University of Southern Queensland

Faculty of Engineering and Surveying

AN INVESTIGATION OF ALUMINIUM/EPOXY PARTICULATE COMPOSITE SYSTEM – IMPACT/LONG-TERM BEHAVIOR.

A dissertation submitted by

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Courses ENG4111 and ENG 4112 Research Project

Towards the degree of

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Abstract

This research project aims to examine the manner in which aluminium particles, reinforce a polymer matrix in respect to impact energy absorption and long term static loaded specimen. In order to observe the behaviour of aluminium particulate two tests were conducted, impact tests and creep tests. The results obtained from these tests were compared with neat resin specimens to evaluate the degree to which the aluminium particles affect the polymer matrix. Vinyl ester serve as the polymer matrix to which aluminium particle were added in different percentage amounts in accordance to the overall mass of resin used. Methyl ethyl ketone peroxide was the catalyst chosen to assist in the curing process. These two chemical agents were chosen due to their low cost and its mechanical properties. Extensive testing conducted in previous studies has shown that these two chemicals allow for the best composite structure. Two separate standards were used for the two tests, each standard referred were used for the preparation of the samples and the testing procedures that were followed. For impact tests ISO 179-2 was used and for creep tests ASTM 1337-96. The impact test proved that the addition of aluminium particle allowed for the absorption of a larger amount of impact energy in comparison to the neat resin specimen. To analyse the impact test results further, Charpy impact strength was calculated, which demonstrated the ability of the aluminium modified polymer matrix to absorb more energy per square metre than neat resin. A creep testing device was designed and made to carry out the tests. However, creep tests proved to be less successful as tests did not provided suitable creep results. Only two specimens were tested for the creep tests as time constraints did not allow for long term tests to be conducted. Finally, future work main will consist of modification to the design creep testing device to obtain results which would represent the creep stages better.

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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Chapter 1 INTRODUCTION

1.0 Introduction

Throughout history, newer and better materials have been discovered and used in order to keep up with the changes in technology. Currently materials are being designed to have a high strength whilst being light weight. Composite materials have shown the most promise to have the most strength while being light weight as well. These materials such as carbon fibre and glass fibre are used in automotive and infrastructure; however the cost of producing these materials still remains one of the major draw backs which have stopped large scale use. For this reason, research is being conducted to find alternative composites which are cheap to manufacture while still retaining the strength and weight attribute of the more costly composite materials. At the University of Southern Queensland research has been conducted into glass powder based composites which have shown great promise.

1.1 Project Objective

As it was mentioned above, research is being conducted to find a cheaper alternative to the more expensive composite materials that are currently available on the market. This research project is a continuation of research conducted on particulate aluminium composites. Tests will be conducted into the impact strength and the creep. The findings aim to pin point the best proportion of aluminium powder to vinyl ester which would yield the best impact strength and creep values. On a broader aim, it is hoped to find the field in which this type of composite may be used.

1.2 Dissertation

Chapter 2 – Research areas

In this chapter the previous years research findings will be presented so that it is possible to see where this research started and the direction that it is heading in.

Chapter 3 – Literacy Review.

This chapter will discuss the research conducted into the project before any samples were produced or tested. An overview of the different chemicals and equipment used in order for this project to be conducted. Also brief safety aspects will be discussed.

Chapter 4 – Safety Review

Safety is a major concern in this project and multiple safety assessments have been conducted before the project commenced.

Chapter 5 - Methodology

This chapter will look at the manner that the aluminium powder composites are made and the manner in which it will be tested.

Chapter 6 – Results

The results that were obtained for the different tests will be shown and discussed on any short comings.

Chapter 7 – Analysis

This chapter will discuss the results and discuss any calculations required. The different meanings of the results in comparison to other composite materials will be further analysed.

Chapter 8 – Conclusion

The final chapter of this dissertation will look at the short comings of the research. It will also present any future work that may be conducted to fully understand the uses of aluminium particulate composites.

1.3 Conclusion

The project was carried out with International Standards Organization (ISO) and American Society for Testing and Materials (ASTM) standards which will be discussed further in the following chapters. The research and testing was carried out in the Centre of Excellence in Engineered Fibre Composites (CEEFC) and University of southern Queensland's (USQ) laboratories (Materials and non-destructive testing labs).

The following chapters will detail the process that was taken to conduct the project and discuss the findings. All experimentation and testing was done under the supervision and guidance of the laboratory staff members.

Chapter 2 OBJECTIVES

2.0 Introduction

In order for this research project to be carried out, an understanding of what the previous year's research findings concluded on is important. The aims, procedures, and final result must all be analysed to form a firm foundation for the current project. By doing this, a solid direction in which the research is to be conducted in can be devised. Also to ensure that any errors will not be repeated while any positive research points can be exploited and used. This chapter will give a quick overview of what research was conducted in previous years and what areas will be used again for the current research project. In addition, a detailed plan of the objectives will be given and any time constraints that may have inhibited the progress of the research will be stated.

2.1 Past Project

Last year the project that was carried out was to find the mechanical properties of aluminium particulate composite materials; in doing so, to find out whether the addition of aluminium particulars to the vinyl ester resin would help in reinforcing the composite matrix in comparison to the neat resin composite sample. The mechanical properties consisted of tensile strength, young's modulus, and shear strength of the composite samples.

The making of the samples was done to ISO standards for tensile and shear testing, which was well maintain throughout the process. The percentage addition of aluminium particulate done in accordance to the mass of vinyl ester and MEKP (these chemicals will be discussed further in chapter 3). The percentages that were used were 5%, 10%, 15%, 20%, and 25%, also a neat resin sample for comparison (0%).

It was found that in these tests, the addition of aluminium particulate to the resin only showed significance in the results of young's modulus. While in the tensile strength, the addition of the particulate actually decreased the strength in comparison to the neat resin sample that was tested (Reushle, 2009).

2.2 Project Objective

In chapter 1, the main objectives were outlined; these stem from the previous years project objectives. The tests that are carried out are not the same, however the primary objective of the current project is to pin point the application in which particulate aluminium composite may be used.

The secondary objectives of this project is where the past and present differ, as in this research an attempt to pin point the best ratio of vinyl ester resin and aluminium particulate, which would yield the best impact and creep result, is being found. Through the use of similar sample preparation and comparison method which will be discussed further in chapter 5.

Overall the objectives are as follows:-

1. Find the best proportions of resin to particulate in comparison to a neat resin sample which yields the highest impact and creep value.

2. Discuss any possible uses for the particulate composite taking into consideration current and previous testing results.

3. Outline future testing that would assist further in the narrowing down or broadening the uses of this type of composite material.

2.3 Time Constraints

One of the most pressing issues that causes the most research issues is the time constraint that are placed on this project. The development of the samples take a few hour however for the sample to full cure it may take up to four days. Impact tests will take less than an hour to complete. As after the specimens are cut to the correct dimensions, the simple process of placing the specimens in the testing device and running the test. However, the creep was the most time consuming of the two tests that were conducted, as such tests can require days to months for desired results to be obtained.

2.4 Conclusion

This chapter only outlines the objectives that are hoped to be achieved at the end of the research project. However due to the time constraints it may be difficult to obtain all the results necessary to obtain the objectives that are desired. However, the basic results will be taken and analysed, and the equipment that could be used to perform future testing and data collection will be modified in detailed steps given in order for future project work to run more smoothly.

Chapter 3 LITERATURE REVIEW

3.0 Introduction

Composite materials are engineered by a chemical reaction between two or more materials or phases. The materials used usually have different physical or chemical properties so that the composite could attain the different properties (Martin, Hanagud & Thadhani, 2007). These materials can be used in many different applications, from automotive to aerospace. The main drawback of composites is their strength to mass ratio, and the fact that composites can be tailor made to suit a specific application thus making these types of materials popular to many fields of study.

The two major composites are, particulate and fibre, the basic method of developing these composites are similar, however the material used as a reinforcing agent differs. Fibre composites or fibre reinforced polymers (FPR) is made of a matrix material (resin) and a reinforcing material in fibre form which increases the stiffness and the strength of the matrix (Martin, Hanagud & Thadhani, 2007). On the other hand, a particulate composite consists of particles being added to a polymer matrix which would result in high tensile strength and ductility. Most of these types of composites are made for a specific job. Particulate composites are commonly used to conduct electricity and also thermal energy (Askeland & Phule, 2006).

In the past few years more and more research has been conducted in the field of composites in order to find new composites with higher strength and stiffness. The University of Southern Queensland has conducted studies into particulate composite, using saw dust and glass powder which has yielded promising results. However, not much research has been conducted into the properties of aluminium particulate reinforced composite. Thus with projects such as this one, more can be found about what applications would benefit the use of this type of material.

The main purpose of this study is to use aluminium powder to develop a particulate composite and test the impact strength. Research will also be conducted into the affects of creep. Another research goal is to use aluminium particles on a nano-scale to find the manner in which it would affect the matrix of the composite. The method in which the composite is fabricated and tested will be discussed further in the following sections.

3.1 Aluminium Particulate Reinforced Composite

Through research conducted in previous years, the matrix material was found to have significant results when mixed with atomized aluminium with vinyl ester. (Reushle, 2009) Vinyl ester or Hetron 992 PAS is a resin made by the esterification of epoxy resin (e.g., bishphenol A) with monocarboxilic acid dissolved in styrene. This resin is the matrix material which forms the base of this study.

