University of Southern Queensland

School of Engineering

Assessment of Issues in Using Advanced Sustainable and Recycled Engineering Materials

A dissertation submitted by

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Abstract

Advanced sustainable and recycled engineering materials have been introduced in the engineering design and construction industry as an alternative to assist with natural resource depletion and as alternatives to traditionally used engineering products. The issue with any new product is there are limitations and constraints associated with their implementation and acceptance.

The aim of this report is to identify the issues involved with using advanced sustainable and recycled engineering materials and assessing the factors that will aid in the implementation of engineering materials along with the benefits over existing products within the industry.

There has been an impetus in using sustainable and recycled products used in the engineering industry such as recycled asphalt pavement (RAP), recycled concrete aggregate (RCA) and cross laminated timer (CLT). The focus of this research will assess the use of advanced sustainable and recycled engineering materials in civil and building construction.

Three case studies which relate to the civil and building construction industry will be reviewed, and the properties of existing proven engineering materials will be compared against unproven advanced sustainable and recycled engineering materials. In addition, a feasibility study will be utilised to identify the issues with advanced sustainable or recycled engineering material in each case study to evaluate their viability.

This research project aims to assess whether recycled and sustainable materials can be a sustainable choice for the engineering building and construction industry using material properties, cost, sustainability, risk, standards, ethics, and long-term factors as measures.

Key words

Advanced sustainable, recycled, engineering materials, civil and construction.

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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.

Mario de la Pena

[redacted]

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Nomenclature

E = Modulus of Elasticity

ρ = Density

υ = Poisson’s Ratio

σr = Modulus of Rupture

Glossary of Terms

BNH - Brinell hardness number

CE – Circular Economy

CLT – Cross laminated timber

CT – Cement treated

EOL – End of Life

EPA – Environmental Protection Authority

FRP – Fibre Reinforced Polymers

FV – Future value

LCA – Life cost assessment

LCCA – Life cycle cost analysis

MDF – Medium-density fibre

PET – Polyethylene Terephthalate

PVC – Polyvinyl chloride

PV – Present Value

RAP – Reclaimed asphalt pavement

RCA – Recycled concrete aggregate

RLT – Repeat Loading Triaxial

ROI – Return on Investment

UCS – Unconfined Compressive Strength

Chapter 1 - Project Specification

1.1 Introduction and Background

'Engineering materials refers to the group of materials that are used in the construction of manmade structures and components. The primary function of an engineering material is to withstand applied loading without breaking and without exhibiting excessive deflection. The major classifications of engineering materials include metals, polymers, ceramics, and composites' (Mechanicalc 2023).

The quantity of Engineering projects in the building and civil construction industry has increased by an average of 1.4% per year in Australia over the last 5 years (IBISworld 2023) and 'many organizations and research groups have alerted us to the negative impacts of producing and using conventional materials and technologies in the construction industry. This is since most of the materials currently used for construction are non-sustainable and derived from non-renewable sources' (Sustainability 2022).

Methods such as recycling, reclaiming, repurposing, and reusing are terms that are used to address the problem of resource overuse along with the use of technology advances in the engineering sector that can produce advanced sustainable materials.

The issues that can result in the use of these alternative engineering materials are their acceptance in the industry along with the cost of producing a useable product, risk of implementing it in the project, life cycle of the material used and basic lack of standards of these engineering materials.

A recent study found 'that critical barriers to the use of sustainable materials are related to cost and profit considerations, the unwillingness of the key stakeholders to incorporate these materials into building projects, lack of incentives and government policies' (Emerald Insight 2021).

'Barriers to the use of recycled or reused materials can be perceived or real. Some of the barriers we have come across include misconceptions about the quality of recycled products, inconsistent and lengthy approval processes and prescriptive technical standards that don't allow for recycled products' (Roads and Infrastructure Australia 2023).

1.2 Incentive for study

The result of an ever-increasing strain on natural resources, in particular engineering materials, supports exploring opportunities such as obtaining other materials to build structures and components for engineering purposes or recycling existing materials that will not burden the environment and provide a pathway for natural resource management.

This could produce an industry that will not only assist in protecting the environment at present but give future generations a pathway in developing products and structures that are sustainable and have less effect on the carbon footprint. It can also open new industries of manufacturing that may create employment opportunities in various engineering materials manufacturing.

As an Engineer who plays a role in planning future growth areas in the land development industry, I am passionate about novel ideas and change that can benefit the industry long term which is looking for innovative ways of manufacturing and constructing that has minimal impact on the environment. I have chosen this research topic to investigate the issues that area associated with this vision and to determine if these measures are a viable and sustainable option.

1.3 Objectives of Research

The objective of this research project is to report on issues associated with advanced sustainable and recycled engineering materials. This can be determined by comparing various traditional engineering materials against recycled and advanced sustainable engineering materials to investigate if they are suitable for a particular application. The focus of the report will concentrate on civil and building construction engineering materials. Issues identified include the long-term sustainability, lack of standards, unproven life cycle, developing design knowledge, excessive cost and financial risk implementing unproven technology with the use of advanced sustainable and recycled engineering materials.

1.4 Aim of Research

The aim of the research project will be to fill the knowledge gap in the above issues of using advanced sustainable and recycled engineering materials and the constraints that are associated with its implementation and to develop a system of measuring alternative materials viability compared to that of traditional engineering materials used.

The issues will be discussed in more depth and plausible solutions will be provided in overcoming the problems by testing and assessing alternative engineering materials with examples of materials that match the traditional engineering materials used and referencing other research already undertaken such as in published books, articles, and journals.

1.5 Expected Outcomes

The outcomes proposed will ensure that by evaluating the engineering materials in each case study, using a feasibility study ensures an engineering material matches or exceeds the properties of a traditional engineering material used, and its additional attributes should be its sustainability, value for money, complies with the same standards as traditional engineering materials and does not create a financial or long-term usage risk. The alternative engineering material must also be readily available and not deplete natural resources as is the case with many currently used engineering materials.

Chapter 2 - Literature Review

The main issues in using advanced sustainable and recycled engineering materials will be researched from relevant material to complete the knowledge gaps that exists. The issues investigated will be used in the testing procedure to evaluate the case studies which have already assessed the properties of the engineering materials. Alternative engineering materials and their benefits will be discussed to provide a balanced assessment.

2.1 Issues using advanced sustainable and recycled engineering materials

2.1.1 Long term sustainability

(Rutgers, 2010) suggests that 'sustainability entails using materials which can be produced at volume without depleting non-renewable resources or disrupting the equilibrium of the environmental and key natural systems'. This is the reason that recycled and sustainable engineering materials need to be tested against traditional materials to determine if they are suitable substitutes for them. The issue is, will these tests be appropriate as a like for like comparison or are their other methods available? This will need to be investigated through experimentation and available information discussed in the methodology.

As an example, recycled glass can be used as a material in road pavement the issue being pollutants such as organic matter, heavy metals, sulphates, chlorides conductivity, pH and surfactant levels contaminating the glass when processed (International Solid Waste Association 2012).

2.1.2 Standards

Standards in engineering is defined by Trinity University (2023) as 'a set of technical definitions and guidelines, "how to" instructions for designers, manufacturers, and users'.

In a recent publication by ACOR (2023) noted that the challenges faced with using recycled materials was long term outcomes and sustainability benefits, procurement issues in obtaining materials, a lack of guidance and education and nationally harmonised standards and guidelines.

Current engineering materials used for construction have been tested, graded, and tabled in a publication of standards such as the Standards Australia which has volumes of information regarding civil and construction material used in the engineering industry. An example of this information can be found in Standards Australia (2002), *Guide to the use of recycled concrete and masonry materials.*

The issue with recycled and sustainable engineering materials is that there is a lack of literature regarding the standards and guidelines which are required to confidently use them and causes apprehension for some organisations in using these products due to the prospect of failure in the material which in turn can become an economic loss.

This creates a problem with using unproven materials for example a recycled steel beam; one of the main properties required is its tensile force which is necessary to select and assess the correct sized beam for a structure. Testing on such a beam would be required and its method of recasting would enable grading of the material and to compare it to manufactured steel that has similar properties, only at this point can the steel be used confidently in a structural sense.

Standards and guidelines do exist for some engineering materials and relate to items such as RCA - guide to use of recycled concrete and masonry - Standards Australia (2002) and Polymers - using recycled materials in plastic pipes - PIPA (2022).

The standards for advanced sustainable and recycled engineering materials currently used in the industry are limited and inconsistent so the intention, in this research project, is to create an awareness that more work is required to create standards with guidelines to facilitate the use of alternative materials.

2.1.3 Unproven life cycle

The product life cycle is formally defined by (International Standards Organisation 2020) as the ‘consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal’. The life cycle of engineering materials used are documented and proven through testing and experiencing the wear on structures or components that have been constructed. For example, an urban asphalt road has a design life of approximately 25 years (Mackay City Council 2008) if it is constructed to the guidelines and maintained during this time. (Li et al. 2019) suggests using recycled solid waste in in pavements for highway construction using a life cycle assessment (LCA) to analyse the material and (Zhang et al. 2019) discusses the life cycle assessment of material footprint using recycled concrete, this demonstrates very few research papers that research the life cycle of alternative engineering materials.

There is inadequate research to prove that advanced sustainable and recycled engineering materials will last the length of time of currently used materials however by testing the characteristics against traditional materials and assessing them long-term may prove otherwise.

2.1.4 Developing design knowledge

(Ezio Manzini 2009) defines that ‘design knowledge is a collection of different cognitive artifacts with different purposes. These include visions to stimulate and steer strategic discussion; proposals to integrate into the development of specific projects; tools to help understand the state of things and implement design ideas; along with reflections on the sense of what we are doing or could do'.

Due to the time in which advanced sustainable and recycled engineering materials have been used in the industry, the information regarding design of the products for its use is limited. There may be trial-and-error scenarios that were used to introduce engineering materials in the past, but their needs to be some formal testing and documentation regarding the performance of a particular engineering material which will in theory allow it to be implemented in an equivalent manner to the current engineering materials.

A Roads and Infrastructure Australia article (2023) suggest that 'to pave the way forward, recycled materials and circular resource practices must be integrated into engineering design practices. This requires collaboration between government agencies, designers, engineers, construction professionals, the recycling industry, and researchers to increase awareness and confidence in materials'.

In the case of using RCA ascertaining a Class A, B, C or D rating which can be achieved in a laboratory as noted in (Vicroads 2017) and compaction tests outlined in (Standards Australia 2014) and these properties would need to match those of aggregates that are used in current road construction.

2.1.5 Excessive cost

The cost of producing or obtaining advanced sustainable and recycled engineering materials can vary depending on the product. Naturally, it would be a high cost due to the extra processes required such as recycling materials which can be labour intensive and (the minimalist vegan 2023) mentions that the cost of advanced sustainable materials is often higher than conventional products due to expensive raw materials but have a lower environmental impact.

