler rollers are 50% the weight of the steel rollers and are manufactured to a very high standard.

2.1.2.2.4 Rulmeca

Rulmeca produces aluminium anti-corrosive idlers and thermoplastic idlers manufactured from HDPE. Since aluminium products are contraband from underground mines it cannot be considered for this project. The HDPE roller, labelled Top Roller is Rulmeca's answer to a light-weight, high-performance non-ferrous roller demand of the modern mining and quarry industry. The body of the roller is manufactured from extruded HDPE tube and prepared in-house for assembly. The yellow bearing housing, featured bottom right in

Figure 2-19, is made by an injection moulding process from homopolymer acetal resin.

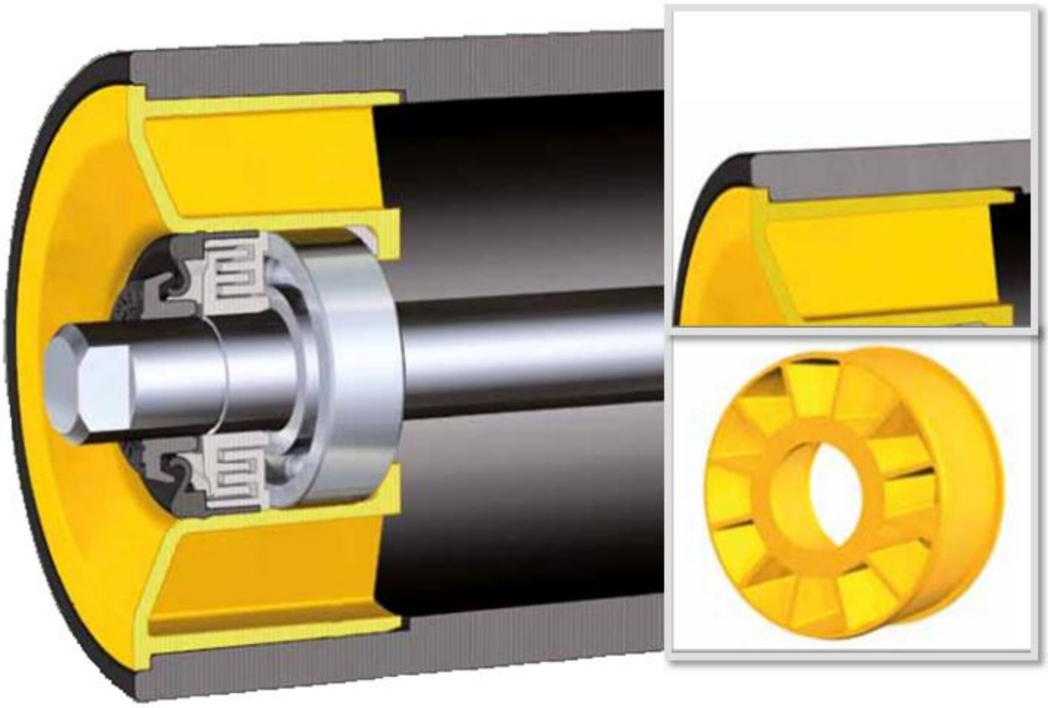

Figure 2-19: Top Roller cut away (main) and insert details (Rulmeca 2012)

This is seated in the tube for the correct alignment of the bearings and spindle. The only non-thermoplastic components are the bearings and solid shaft. The bearings are chosen from the same series of bearings as the Rulmeca steel idler series. The bearing is triple sealed for ultimate protection. One internal seal is used behind the bearing and two seals, lip and labyrinth, are used to protect the front. As with all Rulmeca idlers, a stone guard protects the seals. Top Roller idlers weigh about half the weight of ordinary steel idlers. The idlers vary from 89mm to 133mm diameter with wall thicknesses of 9mm to 11mm. The maximum length that Rulmeca currently produce is 538mm due to the lower modulus of rigidity of HDPE compared to steel.

2.1.2.2.5 Blue King Rollers

Aktiv Industrial solutions produce a weight bearing idler roller that is made from HDPE that is royal blue in colour, hence the name Blue King Roller. The complicated rib-reinforced shell is produced using an injection moulding process which produces concentricity of the system. The shell is very light, wear resistant and corrosion resistant. Aktiv claim that the rollers outperform steel rollers in weight carrying capacity and wear resistance. An additional benefit to the Blue King roller is that the HDPE material does not allow adhesion of processed material which is the primary cause of belt miss-tracking, spillage and leakage. The roller is moulded into the required shape and therefore includes the end plate and bearing housing with no additional manufacturing necessary as shown in Figure 2-20. The bearings are double capped bearings that are factory greased and sealed. The addition of the labyrinth seal further protects the bearing from foreign material influx and ensures long maintenance free service life. The shaft is manufactured from mild steel and provides the structural backbone for the roller. Aktiv claims to be 50% lighter than any steel roller of respective function and size. Blue King rollers contains an anti-static agent preventing charge build up which makes these rollers suitable for grains storage, flour mills and underground mining. Blue King Roller is an excellent roller system with great weight savings even though it uses a solid steel shaft.

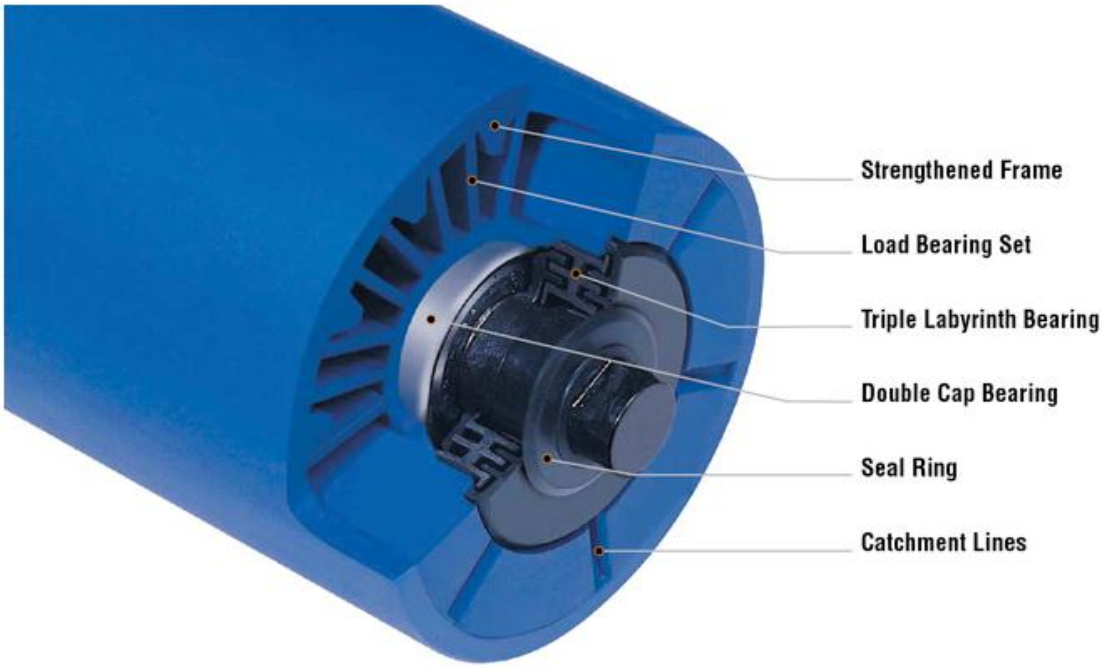

Figure 2-20: Blue King Rollers breakdown (Aktiv 2008)

2.1.2.2.6 Yeloroll

Yeloroll is based in the industrial suburb of Welshpool, Perth and is the sole manufacturer of Yeloroll conveyor products in Australasia. Yeloroll also produces a full range of steel, aluminium, HDPE, PU and rubber rollers. The Polyvinylchloride (PVC) idler roller, called Yeloroll, is Yeloroll's trademark product and is specifically formulated to provide a light weight, low noise, non-corrosive idler with enhanced durability and strength. Yeloroll conveyor idlers, as shown in Figure 2-21, are already in use in the nickel, gold, iron ore, copper and salt industries all over Australia. Yeloroll conveyor idler shells are fabricated from a titanium modified PVC that features excellent abrasion resistance with light weight. The endplate and bearing housing are manufactured by means of precision injection moulding from a durable nylon glass fibre composite with an antistatic copper pin. Factory sealed deep groove ball bearings with C3 clearance are used in a sealed for life arrangement. Bearing sizes currently used include 6204, 6205, 6306 and 6308. The bearing is protected by a bearing seal that is watertight and dust resistant as well as a reverse multi labyrinth seal. The shafts can be made from either mild steel or stainless steel, depending on the application and a protective can be used in conjunction with either mild steel or stainless steel to ensure no exposed steel parts can rust. Idlers are made with roller diameter sizes of 114 mm to 178 mm with the shaft sizes ranging from 16 mm to 40 mm. These idlers are up to 4.4 dB (A) quieter than steel idlers, this is a noise level less than half the intensity. The PVC body and nylon glass fibre bearing housing produce a roller that is 60% lighter than the same size steel roller. Yeloroll offers quieter, lighter, anticorrosive, self-cleaning and belt friendly rollers that can outperform most steel rollers in heavy duty applications.

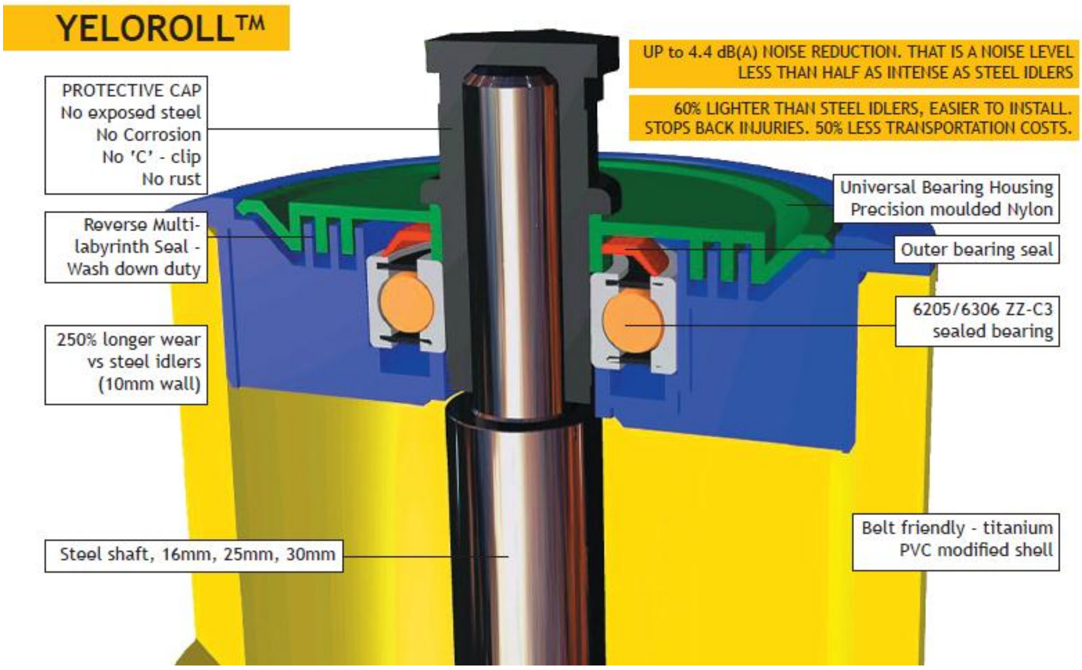

Figure 2-21: Yeloroll idler half roller cut away (Yeloroll 2012)

2.1.2.2.7 Non-ferrous idler remarks

There are no non-ferrous rollers, besides aluminium idlers, that currently span any more than 535mm, due to the relatively lower material strength capacity of non-ferrous materials when compared to steel. The non-ferrous rollers contain greater diversity in the construction and material uses compared to steel idlers. This is mainly due to the relatively new development of non-ferrous idlers and the costs of different grades of polymers. Materials used in the body ranges greatly and the various constructions include aluminium, UHMWPE, PU, PVC and most commonly HDPE. The end caps and bearing houses from various products are produced from polymeric inserts, PU, homopolymer acetal resin, HDPE and glass filled nylon with an antistatic copper pin. All of the investigated idlers use radial single row deep groove ball bearings with a C3 internal clearance. Four types of seals can be found in non-ferrous rollers: labyrinth, reverse labyrinth, four-rake press fit seals and a lip and labyrinth arrangement. Shafts are all made from mild or stainless steel with light duty rollers containing hollow shafts.

2.1.2.3 Final Remarks

Although non-ferrous rollers are not as poplar or versatile as steel rollers, there is an increasing demand for non-ferrous rollers in the industry. The industries that prefer non-ferrous rollers are usually in corrosive environments, such as companies on coastlines or manufacturers that handle corrosive materials like salt. Other companies that are interested in light weight rollers are mines with stacking towers or underground mines. The polymer roller industry can currently produce rollers up to 535mm in length and various diameters. The call for larger, light weight rollers (such as 1200 mm in length and 150+ mm diameters) in the market remains unfulfilled.

2.1.3 Roller design methodology

Large conveyor design and construction companies typically produce large documents, called design manuals, to assist engineers to design and specify conveyors to satisfy their needs. A brief overview of the three design manuals reviewed for this project is shown below. These three manuals were chosen because the publishing companies are the world leaders in their field with a significant presence in Australia. These include:

- Sandvik – HA200 Idlers design manual (2008)
- Rulmeca – Rollers and components for bulk handling (2003)
- Dunlop – Complete Conveyor Belt Design manual (2004)

Sandvik – HA200 Idlers design manual (2008) can be downloaded in Portable Document Format (PDF) from www.sandvik.com. This free document encompasses a brief introduction to conveyor design and roller selection followed by a roller range selection guide. The roller selection guide assists the engineer to select the rollers based on material and duty cycles. The second section of the guide suggests sizes. The next step shows how to select an arrangement type such as 30° trough or vee arrangements. The last section is a complex set of graphs and figures to decide belt size, speed and driving requirements.

Rulmeca – Rollers and components for bulk handling (2003) is a complete guide to conveyors and conveyor systems from design right through to implementation and maintenance. This free downloadable PDF, available from www.rumeca.com, describes the roller design, loading design and mathematical calculations in great detail in all sections of the design steps. Chapter 2 of the document deals specifically with rollers. The selection process is based on the roller diameter, revolution per minute and belt speed. The next section describes required operation factors and loading circumstances. The roller loading determination section is dedicated to calculating the load on a single roller at full capacity (Rulmeca manual, p. 75-79). This set of calculations was very useful and used in the methodology chapter that deals with roller design. The final section of the Rulmeca manual overviews selection of Rulmeca rollers based on the outcomes of the calculations.

Dunlop – Complete Conveyor Belt Design manual (2004) is the metric version of two manuals based on imperial (written and published in the USA) and metric units. The gratis PDF, published in South-Africa and available from www.fennerdunlop.co.za, is a complete guide to conveyor belting that aligns with the South-African, New Zealand, Australian and International Standard Organisation (ISO) standards. This makes the document applicable in Australia and globally. The document uniquely approaches the design based on the bulk materials, material properties and required flow capacity. The entire design manual is based on tables such as material properties, capacities of belts, belt speed and idler spacing. All the tables are intrinsically interlinked with no required starting point. It means that the design can be started from any known parameters and the interlinked tables will guide the user to a final design. The process is less structured than any of the other approaches, but allows for much greater diversity and choice. This document was the ideal guide for this project as the material and roller diameter were the only known parameters, and there was no interest to select an existing roller. The tables and pathway used is discussed in much greater detail in section 3.1.2.

2.1.3.1 Conclusion

The Dunlop conveyor belt design was an ideal design platform for this project based on the various possible selection pathways of the design guide. The Rulmeca roller loading determination equation set was a well-defined foundation to build the engineering analyses on.

2.2 Composite Materials

2.2.1 Wagners Structural Composites

Wagners produces a range of structural grade composites for use in corrosive environments and in applications where light weight and extreme durability is crucial, such as cross arms for the utilities network. The three main products produces by Wagners are 100 mm x 100 m (5 mm thickness) Square Hollow Section (SHS), 125 mm x 125 mm (6 mm thickness) SHS and 100 mm x 75 mm (5 mm thickness) RHS. Variations of the sections are shown in Figure 2-22.

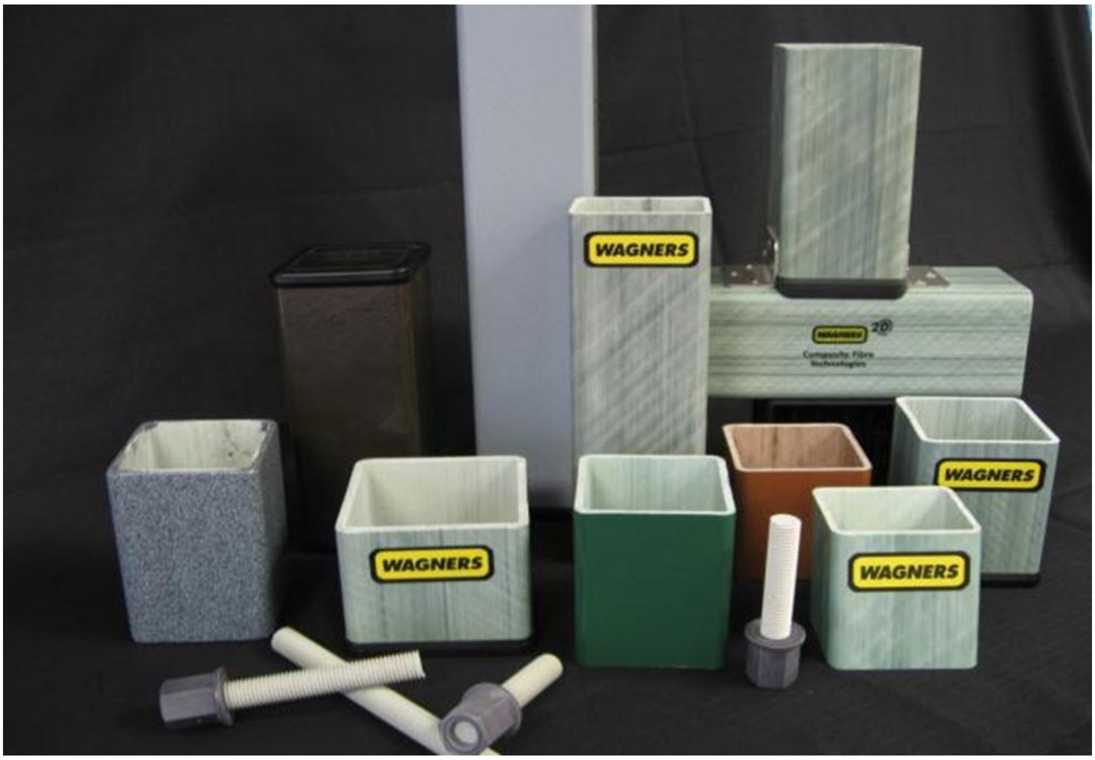

Figure 2-22: Various Wagners SHS and RHS products

2.2.1.1 Wagner CFT CHS

Wagners CFT have recently undertaken a project to produce 3½" OD CHS from continuously pultruded glass fiber vinyl ester composite, see figure Figure 2-23. The CHS has an outside diameter of 88.9 mm, inside diameter of 76.9 mm and a wall thickness of 6.0 mm. This project is based around the 3½" OD CHS and although the diameter is not ideal for all roller sizes, this section is a good starting point for the development of a light idler roller. The CHS, as produced by Wagners, was used in physical testing and theoretical models were used to scale the results to necessary sizes. This is explored in depth in Chapter 3.

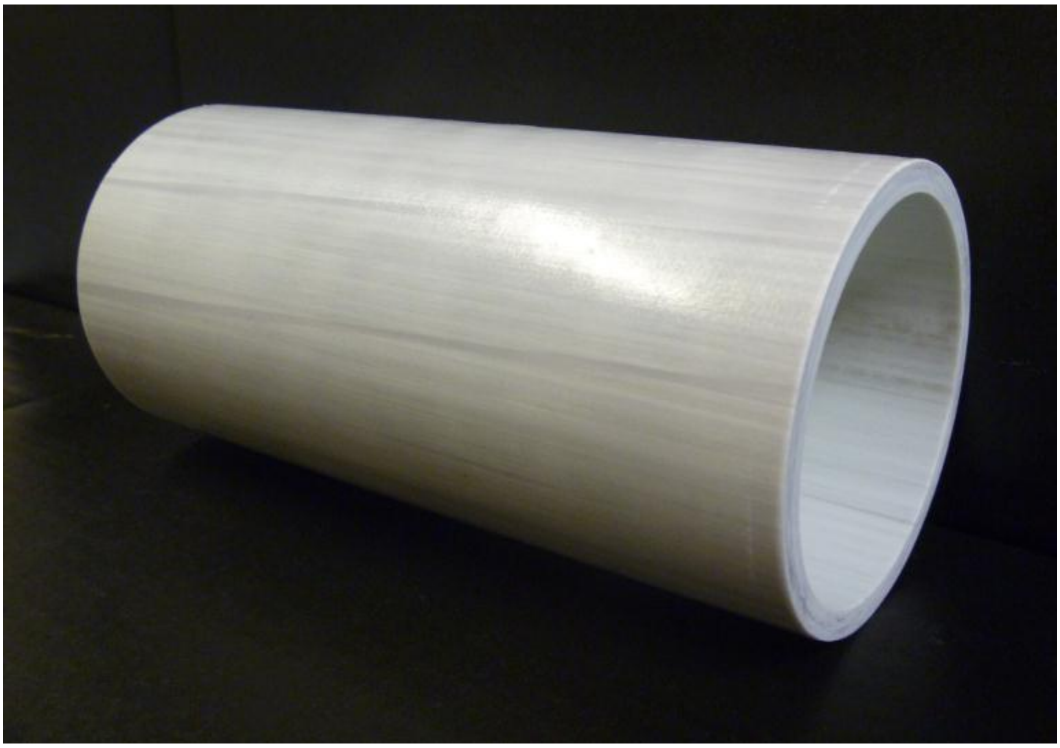

Figure 2-23: Wagners CHS

Section properties as calculated using Australian Standard AS 1163-1991 (1991) can be found in Table 2-1. The Australian Standard AS 1163-1991 is based on the Comité International pour le Dévelopement et l'Etude de la Construction Tubulaire (CIDECT) (1984), *Construction with Hollow Steel Section.* Figure 2-24 shows the simplified CHS cross-section.

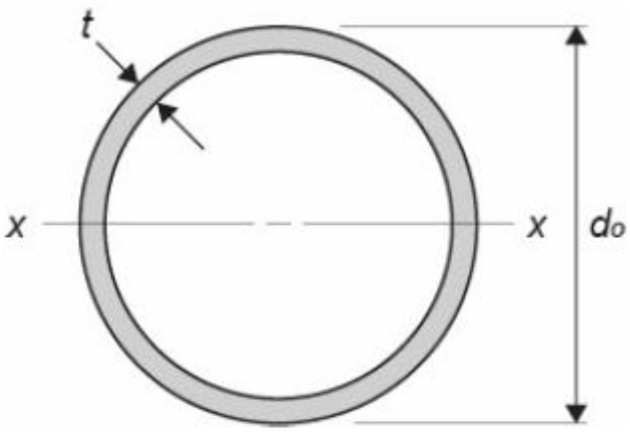

Figure 2-24: Simplified CHS section drawing

Table 2-1: Section properties calculations

Cross-sectional area	$A_C = \frac{\pi}{4} \cdot \left({d_o}^2 - {d_i}^2\right)$	$A_{cs} = 1563\ mm^2$
Mass	$M = \rho \cdot A$	$M = 3.078\ kg \cdot m^{-1}$
Perimeter of cross-section	$P = \pi \cdot d_o$	$P = 279.2\ mm$
External surface area	$A_S = P \cdot 1m$	$A_S = 0.279 m^2 \cdot m^{-1}$
Second moment of area	$I_x = \frac{\pi}{64} \cdot \left({d_o}^4 - {d_i}^4\right)$	$I_x = 1.349 \times 10^6 mm^4$
Section modulus	$Z_x = \frac{2 \cdot I_x}{d_o}$	$Z_x = 30.36\ mm^3$
Radius of gyration	$r_x = \sqrt{\frac{I_x}{A_C}}$	$r_x = 29.39\ mm$

Known section properties are tabulated in Table 2-2 (Skerman 2013).

Table 2-2: Known CHS properties (Skerman 2013)

Axial tensile strength	>400 MPa
Axial compression strength	>400 MPa
Hoop tensile strength	300 MPa
Poison's ratio (material property)	0.3

Wagners CFT are currently developing more pipe sizes that will be suitable for mining idler rollers including 5" OD (127 mm) and 7" OD (178 mm) pipes with wall thicknesses of 8 mm and 10 mm respectively. These sizes was analysed and considered for the design and final suitability statement.

2.2.1.2 Wagners CFT proprietary thread and bonding systems

Wagners CFT produce a three-start thread known as the "Wagner Wedge" thread system. This two part tooling epoxy resin thread is commonly used on Wagners CFT CHS products. Figure 2-25 shows an external example of the Wagner Wedge thread as moulded onto the CHS. The particular moulding process used to fabricate the Wagner Wedge onto the CHS is known as resin transfer moulding. Wagners CFT pioneered another propriety composite-to-metal bond system. This composite-to-metal bond is achieved by preparing both the composite and metal surfaces to the correct surface roughness. The metal is prepared with a primer and bonded together with a two part epoxy, known as green glue.

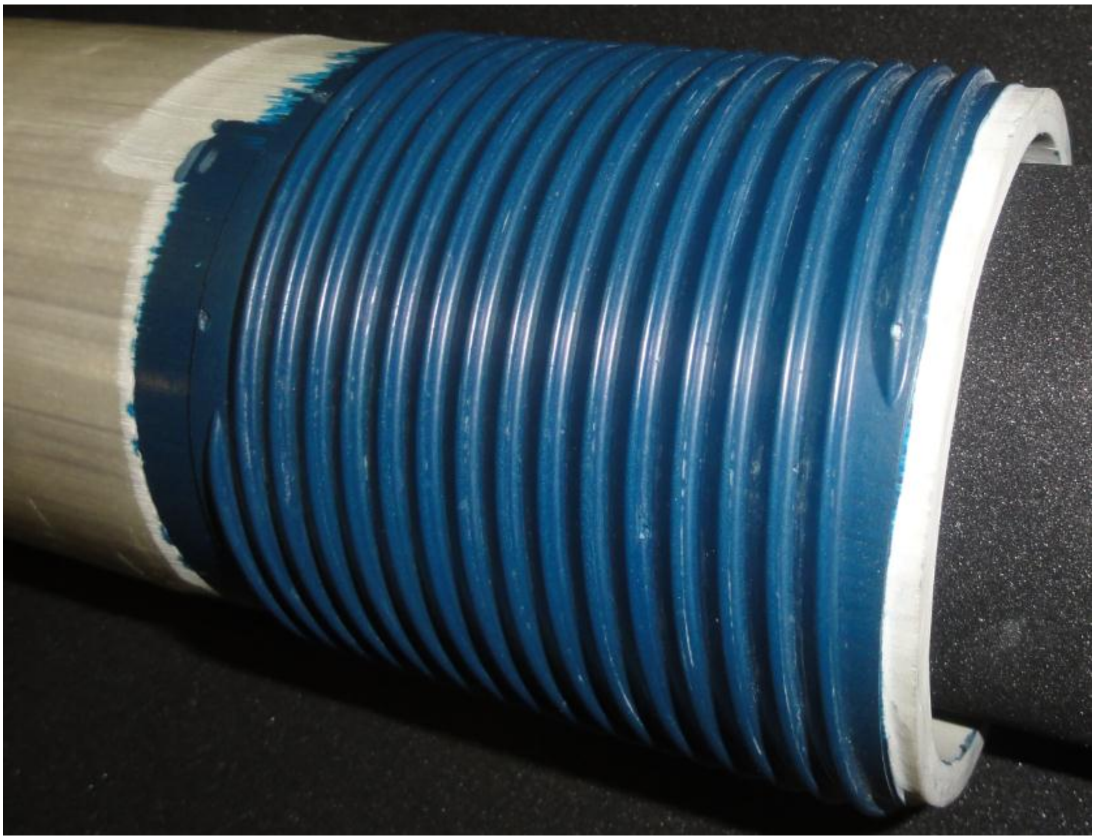

Figure 2-25: Wagner Wedge

2.2.2 Determination of section properties

Many different testing regimes can be used to determine material properties. The two major types of testing are destructive and non-destructive (Norton, 2013). Non-destructive testing involves applying a predetermined load and recording the displacement to ensure that the specimen can tolerate the load. This testing only provides information within the operational limits and is mostly used in quality assurance procedures (Intertek, 2013). Destructive testing comprises of applying a constantly growing load onto a test specimen until the specimen fails. Destructive testing provides information regarding operational behaviour, as well as maximum strength properties (Norton, 2013). Destructive testing delivers the most useful information and suits the purposes of this project.

Wagners CFT uses American Society for Testing and Materials (ASTM) testing methods to test pultruded products. ASTM D638-10 provides the standard test for determining the properties of plastics. The ASTM D638-10 is only suitable for specifically shaped specimens and does not allow for CHS testing. The ASTM D638-10 standard suggests using the following standard, ASTM D790-10 for standard test methods for flexural properties of unreinforced and reinforced plastics of non-rectangular or non-solid cross section.

ASTM D790-10 describes the three point loading system applied to a simply supported beam. However, the test is only valid if the specimen breaks in the outer surface. Pultruded CHS is hollow, posing a significant danger of a localised crush failure occurring below the single load point in a three point bend test. Initial test trails, as performed by Wagners CFT, showed that a three point bend test does not consistently fail in the outer layers of the pipe. The scope for ASTM D790-10 highlights that ASTM D6272 describes a four point loading system applied to a simply supported beam as an alternative for non-complying test specimens. The major difference between the three point and four point flexural tests is the location of the bending moment. The four point bending method allows for uniform stress distribution between the two loading noses, whilst the three point bending method’s stress is located under the loading nose (Intertek, 2013). Nordson (2013) believes performing four point bend tests hold serendipity. The test produces the peak stresses over a larger length of the specimen, giving more potential for flaws and defects to be highlighted. Therefore, the four point bend test is more suitable for this study. The modulus of elasticity can be determined by using the four point bend test.

2.2.2.1 Flexural properties standard test method ASTM D6272-10

The standard test method pertaining to both semi-rigid and rigid materials for plastics and composites, is the determination of flexural properties. This section highlights information of relevance to this project.

The test is performed with a support span to depth ratio of 16:1; greater ratios may be used for high strength reinforced composites up to a ratio of 60:1. This ensures that beam theory applies and no short beam shear will impede the results (ASTM D6272-10). Two variations of the testing can be used, one third or one half of support span as shown in Figure 2-26. The test may be altered slightly as long as the failure does occur on the outer surface of the specimen.

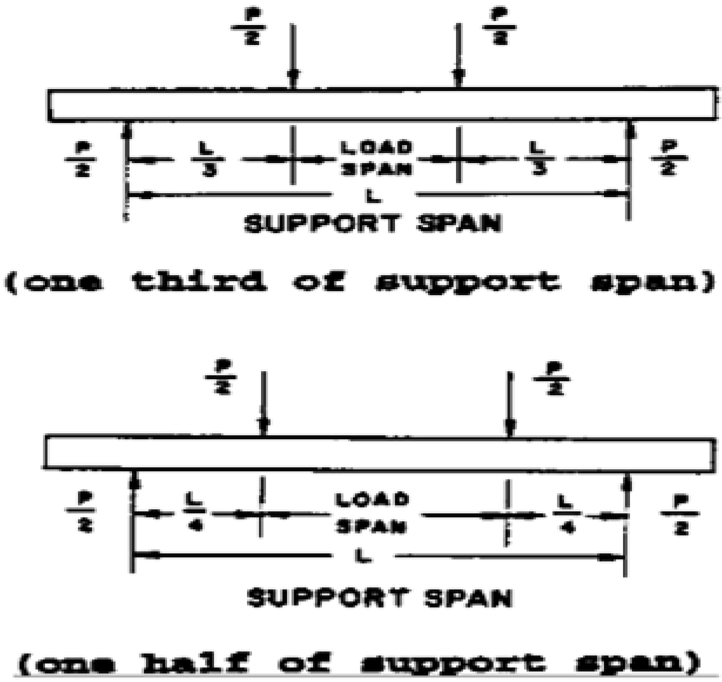

Figure 2-26: The loading diagram options as illustrated in ASTM D272

ASTM D6272-10 (p. 12) states 'the loading noses and supports shall have cylindrical surfaces' as illustrated in Figure 2-27. In order to avoid stress concentration or indentation, directly above the supports or below the noses, flat plates may be used at these regions (ASTM D6272-10). The deflection measuring device must be automatically continuously recording the deflection as well as the corresponding load (ASTM D6272-10).

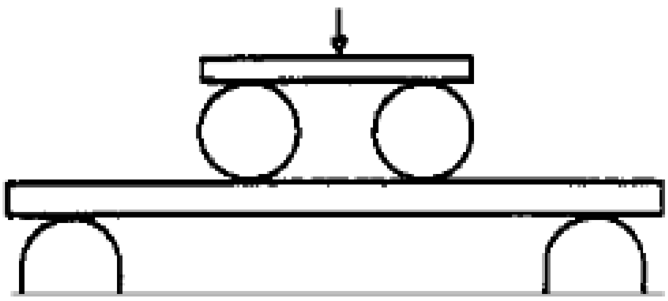

Figure 2-27: Test setup as shown in ASTM D6272-10

The number of specimens required for isotropic materials is five; anisotropic material is five in each direction or 10 in the direction of interest. The modulus of elasticity can be calculated for the one third load span by using the following formula (ASTM D6272-10):

$$E_B = \frac{0.21L^3m}{bd^3}$$

Where E_B = modulus of elasticity in bending, **MPa**
L = support span, **mm**
b = width of beam tested, **mm**
d = depth of beam tested, **mm**
m = slope of tangent to the initial straight line

This calculation method requires further calculation from measured deflection. However, using this test, a theoretical approach can also be used to calculate the modulus.

2.2.2.2 Flexural strength mathematical theory

The deflection can be calculated at the centre using the principles shown by Beer et al. (2006). Consider beam AE, in Figure 2-28, simply supported at both ends with two equal loads symmetrically placed.

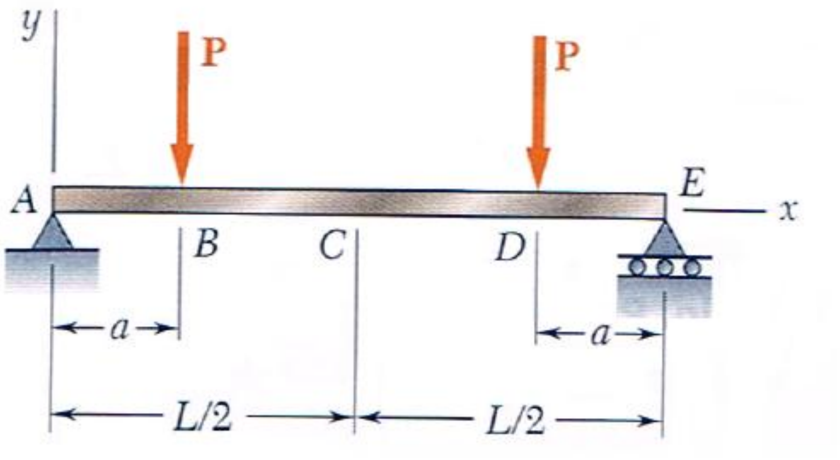

Figure 2-28: Four point bend test (Beer, Johnston & DeWolf, 2006)

Now consider portion ABC only and use symmetry about C

Reactions: $R_A = R_E = P$

$$Boundry\ conditions: [x = 0, y = 0], [x = a, y = y], \left[x = a, \frac{dy}{dx} = \frac{dy}{dx}\right]\ and$$

$$\left[x = \frac{L}{2}, \frac{dy}{dx} = 0\right]$$

<u>For $0 < x < a$</u>

$$EI\frac{d^2y}{dx^2} = M = Px$$

$$EI\frac{dy}{dx} = \frac{1}{2}Px^2 + C_1$$

$$EIy = \frac{1}{6}Px^3 + C_1x + C_2$$

For $a < x < L - a$

$$EI\frac{d^2y}{dx^2} = M = Pa$$

$$EI\frac{dy}{dx} = Pax + C_3$$

$$EIy = \frac{1}{2}Px^2 + C_3x + C_4$$

Use boundary conditions to solve constants

$$[x = 0, y = 0] \rightarrow C_2 = 0$$

$$\left[x = \frac{L}{2}, \frac{dy}{dx} = 0\right] \rightarrow C_3 = \frac{1}{2}PaL$$

$$\left[x = \frac{L}{2}, \frac{dy}{dx} = \frac{dy}{dx}\right] \rightarrow \quad \frac{1}{2}Pa^2 + C_1 = Pa^2 - \frac{1}{2}PaL$$

$$\therefore C_1 = \frac{1}{2}Pa^2 - \frac{1}{2}PaL$$

$$\left[x = \frac{L}{2}, y = y\right] \rightarrow \quad \frac{1}{6}Pa^2 + a\left(\frac{1}{2}Pa^2 - \frac{1}{2}PaL\right) = \frac{1}{2}\,Pa^3 - \frac{1}{2}Pa^2L + C_4$$

$$\therefore C_4 = \frac{1}{6}Pa^3$$

For deflection at point C, set $x = \frac{L}{2}$:

$$y_c = \frac{P}{EI}\left(\frac{1}{8}aL^2 - \frac{1}{4}aL^2 + \frac{1}{6}Pa^3\right)$$

$$y_c = -\frac{Pa}{EI}\left(\frac{1}{8}L^2 - \frac{1}{6}a^2\right)$$

$$y_c = -\frac{Pa}{24EI}(3L^2 - 4a^2)$$

Since the load and deflection can be measured during the four point bend test, the previous equation can be rearranged to isolate the modulus of elasticity (E) as shown in Equation 2-1:

Equation 2-1: Calculation of modulus of elasticity

$$E = -\frac{Pa}{24I \cdot y_c}(3L^2 - 4a^2)$$

where

$$I = \frac{\pi(d_o^4 - d_i^4)}{64}$$

$$I \;=\; \frac{\pi(88.9^4 - 76.9^4)}{64} \;=\; 1\,349\,400\;mm^4$$

2.2.2.3 Shear properties standard test methods

There are multiple ASTM standards that deal with tests to determine shear properties such as ASTM D7078, D5379, E1876-09 and C273. These tests are not suitable for composite hollow section as they are designed for resin-only samples, V-notched samples or honeycomb sandwich laminates. The properties of the CHS can be found using the CIDECT based document, *Steel construction,* (Syam, 1992) in accordance with AS4100-1990.

2.2.2.4 Shear strength test in accordance with AS4100-1990

The shear test is set up with the same support and loading conditions as ASTM D6272-10. ASTM D6272-10 (p. 12) states ‘the loading noses and supports shall have cylindrical surfaces’. Flat plates may be used at these regions to avoid stress concentration and the deflection measuring device must be automatically continuously recording the deflection and the corresponding load (ASTM D6272-10). The 10 sample must be tested in the direction of interest.

The test can be set up as shown in the schematic, Figure 2-29, as prepared by Syam (1992). Section 3.1.1.2 elaborates on the test method in more detail. Syam further declares that the maximum shear stress can found using in the setup of Figure 2-29 and Equation 2-2 as long as a<b:

Equation 2-2: Maximum shear stress

$$\tau = \frac{V_1}{A}$$

where τ is shear stress, $R_1 = V_1 = \frac{P \cdot b}{L}$ and A_{cs} is cross-sectional area

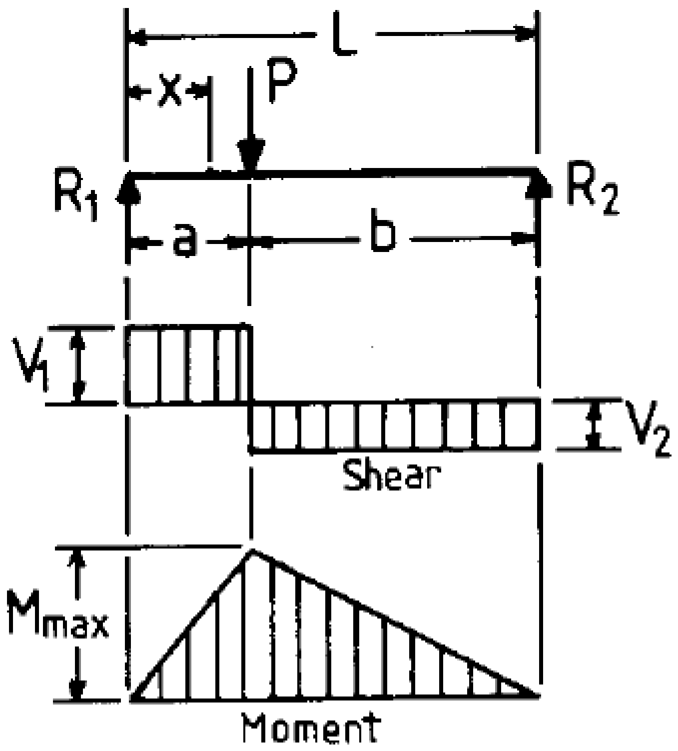

Figure 2-29: Simple beam - concentrated load at a point (Syam, 1992)

A minimum of 10 specimens must be subjected to destructive testing.

2.2.2.5 Three point bend test

Three point bend test is a simple test that can be used to validate theoretical models, such as Finite Element Analyses (FEA), against physical testing. Syam (1992) developed a test method and calculations for a three point test with a uniform load partially distributed along the span as shown in Figure 2-30:

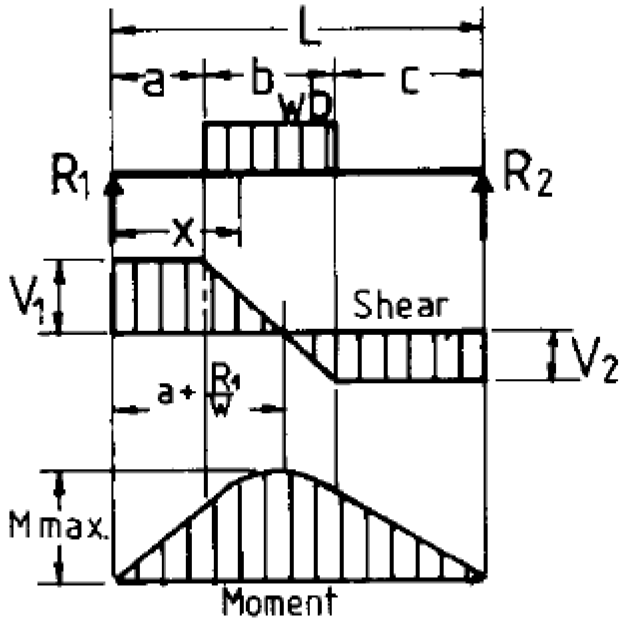

Figure 2-30: Uniform mid-span load (Syam 1992)

The maximum deflection can be calculated using Equation 2-3 when $a = c$:

Equation 2-3: Maximum deflection

$$\delta_{max} = \frac{wb}{384EI}(8L^3 - 4Lb^2 + b^3)$$

A minimum of 10 tests was performed to ascertain adequate deflection and load carrying capacity data. This data was analysed and the extracted information was used to validate the FEA models.

2.2.2.6 Finite Element Analysis

FEA was first developed by R. Courant in 1943 (Widas 1997) and has rapidly become a popular technique to analyse systems. Widas (1997) explains that 'FEA uses a complex system of points called nodes which make a grid called a mesh'. The mesh is programmed with the material properties and the system is programmed with loading scenarios and constraints (Widas 1997). Widas (1997) further states that this information is used to analyse the component structurally, based on a finite element mathematical method. FEA generally relies on isotropic material behaviour. This means the matter behaves identically in any direction or orientation (Askeland & Phule 2008). Composite materials are generally anisotropic, meaning that its properties depend on the direction in which the property is measured (Askeland & Phule 2008). This can pose significant problems for FEA of anisotropic materials and may require complex models to be established. The National Agency for Finite Element Methods and Standards

(1986) suggest that properties of anisotropic materials can be 'smeared' into an average value and used for computation as long as the investigation does not involve a specific failure method. Thus, the calculated values from the physical testing can be used to analyse composite materials as long as the material does not approach the point of failure.

2.2.3 Fatigue behaviour and fatigue modelling of fibre composites

Since fibre composites are a relatively new mass produced product, very few industry guidelines exist. Although researchers have studied fibre composites for an extended period of time, no standardised methods and models have been identified to investigate the fatigue behaviour of composites. The literature reviewed considers briefly how fibre composite fails, the methods used to monitor these failures, models used to predict failure and possible applications for fibre composites with high fatigue strength.

