University of Southern Queensland

Faculty of Health, Engineering and Sciences

MECHANICAL AND TRIBOLOGICAL PERFORMANCE OF EPOXY COMPOSITES BASED ON WASTE CERAMIC POWDER

Dissertation submitted by

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ABSTRACT

Eco-materials are becoming the hot topic in recent years due to the impact of synthetic and conventional materials on environments and the cost of resources. On the other hand, there is another equally important issue related to the disposing of waste materials. This project is motivated to address those two issues by developing new epoxy composites based on waste ceramic powder. Tensile behaviour of the newly developed composites with different weight percent of waste ceramic will be investigated. Adhesive wear and frictional performance of the newly developed composites will be studied. The failure mechanisms will be addressed with the aid of the scanning electron microscopy. The main findings of the work are that tensile strength of the composite reduced with the presence of the waste ceramic due the generation of voids in the composites. The wear resistance of the composites dramatically increased with the presence of the waste ceramics. The wear mechanisms of the composites are controlled by film generated on the composites and its stability. In the case of the composite the film was strong and not easy to get removed in oppose to the pure epoxy.

ACKNOWLEDGMENTS

I would like to express my thanks to the University of Southern Queensland for providing the space and the equipment's for me to complete this project. I would like to thank my father, mother and family for their spiritual and financial supports. Finally, I would like to thank my supervisor for his supervision.

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CHAPTER 1: INTRODUCTION

INTRODUCTION

Nowadays, new materials which can fulfil the environmental regulation requirements is highly desirable. There is a great concern from governments in developed countries towards the pollution generated from materials productions and also the disposal of waste materials. In the recent work by Nie (2016), it is reported that resource extraction, manufacture, application, and disposal of materials consumes high energy which results in environmental deterioration from energy and waste materials point of views.

Waste ceramics can be generated from brick dust, manufacturing of tiles ..etc. Which are an available and challenging material having high chemical stability, availability, environmental safety issues, fineness, and silicate properties, (Dousova et al., 2016). Waste ceramic can be either recycled in aggregates for concrete production or waste fine particles (R. V. Silva, de Brito, & Dhir, 2014). Despite there are manyongoing works to use waste ceramics as aggregates, there are several obstacles facing the adoption of it such as lack of confidence of clients and contractors, uncertainty from environmental side, lack of standards and specifications, low quality of the final product, lack of a constituency, (R. V. Silva et al., 2014).

Currently, waste ceramic powder finds its way indifferentapplications, and industrials are interested more than the aggregate of waste ceramic as reported presently by Kannan, Aboubakr, El-Dieb, and Reda Taha (2017). This is mainly because 30% of required materials to produce tiles is wasted through polishing. Also, water absorption of powder is lesser than to be in aggregate form, (Binici, 2007). Accordingly, this project is motivated to investigate the potential of using waste ceramic in powder formfor epoxy composites. Since there is no much work in the literature on this area, there will be comprehensive work on the mechanical properties and the tribology as well. Tribology is another important aspect of component design. 30% of the designed component failure is due to the tribological loading conditions. In this project, tensile properties of epoxy composites based on waste ceramic powder with different ratio will be studied. Similar samples will be tested under adhesive wear loading condition under various operating parameters. Influence of the prepared materials on the counterface will be studied with the aid of roughness profile.

PROJECT AIM AND OBJECTIVES

The main purpose of the current work is to study the tribological and mechanical characteristics of epoxy composites based on waste ceramic powder (WCP). In details, the objective can be divided into different ones as follows:

1. To fabricate epoxy composites based on thedifferent content percent of waste ceramic powder which includes 0 % - 50% per weight.
2. To study the tensile properties of the developed composites in point 1 of this objective
3. To explore the adhesive wear and frictional performance of the developed composites.
4. Study the microstructure of the developed composites and the worn surfaces using scanning electron microscopy
5. To evaluate the impact of the developed materials on the counterface roughens

1.3 OUTCOME OF THE PROJECT

It is expected different contributions of this work to industries, government policies, environments, thescience of composites, environment, waste management and tribology research area. The main findings of the work indicating that the usage of the waste ceramic have great potential to replace part of the synthetic polymers with the same strength and better wear behaviour. In addition, the current study contribute significantly to the knowledge of the composites and the environmental sciences.

1.4 LAYOUT AND PROJECT ORGANIZATION

The dissertation includes six chapters as introduction, literature and background, materials preparations and experimental details, results and discussion and finally the conclusions and recommendations. Chapter two covers previous related literature Chapter three will cover the selection of the materials, properties of the materials, preparation of the composites, tensile and tribological steps and experimental procedure. Mechanical results and discussion will be introducedin chapter four and some arguments with the literature. Tribological data and discussion will be given in chapter 5 associated with the micrographs of the worn surfaces. Keyfindings will be concluded in chapter six with some future recommendations. Since the project is limited for two semesters, the scope of the work is limited and given in Figure 1.1. All the required forms and risk managements are provided in the appendices (A-C).

Figure 1. 1Project Plan

Task \month	Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2017	Aug 2017	Sep 2017
Establish background.							
Purchase of materials.							
Build the composites.							
Conduct experiential work.							
Analysis of the data.							
Writing of dissertation.							

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION TO CHAPTER 2

This chapter will introduce some primary literature on tribology since it is new to me. Recent works on tribology of advanced composites will be given. The importance of the waste materials and their influence on the environments will be covered in the chapter as well. A gap of the research will be summarised at the end of the chapter.

2.2 SCIENCE OF TRIBOLOGY

Tribology isthe science of interacting with two surfaces in relative motion. The word tribology comes from the Greek *tribes*, meaning rubbing, so the actual translation would be "the science of rubbing ", (Mate, 2008).Tribology is the art of applying interactions in a tribological border are exceedingly difficult,and their understanding requires knowledge of various disciplines,(Bhushan, 2013). In any machine, many parts operate by rubbing or sliding against each other. Such as bearings, gears, cams tappets, tires, brakes, and piston rings, (Ludema, 1996). All of these components have two surfaces which come into contact, support a load, and move oneach other, (Jones & Scott, 1983).

2.2 THE HISTORY OF TRIBOLOGY

The industrial revolution (1750-1850 AD) is recognised as a period of rapid and remarkable development of the machinery of production, (Mokyr, 2008). The use of steam power and the continuousevolution of the railways in the 1830s led to the encouragement of manufacturing skills. Since the dawn of the twentieth century, from large industrial growth leading to demand enhanced, (Dowson, 2012).

Plant and Partners Ltd were occupied in the early development of the Pembury Gear, the original endlessly variable toroidal transmission, (Ruff & Bayer, 1993). Two setups were built for research work, one capable of operating with crowned rollers of just1-inchdiameter, the other capable of accommodating rollers of up to 9 inches diameter, (Ruff & Bayer, 1993).Plant and Partners designed and built some test rigs forBritish Rail Researchsector, (Council, 1961).

2.3 TRIBOLOGY MACHINE TYPES

2.3.1 Block on Ring machine (BOR)

The rolling and sliding action of the block on the ring does a good job of simulating the action of the wheels sliding down a track. In this method, the ring simulates the railroad wheel, and the block is the track. A precise load is applied to the ring as it cycles. This pneumatically loaded adapter allows tests to be performed using the standard pin on disk,(Yousif, 2009).

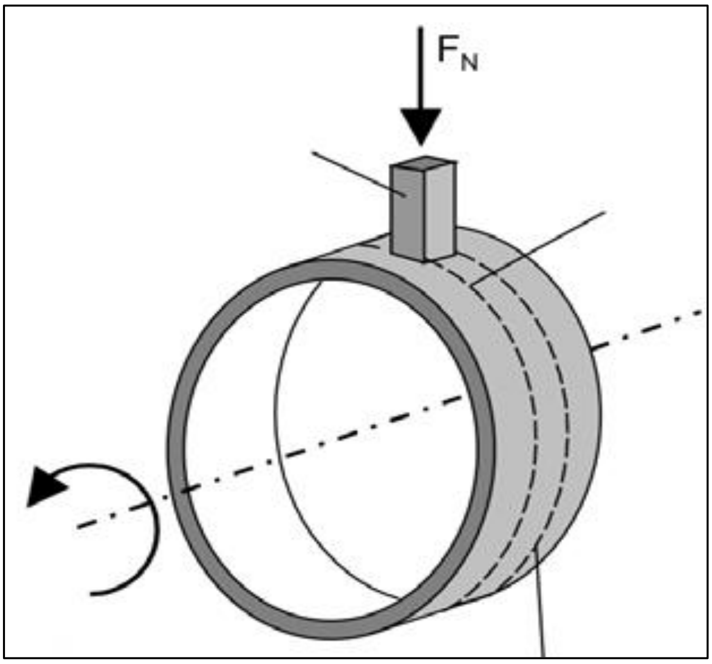


Figure 2. 1Block on Ring schematic drawing

2.3.2 Pin on Disk machine (POD)

A pin-on-disc machine is a versatile unit designed to estimate the wear and friction individuality. Electronic sensors monitor wear and the tangential force of friction as a function of load, speed, lubrication, or environmental condition, (Mang & Dresel, 2007).

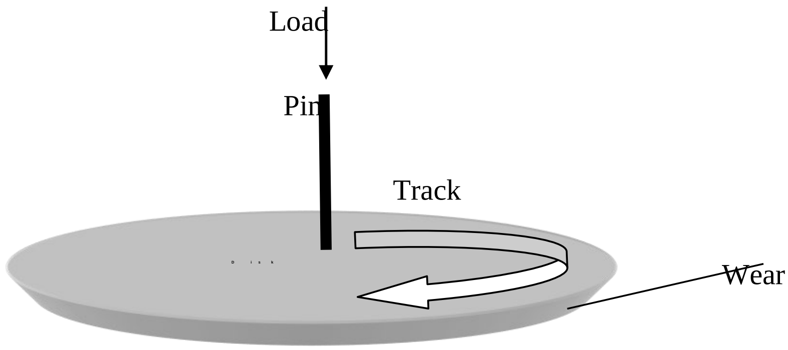


Figure 2. 2Pin on Disk schematic drawing

2.3.3 Block on Flat machine (BOF)

The sample is fixed by on steel holder and the holder heated by electrical resistance elements, anda thermocouple monitors the temperature pressed touching. The heater block is placedon a base, controlled to move in a horizontal plane by linear bearings. This plate is reciprocatedusing a simple crank connected to the drive spindle. The crank pin position may be in step to provide a range of strokes. The reciprocating contact offers a more sensible simulation, (Armstrong-Helouvry, 2012).

The most important role of the pin on disc machine is a tool for the analysis of the wear of materials. The reciprocating pin on plate adapter is the same, an instrument for the analysis of wear. One of the principal differences is in the dynamics of wear particles.

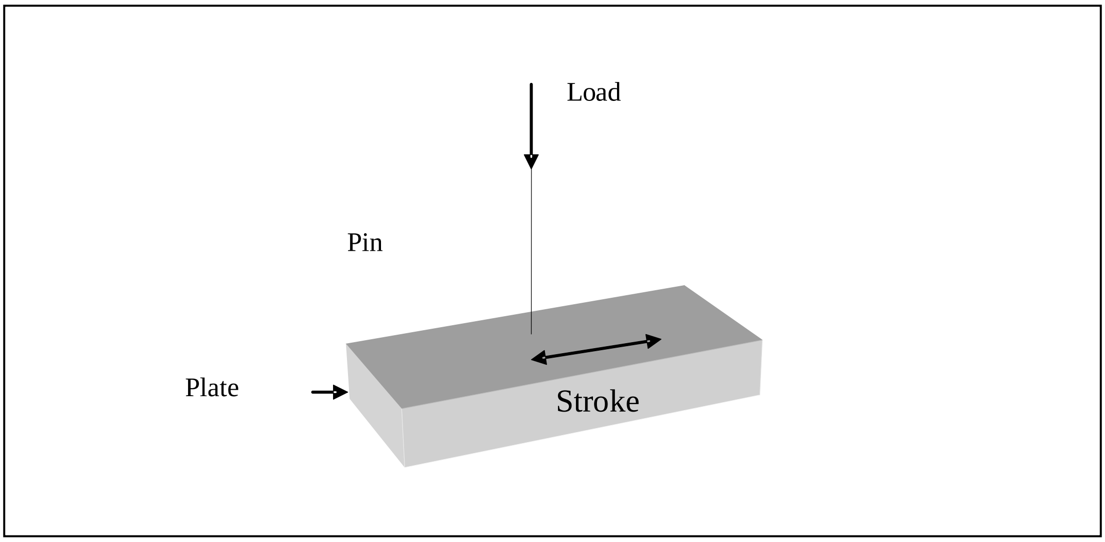


Figure 2. 3Block on Flat Drawing

2.4 FRICTION

Tribology and frictionparticularlyareimportant parts in thedesign.The frictionalforce is the resistance to the sliding. Leonardo da Vinci explored the friction experiments in the 1490's andproved that friction was dependent on the applied load, (Galluzzi, 1987). Friction relation to the applied load can be represented in Equation 2.1 as follows:

$$F_f \leq \mu F_n$$ ……………………………..Equation 2.1

Where *F*is the friction force and *Fn*is the normal load. This is what is called the law of friction or Amonton's law today.

2.5 INTRODUCTION TO COMPOSITE MATERIALS

Composite materials can be defined as engineering materials made from more than one material,(Carter & Norton, 2007). Reinforcements are anessential element in composites which owing to enhance the characteristics of the matrix. The design potentials are incredible due to a variety of matrix and reinforcement materials available. Composite materials are not a new idea for humans as it has been using for thousands of years. For example, takemud bricks. In ancient time, individual embed pieces of straw in a block of mud and let it dry hard, (Yousif, 2013). The result showed the mud brick technically consisted both good compressive and tensile strength, which makes an excellent building material. In avery recent decade, many new composites have been developed due to the improvement in science and technology of composite materials. Engineers and researchers can tailor the properties of composite materials to meet specific requirements by carefully choosing the reinforcement, the matrix, and the manufacturing process that brings them together. Nowadays, composite materials are being used in an increasing number of products as more manufacturers discover the benefits of these versatile materials.

2.5.1 Composites Compound

Composite materials consistofmatrix and type of reinforcement. Reinforcement can be of any material such as carbon fibre, glass bead, sand, or ceramic. Composites can be classified by Lutz and Phillips (1983)into roughly four types according to the fillers types:

- Particulate
- Short fibre
- long fibre

2.5.2 Advantages and Disadvantages of Composites Materials

The main benefit of most composites materials is strength and stiffness combined with lightness, (Mallick, 2007). The downside of composites is usually the cost. Although manufacturing processes are often more efficient when composites are used, the raw materials are expensive. Composites will never totally replace traditional materials like steel, but no doubt new uses will be found as the technology evolves.

2.6 ECO-MATERIALS

Eco-materials can be defined as "*those materials that improve the environment throughout the whole life cycle and maintain accountable performance*", (Halada & Yamamoto, 2001). Nowadays, there is considerable interest in developing new materials those can address the current environmental issues. Some works have been done in relation to the polymeric composites such as natural reinforcements, (El-Abbassi, Assarar, Ayad, & Lamdouar, 2015; Mostafa, Ismarrubie, Sapuan, & Sultan, 2017; Pitt, Lopez-Botello, Lafferty, Todd, & Mumtaz, 2017; Ridzuan et al., 2016; Torres, Vandi, Veidt, & Heitzmann, 2017), natural resins (Khanlou, Woodfield, Summerscales, & Hall, 2017; Sabale, Paranjape, Patel, & Sabale, 2017; Väisänen, Das, & Tomppo, 2017). Those works are absorbing, and there are significant impacts on the development of eco-materials. However, there are many limitations surrounding the applications of this natural fibres and resins especially in the weakness of fire resistance (Fan, Naughton, & Bregulla, 2017; Hörold, Schartel, Trappe, Korzen, & Bünker, 2017; Machado & Knapic, 2017; Naughton, Fan, & Bregulla, 2014), variation in the resources (Azwa & Yousif, 2013; Azwa, Yousif, Manalo, & Karunasena, 2013), variation in the nature of the fibres from the same resources (Dittenber & GangaRao, 2012), and poor interfacial adhesion with the resins which required chemical treatments, (Fiore et al., 2016; Gallos, Paës, Legland, Allais, & Beaugrand, 2017; George & Bressler, 2017; Ridzuan et al., 2016).