An example of recycled materials would be recycled concrete aggregate (RCA) which is requires removing concrete from a site, hauling it, by truck, to another site for crushing and processing. This would be a costly exercise compared to quarrying aggregate from one site for the same purpose and the end user would pay a higher rate per tonne. An example of advanced sustainable material would be cross laminated timber which requires manufacturing in a factory. The production of this material is costly, and labour intensive compared to obtaining natural timber through logging and processing.

2.1.6 Financial risk using unproven technology

As with most new products there will be an added expense if it requires new production techniques and training for the labour component. Many advanced sustainable and recycled engineering materials are yet to be fully tested in the field so there may be a reluctance in using these products due to the risk of failure and the cost of replacing it. If there was more information on materials to assist an organisation making sound decisions in their use, this would alleviate any concern from a financial aspect.

Sustainable materials can often be more expensive than traditional materials due to factors such as higher production costs, limited availability, and the cost of complying with environmental and social standards (Akabogu 2023).

2.2 Benefits of using advanced sustainable and recycled engineering materials

2.2.1 Sustainability

Sustainability is an important factor when introducing advanced sustainable and recycled engineering materials to the industry. There would be no benefit, except not depleting natural resources, in replacing a material that is proven to be long lasting and reliable with one that will not perform to at least the same specifications as the existing engineering materials. On this point it is important to realise that testing must be performed to validate the characteristics of any new product in terms of its ability to be substituted in for an existing engineering material.

As an example of sustainable materials 'industrial and agricultural by-products such as end-of-life tire rubber and wheat straw were used as aggregates to produce unconventional cement mortars prepared by a cheap and environmentally safe process. The artifacts resulted in thermal insulating with respect to the sand-based references, while the presence of another aggregate as perlite was used to improve the mechanical strengths with no detrimental effects on the thermal conductivities due to the porous nature of the inorganic material' (National Library of Medicine 2022).

2.2.2 Reduction of carbon footprint

Carbon footprint is defined as 'the total amount of greenhouse gases (including carbon dioxide and methane) that are generated by our actions', (The Nature Conservancy 2023). This simply means that the energy to produce advanced sustainable and recycled engineering materials should be less than that of using existing engineering materials to be beneficial. Actions such as transport, industry and energy are contributing factors to the carbon footprint in obtaining engineering materials which is minimised through recycling and using sustainable materials (University of Calagary 2023).

Depending on the engineering material used, if there were an adverse effect on the carbon footprint to produce an advanced product or recycled engineering material this would be considered a negative aspect and defeat the purpose of using such material.

2.2.3 Resource management

(Coursera 2023) suggests that 'resource management is a series of processes and techniques used to ensure you have all the necessary resources to complete a project or meet business objectives. It also focuses on making the most efficient use of those resources by eliminating waste for more profits and a high return on investment (ROI)'.

Important factors in using advanced sustainable and recycled engineering materials are that there is the potential of less landfill and waste, less environmental impacts in the form of pollution and depletion of natural resources and less impact on our ecology by not removing natural resources, that can impact flora and fauna habitat, for engineering material purposes.

Using advanced sustainable materials may not fit into the natural resource paradigm and may need assessing before being selecting. Recycled materials that do not require additives to improve or strengthen their characteristics would also be favourable in this instance.

2.2.4 Creating employment and business opportunities

The effect of using advanced sustainable and recycled engineering materials opens an opportunity to create a new industry of manufacturing and business opportunities. The recycling component requires someone to collect and process the material which would be stored for later use and the manufacturing industry would benefit by the production of sustainable materials which are not abundant in the marketplace.

By adopting a novel approach to existing engineering materials manufacturing practices many companies could change the way they operate and create a niche market for themselves in this sector. 'While there is no universal definition of the term 'advanced manufacturing' there is a consensus that it involves a holistic approach to the way a manufacturing business operates, with a high level of technology and expertise applied throughout every step of a value chain.' (Advance Queensland 2018).

2.2.5 Circular design of engineering materials for a circular economy

It has been suggested by (Interaction Design Foundation 2023) that 'circular design is the practice of creating durable, reusable, repairable and recyclable products that generate zero waste to support a circular economy', and 'the circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting' (Ellen Macarthur Foundation 2023).

'Circular economy (CE) as a new model of economic development promotes the maximum reuse/recycling of materials, goods and components in order to decrease waste generation to the largest possible extent' (Ghisellini et al. 2018). This concept has been around for some time but has been noted as a direct benefit of using recycled and advanced engineering materials.

This is an important component of using advanced sustainable and recycled engineering materials and there needs to be an investigation of which products fit into this category as this will supply a sustainable source of material for the engineering construction industry and play an important role in reducing the current environmental impact of removing natural resources.

The cost of the research and inception of a circular design and circular economy would be the only issues associated although government grants and incentives may be available for this purpose.

2.3 Alternatives to using traditional engineering materials

In addition to identifying advanced sustainable and recycled engineering materials it is necessary to compare them with current materials used in the engineering industry for the same purpose. This provides a list of similar suitable materials that can be utilised as opposed to the traditional building and construction materials.

2.3.1 Civil Construction

Pavements are used in roads to form the base and subbase layers during construction. Traditionally aggregates have been used, alternatively recycling and repurposing glass, rubber, steel slag, plastics, reusing aggregate and RCA as an option. A pavement design should also be carried out for these materials using the guidelines and test methods (Vicroads 2023).

Asphalts are used to seal road pavements for vehicle traffic use. Traditionally asphalt composed of binder and aggregate has been used and alternatively reclaimed asphalt pavement (RAP) , glass, rubber, and recycled plastics as admixture has been an accepted method. Reclaimed asphalt pavement (RAP) can also have additives placed in the mixture such as fly ash which affect its flexural fatigue behaviour (Jallu 2020).

Pipes are used for sewer and drainage infrastructure, and house drain connections. Traditionally pipes made from concrete or plastics (PVC), these materials can be replaced with recycled polymers.

Conduits are used to house and protect power, telecommunication, and gas lines. Traditionally pipes made from plastics (PVC) are used and can be replaced with recycled polymers.

Concrete is used to delineate foot and road traffic areas, build drainage pits and vehicle crossings, and carry water to drainage pits with the construction of kerb and channel. Traditionally concrete mixtures using aggregate, sand and cement are used but can be replaced with recycled aggregate, fly ash, recycled plastics, and waste materials as an admixture in cement to produce concrete. Another material that is an additive to cement to produce concrete is PET (Sulyman et al. 2016).

Quarried materials are used for base and bedding for various utilities, infrastructure, and pavement layers for road construction. Traditionally aggregate and sand is sourced from quarries for this purpose, but as an alternative reusing/recycling aggregates, masonry and concrete is an option for certain pavement layers.

Steel products are used for road signage and to strengthen concrete footpaths, vehicle crossings and power substation kiosk housing. Traditionally steel is used but recycled steel which can also be recast so that it is fit for purpose is an option.

Polymers or plastics are used to produce bollards, seats, tables, utility lids and utility boxes. Traditionally PVC plastics have been used for this purpose, alternatively recycled polymers and plastics can be utilised. Composites can also be included as an alternative material made up of bio sourced, recycled materials and waste resources (Mohanty et al. 2018).

2.3.2 Building Construction

Timber products are used in framing, roofing, flooring, windows, doors, foundations and permanent fixturing. Traditionally timber is used but an alternative material such as FRP can be used and is recyclable rather than ending in waste at is EOL (Ribeiro et al.2016). Recycling wood to make laminated timber and MDF to extract nano-crystalline cellulose is another alternative material to timber (Taylor & Francis Online 2017).

Steel products offer multiple applications, and they are designed to last for as long as 50 years, primarily when used in buildings and construction. The different steel products used in construction include sheet piles, corrugated roofing, channels, pipes, steel sheets, angle bars, flanges, and many more (Easy Frames 2023). Traditionally steel is used but an alternative is to use recycled steel which can be recast so that it is fit for purpose.

Polymers are commonly used in the building industry for waterproofing, insulation, roofing membranes, sealants and adhesives, window frames and doors, flooring, and wall coverings (Polymer Process 2024). Traditionally PVC plastics are used but an alternative is to use recycled plastics.

There are innumerable applications of bricks in the field of Civil engineering. They are widely used as a structural as well as a non-structural(aesthetical) element in construction. When used as a structural member, bricks are used for the construction of walls, retaining walls, arches, claddings etc, and as a non-structural member, they can be used as fillers and for ornamental purpose (The Constructor 2024). An alternative is to use composite bricks with similar properties made from recycled products.

Concrete is one of the most frequently used building materials worldwide. The distinctive characteristics like strength, durability, low-maintenance, energy-efficient, sustainability are the reasons for wide range usage of concrete in the field of civil engineering (The Constructor 2024). Concrete is used for floor slabs, walls, sections between levels, underpinning and retaining walls. Traditionally concrete mixtures using aggregate, sand and cement is used but can be replaced with recycled aggregate, fly ash, recycled plastics, and waste materials as an admixture in cement to produce concrete.

2.4 Case studies

This section will explore case studies in which advanced sustainable or recycled engineering materials have been used in civil or construction engineering. Material properties and issues using these materials will be researched and compared to engineering materials used for similar purposes.

2.4.1 Case Study 1 (recycled engineering material).

Crushed Brick as a supplementary material in cement treated crushed rock pavement applications.
Source: Arulrajah et al. (2013)

Background

Traditionally cement treated pavements have been used in road construction for the purpose of delivering road projects particularly in wetter months of the year where dry back and satisfactory compaction of the pavement layers is hard to achieve. The cost of using this product is far exceeds traditional road pavement material so there is an opportunity to develop a product that is cost effective and sustainable that can substitute cement treated pavement.

Purpose of Study

The purpose of this study was to identify if crushed brick could be blended into cement treated pavement for road construction. The pavement material was manufactured and there were several tests performed to develop a set of properties to assist with comparisons with current standards for crushed concrete in cement treated pavement.

Methodology

Tests were performed in a laboratory to obtain the engineering properties of recycled brick blends, as additives, of 0% brick with 100% cement, 15% brick with 85% cement, 30% brick with 70% cement and 50% brick with 50% cement each combined to produce CT pavement which is a 3% additive to crushed rock.

The outcomes of the tests performed obtained the results listed below:

- pH – fell within the limits of crushed concrete between 11.3 -12.0.
- Plasticity Index - Could not be obtained due to the low clay content in bricks.
- Foreign Materials Content - Contained mainly brick with small amounts of concrete, wood and vegetable matter.
- Particle Size Distribution - Acceptable when compared to crushed concrete.
- Hydrometer - Acceptable when compared to crushed concrete.
- Linear Shrinkage – Similar to the test using crushed concrete.
- Test California Bearing Ratio - Had high CBR values due to the cement in the blend.
- Modified Compaction Repeated Load Triaxial Test - Similar results to crushed concrete tested.
- Unconfined Compressive Strength - Consistent with results using crushed concrete.
- Test Flexural Beam Test – Compared to cement treated beam test and found the results to be similar.