It has been suggested that 'One of the unique characteristics of fibre-reinforced composites is that their properties can be tailored to meet different types of loading conditions... even fatigue' (Askeland and Phule, 2008, p. 627). Yu et al. (2011) and Lewis and Gagg (2010) both produced detailed reports of investigations of the performance of glass fibre composites in fatigue and believe that composites have a very high fatigue strength in most cases. Contrary to these findings, Grimmer and Dharan (2008, p. 4488) state that '[g]lass fibre polymer composites have high strength, low cost, but suffer poor performance in fatigue'. Grimmer and Dharan (2008) believe that energy absorbing additives need to be added specifically to raise fatigue strength. The ambiguity regarding the fatigue strength of composites may be a direct result of unclear industry guidance relating to this topic. 'Fatigue crack propagation behaviours for composites have still not been standardized' (Ferreira et al. 2010, p. 3547). This uncertainty leads to the investigation of current practices in determining the fatigue strength of composites.

Fibre composite failure types are mainly contributed to individual composition. Long continuous fibres usually display better fatiguing behaviour than short or chop strand fibres. Although failure modes differ vastly due to the nature of different types of composites, most researchers would agree with Pupurs and Varna (2010) that fatigue failures in composites are due to fibre/matrix debond crack growth during high stress cycles. Pupurs and Varna (2010) further suggest that the fracture mechanics are based on the concepts of mode II energy release as suggested by Paris Law. In a later paper Pupurs and Varna (2011) infer that a broken fibre interface is required to initialize the growth of a fibre/matrix debond in fatigue failure. CSA Illmina (1991) supports the notion of Pupurs and Varna (2011) and suggest that a large portion of defects that affect the fatigue behaviour are defects caused during manufacture, either highly concentrated resin areas, or poorly penetrated fibre areas. The ASM handbooks online (2003, p. 1032) also state 'Fatigue cracks can initiate from porosity in composites'.

In order to fully understand exactly how fibre composites fail, researchers continuously come up with new fatigue monitoring techniques (Japan Carbon Fibre Manufacturers Association 2009). One of the most advanced monitoring techniques currently in use was developed by Limin et al. (2010) and uses strategically placed conductive nanotubes to quantitatively measure the accumulated damage. According to Limin et al. (2010, p. 4088) 'Various damage stages in composite cross-ply laminates under fatigue loading can be clearly detected by adopting the quantitative parameter, damaged resistance change'. Another suggested method is to produce a specimen with a specific change in geometry as to induce a stress concentration region and uses multi-directional strain gauges to monitor elongation. This gives the researcher data to calculate the direction of principal stresses and maximum shear orientations (Tech note, Intertechnology 1995 and Composites Australia 2012). However, Abdullah et al. (2009) believe that trends in experimental results can be used to evaluate the failure type.

Experts in the field have devised many different models in order to predict fatigue failure. Pupurs and Varna (2011) has developed their own model based on Paris Law that uses an analytical solution to model energy release rate to predict failure in long debonds. For short debonds, Pupurs and Varna (2011) suggests FEM modelling in conjunction with the virtual crack closure technique. Zhifei et al. (2008, p. 2248) developed a method of using commercial Finite Element Analysis (FEA) packages and incorporating the energy release rates utilized in Paris Law to approximate the fatigue damage of fibre reinforced composites in fatigue. Andersons and Paramonov (2011) 'believe the most accurate method of fatigue life estimation… is by the modified Goodman diagram' (p. 1708).

Puck's criterion is utilised by Sun et al. (2012, p. 452) to produce master curves from the Accelerated Testing Method (ATM) to determine uniaxial and multiaxial fatigue failure, 'both uniaxial S-N curves can be derived from the fatigue model' (Sun et al. 2012, p. 453). Abdullah et al. (2009, p. 44) used MATLAB to develop a mathematical model to predict fatigue failure. The authors used experimental data to create 'numerical computational algorithm which uses a correlation between the delamination growth rate and crack growth' Abdullah et al. (2009, p. 48). Abdullah et al. (2009, p. 51) further produced experimental results suggesting 'that the available model is qu[ite] sufficient to predict crack growth in fibre metal laminate'.

Despite the ambiguity regarding the fatigue strength of fibre composites, many researchers suggest that adding fibre composite materials to structural applications will greatly increase the fatigue life of these components. NASAeClips (2010) believes that composites are the future material for all applications. ATL composites Australia (2011) uses composite marine frames in the ocean where there is no shortage of fatigue and Abdullah et al. (2009, p. 44) claims that fibre metal laminates significantly improves the fatigue life of light weight aerospace structure. This statement is greatly supported by Eurofighter Jagdflugzeug (2012). Botelho et al, (2008, p. 3166) agrees with the advantages regarding fatigue life by using composites in aerospace structures but raise their concern with the reparability of composites.

'Due to the high fatigue strength of composites', Yu et al. (2011, p. 558) suggest that 'introducing composites into concrete can significantly improve the fatigue life of concrete beams in structures'. This statement is supported by self-devised experiments by the authors.

Whilst reviewing literature for this project, other factors, not discussed in detail in the previous section, became apparent. These factors include, but are not limited to, the thermal environment (Bettini et al. 2011and Manjunatha et al. 2010 and Mivehchi & Varvani-Farahani 2010), the over usage of filler materials (Bettini et al. 2011and Ferreira et al. 2010), additives such as nanoparticles and carbon nanotubes (Bettini et al. 2011and Limin et al. 2010), surface conditions (As per book MEC3203, 2012 and MEC1201, 2009) and different cyclic loading cases (Jung-Hun et al. 2010, p. 2615 and van Paepegem and Degrieck 2004)

Fibre composite materials are becoming more commonly used and better understood than ever. Many researchers use well known methods like the Goodman diagram and models such as the Paris Law or Puck's Criterion to evaluate the fatigue failure modes, fatigue strength and fatigue characteristics of fibre composites. While each of the methods and models carry individual merit, a general consensus leans toward the need for a standardization of failure models and fatigue prediction models to be constructed. Although some claim that fibre composites have poor fatigue life and low fatigue properties, most research suggests that composites are very good materials to use in highly cycled applications.

After examining the current available literature, it suggests that more uniform studies and experiments need to be done and results must be published in a much more rigid structure, addressing the categorisation and standardisation of fatigue behaviour in fibre composite materials. For the purpose of this project, due to a lack of standardised fatigue testing methods, the rollers will be tested with an apparatus constructed to simulate in situ circumstances. Methodology section 3.2.2 provides further information.

2.3 Occupational Health and Safety

The Australian Government Department of Education, Employment and Workplace Relations originated the Work Health and Safety Bill in 2011 that was adopted as the Work Health and Safety Act in 2011(ComLaw, 2011). This act relates to work health and safety, and for related purposes. ComLaw (2011) describes that the main purpose of this act '*is to provide for a balanced and nationally consistent framework to secure the health and safety of workers and workplaces by:*

(a) protecting workers and other persons against harm to their health, safety and welfare through the elimination or minimisation of risks arising from work; and

(b) providing for fair and effective workplace representation, consultation, co-operation and issue resolution in relation to work health and safety; and

(c) encouraging unions and employer organisations to take a constructive role in promoting improvements in work health and safety practices, and assisting persons conducting businesses or undertakings and workers to achieve a healthier and safer working environment; and

(d) promoting the provision of advice, information, education and training in relation to work health and safety; and

(e) securing compliance with this Act through effective and appropriate compliance and enforcement measures; and

(f) ensuring appropriate scrutiny and review of actions taken by persons exercising powers and performing functions under this Act; and

(g) providing a framework for continuous improvement and progressively higher standards of work health and safety; and

(h) maintaining and strengthening the national harmonisation of laws relating to work health and safety and to facilitate a consistent national approach to work health and safety in this jurisdiction'.

Queensland government falls under the national Work Health and Safety Act and shows the Workplace Health and Safety (WHS) (2013) overview in Figure 2-31:

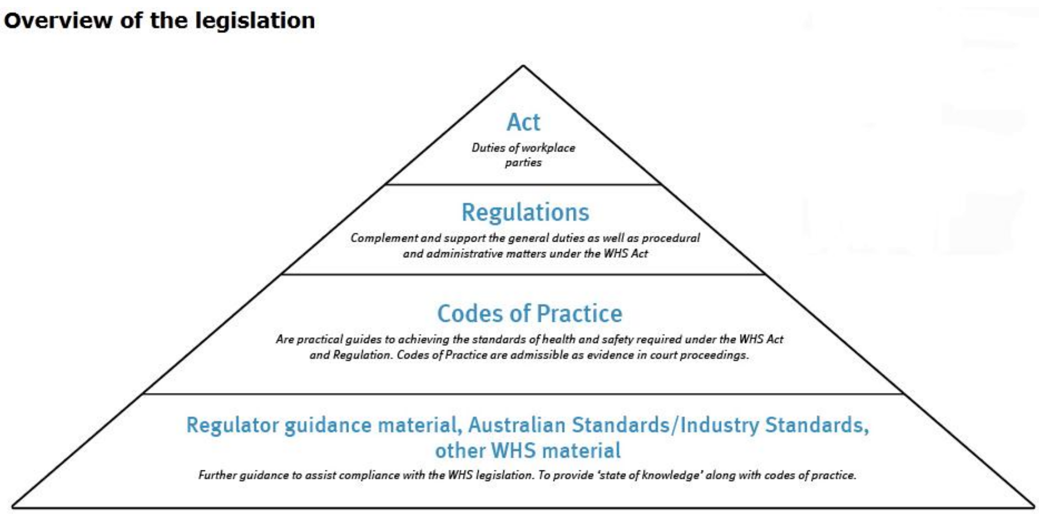

Figure 2-31: Overview of legislation

WHS is the responsibility of all parties involved in the industry. This project specifically addresses the following points:

(a) *protecting workers and other persons against harm to their health, safety and welfare through the elimination or minimisation of risks arising from work; and*

(g) providing a framework for continuous improvement and progressively higher standards of work health and safety.

This project aims to address the WHS issues by minimising the risk of injury caused by heavy idler rollers (currently used in the Australian mining industry) through improving the acceptable and practised standards in the mining work place.

For the purpose of this study two de-identified case studies, a work place safety alert and WHS statistics were used to support the need for the development of light weight idler rollers.

2.3.1 Case study A – Steve

Steve is a Coal Mine Worker (CMW) that works on B crew in a Queensland underground coal mine[1]. Steve is part of the belt crew that commissions and decommissions underground conveyor structure. During November 2012, Steve was installing idler rollers on a maingate conveyor on night shift. This conveyor was approximately 1.6 m suspended in the air and required Steve's team to use ladders to install the rollers.

[1] Personnel and the company wishes to remain anonymous, thus the case study has been de-identified. Author has further information as required.

Steve picked up one half of a suspended roller assembly, as illustrated in Figure 1-7, weighing in excess of 80 kg. With the assembly held in one hand, Steve made his way up the ladder using his free right-hand to support himself. As Steve reached the required height for roller installation, he extended himself towards the hitch point still holding the ladder rails with his right hand. This particularly awkward manoeuvre, together with the large weight of the roller assembly, caused Steve's disc between backbones L4 and L 5 to bulge and pinch the sciatic nerve. Steve immediately dropped the assembly and fell off the ladder to the ground whilst complaining of extreme and back and leg pain. Steve had to be collected with an underground ambulance and taken to hospital. Steve was unable to continue his usual occupation for more than six months.

The incident report recommendations included installing the rollers on the ground before the structure is lifted into position as an interim solution; and calling for a lighter idler roller and roller assembly as a permanent solution.

2.3.2 Case study B – Liam

Liam is a CMW who works at a Queensland-based open cut mine[2]. He is part of a maintenance crew on a coal preparation plant that deals mostly with stacker conveyors (as shown in Figure 1-5), overland conveyors and coal processing equipment. As part of the normal maintenance regime idler rollers are changed every 10,000 operation hours. This means that Liam and his team must replace thousands of rollers over a few weeks. Rollers are usually situated close to the positions they operate in with mechanical help, such as forklifts and cranes. Unfortunately cranes cannot reach the tallest sections of the stacker conveyors and CMWs must carry the new rollers to the installation positions, and also carry the old rollers back to the pallet.

During January 2013, Liam's crew was assigned to a plant shutdown that required an overhaul of most of the plant's conveyors. Liam carried many rollers up the walkways of the stacker conveyors. Most of these conveyors only had access to one side of the conveyor, and therefore rollers on the far side must have been placed by stretching over the structure and placing them in position. On the third day of roller interchange, Liam was assigned to the stacker tower to start replacing the old rollers.

Liam completed the day's task by walking up the tower with a roller under each arm; then placing both the rollers at his feet, reaching over and taking out one roller at a time and replacing them with the new rollers. This procedure was common practice and required the CMW to plant his/her feet

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[2] Personnel and the company wishes to remain anonymous, thus the case study has been de-identified. Author has further information as required.

parallel with the conveyor and twisting the upper body towards the left to reach the conveyor structure.

When Liam got home he started to complain about back pain. The next morning Liam struggled to get out of bed and called in sick. The company's policy required Liam to go and see a doctor. The doctor booked Liam off for two weeks due to repetitive strain injury to his lower back. As this injury required Liam to be suspended from his usual occupation, it was required by law to document this incident as a recordable injury.

The filed incident report obliged the maintenance team to alternate jobs more regularly, as well as suggested that lighter idler rollers needed to be obtained.

2.3.3 Queensland based company Safety Alert

The safety alert shown on the next page highlights a very high risk near miss that involved a dislodged roller falling to the ground from a height of about 8 m[3]. The safety alert also highlighted a similar incident that involved a very heavy idler roller from a much larger height. Although lighter idler rollers might not completely eliminate the risk of serious injury or death due to idler rollers plunging to the ground, it should significantly reduce the seriousness of the incidents.

If a roller weighed roughly half the weight of a standard roller, it will hit the ground with approximately half the kinetic energy. This is a significant reduction in the potential to cause harm to a human.

[3] The company wishes to remain anonymous. The Author can provide details if further information is required.

PLEASE ENSURE A COPY IS PLACED UPON YOUR WHS NOTICEBOARDS

SAFETY ALERT

[redacted]

Safety Alert No. 008 [redacted] 2/10/2013

Near Miss from Falling Object – Conveyor Roller

A High Risk near miss occurrence recently occurred on the Toowoomba site involving a 1kg object falling from height.

On the 17th of September a worker was standing underneath an operating conveyor which was 8m overhead. Without warning one of the rollers became dislodged from the underside of the belt and fell to the ground, very narrowly missing the worker. The worker was wearing a hard hat at the time as well as all other required PPE.

The roller in question weighed 1kg in mass and fell from a height of 8m. This would certainly result in a major injury in the event of striking a worker. This is not the first time this type of incident has occurred in the industry, as evidenced by this excerpt from a recent Mining and Quarrying Department alert:

"A conveyor return roller weighing approximately 15kg fell 15m to the ground from a product conveyor in a process plant."

The risk of falling objects from overhead plant and structures must be considered and controlled in the workplace. **Recommended controls may include;**

- The implementation of a scheduled maintenance checklist involving the inspection and required repairs for conveyor systems,
- The mandatory wearing of safety helmets in the presence of any overhead moving parts,
- The implementation of guarding underneath conveyor systems (entire length),
- Physical exclusion zones implemented around overhead conveyor systems,
- The implementation of overhead cage guarding where walkways are unavoidable under conveyor systems.

One or more of the above controls may be implemented based on a risk assessment carried out on the applicable plant. The aim is to reduce the risk of injury to "As Low As Reasonably Practicable", (ALARP).

Supervisors and Managers in applicable worksites please toolbox this occurrence and the potential risks associated with your own worksite concerning falling objects from height and investigate the implementation of control/s to reduce the risk of injury.

[redacted]
Safety Advisor

THIS SAFETY ALERT APPLIES TO ALL EMPLOYEES, CONTRACTORS AND SUB-CONTRACTORS ACROSS THE [redacted] OF COMPANIES.

WORKING TOGETHER SAFELY

2.3.4 WHS statistics

For the purpose of this project the Workplace Health and Safety statistics were reviewed and reported in two sections. Section 2.3.4.1 reports on the national statistics and section 2.3.4.2 reports specifically on Queensland mining WHS statistics.

2.3.4.1 Key WHS Statistics, Australia

Safe Work Australia (SWA) is an Australian government department that is involved with the coordination and development of national policy and strategies (SWA 2013). Safe Work Australia also assists the implementation of model work health and safety legislation and undertakes studies in the workforce. The data collected is used to reform current legislation and provide a formal national WHS feedback platform.

SWA releases an annual publication named the *Key Work Health and Safety Statistics, Australia (KWHSSA)*. This publication summarises the national WHS performance of the previous years. As part of this project the 2011, 2012 and 2013 reports were reviewed and important information is highlighted in the following sections (section 2.3.4.1.1 to section 2.3.4.1.3).

2.3.4.1.1 Key Work Health and Safety Statistics, Australia 2011

The first graph plots the nature of injury or disease most commonly reported as a serious claim in the 2008-09p (KWHSSA, 2011). It is evident from Figure 2-32 that the majority of serious claims were due to sprains and strains of joints and adjacent muscles.

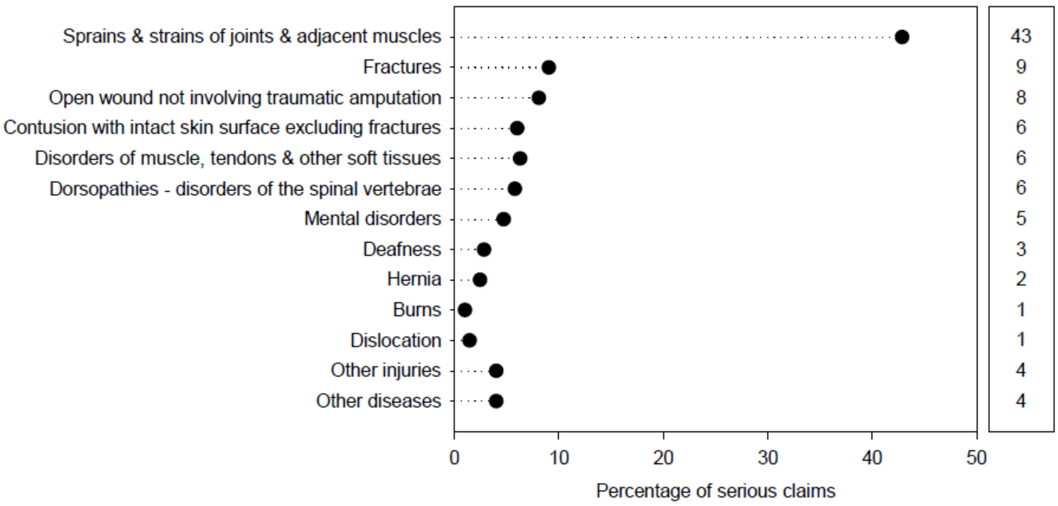


Figure 2-32: Serious claims: % by nature of injury (KWHSSA 2011)

Figure 2-33 plots the mechanism of injury or disease for the 2008-09p (KWHSSA 2011) and indicates that body stress was the most common injury mechanism for serious claims.

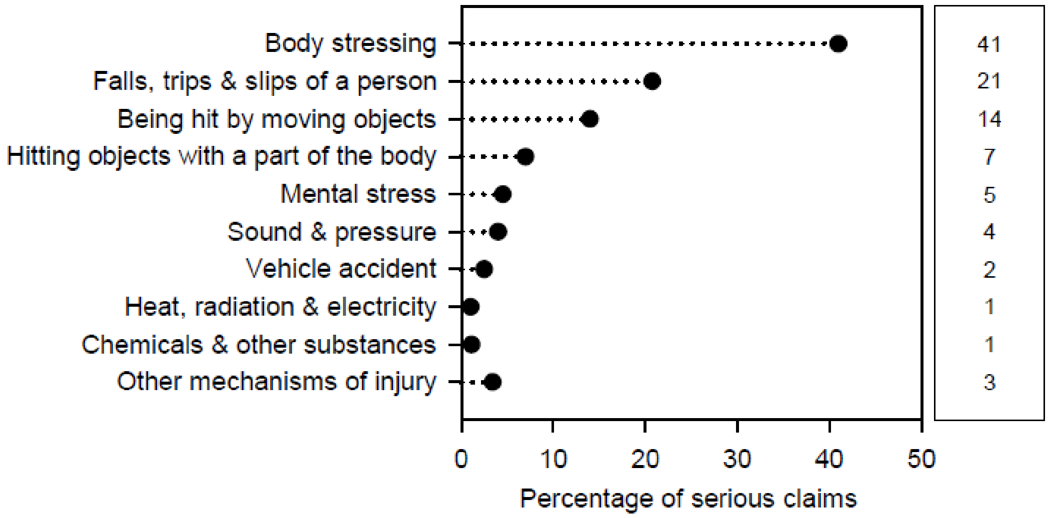


Figure 2-33: Serious claims: % by mechanism of injury (KWHSSA 2011)

The KWHSSA 2011 report shows the serious nature of sprain and strain of joints and adjacent muscle type injury, caused by mostly body over stressing. These two factors are significantly higher than any other type of injury or cause of injury.

2.3.4.1.2 Key Work Health and Safety Statistics, Australia 2012

Figure 2-34 illustrates the nature of injury or disease most commonly reported as a serious claim in the 2009-10p (KWHSSA, 2012). It is apparent that sprains and strains of joints and adjacent muscles are four times higher than any other injury nature.

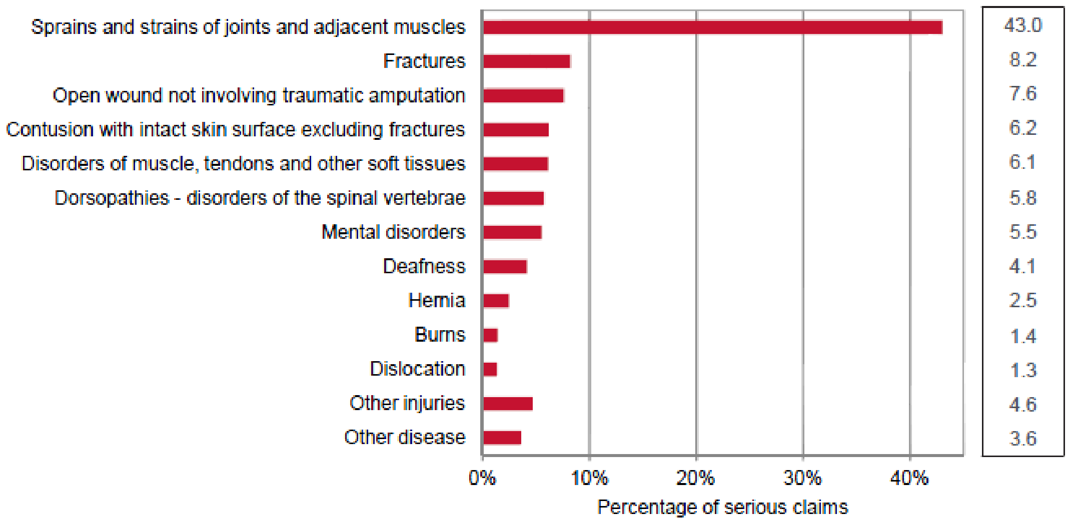


Figure 2-34: Serious claims: % by nature of injury (KWHSSA 2012)

Figure 2-35 highlights the injury mechanism for serious claims. As the year before, body stressing is almost twice as likely to be the mechanism of injury as any other mechanism (KWHSSA 2012).

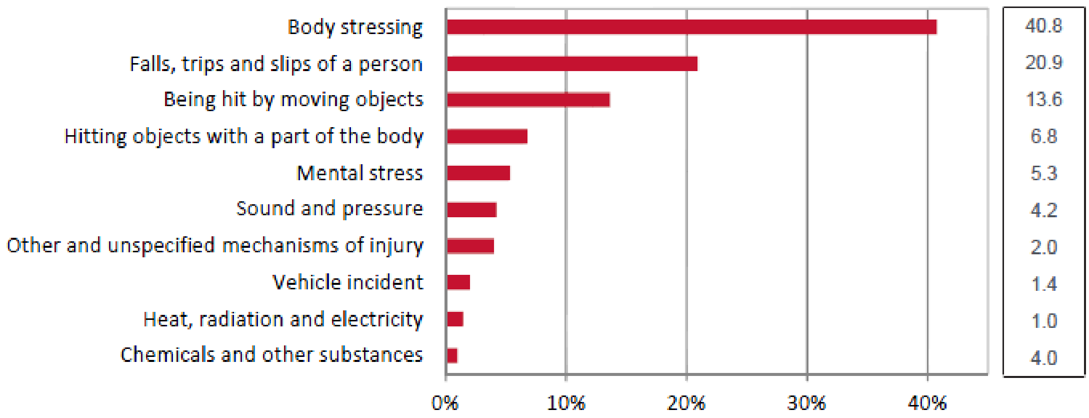


Figure 2-35: Serious claims: % by mechanism of injury (KWHSSA 2012)

The KWHSSA 2012 report shows very similar concerns regarding the injury type and injury mechanism as the year before. These injury mechanisms are predominantly body over stressing, possibly caused by manual labour and handling, which can lead to sprains and strains of joints and adjacent muscles.

2.3.4.1.3 Key Work Health and Safety Statistics, Australia 2013

The 2013 KWHSSA report is much more detailed than the previous years with a very interesting elaboration on incident rates with respect to occupation. Figure 2-36 plots the number of serious claims per 1000 employees grouped in occupation types.

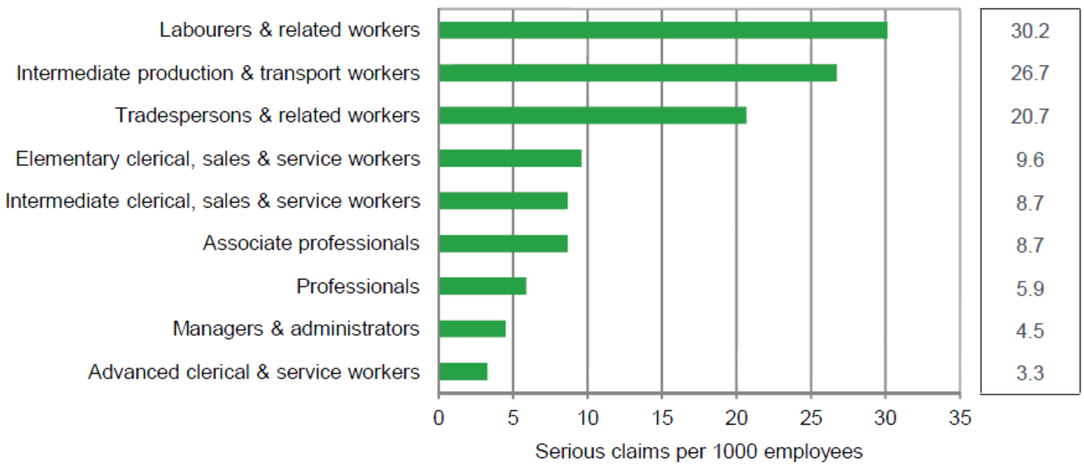


Figure 2-36: Serious claims: incidence by occupation (KWHSSA 2013)

This plot confirms that labourers and transport workers are most likely to be part of injury inducing instances than any other worker. It is well known that labour and logistics workers most do manual tasks that involve manual handing.

The KWHSSA 2012 report shows the exact trends with respect to injury type and injury mechanisms as the two previous reports, the KWHSSA 2011 and KWHSSA 2012 reports. Figure 2-37 illustrates the continuing trend of sprains and strains of joints and adjacent muscles as the leading nature of injury. It is evident from Figure 2-38 that body stressing remains the most common injury mechanism for serious claims.

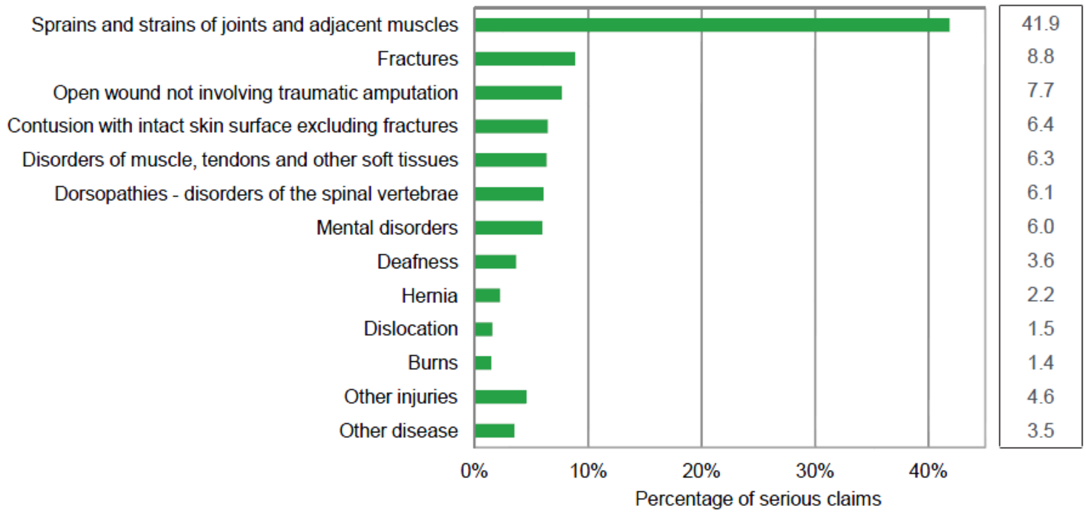


Figure 2-37: Serious claims: % by nature of injury (KWHSSA 2013)

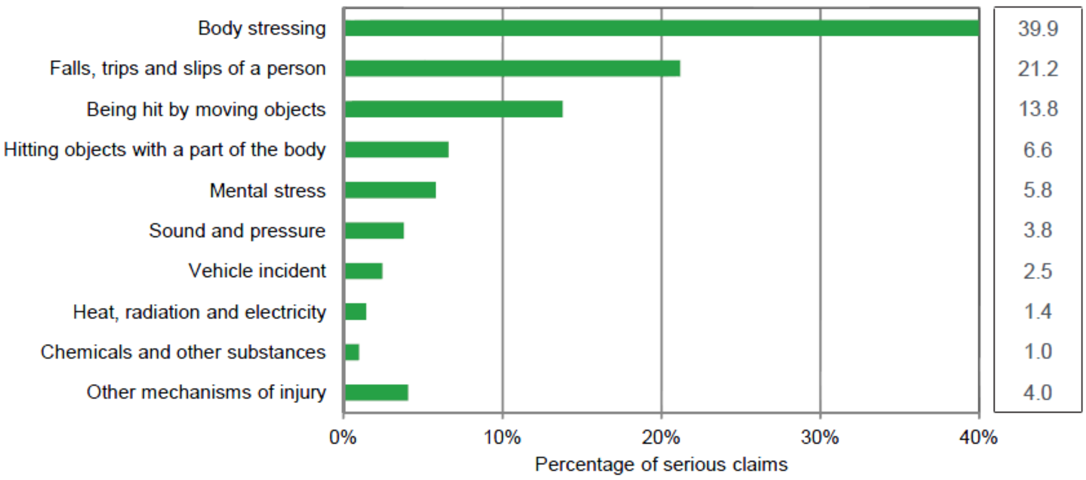


Figure 2-38: Serious claims: % by mechanism of injury (KWHSSA 2013)

The last excerpt shown from the KWHSSA 2013 report is Table 2-3 that shows the number of fatalities by mechanism of injury.

Table 2-3: Number injury fatalities by injury mechanism (KWHSSA 2013)

Mechanism of injury	2008–09	2009–10	2010–11
Vehicle incident	133	103	79
Falls from a height	34	24	29
Being hit by moving objects	36	23	27
Being hit by falling objects	22	18	26
Electrocution	9	13	12
Being trapped between stationary & moving objects	12	9	13
Being trapped by moving machinery or equipment	8	7	11
All other mechanisms	35	23	23
Total	**289**	**220**	**220**

This table highlights a very important issue that corresponds with the safety alert discussed in section 2.3.3. Heavy objects falling from heights poses a serious danger.

2.3.4.2 Queensland Government

The Department of Natural Resources and Mines (DNRM) in Queensland identifies important safety and health aspects on their website (www.mines.industry.gld.og.au), including Lost Time Injury (LTI) statistics. The DNRM collects data and publishes the results for each sub section individually. The illustrations in this section pertain directly to coal mining in Queensland.

Figure 2-39 and Figure 2-40 show that back injuries are the second most common injury found in underground mining and the most common injury encountered in open cut mines, during the period of July 2007 to July 2012.

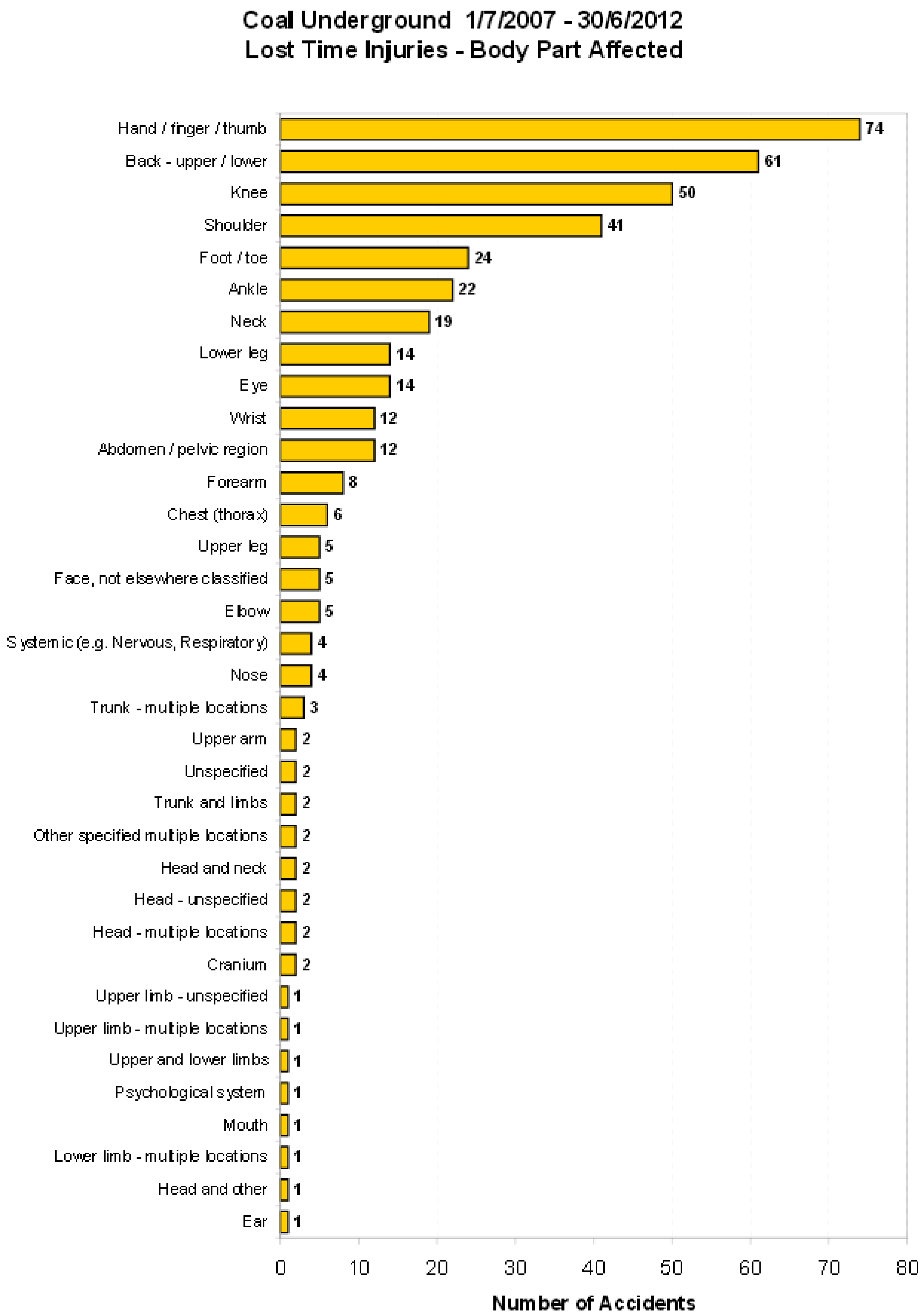


Figure 2-39: LTI - Body parts affected (DNRM 2013)

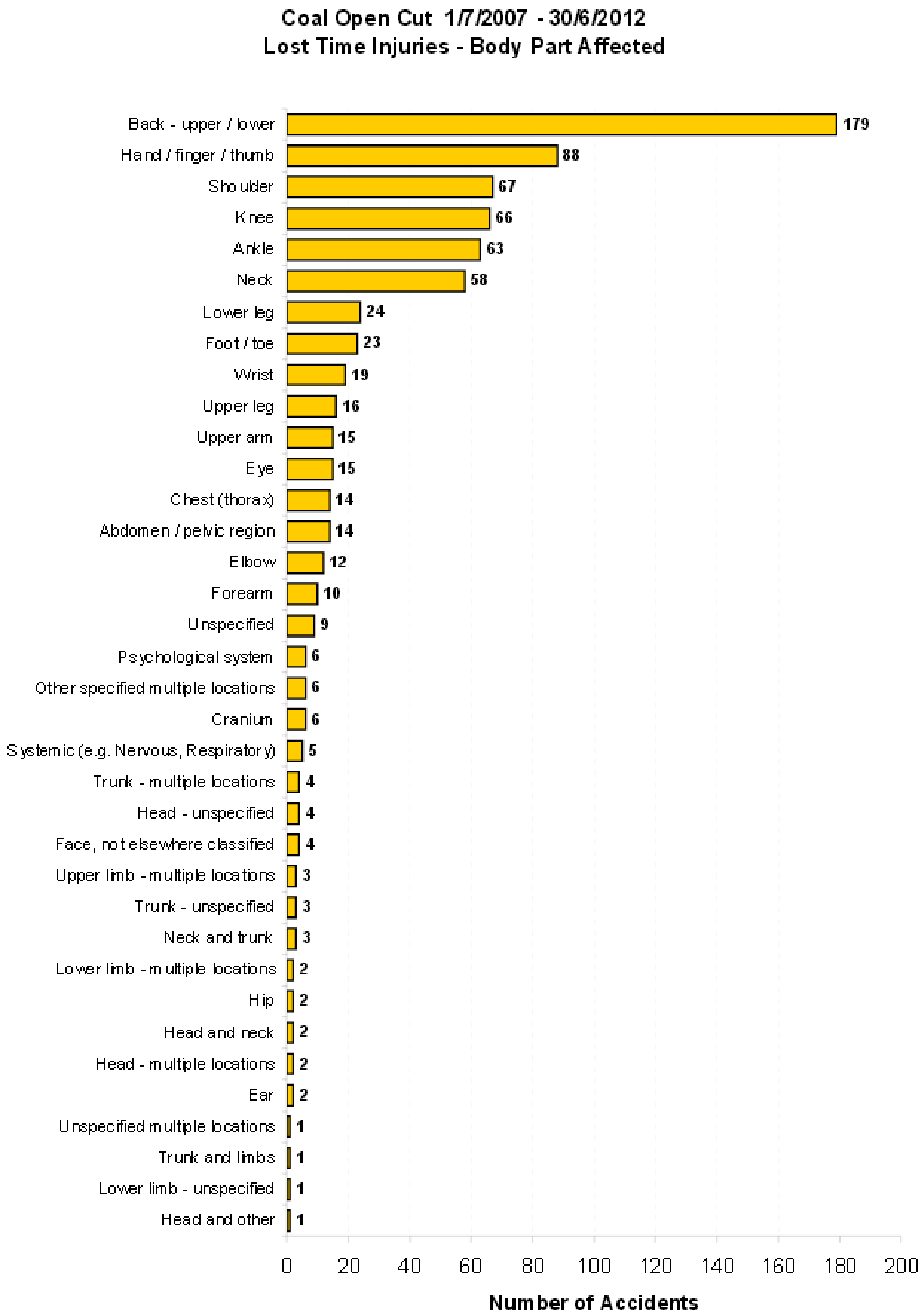


Figure 2-40: LTI - Body parts affected (DNRM 2013)

Figure 2-41 shows that manual handling is the most commonly encountered hazard in underground mines. This is most likely due to the nature of underground work where mechanical help is limited due to low roof clearance and rib to rib allowance. Figure 2-42 shows that manual handing hazards are also very common on open cut mines.

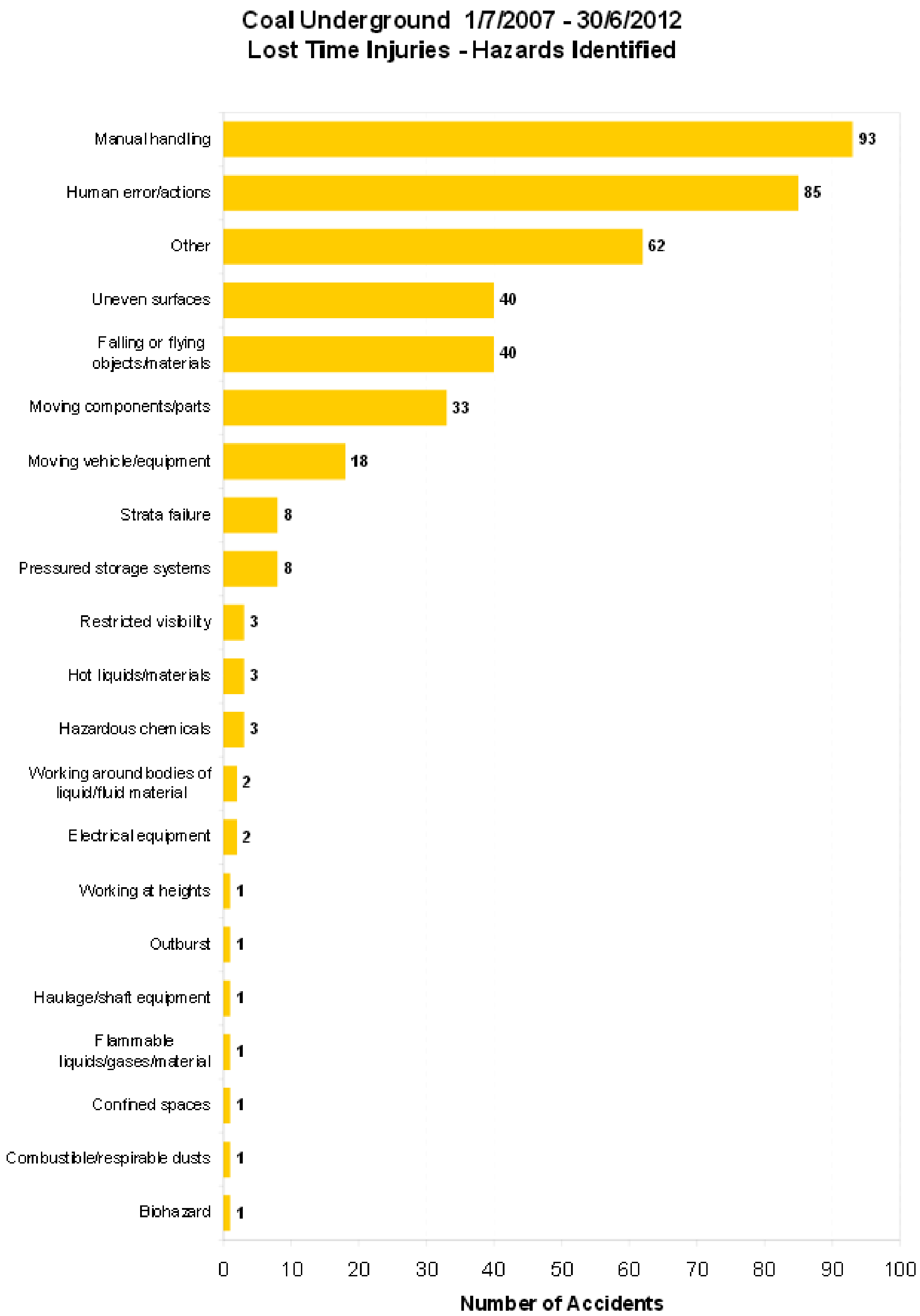


Figure 2-41: Hazards that cause LTI's (DNRM 2013)

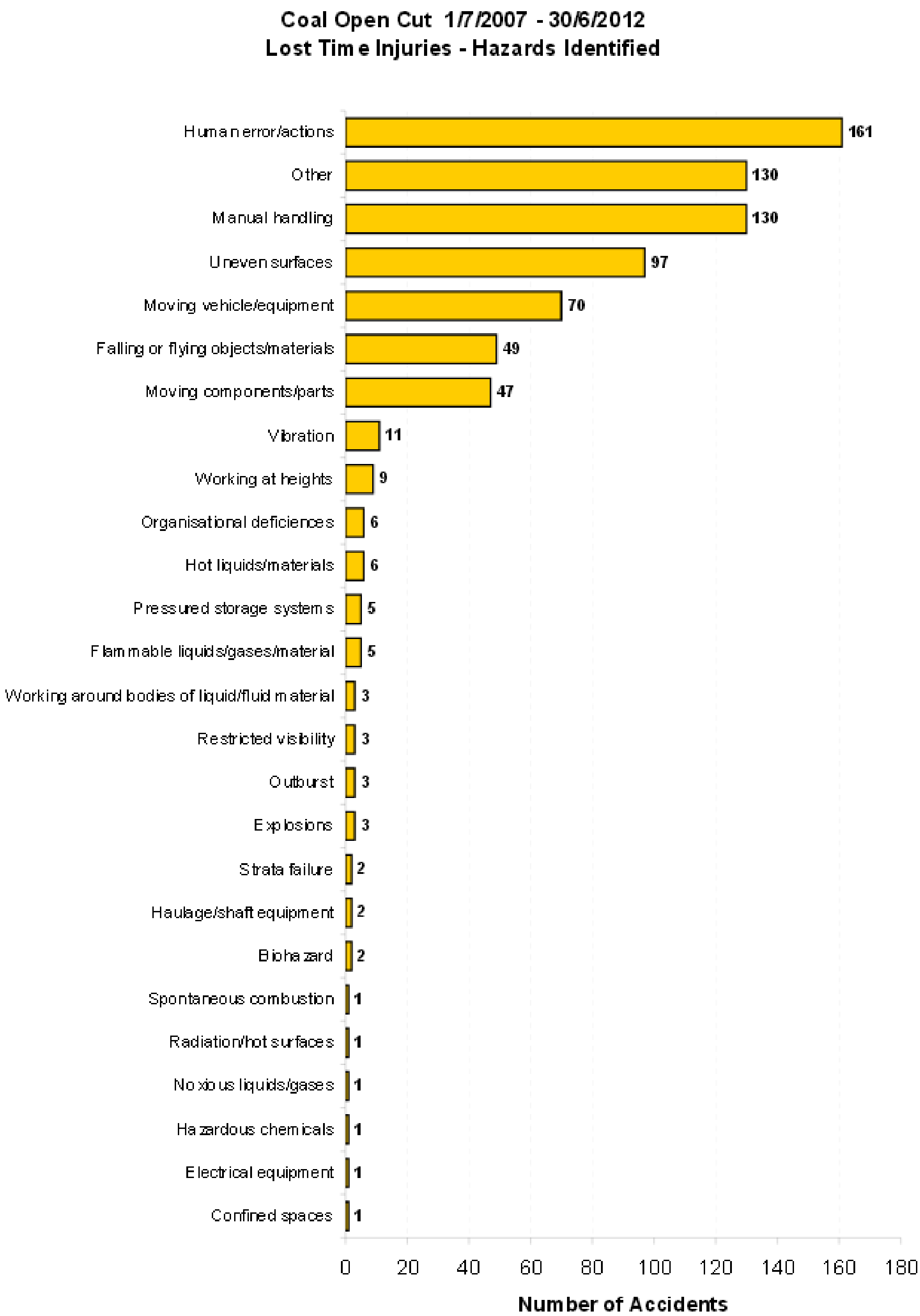


Figure 2-42: Hazards that cause LTI's (DNRM 2013)

The last two sets of plots summarise the DNRM's findings. Figure 2-43 shows the injury type trends in underground coal mining (top) and open cut mining (bottom) and Figure 2-44 portrays the injury mechanism trends in underground coal mining (top) and open cut mining (bottom).