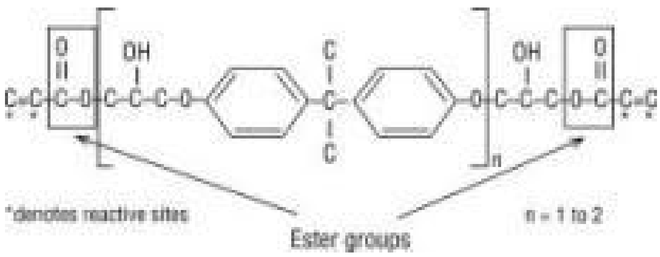

Figure 3.1. Vinyl Ester Chemical Structure (Reushle 2009)

As it can be seen in figure 1 the end of the chains where the carbon double bond exist, is the reaction site. As vinyl ester has less ester groups than other resin such as polyester, and is less likely to hydrolysis. This allows vinyl ester to be used in a wide range of applications, such as chemical storage. The reaction site of the resin is at the ends of the chain which means that the length of the chain is used when absorbing impact and thermal energy. Fifty percent of the composition of vinyl ester in liquid form is styrene, which decreases the viscosity of the resin, making it easier to pour and stir. An additional reason why resin with a high styrene percentage is used is because it allows for a chemical reaction called polymerisation. This is the process in which a monomer (a small atom of molecule) to bind chemically with another monomer to form a polymer which occur to the molecular chains during the curing process without a by-product being produced.

Vinyl ester requires an initiator or a catalyst to start the curing process. For this Nobel butanox la or Methyl ethyl ketone peroxide (MEKP) is used as it allows for faster curing time and also curing occurs at room temperature.

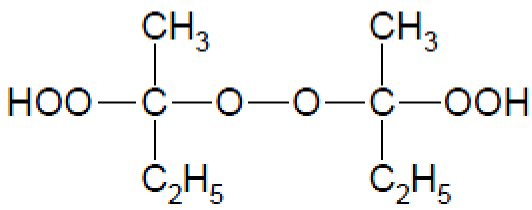

Figure 3.2. MEKP Chemical structure (Wikipedia 2009)

The atomize aluminium is used as a filler; this is done to reduce costs of producing the composite. Not only does the cost of production decrease, in actual fact the composite would in theory attain some of the properties of the filler material, in this case the aluminium. Aluminium was chosen as the filler due to its properties; aluminium is a third as dense as steel which makes it one of the lightest metals that are commercially available today. In the strength category; pure aluminium does not have a high tensile strength however when alloying elements are added the strength can be increased. Aluminium also is a metal that is suited for cold weather as its tensile strength increases as the temperature decreases. An oxide layer forms as soon as aluminium is exposed to the atmosphere which has a great resistance to corrosion. The metal is also fairly resistant to acids but less resistant to alkalis.

Property	Value
Atomic Number	13
Atomic Weight (g/mol)	26.98
Valency	3
Crystal Structure	FCC
Melting Point (°C)	660.2
Boiling Point (°C)	2480
Mean Specific Heat (0-100°C) (cal/g.°C)	0.219
Thermal Conductivity (0-100°C) (cal/cms. °C)	0.57
Co-Efficient of Linear Expansion (0-100°C) ($x10^{-6}$/°C)	23.5
Electrical Resistivity at 20°C (µΩ.cm)	2.69
Density (g/cm^3)	2.6898
Modulus of Elasticity (GPa)	68.3
Poissons Ratio	0.34

Table 3.1. Aluminium Properties (Azom 2005)

Some of the mechanical properties of aluminium are that it can be formed using many mechanical processes such as rolling, and drawing. This is because aluminium can be severely deformed without failure. Pure aluminium has a tensile strength of 90MPa however this can be increased by heat-treating, cold working, and alloying.

Thus the vinyl ester is the starting point with aluminium added to the matrix and finally the MEKP is added to start the curing process.

3.2 Testing

As mentioned, two tests, impact and creeping testing were conducted in order to evaluate the properties of the aluminium particulate reinforced composite. A tensile test will also be carried out to collect the general mechanical properties. In the next chapter the testing equipment and modifications used will be discussed further and the standards that were used will be presented.

3.2.2 Impact Testing

Impact testing involves a 'v' shaped hammer hitting a test specimen at high force; the device will measure the amount of force absorbed by the specimen during fracture. For this test the samples were made to ISO standards with measurements of 25mm by 130mm by 6mm.

3.2.3 Creep Testing

Creep is when a material deforms under high stresses; to measure the creep a strain gauge and a Data Acquisition System (DAS) will be used. A strain gauge changes resistance as the specimen deforms. The strain gauges resistance will change and be logged by the data acquisition system.

3.3 Standard of Testing

Before any test can be completed, standards for testing must be implemented so that the testing is carried out in a safe, effective manner, and disseminate innovation. The testing is then comparable with other research in a similar area, this allows for further project to be done with a far more professional standard. (ISO, 2010)

For this research project two different standards were used in the major testing areas (impact and creep testing). For impact testing the International Standards Organization (ISO) standards were using, standard number ISO 179-2 (1997) and creep testing was conducted according to American Society of Testing and Materials standard, (ASTM) C1337-96 (2005).

3.4 Theoretical Result

The predicted results for each of the following selections will be provided in this section. These predictions on the results will be mostly based on studies conducted on material composites. It must be understood that theoretical result only provide a basic outline of predicted outcomes of the tests conducted.

3.4.1 Impact testing

By evaluating past project research it was seen that specimens demonstrated high young's modulus results in the aluminium percentages of 10% and 15%. This allows for the assumption that the polymer matrix is reinforced, best at the aluminium compositions. Therefore it is theorised that the specimen consisting to 10% and 15% will show the highest energy absorption during impact testing.

3.4.2 Creep Testing

Since temperature control is not present in the testing equipment the result of this test are harder to predict. Most experimental resources, use heat the provide energy to the creep process. Thus in this test the most predictable outcome is that it may only go to the second stage of creep.

Chapter 4 RISK ASSESSMENT

4.0 Introduction

In the process of making and testing the composite, many risk factors must be addressed, from the chemicals that are used to the equipment that is used to test the material. There are three steps in a risk assessment; the steps are identification, evaluation, and control.

4.1 Identification

The first part of risk assessment is identification, this is where one would take a step back and see what would or could cause harm to oneself and others. In this research project there were many risks that would and could cause harm. Firstly, the chemical that are to be used pose a great risk if not handled properly. The machining and testing equipment all pose great risk to the user if not used in the proper manner.

4. 2 Evaluation

Chemicals:-

- Vinyl Ester
  - Toxic substance if ingested or contacts with skin.
  - Inhaling vapours is very harmful
- MEKP
  - Highly corrosive
  - Harmful if ingested or inhaled
  - Harmful if substance comes into contact with eyes
- Atomised Aluminium
  - May cause irritation if inhaled or if substance comes into contact with eyes
  - May cause harm if ingested

Testing and machining:-

- MTS
    - If proper safety precautions are not taken may cause bodily harm
    - When machine operational safety must be lowered fragments of the samples may cause bodily harm.

- Impact testing
    - If proper safety precautions are not taken this may cause bodily harm
    - When machine operational safety must be lowered fragments of the samples may cause bodily harm.
    - Safe distance while machine is in operation

- Creep
    - If proper safety precautions are not taken, this may cause bodily harm
    - When machine operational safety must be lowered or fragments of the samples may cause bodily harm.
    - Keep a safe distance while machine is in operation

4.3 Control

To control all of the risk factors; proper clothing such as, Personal Protective Equipment (PPE) must beworn as directed. Before handling any chemicals, the material safety datasheet is to be read as directed and the user to be familiarised with the risks involved. The appropriate apparel to be worn and finally to follow the instructions given by lecturers and technicians during induction before equipment was used. This applies to the testing and machining equipment as well.

Chapter 5 Methodology

5.1 Introduction

The method that is used to prepare the sample is extremely important, as this would provide results that are consistent and allow for better analysis of data obtained through testing. Therefore samples were made using the same process and testing was carried out according to a set standard. Many different elements of the project had to be designed in order for this project to be carried out, each of these elements will be described and the process of making the samples and testing will be detailed. This chapter consists of the sample preparation methods, testing of these samples and finally any issues that were faced and how these issues were overcome in order for the project to be completed.

5.2 Mould

When the research began there was no mould which could be used in accordance with ISO standard for impact testing, which would give the correct thickness, length, or width. Thus a mould would first have to be designed and made to specification by the USQ Workshop, using form ply for the base, as the surface of the this material does not allow the hardening composite to adhere to it. The sides of the mould were made of plastic strips of 6mm thickness.

The reasons for the use of these two materials for the mould are quite simple. Form ply is a wood base material with the surfaces overlaid with a phenolic paper; this acts as a barrier not allowing the substances to adhere onto the surface. This material is widely used to form concrete into pillar and beam structures (Australian Wood Panels, 2010).

The plastic stripes were used as borders which the specific thickness of 6mm. These plastic stripes were used; as they have been used it past studies for vinyl ester sample preparation and had no bondage issues occurred once a thin lay of wax was added to them.

The final mould measurements were 200mm length, 130mm width, and a 6mm depth.

Figure 5.1. The Mould Used for Sample Preparation

5.3 Sample Preparation Method

Research was conducted into the different chemicals that were to be used and inductions were organized so that the risks and safety was understood.

Once the research into the chemicals was completed the amounts of vinyl ester, MEKP, and aluminium were calculated. Specimens with 0%, 5%, 10%, 15%, 20%, and 25% aluminium were prepared.

%	Aluminium(g)	Vinyl ester(g)	MEKP(ml)
5	9.1	172.6	3.2
10	18.2	163.5	3.1
15	27.3	154.4	2.9
20	36.3	145.4	2.7
25	45.4	136.3	2.5

Table 5.1. Amount of each Chemical that would be added

First the 0% aluminium powder specimen was prepared, creating six samples, each with different mould conditions in order to develop new methods of sample preparation that would yield the best samples.