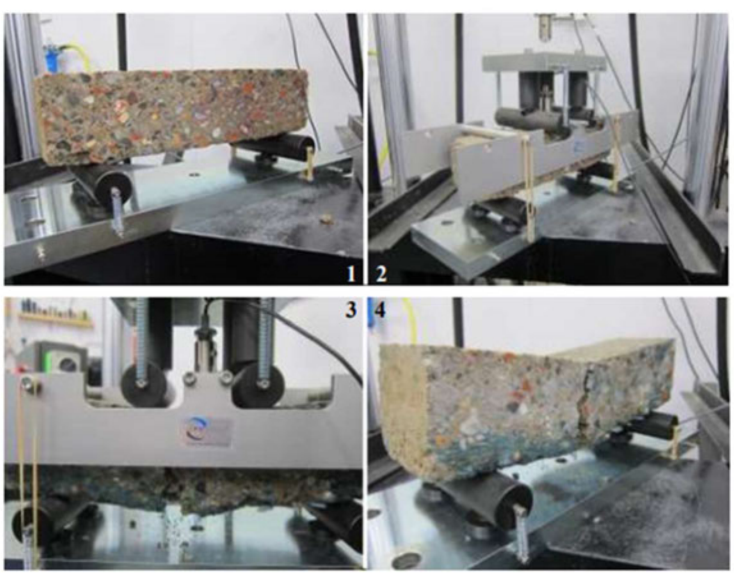

Figure 1.1. Four-point beam fatigue test

Outcomes

The study proved recycled bricks as a supplement can be used for the purpose of enhancement for cement treated pavement in road construction from an engineering properties perspective.

Arulrajah et al. (2013) concluded that crushed concrete blends had physical properties which comply with (VicRoads 2011a Section 821) using UCS and RLT testing.

Arulrajah et al. (2013) also concluded that the 3% additive to the crushed rock is made up of 85% cement and 15% crushed brick is initially recommended as a supplementary material in cement treated crushed concrete pavement sub-base applications and trials would be necessary to increase this percentage.

I will evaluate the results in the methodology and perform other tests to reinforce its use, this will factor in any possible issues as outlined in section 2.1.

2.4.2 Case Study 2 (advanced sustainable engineering material).

Durability and case study of Fibre Reinforced Polymer (FRP). Source: Journal of Mechanical and Civil Engineering (2016)

Background

Traditionally steel, cement and timber have been used for construction purposes and although proven to have the properties that are fit for their purpose, they are derived from natural resources which can have an environmental effect. Fibre reinforced polymers (FRP) create an opportunity to utilise a product that has good physical properties and can be used in multiple applications as a standalone or applied to an existing engineering material to assist in protecting it, strengthening it and increase its design life.

Figure 1.2. Bidirectional/Unidirectional/Mixed knitted/Construction reinforcement carbon fibre fabrics

Purpose of Study

The Journal of Mechanical and Civil Engineering (2016) study provides an overview of an advanced sustainable engineering material FRP. The purpose of this research was to provide information on the characteristics of FRP's and compare them to steel, timber, concrete and other engineering materials as an alternative for use in the engineering industry. In addition, it outlined that FRP's can be implemented to enhance structural support to existing structures such as steel bridges and concrete buildings and has been proven to be robust and long-lasting material.

Methodology

Tests were performed to derive the tensile strain, ultimate strength, specific gravity, elastic modulus, and thermal coefficient to compared against steel a traditional engineering material in graph and table form in this case study which is illustrated below.

Tensile Propeties	Steel Bar	Steel Tendon	GFRP Bar	GFRP Tendon	CFRP Tendon
Ultimate Strength, ksi	70 - 100	200 - 270	75 - 175	200 - 250	240 - 350
Elastic Modulus, ksi	29,000	27 - 29,000	6 - 8,000	7 - 9,000	22 - 24,000
Specific Gravity	7.9	7.9	1.5 - 2.0	2.4	1.5 - 1.6
Tensile Strain, %	>10	>4	3.5 - 5.0	3.0 - 4.5	1.0 - 1.5
Thermal Coeff. $x10^{-6}$/°F	Longitudinal: 6.5	6.5	5.5	5.5	0.38 to -0.68

Table 1.1 Physical properties FRP composites and steel bars

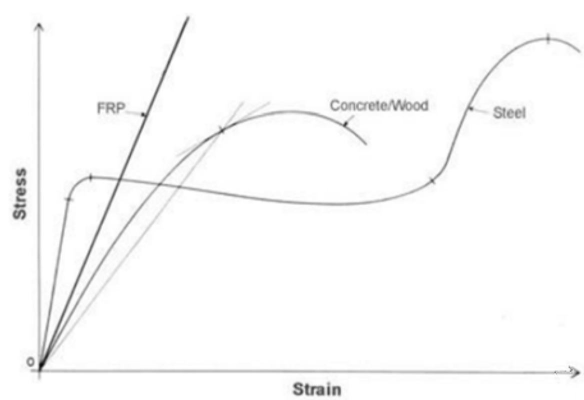

Figure 1.3. Tensile Stress-Strain behaviour of construction materials

Outcomes

Although this study has tested the FRP for its physical properties the various issues should be explored to ascertain its viability as discussed in section 2.1. This will provide greater scrutiny of this engineering material to form a thorough comparison to existing materials. I will evaluate the results of the above tests and combine them with a feasibility study and a questionnaire to enhance its suitability as an alternative to the traditional engineering materials.

It is important to note that in Figure 1.3 the modulus of elasticity (stress/strain) of FRP is more brittle than concrete, wood which are ductile, and steel behaves in a plastic state under load. FRP is used for its strength characteristics in this case.

2.4.3 Case Study 3 (recycled engineering material).

Reuse of Steel in the Construction Industry: Challenges and Opportunities, Source: Kanyilmaz et al. (2023)

Background

The result of carbon emissions and climate change has caused the construction industry, in the United Kingdom, to be aware that it has a responsibility to find innovative ways of resourcing materials outside of traditional methods, recycling steel for use in construction is an option and the process is likened to manufacturing steel.

‘Steel can be manufactured entirely from recycled scrap (secondary steel) or from a mix of recycled scrap and new steel created from iron (primary steel). Ironmaking is part of the primary steelmaking process, and 1200MT of iron is produced annually in the blast furnace (BF) process using coke to reduce iron ore’ (World Steel Association, 2022).

Figure 1.4. New building using reclaimed stee

Purpose of Study

To provide an overview of the reuse of steel and steel recycling process and outline opportunities in the construction industry and issues such as material availability, design rules, regulations, and standards with its use. Current examples of structural steel used in projects was discussed with a cost analysis and carbon saving tabulated.

Outcomes

The outcome of this case study was the challenge to industry to create a circular economy whereby the construction industry is made up of almost 100% recycled and reused steel in the United Kingdom. There is evidence, within the case study, that companies are using reused and recycled steel as alternative materials, but more work is required to provide the benefits and consumer awareness of its sustainability and low-carbon construction. This alternative engineering material in the case study, recycled steel, will be scrutinised through a feasibility study and a questionnaire in the methodology to reinforce its viability as an alternative product in the construction industry. Steel recycling and reusing steel has a place in the future but there is more work required in the areas of regulation, staff expertise by training, availability, and quality certifications.

Summary

Based on the research in this section the key findings are that there are issues in using advanced sustainable and recycled engineering materials that should considered apart from its material properties mainly its long-term sustainability, excessive cost, lifecycle, standards, and design knowledge.

It was evident that testing for properties and characteristics had been performed to compare the engineering material directly to existing materials, but this is only one component of the checking process and further work, mainly the issues outlined, is required to establish the materials adequacy as an alternative.

Researching the results of certain materials using the case studies will assist in bridging the information gap and provide a better understanding of the issues faced by these engineering materials and requires further investigation in the form of testing incorporating a feasibility study and a questionnaire in the methodology section.

The basis of this research will amalgamate the properties of the alternative materials found in the case studies with the results from the questionnaire and feasibility study to obtain an insight into what issues are occurring with the introduction of alternative engineering materials. In addition, what measures are suitable for the industry to streamline this transition, so it becomes simpler for companies to ascertain up to date information on these innovative engineering materials for regular use to eventually replace traditional engineering materials

Chapter 3 – Methodology

3.1 Summary of steps in completing research project

The focus of the methodology is to assess the case studies, literature reviewed and prepare a testing mechanism to evaluate the issues in using advanced and recycled engineering materials which will be achieved using the following steps and lead up to completing the research project:

- Scope and limitations of the engineering materials discussed in the case studies from the literature review.
- Literature review outcomes and further research that needs to be completed.
- Rating the alternative engineering materials against traditional engineering materials.
- Costings of engineering material in each scenario.
- Life cycle of materials in each scenario.
- Development of a feasibility study using the case studies to assist with the evaluation of issues.
- Collate, analyse and graph the feasibility study, cost and properties to obtain a balanced assessment of the issues to properly compare the traditional and alternative engineering materials.
- Summary and discussion of results including tables and/or graphs.
- Conclusion and submission of research project.

As part of the methodology section an illustration of currently used engineering materials will be compared against alternative materials used in the case studies, a risk assessment for the research project will be carried out followed by ethical concerns and resources required to complete the project. See Appendix 5 for Gantt Chart of timelines for the project.

3.2 Methodology Steps

3.2.1 Scope and limitations of research project

<u>In-Scope</u>

The focus of this research project is assessing the issues of three alternative engineering materials found in the three case studies. The results of the findings in each case study will assist in developing a method of assessing any alternative engineering material using a feasibility study regarding the issues outlined below:

- Long-term Sustainability

- Standards
- Excessive cost
- Financial Risk
- Unproven Life Cycle
- Design Knowledge
- Ethics

The advanced sustainable and recycled engineering materials that will be assessed are taken from the case studies although I will not be assessing the case studies only the materials as a comparison which include:

- Case Study 1 – Crushed Brick as a supplementary material in cement treated crushed rock pavement as an example of a recycled engineering material.
- Case Study 2 – FRP as an example of an advanced sustainable engineering material.
- Case Study 3 – Reuse of steel as an example of a recycled engineering material and will assess recasting or reusing existing steel as an example of a recycled engineering material.

Each alternative engineering material will be scored for its properties compared to that of its traditional engineering material used, this will assist in analysis phase of the project. The score will be assessed using the values of the properties tabled. Whichever property is higher will be given one point and the totals will be shown graphically against the other engineering material. For example, the traditional engineering material may have three out of eight higher properties therefore the alternative engineering material will have a score of five.

Out-of-Scope

Ideally, I would have tested a larger range of advanced sustainable and recycled engineering materials but am limited due to the time involved which would make this a difficult task. The plan in this method of testing will enable it to be used across a range of alternative engineering materials for assessment in the future by others who require this information.

The properties of the alternative engineering materials in the case studies have already been determined and will not be tested. They will be tabulated to demonstrate how they compare to existing engineering materials they have substituted.