Further to the above, there are other issues which required significant attention from the academic and industries; these issues are related to the management of waste materials, (Appiah, Berko-Boateng, & Tagbor, 2017; A. Silva, Rosano, Stocker, & Gorissen, 2017). Details on this issue will be further explained in the following sections.

2.6.1 Waste Materials

For centuries, waste materials from urbanised landscapes are an issue to be resolved. With the increase in the products and human consumption, the level of waste materials increases from human lettering and industrial waste materials. The amounts of disposed of materials are either buried, dumped or burnedinto ash,(A. Silva et al., 2017).A. Silva et al. (2017), in this recent work, reported that waste management is transferring from traditional landfill or recycling wastes into integrated waste policy. In other words, the program is targeting zero waste. Hannan, Abdulla Al Mamun, Hussain, Basri, and Begum (2015) reported that global production of solid waste from municipal solid waste reaches 1.3 billion tonnes/year which is equivalent to 1.2 kg/capita/day. The results presented by Hannan et al. (2015) are critical and should be considered by academic, industrial and government parties. Some of the collected data in that work are represented in Table 2.1 giving the significant of some materials wasted from the human side only without considering the industries.

Table 2. 1 waste solid materials in 2012, the results are extracted from (Hannan et al., 2015).

Region			
	Urban MSW generation (kg/capita/day)	**Urban population (millions)**	**Urban MSW generation (kg/capita/day)**
Africa	0.65	518	0.85
East Asia and Pacific	0.95	1,230	1.52
Europe and Central Asia	1.12	240	1.48
Latin America and the Caribbean	1.09	466	1.56
The Middle East and North Africa	1.07	257	1.43
Organization for Economic Co-operation and Development (OECD)	2.15	842	2.07
South Asia	0.45	734	0.77

Waste materials and related issues include numerous areas, and there are so many works have been published to deal with this topic. Policies, management, industrial waste, recycling, animal publications found in the www.sciencedirect.com. Since the project is dealing with the waste of ceramic;I would focus on the industrial waste and how engineers are attempting to resolve those issues.

2.6.1.1 Waste materials applications

Ribeiro et al. (2015)tried to use waste glassfibre reinforced plastic waste materials in construction applications. These composites are tough to recycled or degraded into the life cycle. In this work, glassfibre reinforced polymer compositesprotrusionwaste was used in polyester polymer mortars and mechanical properties were determined. The results were promising since the replacement of sand aggregates by polymer waste materials increases both flexural and compressive strengths of mortar material. Details of the influence can be found in figure 2.4. Theincrease in the content of the waste materials relatively increases the strength of the materials. However, at high percent of above 8%, reduction in the strength can be found which is due to the poor interaction between the particles and the matrix. Thisneeds attention by either treating the waste materials or study the optimum size of particles.In Ghanah, Appiah et al. (2017) successfully used waste plastic in road construction. Moreover, plastic modified bitumen exhibited great promise recycling technique for plastic waste management.

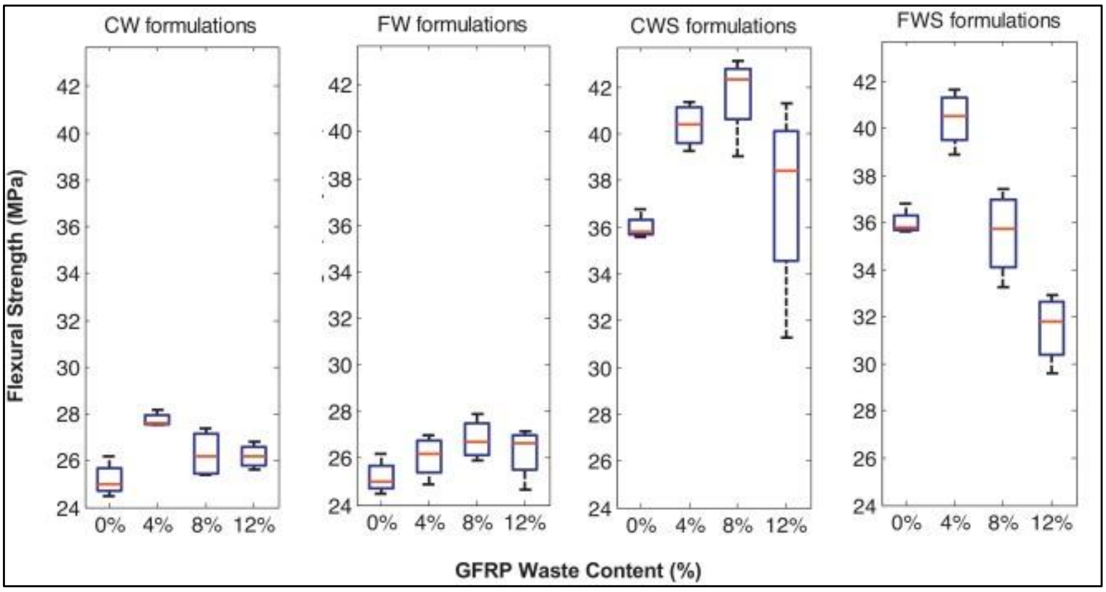


Figure 2. 4 influence of waste materials content on flexural strength of mortar material by Ribeiro et al. (2015)

Petrucci et al. (2015) studied the tensile behaviour of waste cotton in polypropylene laminates. The results showed that the waste cotton assists in improving the tensile properties of the composites despite the pullout of fibres took place during the loadings as shown in figure 2.5. The results are questionable since there is pull-out of fibres which are evidence that the fibres are not able to carry the load during the tensile. This need s further clarifications and study especially the polypropylene material which is thermoplastic, i.e. fibre reinforcement is not recommended for such type of polymer.

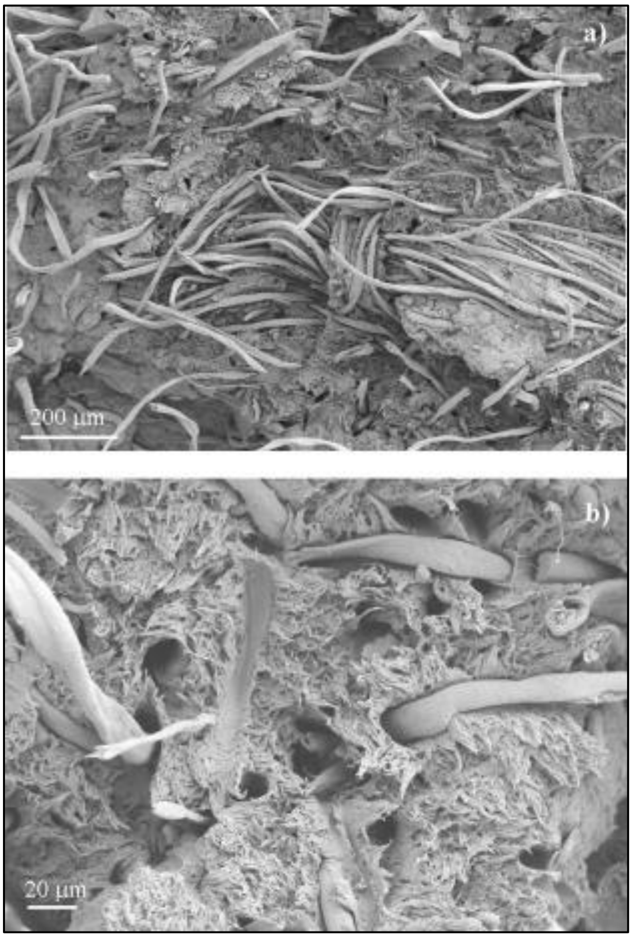


Figure 2. 5 SEM of cotton polypropylene composites after testing by (Petrucci et al., 2015)

2.6.1 Waste of ceramic materials

Construction materials are existed in nature, i.e. blocks, concrete and bricks. Preserving this resources is in concern since there isa massive consumption of those materials due to the increase in buildings, (Amin, Sibak, El–Sherbiny, & Abadir). Moreover, during the fabrication process of such materials there are ahigh amount of carbon monoxide, oxides of sulphur, oxides of nitrogen, and suspended particulate matters are emitted to the environments, (Kneese, Ayres, & d'Arge, 2015). One of the most common consumer materials in construction is the ceramic. Pacheco-Torgal and Jalali (2010) stated that ceramic industry generates large amounts of ceramic wastes each year and the majority of the waste ceramics is gone to landfills. There are different types of waste ceramics which are determined by Amin et al. (2016) and reproduced in figure 2.6.

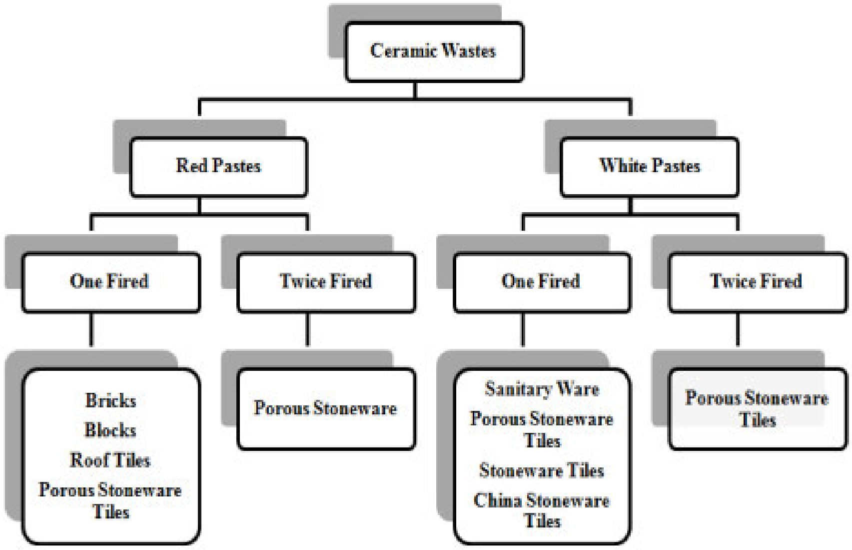


Figure 2. 6 Waste ceramic types listed by Amin et al. (2016)

In the literature, there are many works have been done to use the waste ceramics in civil applications such as concrete as aggregate (Anderson, Smith, & Au, 2016; P. Liu, Farzana, Rajarao, & Sahajwalla, 2017; Zegardło, Szeląg, & Ogrodnik, 2016) or powder (El-Amir, Ewais, Abdel-Aziem, Ahmed, & El-Anadouli, 2016; Kannan et al., 2017). Interestingly, there are few recent works have been attempted to use the waste ceramic in polymer composites such as (Dziadek, Stodolak-Zych, & Cholewa-Kowalska, 2017; Gohil, Suhail, Rose, Vella, & Nair, 2017; Kashyap & Datta, 2017; H. Liu & Webster, 2011). Dziadek et al. (2017) detailed the importance of using the waste ceramics in polymer composites with some considerations. In that work, it has been reported that the properties of both ceramic and polymer significantly improved in combing both materials especially when the ceramic used as fillers compared to use the materials alone. From biological aspect, Robinson, Brudnicki, and Lu (2017) found promising results in the combination of ceramic and polymers as biodegradable materials. It is found that the mechanical properties significantly improved and there is the good interaction of the developed materials with the human body.

Yu, Wu, Wei, and Baier (2015) studied the thermal conductivity of ceramic/epoxy composites reporting that thermal conductivity of epoxy composites with 3 vol% and 5 vol% is dramatically improved since there is an increase in the conductivity of 8.3% and 12.5% about neat epoxy. The micrographs of the prepared composites in that work are extracted and displayed in figure 2.7. The micrographs show good interaction between the ceramic particles and the epoxy. However, the distribution is not uniform. This is common issues with the usage of small particles in fabricating polymer composites.

In another work by Ligoda-Chmiel, Śliwa, and Potoczek (2017), the interaction between the ceramic particles and the epoxy is indigent. Figure 2.8 is extracted from that work which shows clearly the bad interfacial adhesion of the ceramic particles with the epoxy. This is mainly due to the large surface area and the shape of the particle. In other words, large particles of ceramic are not suitable for polymer composites. Therefore, I would use the ceramic powder in this work.

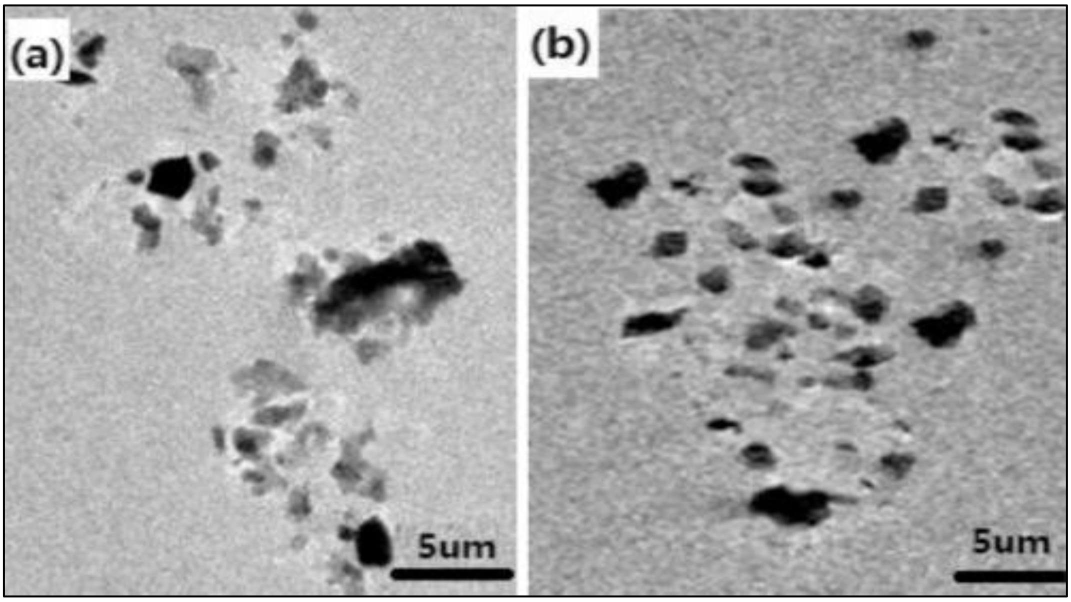


Figure 2. 7 TEM of epoxy/ceramic composites by Yu et al. (2015)