Sample number	Conditions applied	Observations
1	Baking paper laid of mould base, spray oil on mould surface. Sample mixed for 5 minutes in round container with spoon. Sample poured into the mould within 1 minute. Then with heat gun went over mould surface (highest heat setting) to eliminate of any bubbles	The sample was warped and colour differences. No bubble could be observed. Bubbles on bottom side of sample. Wave like pattern on bottom of sample caused by the baking paper
2	Baking paper laid of mould base, spray oil on mould surface. Sample mixed for 5 minutes in round container with spoon. Hit the mould on work bench 20 times to eliminate air bubbles.	Large amount of bubble present. Bubbles on bottom side of sample. Wave like pattern on bottom of sample caused by the baking paper
3	Baking paper laid of mould base, spray oil on mould surface. Sample mixed for 5 minutes in round container with spoon. Hit the mould on work bench 20 times to eradicate of air bubbles. Sample poured into mould. Used heat gun a lowest setting for 1 minute.	Large amount of bubbles, less than sample 2. Slightly warped. Bubbles on bottom side of sample. Wave like pattern on bottom of sample caused by the baking paper. Bubbles on bottom side of sample.
4	Baking paper pasted onto the mould base, spray oil on mould surface. Sample mixed for 5 minutes in round container with spoon. Placed mould on a vibration table for 15 minutes on highest vibration setting.	Sample had wrinkle marks due to the baking paper. Bubbles on bottom side of sample. More bubbles than all the samples.
5	Baking paper pasted onto the mould base, wax on mould surface. Sample mixed for 5minutes in round container with spoon. Hit the mould of the work bench 20 times to eliminate of air bubbles.	Sample had wrinkle marks due to the baking paper. Bubbles on bottom side of sample. Less bubbles than all the samples.
6	The sample was mixed and left for 12 minutes, and then while in mixing container use the heat gun at low temperature to get rid of any air bubbles. Then sprayed oil into the mould and sample poured.	Sample had wrinkle marks due to the baking paper. Bubbles on bottom side of sample. Few small bubbles.

Table 5.2. Observations of neat samples trial and error stage

After those six samples were produced, they were cut using a wet diamond edge saw to the required measurements. Impact testing would have been preferred before the aluminium samples were made so that it could be established which method of sample preparation was the best method. However there were issues with the testing device as it was not in working order. The aluminium samples were made in a similar method to sample 6. The only difference being that the baking paper will be removed and wax will be used instead of the oil, as the bubble on the underside of the sample was caused by the heating of the oil.

The aluminium particulate composite sample only differ in one account; the adding of the aluminium 75µm particles. It was found through a process of trial and error that when the whole mass of aluminium powder was added in a single dose then the mixing process was much more time consuming. The probability of a small portion of powder would collect on the bottom and not be mixed was higher as well.

There was also the question of if the catalyst should be added before or after the aluminium particles. In this case, it was observed in the process of making the neat samples that once the catalyst was added to the resin, the product of the two was a less viscose liquid. Thus this assisted in dispersing the aluminium particles.

It was found that after the matrix material, catalyst and reinforcing materials were added and mixed, the resulting chemical reaction cause gas bubbles to form in the solution. Initially to eliminate these bubbles the solution was poured into the mould and shaken and then finally a heat gun was used to blow hot air over the surface of the sample. However, this caused the final cured sample to become warped and the sample became concave in appearance. This was due to the top surface of the solution heating and curing faster than the bottom surface. Therefore to stop this defect from occurring to the samples, the heat was applied when the solution was mixed in the initial process of mixing so that the samples would not warp or bend.

Samples only take 45-60 minutes to harden, however even if the sample hardens it does not mean that the sample is fully cured. For the sample to fully cure it takes up to four days, or the composite is too soft and elastic in nature; which causes difficulties in the cutting process. The cutting process is required as the mould casts one large rectangular slab which has to be cut according to testing needs.

The cutting of the samples was completed using a wet diamond edged saw, this allowed for a clean cut sample with minimum particles entering the atmosphere (which is a major health and safety risk) during the cutting process (Australian Composites, 2010). The saw has three adjustment wheels, for the x, y, and z directions that were used to adjust the cutting table. In order for correct measurements to be obtained a table consisting of different measurements and the number of turns required by each wheels was provided. The following is the process used in cutting the samples to the required size: -

1. Level the saw blade using the three directional adjustment wheels.
2. Lock the sample in the device as straight as possible.
3. Perform a thin cut through the edge of the sample to allow for a precise cut.
4. Move the tray in an x-direction according to the table until the desired measurement is obtained and cut the sample using the y directional wheel to cut through the specimen.
5. Repeat step 4 until the required number of samples are obtained.
6. Each of the top edges of the cut samples were sanded down in order to ensures the best gripping surface.

An initial induction had to be undertaken at the CEEFC in order for the proper use and safety measures needed to operate the diamond edge wet saw. The sizes of the samples for the different testing will be discussed in the following sections under the different tests that was conducted.

5.4 Creep

Creep testing provides a measurement of time-dependent deformation of a material that is under a constant load at a specific temperature (ASTM C1337-96, 2005). This type of testing allows for an understanding of how the test material will perform when used in situations where a constant load would have been applied. For the purpose of this project, apparatus had to be designed and manufactured to conduct this testing; as neither USQ nor the CEEFC were in possession of a creep testing device. The next sections will describe and discuss the design process and testing procedure in detail to form a firm understanding of the creep testing and issues it entailed.

5.4.1 Design and Manufacture of Testing Device

During the course of the project it was found that there was no current system existed, which was solely designed for creep test. Thus as an additional objective of the project, the frame work was laid down for a prototype system which can be solely used for creep testing.

The initial design process involves the laying out of the exact needs that the device requires which include: -

- The device must be able to handle long term testing with minimal maintenance and constant observation.

- Able to handle constant loads without significant variations.

- Allow for different sized test samples (future use).

- Temperature controlled as creep is directly affected by temperature variations.

- Data collection within a given time interval.

These are the major requirement which the device must be designed for, however further reading of the ASTM C1337-96 standard testing for creep showed that there are ASTM standard that must also be upheld whilst developing this device. The sections that are most vital for the purpose of the project will be further outlined in the following dot points.

- The Gripping Device – passive grip interface uses a direct mechanical link to transmit the load applied by the machine to the test specimen. It is important that the test specimen have uniform contact with the gripping surface, which will prevent slippage of the test piece.

- Load Train Couplers – fixed load train couplers are needed so that the test sample is properly aligned. This is a major factor in the actual testing of the sample, meaning that if the load train and the grip are not aligned the specimen will undergo bending which in turn will affect the final results.

- Strain Measurement – Strain is measured at higher temperatures thus a suitable strain measurement apparatus must be used, which would be able to handle elevated temperatures.

- Heating Apparatus – As creep is measured at elevated temperature, there must be a way in which the test specimen can be heated and the temperature to remain constant.

- Temperature Measurement Apparatus – An accurate method of measuring the temperature of the test samples during the course of the creep test to ensure that the sample is within the temperature limits.

- Data Acquisition – data needs to be acquired with respect to time. The data can be either elongation or strain. Data also needs to be recorded at a given time interval. (ASTM C1337-96 2005, p3-6)

After a full understanding of the requirement was posed, the design process was initiated; however due to time constraints some of the required parts could not be fabricated.

The design for this device was based on a cantilever system, which would be able to hold a constant mass with minimal defection. It was found that the Faculty of Engineering and Surveying (FOES) had a device dedicated to creep testing, but the device had not been used in over 15 years and thus was not in working order. The machine was composed of a cantilever system which could be salvaged for the use in the development of the required creep testing. After reviewing the rest of the device (data recording system and the heating apparatus) it was determined these sections are obsolete. Thus only the cantilever system would be used.

Once the cantilever system was modified by means of the removal of the heating apparatus, data recording system, and other extra parts, the next issue that needed to be addressed was finding a way in which the test specimen could be attached to the actual cantilever system. For this reason grips and a load train must be designed to attach to the cantilever system and allow for the force applied by the system to be directed to the test piece.

Figure 5.1. Creep Testing System

Two grips would hold the specimen; the grips are passive based and also have to be manually tightened. This prevents too much force being applied on the sample. These grips were obtained from the FOES and thus did not require fabrication. The grip design is a simple design consisting of two steel plates which the test piece is placed between and tightened by the use four nuts and bolts.

Figure 5.2. The Grips Used.

These grips were then attached to the cantilever system by means of two metal plates. These plates are flat rectangular pieces consisting of a hole at either end of each plate, to allow for the fixing of the grips and also to the cantilever system. The top plate was attached by removing a pre-existing pin and a plate was attached by a bolt. The bottom plate was secured using a U bracket which hooked around an existing bracket attached to the machine.

Figure 5.3. Upper Section of the Load Train Attached to Cantilever System.

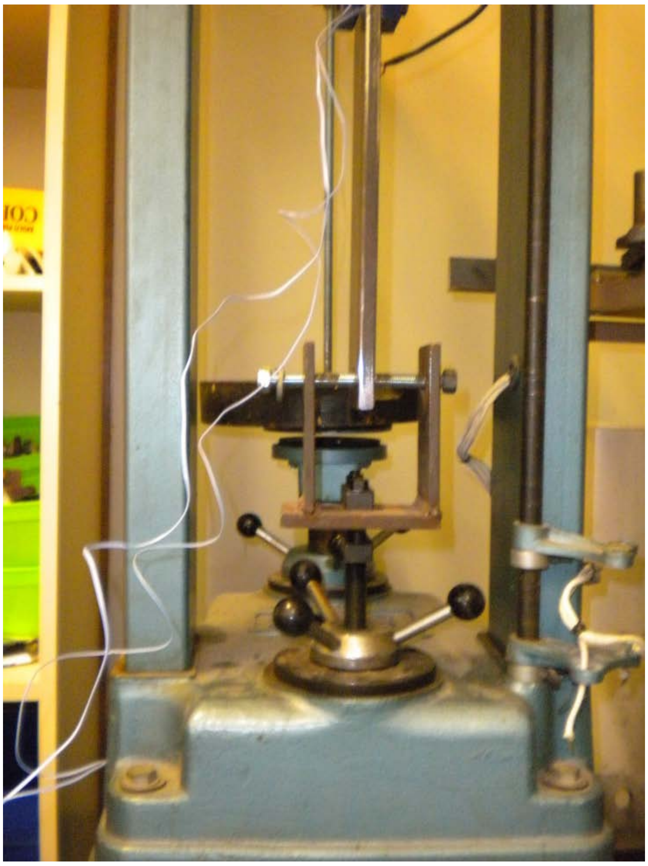

Figure 5.4. Lower Section of Load Train including 'U' Bracket.