3.2.2 Literature review outcomes

It was difficult to find relevant research material regarding this research topic and what was available had not been cited or peer reviewed making the quality of information poor, it included mainly online blogs and question answer forums. During the literature review I did manage to find some information on the issues, (Zhang 2019) and (Li 2019) although not directly related to the research topic assisted in presenting an overview.

There was some literature found from government and larger companies such as (Vicroads 2017), (Road and Infrastructure Australia 2023) and (Standards Australia 2002) that have performed studies on a specific alternative engineering materials which focused on properties or characteristics with issues discussed in a broader sense.

However, I did find an abundance alternative engineering materials used in the industry that have been implemented, and its life cycle and sustainability could not be assessed due to the short period of its inception. A standardised method of introducing an alternative engineering material should be mandatory for any application to avoid any issues.

The cost of these alternative engineering materials was generally excessive compared to the common engineering materials used in the industry, which is attributed to extra labour involved, availability of material and training of staff required for the implementation of the product. The goal is an alternative engineering material that lasts longer and has reduced costs over time compared to that of traditional engineering material. In the future as these alternative materials become more commonly used the cost of producing and acquiring them will reduce as the demand increases.

3.2.3 Direct cost comparison

A cost comparison between the traditional engineering material and the alternative engineering materials will be assessed to further reinforce which material is better suited for an application from an economic perspective. The economic component will also be assessed with its sustainability. This will assist in the full process using the feasibility study and the engineering material properties to determine which material is better suited for an application.

Economic,

The purpose is to assess whether the alternative engineering material used is feasible from a cost perspective for an organisation to implement. It would determine if using the alternative engineering material is beneficial over a period considering its initial cost to source, maintenance costs, and its life cycle compared to that of traditional engineering materials.

Sustainability

The importance of the alternative material as a substitute for commonly used engineering materials needs to be viewed from its benefit as a long lasting and environmentally sound product. These two components will lessen the effect on natural resource extraction which can damage the environment, and that the material has a design life the same or longer than the material it is replacing.

The human element of sustainability is also a consideration which must be factored in. Industrial practices in the past which have attributed to global warming, greenhouse gasses and many pollutants released into our environment are very topical in the media and political circles with people and communities in general expecting change in the way we manufacture, construct, and obtain resources. This process requires a holistic approach of rethinking how engineering materials are sourced to mitigate the rate of habitat loss and environmental destruction. The cost to repair the impact on our environment is significant and will be left for future generations to manage if we do not take some immediate action. Using alternative engineering is materials is one such way to achieve carbon neutrality and an environmentally conscious approach to counter this issue.

Goal eleven of the UN sustainability goals states that we should build sustainable cities and communities (United Nations 2024). One way of achieving this outcome is by providing an alternative material to reduce natural resource removal and recycle and reuse, where possible, traditional engineering materials.

3.2.4 Life cycle of case study materials

Bricks begins a clay that is extracted from the earth and processed in a kiln, this natural resource is abundant but leaves the area from which it is sourced depleted with a lot of area of extraction that becomes a large unusable pit. Bricks are an ideal product to reuse as they are mainly sent to landfill as a waste product when no longer required, it is easy to handle from a crushing and removal sense and is suitable for the application as documented in Case Study 1.

FRP is a material that is manmade geopolymer which traditionally very strong and long lasting. In case study 2 it is used as a standalone product and an addition to strengthen a structure with an existing engineering material. Due to its long-lasting properties, it is an ideal substitute to many traditional engineering materials in the construction industry.

Steel is developed using iron ore, which is mined then processed in a smelter, the environmental effects of mining are like that of bricks and can be reduced by reusing or recycling steel. Recycled and reused steel has the same properties as manufactured steel and recast steel can have similar properties if the process of manufacturing is matched, Case study 3 investigates these scenarios and demonstrates that the steel can be reused if protected from rust degradation and the material is not overburdened.

<u>Feasibility Study</u>

This step will have a table that consists of eight headings which reflect the issues identified in using any engineering material along with its properties and have a weighting score from one to five so that its importance can be determined. This will demonstrate whether it is a suitable alternative engineering material when compared to its traditional engineering material.

The weighting scores considered will be 1 – extremely important, 2 – very important, 3 – important, 4 – moderately important, 5 – not important and 0 – N/A. When the scores are tallied an educated assessment will be made of whether the engineering material that will be substituted performs as well as the current material used. Below is an example of the weighting table for and alternative to steel, recycled or recast steel, achieving a low score is the goal of this table.

The weighted scores will be based on the case study results will have the following weighting:

- A score of 1 has a weighted score of 1.
- A score of 2 or 3 has a weighted score of 2.
- A score of 4 or 5 has a weighted score of 3.
- A score of 6 or 7 has a weighted score of 4.
- A score of 8 has a weighted score of 5.

(See Appendix 5 for the results score and weighted scores.)

Engineering Material	**Properties**	**Long Term Sustainability**	**Risk**	**Life Cycle**	**Design Knowledge**	**Ethics**	**Standards**	**Cost**	**Total**
Recycled Steel	1	1	2	2	2	1	1	1	9
Recast Steel	1	1	2	2	2	1	1	1	9
Steel	1	1	2	2	2	2	1	2	11

Table 3.1. An Example of a feasibility table for steel and its alternative engineering materials

This process will form a method of selection that considers key elements of the engineering material so that a sound choice is made with all the available information. Information regarding the properties of the alternative engineering material found in the case studies will increase the data available to scrutinise the engineering material options available.

3.3 Comparisons and procedures for testing properties of engineering materials

The engineering materials used in the case studies will be tabled alongside traditional engineering materials used for a similar application to demonstrate which material has properties with higher values. The results of the feasibility study will be assessed and compared with current engineering materials used for the same purpose. This will facilitate the viability of the materials for possible use in the engineering industry.

The properties will be scored according to which property has the highest value. These values will be displayed in graphical form as a direct comparison.

Testing for common engineering materials and alternative engineering materials will be discussed below and relate to the case studies presented, this will illustrate the properties required in using these alternative engineering materials in the industry.

3.3.1 Compaction testing of aggregates vs recycled aggregate products

Aggregate compaction test and Grading

The maximum dry density for aggregate in roads, for the subbase layer, are compacted to 95% and the base layer to 98% as indicated in (Standards Australia 2014). The aggregate suggested in road pavements is Class 3 for subbase and Class 2 for the base layer (Vicroads 2017). These guidelines are an industry standard and will be the benchmark for alternative aggregate materials used. A pavement design should also be carried out for these materials, the guidelines and test methods outlined in *Pavement, geotechnical & materials* (Vicroads 2023).

RCA compaction test and grading

The maximum dry density for RCA is required to obtain results that can be directly compared to standard compaction results of aggregate and match the minimum guidelines, this will be performed in a laboratory or obtained from a geotechnical report. Classification of RCA which has Class 2, 3 and 4 is documented via (Standards Australia 2002) and this information will be documented to use as a direct comparison to aggregate. The information would be tabled so that the results can be analysed to allocate an appropriate material for its intended use.

3.3.2 FRP vs Steel mesh

FRP

Selected testing described in the case study on FRP's such as a strength test will be tabled. This information will be graphed or tabulated and analysed to make a comparison with the opposing steel product and its application.

Steel

The tests performed on steel products include the tensile test, compression test, bending test, brinell hardness test, rockwell hardness test, impact test and torsion test (SteelonCall 2023). One or a combination of these tests would be sourced for steel and used as a baseline for determining the appropriate test required for FRP.

3.3.3 Testing manufactured steel vs recycled or remanufactured steel

Steel

The tests performed on steel products include the tensile test, compression test, bending test, brinell hardness test, rockwell hardness test, impact test and torsion test (SteelonCall 2023). One or a combination of these tests will be sourced for steel and used as a baseline for testing the recycled steel.

Recycled and reusing steel

Similarly, testing will be performed on recycled and remanufactured steel based on its intended use which would be completed under laboratory conditions. This information would be graphed or tabulated and analysed to make direct comparisons with the steel tests.

3.4 Risk Assessment

Typical engineering project risks may include dependency, design, construction, safety, internal, and long-term risks (Dowling et al. 2009, pp. 632-638). A risk assessment will be prepared focusing on the feasibility results on the alternative engineering materials for each case study.

1. Literature review accuracy

Is the date of study relevant to the current industry and has the information been peer reviewed, cited and published?

Risk: Low

Risk control: Give plenty of time to research information and use the correct sites such as Google Scholar.

2. Feasibility Study

Is the information provided in the case studies adequate to evaluate against the research topic or are their gaps? All issues need to be addressed in the case studies to provide a balanced assessment for the feasibility study.

Risk: Medium

Risk control: Asses the case studies thoroughly so that no information is missed regarding the issues identified. If not research other papers to complete the assessment of issues.

3. Completing the research project within the allocated time.

Will there be enough time to complete the research project and what can be done to ensure that this happens?

Risk: Medium

Risk control: Plan the whole project to complete each part and if time is a factor an extension can be obtained to complete it.

4. Having all the resources necessary to complete the project.

Are the resources required available to complete the research project?

Risk: High

Risk control: A questionnaire on the issues of using alternative engineering material was going to be part of the analysis but the Human Research Ethics Committee weren't able to complete assessment of the application in time, so this has been left out of the research project.

3.5 Ethical concerns

Ethics for Engineers outlined by (Engineers Australia 2019) 'As engineering practitioners, we use our knowledge and skills for the benefit of the community to create engineering solutions for a sustainable future. In doing so, we strive to serve the community ahead of other personal or sectional interests.' 'In addition, we must demonstrate integrity, practise competency, exercise leadership and promote sustainability' (Engineers Australia 2019).

My aim in this research project is to provide information that I have sourced that it is accurate that demonstrates my competency. I will aim to present ideas that relate to engineering that are objective and develop solutions that are a benefit to the community and professionals in the engineering sector.

In terms of the ethics involved in using advanced sustainable and recycled engineering materials is that the materials already exist and are being recycled, and we are sourcing materials to make a product that is sustainable. This I believe is caring about the environment and attempting in delivering a product that will, as a minimum, last as long as current engineering materials.

3.6 Resources

'Project resources are components that are necessary for successful project implementation. They include people, money, time, knowledge – basically, anything that you may require from the project planning to the project delivery phases' (actiTIME 2022).

Personal time

My own time to assess the properties, costs and feasibility results and put the information into tables and graphs. Any out-of-pocket expenses such as printing, I will fund myself.

Literature

Information necessary to evaluate the issues in using alternative engineering materials. Case studies identified will be the focus.

Software

Software such as Microsoft word to write the report and, excel to tabulate and graph results of the properties, cost and feasibility study.

End note will be used for all referencing and citations.

Access

The university library may be used to review literature on their online databases during the literature review process and any further information necessary to complete the research project.