Figure 2-43: LTI – Injury type (adapted from DNRM 2013)

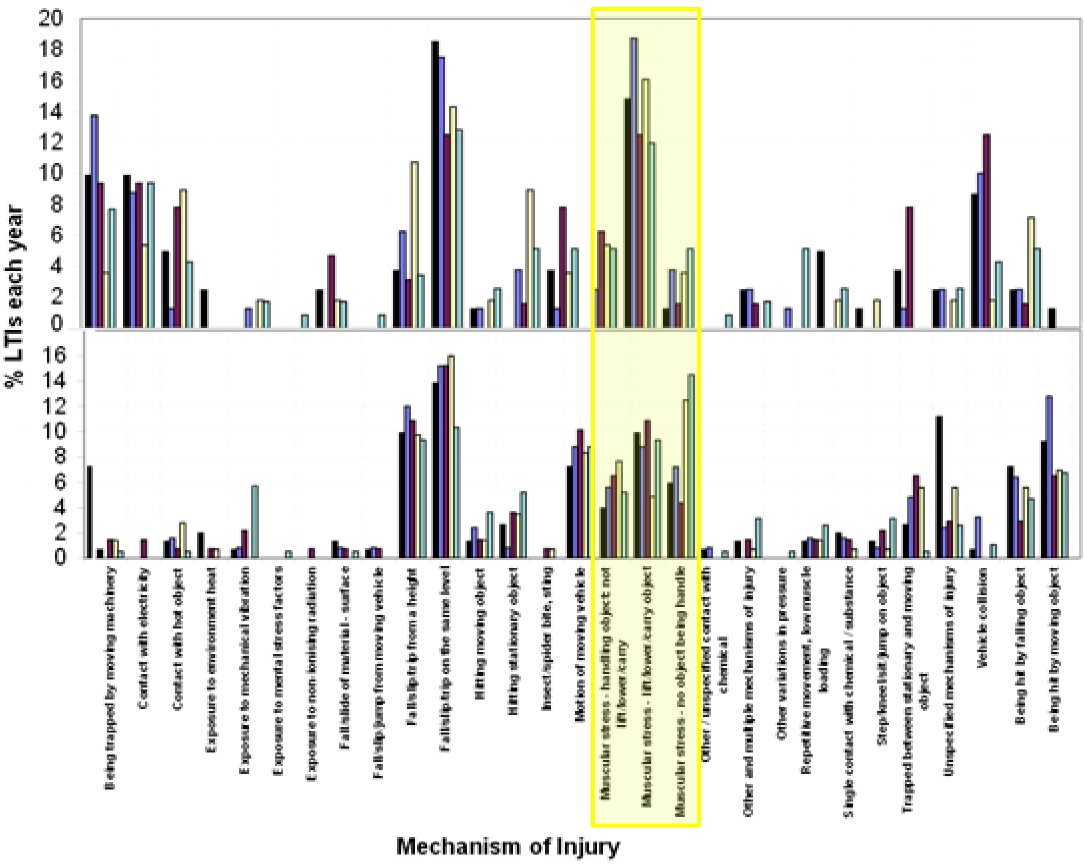


Figure 2-44: LTI – Injury mechanism (adapted from DNRM 2013)

The various colours of the bars indicated various years:

- Black: 2007-08
- Purple: 2008-09
- Pink: 2009-10
- Yellow: 2010-11
- Turquoise: 2011-12.

Figure 2-43 highlights that muscular strains and sprains are the highest occurring LTI type in both underground and open cut mining. The highlighted section Figure 2-44 shows the muscular stress related to manual handling, lifting objects and carrying objects. This mechanism is the highest LTI mechanism in underground mining and a significant contributor in open cut mines

2.3.4.3 WHS statistics final remarks

The two case studies, a safety alert and WHS statistics all point to a serious problem within the current workforce with regards to manual handling, body over stressing and labour intensive tasks. Labour and logistics workers are at the highest risk of injury. The most common type of injuries are sprains and strains of joints and adjacent muscles with the most common injury mechanism being over stressing the body. It is reasonable to suggest that manual handling was the largest contributor to injury statistics. According to the European Agency for Safety and Health at Work (2010), the major problem with manual handling is the possibility and high likelihood of damage to the musculoskeletal system of the body. The two most important factors in manual handling operations are the object's weight and frequency of interaction (European Agency for Safety and Health at work 2010). Other contributing factors include insufficient rest between lifts or continuously performing the same movement and awkward posture (European Agency for Safety and Health at Work 2010).

Personnel involved in the commissioning, maintenance or decommissioning of conveyors often encounter a combination of heavy loads, frequent interaction, continuously performing the same movement and awkward postures. The last three aspects can be managed by frequent breaks, role and task assignment rotation schedules and design improvements. However, the only way to eliminate heavy loads is by introducing mechanical help or reducing the weight of the object itself. As discussed in previous sections, it is not practical or possible to provide mechanical help on tall towers or in underground mines. Therefore, a real need to reduce the weight of idler rollers exists and many companies, for example BMA and Wagners, have voiced their interest in this area.

2.3.5 Conclusion

This chapter reviewed the need for conveyors in modern industry as well of the technologies involved with conveyors. Both ferrous and non-ferrous idler rollers have been examined and it is clear that most non-ferrous rollers do not stand up to steel rollers, however there is a growing need for lighter non-ferrous rollers in the industry. The polymer roller industry cannot supply rollers in excess of about 500 mm and therefore leaves a large market void of rollers in larger sizes.

Various conveyor belt design manuals are currently in use around the conveyor idler design industry. The most relevant design manual for this project is the Dunlop design manual and the Rulmeca roller loading determination equation set is the best guide for engineering calculations.

Testing theory was investigated to develop the testing regime required to determine the section properties of the continuously pultruded glass fibre reinforced vinyl ester composite. The testing includes a standard four-point bend test, a shear test and due to a lack of industry experience and standards, a specifically designed fatigue test that simulates the performance environment of an idler roller.

The workplace health and safety section highlighted a serious problem with respect to manual handling and more specifically conveyor related operations in Australia and Queensland, while the remainder of the literature reviewed strongly suggests the need for a lighter non-ferrous idler roller on conveyors, especially in the mining and resourcing sector. The findings of this literature review were instrumental to the development of the well informed methodology that follows.

Chapter 3

Methodology

The purpose of this chapter is to develop the methodology used in this project by discussing the steps taken in the design phase, test phase, analysis and final design phase. The methodology overview can be seen in the flowchart labelled Figure 3-1. The flowchart maps the remainder of this project, paying particular attention to the methodology. The flowchart shows the various sections of this project in an intricately interlinked system starting with the initial design phase and ending with the final project chapters.

The design and test phases of the methodology overview are directly applicable to this chapter. Firstly, the design phase details how the information gathered from literature and testing was used, in conjunction with the Dunlop and Rulmeca design manuals, to design a prototype idler roller. The prototype idler design is comprehensively illustrated and the construction methods discussed. The final step, deliberated in the design phase, was building the prototype.

The second phase, the design phase, incorporated testing the prototype roller through static and dynamic testing. The test results together with manual calculations were used to validate the FEA modelling.

The data gathered from the test phase is reported in Chapter 4 and the data analysis forms Chapter 5. The information gathered from the testing regime was used to determine whether Wagners CFT's CHS was an appropriate and suitable material for the construction of conveyor belt idler rollers. Lastly 5" and 7" OD CHS was analysed using FEA and considered for the final idler roller design.

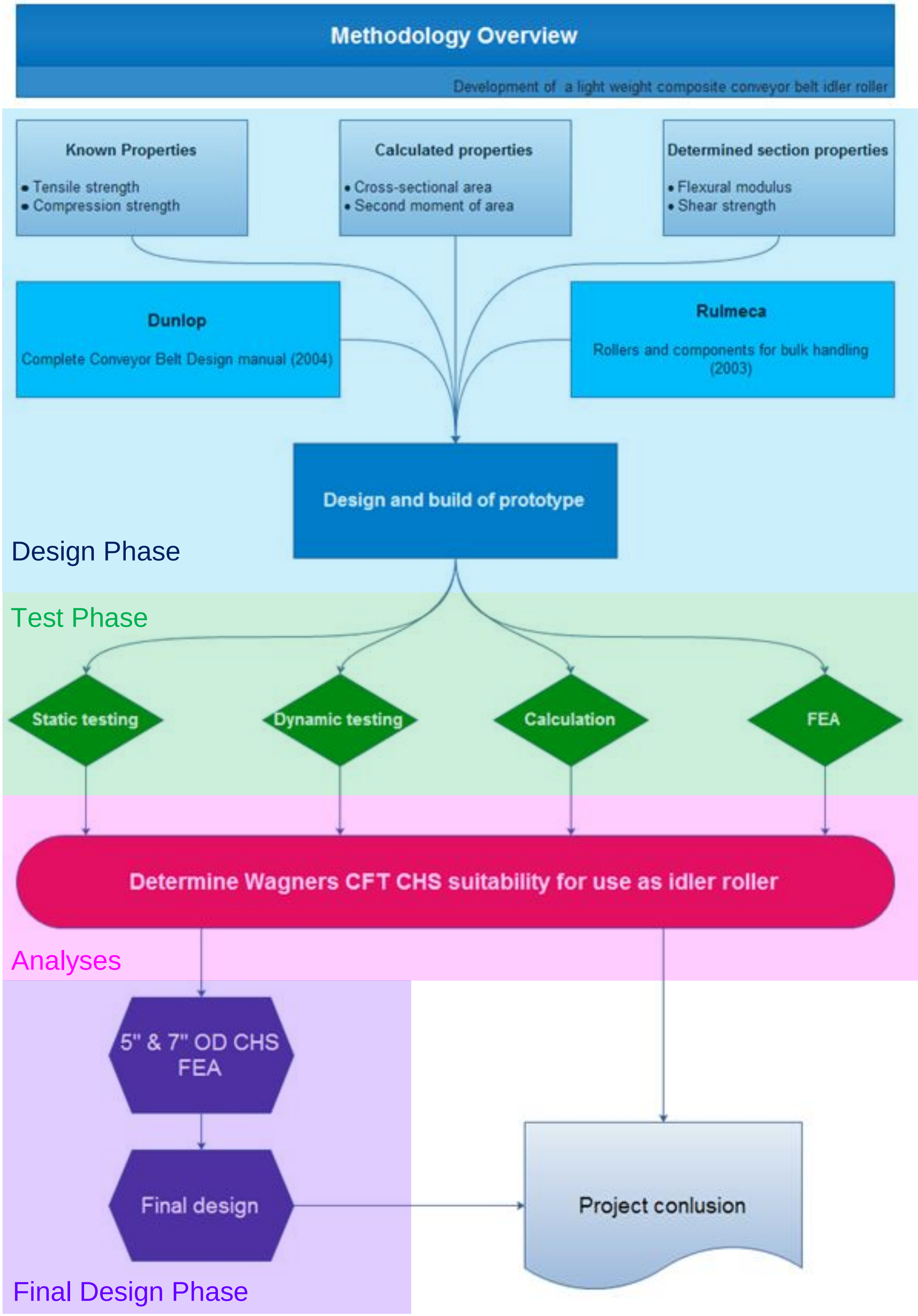


Figure 3-1: Methodology overview

3.1 Design Phase

The design phase was one of the core engineering aspects of this project. It involved using a combination of known, calculated and determined section properties together with industrial guidelines to plan the details of a functional idler roller. The process was achieved through engineering innovation and judgement based on information gathered through the literature review. The known and calculated properties of CHS can be found in Table 2-2 and Table 2-1. The testing regime that was used to determine the CHS section properties was based on the findings of section 2.2.2. The design manuals were used to develop correct geometrical attributes for the prototype idler roller. The last part of the design regime was to weigh similarly sized rollers alongside the prototype roller to determine the percentage of weight saving, which was a key project deliverable.

3.1.1 Determination of section properties

3.1.1.1 Flexural modulus – E (modulus of elasticity)

The four point bend test was setup in accordance with ASTM D6272-10 as described in section 2.2.2.1 and shown in Figure 3-2.

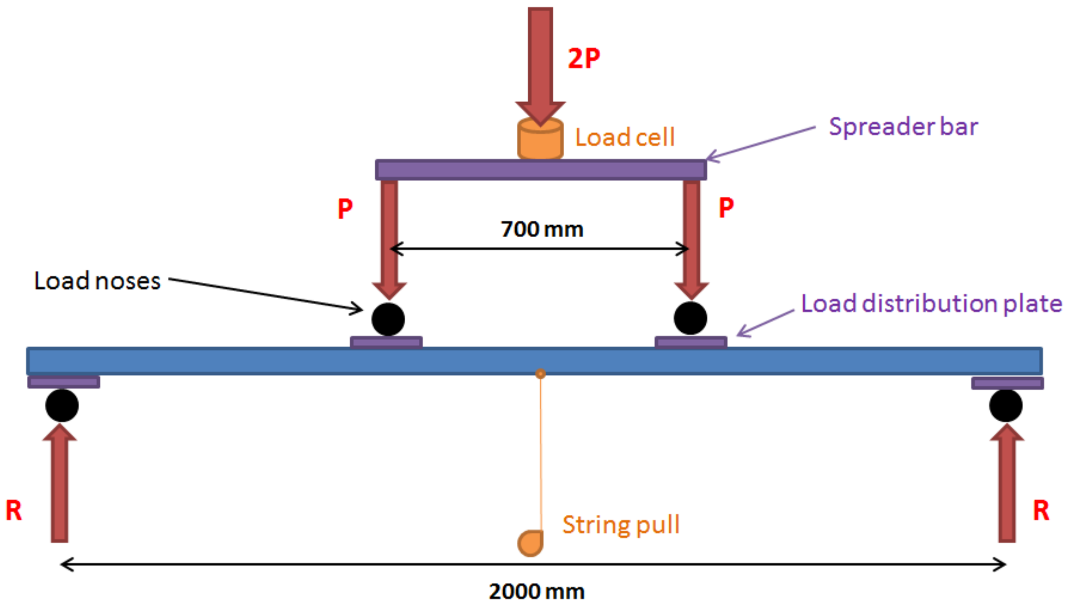


Figure 3-2: Four point bend test setup

The load cell measured the load applied (2P) to the spreader bar and the setup geometry ensured, as accurately as practically possible, that the load (P) was spread equally over the loading noses. The loading noses were round to ensure that the line of force application could be accurately measured and the test piece could rotate freely in the axis extending out of the plane (z axis). The load distribution plates safeguarded the test piece from localised bearing failure. The bearing reaction force was labelled R.

The beam mid span deflection was measured electronically by the string pull. The actual test setup used for this project can be seen in Figure 3-3.

Figure 3-3: Actual four point test setup

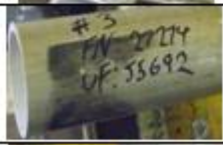
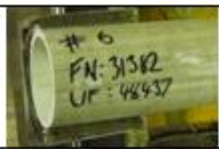
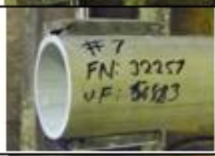
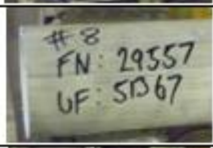
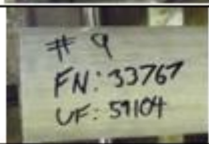
The load and deflection data was automatically recorded into a preconfigured Microsoft Excel spread sheet; presented in Figure 3-4 is an excerpt of the spread sheet (full data sheet available in appendix B). The spread sheet calculations were based on Equation 2-1 and calculated the average flexural modulus for the 10 test pieces.

	A	B	C	D	E	F	G	H	I	J
1	Date	A/Red 213 String	A/5T G10804 N	Normalised W	Deflection					
2			2P	P	?	L	a	I		E
3			N	N	mm	mm	mm	mm4		Mpa
664	8/14/2013	70.861	34598	17443.065	113.319	2000	650	1349400		31852.25
665	8/14/2013	70.285	34751	17519.565	113.895	2000	650	1349400		31830.15
666	8/14/2013	69.691	34905	17596.565	114.489	2000	650	1349400		31804.18
667	8/14/2013	69.186	35031	17659.565	114.994	2000	650	1349400		31777.88
668	8/14/2013	68.627	35193	17740.565	115.553	2000	650	1349400		31769.2
669	8/14/2013	68.15	35329	17808.565	116.03	2000	650	1349400		31759.87
670	8/14/2013	67.648	35437	17862.565	116.532	2000	650	1349400		31718.94
671	8/14/2013	67.236	35536	17912.065	116.944	2000	650	1349400		31694.78
672	8/14/2013	66.859	35644	17966.065	117.321	2000	650	1349400		31688.18
673	8/14/2013	66.48	35725	18006.565	117.7	2000	650	1349400		31657.34

Figure 3-4: Flexural modulus calculation spread sheet excerpt

The test results were automatically generated and can be seen in Table 3-1. First noise produced by test piece, comments about the test and photos as proof of testing, have been added manually in columns 2, 5 and 6.

Table 3-1: Four point bend test result table

Test #	First noise 2P (N)	Ultimate fail 2P (N)	Average E per test (MPa)	Comments	Photo
1	37 771	60 480	33020.1	Failed 2nd attempt	
2	38 435	55 844	32245.15		
3	27 274	55 692	31776.61		
4	34 716	55 166	31308.29		
5	33 579	57 419	31323.93	Jig broke – spreader bar	N/A
6	31 382	48 437	31383.83	Failed early – large amount of cracking	
7	32 257	56 883	33366.6		
8	29 557	51 367	31126.19	Heard noises early- continues till failure	
9	33 767	59 104	31204.42		
10	31 418	50 323	30947.76		

The calculated results for the average flexural modulus of the 3 ½” (88.9 mm) OD CHS was 31.77 GPa. This value was paramount in the prototype calculations as well as the FEA modelling.

3.1.1.2 Shear capacity

The three point shear test was set up in accordance with AS4100-1990 (Syam 1992) as described in section 2.2.2.4 shown in Figure 3-5.

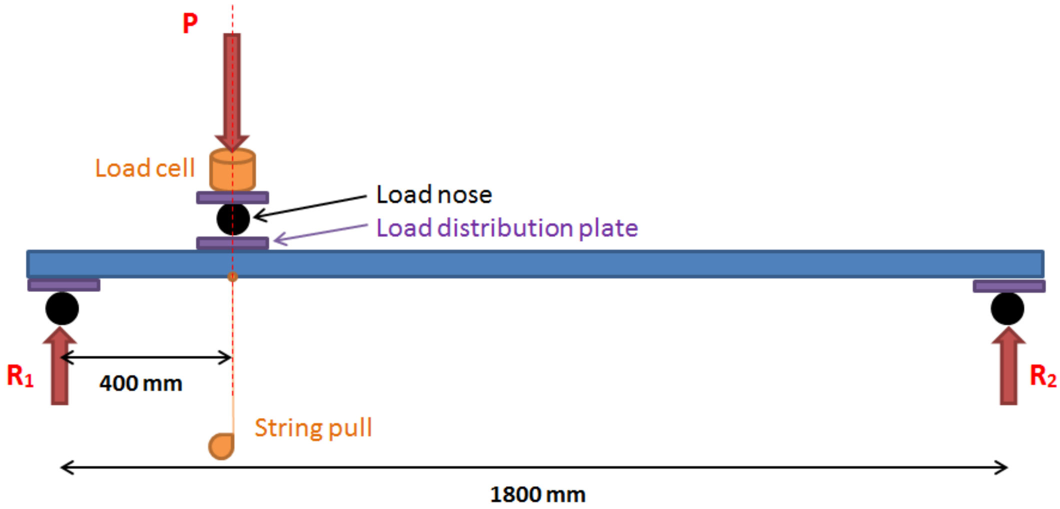


Figure 3-5: Three point shear test arrangement

The load cell measured the load applied (P) to the load nose. The loading noses were round to ensure that the line of force application could be accurately measured and the test piece could rotate freely on the axis extending out of the plane (z axis). The load distribution plates safeguarded the test piece from localised bearing failure. The bearing reaction forces were labelled R_1 and R_2. The beam deflection was measured electronically by the string pull directly under the load application point. The actual test arrangement used for this project can be seen in Figure 3-6.

Figure 3-6: Actual shear test arrangement

The load data was automatically recorded into a preconfigured Microsoft Excel spread sheet, presented in Figure 3-7, which highlighted the highest sustained load for that test run (full data sheet available in appendix B).

	A	B	C	D	E	F	G	H	I
1	Date	A/Red 213 String	A/30t 873419 N						
2		Deflexsion	P	P	Normilised Deflection	Area	b	L	Shear stress
3									τ
4		**mm**	**kN**	**N**	**mm**				**Mpa**
159	9/4/2013 12:20	281.6	50.337	50337	71.62				
160	9/4/2013 12:20	279.95	51.696	51696	73.27				
161	9/4/2013 12:20	278.19	52.547	52547	75.03				
162	9/4/2013 12:20	276.54	53.397	53397	76.68				
163	9/4/2013 12:20	274.86	54.16	54160	78.36				
164	9/4/2013 12:20	273.45	55.688	55688	79.77	1563	1400	1800	27.71138125
165	9/4/2013 12:20	266.84	-1.3145	-1314.5	86.38				
166	9/4/2013 12:20	267.36	-1.0577	-1057.7	85.86				

Figure 3-7: Shear test spread sheet excerpt

The test results were manually generated and tabulated as shown in Table 3-3. The spread sheet calculations were based on Equation 2-2 and calculated the maximum shear strength for each of the 10 test pieces. Photos, as proof of testing, have been added manually in the last column.

The calculated results for the average shear capacity of the 3 ½" (88.9 mm) OD CHS was 25.66 MPa. This value was used in the prototype calculations as well as the FEA modelling.

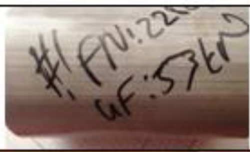
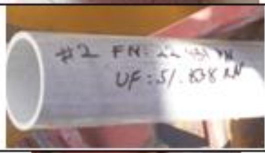
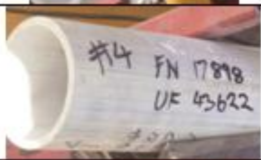
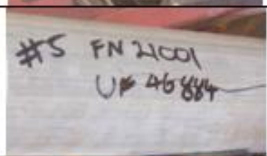
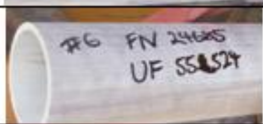
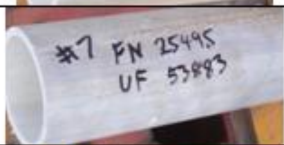
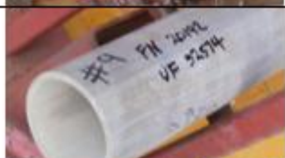
3.1.1.3 Final remarks

The conclusion of the tests to determine the section properties completed all the information needed to proceed with the design. The final section properties table is shown in Table 3-2.

Table 3-2: Final Wagners CHS section properties

Outside diameter (OD)	$D = 88.9\ mm$
Internal diameter (ID)	$d = 76.9\ mm$
Wall thickness	$t = 6\ mm$
Axial tensile strength	$S_T = > 400\ MPa$
Axial compression strength	$S_C = > 400\ MPa$
Hoop tensile strength	$S_H = 300\ MPa$
Cross-sectional area	$A_{cs} = 1563\ mm^2$
Mass	$M = 3.078\ kg \cdot m^{-1}$
Perimeter of cross-section	$P = 279.2\ mm$
External surface area	$A_S = 0.279 m^2 \cdot m^{-1}$
Second moment of area	$I_x = 1.349 \times 10^6 mm^4$
Section modulus	$Z_x = 30.36\ mm^3$
Radius of gyration	$r_x = 29.39\ mm$

Table 3-3: Shear test results

Test #	Ultimate load P (N)	Max shear capacity (MPa)	Comments	Photo
1	53 106	26.43	Failed 2nd attempt	
2	51 838	25.80		
3	55 688	27.71		
4	43 622	21.70	Very rapid loading	
5	46 884	23.33		
6	55 524	27.63		
7	53 882	26.81		
8	40 332	20.07	Dry fibre (damaged stick) - not to be counted	
9	52 574	26.16		
10	50 961	25.36		

3.1.2 Dunlop design manual

Dunlop's Complete Conveyor Belt Design manual (2004) PDF was used to guide the initial prototype design in terms of sizing, operational speed and loading. The roller diameter and bulk material properties were known since the roller design is based on the 3 ½" (88.9 mm) OD CHS for the coal mining industry. All tables in this section (section 3.1.2) were taken from Dunlop Complete Conveyor Belt Design manual (2004), therefore only the document's *table number* (in italics) and page numbers were referenced. *Table 2* (p. 10) was used to determine the bulk material characteristics of coal as shown in the excerpt in Table 3-4.

Table 3-4: Excerpt of Table 2 (p. 10)

Material	Characteristics	Suggested Grade	Bulk Density (t/m3)	Angle of Surcharge (degrees)	Max. Rec. Conv. Slope (degrees)
Coal, anthracite, 3mm and under	NA	N/PVC	0,96	20	18
Coal, anthracite, sized	NA	N/PVC	0,90	10	16
Coal, bituminous, mined 50 mesh and under	NA	N/PVC	0,83	30	24
Coal, bituminous, mined and sized	NA	N/PVC	0,80	20	16
Coal, bituminous, mined, run of mine	MA	N/PVC	0,90	25	18
Coal, bituminous, mined, slack 12mm and under	MA	N/PVC	0,75	25	22
Coal, lignite	MA	N/PVC	0,75	25	22
Cocoa beans	NA	N/GF	0,56	10	12

According to *Table 2(a)* (p. 13) coal has medium flowability and therefore requires a troughed belt to carry the maximum load per belt width without excessive spillage. Figure 3-8 shows a typical troughed belt conveyor and the geometrical relationships between components (Appendix B, p. 35).

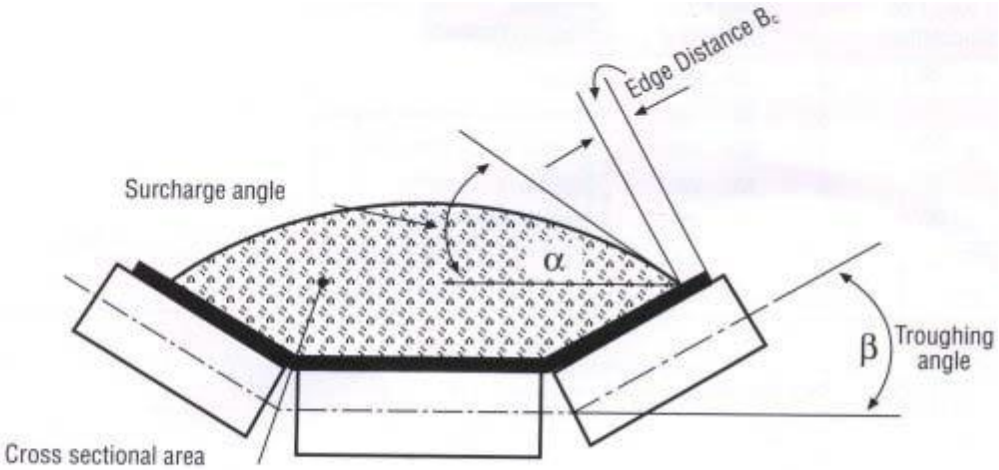
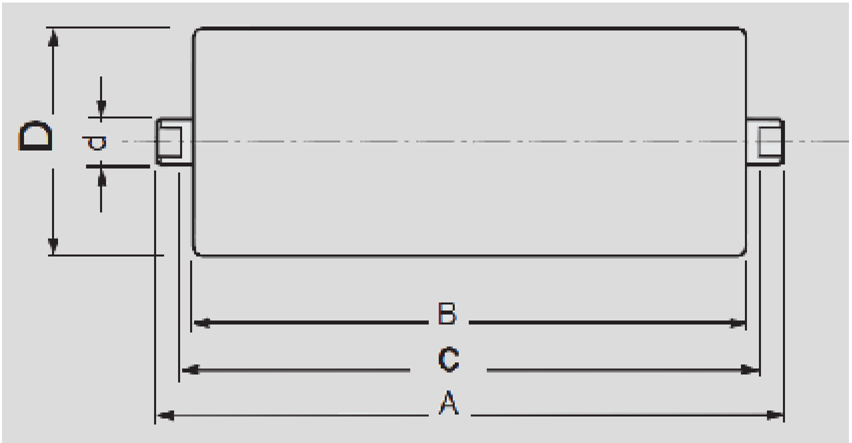


Figure 3-8: Cross sectional view of a typical troughed conveyor (p. 35)

Dunlop *Table 2(c)* (p. 14) was used to select the largest applicable roller length for rollers with an 89 mm diameter as shown in Table 3-5.

Table 3-5: Idler dimensions (p. 14)



ROLLER D mm	Belt Width Arrangements			C mm
			400	168
		300	500	208
		400	650	258
		500	750	313
	300	650		388
		800		473
	400			508
				538
89	500	1000		608
		1200		708
	650			758
		1400		808
		1600		908
	800			958
	1000			1158
	1200			1408
	1400			1608
	1600			1808

The largest roller practical for the prototype was 313 mm. In order to determine the optimum belt speed in $m \cdot s^{-1}$ for coal on a 750 mm through conveyor, *Table 4* (p.15) was used as the excerpt labelled Table 3-6 shows.

Table 3-6: Maximum belt speed ($m \cdot s^{-1}$)(p. 15)

Belt Width (mm)	Grain or Other Free Flowing Material	Run of Mine Coal and Earth +	Hard Ores and Stone - Primary Crushed ++
300	2,5	1,5	1,5
400	2,5	2,0	1,8
500	3,0	2,0	1,8
600	3,0	2,5	2,3
750	3,6	3,0	2,8
900	4,0	3,3	3,0
1050	4,0	3,6	3,0

Knowing that the maximum belt speed is $3\ m.s^{-1}$ the conveyor capacity can be calculated. *Table 3* (p. 14) was used to calculate the maximum belt capacity in ton/hour. As seen in Table 3-7 the 45° trough angle gave the largest cross sectional load area.

Table 3-7: Capacity of trough belt conveyors (ton/hour) (p.14)

Belt Width mm	Recommended Max. Lump Size		Trough Angle Degrees	Area of Load m²	Speed m/s						
	Sized mm	Unsized mm			0,5	0,8	1,2	1,6	2,0	2,5	3,0
600	125	200	20	0,033	59	95	142	190	236	297	357
			27½	0,037	66	106	160	213	266	333	400
			30	0,038	69	110	164	218	274	342	410
			35	0,040	72	115	173	230	288	360	432
			45	0,042	76	121	181	242	303	378	436
750	150	250	20	0,054	97	156	233	311	389	486	583
			27½	0,060	109	173	259	346	432	540	648
			30	0,062	112	179	268	357	446	558	670
			35	0,065	117	187	281	375	468	585	702
			45	0,068	122	196	294	392	490	612	734
900	175	300	20	0,080	144	230	346	461	576	720	864

Table 5 (p. 16) was used to calculate the recommended idler spacing. Table 3-8 shows the calculated idler spacing in meters, using the bulk density of $0.9\ t \cdot m^{-3}$ as calculated in Table 3-4.

Table 3-8: Recommended idler spacing (m) (p. 16)

Belt Width (mm)	Troughing Idler - (m)							Return Idlers (m)
	Bulk Density of Material (t/m3)							
	0,5	0,8	1,2	1,6	2,0	2,5	3,0	
450	1,5	1,5	1,5	1,4	1,4	1,4	1,4	3
600	1,5	1,5	1,5	1,4	1,4	1,2	1,2	3
750	1,5	1,4	1,4	1,2	1,2	1,2	1,0	3
900	1,4	1,4	1,2	1,2	1,0	1,0	1,0	3
1050	1,2	1,2	1,0	1,0	1,0	1,0	0,9	3
1200	1,2	1,2	1,0	1,0	1,0	0,9	0,9	3
1350	1,2	1,0	1,0	1,0	0,9	0,9	0,9	3
1500	1,2	1,0	1,0	1,0	0,9	0,9	0,9	3
1650	1,2	1,0	1,0	0,9	0,9	0,9	0,9	3
1800	1,2	1,0	1,0	0,9	0,9	0,9	0,8	3
2000 and over	1,0	1,0	0,9	0,9	0,9	0,8	0,8	3

The belt mass was approximated by using *Table 8* (p. 17). The heavy duty operating conditions were chosen as this would give the largest weight. The belt mass ($kg \cdot m^{-1}$) approximation calculation can be seen in Table 3-9.

Table 3-9: Belt mass (kg/m) (p.17)

Belt Width (mm)	Operating Conditions		
	Light Duty (kg/m)	Medium Duty (kg/m)	Heavy Duty (kg/m)
500	4,1	6,2	10,3
600	5,0	7,4	12,3
750	6,2	9,3	15,5
900	7,4	11,1	18,5

3.1.2.1 Dunlop Conveyor Design manual conclusion

The Dunlop Complete Conveyor Belt Design manual (2004) was used to determine various initial variables with respect to the idler roller and related conveyor system. The results can be seen tabulated in Table 3-10.

Table 3-10: Dunlop design manual conclusion

Variable	Value
Idler roller diameter	$89\ mm$
Idler roller length	$313\ mm$
Maximum belt speed	$3\ m \cdot s^{-1}$
Belt capacity	$734\ ton \cdot hr^{-1}$
Idler spacing	$1.4\ m$
Belt mass	$15.5\ kg \cdot m^{-1}$

3.1.3 Rulmeca design calculations

Rulmeca Rollers and components for bulk handling (2003), Chapter 2 - *Rollers* (p. 75-79) was used to determine the static and dynamic loads expected on the roller. All tables in this section (section 3.1.3) were taken from Rulmeca Rollers and components for bulk handling (2003), therefore only the document's *table number* (in italics) and page numbers were referenced. Table 3-11 highlights the principle operating factors used in the Rulmeca document:

Table 3-11: Principal operating factors

Symbol	Variable	Unit
I_v	Belt load	$kg \cdot hr^{-1}$
v	Belt speed	$m \cdot s^{-1}$
a_0	Pitch of carrying trough set	m
a_u	Pitch of return set	m
q_b	Weight of belt per linear meter	$kg \cdot m^{-1}$
F_p	Participating factor of the highest stressed roller	-
F_d	Shock factor	-
F_s	Service factor	-
F_m	Ambient factor	-
F_v	Speed factor	-

Tables 17, 18, 19, 20 and 21 (p. 76-77) were used to determine the participation, service, environmental, shock and speed factors respectively as shown in nestled tables labelled Table 3-12.

Table 3-12: Collection of factor tables

Tab. **17 - Participation factor Fp**

0°	20°	20°	30°	35°	45°
1,00	**0.50**	**0.60**	**0.65**	**0.67**	**0.72**

Tab. **18 - Service factors**

Working life	Fs
Less than 6 hours per day	0.8
From 6 to 9 hours per day	1.0
From 10 to 16 hours per day	1.1
Over 16 hours per day	1.2

Tab. **19 - Environmental factors**

Conditions	Fm
Clean and with regular maintenance	0.9
Presence of abrasive or corrosive materials	1.0
Presence of very abrasive or very corrosive materials	1.1

Tab. **20 - Shock factor Fd**

Lump size	Belt speed m/s						
	2	2.5	3	3.5	4	5	6
0 – 150 mm	1	1	1	1	1	1	1
150 ÷ 300 mm	1.02	1.03	1.05	1.07	1.09	1.13	1.18
300 ÷ 450 mm	1.04	1.06	1.09	1.12	1.16	1.24	1.33

Tab. **21 - Speed factors Fv**

Belt speed	Roller diameter mm						
m/s	60	76	89-90	102	108-110	133-140	159
0.5	0.81	0.80	0.80	0.80	0.80	0.80	0.80
1.0	0.92	0.87	0.85	0.83	0.82	0.80	0.80
1.5	0.99	0.99	0.92	0.89	0.88	0.85	0.82
2.0	1.05	1.00	0.96	0.95	0.94	0.90	0.86
2.5			1.01	0.98	0.97	0.93	0.91
3.0			1.05	1.03	1.01	0.96	0.92
3.5					1.04	1.00	0.96
4.0					1.07	1.03	0.99
4.5					1.14	1.05	1.02
5.0					1.17	1.08	1.0

Results and completed principle operating factors can be seen in Table 3-13.

Table 3-13: Completed principal operating factors

Symbol	Value
I_v	$734 \cdot 10^3\ kg \cdot hr^{-1}$
v	$3.0\ m \cdot s^{-1}$
a_0	$1.4\ m$
a_u	$3.0\ m$
q_b	$15.5\ kg \cdot m^{-1}$
F_p	0.72
F_d	1.05
F_s	1.2
F_m	1.0
F_v	1.05

The static load on the idler roller set was determined using Equation 3-1 as cited on p. 78:

Equation 3-1: Static load on idler roller set (p. 78)

$$C_a = a_o \times \left(q_b + \frac{I_v}{3600 \cdot v}\right) \cdot 9.81$$

$$C_a = 1.4 \times \left(15.5 + \frac{734 \cdot 10^3}{3600 \cdot 3.0}\right) \cdot 9.81$$

$$\therefore C_a = 1146\ N$$

To ensure the units were correct a unit analysis was performed:

$$m \times \left(\frac{kg}{m} + \frac{kg \cdot \cancel{s}}{\cancel{s} \cdot m}\right) \cdot \frac{m}{s^2} = \cancel{m} \times \left(\frac{kg}{\cancel{m}}\right) \cdot \frac{m}{s^2} = \frac{kg \cdot m}{s^2} = N$$

The dynamic load on the idler roller set was determined using Equation 3-2 as cited on p. 78:

Equation 3-2: Dynamic load on idler roller set (p. 78)

$$C_{a1} = C_a \cdot F_d \cdot F_s \cdot F_m$$

$$C_{a1} = 1146 \cdot 1.05 \cdot 1.2 \cdot 1.0$$

$$\therefore C_{a1} = 1444\ N$$

The load on the highest stressed roller (central idler in trough arrangement) was obtained by Equation 3-3 as cited on p. 78:

Equation 3-3: Load on central roller in trough assembly (p. 78)

$$c_a = C_{a1} \cdot F_p$$

$$c_a = 1444 \cdot 0.72$$

$$\therefore c_a = 1040\ N$$

3.1.3.1 Rulmeca design calculations conclusion

Rulmeca Rollers and components for bulk handling (2003), Chapter 2 - *Rollers* (p. 75-79) was used to determine static and dynamic loads on the idler roller set as well as the highest stressed centre load carrying idler roller. The results can be seen tabulated in Table 3-14.

Table 3-14: Rulmeca design calculations

Variable	Value
Static load on idler set	$1146\ N$
Dynamic load on idler set	$1444\ N$
Dynamic load on centre idler	$1040\ N$

3.1.4 Initial designs

The design process followed a very logical path starting with the bearing selection, followed by the design of the shaft and bearing houses that would fit the composite CHS. The seal was the final step in the design process.

The initial design was based on the parameters calculated by using the Dunlop and Rulmeca design guides. The first step was to choose a bearing size. This selection was informed by synthesising literature as well as through a review of current industry benchmarks. All reviewed idler rollers with a diameter of 100 mm or smaller used a deep groove radial ball bearing with a C3 internal clearance. The most common size found in these idlers was a light series bearing with a bearing number 6204 (sections 2.1.2.1.7 and 2.1.2.2.6). Once the bearing size was selected the design process could start. Juvinall and Marshek (2006, p. 573) provided a diagram containing ‘shaft and housing shoulder dimensions’ relationships, shown in Figure 3-9.

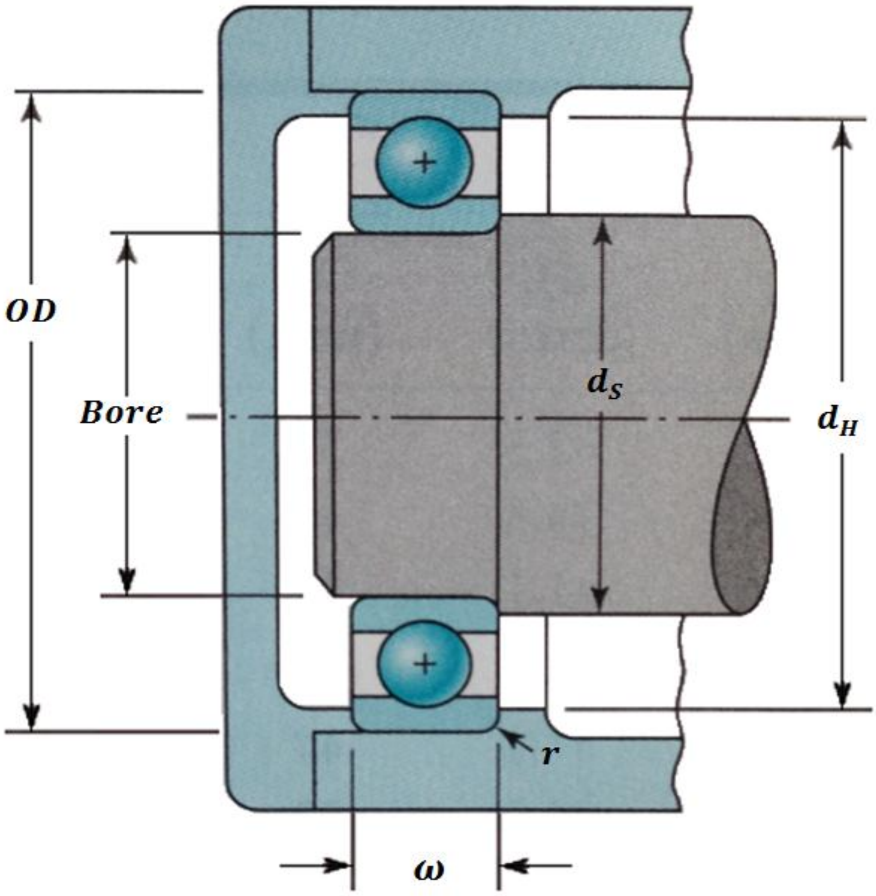


Figure 3-9: Dimensions around bearings (Juvinall & Marshek 2006, p. 573)

The Juvinall and Marshek (2006, p. 574) bearing dimensions table, *Table 14.1*, was used to find the dimensions of the bearing, shaft and bearing housing.