The load train was completed and the final part that was incorporated into the system was the Data Acquisition Device. A system named the ‘Model P3 Strain Indicator and Recorder’ (P3) obtained from the CEEFC. The P3 is a portable device, powered by battery for use with resistive strain gage (Vishay Micro-Measurements, 2007). The system is user friendly and is able to save collected data on to a multimedia card in a text file format.

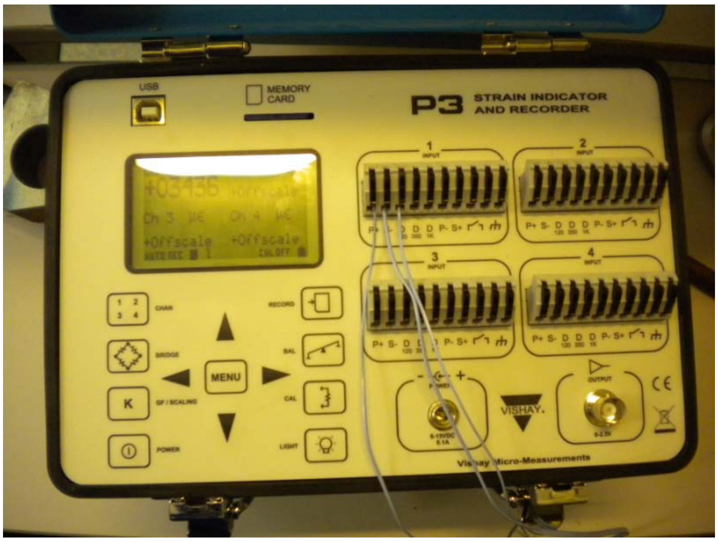

Figure 5.5. P3 Data Recorder.

As previously stated, some of the parts could not be fabricated; this was the heating system consisting of the heat mechanism and the temperature measuring apparatus. Further discussion of the system will be made in chapter 8 under the section future developments. However for the purpose of this project the framework of the creep test device has sufficed and the analysis of the results will be calculated with consideration to the lack of the temperature controlled environment.

5.4.2 Sample Preparation

According to the ASTM standards (C1997-96(2005)) the geometry of the creep test specimen is dependent on what the creep data is used for. Therefore for the purpose of the project a face loaded flat specimen was used. This structure allows for the friction between the specimen and the grip surface, to transfer the uniaxial load that is applied by the cantilever system directly to the test specimen. The measurements of the test specimen are 150mm length, 25mm width, and 6mm depth; however it must be noted that an error 2%, 8%, and

16.67% respectively were recorded on average. These errors with the dimensions can be attributed to cutting errors and shrinkage during the curing process.

In order for a strain reading to be collected by the P3 data recorder a strain gauge must be attached to the test specimen. As the load is applied in an uniaxial manner, the strain gauge is fixed in this direction. In fixing the strain gauge to the specimen several steps had to be followed in order for the results to be accurate.

First the centre of the sample is found by drawing two lines with pencil (one line half the length and the other half the width). The point where these two lines intersect is sanded using fine sand paper (approximately 5mm on either side of the intersecting lines). Then use alcohol to clean the sanded area, if the lines get erased draw them back in. However not all the way into the area that was just cleaned with alcohol as these lines only are needed to align the strain gauge. The preparation of the strain gauge was done by first cleaning the work area with alcohol, the strain gauge was then placed in this area and with the use of a multimeter the resistance of the gauge was checked. If the resistance is approximately 21ohms then it is in working order. Now the gauge is aligned with the lines drawn on the test sample, by the use of scotch tape the sensor is held in this centralized position and then finally using a strong adhesive set it in position. Thereafter, three wires are made read by tinning the ends and joining two of the three wires together. These wires are then soldered on to the strain gauge and the resistance tested again to make sure that the gauge is still operational. The P3 data recorder can be used as a quarter bridge, half bridge, or as a full bridge configuration, for this type of testing a quarter bridge was used. The wires were connected from the sample strain gauge to the quarter bridge using the quarter bridge type configuration.

Figure 5.7. The Guide Line are Drawn in

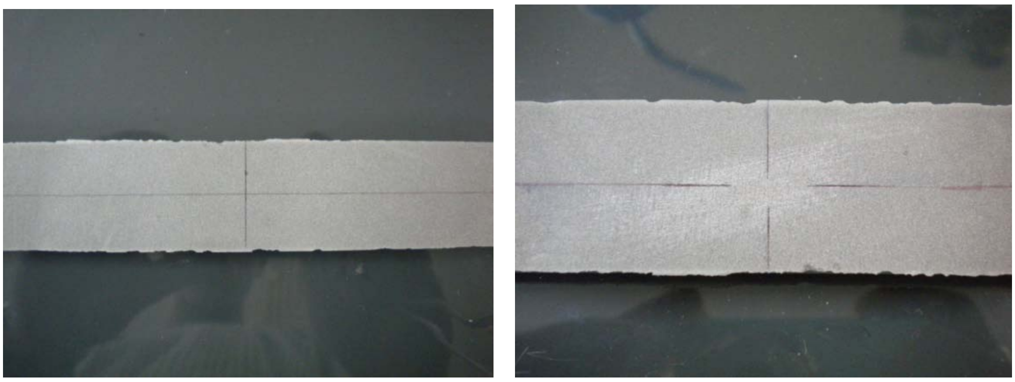

Figure 5.8. Specimen Sanded and cleaned with alcohol.

Figure 5.9. Strain gauge attatch to specimen

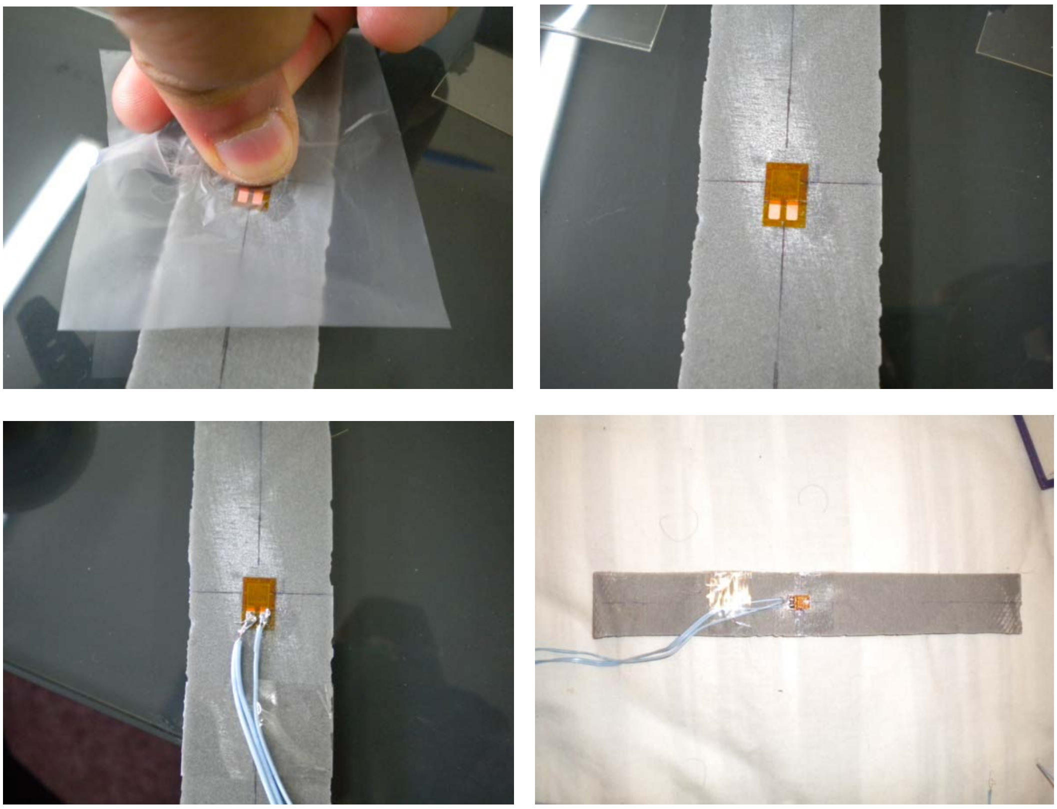

Figure 5.10. The above series of figure demonstrates the procedure as describe above in the sample preparation section.

The system developed for the project for creep testing requires the sample to be calibrated using the material testing system (MTS). Calibration gives a strain reading for a given load, which allows for the loading of the sample in the Creep Testing System (CTS). The sample is loaded in intervals of 2kN from 0.2kN up to 20kN. Once unloaded the strain readings are checked to see whether the strain readings done when loading are the same. In the worst case the strain reading is off by 29$\mu\varepsilon$. A graph of the strain readings vs. Load was then draw so that the desired load can be put on the test sample.

After the strain load correlation is found, the test specimen is loaded on to the CTS, by first tightening the grips so that the specimen is secured both top and bottom. Then the large mass is loaded on to the cantilever system, and by turning the height adjustment wheel until the mass is not touching the plate on which it rests upon. Using the strain- load graph the required load can be loaded by turning the adjustment wheel.

The CTS machine is not perfected and will require future work which will be discussed in the concluding chapter.