Chapter 4 – Results and Discussion

4.1 Case study 1 - Results on CT with recycled brick as an additive in pavement

Case study 1 was used to determine the issues and limitations of CT with a brick additive in pavement against traditional CT in pavement. This has been shown graphically to demonstrate if an alternative engineering material is a suitable substitute. Each limitation was scored from 1 to 5; 1 - being very satisfied, 2 - satisfied, 3 - neutral, 4 - unsatisfied and 5 - very unsatisfied.

4.1.1 Limitations of CT with recycled brick as an additive in pavement

Limitations in using alternative engineering materials as additives such as recycled bricks in cement treated pavement over traditional cement treated pavement.

- There is a lack of design knowledge in using alternative engineering materials as additives such as recycled bricks in cement treated pavement over traditional cement treated pavement. Score:4.
- The standards are the same in using alternative engineering materials as additives such as recycled bricks in cement treated pavement as traditional cement treated pavement. Score :1.
- There is as product availability in using alternative engineering materials as additives such as recycled bricks in cement treated pavement as traditional cement treated pavement. Score: 2.
- It was identified there is a lack of training in using alternative engineering materials as additives such as recycled bricks in cement treated pavement over traditional cement treated pavement. Score:4.
- There is a lack of service authority acceptance in using alternative engineering materials as additives such as recycled bricks in cement treated pavement over traditional cement treated pavement. Score :4.

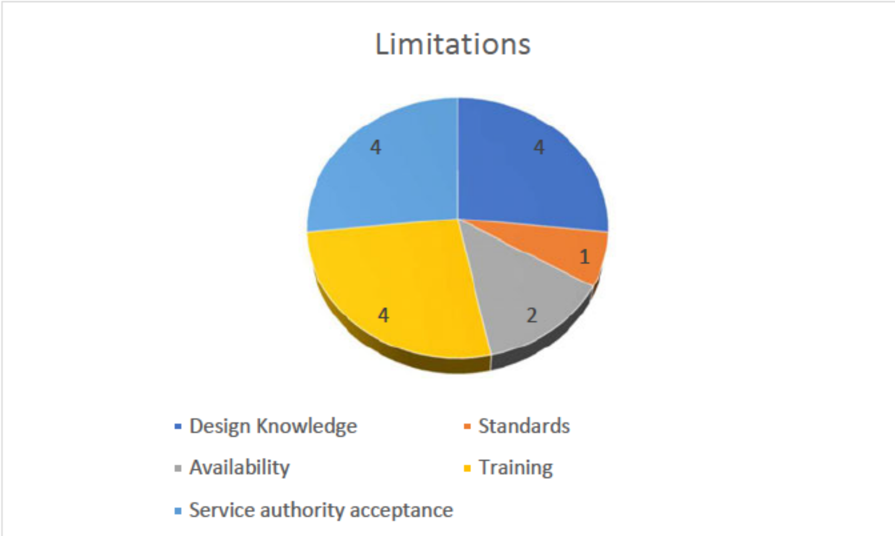

Figure 4.1. Limitations with using recycled brick in CT pavement

4.1.2 Issues on CT with recycled brick as an additive in pavement

Ranking the issues below from 1 to 8, one (1) being the most important eight (8) being least important, in using alternative engineering materials as additives in cement treated pavement.

In order the issues from the case study the rating from most important to least important as follows:

1. Lifecycle
2. Financial Risk
3. Excessive cost
4. Design Knowledge
5. Properties
6. Standards
7. Sustainability
8. Ethics

4.1.3 Summary of results on CT with recycled brick as an additive in pavement

The consensus when working with an alternative engineering material to supplement with CT is that there is a lack of knowledge, industry standards, availability and training within the industry. Rating the issues, as an average, from the case study perspective the lifecycle, design knowledge, excessive cost and financial risk are in the top four and sustainability and ethics are the least important. Standards and properties sit in the middle for issues on average.

An interesting point made was that some local government authorities resist change to alternative engineering materials due to them needing to alter standards and supervise trials for implementation which is time consuming for them.

4.2 Case study 2 and 3 - Results on FRP and Recycled or Recast Steel

Case study 2 and 3 was used to determine the issues and limitations of FRP and recycled or recast steel against using traditional steel for construction. This has been shown graphically to demonstrate if the alternative engineering material is a suitable substitute. Each limitation was scored from 1 to 5; 1 being very satisfied, 2 satisfied, 3 neutral, 4 unsatisfied and 5 very unsatisfied.

4.2.1 Limitations on Recycled or Recast Steel and FRP

Limitations in using alternative engineering materials over traditional engineering materials in construction:

- There is enough knowledge in using alternative engineering materials such as recycled or recast steel and FRP for construction. Score:3.
- There are some standards in using alternative engineering materials such as recycled or recast steel and FRP for construction. Score:3.
- There is availability in using alternative engineering materials such as recycled or recast steel and FRP for construction. Score: 2.
- There is a lack of training in using alternative engineering materials such as recycled or recast steel and FRP for construction. Score:4.
- There is a lack of service authority acceptance in using alternative engineering materials such as recycled or recast steel and FRP for construction. Score: 4.

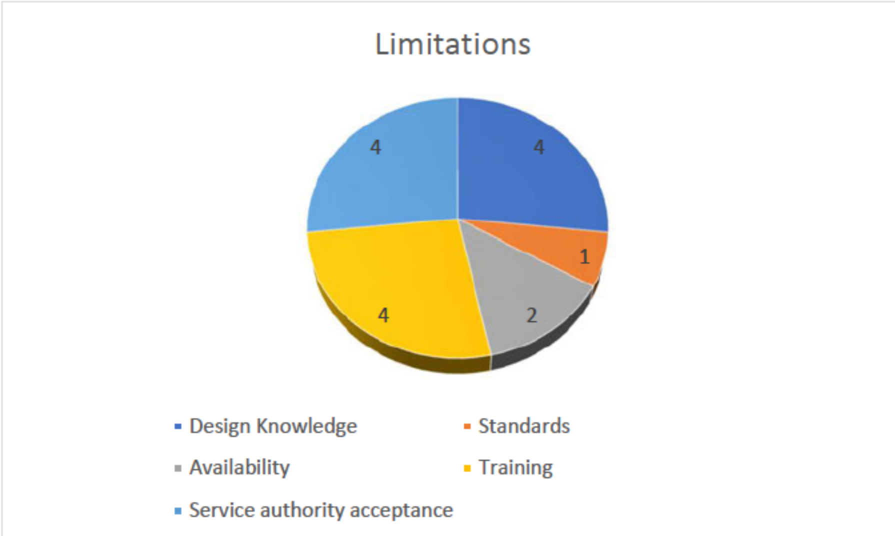

Figure 4.2. Limitations in using Recycled or recast steel and FRP.

4.2.2 Issues on Recycled or Recast Steel and FRP

Ranking the issues below from 1 to 8, one (1) being the most important eight (8) being least important, in using alternative engineering materials such as FRP, recast or recycled steel:

In order the issues from the case studies the rating from most important to least important as follows:

1. Lifecycle
2. Financial Risk
3. Excessive cost
4. Design Knowledge
5. Properties
6. Standards
7. Sustainability
8. Ethics

4.2.3 Summary of results on FRP and Recycled or Recast Steel

The consensus for FRP and recycled steel or recast use as an alternative engineering material was that for FRP there was a lack of knowledge, industry standards and staff training. Comments also made that there were no government incentives readily available to use these materials. Recycled or Recast Steel materials were seen to have better standards, design knowledge, cost and availability.

The ratings found in the case studies were that on average cost, financial risk and an unproven lifecycle were in the top three issues and ethics and sustainability were the least important.

Other factors discussed were that alternative engineering materials are not a recent discovery, and, in the past, a traditional material was an alternative engineering material that was implemented by trial and accepted at that time.

4.3 Ranking the issues of using Traditional Engineering Materials

A ranking for traditional engineering materials issues is ranked and will be graphed in section 4.8 as a comparison against the alternative engineering materials and in order is:

1. Excessive cost
2. Financial Risk
3. Properties
4. Sustainability
5. Design Knowledge
6. Standards
7. Lifecycle
8. Ethics

4.4 Feasibility Study and resultant scores

The case studies have been compiled and used to rank each heading in the feasibility study. The main purpose of this study was to identify which issues were seen as a major concern and which least affected the choice of using an alternative engineering material.

This information is tabled and for each scenario and used to determine if the alternative engineering material ranked at least equal to if not better than its traditionally used engineering material.

As an example, in pavement design the use of cemented treated crushed rock in the subbase traditionally uses three percent cement in the crushed rock mix, as an alternative fifteen percent of the cement additive can be replaced with reused crushed brick so that only eighty-five percent mixed into the crushed rock is made up of cement. This is seen as an automatic cost saving and utilises a recycled material in the cement additive before the properties and issues are analysed.

The results of the feasibility study have been produced in the following sections for each alternative/traditional engineering material comparison.

4.4.1 Table of feasibility C/T / C/T with brick

Engineering Material	Properties	Long Term Sustainability	Risk	Life Cycle	Design Knowledge	Ethics	Standards	Cost	Total
C/T Pavement	3	4	2	1	3	5	4	2	24
C/T with brick pavement	2	3	2	5	4	5	4	1	26

Table 4.1 – Cement/Cement Brick treated aggregate.

4.4.2 Table of feasibility steel/FRP

Engineering Material	Properties	Long Term Sustainability	Risk	Life Cycle	Design Knowledge	Ethics	Standards	Cost	Total
FRP	3	4	2	1	3	5	4	2	24
Steel	2	3	2	5	4	5	4	1	26

Table 4.2 - Steel/FRP

4.4.3 Table of feasibility steel / recycled or recast steel

Engineering Material	Properties	Long Term Sustainability	Risk	Life Cycle	Design Knowledge	Ethics	Standards	Cost	Total
Recycled or Recast Steel	3	4	2	1	3	5	4	2	24
Steel	2	3	2	5	4	5	4	1	26

Table 4.3 - Steel/Recycled or Recast Steel

4.5 Properties of Engineering Materials

The comparable physical properties of the engineering materials in each case study are tabled as a direct comparison which will assist in the analysis of the alternative material and how it rates against the traditional engineering material.

4.5.1 Tables of properties CT/ CT & Recycled Brick

Properties [1]	**CT & CT and recycled brick in pavement**	
	CT pavement - 3% cement content	CT pavement - 3% cement and recycled brick content (85% -15% mix)
Compressive Strength (MPa)	2.2 - 5.1	4 - 7
σr (MPa)	1.23	1.23
E (MPa)	4100 - 6900	11900
Ultimate Strength (MPa)	N/A	N/A
Yield strength (MPa)	N/A	N/A
Hardness (BNH)	N/A	N/A
ρ (kg/m^3) [2]	2400-2900	1900-2900
υ	0.15	0.15

Table 4.4 - Cement/Brick treated aggregate.