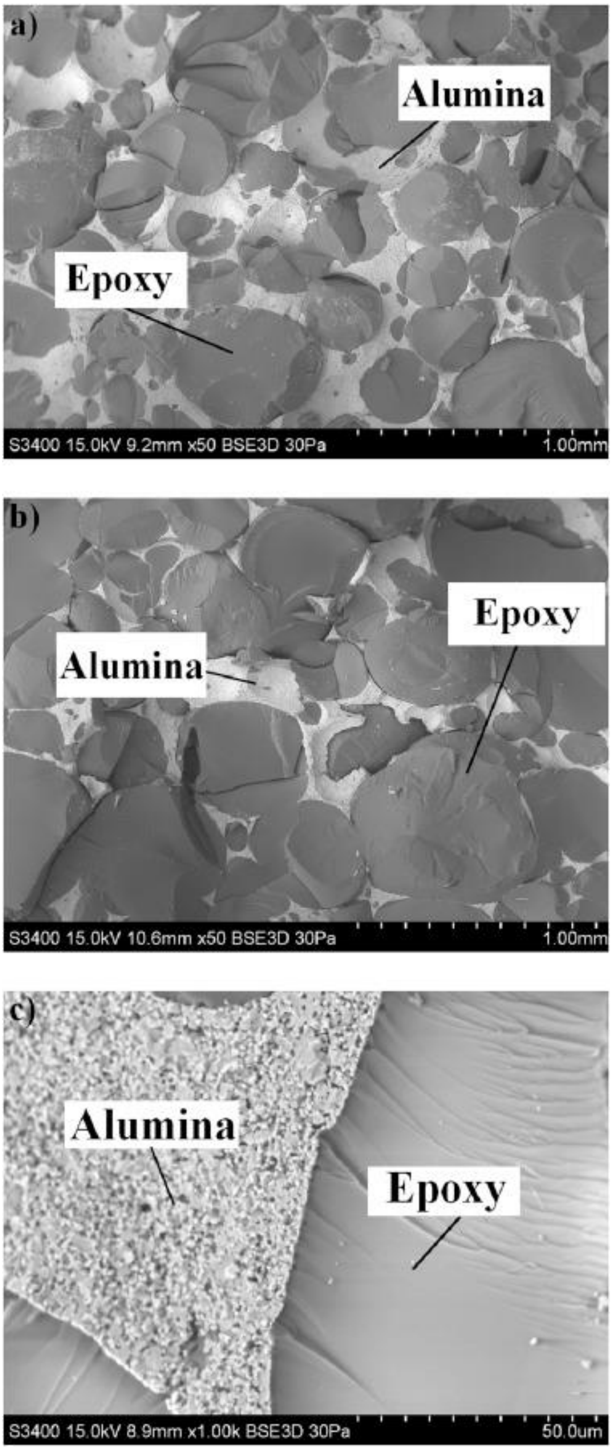


Figure 2. 8SEM of Epoxy Alumina Composite by Ligoda-Chmiel et al. (2017)

2.7 SUMMARY OF THE LITERATURE

There are many points can be drawn from the literature. Firstly, there is a concern with regards to the waste materials especially the disposing process and its impact on the environment. Secondly, there is interest and work going on the usage of waste materials in different engineering applications. Waste ceramics is in a large amount and need attention. There are few successful attempts have been done to use the waste ceramics in structural applications. Few works are going on the usage of waste ceramics in polymer composites. Large particles of ceramics are not recommended for polymer composites.

CHAPTER 3

MATERIALS PREPARATION AND EXPERIMENTAL DETAILS

3.1 MATERIALS SELECTION

Ceramic powder was obtained from a company in the USA through my supervisor, Figure 3.1. The ceramic powder will be used in different weight fraction to build the epoxy composites. The epoxy used in the current study is Platinum epoxy which is supplied by eBay.com.au. The hardener recommended for this type of epoxy is platinum as well with a ratio of 5:1, Figure 3.2.

Figure 3. 1 Nano-Ceramic powder

Figure 3. 2 Epoxy Resin and Hardener

3.2.1 Composite fabrication

Mould technique is used for the current fabrication process of waste ceramic/epoxy composites. There are two moulds were used. The first one is for the tensile samples, and the second for tribological samples. The required equipment and materials for the fabrication are given in Figure 3.3. In the fabrication process, the mixture of epoxy resin and hardener is mixed first and prepared as can be seen in Figure 3.4. After that the amount of waste ceramic is added. Electrical mixture is used to uniform the waste ceramic distribution in the composites.

Figure 3. 3 prepared table for the fabrication of the composites including the materials used in the fabrication

Figure 3. 4 mixing of the hardness and the epoxy

The mould used for the tensile samples is given in Figure 3.5. The prepared mixture was poured into the mould (Figure 3.6) and then the remains at the room for 24 hours for curing. The samples then placed in an oven at temperature above 100 ^{o}C as recommended by the manufacture to complete the curing process. After the completion of the curing the samples were removed from the mould, Figure 3.7. Similar procedure was used to fabricate the tribological composites but using a tribological mould and the final samples have the dimensions of 20 mm x 20 mm x 50 mm, Figure 3.8.

Figure 3. 5 mould used for the tensile samples

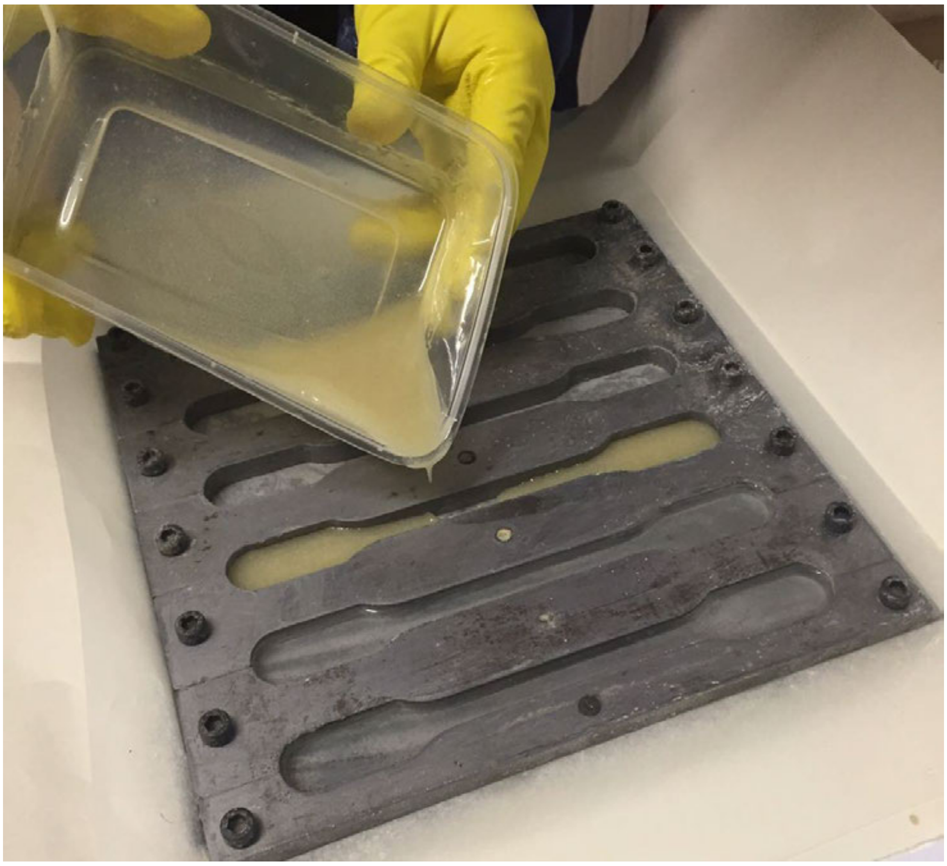


Figure 3. 6 Pouring process of the mixture into the mould of the tensile samples

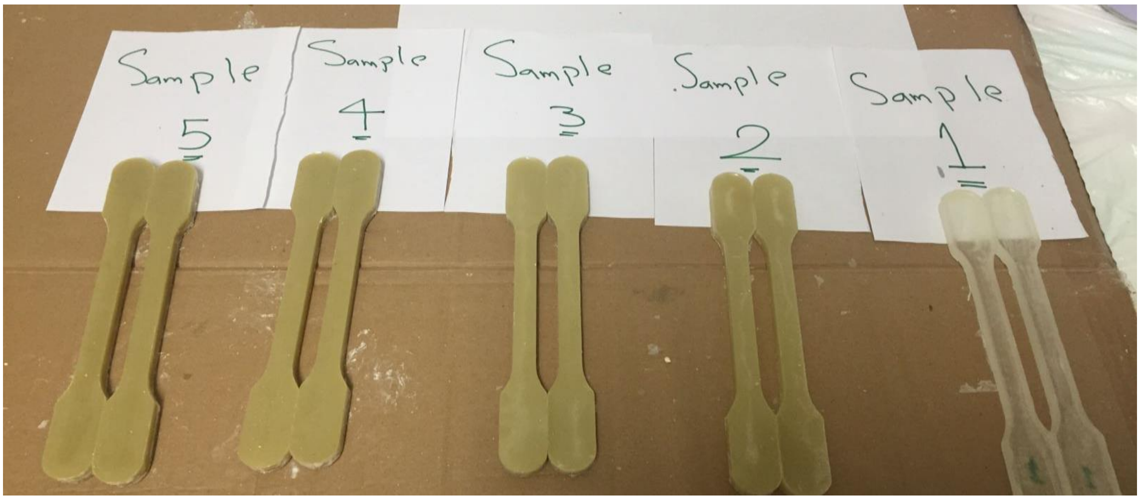


Figure 3. 7 Prepared tensile samples

Figure 3. 8 Prepared tribological Samples

3.2 EXPERIMENTAL SETUP AND PROCEDURE

3.2.1 Tensile testing

For the tensile experiments, a universal tensile machine at the university of southern Queensland will be used at a loading rate of 2 mm / min. for each set of samples there are two repeated tests and the average will be calculated, Figure 3.9. The weight ratio of the ceramic n the samples various from 0-40 %. The data were captured using a software on the computer. The raw data are presented in Appendix D.

3.2.2 tribological testing

For the tribological experiments, same weight ratio of ceramics will be used in the testing of the samples. Tribological machine shown in Figure 3.10 will be used to conduct block on ring sliding under different applied loads of 30N with sliding speed of 3 m/s which is with the limit of PV of the epoxy. The sliding distance will be up to 10.5 km to get the steady state. In the tribological experiments, the prepared samples will be smoothened with sand paper of 1500 grade to reach the required roughness of below 1 µm to get the adhesive wear. At high roughness abrasive wear loading will be generated. The counterface is made of stainless steel which is polished with the same sand paper to get the interaction of the asperities in adhesive condition. The samples will be weighed before and after each test using high precise weight scale (Figure 3.11) to determine the weight loss and then the specific wear rate will be calculated. Friction coefficient will be determined based on the applied load and the measured frictional load from the load cell. The worn surface of the samples will be observed using scanning electron microscopy to see the damages on the surfaces and ensure the adhesive wear is applied. Roughness of the counterface and the worn surface will be measured to determine the modifications took place on the surfaces after the tribological loadings.

Figure 3. 9 universal tensile machine and eh software with the fractured samples after conducting the tests

Figure 3. 10 Tribology machine

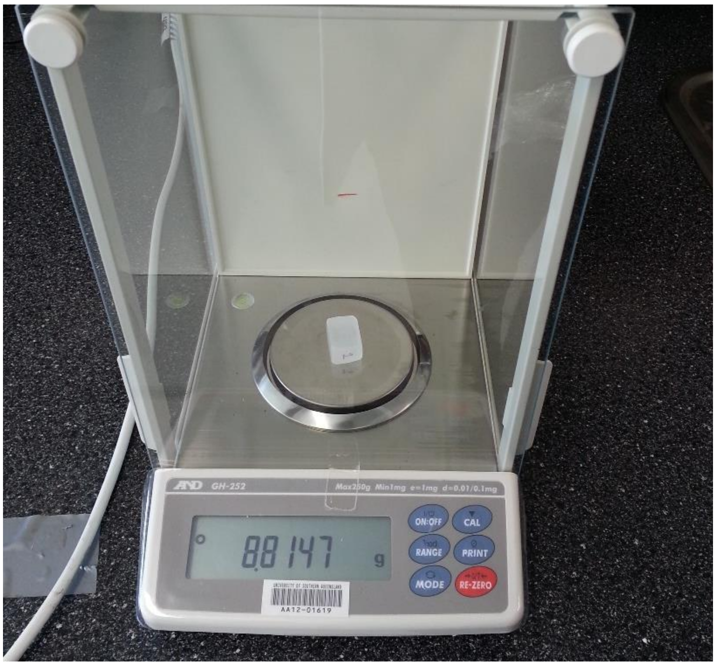


Figure 3. 11 Weight scale with high precision of 0.1 µg

3.3 OTHER MEASUREMENT AND EQUIPMENT

To determine the volume loss of the tribological loading, the density of the composite should be determined first. In the determination of the density, the sample volume was determined using the liquid scaled jar, Figure 3.12. The sample was weighted before and then the density was calculated.

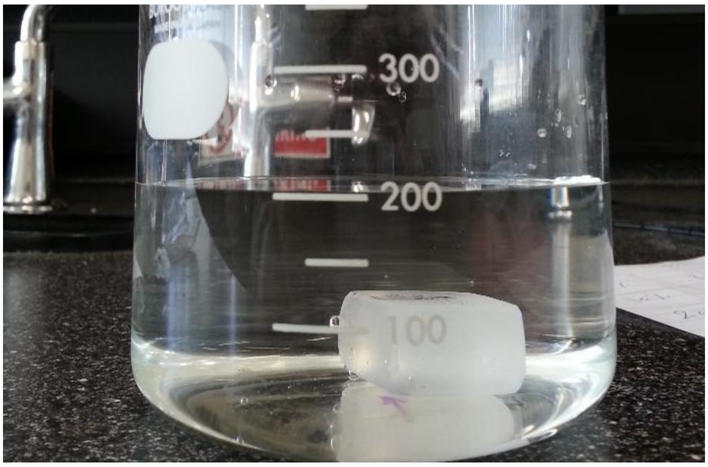


Figure 3. 12 procedure of determining the density of the composites

In addition, the tensile fracture samples and the worn surface of the tribological samples were observed using scanning electron microscopy. Before conducting the examination, the samples were gold coated using smart coating machine as shown in Figure 3.12. The samples then fixed on a holder and placed in the room of the JOEL SEM machine at USQ.