5.5 Impact

The impact testing provides details of the tests specimens ductile vs. brittleness behaviour. If the sample demonstrates ductile qualities then it should be able to absorb a large amount of energy; although if the samples are brittle they will only absorb a smaller amount of the impact energy. Thus in this test the most vital information obtained in the test is that of the energy absorbed by the test specimen. The hope for this test is that the test specimen will be able to absorb a large amount of energy. Standards that were used for both sample preparation and testing process were the International Standards Organization 179-2 (1997). The standard definition which applies to the testing carried out was "Charpy impact strength of an unnotched specimens" (ISO 179-2, 1997).

For this test the equipment was found at the CEEFC, however due to the device requiring repairs the testing was only conducted late this year. Due to this reason a staff member of the CEEFC was present and assisted with the testing to ensure that the impact testing device would not malfunction.

Figure 5.11. Impact Testing device.

The testing process was quite simple, involving the following steps:

1. The test area is checked for any fragile objects that may interfere with the testing process.
2. The system is then powered up and a Charpy test is selected as the type of test to be conducted.
3. Now the hammer lever is released so that it may conduct the experiment.
4. The devices grips are then adjusted to allow for the test specimens.
5. The hammer is raised and held by the stop lever.
6. The program is then activated and the stop lever released.
7. The data is saved by the program.

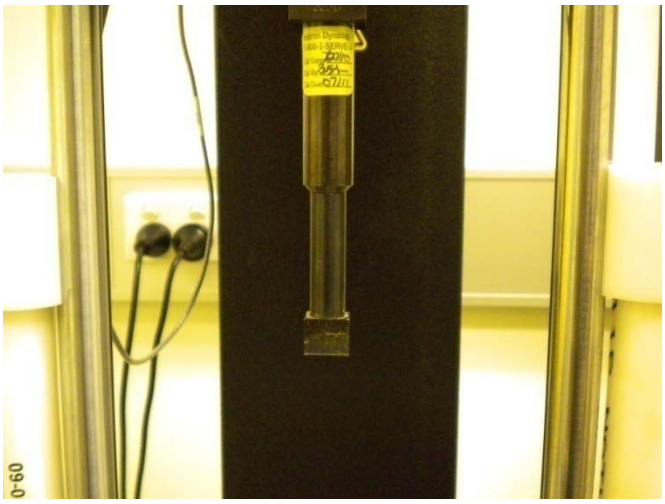

Figure 5.12. The 'v' shape hammer which breaks the specimen.

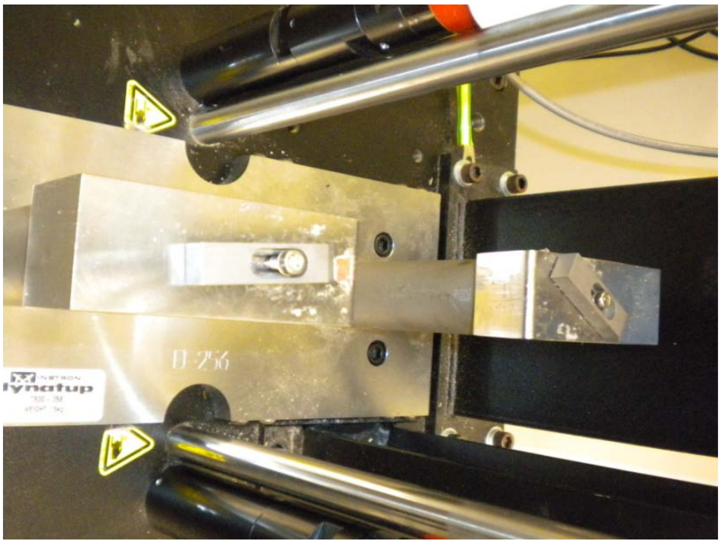

Figure 5.133. The grips attachments.

5.5.1 Sample Preparation

The initial mould was completed for the purpose of impact testing and the cutting of specimen was performed to ISO standards. The sample measurements are 130mm length, 25mm width, and 6mm depth.

5.6 Conclusion

This chapter discussed the methods required for sample preparation and testing procedures that were followed during the course of the project. It was found in creep testing that not all the standards set in the ASTM standards could be followed due to time constraints that were placed on the current project. Creep tests needs to be conducted for more than a year for accurate results to be obtained. The impact tests which were the major part of the project was done with the standards that were found and results obtained. The next chapter will discuss further the results that were obtained and any additional limitations of the current study.

Chapter 6 RESULTS

6.0 Introduction

This chapter will present the results that were obtained during testing. The results will be presented numerically and graphically, in order for analysis of the data to be conducted in the following chapter.

6.1 Creep Results

Creep test results could not be completed because of time constraints that were placed on this project. For a proper creep test to be conducted a minimum of at least one year is required per part thus the actual aim of the creep objective was the development of the testing device. Even so, testing was conducted on two test specimens (10% aluminium particulate and 25% aluminium particulate).

6.1.1 Calibration

All testing devices require calibration for an accurate reading to be recorded thus the creep testing system had to be calibrated. To calibrate this system, the test specimens were loaded into the MTS device, where it is slowly loaded and the strain readings recorded at a rate of 200N at a time from 0N to 2000N. Then unload at the same rate and the obtained results checked.

Load	Strain Reading
0	89
200	479
400	859
600	1205
800	1582
1000	2096
1200	2493
1400	2954
1600	3429
1800	3848
2000	4200

Table 6.1. Calibration Results for the 25% Test Specimen

The results of the table above are then graphed and a line of best fit drawn as seen in figure below.

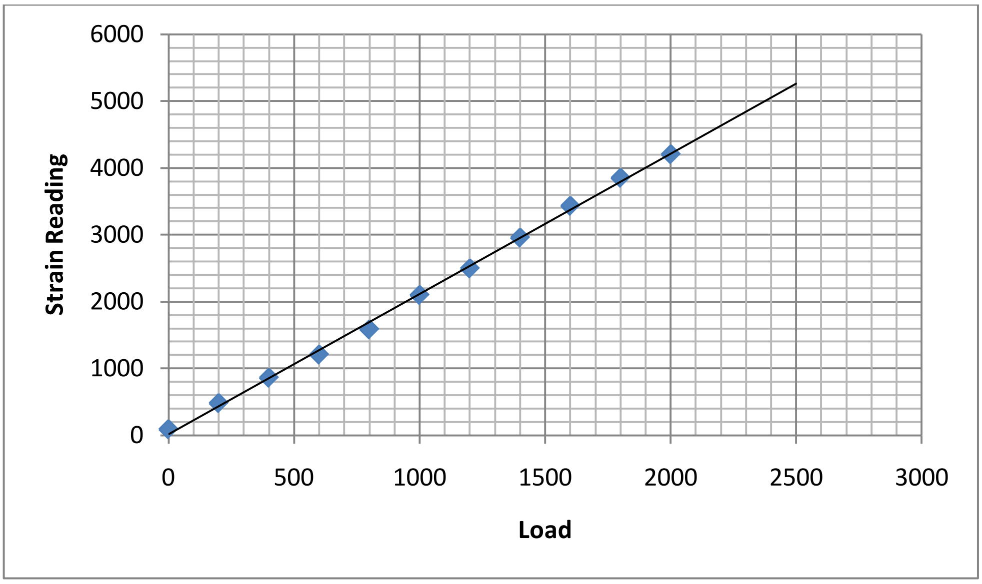

Figure 6.1. Calibration graph for 25% test specimen with line of best fit.

As it can be seen from the graph the calibration readings fit on the line of best fit though there are slight deviations. Thus once the specimen is loaded into the creep test system, it is then possible to find the load the specimen is place under. This eliminates the need for such apparatus as a load cell. Using this information an equation was formed for the relationship between the load and strain readings. This will allow for when the creep testing device is loaded the exact load to be calculated.

$$Load = \frac{Strain}{2.0977}$$

Equation 1. Load - Strain equation for 25% aluminium particulate

The specimen was loaded with a strain reading of 4515με which by the use of the equation equates to a load of 2152.36N. This type of calibration process allows for each test specimen to be loaded with the correct load, although it is not as accurate as using a load cell, due to the projects time constraints this system would be able to provide results, with less demand on the design process.

The MTS machine has been professionally calibrated to Australian standards, which allows for a correct calibration of the test specimen.

6.1.2 Testing Results

Each of the test specimens must be calibrated using the MTS machine for any correct load to be applied. Great care needs to be taken not to overload the specimen as this may lead to plastic deformation. Thus an initial tensile test was conducted to find the specific points where the sample would undergo this type of deformation as it is irreversible. Through the tensile testing it was found that a load up to 3500N for the 25% samples could be applied and 5500N could be applied to the 10% samples, without this type of deformation from occurring. Therefore using this data, load was applied under these values.