4.5.2 Table of properties steel/FRP

Properties [3]	**Steel/FRP**	
	Normal Steel Bars	FRP
Compressive Strength (MPa)[4]	250	69 - 275
σr(MPa)[5]	70 - 700	340
E (MPa)[6]	2×10^5 - 2.1×10^5	1.4×10^5 - 2.3×10^5
Ultimate Strength (MPa)[7]	420 - 630	50×10^6 - 200×10^6
Yield strength (MPa)[8]	300 - 500	70 - 135
Hardness (BNH)	120	N/A
ρ (kg/m^3)	7850	107 - 120
υ [9]	0.15	0.72

Table 4.5 - Steel/FRP

4.5.3 Table of properties steel / recycled or recast steel

Properties [10]	**Steel/Recycled or Recast Steel**	
	Mild Steel	Recycled and Recast Steel
Compressive Strength (MPa)[11]	250	250
σr (MPa)[12]	70 - 700	70 - 700
E (MPa)	200×10^5	200×10^5
Ultimate Strength (MPa)	400 - 500	400 - 500
Yield strength (MPa)	250	250
Hardness (BNH)	120	120
ρ (kg/m^3)	7850	7850
υ [13]	0.30	0.30

Table 4.6 - Steel/Recycled or Recast Steel

[1] Portland Cement Association (PCA) (2006) & Arulrajah et al.(2013)
[2] Civil Lead (2024)
[3] Periodic Table (2024) & NIH (2019)
[4] Medium 2024 & What is Piping (2024)
[5] AtlasFibre (2024)
[6] Periodic table (2024) & RPS Composites (2024)
[7] Bedford reinforced Plastics (2017)
[8] Springer Nature (2024)
[9] Engineering Toolbox (2001) & RPS Composites (0224)
[10] Periodic Table (2024)
[11] Medium 2024
[12] AtlasFibre (2024)
[13] Engineering Toolbox (2001)

4.5.4 Results of Engineering properties

As a direct comparison the data in the table can be assessed and provide a direct relationship from alternative to traditional engineering material. A summary of the findings for each engineering material property is listed below.

The properties of the cement treated pavement mixes are comparable due to the use of cement and aggregate as the main ingredient in each and illustrates they have similar values. The alternative engineering material as having two higher properties and the traditional has one, the other five properties were the same.

The properties vary since the composition of the engineering materials and manufacturing method is completely different between steel and FRP production. The alternative engineering material having four higher properties and the traditional also having four higher properties also.

The same steel material has been used for each application and will give similar results except in the case of recasting steel if the manufacturing process varies from its original method. The alternative and traditional engineering material in this case all had the same value for their properties.

4.6 Direct cost comparison

The factors that can be assessed in direct cost comparison for the three scenarios of an alternative engineering material in comparison to a traditional engineering material include:

Economical

- Cost of producing or sourcing the engineering material.
- Value of the alternative material based on its initial cost and lifecycle
- On going maintenance after implementation of the engineering material.

Sustainable

- Long term performance and lifespan of the engineering material.
- Environmental effect in sourcing or using the engineering material.
- Meeting the standard of its intended use from a social aspect, community expectation and requirements.

4.6.1 Cost comparison of C/T vs C/T recycled brick subbase pavement design

Economic

Cost of engineering materials

The current cost of the engineering material per metric tons is:

- Class 2 with 3% cement treated aggregate (subbase) - $220
- Class 2 with 3% cement treated aggregate and crushed brick (subbase) - $220

Note: The prices were obtained through suppliers Boral Pty Ltd:
https://www.boral.com.au/products/quarry-materials

The cartage and processing costs are similar in addition to the placement of these pavement materials therefore it will be cost neutral as a comparison. The current product costs are also similar so in this case it is cost neutral for both engineering materials.

Maintenance

A maintenance program for both pavements is required to maintain their pavement life cycle which would require checking the pavement annually for potholes, shoving, cracking, and general pavement condition and physically resurfacing the area with asphalt every 5 years to prevent pavement failure.

Sustainability

Lifespan

Literature such as, National Austab Guidelines (1996), illustrate that the lifespan of a pavement, if properly constructed, should last for several decades but there are factors that can affect this outcome. In the pavement construction industry, it is understood that in twenty years, a complete road reconstruction is required for each pavement type and climate conditions such as flood or an increase in heavily loaded traffic would determine whether a partial reconstruction would be required earlier than this period.

Production

Each material is sourced and produced differently which includes Class 2, 20mm aggregate, quarried from rock, on site, and placed in a crusher then sieved into various sized rock particles, cement is manufactured as Portland Cement in a cement plant and crushed brick is sourced from collected used bricks and crushed in a quarry.

Sourcing

The industry has high standards in the way a quarry operates there are several factors that will allow it to operate including it is responsibly sourced in a controlled environment by policies and guidelines the company must have and reviewed on a regular basis, correct approvals such as EPA consent and local government council permits are required to operate the quarry, and the quarry location and operation must be advertised in the media for public comment to raise any possible concerns.

Figure 4.3. Cement Treated Pavement. Source: Nakhaei (2021)

4.6.2 Cost comparison of FRP vs Steel for construction

Economic

Cost of engineering materials

The current price and construction cost of the engineering materials can be compared using a product of similar application:

- 1000mm x 5860mm FRP grate of FRP flooring - $1085
- 1000mm x 5860mm steel grate flooring - $1500
- Installation is cost neutral

Note: The prices were obtained through suppliers using: https://meshstore.com.au/grating/frp/ and https://meshstore.com.au/grating-pattern-a-25x5-loadbar-995x5800mm/

FRP flooring is cheaper alternative to steel in this case so it would be a financial benefit to use this engineering material. FRP costs 30% less than Steel in this scenario

Maintenance

A maintenance program for FRP to maintain its life cycle which would require:

- Checking the FRP regularly for structural and general condition.
- Having an annual report for both materials which would require performing tests on the material for wearing and maintaining its material and /or physical properties.

Sustainability

Lifespan

FRP has a lifespan of around 25 to 50 years (Khalid et al. 2021) depending on its use for load or support which can change its strength and lifespan over time and exposure to elements such as heat, salt, and chemicals which can diminish its lifespan. The FRP material used can also affect its lifespan with natural fibres lasting longer than synthetic fibres.

Production

FRP can be natural, where there is no need for production, or synthetic material which is produced differently depending on which material is used. Natural fibres include cotton, banana, flax or hemp and synthetic fibres include carbon, glass or Kevlar (NIH 2019).

Sourcing

Sourcing of FRP products vary due to the number of materials that can be used, these would be affected by policies and guidelines on its sourcing and production such as the material would have to be responsibly sourced using strict controls and permits and licences obtained from the relevant authorities such as EPA and local government bodies for sourcing.

Figure 4.4. FRP flooring Source: Meshstore (2024)

4.6.3 Cost comparison of Steel vs Recycled or Recast Steel for construction

<u>Economic</u>

Cost of engineering materials

The current cost of the material on a per metric ton basis is:

- Mild steel - $1000 (this includes cartage costs)
- Recast mild steel - $1000 (this includes cartage costs)
- Recycled mild steel – $1000 (this includes removal and cartage costs)

Note: The prices were obtained through: www.hiretrades.com.au/cost-guides/cost-of-steel-per-kg

The purchase cost and construction cost for erecting steel would be the same for each material and would be cost neutral.

Maintenance

A maintenance program for steel to maintain its life cycle which would require checking the steel regularly for structural, corrosion and general condition and, having an annual report for steel which would require performing tests on the material for wearing and maintaining its material and/or physical properties.

<u>Sustainability</u>

Lifespan

The life span of steel depends on its use and 100 years is not uncommon (Kelly Steel 2023). The factors that contribute to lessening its lifespan include exposure to weather particularly rain which causes corrosion, the load bearing on the structure which can affect the strength of steel which causes fatigue and, exposure to salt, chemicals and extreme temperatures which degrades the material.

Production

Steel and recast steel is produced similarly the process begins with steel mined as ore then it, and recast steel, is taken to a smelting plant for production into steel through various processes which involve extremely high temperatures. Recycled steel is sourced from scrap yards and disused structures.

Sourcing

The industry has high standards in the method of ore extraction of steel which would include the material would have to be responsibly sourced using strict controls, mining licences, policies and guidelines, strict EPA policies and local government permits and in addition, advertising the intention to mine for public viewing and comment.

Figure 4.5. Steel structure. Source: Tiger Steel (2024)

4.6.4 Social aspect for all engineering materials

The engineering material should be sourced sustainably and environmentally, and at a cost that benefits the community as whole, financial, be long lasting, and as a result delivers the desired outcome of suitable alternative engineering material. The engineering material should also be fit for purpose and its properties should equal or outweigh that of the traditional material.

4.7 Analysis of combined results

In analysing the results their a several aspects that require consideration and the engineering materials were assessed on:

- A rating of physical properties – Higher value in each category captured to compare between a traditional material and the alternative engineering material. The total score in each material is present graphically.
- Cost score – cost of alternative material compared to traditional material and presented graphically.
- Feasibility score – based on the case studies is a total score than traditional material and presented graphically.

The combined results are shown graphically in section 4.8 to clearly illustrate which material is better suited for a particular application.

4.7.1 C/T and C/T and recycled brick subbase pavement design

Assessing the costs determines that this scenario is cost neutral as a comparison between the pavement materials. Both products sustainably sourced by same method with strict policies and guidelines.

The Feasibility Study score was analysed and found that there was very little between the two materials overall.

The main properties as a direct comparison illustrates that the alternative engineering material (C/T and recycled brick) has a slightly higher modulus of elasticity than traditional C/T, but all other property values are similar. The two engineering materials would be considered as neutral in respect to each other's properties.

4.7.2 Steel and FRP for construction

Assessing the cost results determines that this scenario that FRP is a better option to steel as a comparison between the FRP and Steel in the application assessed, grate flooring. Both products are sustainably sourced and manufactured by various methods and follow strict policies and guidelines.

The Feasibility Study score was analysed and found that there was very little between the two materials overall.

The main properties as a direct comparison illustrates that the alternative engineering material (FRP) has a higher ultimate strength and Poisson value and a lower density value all other properties are similar. The FRP would be considered as higher with respect to the properties of Steel.

4.7.3 Steel and Recycled or Recast Steel

Assessing the cost results determines that this scenario is cost neutral as a comparison between the steel materials. A conservative figure of 5% was used as an increase per annum and resulted in a small increase per year equally for both engineering materials assessed. Steel is sustainably sourced and manufactured by strict policies and guidelines, the recast steel is sustainable manufactured, and the recycled steel is manually sourced and has little impact on the environment.

The Feasibility Study score was analysed and found that there was very little between the two materials overall.

The main properties as a direct comparison illustrates that the Recycled and Recast Steel and Steel have properties values that are the same. The two engineering materials would be considered as neutral in respect to each other's properties.

4.8 Summary of combined results

A summary of all the results is presented, in bar graph form this provides a tool that can be used to determine the suitability of an alternative engineering material over a traditional engineering material based on cost, its feasibility and physical properties,.