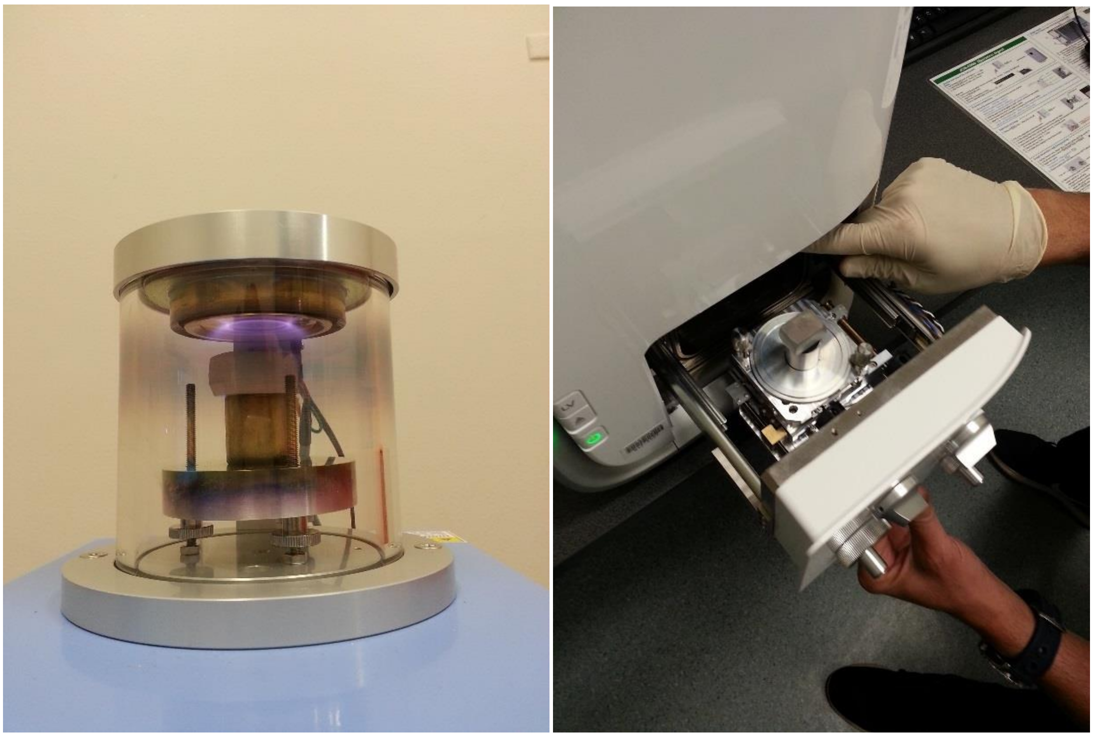


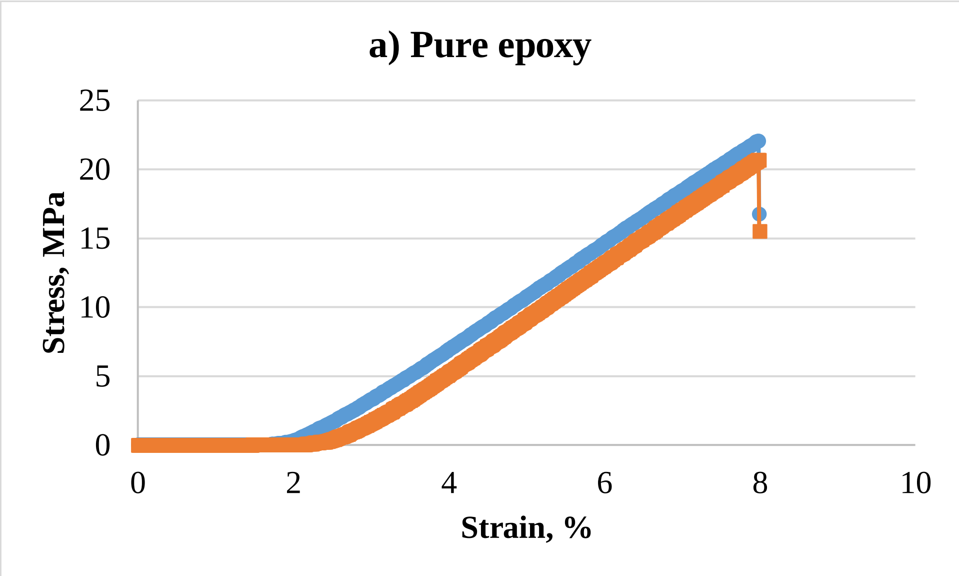
Figure 3. 13 Procedure of conducting SEM examination

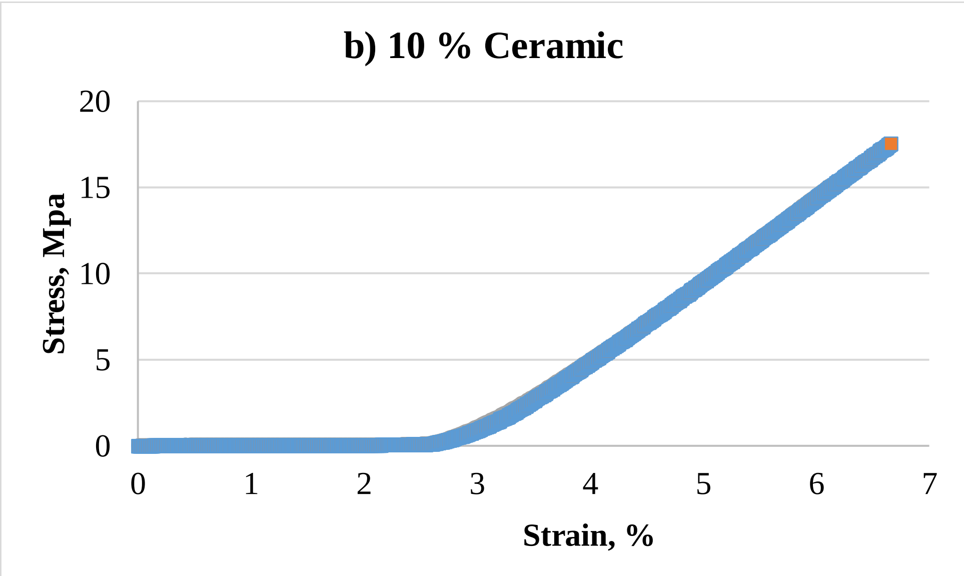
CHAPTER 4 TENSILE AND TRIBOLOGICAL RESULTS AND DISCUSSION

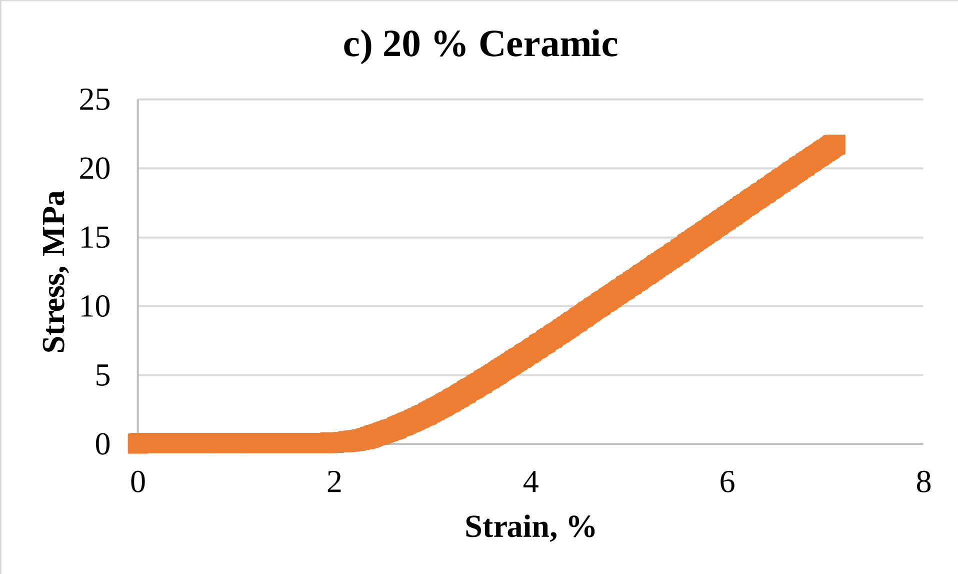
4.1 TENSILE RESULTS

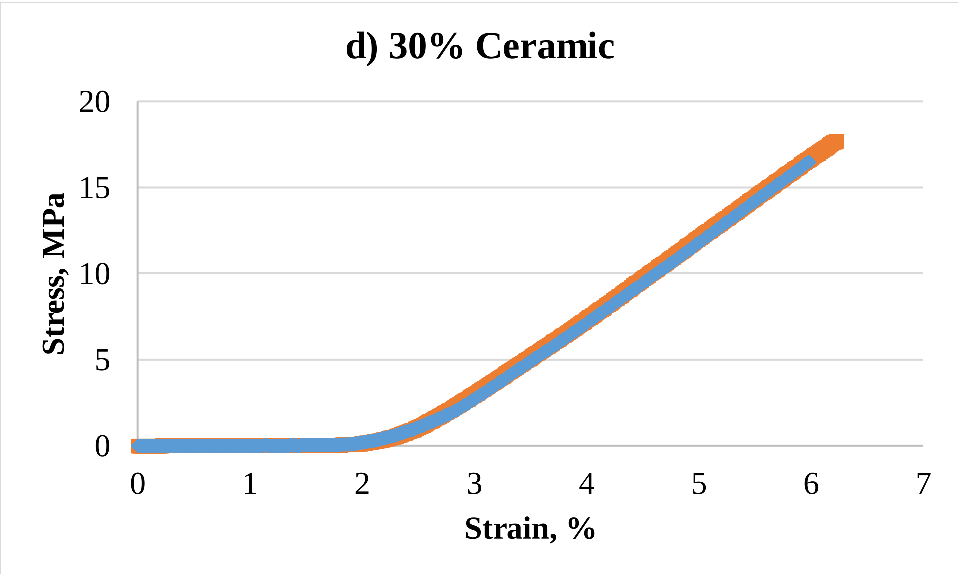
4.1.1 Stress-strain behaviour

Tensile results of the epoxy and it is composites with different percent of ceramics are presented in Figure 4.1 a-e. The results are given for two samples at each set of testing. In general, the figures indicate that there is a pure brittle natural behaviour for all the tested composites. There is clear elastic deformation in a pure linear relation and then the failure took place for the materials. It should be noticed that there is a gripping issue at the first stage of the testing since it can be seen that there is zero stress up to about 2% strain. Due to the brittleness of the samples, it was different to grip the sample straight away in the gripper of the universal tensile machine. Therefore, a holder was designed to carry the sample during the testing and avoid the failure of the sample before completing the test. This cause the zero-stress at large strain in the first stage. The interesting thing in the graphs is the trends and the failure value of the samples at each test are almost the same. This indicate the accuracy of the testing and the fabrication of the samples.


a) Pure epoxy
25
20
15
10
5
0
Stress, MPa
0
2
4
6
8
10
Strain, %


b) 10 % Ceramic
20
15
10
5
0
Stress, Mpa
0
1
2
3
4
5
6
7
Strain, %


c) 20 % Ceramic
25
20
15
10
5
0
Stress, MPa
0
2
4
6
8
Strain, %


d) 30% Ceramic
20
15
10
5
0
Stress, MPa
0
1
2
3
4
5
6
7
Strain, %

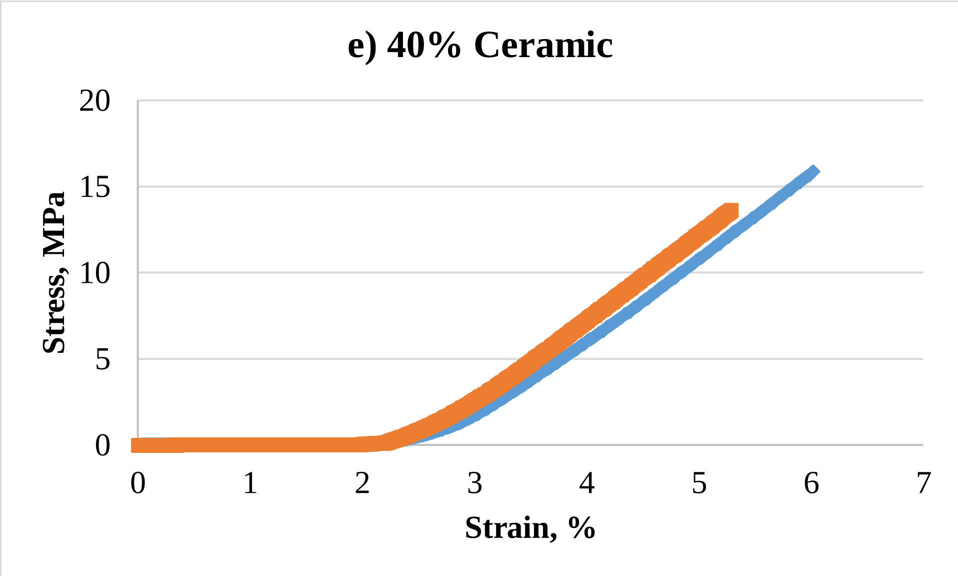


Figure 4. 1 Stress-Strain diagram of epoxy composite containing different percents of waste ceramic

4.1.2 Effect of ceramic content on tensile properties of epoxy

The tensile strength of the epoxy composites with different content of ceramics are presented in Figure 4.2. The figure shows that the addition of 10% of ceramic reduces slightly the strength of the epoxy. At the 20% of ceramic, there is slight increase in the strength of the epoxy which is about 7%. At high percent of the waste ceramic, there is reduction in the strength of the epoxy. The highest reduction takes place when the composite contains 40% since the reduction is about 30%. Jayasuriya (2017) explained the reduction in the strength of polymer contain ceramic by the idea of the incompatibility of two dissimilar phases. This can explain the current poor performance of the epoxy at high percent of the ceramic. In addition, it has been reported by Defebvin, Barrau, Lyskawa, Woisel, and Lefebvre (2017) the aggregation of the ceramic is the main reason of the poor performance of polymer.

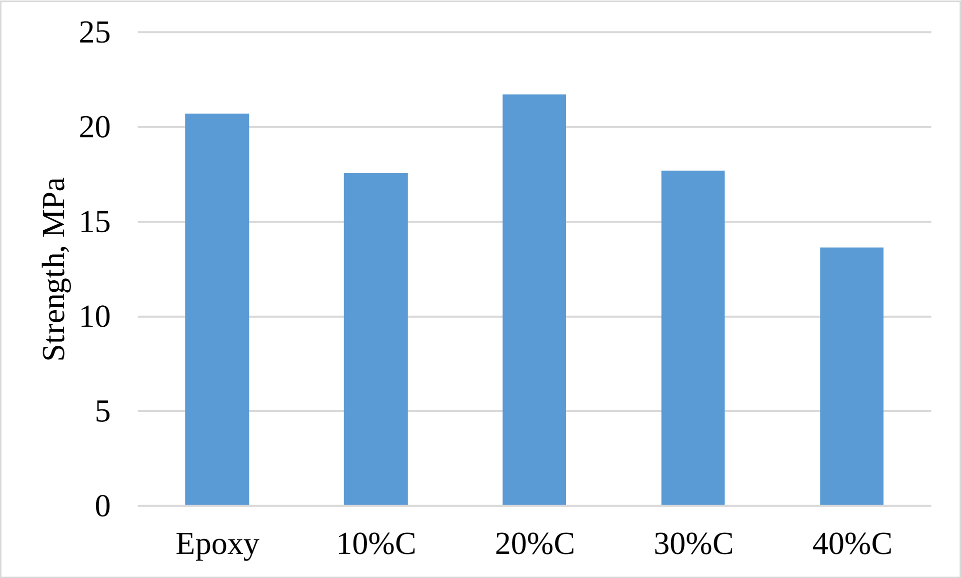


Figure 4. 2Ultimate strength of epoxy composites containing different percent of ceramic

In term of the modulus of elasticity, Figure 4.3 displays the modulus of the epoxy composites. The addition of the ceramic increases the modulus especially at the intermediate content of the ceramics. This is interesting results despite the reduction in the strength. Figure 4.3 shows the ductility of the composites indicating that there is no much improvement to the ductility of the composites whereas there is slight reduction. However, replacing about 40% of a material with a waste product with maintaining a good property can be a good achievement of this work. This is a promising results which can utilise the waste ceramic in epoxy products base.