This load was placed on the 25% and 10% specimens for a period of 4.5 days approximately, the number of days varied due to issues faced during the course of conducting the creep research; the data recorder takes a readings every 30 minutes into a text format. At the end of the testing period the data was copied from the P3 data recorder and exported into an excel spreadsheet. As the list of data is in the appendix as it is quite long, a graphical representation of the data is provided below:-

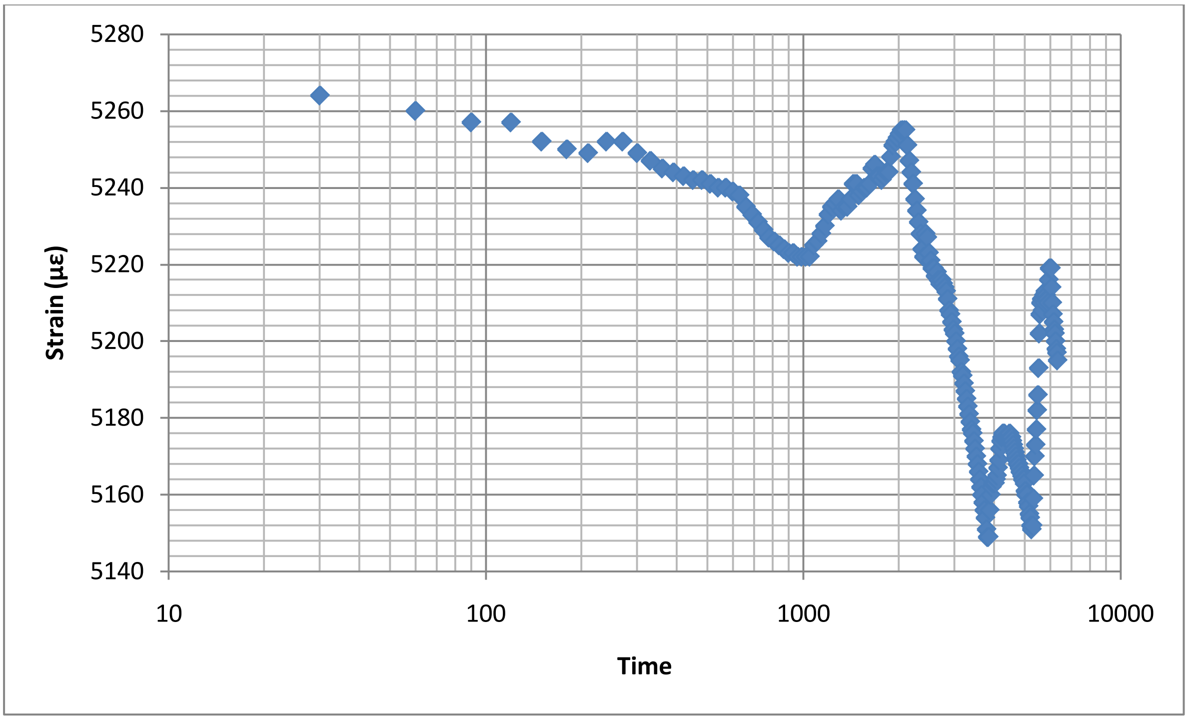

Figure 6.2. 25% Aluminium Particulate Composite Creep Test

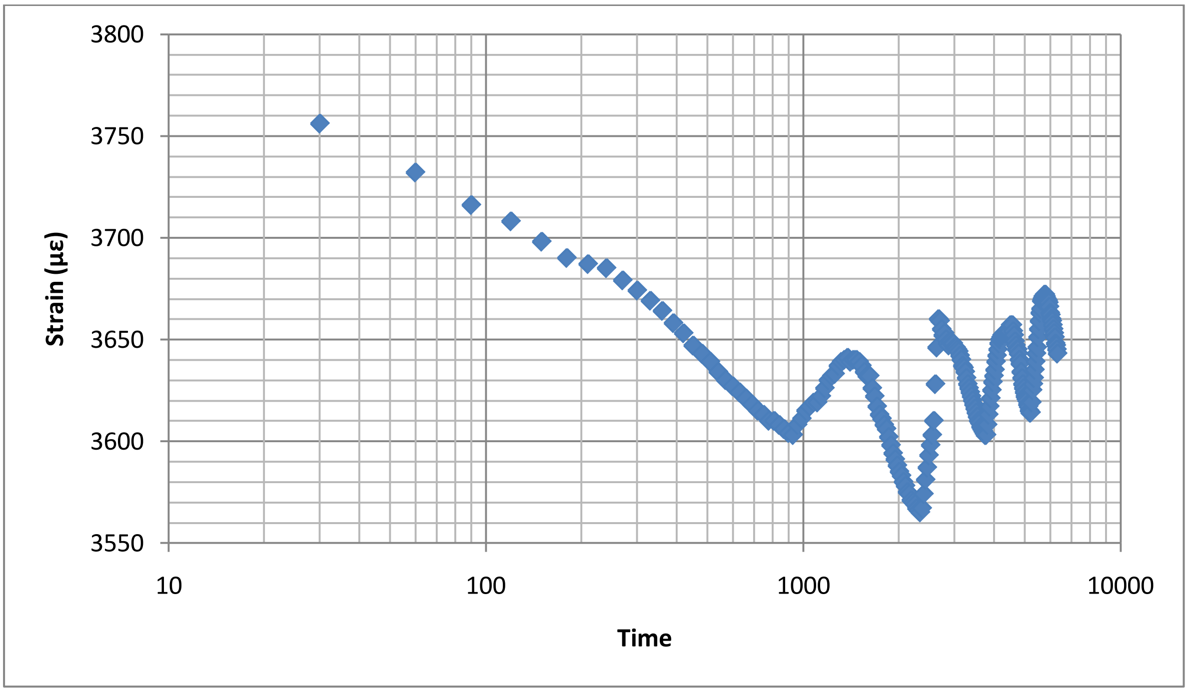

Figure 6.3. 10% Aluminium Particulate Composite Creep Test

The results displayed in the graphical format were not expected, this may be due to a few reasons.

1. The cantilever system has a hanging mass which keeps the load on the specimen constant. It was observed that this mass swayed when the specimen was first placed the creep testing device. This swaying causes the load on the specimen to vary which causes the load to increase and decrease. Since the laboratory facilities used for the testing was home to the MTS machine, other student and staff would go into the room causing the mass on the cantilever system to sway.

2. There could be slight slippage of the grips which are holding the test specimen. Due to time constraints the testing rig could not be fully tested. Though this scenario is highly unlikely; as the grips were industrial strength and the surface that the grips attached to the specimens are designed to prevent slippage.

3. The time required for an aluminium particulate composite to start to creep is a longer period than the time the specimen was placed in the testing device. The specimen was still undergoing elastic deformation to a certain extent. This is the most likely cause as the pattern that is shown in the graph resembles the specimen being elongated and then attempting to return to its original length. Although due to the constant load being applied it only is able to regain a fraction of this length.

Further discussion about the creep data and what the expected results should have been will be discussed in the following chapter.

6.2 Impact Results 800

The impact testing was conducted at the CEEFC, as a work permit was required to do testing thus, a staff member of the centre supervised while the testing was conducted. The testing equipment was out of order until late August. For impact testing four specimens were prepared from each aluminium percentage and a neat resin composite. This will allow for comparison and further discussion.

6.2.1 Test Results

The results from the impact test device are outputted as document file, which can then be opened using Microsoft word. The data is presented in a graphical and tabular form, the data from the tables are as shown below. The graphical data can be found in the appendix of the dissertation.

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	3.3569	0.1924	2.9517	0.8099	3.7964
2	1.6357	0.2163	2.9430	0.5370	2.0264
3	1.7334	0.1924	2.9451	0.4764	1.9653
4	2.0020	0.2454	2.9432	0.6874	2.1606
Average	2.1820	0.2116	2.9457	0.6277	2.4872
Median	1.8677	0.2044	2.9441	0.6122	2.0935
Minimum	1.6357	0.1924	2.9430	0.4764	1.9653
Maximum	3.3569	0.2454	2.9517	0.8099	3.7964
Coef. of Var.	36.5921	11.9045	0.1381	23.9670	35.2450
Std. Dev.	0.7984	0.0252	0.0041	0.1504	0.8766

Table 6.2. NEAT Resin Impact Test Results

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	1.8066	0.4855	2.9439	1.1205	1.9531
2	2.5024	0.6015	2.9493	2.2938	2.8687
3	4.5410	0.4538	2.9508	3.5622	8.4839
4	1.8921	0.5453	2.9501	1.5833	2.2949
Average	2.6855	0.5215	2.9485	2.1399	3.9001
Median	2.1973	0.5154	2.9497	1.9385	2.5818
Minimum	1.8066	0.4538	2.9439	1.1205	1.9531
Maximum	4.5410	0.6015	2.9508	3.5622	8.4839
Coef. of Var.	47.4835	12.5521	0.1056	49.7157	78.9479
Std. Dev.	1.2752	0.0655	0.0031	1.0639	3.0791

Table 6.3. Aluminium particulate 5% impact test results

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	2.4414	0.5842	2.9487	1.7348	2.5879
2	2.3682	0.5563	2.9504	1.6247	2.5146
3	2.2827	0.5224	2.9482	1.5538	2.4292
4	2.1118	0.4750	2.9488	1.4356	2.3560
Average	2.3010	0.5345	2.9490	1.5872	2.4719
Median	2.3254	0.5393	2.9487	1.5893	2.4719
Minimum	2.1118	0.4750	2.9482	1.4356	2.3560
Maximum	2.4414	0.5842	2.9504	1.7348	2.5879
Coef. of Var.	6.1639	8.7950	0.0321	7.9121	4.0822
Std. Dev.	0.1418	0.0470	0.0009	0.1256	0.1009

Table 6.4. Aluminium Particulate 10% Impact Test Results

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	2.5269	0.4944	2.9505	1.5291	2.6733
2	2.6489	0.5760	2.9497	1.9347	3.0518
3	5.8716	0.2735	2.9523	3.0966	9.8267
4	2.5879	0.6144	2.9481	2.1027	2.9907
5	2.4292	0.5187	2.9489	1.5188	2.5635
Average	3.2129	0.4954	2.9499	2.0364	4.2212
Median	2.5879	0.5187	2.9497	1.9347	2.9907
Minimum	2.4292	0.2735	2.9481	1.5188	2.5635
Maximum	5.8716	0.6144	2.9523	3.0966	9.8267
Coef. of Var.	46.3280	26.7906	0.0546	31.6739	74.3945
Std. Dev.	1.4885	0.1327	0.0016	0.6450	3.1403

Table 6.5. Aluminium Particulate 15% Impact Test Results

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	2.0996	0.6294	2.9481	1.4089	2.2339
2	2.3804	0.5805	2.9465	1.6734	2.5391
3	4.9438	0.3026	2.9499	1.7419	5.0659
4	2.6978	0.5718	2.9490	1.8091	2.8564
Average	3.0304	0.5211	2.9484	1.6583	3.1738
Median	2.5391	0.5762	2.9486	1.7077	2.6978
Minimum	2.0996	0.3026	2.9465	1.4089	2.2339
Maximum	4.9438	0.6294	2.9499	1.8091	5.0659
Coef. of Var.	42.8599	28.3782	0.0501	10.5676	40.5424
Std. Dev.	1.2988	0.1479	0.0015	0.1752	1.2867

Table 6.6. Aluminium Particulate 20% Impact Test Results

From these tables the most valuable information that is required is the total energy that is absorbed by the specimen during impact. As it can be seen from the data tables, compared to the neat resin sample, the ones which have aluminium particulate reinforced the composite matrix. Aluminium particulates specimens have greater impact energy absorption qualities than that of neat resin specimens. In order to demonstrate this further, in the next chapter calculations of the Charpy impact strength of the specimen will be conducted (ISO 1337-96 1997). The specimen shown similar observational result when the impact test was conducted. As the hammer hit the specimen, it broke not only at the site of the impact but breaks occurred throughout the test pieces. The specimen broke on average into four sections which show a degree of brittleness which allows them to absorb the impact energy.