The Scoring is based on the following determination:

- **Properties** are scored by the number of higher properties the engineering material has have. For example: Steel has 4 out of 8 higher properties than FRP, therefore the score is Steel =4 and FRP = 4. (See the tables in section 4.5 for properties).

- **Cost** is the highest amount being a factor of 10 and the lowest amount a ratio compared to the highest amount. Example: If $1500 is the highest amount = 10 and the lowest amount is $1085 it = 7 (1500/1085 x 100 = 7.2 ≈ 7) (See section 4.6 for costs).
- **Feasibility** is the total weighted score in each table in section 4.4 and calculated using the case study results.

4.8.1 CT vs CT Brick

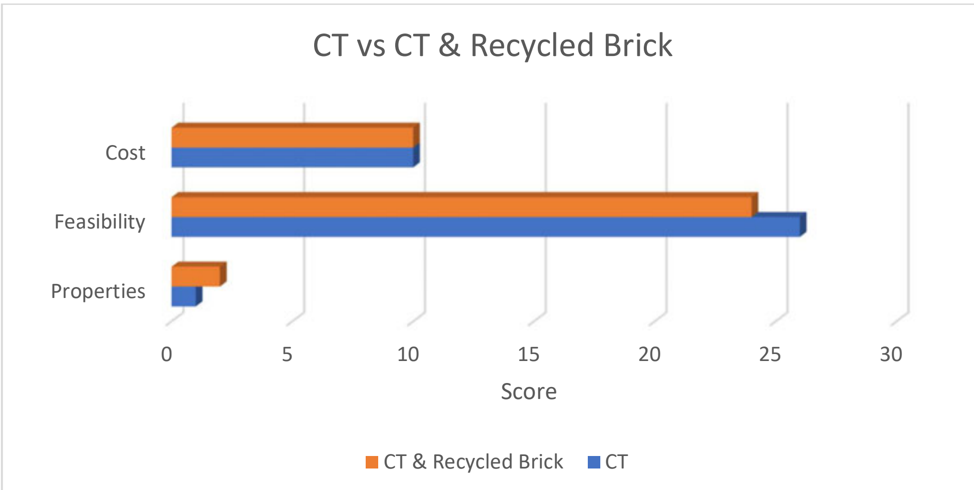

Figure 4.6. Score distribution (CT/CT brick)

The combined results reflect that there is very little between the traditional and alternative engineering materials overall. The deciding factor would be the reuse of bricks rather than using 100% cement as an additive in this case.

4.8.2 FRP vs Steel

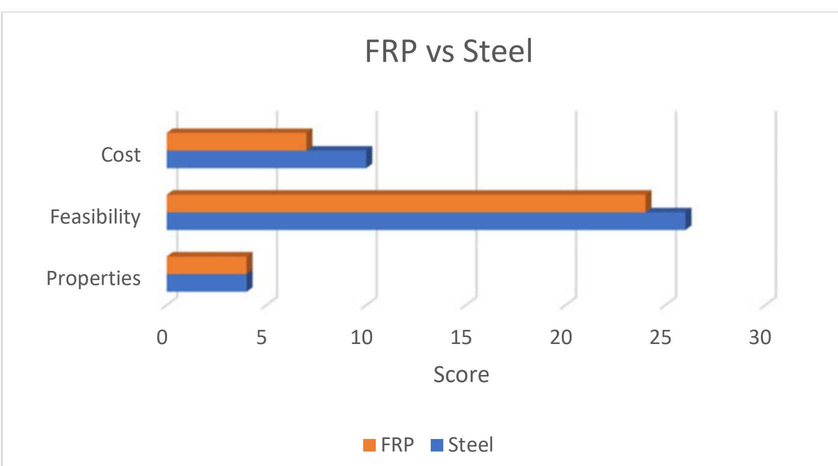

Figure 4.7. Score distribution (FRP/Steel)

The combined results reveal that steel costs more than FRP but similar for feasibility and properties in this scenario. FRP would be a good substitute to use as an alternative engineering material.

4.8.3 Steel vs Recycled or Recast Steel

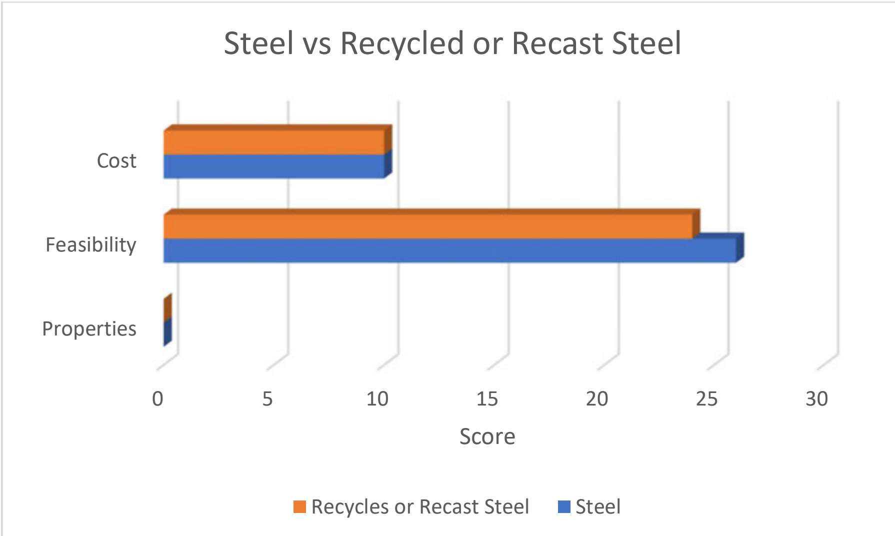

Figure 4.8. Score distribution (Steel/Recycled or Recast Steel)

The combined results reflect that there is very little between the traditional and alternative engineering materials overall. The deciding factor would be the reuse of steel in recycling and recasting in this case as a sustainable and environmental alternative.

Chapter 5 – Conclusion and Discussion

A discussion relating to the results of this research project will discuss whether:

- The outcomes outlined were achieved;
- The results were as expected;
- Any improvements could be made in the research methods; and
- Further work that could be completed in this research topic.

5.1 Outcomes achieved

The outcomes outlined in chapter one was achieved through the processes detailed in the methodology section. The process was to make comparisons which assessed the engineering materials properties, sustainability and environment, costings, standards and long-term usage risk. In addition, a feasibility study demonstrated which alternative engineering material was suitable to replace its traditional equivalent.

Properties

The properties found that the pavement, FRP and steel comparisons had similar values. In this case its application would consider which type of properties were important and was higher before selecting the appropriate alternative engineering material.

Sustainability and Environment

The sustainability outcomes demonstrated that the comparisons of pavement and steel were similar in sourcing, production and lifespan. FRP had alternative sourcing and production methods and did not have a lifespan greater than steel. Overall FRP sourcing and production had better environmental outcome due to many FRP products used are natural and production methods are not as rigorous as sourcing and producing steel from iron ore.

Costing

The comparison proved that pavement and steel alternatives were considered cost neutral and FRP was cheaper than steel in the application outlined in the results. The results demonstrated that the CT and CT with a brick additive had the same cost and maintenance schedules, steel and recycled or recast steel had similar cost and maintenance schedules and for FRP and Steel the FRP was cheaper than steel and maintenance schedules were similar to steel.

Standards

As was discussed standards for some alternative engineering materials do exist and from the tested materials in this research project CT pavements, recast steel and some FRP products have standards but recycled steel and other FRP products still require standards for their use and application.

Long-term usage risk

The long-term usage factors were discussed, and it was concluded that not enough time for some alternative engineering materials has passed to determine whether they last longer than traditional engineering materials. In the case of CT with brick as an additive in pavement, FRP and recycled or recast steel which was researched in this project, that this is certainly the case, and time will be the determining factor.

Case Studies and Feasibility Study

Case studies

The case studies gave a broad response to the issues and limitations faced in implementing an alternative engineering material. There was enough information to suggest that sourcing alternative engineering materials can have a positive cost and environmental benefit to using traditionally sourced engineering materials which makes the exercise well worth exploring.

Feasibility Study

The overall scores in the feasibility study demonstrated that lifecycle, financial risk and cost were important. Comparatively all the alternative engineering materials had the same scores.

The expectation was that engineering materials with similar properties and cost would score similar and engineering materials that were a different composition such as FRP and steel would reflect their scores based on properties and their cost which meant that FRP would be favoured.

In conclusion the outcome of the research proved that an engineering material that has superior properties, lower cost, some standards and proven life cycle can be a viable as a replacement to a traditional engineering material and that similar compared engineering materials can be seen as a more sustainable and environmentally sound product such as recycled or recast steel.

5.2 Expectation of results

Based on the research the results were as expected with most respondents having a similar view on the use of alternative engineering materials. The main issues that the respondents identified in no order were:

- Financial risk;

- Lack of knowledge of the alternative engineering materials;
- Current standards available;
- Product availability;
- Lack of design knowledge; and
- Information on the lifecycle of the product

The issue of sustainability and environmental concerns were a lesser concern in this research materail although it is a major factor that cannot be ignored. Education and training to demonstrate the benefits of having a sustainable outcome are the key to changing these attitudes particularly in the engineering sector.

5.3 Improvements on method of research

The method of research used was to provide key words into google scholar and add a timeline of the last ten years to obtain current information. The addition of textbooks concerning engineering materials also assisted me during my research along with study material used during the Bachelor of Engineering (Honours) program.

Improvements to my research could have involved speaking to more professionals in the engineering sector about their experiences with alternative engineering materials. I find engineering professionals have a wealth of knowledge on the status of new products and methods of completing engineering tasks in the industry and are generally looking for improvements regularly.

The greatest constraint in this project was time and working in a team would have lessened the literature review period greatly and possibly yielded more information on the issues of using alternative engineering materials. More engineering materials could have been tested giving a broader view of the issues of alternative engineering materials.

5.4 Further work

Research is required in compiling a list of the main engineering materials used in building, construction and manufacturing which requires matching them up with advanced sustainable or recycled engineering materials. A list of each of their properties, which have all been appropriately tested, and issues associated with material would be a valuable tool for the industry to make informed decisions when selecting alternative engineering materials. This would be a large-scale project and require a team effort to undertake the research based on time factors and to ensure the information is current.

A questionnaire's may have given a more insight to the issues and limitations to using alternative engineering materials in the current engineering construction climate but due to the time it takes to receive the approval from the Human Ethics Research Committee, this was not a feasible option.

A web-based system using the compiled information would be a novel way of entering an alternative engineering material and obtaining information on it to compare against a traditional engineering material. This would use the parameters used in the research project and give the user an informed understanding of the material they require for a particular engineering application.