Table 3-15: Dimensions around bearings (Juvinall & Marshek 2006, p. 573)

TABLE 14.1 Bearing Dimensions (*continued*)

		Ball Bearings					Roller Bearings				
Bearing Basic Number	Bore (mm)	OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)	OD (mm)	w (mm)	r^a (mm)	d_S (mm)	d_H (mm)
L03	17	35	10	0.30	19.8	32.3	35	10	0.64	20.8	32.0
203	17	40	12	0.64	22.4	34.8	40	12	0.64	20.8	36.3
303	17	47	14	1.02	23.6	41.1	47	14	1.02	22.9	41.4
L04	20	42	12	0.64	23.9	38.1	42	12	0.64	24.4	36.8
204	20	47	14	1.02	25.9	41.7	47	14	1.02	25.9	42.7
304	20	52	15	1.02	27.7	45.2	52	15	1.02	25.9	46.2
L05	25	47	12	0.64	29.0	42.9	47	12	0.64	29.2	43.4
205	25	52	15	1.02	30.5	46.7	52	15	1.02	30.5	47.0
305	25	62	17	1.02	33.0	54.9	62	17	1.02	31.5	55.9
L06	30	55	13	1.02	34.8	49.3	47	9	0.38	33.3	43.9
206	30	62	16	1.02	36.8	55.4	62	16	1.02	36.1	56.4
306	30	72	19	1.02	38.4	64.8	72	19	1.52	37.8	64.0

Using the dimensions as suggested by Juvinall and Marshek (2006, p. 573-574) and the known CHS dimension, a full size design sketch was hand drawn as portrayed in Figure 3-10. This sketch was used to design the overall dimensions and component interactions. The shaft and bearing fits and tolerances were determined using the NTN bearing guide (2013). The chosen fit was a H7-k6 fit (Hole-shaft). The initial seal chosen was a basic lip seal commercially available from CBC Bearings Power Transmission.

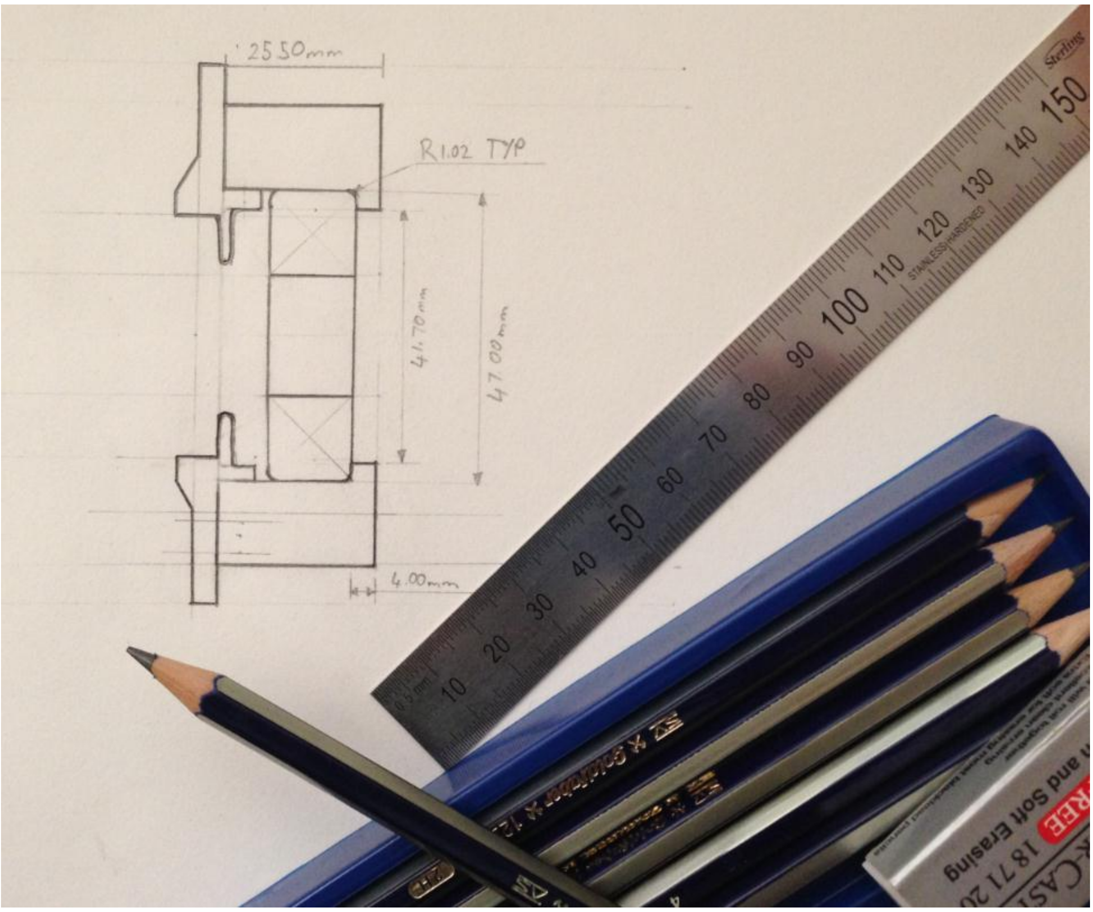


Figure 3-10: Full size hand drawn design sketch

The hand drawn design sketches were redrawn in ProEngineer and SolidWorks (solid modelling packages). ProEngineer was used to create the components to ensure the components fit together with correct tolerances. The ProEngineer prototype idler roller assembly and exploded view prototype idler roller assembly can be seen in Figure 3-11 and Figure 3-12, respectively. The SolidWorks models were used to create detailed drawings of the part required to be manufactured namely the shaft, bearing houses (named roller insert) and roller end caps (named roller cap). An excerpt of the roller cap detailed drawing can be seen in Figure 3-13. The full detailed manufacturing drawings can be seen in Appendix D.

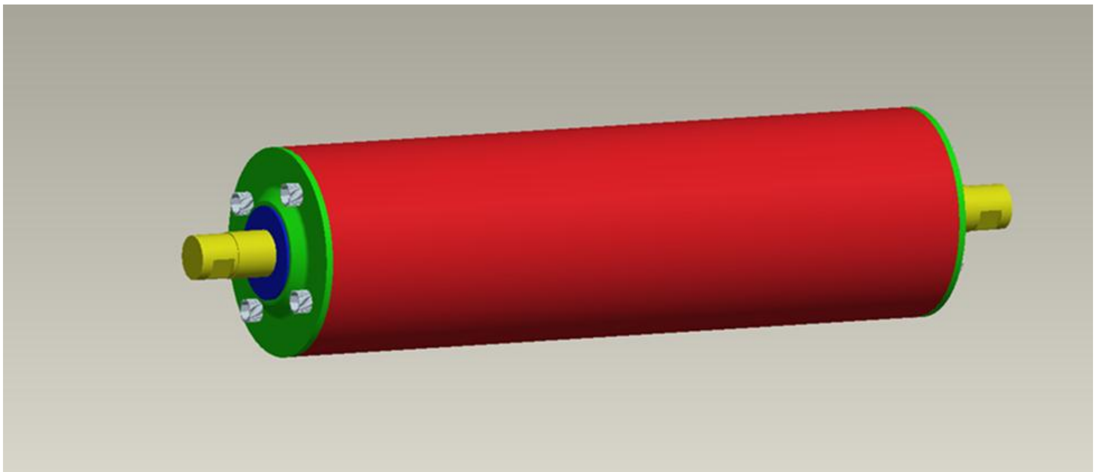


Figure 3-11: ProEngineer prototype idler roller assembly

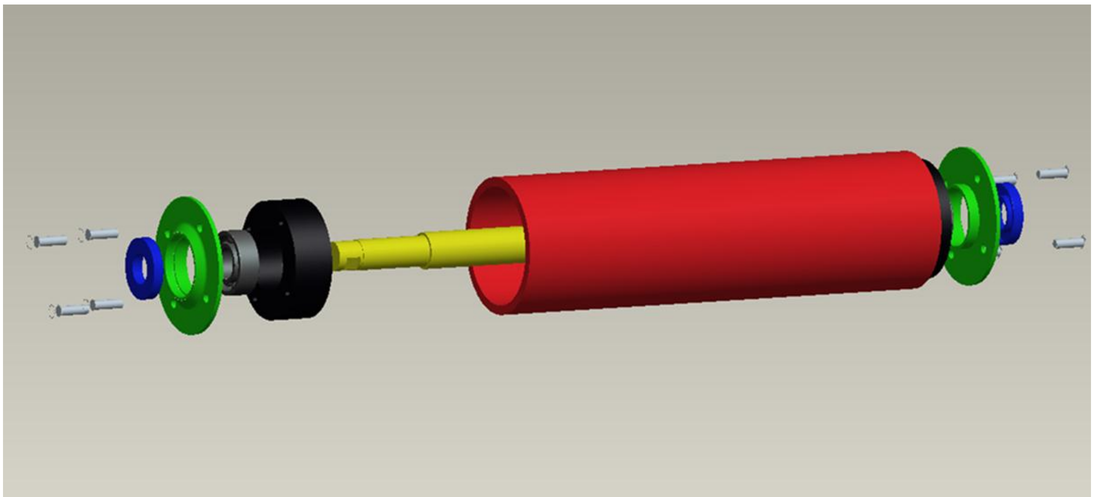


Figure 3-12: ProEngineer exploded view

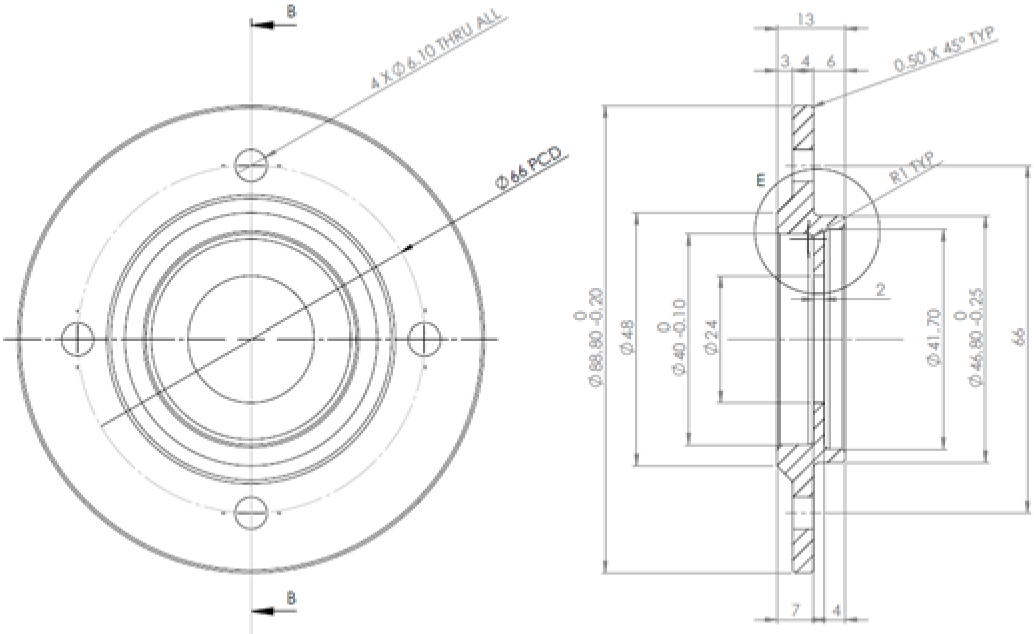


Figure 3-13: Excerpt of detailed roller cap drawing

3.1.5 Prototype

The detailed drawings were sent for quotation to *San-Tech Machining Pty Ltd*, *G & L Manufacturing* and *Wellbrook Engineering & Technologies*. The two most important factors for selecting a manufacturer was lead time and cost. The full quotes are included in Appendix D and the results are shown in Table 3-16.

Table 3-16: Quotation results

Manufacturer	Lead time	Cost
San-Tech Machining Pty Ltd	20 work days	$ 1518
G & L Manufacturing	7 days	$ 1485
Wellbrook Engineering & Technologies	14 days	$ 1500

G & L Manufacturing was chosen and given a purchase order to manufacture the components. Bearings and seals were procured from CBC Bearings Power Transmission. The roller inserts were bonded into position and cured. All of the remaining components were fitted after the bond was cured. The completed prototype idler roller is illustrated in Figure 3-14 and Figure 3-15.

Figure 3-14: Top view of completed prototype roller

Figure 3-15: Angled view of built prototype roller

The set of prototype rollers were used for the static and dynamic testing.

3.1.6 Prototype weight vs. steel roller weight

Ten steel rollers and ten composite prototype rollers were weighted to determine the average mass. The average 300 mm steel roller weight was 5.33 kg and the average prototype weight was 3.98 kg. The prototype weighs approximately 75% of a traditional steel roller. This is a significant reduction in weight.

3.2 Prototype idler roller testing

A series of tests, including static and dynamic loading cases, were devised to ensure that the prototype rollers could perform to their designed function. The testing results were complimented with manual calculations from a mathematical model. The final step in this testing regime was to use the test results and manual calculations to validate the FEA model. If the FEA model could be validated, it could be used in the determination if the Wagners CFT CHS's suitability for an idler roller body material. The last step was to use the FEA technique to conclude if the larger CHS size was suitable for mining rollers

3.2.1 Static testing

The static testing was performed in accordance with Syam (1992) as described in section 2.2.2.5. The test was structured to proof load 10 prototype rollers to the required proof test load as determined by the roller design calculations in section 3.1.3.1. Figure 3-16 illustrates the test setup. The load cell measured the load applied (P) to the load distribution plates. The load distribution plates safeguarded the test piece from localised load bearing failure. The bearing reaction forces were labelled R. The roller deflection was measured electronically by the string pull directly under the load application point.

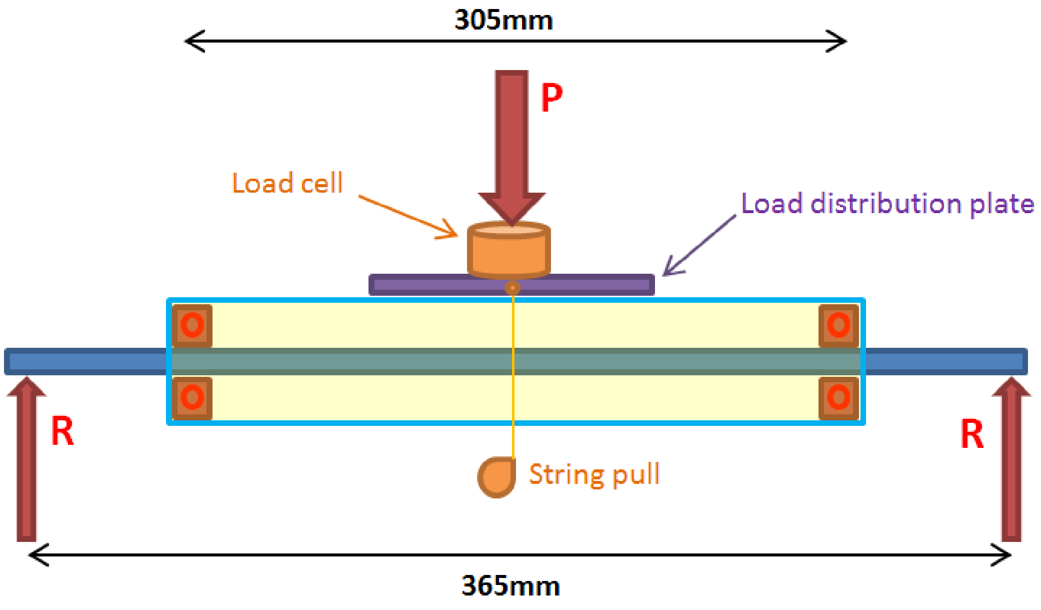


Figure 3-16: Prototype roller static proof test

The actual test arrangement can be seen in Figure 3-17.

Figure 3-17: Actual static prototype roller test

The load and deflection data was automatically recorded into a spread sheet. This spread sheet was manually configured to show the load on the idler roller and the corresponding deflection. The test results can be seen in section 4.2 (full data sheet available in appendix B).

3.2.2 Dynamic testing

As discussed in section 2.2.3, there was a need for the standardisation of failure models and fatigue prediction models for the composite industry. However, due to a lack of standardised fatigue testing methods, a prototype roller was tested with a purpose built machine using a hypothetical arrangement simulating an extreme in situ operational situation.

The dynamic test was performed as a fatigue test at maximum load capacity. Figure 3-18 schematically describes how the dynamic test simulated the idler roller operating at full capacity, $P = 1040\ N$.

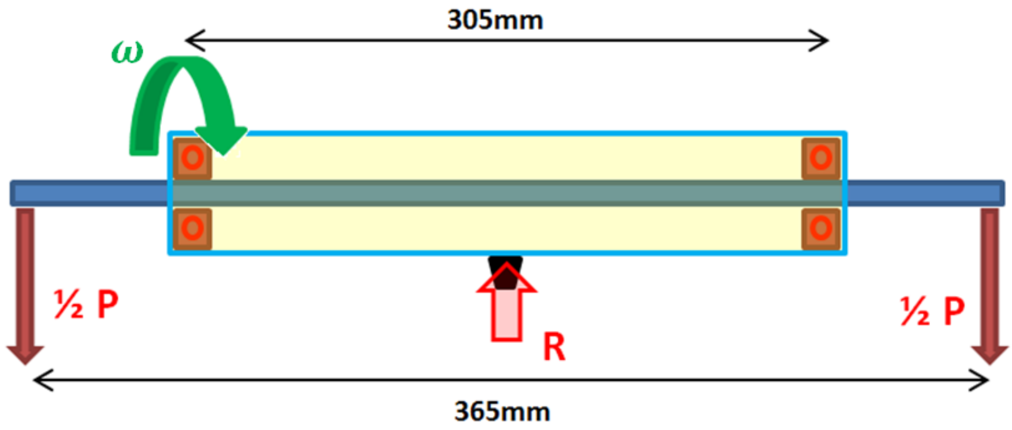


Figure 3-18: Schematic representation of fatigue jig

The black fan belt with the reaction force (R) superimposed simulated the driving conveyor belt and load. The two loads $(2 \cdot P/2)$ simulated the reaction forces on the shaft. Effectively, the roller operated upside down. The load was concentrated over a 25 mm width in the centre of the roller. This caused the idler roller to perform under the worst case scenario, where the entire load is as far away from the supports as possible. The test apparatus, shown in Figure 3-19, was fabricated by the author for this project as a fatigue test rig. The apparatus had a trip switch built in so that the machine would stop if the belt or roller failed.

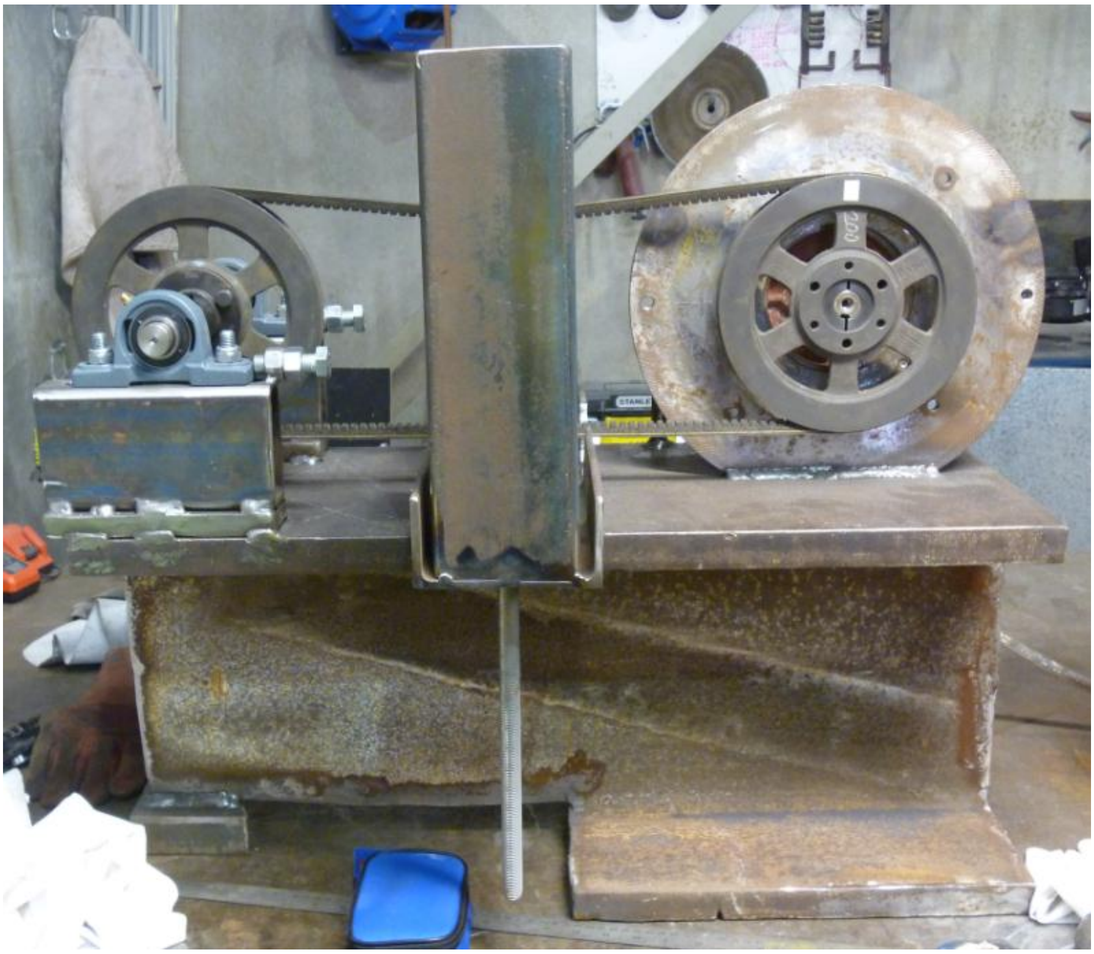


Figure 3-19: Fabricated fatigue rig

The test idler roller was suspended on the three-phase-motor-driven belt with half of the maximum capacity loads hanging from either side of the shaft (down the vertical SHS), as illustrated in Figure 3-20.

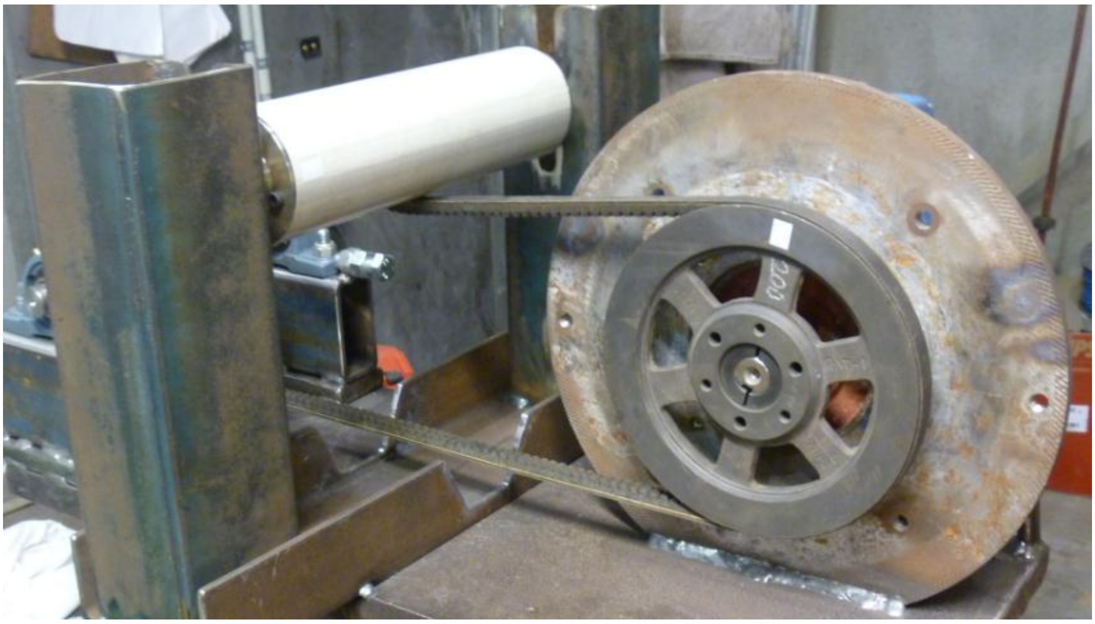


Figure 3-20: Fatigue rig assembled with roller

Figure 3-21 shows the motor mounting and assembled driving wheel and Figure 3-22 shows the slot that constrained the shaft. The slot allowed for free movement in the vertical direction, small movement along the axis and no movement in a horizontal direction perpendicular to the shaft axis.

Figure 3-21: Motor mount and drive wheel assembly

Figure 3-22: Shaft constraint

The fatigue test ran from a Monday morning through to a Saturday afternoon. The motor was initially run at the normal operating speed of 750 rpm. The starting and stopping of the roller at each end of the cycle replicates normal operations starting and stopping. The roller was regularly inspected for any significant damage or elevated operating temperatures. In order to complete a significant amount of operating hours, the fatigue machine must run for an equivalent of 5000 work hours, which is half of an idler roller’s life cycle. Due to the time constraints of this project, the roller was operated at higher speeds to reduce the amount of time required to rotate the same amount of revolutions as 5000 work hours. After a week of operation at 750 rpm, the speed was increased to 1500 rpm. During the third week the idler roller operation speed was increased to 2230 rpm. The idler continued at this operation speed for the remainder of the test. Figure 3-23 illustrates the method of establishing the roller rpm by using a digital tachometer with a 1500 rpm insert in the bottom left corner. The motor speed was controlled using variable voltage variable frequency drive.

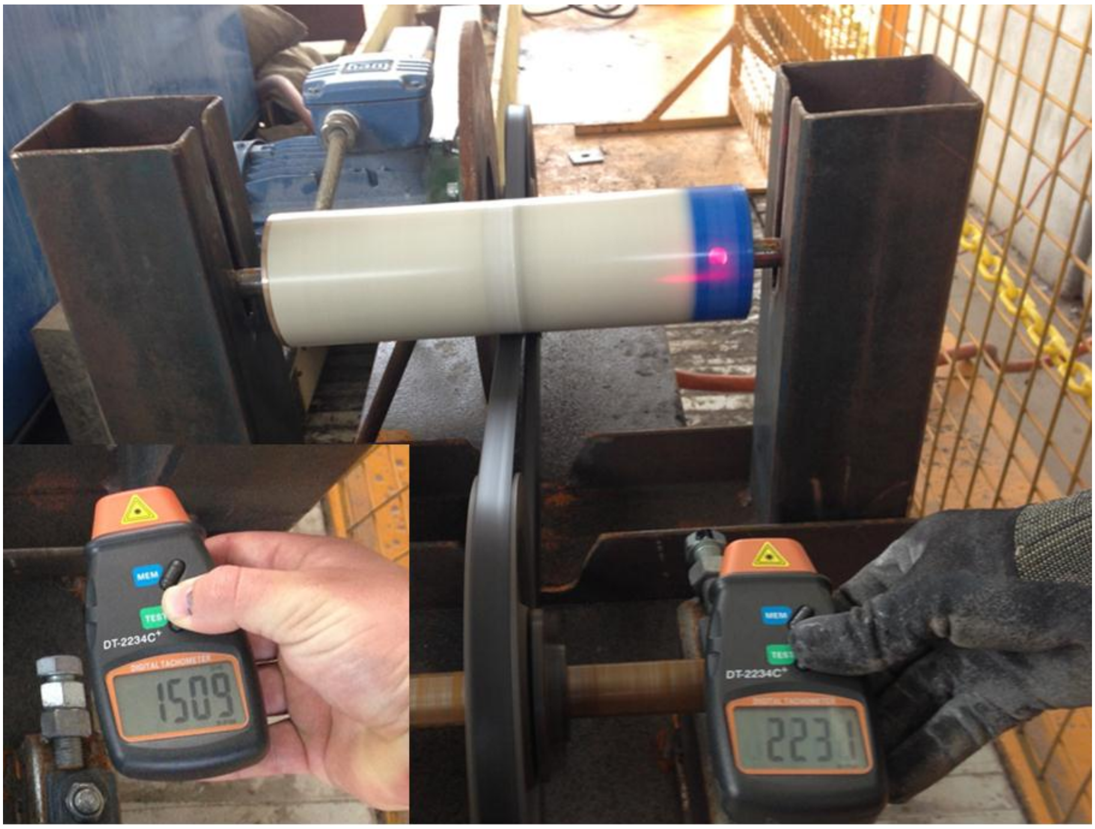


Figure 3-23 Measure the roller rpm on operating fatigue rig

The start and stop times of the operations were recorded on a results sheet that can be seen in the results section 4.3.1. The results sheet also includes a column for any notes regarding the idler roller performance or general observations. At the end of the 5000 hour fatigue test the roller was disassembled and inspected for performance.

The number of revolutions in a 5000 hour operation period at 750 rpm was calculated:

$$N_{5k} = 5000 \cdot 60 \cdot 750 = 225 \cdot 10^6 = \ 2.25 \cdot 10^8 \ revolutions$$

3.2.3 Calculations

Manual calculations were performed to determine deflection and stress in the shaft and composite roller body. The shaft was analysed using Juvinall and Marshek's (2006, p. 187) approach to 'deflection determination for an end-supported stepped steel shaft with two concentrated loads'. The deflection of the composite roller body was determined using Equation 2-3:

$$\delta_{max} = \frac{wb}{384EI}(8L^3 - 4Lb^2 + b^3)$$

The maximum stress of both components at the point of maximum deflection was calculated using Beer et al. (2006, p. 217) *Equation 4.15*:

Equation 3-4: Maximum stress for beam bending

$$\sigma_m = \frac{M \cdot c}{I}$$

Where σ_m is the maximum absolute value of stress,

M is the moment,

c is distance from neutral surface,

and I is the second moment of area and can be found by:

$$I = \frac{\pi d^4}{64}$$

3.2.3.1 Shaft and roller body deflection calculation

The midpoint shaft deflection was calculated to be $0.0499\,mm$ and the deflection at the point of bearing contact was calculated to be $2.23\ \mu m$ (full shaft deflection calculation can be found in appendix B). The composite roller body deflection was found:

$$\delta_{max} = \frac{1040}{384 \cdot 31770 \cdot 1.349 \times 10^6}(8 \cdot 305^3 - 4 \cdot 305 \cdot 100^2 + 100^3) = 0.136\,mm$$

3.2.3.1 Shaft and roller body stress calculation

3.2.3.1.1 Shaft

The moment on the midpoint shaft was calculated to be $24.96\,kN \cdot mm$ (full shaft deflection calculation can be found in appendix B) and the shaft has a diameter of $23.90\,mm$. Therefore the stress on the compression (top) and tension (bottom) sides was:

$$\sigma_m = \frac{M \cdot c}{\frac{\pi d^4}{64}} = \frac{24.96 \cdot 10^3 \cdot \left(\frac{23.90}{2}\right)}{\frac{\pi \cdot (23.9)^4}{64}} = 18.62\,MPa$$

3.2.3.1.2 Composite roller body

The moment on the midpoint of the body was estimated by assuming a point load (worst case scenario) and using Beer et al. (2006, p. 312):

$$M = \frac{1}{4} \cdot P \cdot L = \frac{1}{4} \cdot 1040 \cdot 305 = 79.30\,kN.mm$$

Therefore the stress on the compression (top) and tension (bottom) sides was:

$$\sigma_m = \frac{79.30 \cdot 10^3 \cdot \frac{88.9}{2}}{1.349 \cdot 10^6} = 2.62\,MPa$$

3.2.3.2 Final remarks

The results of the manual calculations was compared with the physical testing and the FEA results

3.2.4 Finite Element Analyses

Ansys 14.5 was the FEA software used in this project. The FEA modelling was done to mimic all the physical testing for the purpose of validating the FEA method. If the FEA method and models can be validated, it can be used to analyse the theoretical 5” and 7” OD CHS.

A four point bend test was modelled and analysed in accordance with section 3.1.1.1. A model was analysed for the 3 ½” (88.9 mm) OD static tests as described in section 3.2.1. The prototype shaft and composite body components were modelled separately. The deflections at the point of contact on the shaft were added to the maximum deflection of the roller body to compare results with the physical tests. The bearings and bearing housing were considered to be much stiffer than the shaft and roller body and therefore were omitted in the FEA. Lastly the fatigue test load conditions were modelled as a static test to gain an indication of the stresses the prototype idler roller was subjected to (section 3.2.2).

This methodology section showed how each of the models was meshed, constrained and loaded.

3.2.4.1 Four point bend FEA test method

The default mesh was used on the model as the CHS is a simple shape. The model and mesh can be seen in Figure 3-24 with a close up of the end in the top right corner.

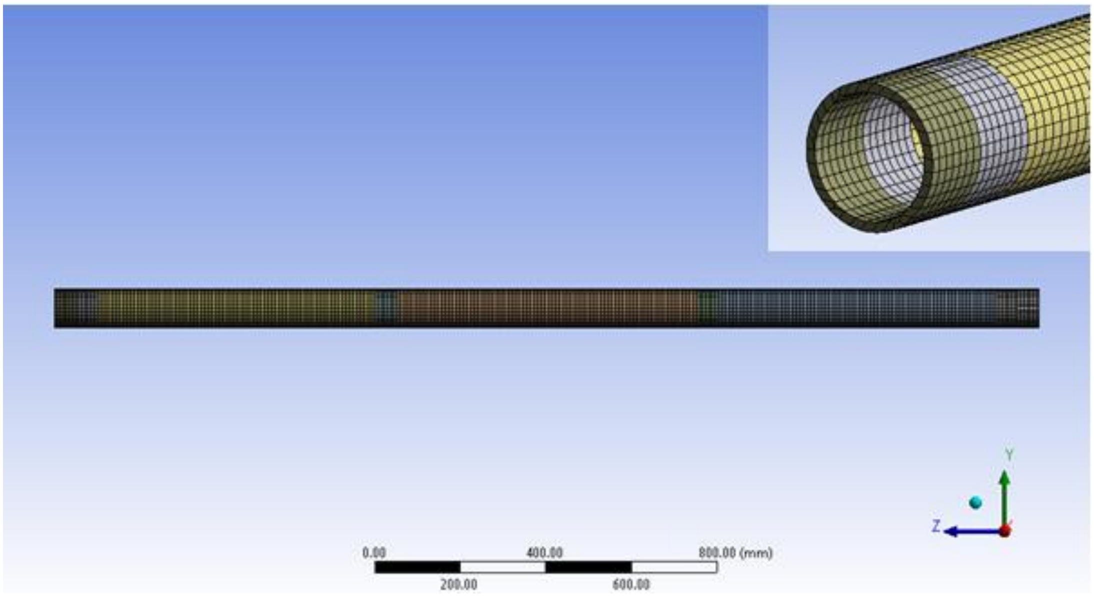


Figure 3-24: Four point bend test meshed model

The loading conditions are shown in Figure 3-25. The forces were applied as shown in Figure 3-2 and the reaction forces were modelled as forces to ensure the correct end conditions were imitated and the CHS was allowed to rotate about the axis extending out of the page.

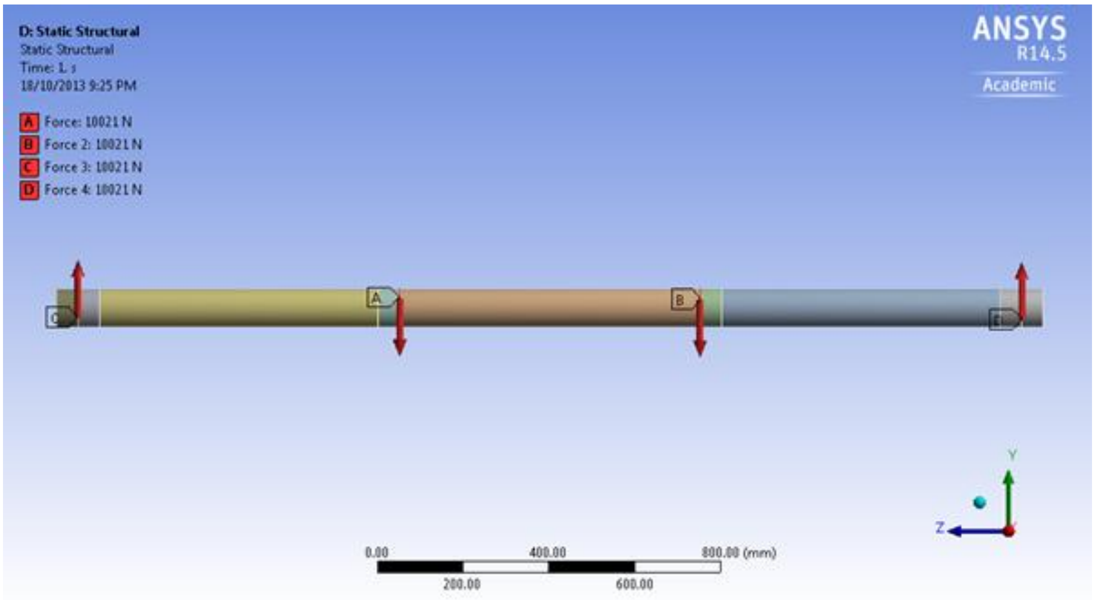


Figure 3-25: Four point bend test loading

3.2.4.2 Static shaft FEA test method

The steel shaft mesh can be seen in Figure 3-26. Figure 3-27 illustrates the mesh refinements. The mesh was refined for higher accuracy on the shoulders as these are known stress raisers.

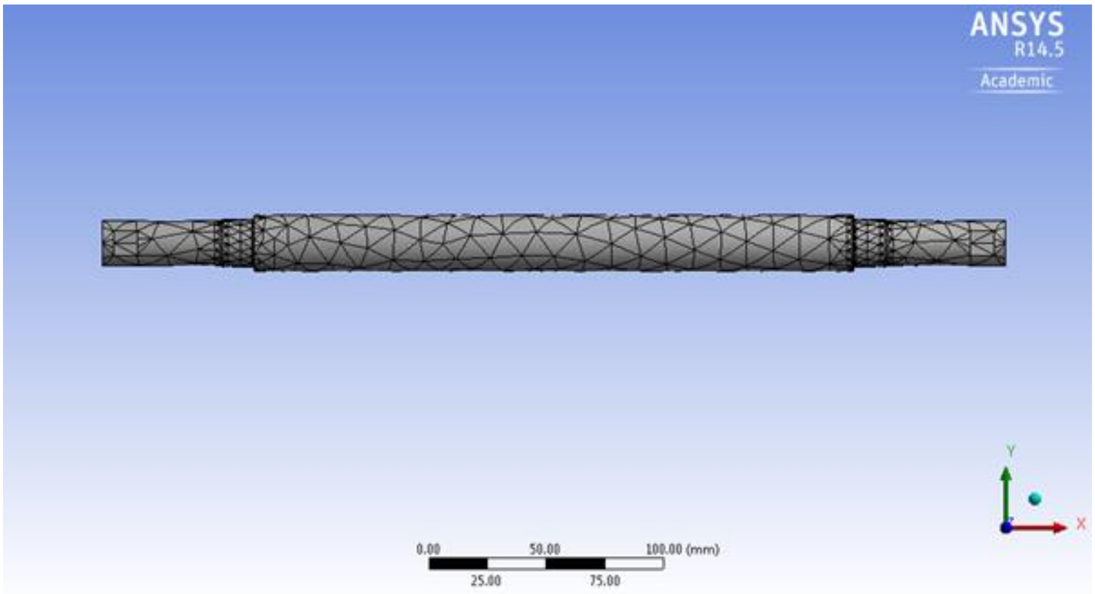


Figure 3-26: Steel prototype shaft model

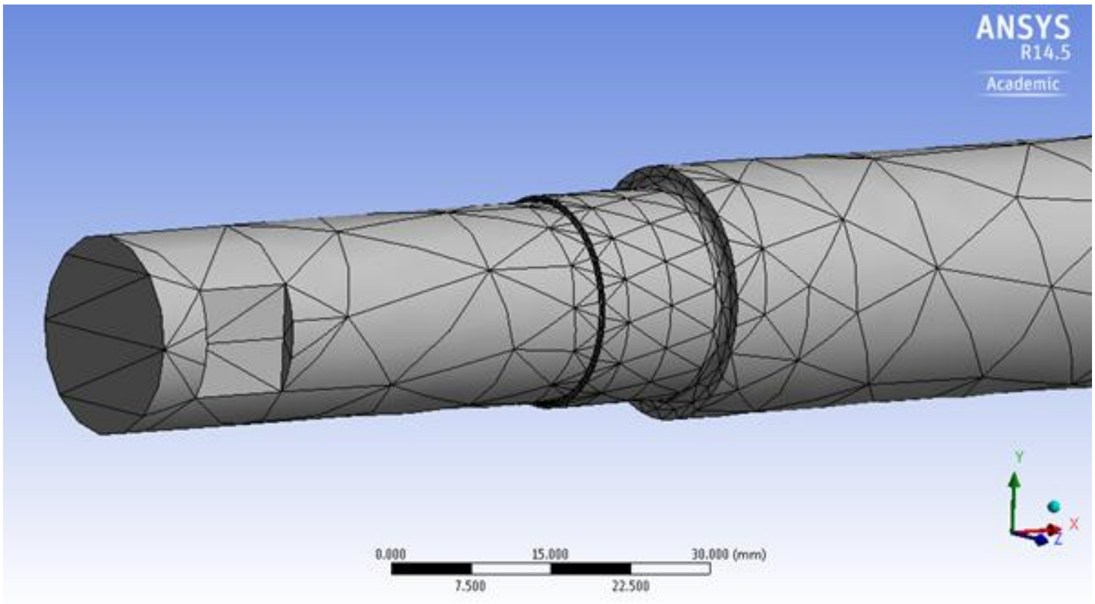


Figure 3-27: Mesh refinements around shaft shoulders

The model was loaded with the force distributed onto two bearing seat platforms as per the design. The location slots on the shafts end were constrained as a fixed support. Figure 3-28 shows the static structural setup.

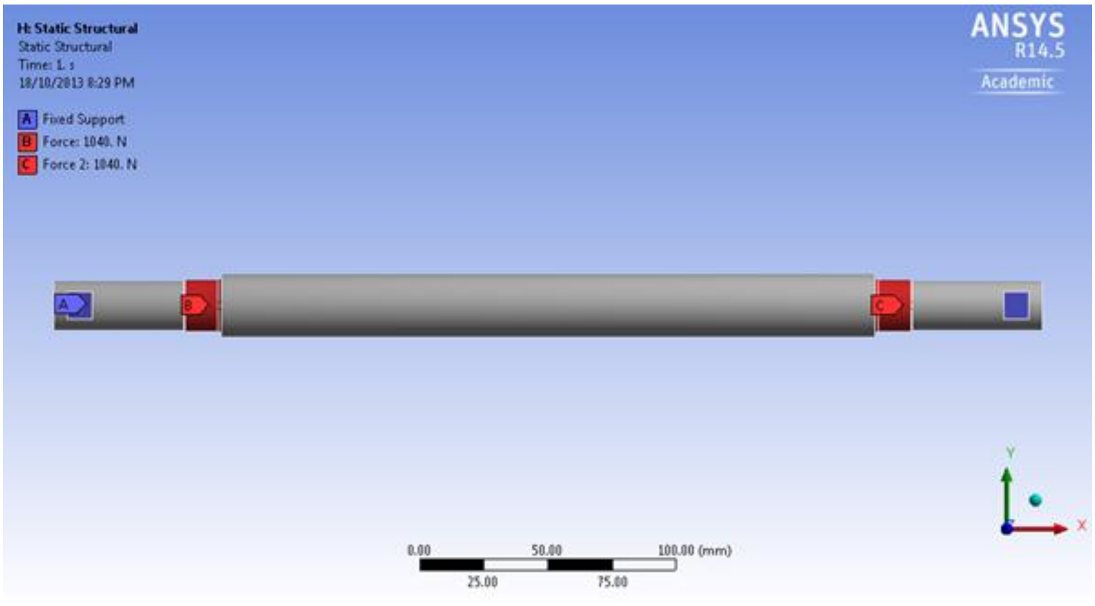


Figure 3-28: Prototype shaft loading conditions

3.2.4.3 Static roller body FEA test method

The default mesh was used on the static test model as depicted in Figure 3-29.