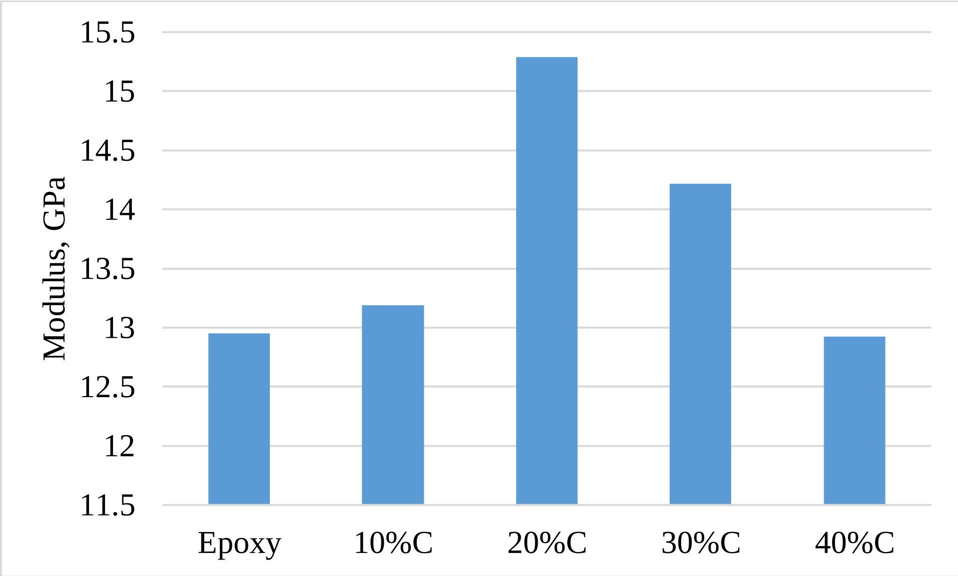


Figure 4. 3Modulus of elasticity of epoxy composites containing different percent of ceramic

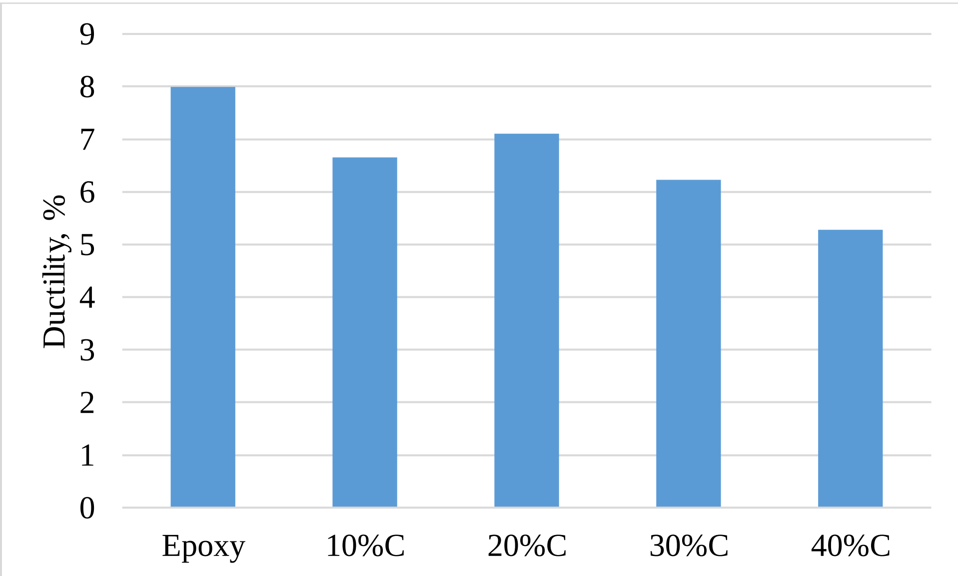


Figure 4. 4 Ductility of epoxy composites containing different percent of ceramic

4.1.3 SEM observation on the fracture surfaces

The fracture behaviour of the tensile samples of the pure epoxy and the epoxy composite with 40% ceramic is given in Figure 4.5 and 4.6. In Figure 4.5 there is a clear fracture indicating the brittle behaviour of the pure epoxy. The fracture is like lips and river-like pattern which are the common brittle behaviour of thermosets as reported by many researchers such (Ahmadloo, Gharehaghaji, Latifi, Mohammadi, & Saghafi, 2017; Imanaka, Liu, & Kimoto, 2017)

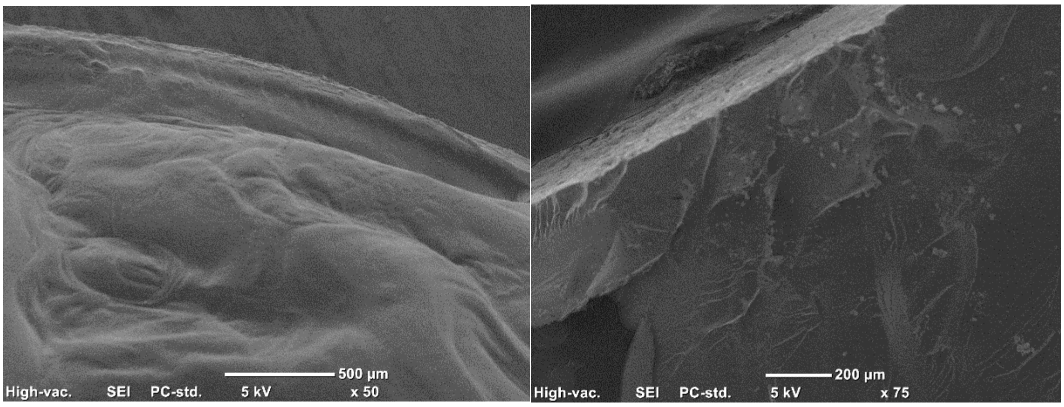


Figure 4. 5 Graphs of tensile samples of pure epoxy

Figure 4.6 shows the micrographs of the tensile samples of 40% ceramic/Epoxy composites. There are many important features in the SEM which are the voids, aggregation of ceramics and fracture behaviour. The presence of the void in the structure of the composites has been reported by Misseroni (2016). It is very common issue which resulted in the deterioration of the composite strength as reported in the current results (Figure 4.2). In addition, the aggregation of the ceramic particle could be another reason of the low strength of the composites. There's no obvious sign of fracture showing the brittle behaviour of the composites which is due to the detachments of the particle and the poor interaction between the ceramic particle and the epoxy resin.

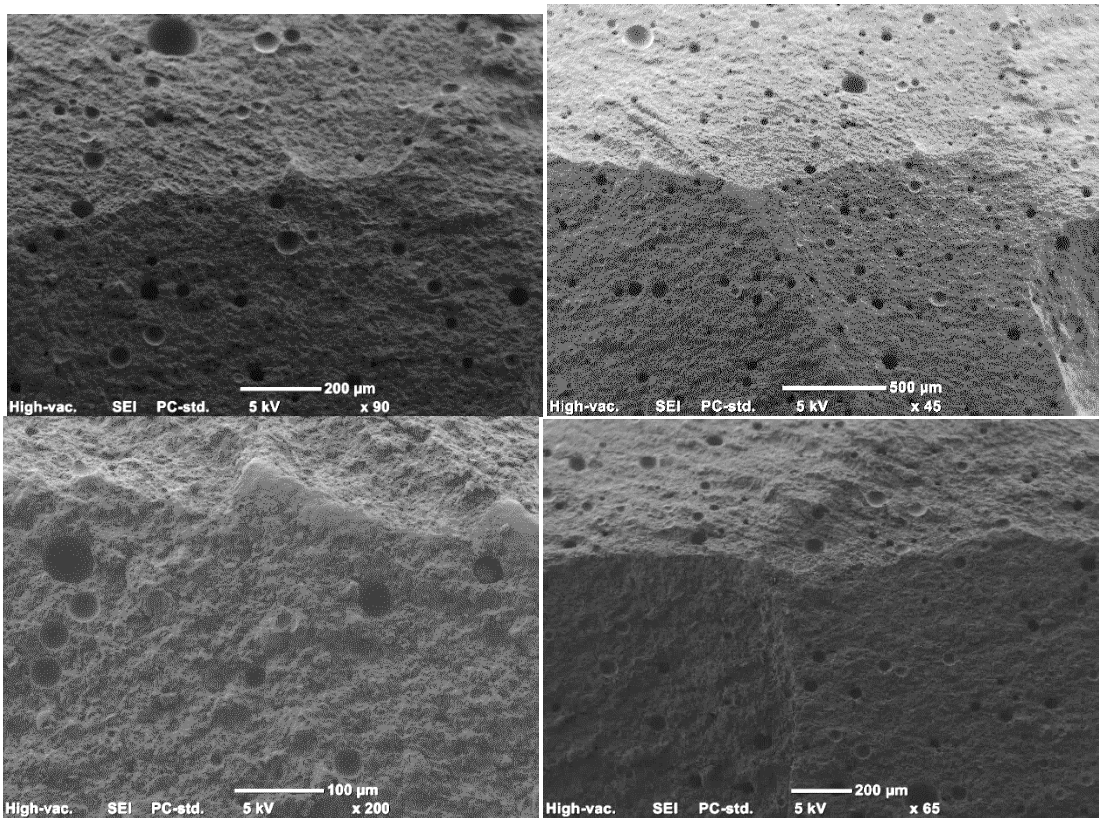


Figure 4. 6 Graphs of tensile samples of epoxy composite containing 40% Ceramics

4.2 TRIBOLOGICAL RESULTS

4.2.1 Specific wear rate

Specific wear rate of the epoxy composites with different content of ceramics are given in Figure 4.7. It seems after about 6 km sliding distance, a steady state of the wear takes place. Before the 6 km, there is high wear rate in most of the composites except the 40% and the 10%. The high wear rate at the initial sliding is due to the removal of the peaks on the surface of the composites easily and the interaction between the asperities got stable after 6 km sliding distance. Albdiry and Yousif (2013) reported similar trends when polyester composites based on nanoclay was tested against steel counterface. In that work, the roughness of the counterface was the evidence of the high material removal at the first stage of the sliding. Also, there composite surface roughness was increased with the sliding distance due to the presence of the hard materials such a ceramic or nanoclay.

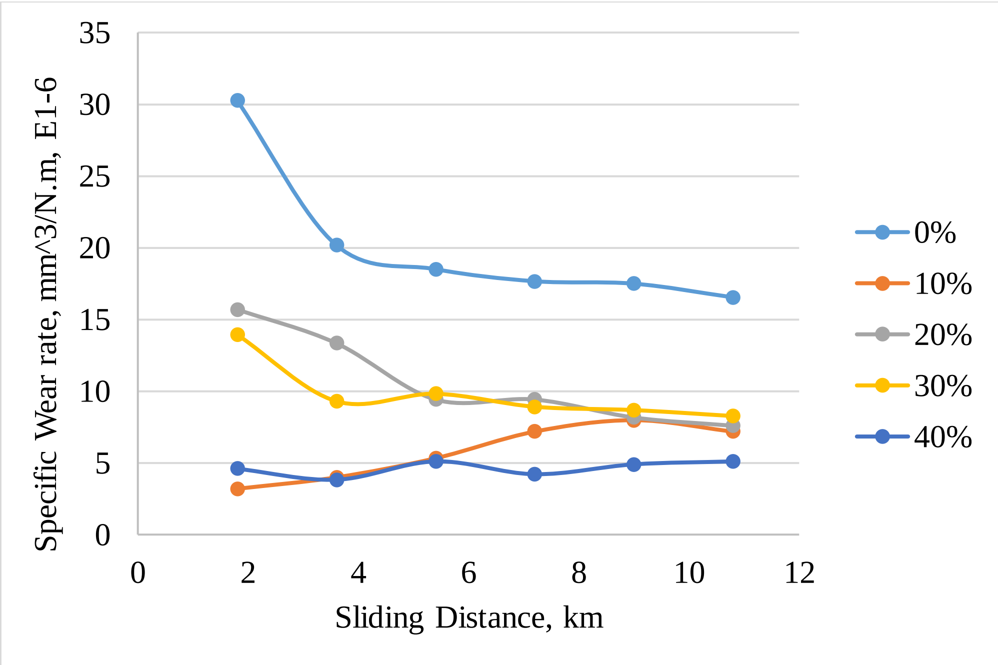


Figure 4. 7 Specific wear rate of epoxy composites with different ceramic contents

For comparison purposes, the steady state value of the specific wear rate of the composites was extracted and represented in Figure 4.8. Interestingly, the specific wear rate of the epoxy composites is much lower than the pure epoxy. The reduction in the specific wear rate is about 60%. In other word, the presence other ceramic improves the wear resistance of the composites by about 60%. Ceramic is much harder material compared to the epoxy and the presence of the ceramic assist to protect the epoxy and reduce the material removal of from the epoxy surface. Ha and Rhee (2008) found similar findings when epoxy was reinforced with nano-clay. Kang, Chen, Song, Yu, and Zhang (2012) used epoxy composites based on Nano silica as coating layer on material and the wear resistance was dramatically increases.

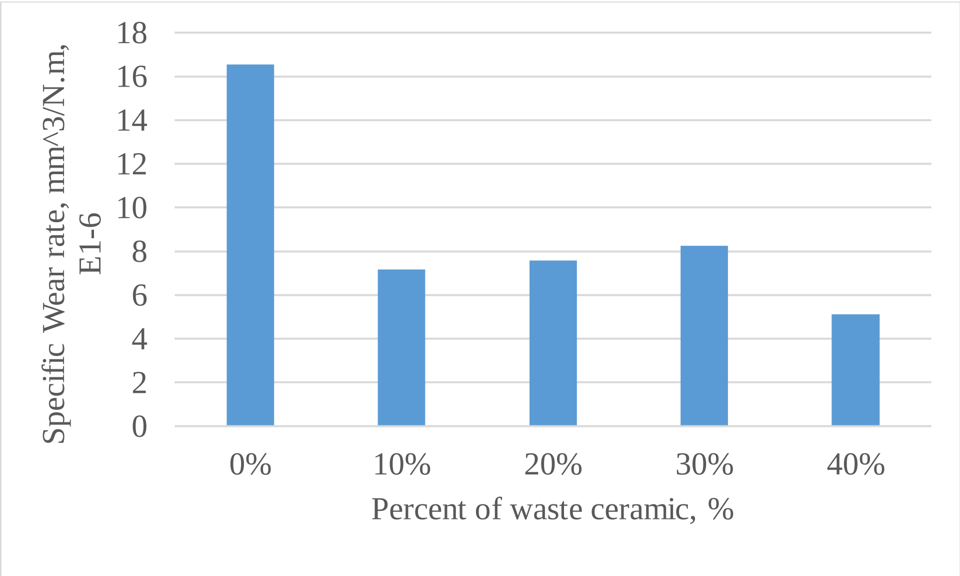


Figure 4. 8 Specific wear rate of epoxy composites with different ceramic contents the steady state

4.2.2 Friction coefficient

Friction coefficient of the epoxy composites vs. sliding distance is given in Figure 4.9 for all the epoxy composites. Trend of the friction coefficient is steady for all the composites. This shows the stability of the composites surface during the rubbing process. Low value of the friction coefficient can be seen when the composite contains 30% of the ceramics. In Figure 4.8, the 30% ceramic/epoxy composite has relatively high specific wear rate among other composites. This can explain the low friction coefficientsince it represents the low resistance in the interface and the high removal of materials from the composite surface. Pure epoxy exhibits high friction coefficient compared to its composites. The high friction of the pure epoxy has been reported by many works in the literature and the reason of it is due to the sticky behaviour of the epoxy when the temperature increase in the interface, (Pattanaik, Satpathy, & Mishra, 2016).