6.3 Conclusion

As the creep test did not yield significant result, the framework will provided for a better testing for future project. The impact tests have shown promising results which through better analysis will be explain in chapter 7 of this dissertation.

Chapter 7 ANALYSIS

7.0 Introduction

After the collection of data from each of the two tests, analysis must be performed to find the strengths and weakness of the aluminium particulate composite material. The impact tests yielded sufficient result which can be used for the purpose of this research. However, the creep tests were not as successful, and as notes in the results chapter did not demonstrate the desired result. This chapter will look at the aspects of the creep tests that may have been the cause of the unexpected results and discuss further the actual results that should have been found. Also a detailed analysis of the impact results will be given; calculations to the energy absorbed and comparisons of the aluminium particulate and neat resin will be evaluated.

7.1 Impact

The impact test results have shown promise, as it was discussed in chapter 6, the aluminium particulate composite sample have a far greater energy absorption than that of neat resin specimen. As said in the previous chapter, the Charpy impact strength will be calculated. Charpy impact shows the amount of kinetic energy that is required to fracture a specimen until it reaches breaking point. This value can then be used in quality control and show toughness of a material (Intertek PTL Technical, 2010).

The Charpy impact strength value (a_{cU}) is measured in kilojoules per square metre, and is calculated using the following equation:

$$a_{cU} = \frac{A}{t.w} \times 10^3$$

Equation 2. Charpy Impact Strength for Unnotched Specimen (ISO 179-2 (1997))

The International Standards organisation (179-2, 1997) defines two equations, one for notched specimens the other for unnotched. As the samples prepared were unnotched the equation used coincides with this. Thus the term in the equation refers to: -

A is the impact energy absorbed by the specimen, this value is found on the table of test values under total energy.

t is the thickness of the test specimen.

w is the width of the tested specimen.

Due to shrinkage the thicknesses of the specimens and machining errors the widths are not uniform these deviations as stated in chapter 5. Therefore calculations will be done for each specimen and then the average values will be used to calculate Charpy impact strength.

eat Resin

Thickness(mm)	Width(mm)	Energy(J)	Charpy Impact Strength
6.08	25.03	0.8099	5.3219
5.86	25.08	0.537	3.6538
5.96	24.86	0.4764	3.2153
5.98	25.15	0.6874	4.5706
5.97	25.03	0.6277	4.2007

5%

Thickness(mm)	Width(mm)	Energy(J)	Charpy Impact Strength
6.16	24.9	1.1205	7.3052
5.65	24.69	2.2938	16.4432
6.02	25.02	3.5622	23.6502
6.08	25.09	1.5833	10.3791
5.9775	24.925	2.13995	14.3631

10%

Thickness(mm)	Width(mm)	Energy(J)	Charpy Impact Strength
6.06	25.05	1.7348	11.4280
6.1	25.15	1.6247	10.5902
6.05	24.86	1.5538	10.3309
5.98	25.1	1.4356	9.5644
6.0475	25.04	1.587225	10.4816

15%

Thickness(mm)	Width(mm)	Energy(J)	Charpy Impact Strength
5.96	25.06	1.5291	10.2378
6.02	24.97	1.9347	12.8706
6.09	24.89	3.0966	20.4288
6.01	25.05	2.1027	13.9667
6.02	24.9925	2.165775	14.3949

20%

Thickness(mm)	Width(mm)	Energy(J)	Charpy Impact Strength
6.06	25.05	1.4089	9.2811
6.1	25.15	1.6734	10.9077
6.05	24.86	1.7419	11.5816
5.98	25.1	1.8091	12.0528
6.0475	25.04	1.658325	10.9511

Table 7.1. Charpy Impact Strength Calculations.

It is observed that the Charpy impact strength of composite material containing aluminium particles is much higher than that of the neat resin.

Neat Resin	4.2007
5%	14.3631
10%	10.4816
15%	14.3949
20%	10.9511

Table 7.2. Average Charpy Impact Strength

From the results it can be seen that the 5% and 15% aluminium particulate specimens have shown to absorb more energy than the other percentages of composite materials. This is especially apparent when compared to the neat resin. The values are more than double, which supports the fact that by adding aluminium particles to the vinyl ester resin it is possible to strengthen the composite matrix, allowing the specimens to absorb more impact energy.

The reasons for the 15% specimens being able to absorb a large amount of energy than the other specimen is due to this specimen being the optimum percentage addition of aluminium particles.

There are some inconsistencies with the results as the 10% compared with the 5%, absorbs less energy. This may be due to imperfection has as air bubbles or the aluminium particles did not disperse evenly through the 10% specimen. It was expected that the 20% specimen would absorb less energy as when reviews of the previous years project, conclude that specimen consisting of 20% or more aluminium particles tended to become weak as the polymer matrix is saturated with the aluminium particles and thus does not bond properly with the vinyl ester resin.

7.2 Creep

When the aluminium particulate composite undergoes a force, the atomic lattice will oppose the force in an attempt to maintain equilibrium (Garofalo, 1966). Thus when a constant load is applied to the specimen the atomic lattices of the composite material will attempt to maintain equilibrium by means of deformation. This deformation is not comparable unless given a unit of reference; therefore it is referred to as a unit less quantity called strain is used (Garofalo). The manner in which strain is measured in given in the equation below,

$$\varepsilon = \int_{l_0}^{l} \frac{dl}{l_0} = \frac{l - l_0}{l_0}$$

Equation 3. Strain Equation (Garofalo 1966, p1)

Therefore, strain is the changing in length divided by the original length of the specimen. In the creep tests, by the use of a strain gauge it was possible to find the strain reading directly for a given instance of time.

It is evident in the results obtained in creep tests for this research, that when the data is represented graphically to a certain degree it represents an oscillating pattern. The reason for this type of result is due to the specimen not being under adequate stresses. Although only strain is measured, stress on the sample is fundamental as stress is directly proportional to the strain applied to the sample test piece. The value of E is young's modulus of the material.

$$\varepsilon = \frac{\sigma}{E}$$

Equation 4. Strain-Stress Relationship (Garofalo 1966, p2)

Therefore, to obtain better results a higher stress needs to be applied. However, stress is not the only factor that affected the test results; creep is also affected more directly by temperature. Through past experiments it has been concluded that creep can be activated thermally. This means that increased temperature provides energy, which allows for creep to occur.

Other factors that affect creep deformation are the microstructure of the composite and also the environment in which testing is conducted. In regards to the microstructure, the manner in which the atomic lattice is structure affects the manner in the way the specimen achieves equilibrium. Grain size and the dispersion of the phases give the resulting strain. The environment in which the tests are conducted also affects the results, as the optimum environment could not be found or developed.

The key factors that affected the outcome of testing can be narrowed down to three key reasons: -

1. Low stress on the test specimens as referred to by Garofalo (1966). He states that when low stresses are present during testing for creep an oscillation range is present in the final data collected.

2. Temperature factors also affected the results as a heating system could not be incorporated into the creep testing system. Thus the energy required for the creep deformation to initiate was not up to standards.

3. Finally, the test environment also would have played a key role in not getting the desired results. The environment used was accessed by students and staff to conduct testing with the MTS machine therefore temperature could not be controlled. The area was not sealed off and thus air from the air conditioning and the outer environment interfered with current apparatus setup to maintain constant temperature.

Although not likely, the results could also be linked to errors with the data recording equipment. Electrical interference could cause the result to form an oscillating sign output.

This is unlikely as the data recorder circuit prevents interference from occurring which allows for optimum recording.

If analysis is conducted on the results that were obtained, it can be seen that although not uniform the oscillations are decreasing in size peak to peak. This could mean that given time the oscillations would decrease and proper creep results could be obtained. Garofalo summaries these point when stating, “Whether all creep stages are observed in any one test depends on temperature, stress, and duration of the test.” (Garofalo 1966, p6)

7.3 Conclusion

In conclusion, it was observed that the impact test results, and the aluminium particles allowed for a more brittle compare with the neat resin. The specimen absorbed energy and dispersed it through the specimen which resulted in the multiple break regions.

Chapter 8 CONCLUSION

8.0 Introduction

During the course of the research, information about aluminium particulate composites has been presented. A better way of preparing the samples, with the least number of imperfections such as air bubbles (which can form in the samples cause premature fractures). Through the tests conducted a greater understanding of the uses of this composite can now be evaluated. There were issues that caused delays and in the case of the creep tests time constraints.

The result showed that in the case of impact strength, the aluminium particulate specimens are much better at absorbing energy. Through the Charpy impact strength calculations it is evident that the specimens containing aluminium particles are able to absorb more energy per square meter than neat resin specimens. All the tests were conducted under ISO and ATSM standards, however initially for the purpose of research Australian Standards were used but were found to be obsolete. Therefore much of the research structure had to be changed to fit the ISO standards. The impact absorption could be performed with minimal time requirements as the device was at the CEEFC. The only issue that was faced for the impact tests research was that the device was out of order for more than four months. This limited some of the research goals set, namely in discovering the best method for preparing samples for impact tests. It was hoped that the neat resin specimens that were prepared to develop methods of sample preparation with least imperfections, then these could have been tested with the impact testing device. Then by using this optimum method, the aluminium particulate sample could be prepared and tested with the impact device as well. However, since the device could not be used, detailed observations and MTS machine tests were conducted to find the specimens with the least imperfections. Thus yielding the best results for the research project.