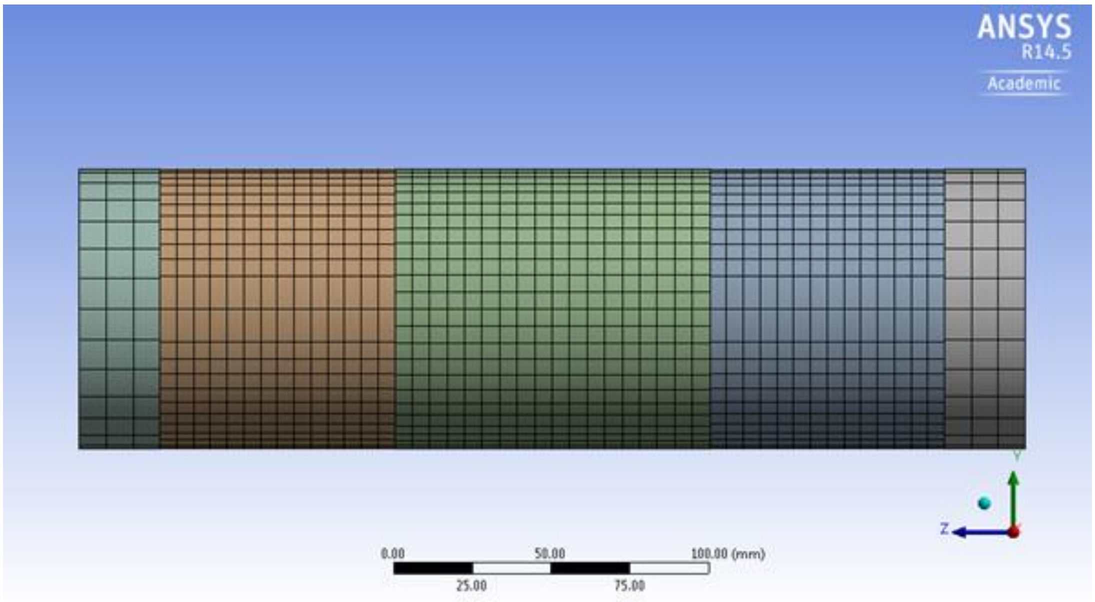


Figure 3-29: Static roller body model

The model was loaded similarly to the physical test. The physical test loaded the model only on the top surface of the roller whilst the Ansys model is loaded around this surface. Since the model will not be used to analyse failure, it provides an accurate representation of the overall phenomenon. This method was used on all the FEA models.

Figure 3-30 and Figure 3-31 shows the model loading condition and a zoomed view of the end constraints, respectively.

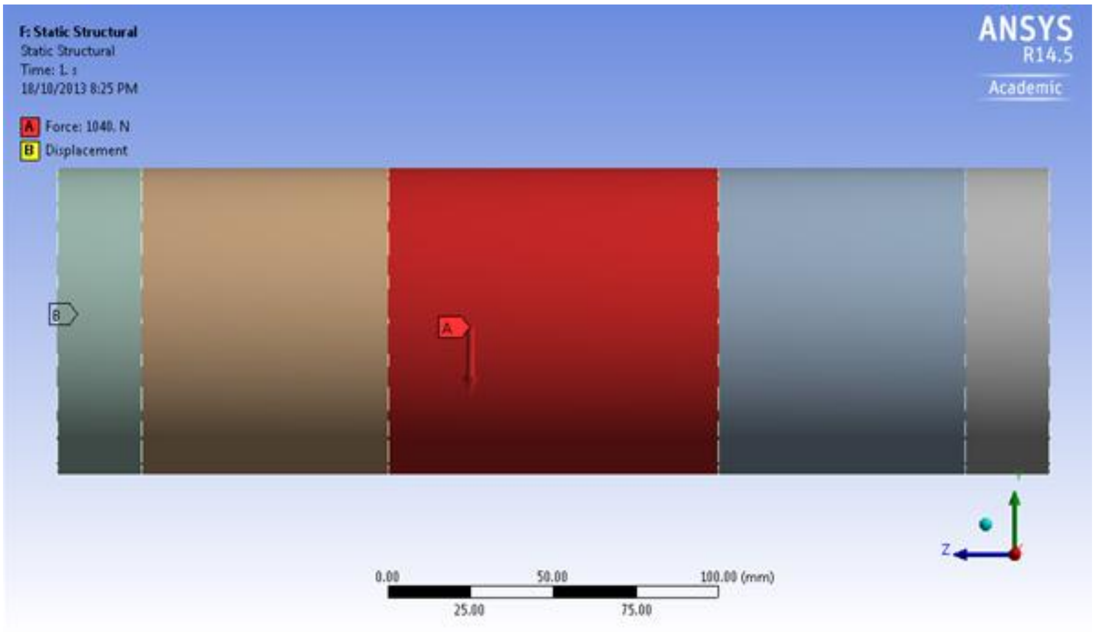


Figure 3-30: Loading scenario on FEA model

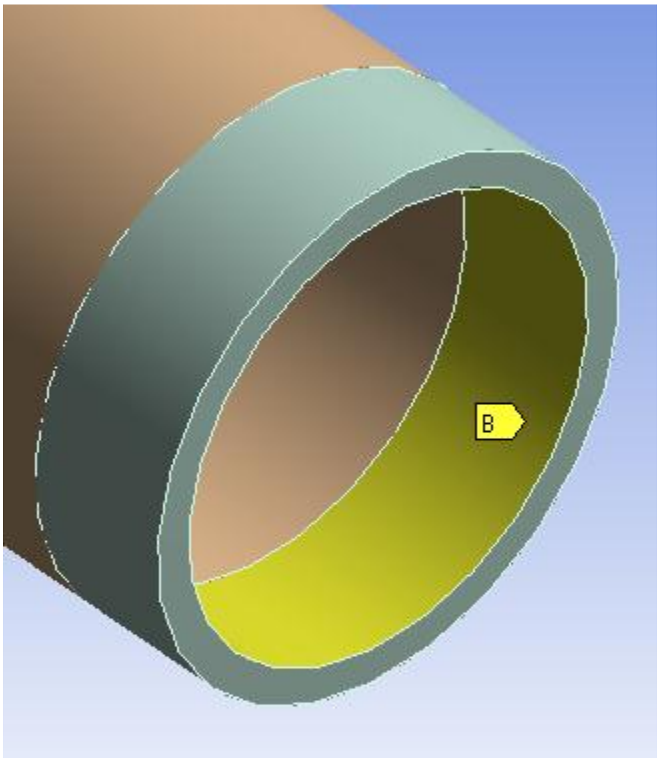


Figure 3-31: Displacement constraint allowing movement in the z direction

3.2.4.4 Dynamic test representation

The mesh used can be seen in Figure 3-32 and the loading conditions are shown in Figure 3-33. The only difference is the width over which the load was applied.

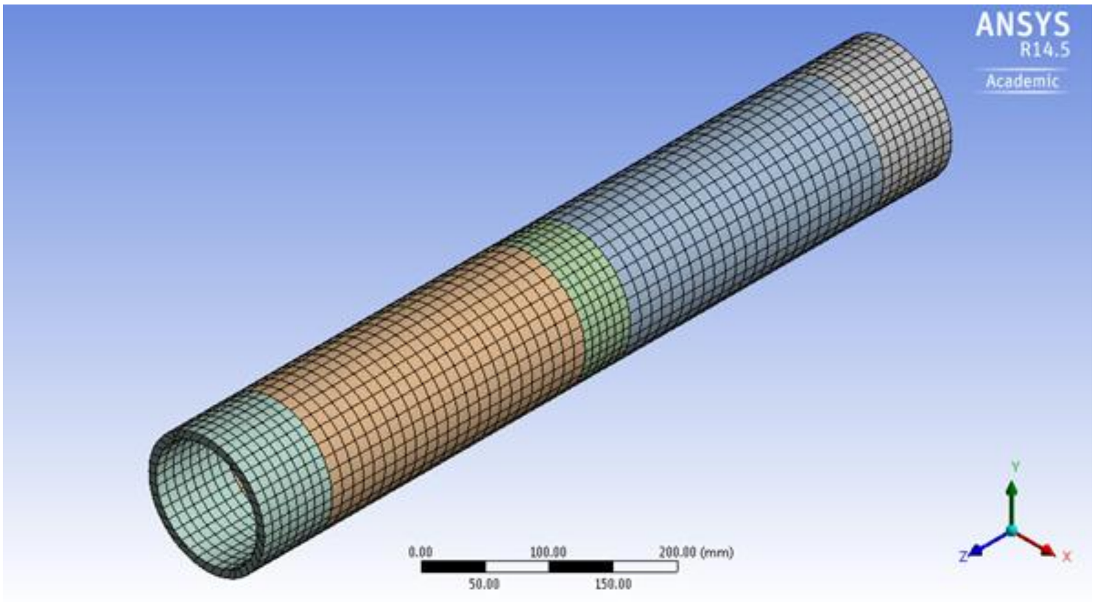


Figure 3-32: Dynamic test meshed model

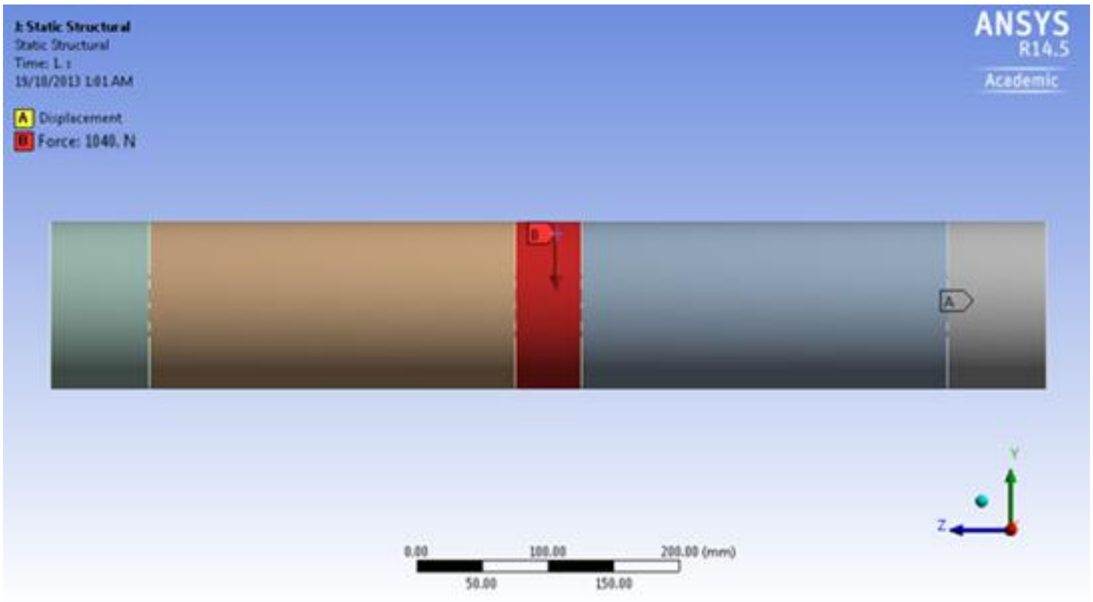


Figure 3-33: Reduced load application width for dynamic test representation

3.2.4.5 Final remarks

The FEA models shown were all developed to represent the physical testing as close as practically possible. The results obtained from the models are shown and discussed in Chapter 4.

3.3 Conclusion

This chapter discussed the project methodology in intricate detail with particular emphasis on the design and test phases. Schematically the methodology discussed the green and blue shaded areas of Figure 3-1.

The design phase detailed how the information gathered from literature and testing was used in conjunction with the Dunlop and Rulmeca design manuals to determine the physical parameters of the idler roller. Once the parameters were known, the bearing and CHS dimensions were used as the base to develop the individual components. The components were modelled using solid modelling software and the final step of the design phase was to produce detailed drawings in order to obtain quotes for the components to be manufactured. The prototype was then built using construction methods consistent with Wagners CFT proprietary construction guidelines.

The test phase incorporated all testing on the prototype roller including static testing and dynamic testing. Manual calculations were performed with respect to stress and deflection. FEA models were comprehensively explained and illustrated.

The methodology overviewed in this chapter provides the foundations for the analysis of the test results in Chapter 4.

Chapter 4

Results and Discussion

This chapter is a presentation of the results obtained from the testing regime previously discussed in the Methodology chapter. The physical testing results are tabulated and juxtaposed with the theoretical calculations and FEA outcomes. The results of the prototype roller design are then discussed with respect to static and fatigue analysis. Since the weight of the prototype roller had been determined to be 75% of a traditional steel roller, the two further challenges were to investigate the suitability of the Wagners CFT CHS as an idler roller body material and to validate the FEA models.

4.1 Four point bend test FEA

The physical four point bend test was used to determine the modulus of elasticity, making the four point bend test the primary test to compare real results with FEA results. The results chosen to compare, were the deflection at a load of $P = 10021\,N$ (some interpolation was needed of the physical test data results). Figure 4-1 shows the FEA results. A deflection probe was placed on the test results at a height from which the physical test deflection was measured. This allowed the test to be more accurately compared. The deflection results of the physical testing have been tabulated in column two of Table 4-1. The third column shows the average deflection and the last column shows the results obtained with the FEA model.

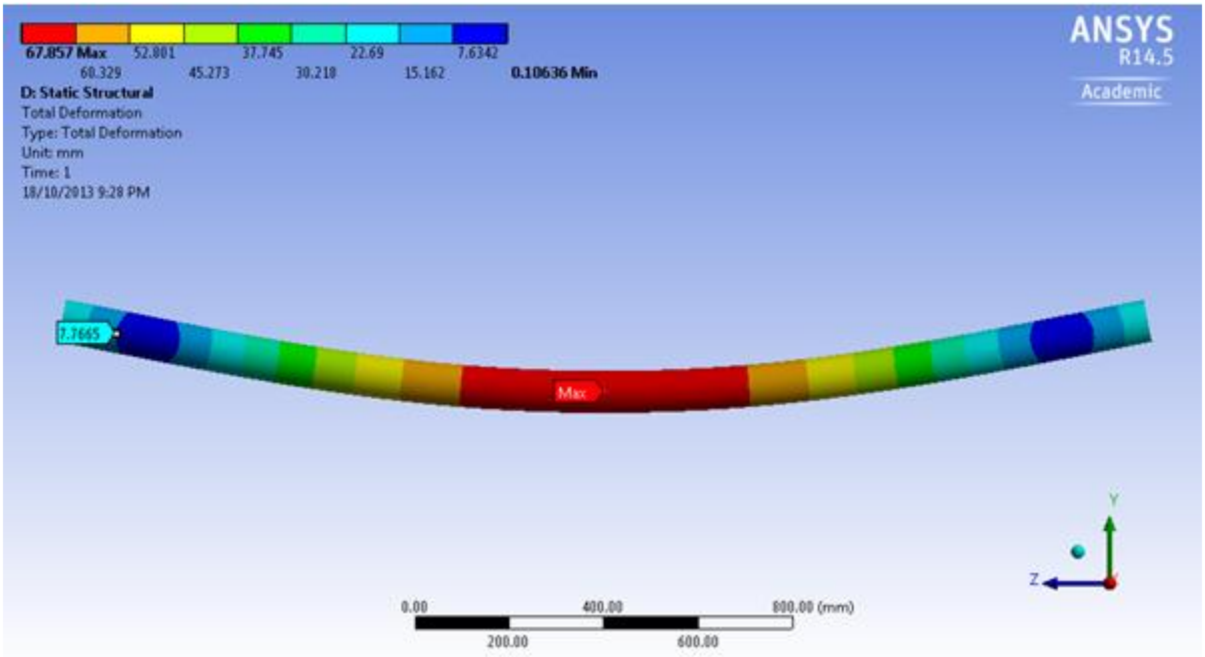


Figure 4-1: FEA deflection results for P=10021N

Table 4-1: Four point bend test results for P=10021N

Test #	Physical deflection (mm)	Average deflection (mm)	FEA deflection (mm)
1	60.47	61.20	$\delta = \delta_{max} - \delta_{support}$ $\delta = 67.857 - 7.767$ 60.09
2	62.32		
3	61.43		
4	59.41		
5	64.37		
6	61.85		
7	60.81		
8	59.94		
9	62.60		
10	58.81		

The average percentage error can be calculated by using Equation 4-1 (James 2007, p. 50):

Equation 4-1: Percentage error

$$\%\ error = \left| \frac{approximate\ value - actual\ value}{actual\ value} \right| \cdot 100$$

$$\%\ error = \left| \frac{60.09 - 61.20}{61.20} \right| \cdot 100 = 1.81\ \%$$

The FEA is only 1.11 mm lower than the measured experiment data. This is a relatively small 1.8% error. The difference can arise from the method of force or reaction force application in the model. Overall, the results are comparable.

4.2 Static test analyses

The static test was used to proof load 10 prototype idler rollers to the maximum expected operational load of 1040 N. Extraordinarily, all 10 of the tested prototype idler rollers failed at loads in excess of 90 kN and the roller bodies were still intact. The prototype rollers failed by bending the shaft beyond the limit of the test apparatus restraints. This proved that the rollers could withstand loads 100 times the magnitude of the design load. It was concluded that the roller bodies were much stronger than required.

The superior performance of the prototype rollers during static testing led to an interesting conclusion with respect to its design. The shaft of an idler roller predominantly carried the moment and provided support for the roller body. The static tests showed that the roller body could carry moments of very large magnitude and therefore the Wagners CFT CHS could be a suitable material for shaftless rollers as manufacturer by CII in section 2.1.2.1.8.

The physical testing data measured load and deflection. The manual calculations and FEA were completed for deflection at the designed maximum operational load of 1040 N. Figure 4-2 shows the FEA results for deflection of the shaft and Figure 4-3 shows deflection of the roller body. Table 4-2 shows the average measured deflection of the static tests, as described in section 3.2.1, at a load of $P = 1040\,N$ in column 2 (some interpolation was needed of the physical test data results). The next column of Table 4-2 shows the average tested deflection, column three shows the sum of the manual calculations for the shaft and roller body and the fourth column show the sum of the deflection of the FEA modelled shaft and roller body.

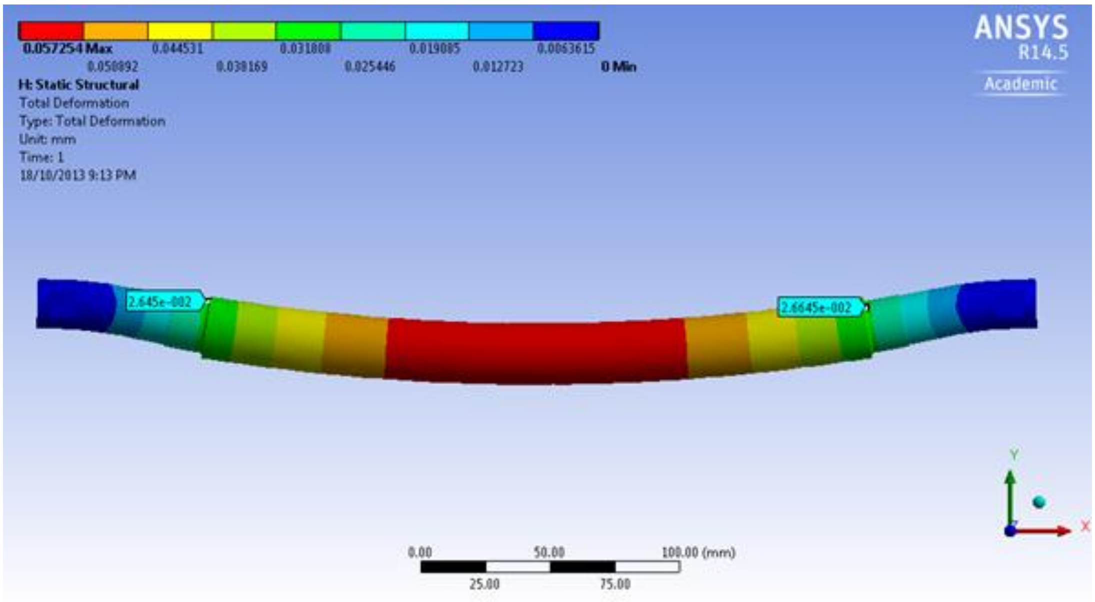


Figure 4-2: FEA shaft deflection at P=1040N

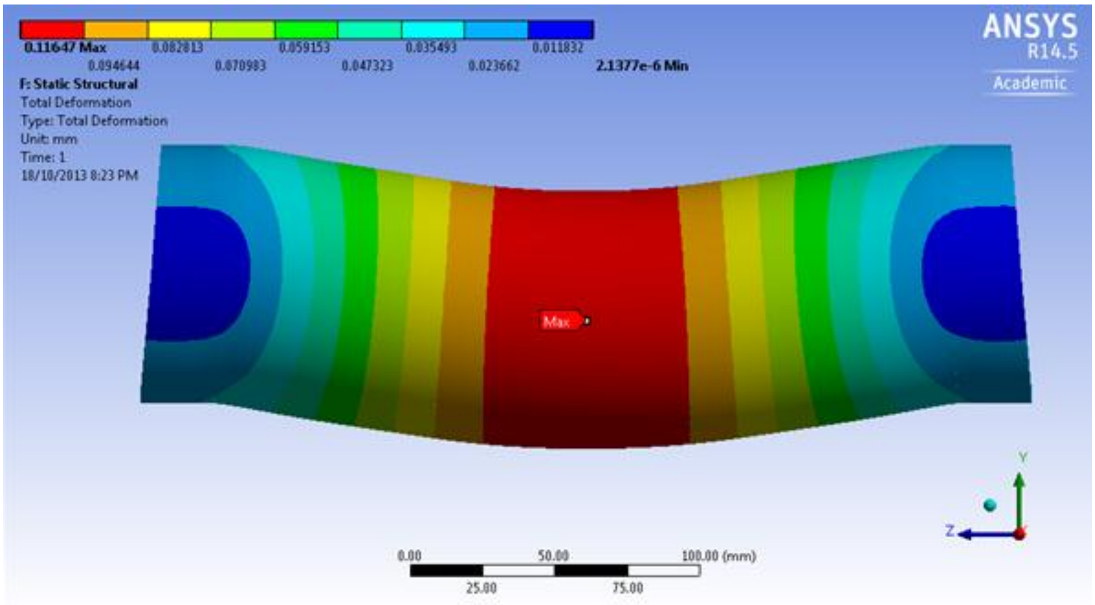


Figure 4-3: FEA roller body deflection at P=1040N

In order to compare the measured deflection with the manual calculation and the FEA calculation, the maximum roller body deflection needed to be added to the bearing seat deflection on the shaft. This assumes the bearings did not contribute a significant amount in the deflection at P = 1040 N.

Table 4-2: Static test results for the design load of P=1040N

Test #	Physical deflection (mm)	Average deflection (mm)	Manual calculation (mm)	FEA deflection (mm)
1	0.15	0.14	$\delta = \delta_{shaft} + \delta_{CHS}$ $\therefore 2.23 \cdot 10^{-3} + 0.136$ $= 0.138$ $\approx \mathbf{0.14}$	$\delta = \delta_{shaft} + \delta_{CHS}$ $\therefore 2.645 \cdot 10^{-2} + 0.11647$ $= 0.14292$ $\approx \mathbf{0.14}$
2	0.13			
3	0.14			
4	0.13			
5	0.15			
6	0.16			
7	0.14			
8	0.14			
9	0.13			
10	0.13			

The deflection results of the physical testing compared directly with both the hand calculations and the FEA computed values. This means that the FEA model was very accurate when compared to actual test results and theoretical calculations.

Stress calculations were performed manually and modelled on the FEA software to compare results. The FEA stress results for the shaft and roller body can be seen in Figure 4-4 and Figure 4-5, respectively.

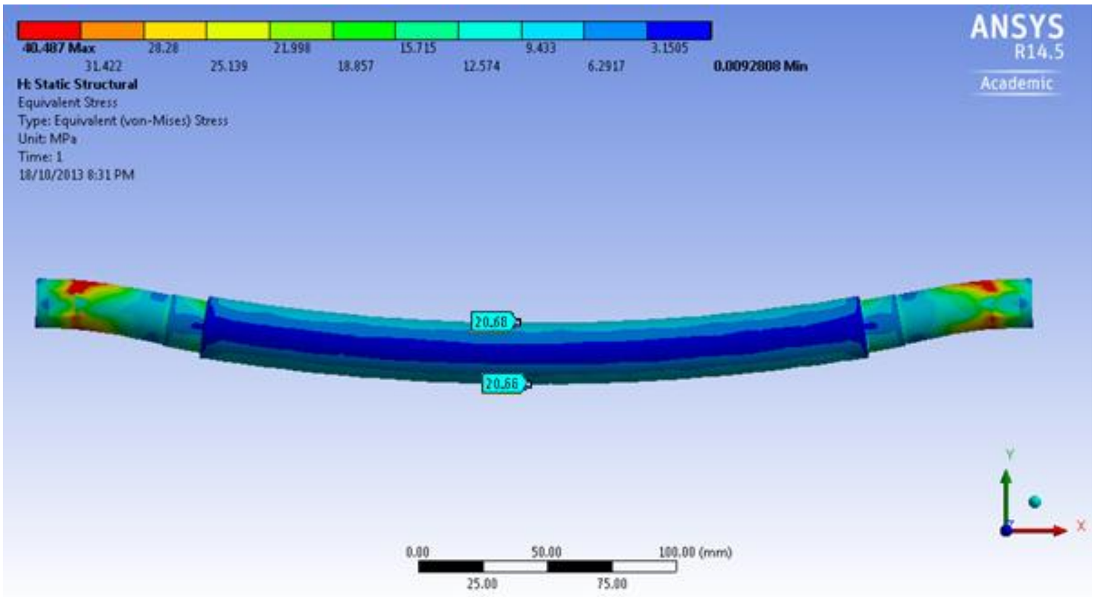


Figure 4-4: Stress in modelled shaft at P=1040N

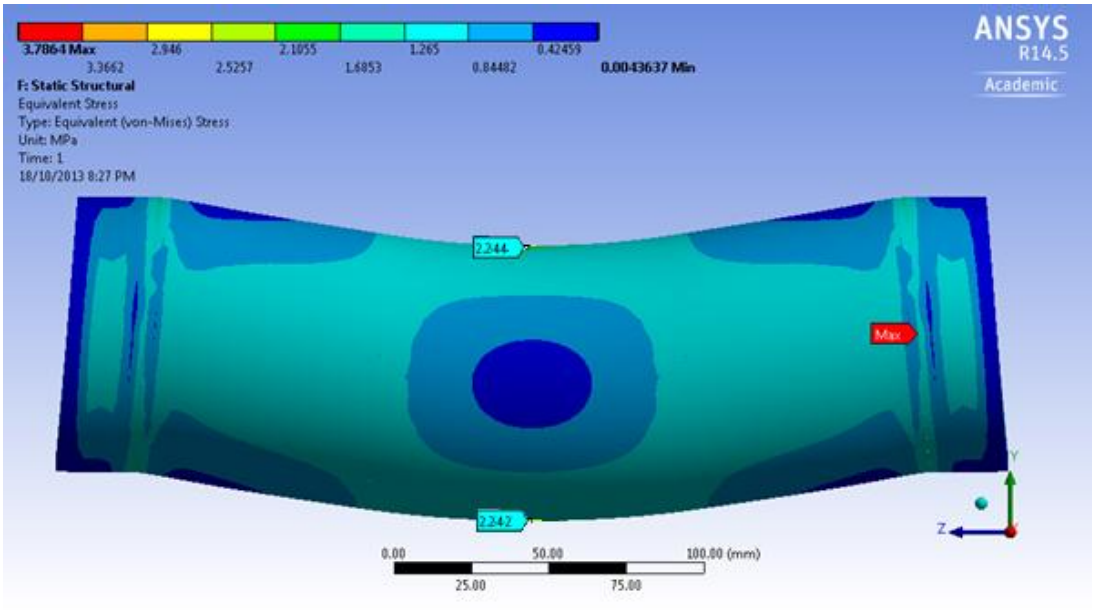


Figure 4-5: Stress in modelled roller body at P=1040N

Table 4-3 compares the results of the manual calculations for the shaft and the roller with the FEA results.

Table 4-3: Manual and FEA stress calculations results

	Manual calculation (MPa)	**FEA calculation** (MPa)
Shaft	18.62	20.68
Roller body	2.62	2.24

The results for the simple shaped CHS roller bodies were very similar. There was a small difference in the stress calculated at the midpoint of the shaft. The manual calculation did not allow for any stress raisers and only showed the average stress at a particular radius. The FEA method calculated the stress for each element and provided a much more accurate representation of a particular point. Based on the information discussed, the FEA may be more accurate than the manual calculation.

4.3 Dynamic test results

The dynamic tests results were based on whether the roller performed the equivalent cycles of 5000 operation hours without failure of the Wagners CFT CHS body roller component. The roller body was closely inspected for damage and any signs of failure. The roller was decommissioned and dismantled for inspection. Lastly, a FEA model was used to estimate the cyclic stress that the roller was subjected to. This could then be compared with the mechanical properties to give an indication of the expected fatigue life.

4.3.1 Dynamic test results

Table 4-4 was used to calculate the number of cycles the roller had performed. The prototype idler was semi-continuously tested up to an accumulation of in excess of $2.25 \cdot 10^8$ revolutions.

Table 4-4: Fatigue test log

Date started	Time started	Date stopped	Time stopped	rpm	Hours of operation	Number of revolutions (million)	Accumulative number of revolutions (million)
28/6/13	09:00	29/6/13	09:30	750	24.5	1.1025	1.1025
1/7/13	08:00	5/7/13	09:00	750	97	4.365	5.4675
5/7/13	09:00	6/7/13	14:00	1500	29	2.61	8.0775
8/7/13	06:30	13/7/13	16:00	1500	129.5	11.655	19.733
15/7/13	07:00	20/7/13	14:30	2230	127.5	17.0595	36.792
22/7/13	06:00	3/8/13	12:00	2230	270	36.126	72.918
5/8/13	06:30	10/8/13	16:30	2230	130	17.394	90.312
12/8/13	08:30	24/8/13	10:30	2230	290	38.802	129.11
26/8/13	06:00	30/8/13	18:30	2220	108.5	14.4522	143.566
2/9/13	07:00	21/9/13	16:30	2230	465.5	62.2839	205.850
23/9/13	09:00	10/9/13	09:00	2230	408	54.5904	260.440

The roller was decommissioned and dismantled after $2.60 \cdot 10^8$ revolution without the Wagners CHS failing. This test proved that the prototype idler roller performed semi-continuously for the equivalent of 5000 hours of normal operation.

4.3.2 Dismantling of the prototype roller

After successful completion of the required cycles the prototype idler roller was dismantled. The CHS surface was carefully inspected with particular attention to the area where the belt came into contact with the roller. Figure 4-6 shows the roller with the area of belt contact in the centre of the photo. Figure 4-7 and Figure 4-8 concentrated closely on the area of belt contact.

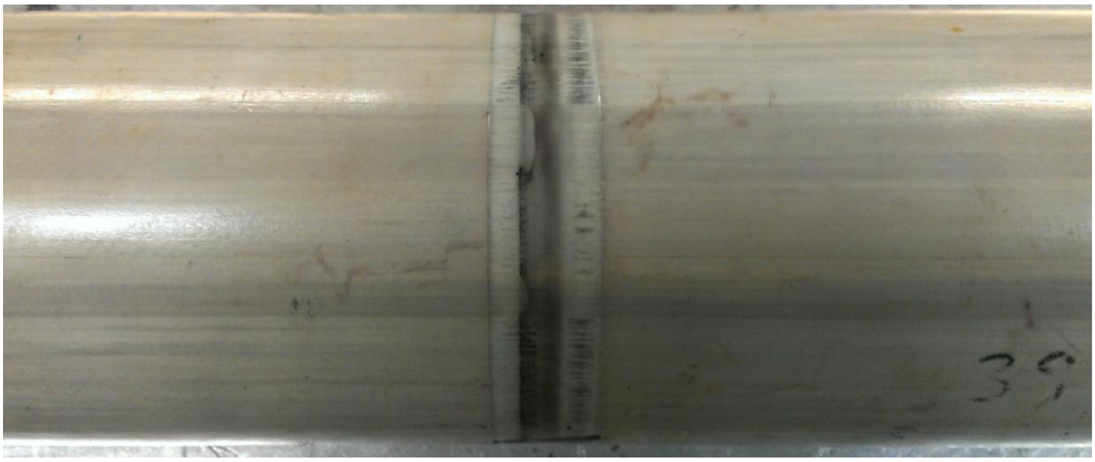


Figure 4-6: Roller surface inspection

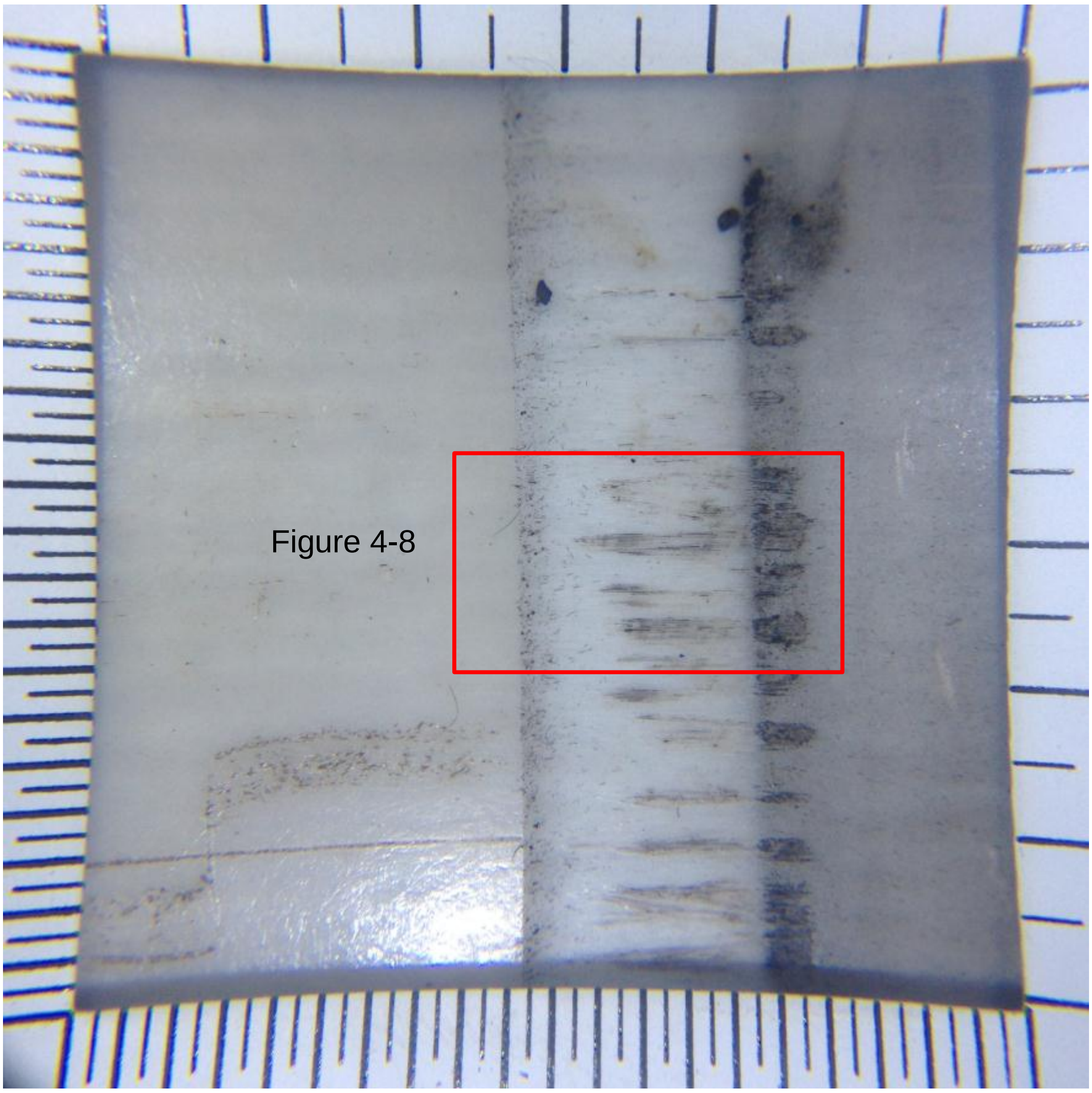


Figure 4-7: Close up of the area of belt contact

Figure 4-8: Microscopic view of area highlighted

The photos show light gouging in the area where the belt contacted the roller. The gouging was amplified by the concentrated load area and may have been less prevalent with full belt contact. Small sections of exposed subterraneous fibres are visible in Figure 4-8. This was superficial and will not affect the overall strength of the CHS. The surface performed extremely well. The Wagners CHS roller body completed the required fatigue test.

After inspecting the CHS roller body the rest of the components were inspected. Figure 4-9 shows the fatigued roller from the side. This shows a definite failure of a component.

Figure 4-9: Side view of fatigued roller

After disassembling the prototype roller it was evident that the shaft failed during the fatigue test. Figure 4-10 shows a side view of the shaft. The shaft showed extreme areas of wear on the bearing seats. The shaft was tested for the apparent hardness by pulling a file across the surface and a spark test. The tests suggested that the shaft was made from mild steel. Using a Brinell hardness tester, it was confirmed that the shaft was fabricated from mild steel and not hardened, high-carbon steel as specified.

Although the shaft failed, the CHS roller body completed the required fatigue test cycles and therefore the test remains valid. The fact that the CHS roller body performed well even though other components failed, suggests that the Wagners CFT CHS was a superior component in the design.

Figure 4-10: Failed shaft

4.3.3 FEA representation

The static FEA model of the fatigue test loading scenario was analysed to provide an indication of the cyclic stress experienced by the roller body with respect to the ultimate strength of the material. Figure 4-11 shows that the maximum cyclic stress was about 27 MPa. This indicates the reason the prototype performed so well. The material's ultimate strength was in excess of 400 MPa, making 27 MPa less than 10 % of the stress required to fail.

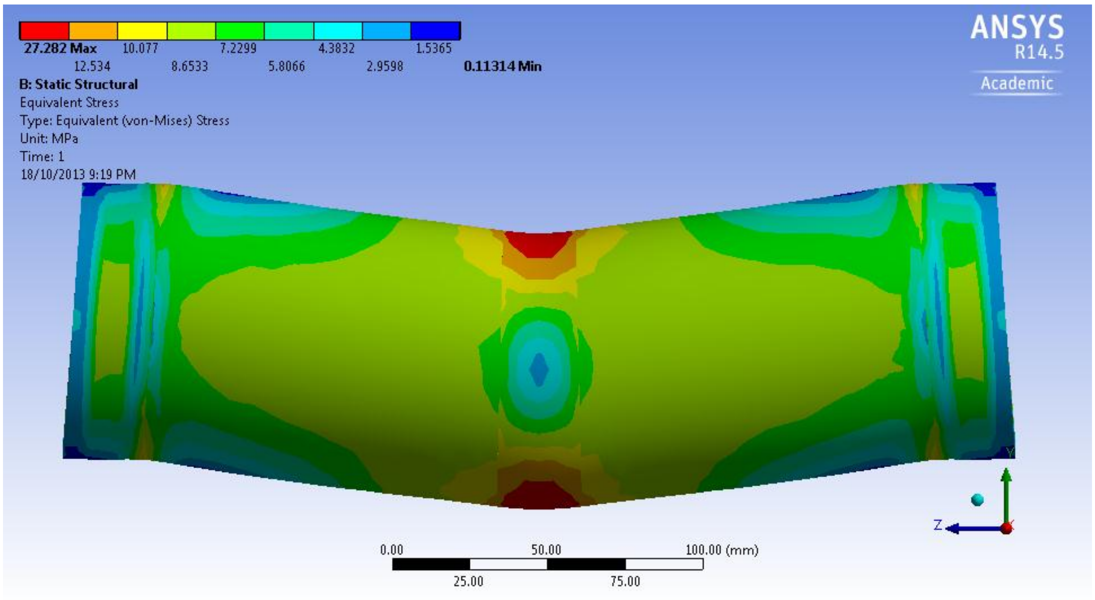


Figure 4-11: Expected cyclic stress on idler roller body

4.4 Concluding remarks

The superior performance of the prototype rollers during the testing phase concluded that the Wagners CFT CHS is most certainly a suitable material for the construction of idler roller bodies. The static testing concluded that the Wagners CFT CHS may be a suitable material for shaftless rollers as manufactured by CII. This is a significant finding because given that the design is possible, it becomes the only shaftless composite roller in existence. In fact, the Wagners CFT CHS was so successful that further analysis was done in Chapter 5 to establish the final conceptual idler roller design.

The FEA models performed exceptionally well with the largest percentage error margin being less than 2%. The deflection calculations of the static test exactly matched the average measured value and the manual theoretical calculations. It was concluded that the accuracy of the FEA results, when compared with real life measurement and mathematical calculations, deemed the FEA models valid and thus could be used to analyse the theoretical 5” OD (127 mm) and 7” OD (178 mm) CHS in Chapter 5.

The project aimed to develop a lightweight composite conveyor belt idler roller for use in the mining industry. The prototype idler weighed 25 % less than the traditional steel roller and performed to all required design specifications. Thus the project objectives were achieved.

Chapter 5

Final design

The purpose of this chapter is to provide an overview of the extension of the original project brief, based on the findings presented in Chapter 4.The first part of the chapter reports on the FEA results of the theoretical CHS and the suitability of these sections to be used as idler roller body construction material. The second section develops the final conceptual shaftless idler that can be scaled to suit all CHS sizes.

5.1 Dunlop and Rulmeca design calculations

The first step in the final design was to use the Dunlop Complete Conveyor Belt Design manual (2004) and Rulmeca Rollers and components for bulk handling (2003) to determine the design parameters for the 5” OD (127 mm) and 7” OD (178 mm) CHS. The design parameters were calculated step by step as illustrated in section 3.1.2 and section 3.1.3. Table 5-1 shows the final parameters.

Table 5-1: Design parameters for 5” OD and 7” OD CHS

Variable	5” OD CHS	7” OD CHS
Idler roller diameter	$127\ mm$	$178\ mm$
Idler roller length	$758\ mm$	$808\ mm$
Maximum belt speed	$4\ m \cdot s^{-1}$	$4\ m \cdot s^{-1}$
Belt capacity	$6415\ ton \cdot hr^{-1}$	$6966\ ton \cdot hr^{-1}$
Idler spacing	$1\ m$	$1\ m$
Belt mass	$43.3\ kg \cdot m^{-1}$	$45.3\ kg \cdot m^{-1}$
Static load on idler set	$4795\ N$	$5190\ N$
Dynamic load on idler set	$6272\ N$	$6789\ N$
Dynamic load on centre idler	$4516\ N$	$4888\ N$

5.2 Analyse theoretical CHS for idler suitability

The theoretical CHS was analysed by the validated FEA as developed in Chapter 3. This section shows the mesh and loading conditions used as well as the results obtained. The results were discussed to determine if the CHS could be used in the shaftless designs. The load was placed as a relatively concentrated mid-span load to ensure worst case scenario.

5.2.1 5” OD CHS (127 mm)

The mesh used for the 5” OD CHS can be seen in Figure 5-1 and the loading conditions are shown in Figure 5-2.

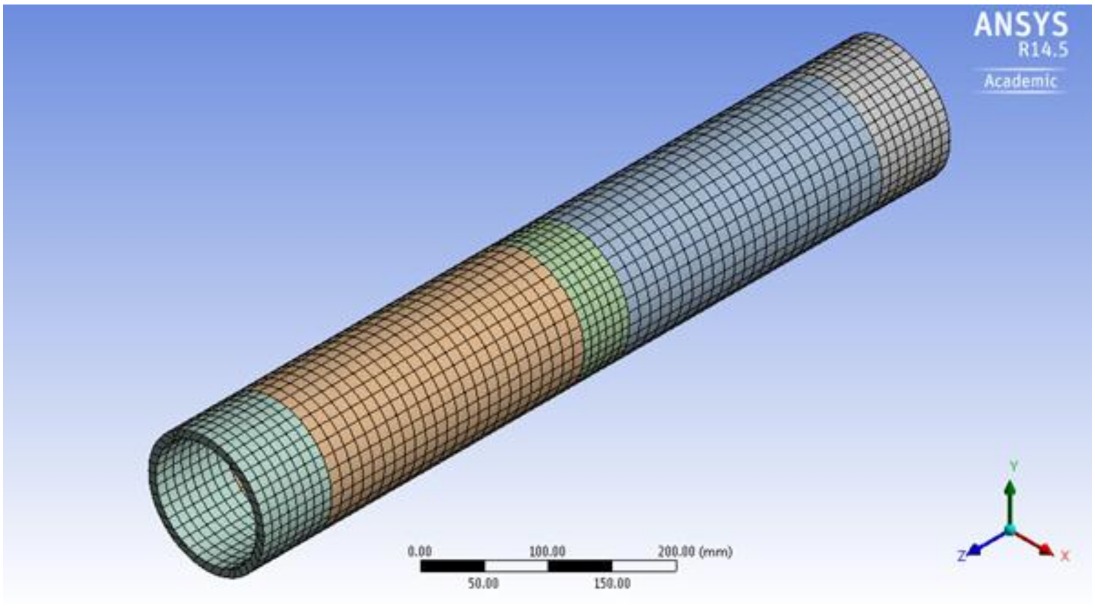


Figure 5-1: 5" OD CHS model

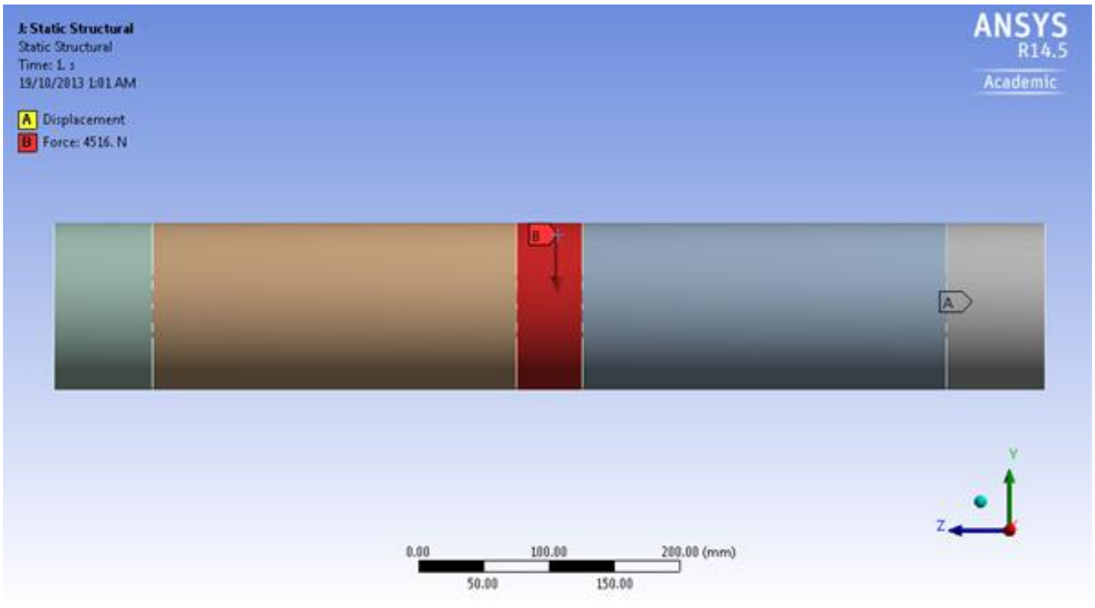


Figure 5-2: Loading conditions of the 5" OD CHS

The maximum expected deflection was 0.1 mm according to the results in Figure 5-3 and the maximum stress for the fully loaded idler was 10 MPa as shown in Figure 5-4.