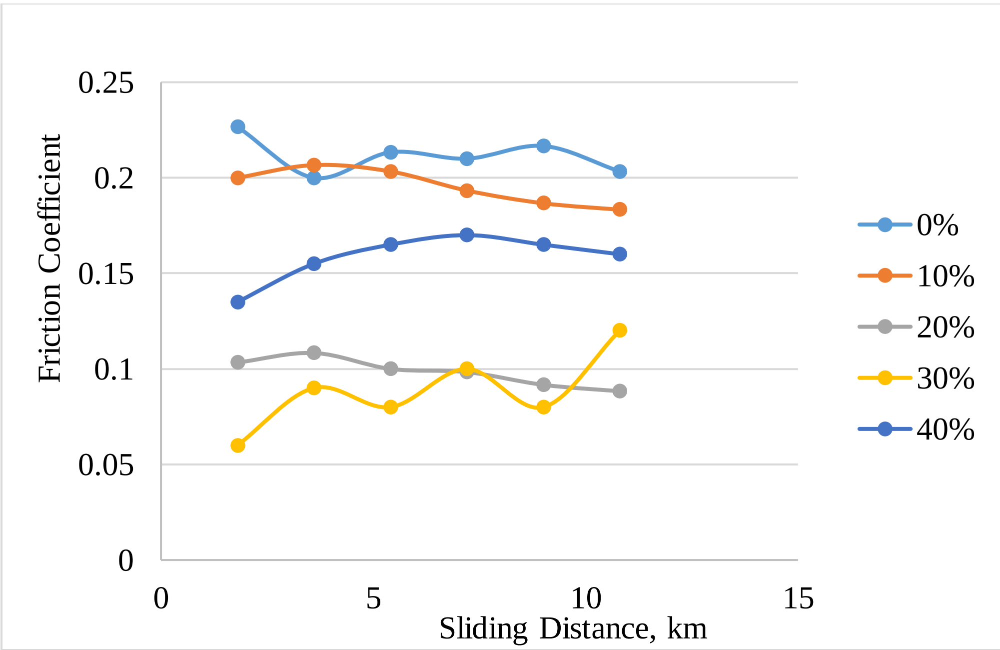


Figure 4. 9Friction coefficient of epoxy composites with different ceramic contents

4.2.3 SEM observation on the worn surfaces and counterface roughens

The roughness of the counterface is presented in Figure 4.10 after testing the epoxy composites with different content of ceramics. The figure shows that the presence of the ceramics increases the roughness of the counterface. This is expected since the ceramic has aggressive behaviour towards metals. The presence of the ceramic powder in the interface may acted as third body in the interface and attack the stainless steel which caused the increase in the roughness of the counterface. The pure epoxy has no much effect on the surface roughness since the roughness of the counterface did not change that much after testing.

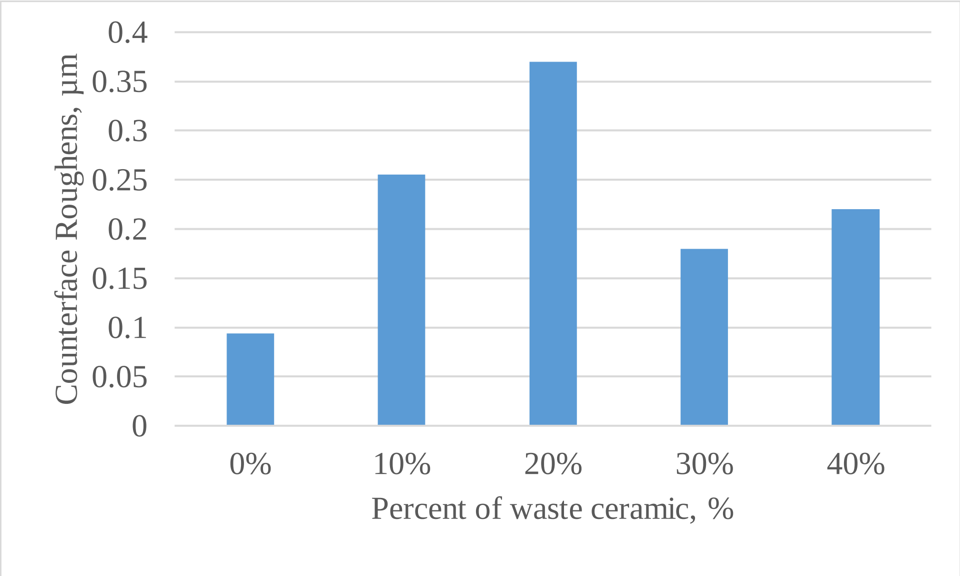


Figure 4. 10 Counterface roughness after testing epoxy composites with different ceramic contents

The worn surface of the pure epoxy is given in Figure 4.11 showing clear plastic deformation on the surface which may indicate the formation of the film on the surface. However, it seems the film is not stainless and can be removed easily. This can explain the high material removal of the pure epoxy when it was tested against stainless steel, Figure 4.8.

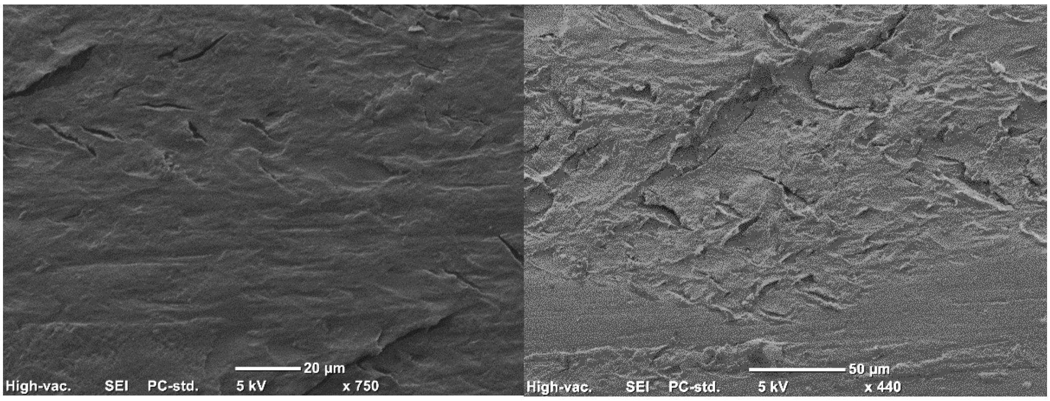


Figure 4. 11worn surface of pure epoxy

With the case of the composites, Figure 4.12 displays the worn surface of the composite contain 20% of the ceramic. Rough surface can be seen despite the film formation surface the same time. The film on the worn surface seems to be stable and well adhered on the composite surface. This can be the reason of the better wear resistance of the composite contain ceramic compared to the pure epoxy presented in figure 4.8. For the high percent of the epoxy composites with ceramics, Figure 4.13 shows similar surface to the one given in Figure 4.12. However, the film formation on the surface seems to be much larger than the ones given when the 20% ceramic composite worn surface observed. The stronger and larger film on the worn surface of the high percent ceramic content composites is the main reason of the high resistance of the composites at this condition.

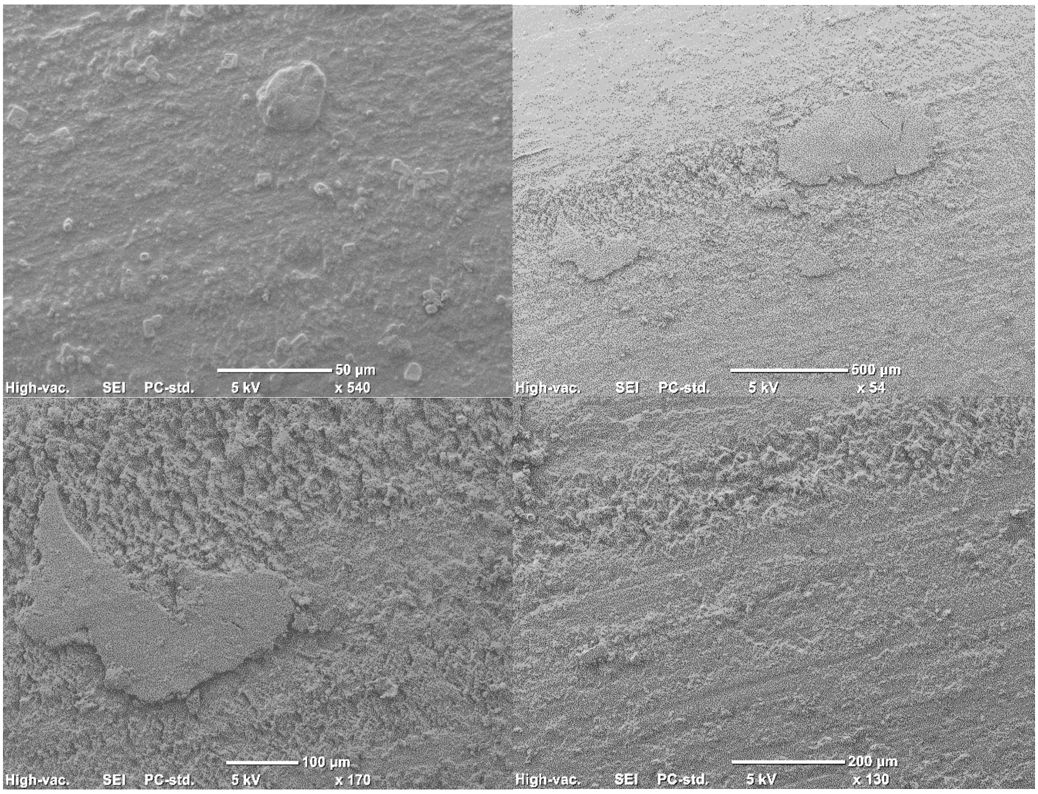


Figure 4. 12 worn surface of epoxy composites containing 20% ceramics

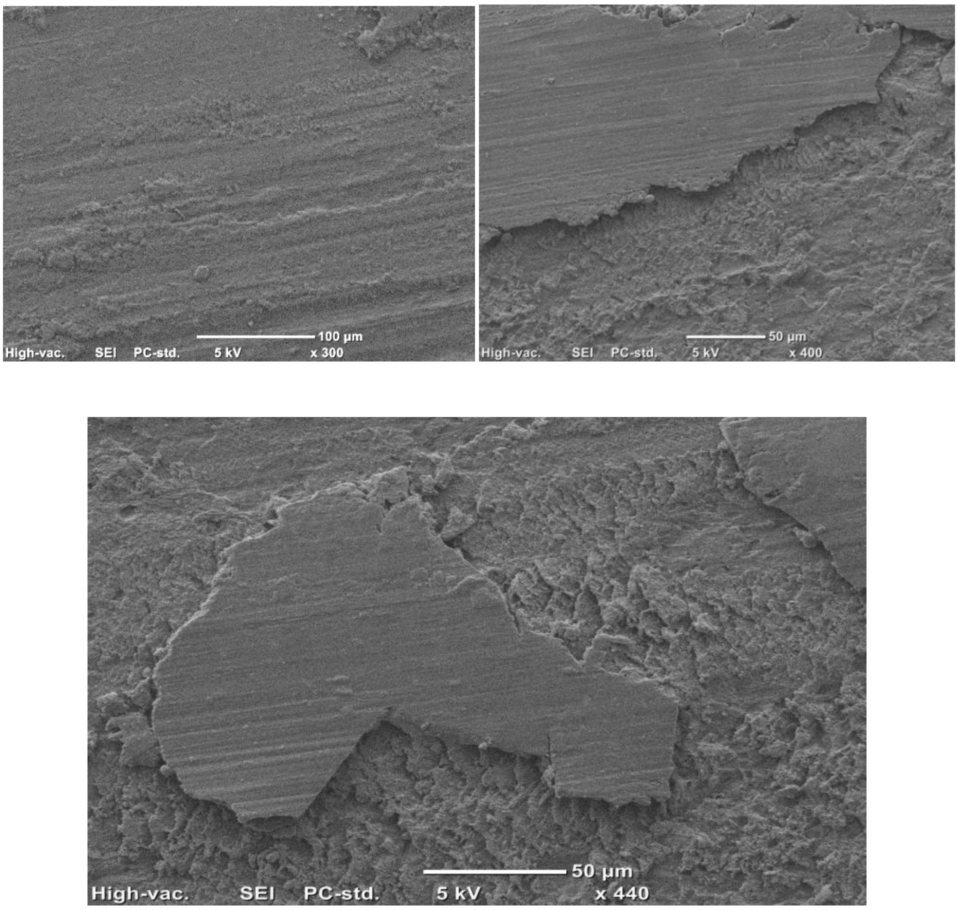


Figure 4. 13 worn surface of epoxy composites containing 40% ceramics

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

In this project, the main aim was to investigate the usage of waste ceramic in polymer composites from tribological and mechanical. The composites were fabricated locally at the University of Southern Queensland. After conducting the tensile and the tribological experiment on epoxy composite with different content of waste ceramic powder, the results indicate different findings which can be concluded as follows:

- Tensile strength of the composite reduced with the presence of the waste ceramic due the generation of voids in the composites. The presence of the void deteriorate the structure of the composites.
- The modules of the composite increases with the presence of the waste ceramics. This was very interesting findings which contribute to the possibility of using such materials in different designed components.
- The wear resistance of the composites dramatically increased with the presence of the waste ceramics. In other words, there is a great reduction in the specific wear rate of the composites with the increase of the sliding distance.
- The friction coefficient also improved with the presence of the ceramic since there is reduction in the friction coefficient. However, with the high percent of the waste ceramic the wear rate also increase. Therefore, it is recommended to not exceed the percent of the waste ceramic in the composites to more than 20 %.
- The wear mechanisms of the composites are controlled by film generated on the composites and its stability. In the case of the composite the film was

strong and not easy to get removed in oppose to the pure epoxy. The scanning electron microscopy showed that the film of the pure epoxy was very weak and there is clear plastic deformation and softening which was the reason of the high material removal from the surface of the epoxy compared to its composites.

RECOMMENDATIONS

In the current study, there was no time to focus on how the ceramic powder interact with the epoxy chemically and physically. Therefore, further study is required in the area of the interaction of the ceramic powder and the ceramic and how can be improved. Also, the void generation need an attention on how can be reduced since they are the main cause of the poor structure of the composites at high percent of the waste ceramics.

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Appendix A Project Specification

University Of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111 Research Project

PROJECT SPECIFICATION

FOR: Saad Alfadhly

TOPIC: Mechanical and tribological performance of epoxy composites based on waste ceramic powder.

SUPERVISOR: Dr B.F. Yousif

PROJECT AIM: The main aim of this work is investigate the influence of the waste ceramics powder on the tensile and adhesive wear behaviour of epoxy composites.

PROGRAMME:

1) Establish the literature review and writing chapter 2.
2) Purchase the raw materials for the preparation of the composites.
3) Build the composites.
4) Conduct the mechanical and adhesive wear testings.
5) Examine the worn surfaces of the samples after the test to identify the wear mechanism.

As time permits:

6) Develop empirical equation for the correlation between the mechanical and the tribological properties.

Appendix B Project Resources

1. Ceramic powder will be provided by the ceramic manufacturer.
2. Epoxy resin will be purchase through USQ.
3. Preparation of the composites will be conducted locally.
4. All the experimental equipment are provided by USQ.