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Appendix 1

DOCUMENT APPROVAL

Project Supervisor	
Name: Dr. David Thorpe	Signed:
Position: Honorary Professor	Date:

Project Owner	
Name: Mario de la Pena	Signed: [redacted]
Position: Student (USQ) BENH (Civil)	Date: 24/02/2025

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1.0	Mario de la Pena	Draft Dissertation and Preliminary Results	13/10/2024
2.0	Mario de la Pena	Final Dissertation	24/02/2025

Appendix 2 – Case study 1 (Excerpt of background)

1 PROJECT BACKGROUND

Traditional pavement base and sub-base materials is becoming scarce in some regions. In some cases, the use of these materials is unsustainable from both an environmental and cost perspective. VicRoads manages a road network of 151,000 kilometres, from major freeways to minor local roads. Approximately 50,000 kilometres of this road network is located in metropolitan Melbourne and requires cement treatment of pavement bases/sub-bases, there are also similar requirements for municipal roads, which frequently use similar pavement compositions on local roads. Traditionally, only cement treated crushed rock and crushed concrete have been used in cement treated pavement bases/sub-bases. There is presently a state government sustainability initiative to use recycled materials where appropriate and where they are fit for purpose, particularly in roads and other infrastructures.

This project proposes to investigate the use of crushed brick as a supplementary material with recycled concrete aggregates in cement treated bound pavement applications. The development of a procedure for the evaluation of these reclaimed products as a base/sub-base material would result in an increased level of confidence within industry as to their likely in-service performance and appropriate application as well as result in a higher uptake of recycled materials in urban areas where cement treated sub-base pavements are commonly used.

Currently in Victoria approximately 2.0 million tonnes of crushed concrete and 1.4 million tonnes of crushed brick are stockpiled annually and these stockpiles are growing. The reuse of these recycled materials in applications such as road bases/sub-bases will result in a low carbon solution for future roads, considering that recycled materials have significant carbon savings compared with virgin quarried materials. The focus of this new research project is on the laboratory evaluation of crushed brick when used as supplementary material in cement treated crushed concrete pavement sub-base applications.

Swinburne University has previously been actively undertaking research with VicRoads since 2006 on the use of various recycled demolition materials as pavement sub-bases. Completed joint research projects and Victorian outcomes to date are as follows:

Appendix 3 – Case study 2 (Excerpt of Abstract and Introduction)

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Reuse of Steel in the Construction Industry: Challenges and Opportunities

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Abstract

The construction industry plays a critical role in tackling the challenges of climate change, carbon emissions, and resource consumption. To achieve a low-emission built environment, urgent action is required to reduce the carbon emissions associated with steel production and construction processes. Reusing structural steel elements could make a significant impact in this direction, but there are five key challenges to overcome: limited material availability, maximizing different reusable materials from demolition, lack of adequate design rules and standards, high upfront costs and overlooked carbon impact of the demolition prior to construction, and the need to engage and coordinate the complete construction ecosystem. This article described these barriers and proposed solutions to them by leveraging the digital technologies and artificial intelligence. The proposed solutions aim to promote reuse practices, facilitate the development of certification and regulation for reuse, and minimize the environmental impact of steel construction. The solutions explored here can also be extended to other construction materials.

Keywords Steel reuse · Circular economy · Artificial intelligence · Resource efficiency · Digitalization · Construction industry

1 Introduction

The building construction drives current energy consumption and greenhouse gas (GHG) emissions, representing 36% of total energy use and 37% of the global GHG emissions, respectively (RICS Professional Standard, 2023; UNEP, 2021). Approximately, 10% of these emissions are related to the carbon emissions caused by the production of materials in buildings (le Den et al., 2022): the current amount of embodied carbon emissions in a new building is 600 $kgCO_2e/m^2$ on average, of that 70% of this embodied carbon is emitted upfront, during the building production and construction (A1–A5 life cycle) stages. Besides, construction activities consume a significant amount of natural resources and produce the highest amount of waste among all other sectors (BIO Intelligence Service, 2013). In order to comply with the EU Taxonomy requirements (Directorate-General for Financial Stability, 2023), new building construction must include a life-cycle Global Warming Potential (GWP) assessment for each stage in the life cycle, and disclose it to its investors and cliends on demand. Moreover, regarding the use of "metals", at least 70% of the total material must come from secondary sources (reused and recycled). As a result, the construction industry is under more scrutiny than ever to reduce resource consumption, construction, and demolition-related waste (NBS, 2022; Askarizadeh et al., 2016; McFarland et al., 2021; Geissdoerfer et al., 2017). Building renovation of existing buildings and adaptive reuse of materials and components of a building can contribute to slowing down the resource consumption and the negative environmental impact due to material disposal, and new manufacturing.

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Appendix 4 – Case study 3 (Excerpt of introduction and FRP definition)

IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
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www.iosrjournals.org

Durability and Case Study of Fiber Reinforced Polymer (Frp)

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Abstract: *Fiber reinforced polymer (FRP) composites have become important materials for the new structures and application of FRP is efficient in repairing and strengtheningconstructionswhich werearchitecturallyweak. For applications of structures, an overview of different FRP composites are provided by various polymer composites and in civil structures FRP composites are used for reinstatement or firming up the elemental constituent. Now a days various researches are going oninternationally regarding the use of FRP, wraps, laminates and sheets in the renovation and hardening concrete members.FRPis an alternate process to renovation of structures which is also economical. FRPis being usingeffectively in various cases like lessload, high strength and stability. The purpose of this paper is to discuss about different properties, types, applications of FRP. Some case studies & practical applications used in worldwide are also discussed in this paper.*

Keywords: *FRP, Properties of FRP, Advantages and Drawbacks of FRP, Application.*

I. Introduction

The materials used in civil structures for restoration or firming up the elemental constituent are the fiber-reinforced polymer (FRP) composites.[1]FRPis a compound made up of reinforced fibers of polymer matrix. These are like glass, aramid,basalt and carbon,wood,paper,asbestos etc. FRP composite materials have a significant advantages that includes high stiffness and tensile strength properties, low weight, easy touse, adaptableness to curved surfaces and corrosion proof. Further it is realized that the use of FRP is often governed bystrain limits, due to its brittle characteristics[2]. In 1994, Saadatmanesh and Schwegler, were the first researchers to examine the useof FRP for the consolidation of masonry structures[3].Since then, FRPs are used tostrengthen structural masonry components as walls, vaults, arches and to confine columns. Currently, the principal issue associated with the use of externally bonded FRP composite systems for hardening concrete and masonry structures is toughness, specially the aspects associated tofire and environmental agents. There are very less studies which were conducted for FRP-strengthened masonry elements but much more studies were done on the properties of dampness and temperature effects on the joining performance of external FRP-hardened concrete elements.In civil engineering stability refers to the conditions under which a structure is still considered advantageous. Astructurally stable and sound structure is always considered fit,in spite of its cost issues, it has significant practicaladvantagein long term and durability performance in civil engineering[4].

II. Fiber Reinforced Polymer

FRP is a compound made up of reinforced fibers of polymer matrix. The collection of FRP bars for depends on numerousmatters according to structural point of view. Fiber plastics have various application due to its corrosion resistance, light weight, and non-magnetic propertywith high tension strength, good toughness, less mechanical reductionand resistance in high fatigue[5].Generally, due to its initial and maintenance cost these composite materials were restricted in RC construction use. Excessivecorrosion due to climate of coastal belt and continuous use as ice reducing material on roads and bridges are sufficiently captivated so as to studyfor corrosion lessFRP materials. Numeroustypes of FRP bars for structural purposes havingmass-produced now a days starting from 1-D bars and cables to 2-Dlattices and networks. Different types ofcomponents are shown below.

Figure 1: Types of FRP Bars

Appendix 5 – Gantt Chart

Stage	Category	Task	Action	Action Start	Action End	Work days	Comments
All Stages	Task	1.0	SPECIFICATION AND WORKPLAN	Mon 22 Jan 2024	Mon 12 Feb 2024	18	
All Stages	Sub-task	1.1	Choose topic	Mon 22 Jan 2024	Mon 22 Jan 2024	1	
All Stages	Sub-task	1.2	Write up proposal	Mon 22 Jan 2024	Mon 12 Feb 2024	16	Background,Objective, Aim, Outcomes
All Stages	Sub-task	1.3	Submit specification and work plan	Mon 12 Feb 2024	Mon 12 Feb 2024	1	
All Stages	Task	2.0	LITERATURE REVIEW	Tue 13 Feb 2024	Tue 02 Apr 2024	37	
All Stages	Sub-task	2.1	Source literature on research topic	Tue 13 Feb 2024	Tue 05 Mar 2024	16	Use Google Scholar for cited literature
All Stages	Sub-task	2.2	Write up and reference literature found	Wed 06 Mar 2024	Tue 02 Apr 2024	20	
All Stages	Sub-task	2.3	Submit literature review	Tue 02 Apr 2024	Tue 02 Apr 2024	1	
All Stages	Task	3.0	METHODOLOGY	Sat 13 Apr 2024	Mon 20 May 2024	26	
All Stages	Sub-task	3.1	Commence methodology of project summary	Sat 13 Apr 2024	Tue 16 Apr 2024	2	
All Stages	Sub-task	3.2	Source three case studies	Wed 17 Apr 2024	Wed 01 May 2024	11	Cement treated pavement, FRP, Recycled/Reused Steel
All Stages	Sub-task	3.3	Detail questionnaire and feasibility study process	Thu 02 May 2024	Sun 19 May 2024	12	Submit questionnaire to Human Ethics Research Committee
All Stages	Sub-task	3.4	Submit methodology	Mon 20 May 2024	Mon 20 May 2024	1	
All Stages	Task	4.0	DRAFT DISSERTATION AND PRELIMINARY RESULTS	Mon 20 May 2024	Sun 13 Oct 2024	105	
All Stages	Sub-task	4.1	Commence layout of summary of results	Mon 20 May 2024	Thu 30 May 2024	9	
All Stages	Sub-task	4.2	Send out questionnaire	Fri 31 May 2024	Mon 15 Jul 2024	32	Send out to 5 respondents for Cement treated and 5 for Steel/FRP
All Stages	Sub-task	4.3	Process and analyse results from questionnaire	Tue 16 Jul 2024	Sat 10 Aug 2024	19	
All Stages	Sub-task	4.4	Complete feasibility study, cost/benefit analysis and collate all the information.	Sun 11 Aug 2024	Sat 12 Oct 2024	45	
All Stages	Sub-task	4.5	Submit draft dissertation and preliminary results	Sun 13 Oct 2024	Sun 13 Oct 2024	0	
All Stages	Task	5.0	PRESENTATION/REFELECTION/FINAL DISSERTATION	Mon 14 Oct 2024	Mon 24 Feb 2025	96	
All Stages	Sub-task	5.1	Complete reflection of dissertation and submit	Mon 14 Oct 2024	Mon 21 Oct 2024	6	Exemption from presentation
All Stages	Sub-task	5.2	Complete final dissertation	Tue 22 Oct 2024	Sat 22 Feb 2025	89	
All Stages	Sub-task	5.3	Check and submit final dissertation	Sat 22 Feb 2025	Mon 24 Feb 2025	1