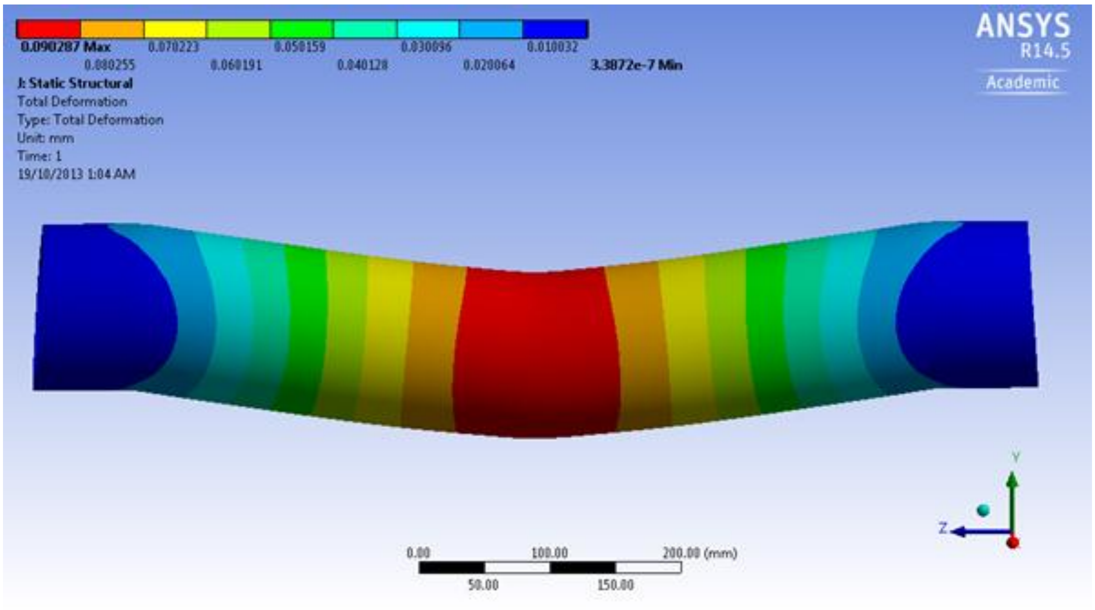


Figure 5-3: Maximum deflection results

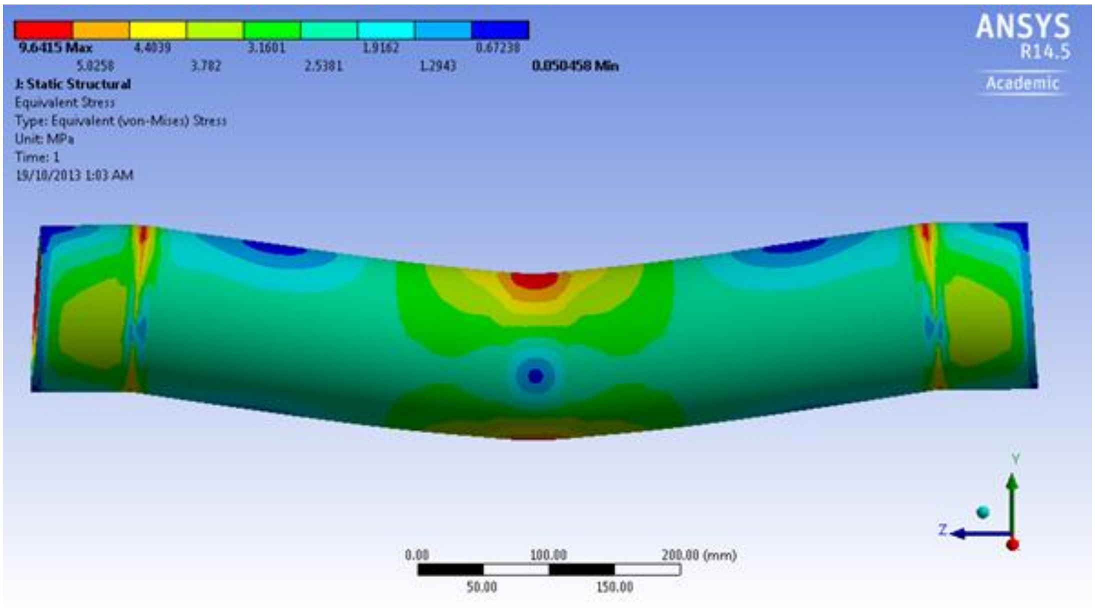


Figure 5-4: Maximum expected stress on idler

The FEA model showed that the 5" OD CHS would be a suitable section to use as a shaftless idler roller body. The maximum stress was much lower than the ultimate material capacity and therefore could be expected to perform well in high operation cyclic fatigue.

5.2.2 7” OD CHS (178 mm)

The mesh used for the 7” OD CHS can be seen in Figure 5-5.The loading conditions used in this model are shown in Figure 5-6.

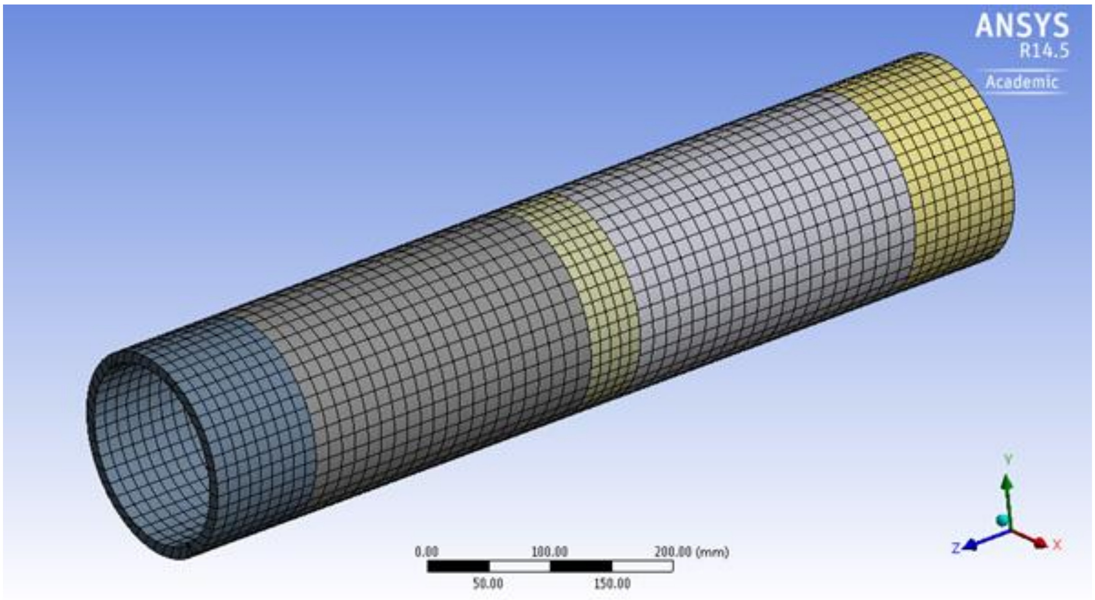


Figure 5-5: The meshed 7" OD CHS model

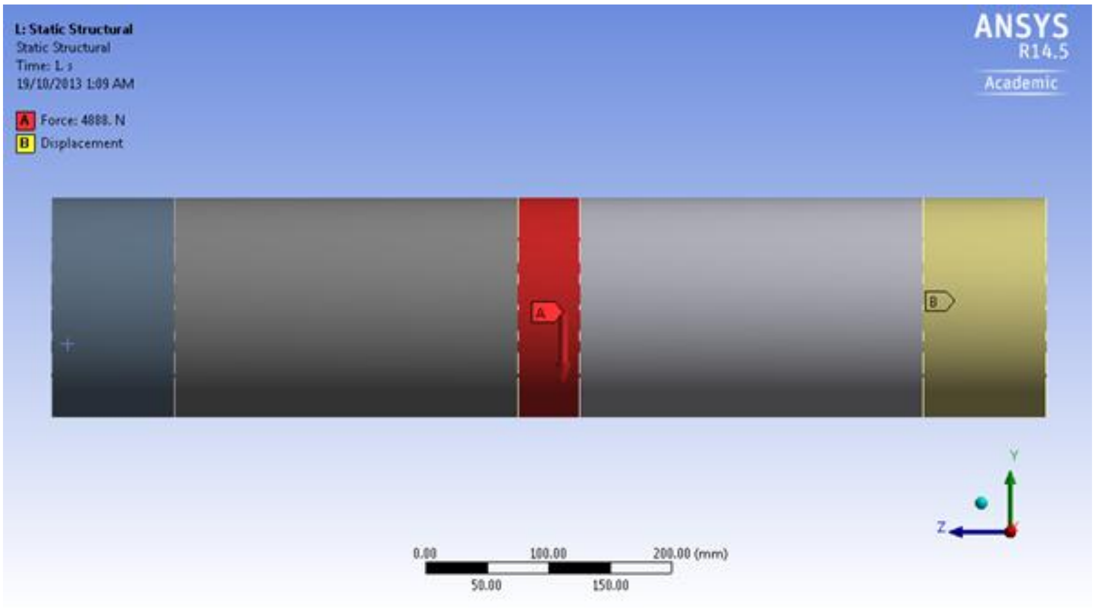


Figure 5-6: Static structural loads and supports

The results were favourable with a maximum deflection of 0.05 mm, depicted in Figure 5-7, and a maximum stress of 5 MPa as shown in Figure 5-8.

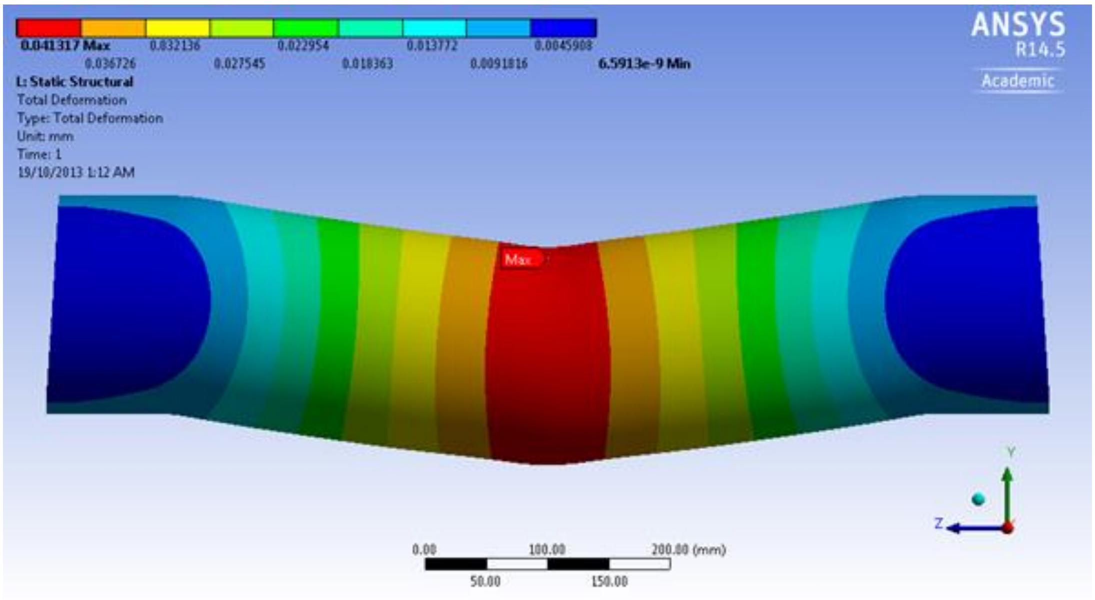


Figure 5-7: FEA deflection calculation

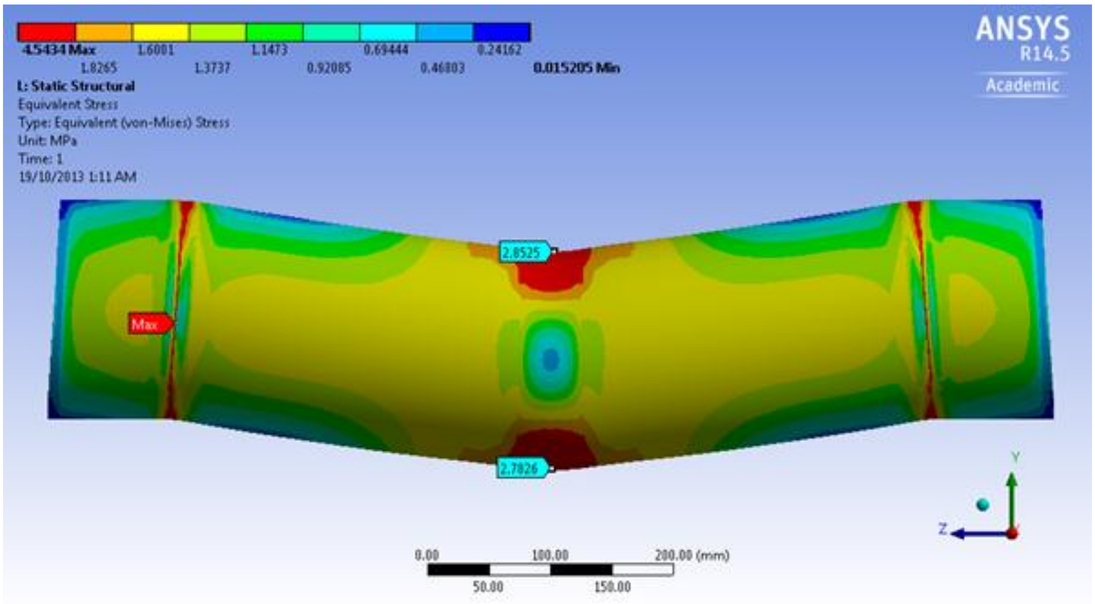


Figure 5-8: FEA stress results

The FEA model shows that the 7” OD CHS would be a suitable section to use as a shaftless idler roller body. The maximum stress was much lower than the ultimate material capacity and therefore could be expected to perform well in high operation cyclic fatigue.

5.3 Conceptualise Final design

In conceptualising a final design for a light weight composite conveyor belt idler roller for use in the mining industry, the Wagners CFT CHS has proven to be a superb material for the roller body. The FEA determined the theoretical CHS capable of carrying the required load and moment for a shaftless idler roller design. While this initial design was based on a 100mm diameter roller, to be comparable with the prototype and weighed rollers, it is possible that this could scaled to suit the larger 5"OD and 7"OD sizes. The same design methodology was followed as in section 3.1.4 starting with the bearing selection.

5.3.1 Bearing selection

The bearing type was selected by the need to have a large moment carrying capacity. The superior moment carrying capacity bearing was the double row tapered roller bearing as used by CII (section 2.1.2.1.8). Figure 5-9 portrays a double row tapered roller bearing (NTN 2013).

Figure 5-9: Double row tapered roller bearing (NTN 2013)

5.3.2 Bearing housing

The bearing housing was designed to withstand large shear forces generated by the moment on the idler. The housing featured a Wagners Wedge thread system that mated with a bonded female thread on the inside of the CHS roller body. The two threads on either end of the roller were left handed and righted threads to ensure the roller was always self-tightening. A water tight resin could be used to seal and locate the bearing housing to the roller body.

The housing was designed with glass filled nylon as the material, for its strength and light weight. The bearing housing provided the upper surface for the sealing system as well as a location groove for the end plate. Locking rings and a tight press fit held the outer bearing race in position. Figure 5-10 shows the bearing housing.

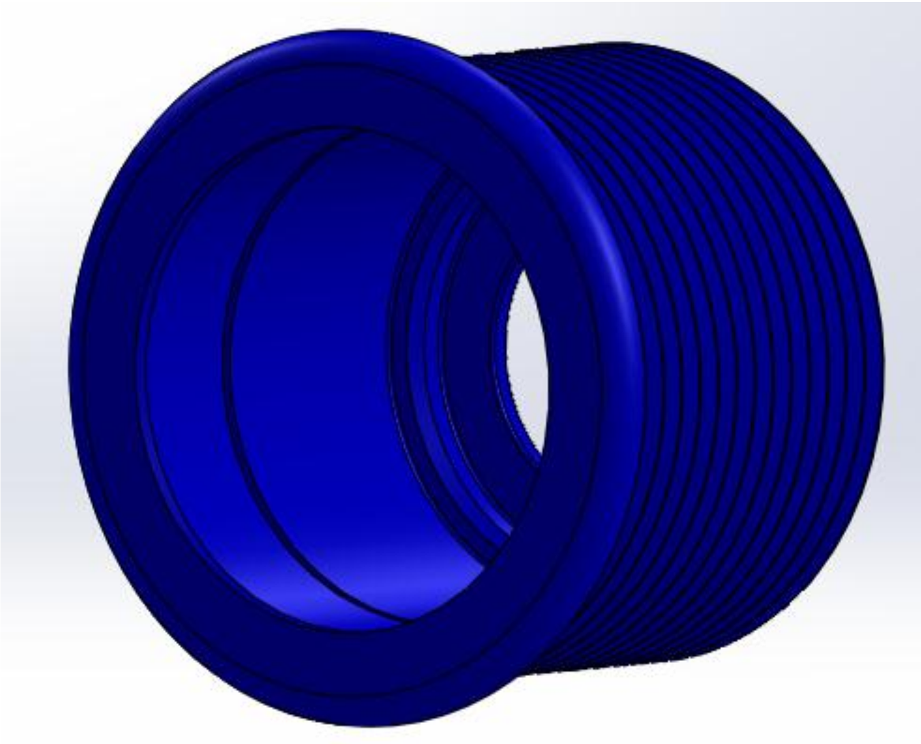


Figure 5-10: Glass filled nylon bearing housing

5.3.3 Seal system

The main constituent of the seal system was a labyrinth seal. This was complimented with a press fit dust and stone guard known as the groove-fitted endplate and a resin sealed thread. This ensured that no foreign materials infiltrate the bearings.

5.3.4 Stub axle

The stub axle transfers the load from the idler roller body, through the bearings, to the idler roller conveyor structure. The bearings were press fit into position and held there by a locking ring. The stub, locking rings and bearings were the only metal components in the shaftless composite idler.

5.3.5 Final design

The final conceptualised shaftless idler roller is shown in Figure 5-11.

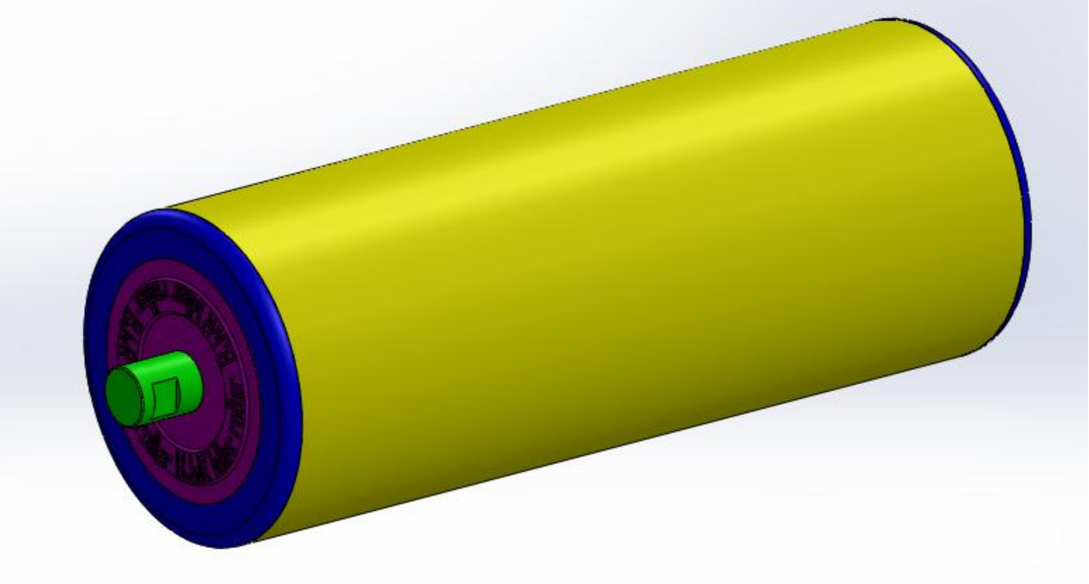


Figure 5-11: Conceptual final shaftless idler design

Figure 5-12 illustrates the arrangement of components featured in the shaftless design.

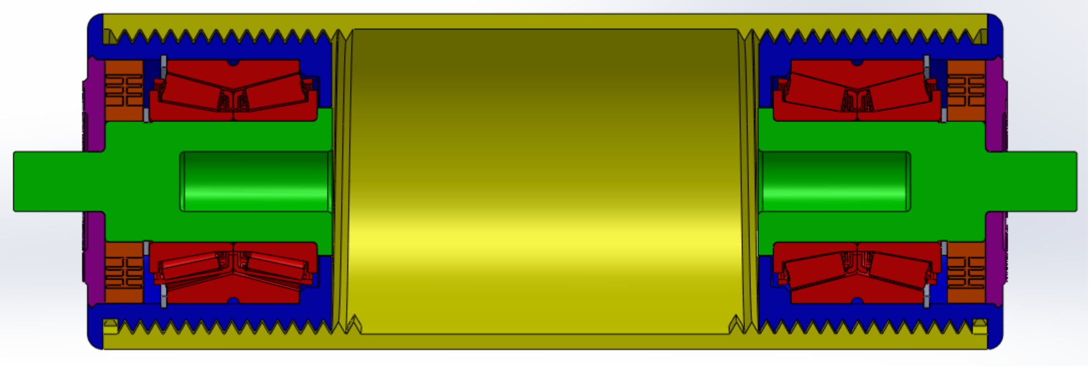


Figure 5-12: Sectioned view of the assembled conceptual roller

Figure 5-13 provides a staggered sectional view of the components to show the relationship between each component.

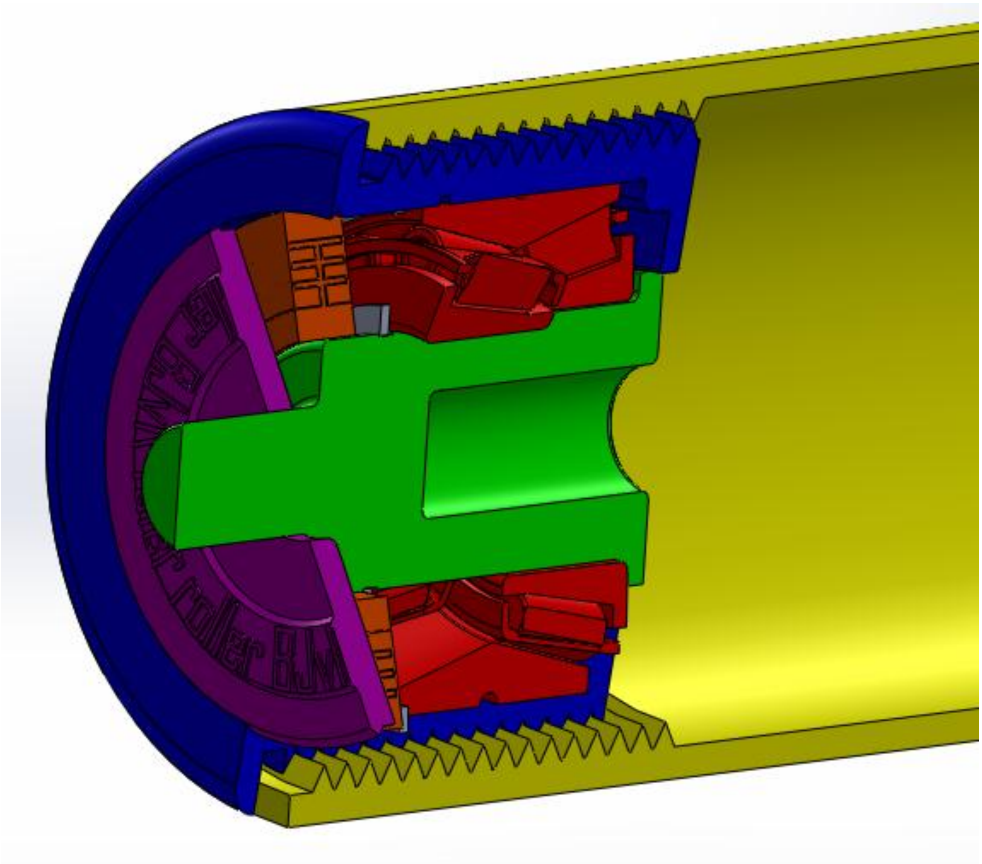


Figure 5-13: Staggered section view of conceptual design

The estimated weight for this roller was 3.15 kg. This was less than 60% the weight of similar traditional steel rollers. As can be seen in Figure 5-12 the majority of the mass of this design is in the bearing housing section. This means that as the length of the idler increases the proportion of weight saved would increase. For a roller that is 100 mm longer, the approximated weight would be less than 50% the weight of an average 100 mm OD, 400 mm long steel idler roller.

5.4 Conclusion

The FEA models showed that the 5” OD and 7” OD CHS could be used as shaftless idler roller bodies. The larger CHS could be used to develop suitably sized rollers for use in the mining industry. The final conceptual design of the shaftless roller together with the theoretical CHS capacity provided the foundation for the development of a range of commercially suitable light weight composite rollers. The estimated weight of the shaftless composite idlers ranged from 40% - 50% the weight of similar steel idlers. This was a significant reduction in weight.

Chapter 6

Conclusion and Recommendations

6.1 Project conclusion

The project was designed to develop a light weight conveyor belt idler roller for use in the mining industry. The project stemmed from the need to drastically reduce the weight of traditional idler rollers, as identified by major mining industry stakeholders such as BMA, to protect the coal mine workers from injuries obtained through excessive body strain. The study sought to use the pultruded continuous glass fibre, vinyl ester composite circular hollow section, produced by Wagners CFT, as the idler roller body construction material. Literature on this subject highlights the need for light weight idler rollers but offers no real solution, especially pertaining to large idlers used in the mining industry. The project aimed to conceptually develop a feasible solution to satisfy the need for a light weight mining idler.

A thorough literature review and methodology laid the foundations for the design of the prototype roller and the prototype roller testing regime. The prototype rollers performed extremely well in static and dynamic testing and the finite element analysis models were found to be accurate and therefore validated. Importantly, the key outcome was a prototype roller body that has exceptional load carrying capacity. The circular hollow section was further analysed to reveal the possibility of producing shaftless composite idler rollers.

Based on the findings of the physical testing, finite element analysis and theoretical calculations, a conceptual shaftless light weight composite idler roller was developed. The concept used state of the art technologies and engineering innovation to produce shaftless composite idler rollers that were estimated to be 40-50% lighter than traditional steel rollers. The analyses performed on the concept idler roller suggested that rollers, greater than the current non-ferrous limit, are possible. Taking into consideration the light weight of the concept idler roller and the possibility of manufacturing idler rollers that are dimensionally suitable for mining, the project outcomes successfully addressed what the project aimed to achieve; to develop a light weight conveyor belt idler roller for use in the mining industry.

6.2 Recommendation for future research

The successful development of a conceptual idler roller design was the final outcome of this project. However, to commercially realise such a product, further investigation needs to be done beyond the scope of this project. Since the final design is a concept, the first step for further study would be to build and test the shaftless composite idler. Further, during the progression of this project, other areas for future work were identified:

- Resin trials – this study involves substituting the vinyl ester resin with other resins that may show more favourable properties such as higher strength to weight ratios;
- Glass fibre layup optimisation – the Wagners CHS is primarily manufactured to have very large hoop strength. This study would involve optimisation of the glass layup for moment carrying capacity to reduce section thickness and weight;
- Manufacturing techniques – the complex geometrical design of the shaftless roller components poses challenges to produce and construct commercially. This study can be approached from a production engineering perspective;
- Shaftless idler roller component material selection;
- Development of non-ferrous components, such as the stub axle;
- Mining legislation compliance testing;
- Fire rating, anti-static testing;
- Acoustic analyses of composite rollers vs. steel rollers; and
- Development of a full modular composite conveyor structure.

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Appendix A

USQ FOHES ENG4111 & ENG4112

Project specification

Name: **Barnard Janse van Rensburg**

Topic: Development of a light weight composite conveyor belt idler roller.

USQ Supervisor: Chris Snook

Industry supervisors: James Bourke (Wagners)

Enrolment: ENG4111, S1, 2013; ENG4112, S2, 2013

Project Aim: Determine the suitability of Wagners produced Circular Hollow Section (CHS) composite as idler roller body material.

Sponsorship: Wagners Composite Fibre Technologies (CFT)

Programme: Issue D, 15th October 2013

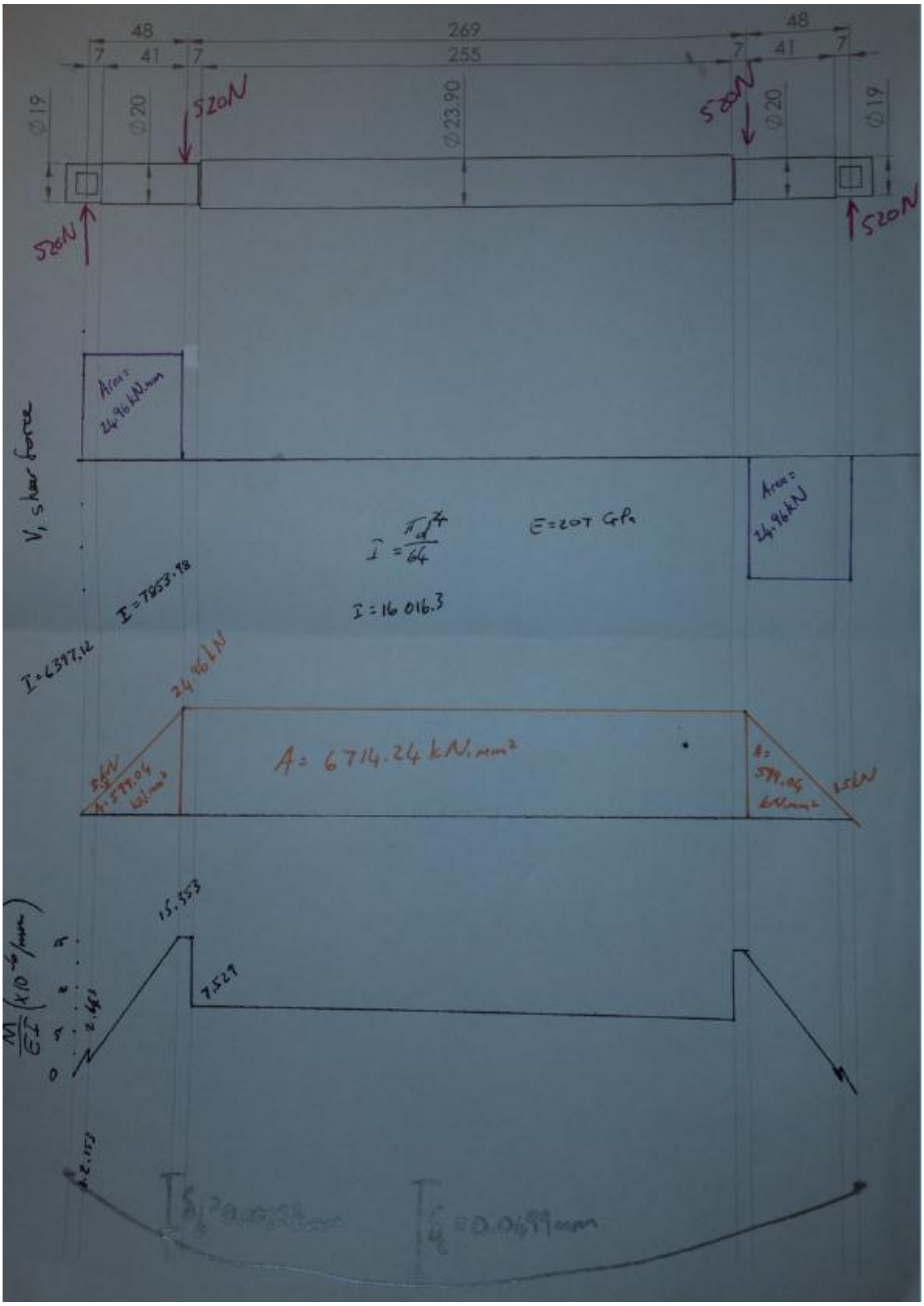
1. Research and investigate current idler rollers technologies used in conveyor belts
2. Define Wagners CFT CHS composite and determine required section properties
3. Review literature pertaining to composite's performance in fatigue
4. Investigate issues with conveyor belt systems in the Australian mining industry with particular interest in conveyor belt system related injuries during installation, maintenance and decommissioning through case studies and Workplace Health and Safety statistics
5. Define problem and need for research
6. Develop methodology for the development of a light weight composite idler roller
7. Conceptually design possible idler rollers and choose prototype design. Substantiate prototype design by recognised mechanical engineering methods
8. Build prototype
9. Evaluate design. This will be achieved by mechanical laboratory static and fatigue testing, mathematical calculations and Finite Element Analysis
10. Analyse results from various tests and determine suitability of belt idler rollers shell constructed from pultruded glass fibre vinyl ester composite
11. Conceptualise final design
12. Make recommendations and suggest further studies

Agreed

Barnard Janse van Rensburg	**Chris Snook**	**James Bourke**
______________________	______________________	______________________

Appendix B – Calculations and Testing Data

Juvinall and Marshek's (2006, p. 187) approach to 'deflection determination for an end-supported stepped steel shaft with two concentrated loads'



Four point bend test – Flexural modulus (E)

Test number 1, out of the set of 10, data has been provided. If further test data is required, see author.

Date	A/Red 213 Strin	A/5T G10804 N	Normalised W	Deflection					
		2P	P	?	L	a	I		E
		N	N	mm	mm	mm	mm4		Mpa
Test 1									
8/14/2013	183.41	-217.32	0	0	2000	650	1349400		#DIV/0!
8/14/2013	183.44	-217.32	0	0.03	2000	650	1349400		0
8/14/2013	183.42	-217.32	0	0.01	2000	650	1349400		0
8/14/2013	183.41	-217.32	0	0	2000	650	1349400		#DIV/0!
8/14/2013	183.42	-217.32	0	0.01	2000	650	1349400		0
8/14/2013	183.44	-217.32	0	0.03	2000	650	1349400		0
8/14/2013	183.41	-227.06	-4.87	0	2000	650	1349400		#DIV/0!
8/14/2013	183.42	-217.32	0	0.01	2000	650	1349400		0
8/14/2013	183.42	-199.33	8.995	0.01	2000	650	1349400		186132.1
8/14/2013	183.42	-199.33	8.995	0.01	2000	650	1349400		186132.1
8/14/2013	183.45	-217.32	0	0.04	2000	650	1349400		0
8/14/2013	183.45	-189.59	13.865	0.04	2000	650	1349400		71726.55
8/14/2013	183.44	-199.33	8.995	0.03	2000	650	1349400		62044.03
8/14/2013	183.13	-5.2572	106.0314	0.28	2000	650	1349400		78360.38
8/14/2013	182.1	252.89	235.105	1.31	2000	650	1349400		37137.33
8/14/2013	181.44	409.49	313.405	1.97	2000	650	1349400		32920
8/14/2013	181.1	464.57	340.945	2.31	2000	650	1349400		30541.64
8/14/2013	180.78	556.73	387.025	2.63	2000	650	1349400		30451.13
8/14/2013	180.61	612.19	414.755	2.8	2000	650	1349400		30651.64
8/14/2013	180.4	667.27	442.295	3.01	2000	650	1349400		30406.44
8/14/2013	180.3	676.63	446.975	3.11	2000	650	1349400		29740.13
8/14/2013	180.18	703.98	460.65	3.23	2000	650	1349400		29511.32
8/14/2013	180.14	741.08	479.2	3.27	2000	650	1349400		30324.18
8/14/2013	180.05	759.44	488.38	3.36	2000	650	1349400		30077.29
8/14/2013	180.02	777.78	497.55	3.39	2000	650	1349400		30370.86
8/14/2013	179.95	796.14	506.73	3.46	2000	650	1349400		30305.44
8/14/2013	179.83	814.5	515.91	3.58	2000	650	1349400		29820.23
8/14/2013	179.77	869.95	543.635	3.64	2000	650	1349400		30904.81
8/14/2013	179.63	906.67	561.995	3.78	2000	650	1349400		30765.27
8/14/2013	179.52	934.41	575.865	3.89	2000	650	1349400		30633.11
8/14/2013	179.45	971.11	594.215	3.96	2000	650	1349400		31050.49
8/14/2013	179.25	1026.2	621.76	4.16	2000	650	1349400		30927.84
8/14/2013	179.06	1081.6	649.46	4.35	2000	650	1349400		30894.65
8/14/2013	178.91	1127.7	672.51	4.5	2000	650	1349400		30924.76
8/14/2013	178.8	1182.8	700.06	4.61	2000	650	1349400		31423.49
8/14/2013	178.63	1228.9	723.11	4.78	2000	650	1349400		31303.76
8/14/2013	178.45	1293.3	755.31	4.96	2000	650	1349400		31511.1
8/14/2013	178.25	1348.4	782.86	5.16	2000	650	1349400		31394.57
8/14/2013	178.06	1412.8	815.06	5.35	2000	650	1349400		31525.06
8/14/2013	177.86	1449.6	833.46	5.55	2000	650	1349400		31075.05
8/14/2013	177.71	1514	865.66	5.7	2000	650	1349400		31426.25
8/14/2013	177.61	1569.1	893.21	5.8	2000	650	1349400		31867.33
8/14/2013	177.47	1615.2	916.26	5.94	2000	650	1349400		31919.23
8/14/2013	177.29	1661.3	939.31	6.12	2000	650	1349400		31759.79
8/14/2013	177.17	1651.9	934.61	6.24	2000	650	1349400		30993.16
8/14/2013	177.08	1744.1	980.71	6.33	2000	650	1349400		32059.52
8/14/2013	176.88	1799.1	1008.21	6.53	2000	650	1349400		31949.05
8/14/2013	176.69	1863.6	1040.46	6.72	2000	650	1349400		32038.8
8/14/2013	176.48	1872.9	1045.11	6.93	2000	650	1349400		31206.77
8/14/2013	176.38	1973.7	1095.51	7.03	2000	650	1349400		32246.39
8/14/2013	176.28	1992.4	1104.86	7.13	2000	650	1349400		32065.48

8/14/2013	176.16	2029.2	1123.26	7.25	2000	650	1349400		32059.91
8/14/2013	176.09	2047.5	1132.41	7.32	2000	650	1349400		32011.99
8/14/2013	176.05	2065.9	1141.61	7.36	2000	650	1349400		32096.67
8/14/2013	175.98	2056.5	1136.91	7.43	2000	650	1349400		31663.39
8/14/2013	175.94	2102.6	1159.96	7.47	2000	650	1349400		32132.35
8/14/2013	175.92	2102.6	1159.96	7.49	2000	650	1349400		32046.55
8/14/2013	175.85	2130.3	1173.81	7.56	2000	650	1349400		32128.92
8/14/2013	175.79	2148.7	1183.01	7.62	2000	650	1349400		32125.77
8/14/2013	175.74	2157.7	1187.51	7.67	2000	650	1349400		32037.75
8/14/2013	175.73	2157.7	1187.51	7.68	2000	650	1349400		31996.03
8/14/2013	175.73	2167	1192.16	7.68	2000	650	1349400		32121.32
8/14/2013	175.51	2277.2	1247.26	7.9	2000	650	1349400		32670.06
8/14/2013	175.27	2304.9	1261.11	8.14	2000	650	1349400		32058.9
8/14/2013	174.96	2387.7	1302.51	8.45	2000	650	1349400		31896.6
8/14/2013	174.78	2461.1	1339.21	8.63	2000	650	1349400		32111.31
8/14/2013	174.57	2525.2	1371.26	8.84	2000	650	1349400		32098.71
8/14/2013	174.36	2589.6	1403.46	9.05	2000	650	1349400		32090.13
8/14/2013	174.21	2663.1	1440.21	9.2	2000	650	1349400		32393.51
8/14/2013	174.12	2681.4	1449.36	9.29	2000	650	1349400		32283.5
8/14/2013	173.98	2736.5	1476.91	9.43	2000	650	1349400		32408.76
8/14/2013	173.81	2773.3	1495.31	9.6	2000	650	1349400		32231.47
8/14/2013	173.73	2828.7	1523.01	9.68	2000	650	1349400		32557.23
8/14/2013	173.59	2856.1	1536.71	9.82	2000	650	1349400		32381.76
8/14/2013	173.47	2883.8	1550.56	9.94	2000	650	1349400		32279.16
8/14/2013	173.38	2920.5	1568.91	10.03	2000	650	1349400		32368.1
8/14/2013	173.18	2993.9	1605.61	10.23	2000	650	1349400		32477.64
8/14/2013	173.11	3012.3	1614.81	10.3	2000	650	1349400		32441.75
8/14/2013	173	3067.4	1642.36	10.41	2000	650	1349400		32646.58
8/14/2013	172.8	3094.7	1656.01	10.61	2000	650	1349400		32297.41
8/14/2013	172.64	3177.5	1697.41	10.77	2000	650	1349400		32613.03
8/14/2013	172.49	3232.6	1724.96	10.92	2000	650	1349400		32687.11
8/14/2013	172.3	3269.3	1743.31	11.11	2000	650	1349400		32469.88
8/14/2013	172.16	3352.1	1784.71	11.25	2000	650	1349400		32827.3
8/14/2013	171.98	3379.4	1798.36	11.43	2000	650	1349400		32557.46
8/14/2013	171.8	3462.3	1839.81	11.61	2000	650	1349400		32791.47
8/14/2013	171.63	3516.9	1867.11	11.78	2000	650	1349400		32797.8
8/14/2013	171.49	3581.4	1899.36	11.92	2000	650	1349400		32972.44
8/14/2013	171.27	3645.4	1931.36	12.14	2000	650	1349400		32920.36
8/14/2013	171.07	3718.9	1968.11	12.34	2000	650	1349400		33003.07
8/14/2013	170.86	3774	1995.66	12.55	2000	650	1349400		32905.08
8/14/2013	170.65	3838.4	2027.86	12.76	2000	650	1349400		32885.72
8/14/2013	170.49	3911.9	2064.61	12.92	2000	650	1349400		33067.06
8/14/2013	170.23	4003.3	2110.31	13.18	2000	650	1349400		33132.25
8/14/2013	169.96	4095.1	2156.21	13.45	2000	650	1349400		33173.31
8/14/2013	169.74	4177.5	2197.41	13.67	2000	650	1349400		33263.1
8/14/2013	169.5	4232.5	2224.91	13.91	2000	650	1349400		33098.28
8/14/2013	169.31	4324.4	2270.86	14.1	2000	650	1349400		33326.62
8/14/2013	169.08	4388.4	2302.86	14.33	2000	650	1349400		33253.81
8/14/2013	168.84	4480.3	2348.81	14.57	2000	650	1349400		33358.65
8/14/2013	168.58	4544.3	2380.81	14.83	2000	650	1349400		33220.31
8/14/2013	168.36	4608.8	2413.06	15.05	2000	650	1349400		33178.11
8/14/2013	168.17	4663.4	2440.36	15.24	2000	650	1349400		33135.15
8/14/2013	168.02	4700.1	2458.71	15.39	2000	650	1349400		33058.93
8/14/2013	167.93	4755.3	2486.31	15.48	2000	650	1349400		33235.67
8/14/2013	167.84	4791.9	2504.61	15.57	2000	650	1349400		33286.76
8/14/2013	167.71	4847	2532.16	15.7	2000	650	1349400		33374.25
8/14/2013	167.61	4856	2536.66	15.8	2000	650	1349400		33221.96
8/14/2013	167.56	4901.8	2559.56	15.85	2000	650	1349400		33416.13
8/14/2013	167.43	4911	2564.16	15.98	2000	650	1349400		33203.85
8/14/2013	167.39	4920	2568.66	16.02	2000	650	1349400		33179.07