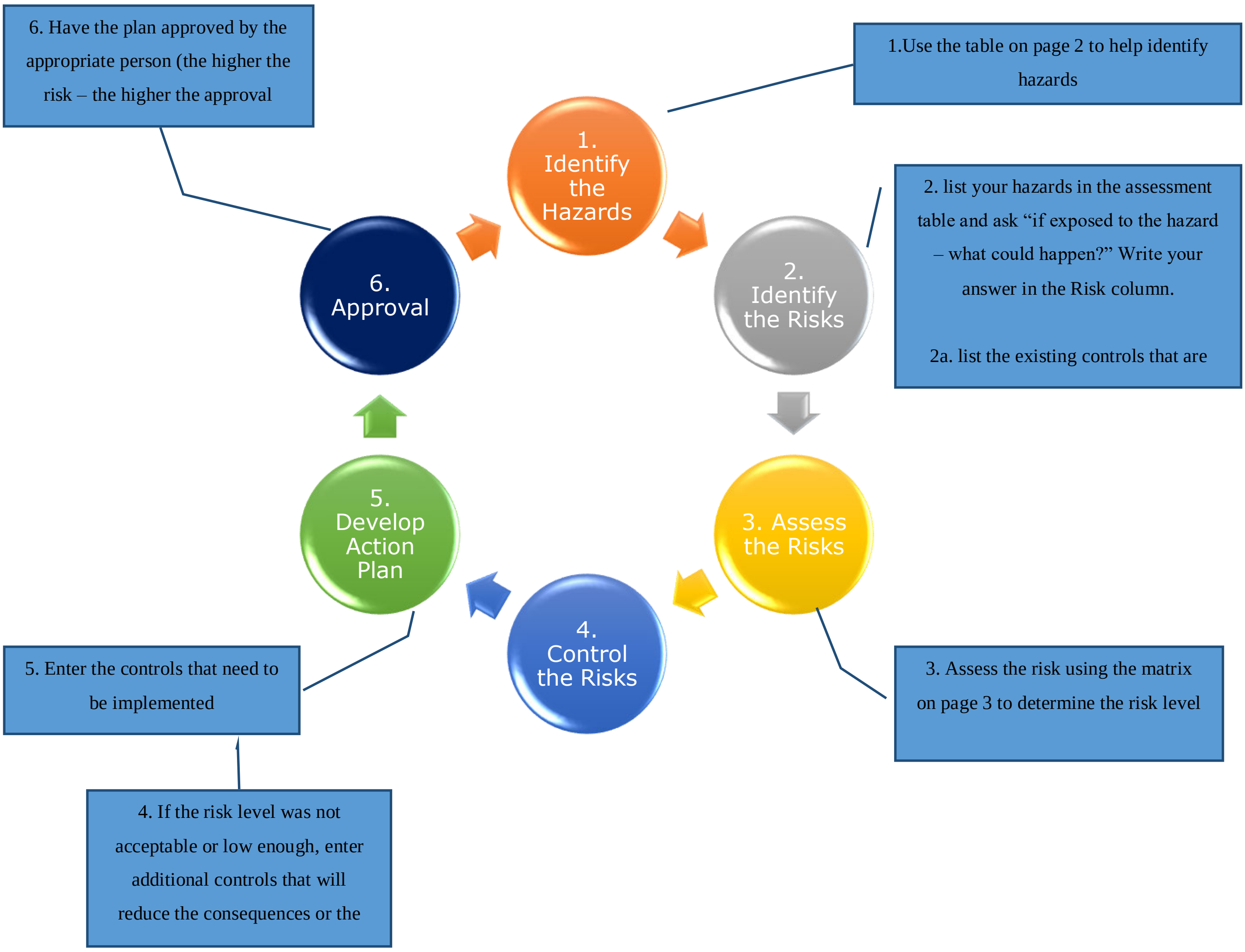
Appendix C Generic Risk Management Plan

University of Southern Queensland

Generic Risk Management Plan

Workplace (Division/Faculty/Section): Z block ground floor corrosion lab		
Assessment No (if applicable):	Assessment Date: 6/5/2017	Review Date: (5 years maximum) 6/5/2017
Context: What is being assessed? Describe the item, job, process, work arrangement, event etc: **MECHANICAL AND TRIBOLOGICAL PERFORMANCE OF EPOXY COMPOSITES BASED ON WASTE CERAMIC POWDER**		
Assessment Team – who is conducting the assessment?		
Assessor(s): Dr. Belal Yousif, Others consulted: (eg elected health and safety representative, other personnel exposed to risks) Mr. Mohan Trada		

The Risk Management Process



Step 1 - Identify the hazards (use this table to help identify hazards then list all hazards in the risk table)		
General Work Environment		
☐ Sun exposure	☐ Water (creek, river, beach, dam)	☐ Sound / Noise
☐ Animals / Insects	☐/Wind/Lightning/Wind/Lightning	☐ Temperature (heat, cold)
☐Air Quality	☐Lighting	☐Uneven Walking Surface
☐Trip Hazards	☐Confined Spaces	☐Restricted access/egress
☐Pressure (Diving/Altitude)	☐Smoke	☐
Other/Details:		
Machinery, Plant and Equipment		
☐ Machinery (fixed plant)	☐ Machinery (portable)	☐ Hand tools
☐ (Class 2 or above))	☐Elevated work platforms	☐Traffic Control
☐Non-powered equipment	☐Pressure Vessel	☐Electrical

☐Vibration	☐Moving Parts	☐Acoustic/Noise
☐Vehicles	☐Trailers	☐ Hand tools
Other/Details:		
Manual Tasks / Ergonomics		
☐ Manual tasks (repetitive, heavy)	☐ Working at heights	☐ Restricted space
☐Vibration	☐Lifting Carrying	☐Pushing/pulling
☐Reaching/Overstretching	☐Repetitive Movement	☐Bending
☐Eye strain	☐ Machinery (portable)	☒ Hand tools
Other/Details:		
Biological (e.g. hygiene, disease, infection)		
☐Human tissue/fluids	☐ Virus / Disease	☐ Food handling
☐Microbiological	☐Animal tissue/fluids	☐Allergenic
Other/Details:		
Chemicals Note: Refer to the label and Safety Data Sheet (SDS) for the classification and management of all chemicals.		
☐ Non-hazardous chemical(s)	☐' chemical (Refer to a completed hazardous chemical risk assessment))	
☐Engineered nanoparticles	☐Explosives	☐Gas Cylinders
Name of chemical(s) / Details:		
Critical Incident – resulting in:		
☐ Lockdown	☐ Evacuation	☐ Disruption
☐Public Image/Adverse Media Issue	☐Violence	☐Environmental Issue
Other/Details:		
Radiation		
☐Ionising radiation	☐Ultraviolet (UV) radiation	☐Radio frequency/microwave
☐infrared (IR) radiation	☐Laser (class 2 or above)	☐
Other/Details:		
Energy Systems – incident / issues involving:		
☐ Electricity (incl. Mains and Solar)	☐ LPG Gas	☐ Gas / Pressurised containers
Other/Details:		
Facilities / Built Environment		
☐ Buildings and fixtures	☐ Driveway / Paths	☐ Workshops / Work rooms
☐ Playground equipment	☐ Furniture	☐ Swimming pool
Other/Details:		
People issues		
☐ Students	☐ Staff	☐ / Others / Others
☐ Physical	☐ Psychological / Stress	☐Contractors
☐Fatigue	☐Workload	☐Organisational Change
☐Workplace Violence/Bullying	☐Inexperienced/new personnel	☐
Other/Details:		

Step 1 (cont) Other Hazards / Details (enter other hazards not identified on the table)

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide

- **E** =Extreme Risk – Task ***MUST NOT*** proceed
- **H**=High Risk – Special Procedures Required (See USQSafe)
- **M**=Moderate Risk – Risk Management Plan/Work Method Statement Required
- **L**=Low Risk – Use Routine Procedures

Risk Matrix

Risk register and Analysis

Step 1 (cont)	Step 2	Step 2a	Step 3			Step 4				
Hazards: From step 1 or more if identified	**The Risk:** What can happen if exposed to the hazard with existing controls in place?	**Existing Controls:** What are the existing controls that are already in place?	**Risk Assessment:** (use the Risk Matrix on p3) Consequence x Probability = Risk Level			Additional controls: Enter additional controls if required to reduce the risk level	**Risk assessment with additional controls:** (use the Risk Matrix on p3 – has the consequence or probability changed?)			**Controls Implemented?** Yes/No
			Consequence	**Probability**	**Risk Level**		**Consequence**	**Probability**	**Risk Level**	
Example										
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	Regular breaks, chilled water available, loose clothing, fatigue management policy.	catastrophic	possible	high	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
			Minor	Rare	Low	NA	Insignificant	Rare	Low	Yes
Debris during the tribological experiments	Fly to the eyes	eye protectors during the experiments.	Minor	Unlikely	Low	NA	Insignificant	Rare	Low	Yes
			Moderate	Rare	Low	NA	Insignificant	Rare	Low	Yes
Manual Placement of sample	Pinching	eye protectors during the experiments.	Insignificant	Unlikely	Low		Minor	Rare	Low	Yes

Step5 – Action Plan (for controls not already in place)			
Control Option	**Resources**	**Person(s) responsible**	**Proposed implementation date**

Step 6 – Approval

Drafter's Comments:

With the personal protective equipments and close supervision all the risk has come to low possibility of getting injured is rare.

Drafter Details:

Name: Signature: Date: / /

Assessment Approval:(Extreme or High = VC, Moderate = Cat 4 delegate or above, Low = Manager/Supervisor)

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Name: Belal yousif Signature: BFY Date:15 /5/2017

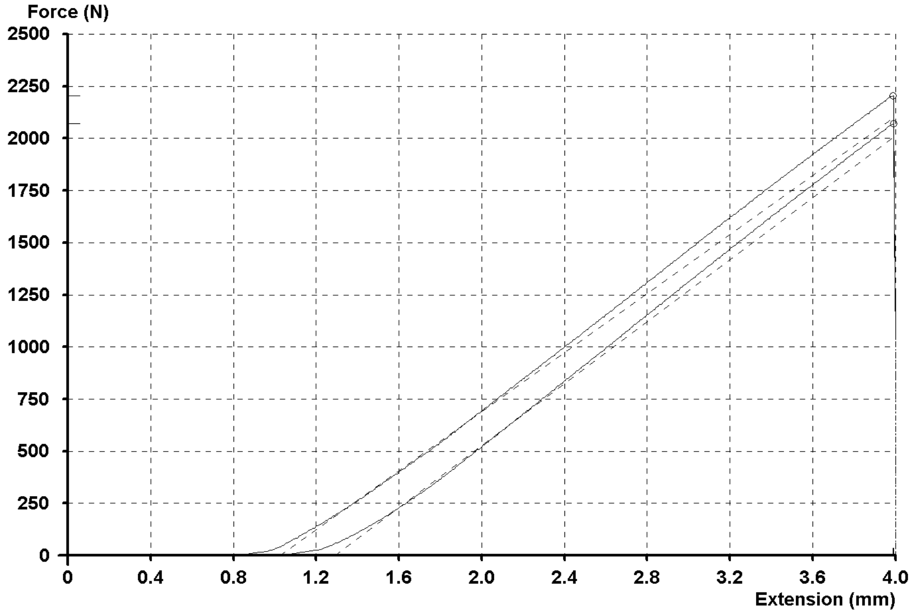
Position Title:

APPENDIX D RAW DATA OF TENSILE TESTING

Plastic Film Tensile with Energy [X-Head]

Product Code	: saad	**Load Range**	: 1000 N
Batch Reference	:	**Extension Range**	: 10 mm
Product Description	:	**Speed**	: 2.0 mm/min
Operator	:	**Gauge Length**	: 90 mm
Date	: 18/08/2017	**Preload**	: 0.0 N
Temperature [C]	:	**Auto Return**	: On
Relative Humidity	:		

Specimen	Thickness mm	Width mm	E.Mod MPa	Yield Str. MPa	Yield Ext. %	Strength MPa	Brk. Elong %	Max Load N	Energy J/M^2
sample 1	7.00	10.09	902	31.22	4.431	31.22	4.444	2205	46192
1.2	7.10	10.09	934	28.89	4.436	28.89	4.444	2070	39229
		Mean	918	30.06	4.433	30.06	4.444	2138	42711
		Median	918	30.06	4.433	30.06	4.444	2138	42711
		Std. Dev.	22.54	1.643	0.0031	1.643	0	95.5	4924
		Coe. Var.	2.455	5.47	0.0709	5.47	0	4.466	11.53
		Maximum	934	31.22	4.436	31.22	4.444	2205	46192
		Minimum	902	28.89	4.431	28.89	4.444	2070	39229



- Page 1 -

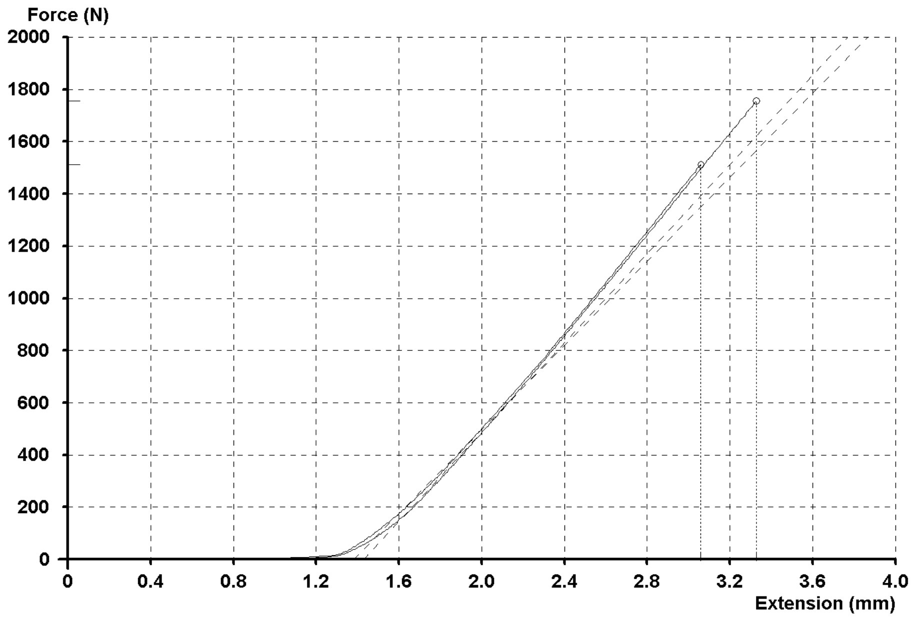
QMat 5.41a / Q4629 - University of Southern Queensland

H5KS/06 - 2500N / [PLAS-001.TSX - 1.0] - Plastic Film Tensile with Energy [X-Head]

Plastic Film Tensile with Energy [X-Head]

Product Code	: saad		**Load Range**	: 1000 N
Batch Reference	:		**Extension Range**	: 10 mm
Product Description	:		**Speed**	: 2.0 mm/min
Operator	:		**Gauge Length**	: 90 mm
Date	: 18/08/2017		**Preload**	: 0.0 N
Temperature [C]	:		**Auto Return**	: On
Relative Humidity	:			

Specimen	Thickness	Width	E.Mod	Yield Str.	Yield Ext.	Strength	Brk. Elong	Max Load	Energy
	mm	mm	MPa	MPa	%	MPa	%	N	J/M^2
epoxy+3.3 ceramic(sam2)	8.80	10.09	815	17.03	3.400	17.03	3.400	1512	13799
epoxy+3.3 ceramic (sam2.2)	8.75	10.06	873	19.95	3.698	19.95	3.698	1756	18606
		Mean	844	18.49	3.549	18.49	3.549	1634	16202
		Median	844	18.49	3.549	18.49	3.549	1634	16202
		Std. Dev.	40.84	2.065	0.2106	2.065	0.2106	172.5	3399
		Coe. Var.	4.838	11.17	5.93	11.17	5.93	10.56	20.98
		Maximum	873	19.95	3.698	19.95	3.698	1756	18606
		Minimum	815	17.03	3.400	17.03	3.400	1512	13799



- Page 1 -

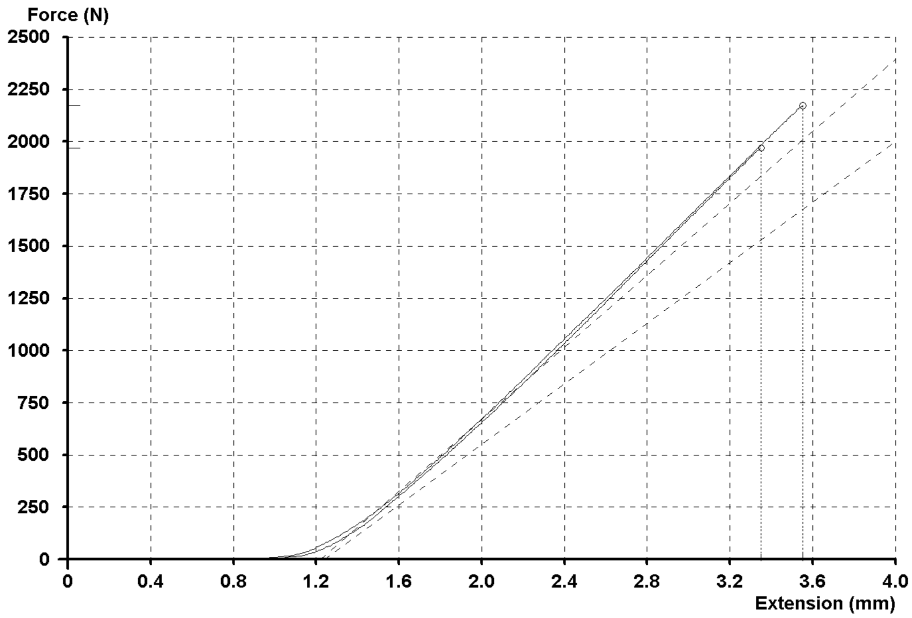
QMat 5.41a / Q4629 - University of Southern Queensland

H5KS/06 - 2500N / [PLAS-001.TSX - 1.0] - Plastic Film Tensile with Energy [X-Head]

Plastic Film Tensile with Energy [X-Head]

Product Code	: saad	**Load Range**	: 1000 N
Batch Reference	:	**Extension Range**	: 10 mm
Product Description	:	**Speed**	: 2.0 mm/min
Operator	:	**Gauge Length**	: 90 mm
Date	: 18/08/2017	**Preload**	: 0.0 N
Temperature [C]	:	**Auto Return**	: On
Relative Humidity	:		

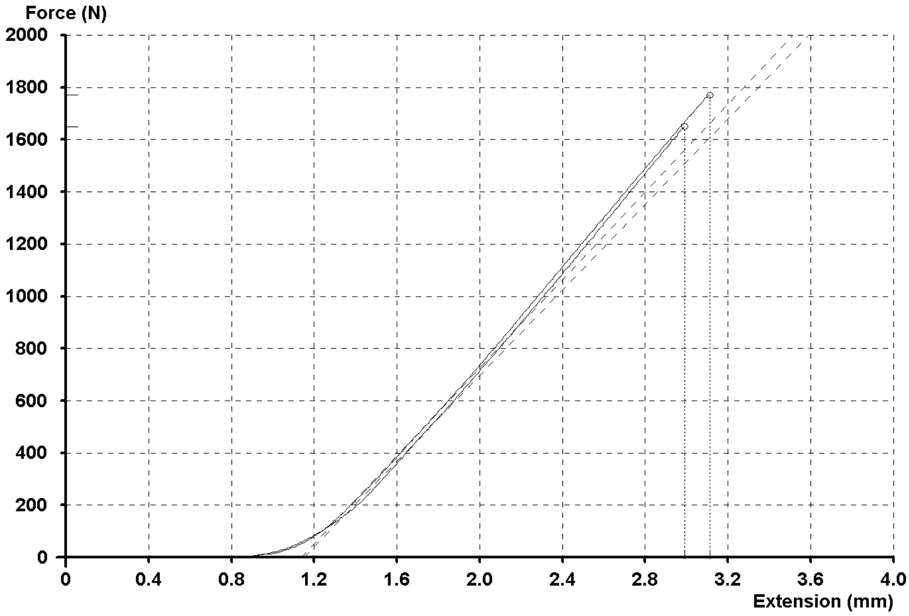
Specimen	Thickness	Width	E.Mod	Yield Str.	Yield Ext.	Strength	Brk. Elong	Max Load	Energy
	mm	mm	MPa	MPa	%	MPa	%	N	J/M^2
sample 3 (epx+6.6 ceramic)	9.00	10.13	847	21.61	3.724	21.61	3.724	1970	22300
sample3.2 (epox+6.6 ceramic)	8.80	10.13	870	24.37	3.947	24.37	3.947	2173	27887
		Mean	858	22.99	3.836	22.99	3.836	2071	25094
		Median	858	22.99	3.836	22.99	3.836	2071	25094
		Std. Dev.	16.59	1.953	0.1571	1.953	0.1571	143.2	3951
		Coe. Var.	1.933	8.50	4.097	8.50	4.097	6.91	15.74
		Maximum	870	24.37	3.947	24.37	3.947	2173	27887
		Minimum	847	21.61	3.724	21.61	3.724	1970	22300



Plastic Film Tensile with Energy [X-Head]

Product Code	: saad		**Load Range**	: 1000 N
Batch Reference	:		**Extension Range**	: 10 mm
Product Description	:		**Speed**	: 2.0 mm/min
Operator	:		**Gauge Length**	: 90 mm
Date	: 18/08/2017		**Preload**	: 0.0 N
Temperature [C]	:		**Auto Return**	: On
Relative Humidity	:			

Specimen	Thickness	Width	E.Mod	Yield Str.	Yield Ext.	Strength	Brk. Elong	Max Load	Energy
	mm	mm	MPa	MPa	%	MPa	%	N	J/M^2
sample4 (epox+ 10 ceramic)	9.20	10.16	789	17.65	3.324	17.65	3.324	1650	15854
sample4.2 (epox+10 ce..)	9.30	10.17	801	18.71	3.458	18.71	3.458	1770	18261
		Mean	795	18.18	3.391	18.18	3.391	1710	17057
		Median	795	18.18	3.391	18.18	3.391	1710	17057
		Std. Dev.	8.56	0.751	0.0943	0.751	0.0943	84.9	1702
		Coe. Var.	1.076	4.129	2.780	4.129	2.780	4.962	9.98
		Maximum	801	18.71	3.458	18.71	3.458	1770	18261
		Minimum	789	17.65	3.324	17.65	3.324	1650	15854



- Page 1 -

QMat 5.41a / Q4629 - University of Southern Queensland

H5KS/06 - 2500N / [PLAS-001.TSX - 1.0] - Plastic Film Tensile with Energy [X-Head]

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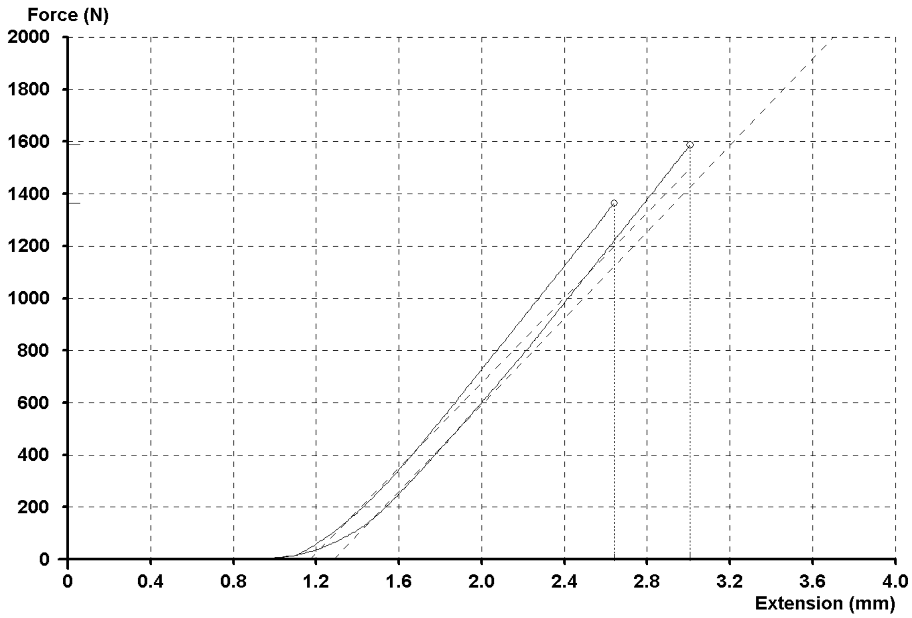
Product Code	: saad	**Load Range**	: 1000 N
Batch Reference	:	**Extension Range**	: 10 mm
Product Description	:	**Speed**	: 2.0 mm/min
Operator	:	**Gauge Length**	: 90 mm
Date	: 18/08/2017	**Preload**	: 0.0 N
Temperature [C]	:	**Auto Return**	: On
Relative Humidity	:		

Specimen	Thickness	Width	E.Mod	Yield Str.	Yield Ext.	Strength	Brk. Elong	Max Load	Energy
	mm	mm	MPa	MPa	%	MPa	%	N	J/M^2
1	9.00	10.20	811	17.30	3.342	17.30	3.342	1588	14432
sample 5.2 (epoxy+13.3 ceramic)	9.20	10.22	779	14.52	2.933	14.52	2.933	1365	10272
		Mean	795	15.91	3.138	15.91	3.138	1477	12352
		Median	795	15.91	3.138	15.91	3.138	1477	12352
		Std. Dev.	22.76	1.966	0.2891	1.966	0.2891	157.7	2941
		Coe. Var.	2.862	12.36	9.21	12.36	9.21	10.68	23.81
		Maximum	811	17.30	3.342	17.30	3.342	1588	14432
		Minimum	779	14.52	2.933	14.52	2.933	1365	10272



APPENDIX E RAW DATA OF WEAR TESTING

		Material Type		0%		
		Applied load	30	Speed, m/s	2	
sliding time	Sliding distance, km	weight before, g	Wa, g	DW, g\	DV, mm3	SWR, mm3/N.m
10	1.8	8.8147	8.8129	0.0018	1.634877384	30.27550711
20	3.6	8.8147	8.8123	0.0024	2.179836512	20.18367141
30	5.4	8.8147	8.8114	0.0033	2.997275204	18.50169879
40	7.2	8.8147	8.8105	0.0042	3.814713896	17.66071248
50	9	8.8147	8.8095	0.0052	4.72297911	17.49251522
60	10.8	8.8147	8.8088	0.0059	5.358764759	16.53939741

		Material Type		10%		
		Applied load	30	Speed, m/s	2	
sliding time	Sliding distance, km	weight before, g	Wa, g	DW, g\	DV, mm3	SWR, mm3/N.m
10	1.8	10.4529	10.453	0.0002	0.172265289	3.190097936
20	3.6	10.4529	10.452	0.0005	0.430663221	3.98762242
30	5.4	10.4529	10.452	0.001	0.861326443	5.316829893
40	7.2	10.4529	10.451	0.0018	1.550387597	7.177720356
50	9	10.4529	10.45	0.0025	2.153316107	7.97524484

60	10.8	10.4529	10.45	0.0027	2.325581395	7.177720356

		Material Type		20%		
		Applied load	30	Speed, m/s	2	
sliding time	Sliding distance, km	weight before, g	Wa, g	DW, g\	DV, mm3	SWR, mm3/N.m
10	1.8	9.9426	9.9416	0.001	0.847457627	15.69365976
20	3.6	9.9426	9.9409	0.0017	1.440677966	13.3396108
30	5.4	9.9426	9.9408	0.0018	1.525423729	9.416195857
40	7.2	9.9426	9.9402	0.0024	2.033898305	9.416195857
50	9	9.9426	9.94	0.0026	2.203389831	8.160703076
60	10.8	9.9426	9.9397	0.0029	2.457627119	7.585268885

		Material Type		30%		
		Applied load	30	Speed, m/s	2	
sliding time	Sliding distance, km	weight before, g	Wa, g	DW, g\	DV, mm3	SWR, mm3/N.m
10	1.8	10.7595	10.759	0.0009	0.753138075	13.94700139
20	3.6	10.7595	10.758	0.0012	1.0041841	9.29800093
30	5.4	10.7595	10.758	0.0019	1.589958159	9.814556537
40	7.2	10.7595	10.757	0.0023	1.924686192	8.910584224
50	9	10.7595	10.757	0.0028	2.343096234	8.678134201
60	10.8	10.7595	10.756	0.0032	2.677824268	8.264889715

		Material Type		40%		
		Applied load	30	Speed, m/s	2	
sliding time	Sliding distance, km	weight before, g	Wa, g	DW, g\	DV, mm3	SWR, mm3/N.m
10	1.8	12.1029	12.103	0.0003	0.247933884	4.591368228
20	3.6	12.1029	12.102	0.0005	0.41322314	3.82614019
30	5.4	12.1029	12.102	0.001	0.826446281	5.101520253
40	7.2	12.1029	12.102	0.0011	0.909090909	4.208754209
50	9	12.1029	12.101	0.0016	1.32231405	4.897459443
60	10.8	12.1029	12.101	0.002	1.652892562	5.101520253

APPENDIX F OTHER DOCUMENTS

SWP 001

FACULTY OF ENGINEERING & SURVEYING

WORK PERMIT

Permit No: 0384

This form is to be used where a Standard Work or Operating Procedure (SWP/SOP) indicates that a permit is required to use Engineering and Surveying facilities and equipment.

APPLICATION

Name of Applicant: Said Alfadhly

I wish to apply for approval to use the Faculty of Engineering and Surveying equipment and facilities:

Work Area / Location: Z106
(Work area staff must be consulted BEFORE using any facilities)

Equipment / Process: Resin sample preparation

Relevant SWPs: ____ For Unit / Project: ____

From (Start): ____ AM/PM Date: 15/5/2017

To (Permit Expires): ____ AM/PM Date: 20/12/2017

I certify that I have read and understand the requirements of the Standard Work Procedure applicable to this permit. I agree to comply with those requirements and any special precautions/instructions listed below.

Signature: [signature] **Date :** 15-5-2017

APPROVAL
(To be completed by Work Area Manager) - Training provided by Belal
- Induction provided by Marian

Special Precautions/Instructions: - USE PPE as apron, eye protection, enclose footwear, Respiratory, gloves etc

ALL WORK AREAS AND EQUIPMENT MUST BE CLEANED AFTER USE.

The above applicant has shown to me that he/she is competent to carry out the procedure and/or operate the equipment specified in this work permit. The Permit is granted for the period stated above.

Name: MARIAN TRADA **Date:** 15/5/2017

Position : Sr. coordinator **Signature:** [signature]

THIS PERMIT MAY BE REVOKED AT ANY TIME.

SWP 001

FACULTY OF ENGINEERING & SURVEYING

WORK PERMIT

Permit No: 0386

This form is to be used where a Standard Work or Operating Procedure (SWP/SOP) indicates that a permit is required to use Engineering and Surveying facilities and equipment.

APPLICATION

Name of Applicant: Saad Alfadhly

I wish to apply for approval to use the Faculty of Engineering and Surveying equipment and facilities:

Work Area / Location: Z106, Z107
(Work area staff must be consulted BEFORE using any facilities)

Equipment / Process: Tribology & Polishing of Samples

Relevant SWPs: ____ For Unit / Project: ____

From (Start): ____ AM/PM Date: 9/8/2017

To (Permit Expires): ____ AM/PM Date: 20/8/2018

I certify that I have read and understand the requirements of the Standard Work Procedure applicable to this permit. I agree to comply with those requirements and any special precautions/instructions listed below.

Signature: [signature] **Date:** 9/8/2017

APPROVAL
(To be completed by Work Area Manager) - Training provided by Belal
- Induction provided by MOHAN

Special Precautions/Instructions: - Use PPE as per RMP

ALL WORK AREAS AND EQUIPMENT MUST BE CLEANED AFTER USE.

The above applicant has shown to me that he/she is competent to carry out the procedure and/or operate the equipment specified in this work permit. The Permit is granted for the period stated above.

Name: MOHAN TRADA **Date:** 9/8/2017

Position: Sr. coordinating M **Signature:** [signature]

THIS PERMIT MAY BE REVOKED AT ANY TIME.