8/14/2013	167.34	4947.8	2582.56	16.07	2000	650	1349400		33254.82
8/14/2013	167.23	4975.1	2596.21	16.18	2000	650	1349400		33203.31
8/14/2013	167.14	5002.5	2609.91	16.27	2000	650	1349400		33193.88
8/14/2013	167.01	5039.3	2628.31	16.4	2000	650	1349400		33162.92
8/14/2013	166.98	5075.9	2646.61	16.43	2000	650	1349400		33332.85
8/14/2013	166.8	5112.6	2664.96	16.61	2000	650	1349400		33200.23
8/14/2013	166.74	5158.4	2687.86	16.67	2000	650	1349400		33365
8/14/2013	166.62	5204	2710.66	16.79	2000	650	1349400		33407.53
8/14/2013	166.48	5249.8	2733.56	16.93	2000	650	1349400		33411.17
8/14/2013	166.37	5313.1	2765.21	17.04	2000	650	1349400		33579.84
8/14/2013	166.24	5340.8	2779.06	17.17	2000	650	1349400		33492.51
8/14/2013	166.06	5395.9	2806.61	17.35	2000	650	1349400		33473.62
8/14/2013	165.88	5488	2852.66	17.53	2000	650	1349400		33673.49
8/14/2013	165.7	5533.8	2875.56	17.71	2000	650	1349400		33598.81
8/14/2013	165.5	5589.3	2903.31	17.91	2000	650	1349400		33544.24
8/14/2013	165.29	5671.6	2944.46	18.12	2000	650	1349400		33625.41
8/14/2013	165.11	5736.1	2976.71	18.3	2000	650	1349400		33659.33
8/14/2013	164.89	5837.3	3027.31	18.52	2000	650	1349400		33824.86
8/14/2013	164.72	5865	3041.16	18.69	2000	650	1349400		33670.54
8/14/2013	164.52	5947.4	3082.36	18.89	2000	650	1349400		33765.37
8/14/2013	164.32	6011.9	3114.61	19.09	2000	650	1349400		33761.2
8/14/2013	164.12	6085.3	3151.31	19.29	2000	650	1349400		33804.85
8/14/2013	163.93	6158.8	3188.06	19.48	2000	650	1349400		33865.51
8/14/2013	163.75	6204.8	3211.06	19.66	2000	650	1349400		33797.53
8/14/2013	163.55	6278.3	3247.81	19.86	2000	650	1349400		33840.08
8/14/2013	163.35	6342.6	3279.96	20.06	2000	650	1349400		33834.34
8/14/2013	163.1	6434.5	3325.91	20.31	2000	650	1349400		33886.03
8/14/2013	162.76	6516.9	3367.11	20.65	2000	650	1349400		33740.95
8/14/2013	162.56	6618	3417.66	20.85	2000	650	1349400		33918.99
8/14/2013	162.19	6728.3	3472.81	21.22	2000	650	1349400		33865.36
8/14/2013	161.84	6847.4	3532.36	21.57	2000	650	1349400		33887.14
8/14/2013	161.54	6985.3	3601.31	21.87	2000	650	1349400		34074.68
8/14/2013	161.14	7113.8	3665.56	22.27	2000	650	1349400		34059.65
8/14/2013	160.73	7251.3	3734.31	22.68	2000	650	1349400		34071.2
8/14/2013	160.38	7379.8	3798.56	23.03	2000	650	1349400		34130.69
8/14/2013	159.95	7498.9	3858.11	23.46	2000	650	1349400		34030.37
8/14/2013	159.64	7618	3917.66	23.77	2000	650	1349400		34104.97
8/14/2013	159.27	7746.5	3981.91	24.14	2000	650	1349400		34132.98
8/14/2013	158.89	7893.4	4055.36	24.52	2000	650	1349400		34223.86
8/14/2013	158.47	8058.3	4137.81	24.94	2000	650	1349400		34331.61
8/14/2013	158.02	8177.4	4197.36	25.39	2000	650	1349400		34208.47
8/14/2013	157.56	8360.5	4288.91	25.85	2000	650	1349400		34332.58
8/14/2013	157.11	8488.8	4353.06	26.3	2000	650	1349400		34249.87
8/14/2013	156.81	8626.3	4421.81	26.6	2000	650	1349400		34398.42
8/14/2013	156.43	8736	4476.66	26.98	2000	650	1349400		34334.62
8/14/2013	156.11	8827.8	4522.56	27.3	2000	650	1349400		34280.08
8/14/2013	155.78	8910.3	4563.81	27.63	2000	650	1349400		34179.58
8/14/2013	155.59	8992.5	4604.91	27.82	2000	650	1349400		34251.85
8/14/2013	155.37	9065.8	4641.56	28.04	2000	650	1349400		34253.59
8/14/2013	155.11	9139	4678.16	28.3	2000	650	1349400		34206.51
8/14/2013	154.82	9249	4733.16	28.59	2000	650	1349400		34257.61
8/14/2013	154.46	9422.8	4820.06	28.95	2000	650	1349400		34452.75
8/14/2013	153.9	9587.5	4902.41	29.51	2000	650	1349400		34376.41
8/14/2013	153.48	9752	4984.66	29.93	2000	650	1349400		34462.67
8/14/2013	153	9917	5067.16	30.41	2000	650	1349400		34480.08
8/14/2013	152.52	10091	5154.16	30.89	2000	650	1349400		34527.1
8/14/2013	152.1	10219	5218.16	31.31	2000	650	1349400		34486.92
8/14/2013	151.74	10310	5263.66	31.67	2000	650	1349400		34392.19
8/14/2013	151.35	10420	5318.66	32.06	2000	650	1349400		34328.81
8/14/2013	151.06	10520	5368.66	32.35	2000	650	1349400		34340.9

8/14/2013	150.62	10657	5437.16	32.79	2000	650	1349400		34312.37
8/14/2013	150.21	10804	5510.66	33.2	2000	650	1349400		34346.75
8/14/2013	149.8	10941	5579.16	33.61	2000	650	1349400		34349.5
8/14/2013	149.39	11077	5647.16	34.02	2000	650	1349400		34349.14
8/14/2013	149	11224	5720.66	34.41	2000	650	1349400		34401.83
8/14/2013	148.54	11361	5789.16	34.87	2000	650	1349400		34354.5
8/14/2013	148.04	11543	5880.16	35.37	2000	650	1349400		34401.24
8/14/2013	147.46	11708	5962.66	35.95	2000	650	1349400		34321.1
8/14/2013	147.01	11890	6053.66	36.4	2000	650	1349400		34414.12
8/14/2013	146.5	12045	6131.16	36.91	2000	650	1349400		34373.1
8/14/2013	145.92	12246	6231.66	37.49	2000	650	1349400		34396.04
8/14/2013	145.35	12438	6327.66	38.06	2000	650	1349400		34402.85
8/14/2013	144.83	12612	6414.66	38.58	2000	650	1349400		34405.79
8/14/2013	144.35	12813	6515.16	39.06	2000	650	1349400		34515.4
8/14/2013	143.73	13005	6611.16	39.68	2000	650	1349400		34476.73
8/14/2013	143.14	13207	6712.16	40.27	2000	650	1349400		34490.6
8/14/2013	142.59	13408	6812.66	40.82	2000	650	1349400		34535.34
8/14/2013	142	13591	6904.16	41.41	2000	650	1349400		34500.52
8/14/2013	141.41	13783	7000.16	42	2000	650	1349400		34488.85
8/14/2013	140.86	13975	7096.16	42.55	2000	650	1349400		34509.92
8/14/2013	140.2	14212	7214.66	43.21	2000	650	1349400		34550.29
8/14/2013	139.47	14477	7347.16	43.94	2000	650	1349400		34600.27
8/14/2013	138.73	14705	7461.16	44.68	2000	650	1349400		34555.19
8/14/2013	138.11	14934	7575.66	45.3	2000	650	1349400		34605.28
8/14/2013	137.38	15198	7707.66	46.03	2000	650	1349400		34649.87
8/14/2013	136.59	15436	7826.66	46.82	2000	650	1349400		34591.16
8/14/2013	135.83	15682	7949.66	47.58	2000	650	1349400		34573.57
8/14/2013	135.18	15901	8059.16	48.23	2000	650	1349400		34577.42
8/14/2013	134.54	16110	8163.66	48.87	2000	650	1349400		34567.08
8/14/2013	133.95	16320	8268.66	49.46	2000	650	1349400		34594.03
8/14/2013	133.36	16512	8364.66	50.05	2000	650	1349400		34583.13
8/14/2013	132.71	16730	8473.66	50.7	2000	650	1349400		34584.63
8/14/2013	132.02	16939	8578.16	51.39	2000	650	1349400		34541.06
8/14/2013	131.38	17195	8706.16	52.03	2000	650	1349400		34625.25
8/14/2013	130.63	17431	8824.16	52.78	2000	650	1349400		34595.85
8/14/2013	129.89	17677	8947.16	53.52	2000	650	1349400		34593.08
8/14/2013	129.19	17913	9065.16	54.22	2000	650	1349400		34596.81
8/14/2013	128.46	18141	9179.16	54.95	2000	650	1349400		34566.49
8/14/2013	127.7	18359	9288.16	55.71	2000	650	1349400		34499.8
8/14/2013	126.98	18577	9397.16	56.43	2000	650	1349400		34459.32
8/14/2013	126.36	18777	9497.16	57.05	2000	650	1349400		34447.54
8/14/2013	125.81	18959	9588.16	57.6	2000	650	1349400		34445.53
8/14/2013	125.26	19123	9670.16	58.15	2000	650	1349400		34411.53
8/14/2013	124.82	19251	9734.16	58.59	2000	650	1349400		34379.14
8/14/2013	124.36	19370	9793.66	59.05	2000	650	1349400		34319.84
8/14/2013	123.87	19497	9857.16	59.54	2000	650	1349400		34258.08
8/14/2013	123.44	19661	9939.16	59.97	2000	650	1349400		34295.39
8/14/2013	122.94	19825	10021.16	60.47	2000	650	1349400		34292.42
8/14/2013	122.36	20026	10121.66	61.05	2000	650	1349400		34307.27
8/14/2013	121.77	20217	10217.16	61.64	2000	650	1349400		34299.49
8/14/2013	121.16	20390	10303.66	62.25	2000	650	1349400		34250.92
8/14/2013	120.65	20563	10390.16	62.76	2000	650	1349400		34257.79
8/14/2013	120.17	20745	10481.16	63.24	2000	650	1349400		34295.53
8/14/2013	119.67	20882	10549.66	63.74	2000	650	1349400		34248.89
8/14/2013	119.19	21018	10617.66	64.22	2000	650	1349400		34212.01
8/14/2013	118.8	21136	10676.66	64.61	2000	650	1349400		34194.46
8/14/2013	118.23	21300	10758.66	65.18	2000	650	1349400		34155.76
8/14/2013	117.8	21428	10822.66	65.61	2000	650	1349400		34133.75
8/14/2013	117.43	21564	10890.66	65.98	2000	650	1349400		34155.6
8/14/2013	116.94	21691	10954.16	66.47	2000	650	1349400		34101.5

8/14/2013	116.53	21837	11027.16	66.88	2000	650	1349400		34118.31
8/14/2013	116.08	21955	11086.16	67.33	2000	650	1349400		34071.61
8/14/2013	115.67	22109	11163.16	67.74	2000	650	1349400		34100.6
8/14/2013	115.06	22291	11254.16	68.35	2000	650	1349400		34071.77
8/14/2013	114.43	22518	11367.66	68.98	2000	650	1349400		34101.07
8/14/2013	113.54	22818	11517.66	69.87	2000	650	1349400		34110.93
8/14/2013	112.63	23117	11667.16	70.78	2000	650	1349400		34109.45
8/14/2013	111.46	23462	11839.66	71.95	2000	650	1349400		34050.89
8/14/2013	110.24	23907	12062.16	73.17	2000	650	1349400		34112.39
8/14/2013	108.84	24405	12311.16	74.57	2000	650	1349400		34162.91
8/14/2013	107.05	24967	12592.16	76.36	2000	650	1349400		34123.56
8/14/2013	105.2	25537	12877.16	78.21	2000	650	1349400		34070.45
8/14/2013	103.46	26164	13190.66	79.95	2000	650	1349400		34140.36
8/14/2013	101.5	26754	13485.66	81.91	2000	650	1349400		34068.68
8/14/2013	99.529	27371	13794.16	83.881	2000	650	1349400		34029.2
8/14/2013	97.605	27969	14093.16	85.805	2000	650	1349400		33987.24
8/14/2013	95.66	28549	14383.16	87.75	2000	650	1349400		33917.77
8/14/2013	93.842	29101	14659.16	89.568	2000	650	1349400		33866.97
8/14/2013	91.961	29617	14917.16	91.449	2000	650	1349400		33754.16
8/14/2013	90.207	30141	15179.16	93.203	2000	650	1349400		33700.62
8/14/2013	88.484	30711	15464.16	94.926	2000	650	1349400		33710.19
8/14/2013	86.68	31243	15730.16	96.73	2000	650	1349400		33650.54
8/14/2013	84.926	31758	15987.66	98.484	2000	650	1349400		33592.27
8/14/2013	83.121	32254	16235.66	100.289	2000	650	1349400		33499.38
8/14/2013	81.246	32821	16519.16	102.164	2000	650	1349400		33458.78
8/14/2013	79.365	33366	16791.66	104.045	2000	650	1349400		33395.85
8/14/2013	77.592	33909	17063.16	105.818	2000	650	1349400		33367.22
8/14/2013	75.762	34433	17325.16	107.648	2000	650	1349400		33303.61
8/14/2013	74.064	34911	17564.16	109.346	2000	650	1349400		33238.74
8/14/2013	72.645	35290	17753.66	110.765	2000	650	1349400		33166.94
8/14/2013	71.379	35632	17924.66	112.031	2000	650	1349400		33107.99
8/14/2013	70.166	35939	18078.16	113.244	2000	650	1349400		33033.84
8/14/2013	69.154	36218	18217.66	114.256	2000	650	1349400		32993.9
8/14/2013	68.162	36470	18343.66	115.248	2000	650	1349400		32936.14
8/14/2013	67.246	36722	18469.66	116.164	2000	650	1349400		32900.87
8/14/2013	66.342	37083	18650.16	117.068	2000	650	1349400		32965.86
8/14/2013	64.715	37856	19036.66	118.695	2000	650	1349400		33187.8
8/14/2013	61.829	38710	19463.66	121.581	2000	650	1349400		33126.75
8/14/2013	58.929	39527	19872.16	124.481	2000	650	1349400		33034.07
8/14/2013	56.062	40332	20274.66	127.348	2000	650	1349400		32944.39
8/14/2013	53.555	41070	20643.66	129.855	2000	650	1349400		32896.38
8/14/2013	51.151	41691	20954.16	132.259	2000	650	1349400		32784.24
8/14/2013	48.896	42292	21254.66	134.514	2000	650	1349400		32696.91
8/14/2013	46.631	42921	21569.16	136.779	2000	650	1349400		32631.26
8/14/2013	44.472	43513	21865.16	138.938	2000	650	1349400		32565.05
8/14/2013	42.453	44015	22116.16	140.957	2000	650	1349400		32467.07
8/14/2013	40.649	44463	22340.16	142.761	2000	650	1349400		32381.49
8/14/2013	39.065	44884	22550.66	144.345	2000	650	1349400		32327.91
8/14/2013	37.721	45188	22702.66	145.689	2000	650	1349400		32245.57
8/14/2013	36.585	45456	22836.66	146.825	2000	650	1349400		32184.94
8/14/2013	35.669	45671	22944.16	147.741	2000	650	1349400		32135.95
8/14/2013	34.971	45814	23015.66	148.439	2000	650	1349400		32084.52
8/14/2013	34.384	45922	23069.66	149.026	2000	650	1349400		32033.12
8/14/2013	33.96	45957	23087.16	149.45	2000	650	1349400		31966.47
8/14/2013	33.84	45922	23069.66	149.57	2000	650	1349400		31916.61
8/14/2013	33.832	45886	23051.66	149.578	2000	650	1349400		31890
8/14/2013	33.826	45832	23024.66	149.584	2000	650	1349400		31851.37
8/14/2013	33.828	45806	23011.66	149.582	2000	650	1349400		31833.81
8/14/2013	33.828	45788	23002.66	149.582	2000	650	1349400		31821.36
8/14/2013	33.826	45770	22993.66	149.584	2000	650	1349400		31808.49
8/14/2013	33.826	45734	22975.66	149.584	2000	650	1349400		31783.59
8/14/2013	33.829	45725	22971.16	149.581	2000	650	1349400		31778
8/14/2013	33.832	45680	22948.66	149.578	2000	650	1349400		31747.51
8/14/2013	33.829	45644	22930.66	149.581	2000	650	1349400		31721.97
8/14/2013	33.828	45653	22935.16	149.582	2000	650	1349400		31727.99

8/14/2013	33.831	45617	22917.16	149.579	2000	650	1349400		31703.72
8/14/2013	33.829	45591	22904.16	149.581	2000	650	1349400		31685.31
8/14/2013	33.828	45599	22908.16	149.582	2000	650	1349400		31690.64
8/14/2013	33.828	45653	22935.16	149.582	2000	650	1349400		31727.99
8/14/2013	33.727	45653	22935.16	149.683	2000	650	1349400		31706.58
8/14/2013	33.481	45859	23038.16	149.929	2000	650	1349400		31796.71
8/14/2013	32.856	46109	23163.16	150.554	2000	650	1349400		31836.52
8/14/2013	32.051	46395	23306.16	151.359	2000	650	1349400		31862.7
8/14/2013	31.049	46724	23470.66	152.361	2000	650	1349400		31876.57
8/14/2013	29.915	47091	23654.16	153.495	2000	650	1349400		31888.45
8/14/2013	28.755	47468	23842.66	154.655	2000	650	1349400		31901.48
8/14/2013	27.438	47871	24044.16	155.972	2000	650	1349400		31899.44
8/14/2013	26.081	48319	24268.16	157.329	2000	650	1349400		31918.92
8/14/2013	24.698	48731	24474.16	158.712	2000	650	1349400		31909.36
8/14/2013	23.325	49124	24670.66	160.085	2000	650	1349400		31889.68
8/14/2013	22.021	49527	24872.16	161.389	2000	650	1349400		31890.38
8/14/2013	20.692	49947	25082.16	162.718	2000	650	1349400		31896.97
8/14/2013	19.319	50331	25274.16	164.091	2000	650	1349400		31872.2
8/14/2013	18.094	50643	25430.16	165.316	2000	650	1349400		31831.29
8/14/2013	16.941	50938	25577.66	166.469	2000	650	1349400		31794.17
8/14/2013	15.864	51188	25702.66	167.546	2000	650	1349400		31744.18
8/14/2013	14.821	51330	25773.66	168.589	2000	650	1349400		31634.93
8/14/2013	14.629	51250	25733.66	168.781	2000	650	1349400		31549.91
8/14/2013	14.627	51214	25715.66	168.783	2000	650	1349400		31527.46
8/14/2013	14.627	51161	25689.16	168.783	2000	650	1349400		31494.98
8/14/2013	14.627	51134	25675.66	168.783	2000	650	1349400		31478.42
8/14/2013	14.626	51089	25653.16	168.784	2000	650	1349400		31450.65
8/14/2013	14.626	51054	25635.66	168.784	2000	650	1349400		31429.2
8/14/2013	14.627	51027	25622.16	168.783	2000	650	1349400		31412.83
8/14/2013	14.627	51018	25617.66	168.783	2000	650	1349400		31407.32
8/14/2013	14.626	50991	25604.16	168.784	2000	650	1349400		31390.58
8/14/2013	14.627	50956	25586.66	168.783	2000	650	1349400		31369.31
8/14/2013	14.627	50938	25577.66	168.783	2000	650	1349400		31358.28
8/14/2013	14.626	50947	25582.16	168.784	2000	650	1349400		31363.61
8/14/2013	14.627	48659	24438.16	168.783	2000	650	1349400		29961.25
8/14/2013	30.434	40386	20301.66	152.976	2000	650	1349400		27461.76
8/14/2013	55.876	32632	16424.66	127.534	2000	650	1349400		26649.59
8/14/2013	80.666	25420	12818.66	102.744	2000	650	1349400		25817.03
8/14/2013	104.06	19095	9656.16	79.35	2000	650	1349400		25181.27
8/14/2013	123.82	13856	7036.66	59.59	2000	650	1349400		24435.05
8/14/2013	139.45	9193.8	4705.56	43.96	2000	650	1349400		22150
8/14/2013	152.7	5432.6	2824.96	30.71	2000	650	1349400		19034.99
8/14/2013	163.22	2690.8	1454.06	20.19	2000	650	1349400		14902.74
8/14/2013	171.64	372.41	294.865	11.77	2000	650	1349400		5184.022
8/14/2013	178.82	-189.59	13.865	4.59	2000	650	1349400		625.068
8/14/2013	179.23	-189.59	13.865	4.18	2000	650	1349400		686.3785
8/14/2013	179.44	-217.32	0	3.97	2000	650	1349400		0
8/14/2013	179.57	-189.59	13.865	3.84	2000	650	1349400		747.1516
8/14/2013	179.65	-208.7	4.31	3.76	2000	650	1349400		237.1972
8/14/2013	179.76	-171.23	23.045	3.65	2000	650	1349400		1306.483
8/14/2013	179.81	-217.32	0	3.6	2000	650	1349400		0
8/14/2013	179.87	-189.59	13.865	3.54	2000	650	1349400		810.4695

Shear test – Shear capacity

Test number 1, out of the set of 10, data has been provided. If further test data is required, see author.

Test 1			
9/4/2013 11:57	347.58	-1.0754	-1075.4
9/4/2013 11:57	347.48	-1.1622	-1162.2
9/4/2013 11:57	347.56	-0.98521	-985.21
9/4/2013 11:57	346.79	-1.1622	-1162.2
9/4/2013 11:57	342.43	-0.04829	-48.29
9/4/2013 11:57	337.77	3.5225	3522.5
9/4/2013 11:57	333.07	6.5067	6506.7
9/4/2013 11:57	328.75	9.5015	9501.5
9/4/2013 11:57	324.24	12.576	12576
9/4/2013 11:57	319.84	17.101	17101
9/4/2013 11:57	315.59	19.915	19915
9/4/2013 11:57	311.41	22.899	22899
9/4/2013 11:58	307.41	25.627	25627
9/4/2013 11:58	303.97	27.5	27500
9/4/2013 11:58	300.46	29.971	29971
9/4/2013 11:58	297.12	32.355	32355
9/4/2013 11:58	294.1	33.889	33889
9/4/2013 11:58	291.03	35.846	35846
9/4/2013 11:58	288.08	37.38	37380
9/4/2013 11:58	285.26	39.847	39847
9/4/2013 11:58	282.7	40.614	40614
9/4/2013 11:58	280.12	42.314	42314
9/4/2013 11:58	277.59	43.845	43845
9/4/2013 11:58	275.27	45.118	45118
9/4/2013 11:58	272.99	46.648	46648
9/4/2013 11:58	270.88	47.499	47499
9/4/2013 11:58	268.74	48.859	48859
9/4/2013 11:58	266.66	49.963	49963
9/4/2013 11:58	264.68	51.152	51152
9/4/2013 11:58	262.92	52.513	52513
9/4/2013 11:58	261.11	53.106	53106
9/4/2013 11:58	259.36	4.4558	4455.8
9/4/2013 11:58	116.65	0.3716	371.6

Prototype roller static testing

Test number 1, out of the set of 10, data has been provided. If further test data is required, see author.

A/Red 213 String	A/30t 873419 N	String Zero	Newtons	Normalised N
δ	P	**δ**	P	**P**
mm	**kN**	**mm**	**N**	**N**
474.58	0.38881	0	388.81	0
474.55	0.6456	0.03	645.6	256.79
474.59	0.6456	0.01	645.6	256.79
474.6	0.6456	0.02	645.6	256.79
474.56	0.55537	0.02	555.37	166.56
474.59	0.6456	0.01	645.6	256.79
474.63	0.7254	0.05	725.4	336.59
474.55	0.6456	0.03	645.6	256.79
474.59	0.90239	0.01	902.39	513.58
474.53	0.7254	0.05	725.4	336.59
474.56	0.81563	0.02	815.63	426.82
474.56	0.6456	0.02	645.6	256.79
474.53	0.90239	0.05	902.39	513.58
474.53	0.90239	0.05	902.39	513.58
474.53	0.90239	0.05	902.39	513.58
474.53	0.7254	0.05	725.4	336.59
474.51	0.81563	0.07	815.63	426.82
474.52	0.90239	0.06	902.39	513.58
474.54	0.90239	0.04	902.39	513.58
474.48	1.3292	0.1	1329.2	940.39
474.44	1.409	0.14	1409	1020.19
474.42	1.586	0.16	1586	1197.19
474.4	1.4958	0.18	1495.8	1106.99
474.4	1.586	0.18	1586	1197.19
474.35	1.756	0.23	1756	1367.19
474.34	1.8428	0.24	1842.8	1453.99
474.36	2.0128	0.22	2012.8	1623.99
474.3	2.1794	0.28	2179.4	1790.59
474.34	2.0995	0.24	2099.5	1710.69
474.3	2.1794	0.28	2179.4	1790.59
474.35	2.3494	0.23	2349.4	1960.59
474.38	2.4362	0.2	2436.2	2047.39
474.3	2.5264	0.28	2526.4	2137.59
474.26	2.4362	0.32	2436.2	2047.39
474.29	2.863	0.29	2863	2474.19
474.29	3.21	0.29	3210	2821.19

474.24	3.4668	0.34	3466.8	3077.99
474.21	3.7236	0.37	3723.6	3334.79
474.22	3.8034	0.36	3803.4	3414.59
474.16	3.9735	0.42	3973.5	3584.69
474.2	4.4072	0.38	4407.2	4018.39
473.59	4.657	0.99	4657	4268.19
473.63	5.1707	0.95	5170.7	4781.89
473.63	5.6876	0.95	5687.6	5298.79
473.6	6.1111	0.98	6111.1	5722.29
473.56	6.7981	1.02	6798.1	6409.29
473.52	7.7385	1.06	7738.5	7349.69
473.48	8.2451	1.1	8245.1	7856.29
473.36	8.7588	1.22	8758.8	8369.99
473.16	9.0154	1.42	9015.4	8626.59
473.02	9.9595	1.56	9959.5	9570.69
472.95	10.643	1.63	10643	10254.19
472.8	12.003	1.78	12003	11614.19
472.59	13.454	1.99	13454	13065.19
472.41	14.564	2.17	14564	14175.19
472.38	15.168	2.2	15168	14779.19
472.39	15.852	2.19	15852	15463.19
472.2	17.302	2.38	17302	16913.19
472.16	17.729	2.42	17729	17340.19
472.02	19.093	2.56	19093	18704.19
472.02	19.52	2.56	19520	19131.19
471.86	20.713	2.72	20713	20324.19
471.81	21.48	2.77	21480	21091.19
471.75	21.48	2.83	21480	21091.19
471.75	21.567	2.83	21567	21178.19
471.77	21.48	2.81	21480	21091.19
471.75	21.567	2.83	21567	21178.19
471.72	21.48	2.86	21480	21091.19
471.68	21.65	2.9	21650	21261.19
471.57	22.334	3.01	22334	21945.19
471.59	22.761	2.99	22761	22372.19
471.56	23.184	3.02	23184	22795.19
471.48	23.698	3.1	23698	23309.19
471.47	23.698	3.11	23698	23309.19
471.4	24.721	3.18	24721	24332.19
471.34	25.658	3.24	25658	25269.19
471.29	26.425	3.29	26425	26036.19
471.22	27.275	3.36	27275	26886.19
471.1	28.386	3.48	28386	27997.19
470.92	29.066	3.66	29066	28677.19
470.93	29.663	3.65	29663	29274.19

470.81	30.343	3.77	30343	29954.19
470.74	30.6	3.84	30600	30211.19
470.73	30.853	3.85	30853	30464.19
470.66	31.11	3.92	31110	30721.19
470.65	31.367	3.93	31367	30978.19
470.65	31.79	3.93	31790	31401.19
470.61	32.217	3.97	32217	31828.19
470.6	32.727	3.98	32727	32338.19
470.49	33.24	4.09	33240	32851.19
470.47	33.834	4.11	33834	33445.19
470.42	34.091	4.16	34091	33702.19
470.4	34.431	4.18	34431	34042.19
470.38	35.197	4.2	35197	34808.19
470.35	35.28	4.23	35280	34891.19
470.34	35.878	4.24	35878	35489.19
470.22	36.728	4.36	36728	36339.19
470.09	37.067	4.49	37067	36678.19
470.06	37.665	4.52	37665	37276.19
470.02	38.005	4.56	38005	37616.19
470.01	38.602	4.57	38602	38213.19
469.88	38.941	4.7	38941	38552.19
469.81	39.792	4.77	39792	39403.19
469.73	40.302	4.85	40302	39913.19
469.7	41.322	4.88	41322	40933.19
469.48	42.343	5.1	42343	41954.19
469.38	43.366	5.2	43366	42977.19
469.29	44.13	5.29	44130	43741.19
469.27	44.979	5.31	44979	44590.19
469.13	45.66	5.45	45660	45271.19
469.11	46.087	5.47	46087	45698.19
469.04	46.51	5.54	46510	46121.19
468.98	47.021	5.6	47021	46632.19
468.91	47.443	5.67	47443	47054.19
468.86	47.87	5.72	47870	47481.19
468.76	48.124	5.82	48124	47735.19
468.68	48.634	5.9	48634	48245.19
468.63	48.804	5.95	48804	48415.19
468.53	48.891	6.05	48891	48502.19
468.47	49.061	6.11	49061	48672.19
468.4	49.57	6.18	49570	49181.19
468.27	49.654	6.31	49654	49265.19
468.2	49.994	6.38	49994	49605.19
468.16	50.164	6.42	50164	49775.19
468.08	50.504	6.5	50504	50115.19
467.92	50.845	6.66	50845	50456.19

467.85	51.354	6.73	51354	50965.19
467.7	51.694	6.88	51694	51305.19
467.56	52.118	7.02	52118	51729.19
467.34	52.288	7.24	52288	51899.19
467.16	52.798	7.42	52798	52409.19
466.95	53.308	7.63	53308	52919.19
466.8	53.562	7.78	53562	53173.19
466.59	53.988	7.99	53988	53599.19
466.34	54.665	8.24	54665	54276.19
466.16	55.345	8.42	55345	54956.19
465.85	56.025	8.73	56025	55636.19
465.55	56.872	9.03	56872	56483.19
465.24	57.893	9.34	57893	57504.19
464.86	58.742	9.72	58742	58353.19
464.48	59.419	10.1	59419	59030.19
464.02	60.439	10.56	60439	60050.19
463.62	61.286	10.96	61286	60897.19
463.3	61.796	11.28	61796	61407.19
463.1	62.39	11.48	62390	62001.19
462.88	62.643	11.7	62643	62254.19
462.7	63.066	11.88	63066	62677.19
462.51	63.236	12.07	63236	62847.19
462.35	63.746	12.23	63746	63357.19
462.22	64	12.36	64000	63611.19
462.02	64.246	12.56	64246	63857.19
461.88	64.842	12.7	64842	64453.19
461.74	64.842	12.84	64842	64453.19
461.54	65.27	13.04	65270	64881.19
461.25	65.865	13.33	65865	65476.19
460.98	66.377	13.6	66377	65988.19
460.66	66.973	13.92	66973	66584.19
460.37	67.396	14.21	67396	67007.19
460.03	67.736	14.55	67736	67347.19
459.75	68.246	14.83	68246	67857.19
459.28	68.844	15.3	68844	68455.19
458.8	69.354	15.78	69354	68965.19
458.38	69.863	16.2	69863	69474.19
457.84	70.461	16.74	70461	70072.19
457.44	70.801	17.14	70801	70412.19
456.9	71.311	17.68	71311	70922.19
456.37	71.738	18.21	71738	71349.19
455.88	72.078	18.7	72078	71689.19
455.35	72.502	19.23	72502	72113.19
454.88	72.844	19.7	72844	72455.19
454.41	73.268	20.17	73268	72879.19

453.78	73.947	20.8	73947	73558.19
453.27	74.289	21.31	74289	73900.19
452.41	73.438	22.17	73438	73049.19
451.88	74.715	22.7	74715	74326.19
451.41	75.564	23.17	75564	75175.19
450.86	76.076	23.72	76076	75687.19
450.32	76.756	24.26	76756	76367.19
449.76	76.926	24.82	76926	76537.19
449.38	78.199	25.2	78199	77810.19
449.1	79.137	25.48	79137	78748.19
448.8	79.477	25.78	79477	79088.19
448.66	79.477	25.92	79477	79088.19
448.55	79.986	26.03	79986	79597.19
448.39	80.326	26.19	80326	79937.19
448.29	80.832	26.29	80832	80443.19
448.06	81.77	26.52	81770	81381.19
447.86	82.279	26.72	82279	81890.19
447.55	83.043	27.03	83043	82654.19
446.91	84.574	27.67	84574	84185.19
446.36	85.25	28.22	85250	84861.19
445.99	86.271	28.59	86271	85882.19
445.67	87.631	28.91	87631	87242.19
445.19	88.395	29.39	88395	88006.19
444.77	89.668	29.81	89668	89279.19
444.39	90.684	30.19	90684	90295.19
429.7	-0.96802	44.88	-968.02	-1356.83
415.39	-0.79797	59.19	-797.97	-1186.78
400.96	-0.70775	73.62	-707.75	-1096.56
387.21	-0.96802	87.37	-968.02	-1356.83
378.21	-0.87779	96.37	-877.79	-1266.6
369.69	-0.70775	104.89	-707.75	-1096.56
365.49	-0.20111	109.09	-201.11	-589.92
365.48	-0.1109	109.1	-110.9	-499.71
365.51	-0.28093	109.07	-280.93	-669.74
365.55	0.13896	109.03	138.96	-249.85
365.58	0.309	109	309	-79.81
365.58	0.05915	109	59.15	-329.66
365.55	-0.03108	109.03	-31.08	-419.89
365.59	-0.03108	108.99	-31.08	-419.89
365.61	0.13896	108.97	138.96	-249.85
365.59	0.05915	108.99	59.15	-329.66
365.58	-0.03108	109	-31.08	-419.89
365.43	-0.20111	109.15	-201.11	-589.92
365.57	-0.03108	109.01	-31.08	-419.89

Appendix C – Risk assessment, Wagners SOP and SWI

Please note the documents below are not the originals. These are only copies of the documents that are signed and filed at the relevant organisations. The list below has been supplied in this appendix:

- WCFT JSEA: Manual Handling
- WCFT JSEA: Moving composite pipe
- WCFT JSEA: Using H26 and R26 (Green glue) in assemblies
- WCFT WI: Portable power tool
- WCFT WI: Welding and Hot work
- WCFT WI: Use of hydraulic testing equipment

GUIDANCE NOTES FOR COMPLETING FORM

STEP 1. Define Area and Title and Document Number and Version
STEP 2. Define the Operational Environment
STEP 3. Define Operational Activity
STEP 4. List all of the Team Members
STEP 5. List any Reference Materials used
STEP 6. Complete the Risk Assessment
STEP 7. Complete the Action Plan where applicable
STEP 8. Check for other documents, sign off and give the Form to your Supervisor

Operational Activity Photographs, Diagrams, Plans, Sketches etc. (Equipment Type/Mining Methods etc)

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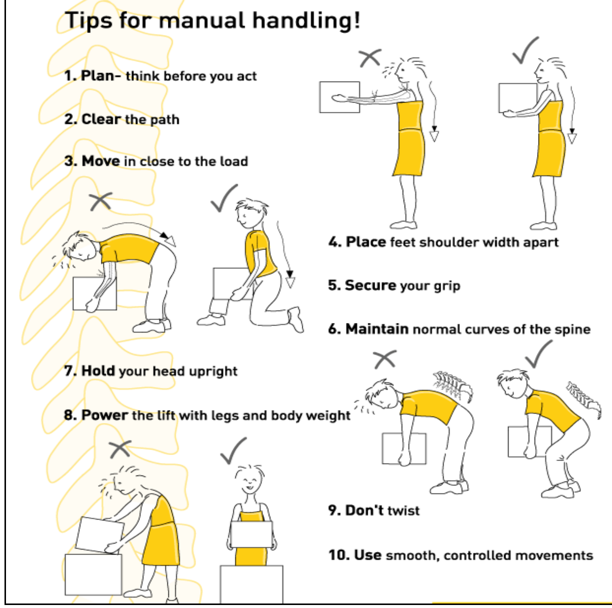

JOB SAFETY & ENVIRONMENTAL ANALYSIS (JSEA)

This document when completed correctly is intended to satisfy the legislative requirements and the Wagners Health, Safety & Environmental Management System

STEP 1. Area: ☒ **MAINTENANCE** ☐ **CHPP** ☒ **HSE**

☒**MINING** ☐ **HIGH WALL** ☒ **ADMINISTRATION** ☐ **OTHER**

Title: Manual Handling

Date: 30/08/2012	**Version:**	**1**

STEP 2: OPERATIONAL ENVIRONMENT: Various – indoor and outdoor conditions

STEP 3: OPERATONAL ACTIVITY: Lifting of various material and objects by worker/s

STEP 4: JSEA Team members:

Name	Organisational Role	Process Role (Facilitator/Team Member)	Process / Task Experience	Consensus Yes / No	Signature
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Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.

Wagners Australia Risk Matrix	**Hazard Effect/ Consequence**				
Loss Type	**1 Insignificant**	**2 Minor**	**3 Moderate**	**4 Major**	**5 Catastrophic**
(P) Harm to People	Slight injury or health effects – first aid/ minor medical treatment level	Minor injury or health effects – restricted work or minor lost workday case	Major injury or health effects – major lost workday case/ permanent	Permanent total disabilities, single fatality	Multiple fatalities

				disability		
(B) Environmental Impact		Environmental nuisance	Material environmental harm	Serious environmental harm	Major environmental harm	Extreme environmental harm
(AD) Asset Damage & Other Consequential Losses		Slight damage <$0.01 M. No disruption to operation	Minor damage $0.01 M to $0.1 M. Brief disruption to operation	Local damage $0.1 M to $1.0 M. Partial shutdown	Major damage $1.0 M to $10.0 M. Partial loss of operation	Extreme damage > $10.0 M. Substantial or total loss of operation
(R) Impact on Reputation		Slight impact – public awareness may exist but no public concern	Limited impact – some local public concern	Considerable impact – regional public concern	National impact – national public concern	International impact – international public attention
Likelihood	Likelihood Examples (use only as a guide)	**Risk Rating**				
A (Almost certain)	Likely that the unwanted event could happen several times per year at this location	**15 (M)**	**10 (H)**	**6 (H)**	**2 (Ex)**	**1 (Ex)**
B (Likely)	Likely that the unwanted event could happen several times a year at this location or could happen annually	**19 (M)**	**14 (M)**	**9 (H)**	**4 (Ex)**	**3 (Ex)**
C (Possible)	The unwanted event could well have occurred at Wagners at some time in the past 10 years	**22 (L)**	**18 (M)**	**13 (H)**	**8 (H)**	**5 (Ex)**
D (Unlikely)	The unwanted event has happened in the mining industry at some time, or could happen in 100 years	**24 (L)**	**21 (L)**	**17 (M)**	**12 (H)**	**7 (H)**
E (Rare)	The unwanted event has never been known to occur in the mining industry, or is highly unlikely that it could ever occur	**25 (L)**	**23 (L)**	**20 (M)**	**16 (M)**	**11 (H)**

Risk Matrix Rating	Risk Level	Guidelines for Risk Management
1 to 5	**(Ex) – Extreme**	**Eliminate, avoid or implement specific plans/ procedures to manage & monitor**
6 to 13	**(H) – High**	**Proactively manage via the HSE Management System**
14 to 20	**(M) – Moderate**	**Manage via the HSE Management System**
21 to 25	**(L) - Low**	**Monitor & manage as appropriate via the HSE Management System**

Damaging Energy Types (Consider these damaging energy types when completing your job steps)			Hierarchy of Controls – Environmental and Community Components		
Energy Type	**Description**		**Receptor Type**		**Description**
Stored Energy	**Consider fluids or gas under pressure, springs under compression, /wedges/chocks under compression, Chains or slings under tension, stored electrical energy**	Have you positively isolated the energy source/bled down the system?	Water	**Contaminated Water Consider: The potential for release of contaminated water to the Environment**	Have downstream water users been considered? Do my activities comply with site environmental license? Consider freeboard management. Have both surface and groundwater impacts been considered?
Electrical Energy	**Isolation of equipment – Consider contact with electricity, Exposed electrical wiring through damage of LTA maintenance.**	Has this been isolated or deenergised? Do I have appropriate equipment?			
Human Energy	**Lifting, Pushing, Pulling Consider: Over exertion, incorrect lifting technique, Repetitive action, Poor housekeeping, and Poor workplace layout.**	Does this lift need to be done? Can a mechanical lifting device be used? Does the lift require more than once person?	Water/Land	**Contaminated Land/Water Consider: Spillage of fuels, oils, etc.** Has the exposure of spillage to the environment been	Are spill kits and equipment in place for appropriate management? Have oil drums etc been appropriately labelled? Are fuel storage areas appropriately bunded? Are regular inspection of fuel storage areas being

				considered?	actioned?
Gravitational People	**People Falling** **Consider: The potential for serious injury if people fall.**	Is there a risk of falling when performing this task? Is a safety harness required? Is a ladder required?	Land	**Disposal of Wastes** **Consider: spillage of fuels. Oils, asbestos, general waste etc.**	Do my activities comply with the site environmental license? Have I considered land and water interactions? Am I disposing of waste streams appropriately?
Gravitational Objects	**Objects falling:** **Consider: The potential for serious injury caused by falling objects.**	Can something or someone fall and hurt others while this task is being performed?		**Disturbance to Land** **Consider: Potential Impacts upon natural/rehabilitated land from mining activities.** Has a permit to Disturb been completed and approved by environmental personnel?	Have impacts upon flora, fauna, topsoil, waterways, cultural heritage, etc been considered, planned and controlled. Has land impact information been communicated to the operators(s)? Am I preventing the spread of declared weeds?
Vehicular	**Vehicular interaction** **Consider: The potential for serious injury from vehicular interaction.**	Jolting and jarring, Vehicle to vehicle interaction, Vehicle to object interaction, Vehicle to person interaction.			
Other Energy Sources	**Machine Energy** **Object energy** **Thermal energy** **Radiation**	Can a person be pulled into, struck by or cut by machine. Jarring or vibration when using portable machinery etc. Flying objects, disintegrating machinery etc. Injury caused by exposure to temperature extremes e.g. Hot machinery parts or oil. Radioactive sources (density gauged, coal scans) and ultraviolet light/solar radiation.	Air	**Dust Generation and Greenhouse Gas Emissions** **Consider: Impact upon community.** Do my activities comply with site environmental license?	Am I aware of areas on site which could potentially impact the community? Are appropriate dust suppression systems operational? Do I consider potential community impacts when I make decisions?
Environmental Considerations	**Consider access to/from work area.** **Consider housekeeping** **Consider ventilation and light**	Is there adequate means of access? Is housekeeping of an acceptable standard? Is there adequate ventilation and light at the work area?	Noise	**Air Blast Overpressure and Vibration** **Consider: Impact upon community** Do my activities comply with the site environmental license?	Am I aware of areas on site which could potentially impact the community? Are appropriate noise control systems operational? Do I consider potential community impacts when I make decisions?

Step 6 – Break the Process down into Activity, Task or Job Steps; Identify the potential hazards. Consider and ask questions about potential human factors/errors slips/lapses, mistakes and shortcuts, fatigue and changes etc. Identify existing or current controls and review any prior similar incidents, assess each hazard for consequence and likelihood, allocate a Risk Rating. Identify new or recommended additional controls. Reassess the consequence and likelihood and allocate the Residual Risk Rating. (Refer to the Wagners Health, Safety & Environmental Management System).

No.	Activity/Task/Job Steps	Potential Hazards	Existing or Current Controls	C	L	Risk Rating	New or Recommended Additional Controls	ALARA (Y/N)
1	Prepare for lifting task as directed by supervisor	Slip and trip, cuts and abrasions	All workers are to be supplied and wear the required PPE – (gloves, Eye protection, safety footwear, hy-vis long sleeved shirts, long trousers and, hearing protection, hard hats (where applicable).	2	E	L	All workers to be addressed and sign off on Toolbox Topic – Manual handling.	Y

			Workers are to ensure work area is free of tripping hazards and slippery surfaces. All workers are to be inducted into the site. CFT safe lifting limit is 20kg per person					
2	Assess the load	Cuts and abrasions, Lower back injury,	All workers are to be supplied and wear the required PPE – (gloves, Eye protection, safety footwear, hy-vis long sleeved shirts, long trousers and, hearing protection, hard hats (where applicable). Worker must employ the correct lifting techniques, when assessing a load, - (bend the knees, raise your head, keep back as straight as possible, and lift from the knees not the back) Workers must assess the load before attempting to lift – gently perform a test lift by partially lifting the load. CFT safe lifting limit is 20kg per person	2	D	L		Y
3	If required seek help	Lower back injury	Once the worker has assessed the weight of the load – if the load seems too heavy DO NOT attempt the lift. • Team lift • Mechanical lift • Endeavour to separate the load CFT safe lifting limit is 20kg per person	2	D	L	Worker must inform supervisor if a load is too heavy and assistance is required.	Y
4	Initiate Lift	Cuts and Abrasions, Lower Back Injury, Muscle Strain.	Worker must employ the correct lifting techniques, when assessing a load, - (bend the knees, raise your head, keep back as straight as possible, and lift from the knees not the back) All workers are to be supplied and wear the required PPE – (gloves,	2	D	L	Workers must maintain a clear and unobstructed path of travel	Y

			Eye protection, safety footwear, hy-vis long sleeved shirts, long trousers and, hearing protection, hard hats (where applicable). Worker must keep feet evenly spaced apart and on a level firm surface. Worker must keep the load as close to the body as possible. Hold the load by handles (if applicable) otherwise has hands placed under the load. If team lifting is used, clear communication must be maintained between workers. If mechanical lift is used, the mobile plant must only be operated by a competent or authorised person.					
5	Carrying material	Lower Back Injury, Muscle Strain, slip and trip, collision	If mechanical lift is used, the mobile plant must only be operated by a competent or authorised person. Worker/s must have clear and unobstructed path of travel. Only move/travel the shortest distance possible when travelling by foot. Worker must keep the load as close to the body as possible.	2	D	L	If the load becomes overbearing lower to the ground or bench, using correct techniques.	Y
6	Placing the load	Lower Back Injury, Muscle Strain,	Place the load by bending the knees – DO NOT lean forward and place the strain on the back. If placing on a bench or shelf do not over exert to above shoulder height. Ensure placement area is free of obstructions.	3	D	M	Ensure load is placed on or in a stable position and will not move or fall.	Y
7	Repetitive lifting or load	Fatigue, Lower back	Supervisor to ensure job rotation	3	D	M	Workers to cover Toolbox Topic – Managing Fatigue	Y

	shifting	injury, muscle strain	is available for workers operating long hours on the one task. More frequent breaks may be introduced after an 8 hr period Work areas may need ergonomic matting when operating on hard surfaces.					

STEP 7. Complete Action Plan

No.	ITEM/ISSUE	AGREED ACTION	WHO	WHEN	Comp Date
1	Toolbox Topic – manual handle	Deliver Manual Handling toolbox topic			

GUIDANCE NOTES FOR COMPLETING FORM

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STEP 1. Area: ☐**MAINTENANCE** ☐**CHPP** ☒**HSE**

☐**MINING** ☐**HIGH WALL** ☐**ADMINISTRATION** ☐**OTHER**

Title: Moving composite pipe trough out the shed

Date: Click here to enter a date. | **Version:** Click here to enter text.

STEP 2: OPERATIONAL ENVIRONMENT: Click here to enter text.

STEP 3: OPERATONAL ACTIVITY: Click here to enter text.

REQUIRED PERMITS:

Does the activity require any clearing of trees / grass or excavation / trenching?
☐ YES ☐ NO

If Yes. Has the Permit to Disturb (FRM **xxxx**) been communicated and understood)
☐ YES ☐ NO

If Yes. Has the Permit to Dig been communicated and understood?
☐ YES ☐ NO

STEP 4: JSEA Team members:

Name	Organisational Role	Process Role (Facilitator/Team Member)	Process / Task Experience	Consensus Yes / No	Signature
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Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.

STEP 5. REFERENCE MATERIALS: (Including Permits to disturb, Permits to dig, Golden Rules etc)
Click here to enter text.

PLEASE RETURN THE COMPLETED AND SIGNED FORM TO YOUR SUPERVISOR FOR REVIEW

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Damaging Energy Types (Consider these damaging energy types when completing your job steps) **Hierarchy of Controls – Environmental and Community Components**

Energy Type	Description	
Stored Energy	**Consider fluids or gas under pressure, springs under compression, /wedges/chocks under compression, Chains or slings under tension, stored electrical energy**	Have you positively isolated the energy source/bled down the system?
Electrical Energy	**Isolation of equipment – Consider contact with electricity, Exposed electrical wiring through damage of LTA maintenance.**	Has this been isolated or deenergised? Do I have appropriate equipment?
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Gravitational People	**People Falling** **Consider: The potential for serious injury if people fall.**	Is there a risk of falling when performing this task? Is a safety harness required? Is a ladder required?

Receptor Type		Description
Water	**Contaminated Water** **Consider: The potential for release of contaminated water to the Environment**	Have downstream water users been considered? Do my activities comply with site environmental license? Consider freeboard management. Have both surface and groundwater impacts been considered?
Water/Land	**Contaminated Land/Water** **Consider: Spillage of fuels, oils, etc.** Has the exposure of spillage to the environment been considered?	Are spill kits and equipment in place for appropriate management? Have oil drums etc been appropriately labelled? Are fuel storage areas appropriately bunded? Are regular inspection of fuel storage areas being actioned?
Land	**Disposal of Wastes** **Consider: spillage of fuels. Oils, asbestos, general waste etc.**	Do my activities comply with the site environmental license? Have I considered land and water interactions? Am I disposing of waste streams appropriately?

Gravitational Objects	**Objects falling:** **Consider: The potential for serious injury caused by falling objects.**	Can something or someone fall and hurt others while this task is being performed?		**Disturbance to Land** **Consider: Potential Impacts upon natural/rehabilitated land from mining activities.** Has a permit to Disturb been completed and approved by environmental personnel?	Have impacts upon flora, fauna, topsoil, waterways, cultural heritage, etc been considered, planned and controlled. Has land impact information been communicated to the operators(s)? Am I preventing the spread of declared weeds?
Vehicular	**Vehicular interaction** **Consider: The potential for serious injury from vehicular interaction.**	Jolting and jarring, Vehicle to vehicle interaction, Vehicle to object interaction, Vehicle to person interaction.			
Other Energy Sources	**Machine Energy** **Object energy** **Thermal energy** **Radiation**	Can a person be pulled into, struck by or cut by machine. Jarring or vibration when using portable machinery etc. Flying objects, disintegrating machinery etc. Injury caused by exposure to temperature extremes e.g. Hot machinery parts or oil. Radioactive sources (density gauged, coal scans) and ultraviolet light/solar radiation.	Air	**Dust Generation and Greenhouse Gas Emissions** **Consider: Impact upon community.** Do my activities comply with site environmental license?	Am I aware of areas on site which could potentially impact the community? Are appropriate dust suppression systems operational? Do I consider potential community impacts when I make decisions?
Environmental Considerations	**Consider access to/from work area.** **Consider housekeeping** **Consider ventilation and light**	Is there adequate means of access? Is housekeeping of an acceptable standard? Is there adequate ventilation and light at the work area?	Noise	**Air Blast Overpressure and Vibration** **Consider: Impact upon community** Do my activities comply with the site environmental license?	Am I aware of areas on site which could potentially impact the community? Are appropriate noise control systems operational? Do I consider potential community impacts when I make decisions?

Step 6 – Break the Process down into Activity, Task or Job Steps; Identify the potential hazards. Consider and ask questions about potential human factors/errors slips/lapses, mistakes and shortcuts, fatigue and changes etc. Identify existing or current controls and review any prior similar incidents, assess each hazard for consequence and likelihood, allocate a Risk Rating. Identify new or recommended additional controls. Reassess the consequence and likelihood and allocate the Residual Risk Rating. (Refer to the Wagners Health, Safety & Environmental Management System).

No.	Activity/Task/Job Steps	Potential Hazards	Existing or Current Controls	C	L	Risk Rating	New or Recommended Additional Controls	ALARA (Y/N)
1	Prestart checks of all equipment involved	Cuts and abrasions, manual handling, slip and trip, compressed air	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Ensure work area is clear of all tripping hazards and the floor surface is free of slippery substances and conditions. All electrical leads tagged with current test tag.	2	D	21 (L)		Y

			Complete “Take 5” for specific task. Report all defects and/or damage equipment to your supervisor. Prestart checklist is completed for machines					
2	Operating pultrusion machine to produce pipe	Cuts and abrasions, slip and trip hazards, manual handling and pinch point hazards, compressed air, hazardous chemicals	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Ensure work area is clear of all tripping hazards and the floor surface is free of slippery substances and conditions. Report all defects and/or damage equipment to your supervisor. Ensure operators are competent for the task at hand When using hazardous chemicals ensure the correct Personal Protective equipment is warn Operators to read all relevant Material Safety Data Sheets	2	D	21(L)		Y
3	Manually lifting pipe from pultrusion machine to the stays that are located on the ground	Manual handling injuries, Pinch points,	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Minium two person lift is needed to lift pipe from pultrusion machine to the ground Ensure work area is clear of all tripping hazards and the floor surface is free of slippery substances and conditions.	3	C	13(H)		Y

			Worker must employ the correct lifting techniques, when assessing a load, - (bend the knees, raise your head, keep back as straight as possible, and lift from the knees not the back) Pipe weight is approximately 3.1 kg/per metre, so a 12 metre length weighs 37.2kg and 9 metre weighs 27.9kg					
4	Once quantity is reached, green strap pack together for transportation	Manual handling injuries, pinch points,	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Always make sure the pipe is stacked in rows of nine Ensure work area is clear of all tripping hazards and the floor surface is free of slippery substances and conditions. Ensure all tools used are in good condition, if they are not tag them out and report to your supervisor immediately	D	3	17(M)		Y
5	Lift pack of pipe using spreader bar and gantry crane	Manual handling, pinch points, crane hazards, suspended loads,	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Crane operator to be formally qualified, Hard hats to be warn Ensure all lifting equipment is in sound condition before commencing lift Ensure there is a clear line of travel for the load before commencing lift	C	4	8 (H)		Y

6	Moving pipe through the shed by using crane and spreader bar	Manual handling, pinch points, crane hazards, suspended loads,	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Ensure there is a clear line of travel trough the shed before commencing lift Ensure two tag lines are used Ensure hard hats are warn Ensure the line of travel the crane will be moving is free from pedestrians Ensure work area is clear of all tripping hazards and the floor surface is free of slippery substances and conditions. Crane operator to be formally qualified,	C	4	8(H)		Y
7	Placing pipe in the designated storage area	Manual handling, pinch points, crane hazards, suspended loads,	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, and safety footwear). Ensure work area is clear of all tripping hazards and the floor surface is free of slippery substances and conditions. Crane operator to be formally qualified, Ensure hard hats are warn Ensure crane operator implements spotters to ensure fellow workers safety	C	4	8(H)		Y
8	Placing spreader bar back in its storage location	Manual handling, pinch points, crane hazards, suspended loads	All operators are required to wear the correct PPE – (gloves, eye protection, hearing protection, long sleeved hy-vis shirt, long trousers, footwear).	C	4	8(H)		Y

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This document when completed correctly is intended to satisfy the legislative requirements and the Wagners Health, Safety & Environmental Management System

STEP 1. Area: ☐ **MAINTENANCE** ☐ **CHPP** ☐ **HSE**
☐**MINING/QUARRYING** ☐ **HIGH WALL** ☐ **ADMINISTRATION**
☐**TRANSPORT** ☐ **CONCRETE** ☐ **OTHER**

Operational Activity Photographs, Diagrams, Plans, Sketches etc. (Equipment Type/Mining Methods etc)
Click here to enter text.

Title: Using H26 and R26 (Green Glue) in assemblies

Date: 23/01/2013 | **Version:** 0001

STEP 2: OPERATIONAL ENVIRONMENT: Inside factory

STEP 3: OPERATONAL ACTIVITY: Weighing, Use and Clean-up of H26 and R26

STEP 4: JSEA Team members:

Name	Organisational Role	Process Role (Facilitator/Team Member)	Process / Task Experience	Consensus Yes / No	Signature
Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.
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Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.	Click here to enter text.

REQUIRED PERMITS:

Does the activity require any clearing of trees / grass or excavation / trenching?
☐ YES ☐ NO

If Yes. Has the Permit to Disturb (FRM **xxxx**) been communicated and understood)
☐ YES ☐ NO

If Yes. Has the Permit to Dig been communicated and understood?
☐ YES ☐ NO

STEP 5. REFERENCE MATERIALS: (Including Permits to disturb, Permits to dig, Golden Rules etc)
Click here to enter text.

Risk Matrix	**Hazard Effect/ Consequence**					
Category	**A - None**	**B - Negligible**	**C - Minor**	**D - Moderate**	**E - Major**	**F - Catastrophic**
People Safety	No injury of illness	Injury or illness requiring first aid or precautionary medical consultation only	Medical treatment injury (MTI) or short term health effects	Lost time injury (LTI) with restricted/alternate work duties. Long term but not permanent health effects	Permanent disability or permanent health effects	Fatality

Environment	No environmental impact	Environment will return to normal	Environment can be returned to normal with no long term effects at minimal cost	Environment can be returned to normal with no long term effects but costly to fix	Widespread and costly to fix with long term impact to the environment	Permanent widespread harm to the environment and costly to manage
Regulatory and Legal	No laws breached	An offence which breaches laws and/or regulations. An infringement or improvement notice is issued	An offence for which company prosecution is contemplated and legal response is required	An offence which results in a company prosecution; and/or regulatory intervention, and issue of on the spot fine	The revoking of licences/certificates an or legal action to defend company	An offence which results in company prosecution and may result in Directors/executive managers prosecution
Finance PBT	No financial impact	up to $5K	$5K-$10K	$10K - $20K	$20K - $100K	>$100K
Reputation/Public Confidence	No negative impact to reputation	Short term local media reporting. No impact to customer relationships	Extended negative local/national media coverage. Minor impact to customer relationships	Extended nationwide negative media coverage. Short term harm to customer relationships	Extended international wide negative media coverage. Long term harm to customer relationships. Some customers lost	Material change in the public perception of Wagners as a safe organisation
Operational Safety	No impact to operations. No safety implications	No impact to operations. Some safety concerns. Negligible damage	Damage to property. Repairable. Serious safety concerns.	Damage to property. Replacement parts required. Total breakdown of safety systems.	Significant damage to property.	Total property loss.
Likelihood	**Risk Rating**					
1 - Rare Never heard of ever happening	**Low**	**Low**	**Low**	**Low**	**Medium**	**Medium**
2 - Unlikely Has happened before in the industry	**Low**	**Low**	**Low**	**Medium**	**Medium**	**Medium**
3 - Possible Has happened several times in the industry	**Low**	**Low**	**Medium**	**Medium**	**High**	**High**
4 - Likely Has happened before in this company	**Low**	**Low**	**Medium**	**Medium**	**High**	**Exreme**
5 - Probable Has happened several times in this company	**Low**	**Medium**	**Medium**	**High**	**High**	**Exreme**
6 - Certain Happens often in this company	**Low**	**Medium**	**Medium**	**High**	**Exreme**	**Exreme**

Risk Level	Guidelines for Risk Management
(E) – Extreme	**Work not to proceed unless risk eliminated or reduced to an acceptable level. Only Wagners Board can approve continued operations.**
(H) – High	**Work not to proceed unless risk eliminated or reduced to an acceptable level. Only CEO can approve continued operations.**
(M) – Moderate	**Risk must be approved by Site Manager. Any risk of injury/illness must be eliminated or reduced to As Low As Reasonably Practicable (ALARP)**
(L) - Low	**Monitor & manage as appropriate via the HSE Management System**

Step 6 – Break the Process down into Activity, Task or Job Steps; Identify the potential hazards. Consider and ask questions about potential human factors/errors slips/lapses, mistakes and shortcuts, fatigue and changes etc. Identify existing or current controls and review any prior similar incidents, assess each hazard for consequence and likelihood, allocate a Risk Rating. Record the consequence (A-F), likelihood (1-6) and risk level (low, medium, high, extreme) in the JSEA table below. Identify new or recommended additional controls. Reassess the consequence and likelihood and allocate the Residual Risk Rating. (Refer to the Wagners Safety Management System Manual).

No.	Activity/Task/Job Steps	Potential Hazards	Existing or Current Controls	C	L	Risk Rating	New or Recommended Additional Controls	C	L	Risk Rating	ALARP (Y/N)
1	Conduct pre start activities	Slip and trip , pinch points, manual handling injuries, cuts and abrasions, tripping hazards	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. All pinch points are identified with signage. All defects to be reported to the area supervisor and/or tagged out if necessary Ensure work area is clean and tidy All operators to use correct manual handling techniques when undertaking manual handling process Water bath to be cleaned out before conducting gluing activities All Acetone buckets that are placed on the shop floor must be correctly labelled, only filled to half way and have lids fitted NO EXCEPTIONS								

2	Weigh out H 26 and R26 according to mix sheets in the chemical mixing room	Slip and trip, chemical hazards, manual handling injuries	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. Ensure all operators have read and signed the applicable S.D.S before conducting this task Operators are to be vigilant of other activities that are being conducted in the mix room Operators are to ensure the leave the work area clean and tidy All empty R26 and H26 containers are to be disposed of correctly Do not overfill containers								
3	Mixing H 26 and R26 together to form a homogenous mix	Manual handling injuries, pinch points, sprains and strains	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. Always rest the container the adhesive is being mixed in on a flat and level surface All empty containers are to be disposed of correctly Mixing utensils to be soaked in Acetone All Acetone buckets that are placed on the shop floor must be correctly labelled, only filled to half way and have lids fitted NO EXCEPTIONS Ensure all operators have read and signed the applicable S.D.S before conducting this task								

4	Clean pultrusion with Acetone before applying H26 and R26 mix	Chemical hazards, slip and trip hazards, manual handling injuries	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. Ensure all operators have read and signed the applicable S.D.S before conducting this task Ensure there is sufficient ventilation for the task at hand									
5	Apply H26 and R26 mix to the surface that is to be bonded	Chemical hazards, pinch points, slip and trip hazards,	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. Ensure all operators have read and signed the applicable S.D.S before conducting this task Ensure there is always a high level of housekeeping in the work area Dispose of any used mixing containers into the water bath located outside the chemical storage room									

6	Lifting sections to be bonded into glue jig	Chemical hazards, manual handling injuries, strains and sprains, pinch points	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. All persons undertaking this task are to conduct a manual handling risk assessments before lifting pultruded product, this is to ensure that no person lifts over the WAGNERS CFT safe working load limit which is 20 kg per person Team lifts are to be of any organised nature with clearly defined instructions to be communicated to persons undertaking this task Ensure there is always a high level of housekeeping in the work area If sections to be bonded are to be lifted by gantry crane then the operator must be ticketed and hard hats must be worn								
7	Clamping bonded pieces together in glue jigs	Pinch points, manual handling injuries, compressed air	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. Operators are to read and sign “CFT-004 Use of Compressed Air “ before charging the brake boosters with compressed air Operators are to exercise caution when placing packing underneath brake boosters								

8	Removal of excess glue from bonded sections	Manual handling injuries, pinch points, trip hazards	Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear. Ensure all operators have read and signed the applicable S.D.S before conducting this task All Acetone buckets that are placed on the shop floor must be correctly labelled, only filled to half way and have lids fitted NO EXCEPTIONS								
9			Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear.								
10			Operators must wear all required PPE – gloves, eye protection, Long sleeve shirts and trousers, safety footwear.								

PURPOSE

The purpose of this SOP is to ensure employees are familiar with the procedures to be used when working with portable power tools.

SCOPE

This SOP covers all operations using portable power tools.

Key points to remember:

- It is important to follow each job step and all key points to maximise efficiency, safety and to reduce the risk of any potential incidents.
- Plant training & operation manual is to be used in conjunction with this SOP.
- If any part of plant or equipment being used is unsafe, 'Tag out' and report to supervisor.

CORRECT PPE MUST BE WORN FOR ALL TASKS

Hazards **Lacerations and Cuts, Sharp Ends, Electric Shock (poor earthing), Manual Handling, Vibration.**

References:

1. *Work Health and Safety Act 2011*
2. *Plant Code of Practice 2005*
3. *Work Health and Safety Regulations 2011*

DEFINITIONS

A portable power tool is any tool with a power source (electric, internal combustion engine) that is not a fixture or is able to be moved manually.

PROCEDURE

1. Visual pre start must be carried out by all operators involved prior to commencement of shift.
2. All defects must be reported to area supervisor.
3. Correct/ required PPE must be worn at all times by operators (gloves, eye protection, long sleeved shirts with fastened cuffs, long trousers and safety footwear).
4. All hazards must be reported to supervisor and recorded in HAZ-ID book.
5. Keep your work area clean and tidy. When tools are not in use, they should be returned to the designated place of storage.

6. Wear eye and hearing protection when operating power tools, some power tools will require use of a face shield
7. Use the right tool for the job. Do not force a small tool to do the job of a heavy duty tool.
8. Avoid using power tools in a gaseous or explosive environment.
9. Never carry the tool by the cord or pull the cord to disconnect the plug.
10. Before use inspect extension cords for loose or exposed wires and damaged insulation. All leads must have current inspection tags.
11. Any damaged or faulty electrical equipment must be tagged out as unsound by the person reporting the fault, and handed into the store.
12. All cutting and grinding tools must have the correct guards in place before use.
13. Inspect grinding or cutting discs for cracks or chips before use. Always use the correct sized discs for the machine.
14. Check the correct arbor nut and/or flange is fitted when changing cutting or grinding discs or saw blades
15. Be aware of sending sparks while working. Use a screen if necessary to protect other workers or machines.
16. Chuck keys and spanners must not be attached to electrical leads with metal wires or chains in case the lead is faulty.

LEGISLATION

The workplace health & safety Act 2011, Division 4, section 28, Duties of workers; states;

While at work, a worker must-

(a) ttake reasonable care for his or her own health and safety; and
(b) Ttake reasonable care that his or her acts or omissions do not adversely affect the health and safety of other persons; and
(c) Ccomply, so far as the worker is reasonably able, with any reasonable instruction that is given by the person conducting the business or undertaking to allow the person to comply with this act; and
(d) Cco-operate with any reasonable policy or procedure of the person conducting the business or undertaking relating to health and safety at the workplace that has been notified to workers.

I have read and understand the above standard operating procedure (SOP) for my workplace. I have read and understand the above duties of workers, Work Health and Safety Act 2011, Division 4, section 28, and to comply with this SOP in my workplace.

Worker's Name (Print): ________________________

Worker's Signature: __________________________

Date: _____/_____/________

SCOPE

This document covers the safe use and handling of oxy/acetylene and electric arc cutting and welding.

Key points to remember:

- It is important to follow each job step and all key points to maximise efficiency, safety and to reduce the risk of any potential incidents.
- Plant training & operation manual is to be used in conjunction with this SOP.
- If any part of plant or equipment being used is unsafe, ‘Tag out’ and report to supervisor.

CORRECT PPE MUST BE WORN FOR ALL TASKS

Hazards **Burns, Welding Flash, Sharp Ends, Electric Shock (poor earthing), Manual Handling, Flying slag chips**

References:

4. *Work Health and Safety Act 2011*
5. *Plant Code of Practice 2005*
6. *Work Health and Safety Regulations 2011*

DEFINITIONS

Oxy/acetylene welding uses compressed oxygen and acetylene combined and burned at a high temperature and is used to liquefy metals.

Electric arc welding uses an electrical arc to liquefy metals and with the aid of a catalyst which allows these metals to join by fusion.

GMA – commonly referred to as Metal Inert Gas (MIG) – welding embraces a group of arc welding processes in which a continuous electrode (the wire) is fed by powered feed rolls (wire feeder) into the weld pool. An electric arc is created between the tip of the wire and the weld pool. The wire is progressively melted at the same speed at which it is being fed and forms part of the weld pool. Both the arc and the weld pool are protected from atmospheric contamination by a shield of inert (non-reactive) gas, which is delivered through a nozzle that is concentric with the welding wire guide tube.

PROCEDURE

1. Before hot work commences, the site shall be thoroughly inspected and made safe, also where applicable a *HOT WORK PERMIT* must be filled out or alternative methods of carrying out the work shall be adopted.

2. Always wear adequate personal protective equipment - the operator or persons directly assisting shall use: a face shield or helmet fitted with the appropriate filter for electric welding; suitable eye protection for gas cutting; Wear protective gloves and goggles when chipping off slag and wire brushing a weld.

3. Suitable fire-resistant gloves, long sleeves, long trousers and steel-capped footwear shall be worn; apron, leather coat and/or spats may also be required.

Clothing should be in good condition and not frayed or provide fuel source

4. Never use water or gas pipes as part of an arc welding circuit.

5. Make sure screens are in position before commencing welding work if work is near other personnel or equipment that could be damaged.

6. Adequate fire fighting equipment shall be located within the hot work area and personnel involved should be familiar with its location and use.

7. Consider the possibility of changing circumstances during the progress of work, which may make the area unsafe for work to continue and require reassessment.

8. Ensure light and ventilation is adequate in the work area.

9. Consider the need for other safety precautions such as barricades and caution signs.

10. Ensure that the electric welding equipment has been tested and tagged.

11. Ensure that the electric are welding equipment has adequate air circulation, ventilation and is not covered by clothing, rags etc.

12. Examine all electric cables and leads periodically for cuts, burns and abrasions and if defective, replace immediately.

13. Examine all gas hoses for cuts, burns, leaks and abrasions and gauge sets for damage. If defective, replace hoses or have gauges repaired immediately.

14. Guard electric cables, leads and gas hoses against falling sparks and hot slag.

15. Check cable connections for tightness. Overheating and power loss will occur if connections are loose.

16. Never move the amperage regulator whilst an arc exists.

17. Do not put the electrode holder on the ground, on the work piece or on anything electrically connected to earth.

18. Always use flashback arresters when using cutting and gas welding equipment.

19. All compressed gas cylinders should be used in accordance with SOP for gas handling and storage.

20. Refer to guidelines for working in confined spaces.

21. After work has been completed, inspections shall be carried out to ensure that no smouldering materials remain.

22. Arrange for mandatory six (6) monthly inspections and test by a competent person and ensure all items of electrical arc welding equipment are listed and that tests performed are recorded in the register.

23. Supervisors should conduct periodic inspections to ensure safe work practices

are being followed and that the equipment is being used correctly and maintained in good order.

24. Be aware of deposition of hot metal, slag and generated heat.

25. Check for and identify if necessary hot metal remaining in the workplace.

26. Suitable ergonomic positions and manual handling should be considered. Refer SOP Manual Handling

27. Housekeeping should include waste products, fuel sources (eg rags) and access and egress

LEGISLATION

The workplace health & safety Act 2011, Division 4, section 28, Duties of workers; states;

While at work, a worker must-

(e) ttake reasonable care for his or her own health and safety; and
(f) Ttake reasonable care that his or her acts or omissions do not adversely affect the health and safety of other persons; and
(g) Ccomply, so far as the worker is reasonably able, with any reasonable instruction that is given by the person conducting the business or undertaking to allow the person to comply with this act; and
(h) Cco-operate with any reasonable policy or procedure of the person conducting the business or undertaking relating to health and safety at the workplace that has been notified to workers.

I have read and understand the above standard operating procedure (SOP) for my workplace. I have read and understand the above duties of workers, Work Health and Safety Act 2011, Division 4, section 28, and to comply with this SOP in my workplace.

Worker's Name (Print):________________________

Worker's Signature: __________________________

Date: _____/_____/________

SCOPE

This procedure details guidelines for working with hydraulics.

Key points to remember:

- It is important to follow each job step and all key points to maximise efficiency, safety and to reduce the risk of any potential incidents.
- Plant training & operation manual is to be used in conjunction with this SOP.
- If any part of plant or equipment being used is unsafe, 'Tag out' and report to supervisor.

CORRECT PPE MUST BE WORN FOR ALL TASKS

Hazards **Contamination of skin, Eye Damage, Crush zones, Pinch points**

References:

7. *Work Health and Safety Act 2011*
8. *Plant Code of Practice 2005*
9. *Work Health and Safety Regulations 2011*

DEFINITIONS

Hydraulics refers to any oils or related substances held or operated under pressure.

PROCEDURE

1. When inspecting the hydraulic system check for:
   - leaks
   - frayed or damaged lines
   - loose or cracked connections
   - excessive pressure
   - dark oil indicating exposure to excessive heat
   - milky coloured oil indicating water contamination
   - unusual noise or vibration
   - jerky or uneven movement indicating air in the system or incorrect pressure relief
2. Do not use your hand to check for leaks, use a piece of paper or cardboard.
3. Depressurise the system, including accumulators, and cycle the control valves fully before working on hydraulics.
4. Do not stand or extend body parts under a load supported by hydraulics being worked on.

5. Crack connections carefully before fully loosening fittings. Use caution when removing breathers or filters, pressure may remain in accumulators even when the power supply is turned off.
6. Do not disassemble an accumulator without first releasing the nitrogen pre-charge into a ventilated area.
7. When using hydraulic jacks make sure the foundation is firm, flat and the jack is not angled in relation to the load.
8. Never weld hydraulic tubing, fittings or components.
9. Do not apply pressure to a hose that is kinked.
10. When reassembling be sure all connections are properly tightened before use.
11. On start up, be aware that accumulators and other components may move due to air entrapment, without any control inputs.
12. Reduce skin contamination by removing oil soaked clothes and washing exposed skin with soap.
13. Isolation lock out and tag applies when working on machinery

WARNING:

- **High pressure oil can easily penetrate skin and enter the bloodstream causing major health problems.**
- **Hydraulic equipment can create pinch points.**
- **Hydraulic oil and components may be hot.**

LEGISLATION

The workplace health & safety Act 2011, Division 4, section 28, Duties of workers; states;

While at work, a worker must-

(i) ttake reasonable care for his or her own health and safety; and
(j) Ttake reasonable care that his or her acts or omissions do not adversely affect the health and safety of other persons; and
(k) Ccomply, so far as the worker is reasonably able, with any reasonable instruction that is given by the person conducting the business or undertaking to allow the person to comply with this act; and
(l) Cco-operate with any reasonable policy or procedure of the person conducting the business or undertaking relating to health and safety at the workplace that has been notified to workers.

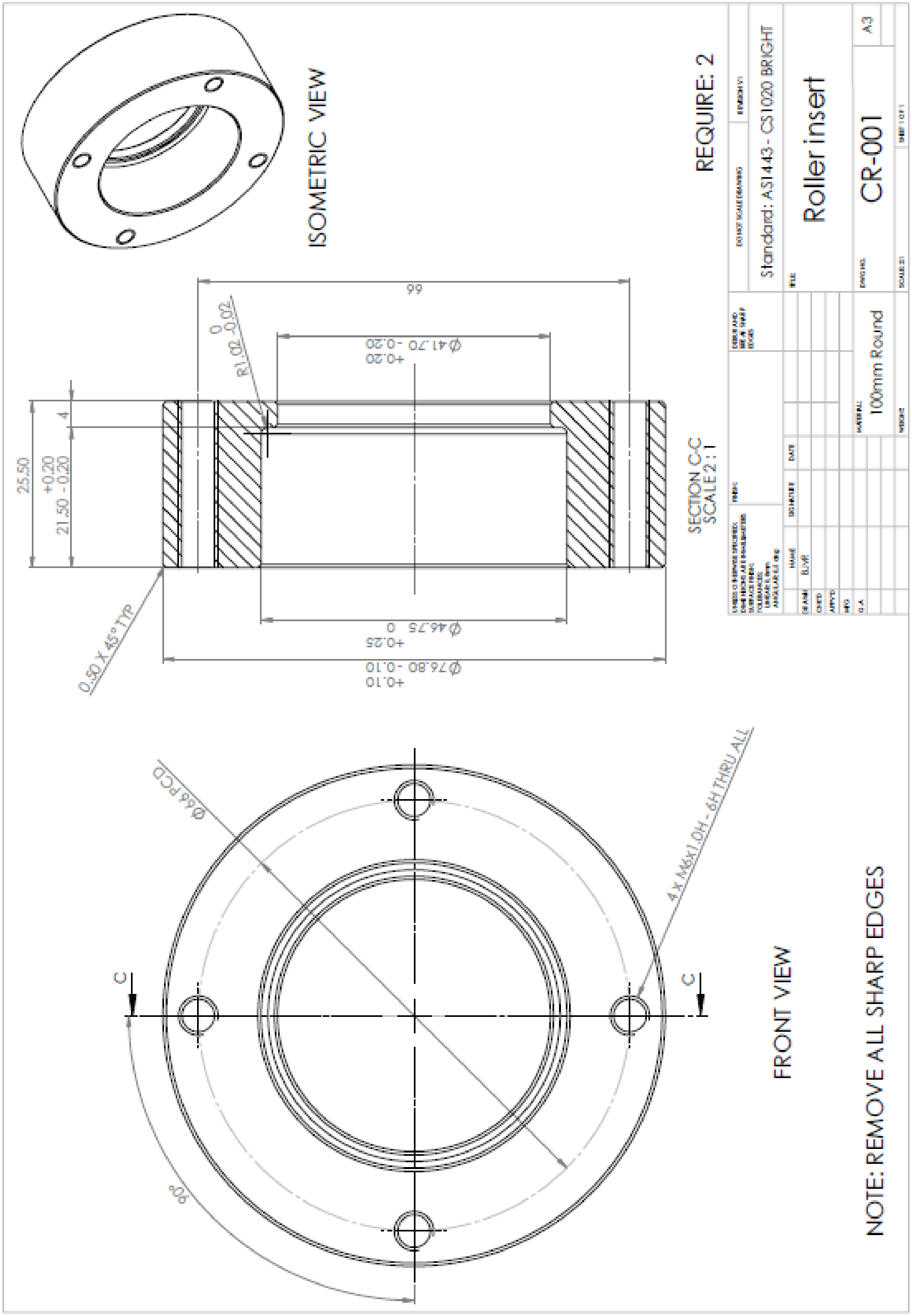
I have read and understand the above standard operating procedure (SOP) for my workplace. I have read and understand the above duties of workers, Work Health and Safety Act 2011, Division 4, section 28, and to comply with this SOP in my workplace.

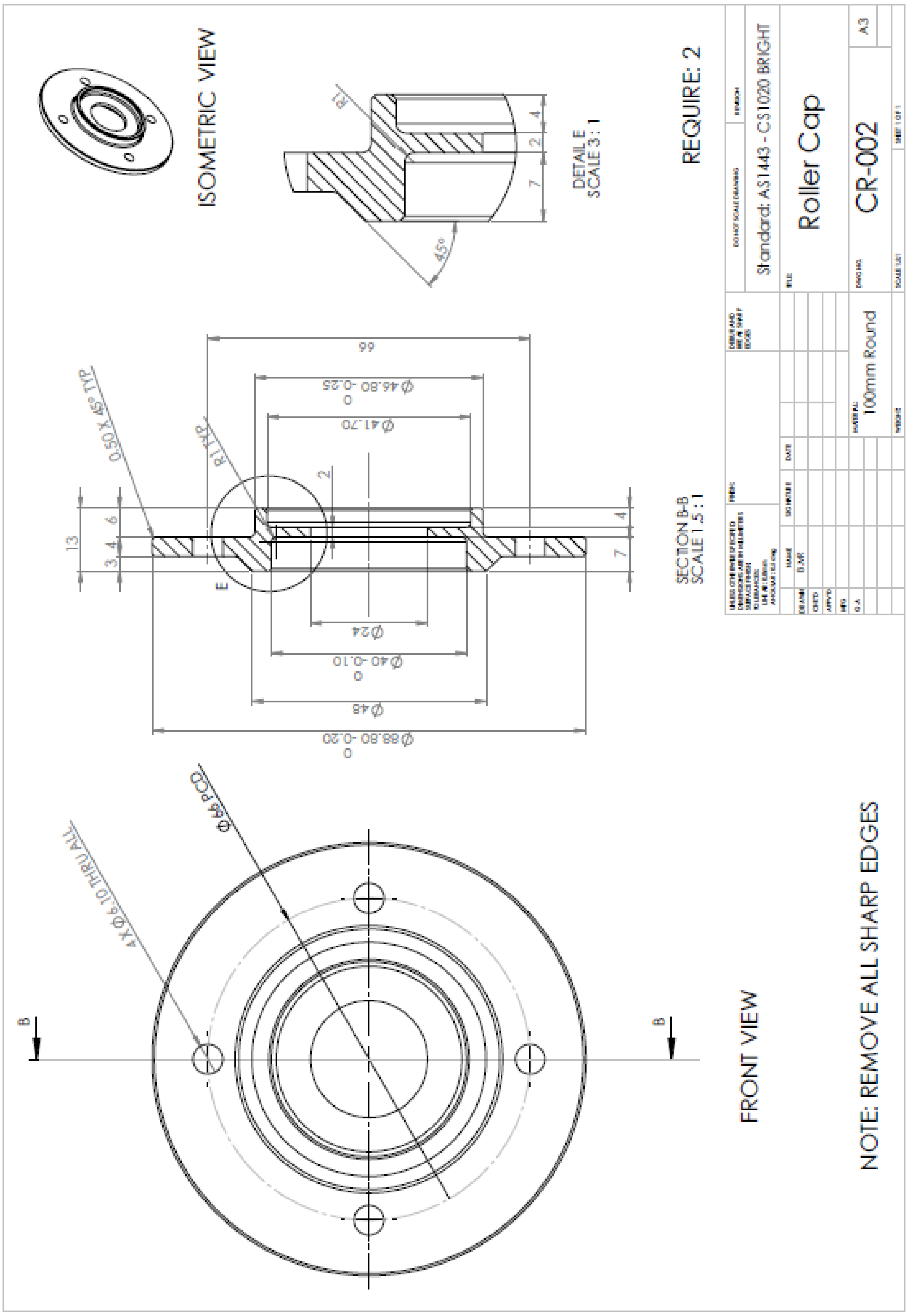
Worker's Name (Print):_________________________

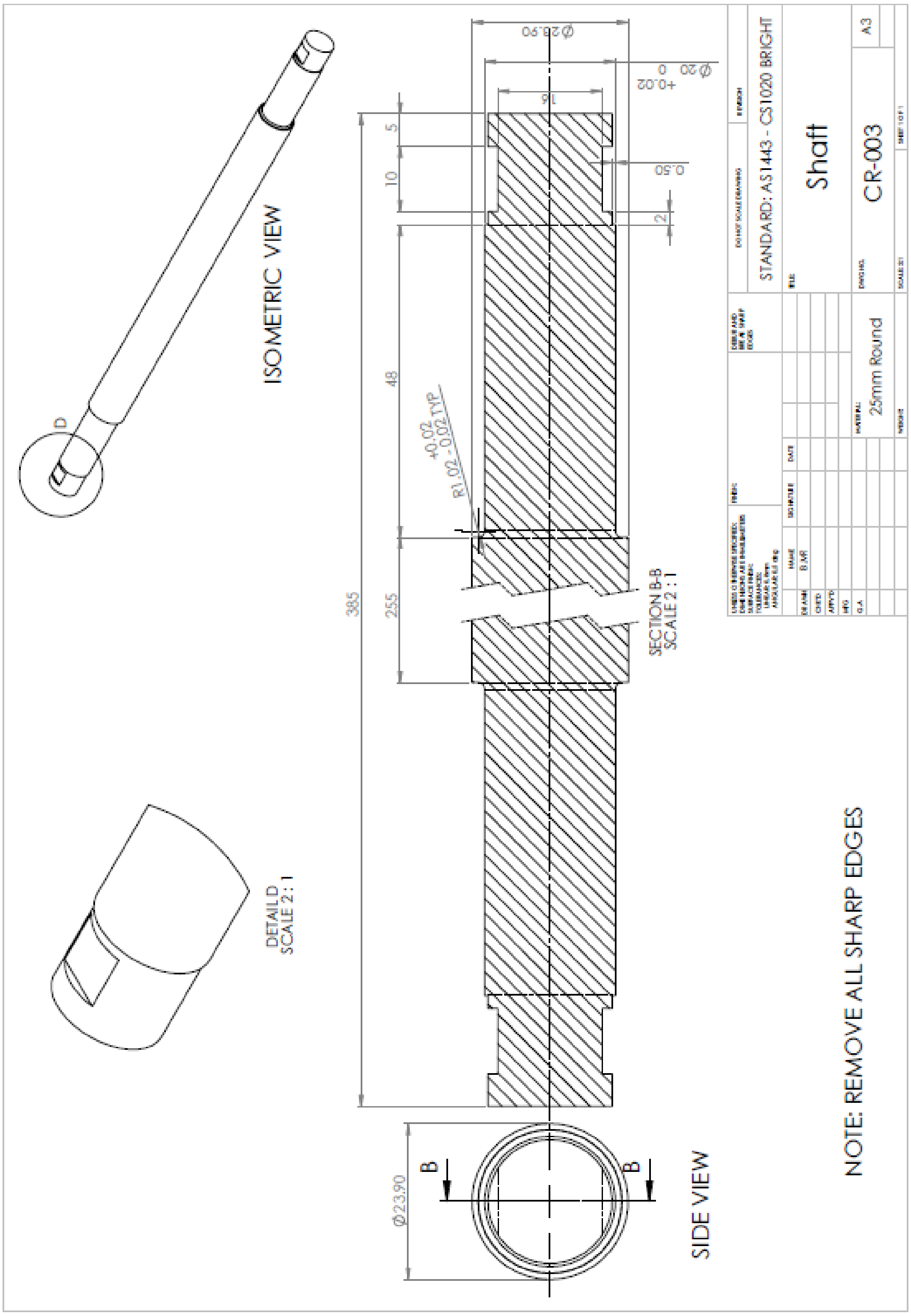
Worker's Signature: ___________________________

Date: _____/_____/________

Appendix D – Detailed Drawings




ISOMETRIC VIEW
REQUIRE: 2
DETAIL E
SCALE 3 : 1
45°
R1
SECTION B-B
SCALE 1.5 : 1
0.50 X 45° TYP
R1 TYP
Ø46.80 -0.25 0
Ø41.70
66
Ø24
Ø40 -0.10 0
Ø48
Ø88.80 -0.20 0
13
E
FRONT VIEW
4 X Ø6.10 THRU ALL
Ø66 PCD
NOTE: REMOVE ALL SHARP EDGES
Standard: AS1443 - CS1020 BRIGHT
Roller Cap
CR-002
A3
100mm Round


ISOMETRIC VIEW
D
DETAIL D
SCALE 2 : 1
SECTION B-B
SCALE 2 : 1
SIDE VIEW
B
B
Ø23.90
Ø28.90
Ø20 0 +0.02
16
0.50
2
5
10
48
255
385
R1.02 +0.02 -0.02 TYP
NOTE: REMOVE ALL SHARP EDGES
STANDARD: AS1443 - CS1020 BRIGHT
Shaft
CR-003
25mm Round
A3
B.MR

San-Tech Machining Pty Ltd
9 Rocla Court
TOOWOOMBA QLD 4350
Ph: 07 4633 4509 Fax: 07 4633 1998
A.B.N. 32 080 094 702

ENGINEERING EXCELLENCE

Barnard Janse van Rensburg
Wagners CFT

29 April 2013

,

Quotation no. **13338**

Dear Barnard Janse van Rensburg,

STM Ref.	QTY	DESCRIPTION	DRWG. NO.	PRICE EACH	TOTAL ex GST
WAG-CR-001	4	Supply & Machine Roller Insert	CR-001	$123.50	$494.00
WAG-CR-002	4	Supply & Machine Roller Cap	CR-002	$123.00	$492.00
WAG-CR-003	2	Supply & Machine Shaft	CR-003	$197.00	$394.00

Total Inc GST: $1518.00

TERMS AND CONDITIONS

- This quotation is valid for 60 days.
- All goods remain property of San-Tech Machining Pty Ltd until paid in full.
- Invoices must be paid within invoiced terms provided.

G & L Manufacturing

ABN:27 151 081 006

Greg Regan: 0428 683 646
Email: greg@gandlmanufacturing.com
Lucas Briggs: 0408 874 044
Email: lucas@gandlmanufacturing.com
Phone: (07) 46325318
Fax: (07) 46325286

45-61 Isaac Street
Toowoomba Qld 4350
www.gandlmanufacturing.com

Quotation

Q206

Customer

30/04/13

Name: Wagners Composite Fibre Technologies
Address: PO Box 151,
Drayton North,Qld
Post Code: 4350
Phone: 07)4637 7755
Fax: 07)4637 7756
Contact Name:Barnard Janse van Rensberg

Qty	Description	Unit Price	TOTAL
4	Supply & Machine-CR-001-Roller Insert	110.00	$ 440.00
4	Supply & Machine-CR-002-Roller Cap	130.00	$ 520.00
2	Supply & Machine-CR003-Shaft	195.00	$ 390.00
		SubTotal	$ 1,350.00
		Freight	
		GST	$ 135.00
		TOTAL	**$ 1,485.00**

Quoted By: Greg Regan
Signed:

Quote no. 13024

25/04/13

Hello Baz ,

Thank you for the opportunity to quote.

Prices as requested :

4# x CR-001 - $128 each + gst

4# x CR-002 - $125 each + gst

4# x CR-003 - $244 each + gst

Lead time 14 days. Can be sooner if needed.

If you have any queries please do not hesitate to contact me.

Regards,

Leigh Oloman

Wellbrook Engineering & Technologies