Creep tests proved to be the most difficult and problematic of the two tests conducted. Due to time constraints much of the plan work could not be completed. However sufficient device development allowed for the testing of creep in two specimens (20% and 10%). Although these results were not the desired outcome of the testing process, it provides a framework for future creep testing based projects to build on and improve the current basic creep testing system.

8.2 Future development

Through the details provided in this dissertation it will be possible for future projects to build upon. The system that would require a great deal of re-designing would be the creep testing system. The following will be the re-design requirement and also the additional component which are needed for ASTM standard compliant creep tests.

Firstly, the load train width needs to be decreased by at least 40mm which would allow for less contact with the cantilever system. At the moment there is slight contact between the cantilever system and the load train which causes slight bending to occur in the test specimen. Also a better ‘u’ bracket needs to be designed which would allow the bottom load train to be easily attached.

A heating system to raise the temperature of the specimen is also required. This is one part that was designed, however could not be built due to time constraints. The system that was design consisted of two heating elements attached to a ceramic hollow cylinder. This cylinder can be slide over the test specimen however would not come in contact with it. The temperature would be controlled by a temperature sensor integrated circuit such at an HC12. The IC would turn the heating elements on until the desired temperature is obtained then off and on to keep the temperature constant.

8.3 Conclusion

The research study observed and evaluated the manner in which aluminium particulate composite absorbs energy during impact. In an attempt to discover how this type of composite reacts to long term testing, a creep testing structure was used. However as it can be seen in the results of the creep tests; this test was not as successful as previously thought.

The impact tests conclude that aluminium particle is a vinyl ester resin that would strengthen the composite matrix, allowing the composite to absorb more energy during impact. Testing can be conducted into the particle size of the aluminium as it has shown that the smaller the particle the stronger the bonds between the particles becomes. Thus it is suggested that nano scale aluminium particles should be used and compared with this current research project.

The research objectives that were set out in chapter 2 were vague descriptions of what was needed to be accomplished in order for the project to be successful. The first objective was to find the composition which would yield the best impact and creep results. The best impact results were at the 15% aluminium particulate region; this sample absorbed the most amount of energy. In the creep tests, no specimen can be isolated as the best composition as testing could not be successfully completed.

As explained in chapter 7 and 8, the creep testing device will need to undergo several modifications with regards to the heating apparatus and environment that the testing is conducted in. Further creep tests will be required to find how the composite would perform at high temperatures with constant loads.

The final objective was to find a field of use for aluminium particulate composites. To find uses for this type of composite material more research is needs to be conducted. As this type of composite material is a relatively new development, limited sources of information could be found. Thus further studies are required to form a firm basis to the uses and needs of this type of composite material. Future studies should compare impact energy and creep strength to other composites such as powder based composites.

Finally, to a certain extent this research project was successful even though there were some issues throughout. It was found that aluminium does reinforce the polymer matrix so that it is able to absorb impact energy. The creep testing system skeleton was designed and developed, and specimens were tested even though were not as unsuccessful as initially expected. Overall, all the objectives were addressed in the research and experiments were conducted yielding results.

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 University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: BUDDHI NUWAN LANKA ASSIRIYAGE

TOPIC: AN INVESTIGATION OF ALUMINIUM/EPOXY PARTICULATE COMPOSITE SYSTEM – IMPACT/LONG-TERM BEHAVIOR.

SUPERVISOR: Dr. Jayantha Epaarachchi

SPONSORHSIP: Faculty of Engineering and Surveying

PROJECT AIM: This project aims to investigate the impact and long-term behaviour of aluminium composite through a series of sample testing.

PROGRAMME: (**Issue A, 23/03/2010**)

1. Research particulate composites, aluminium properties, impacting testing and other forms of laboratory testing.
2. Design and build a mould which would allow for the composite to be made and tested.
3. Using the CEEFC impact testing device for testing material.
4. Evaluate current creep testing equipment and modify to fit required testing criteria.
5. Research further studies that maybe be conducted in future studies to develop aluminium filler composites.
6. Analysis the data obtain by conducting impact and creep testing and suggest possible uses for composite material.
7. For future studies write detailed methodology into making aluminium composite with the least amount to defects (eg air bubbles).
8. Write and submit dissertation.

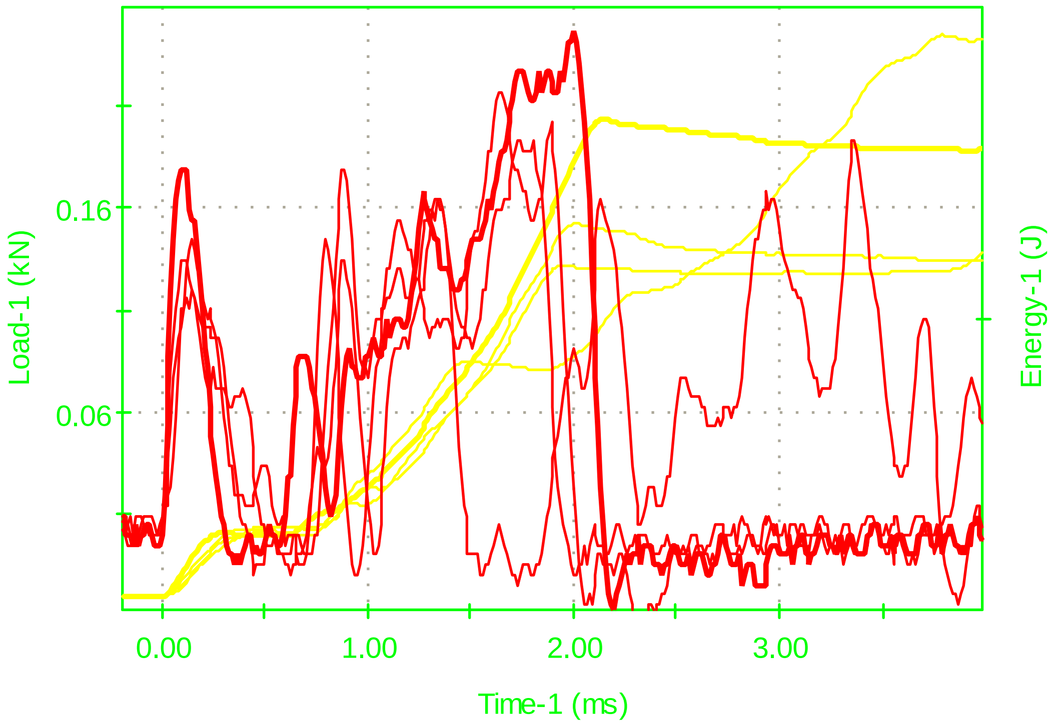
AGREED (student) (supervisor)

Date: / / 2010 Date: / / 2010

Appendix B IMPACT TESTS

Neat Resin

Graph 1

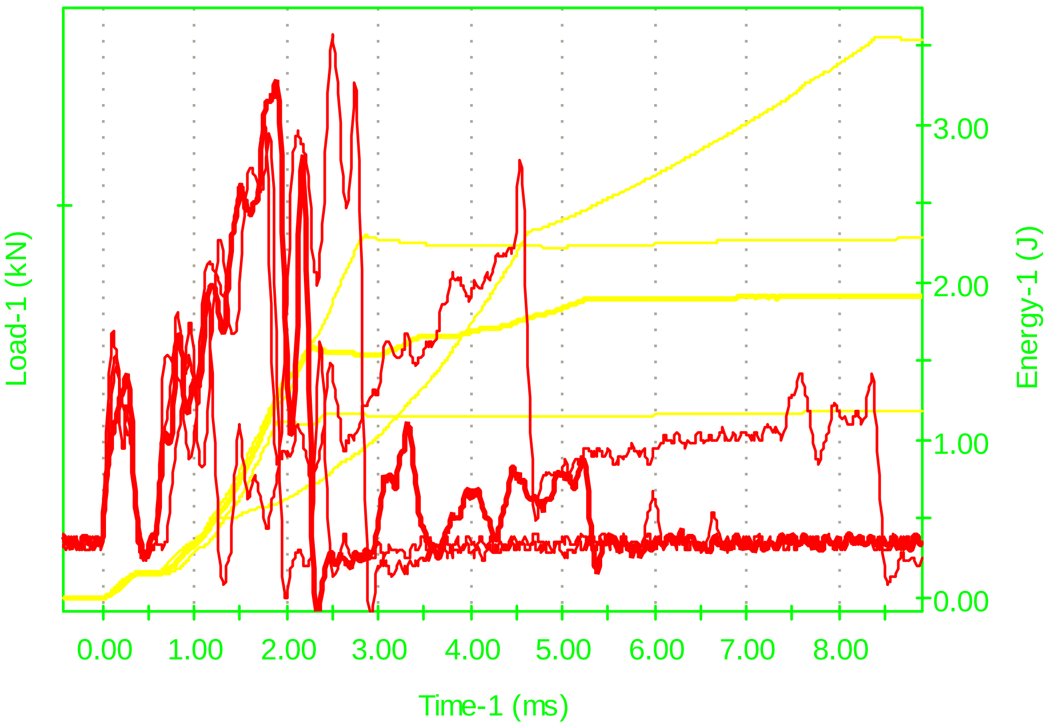


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	3.3569	0.1924	2.9517	0.8099	3.7964
2	1.6357	0.2163	2.9430	0.5370	2.0264
3	1.7334	0.1924	2.9451	0.4764	1.9653
4	2.0020	0.2454	2.9432	0.6874	2.1606
Average	2.1820	0.2116	2.9457	0.6277	2.4872
Median	1.8677	0.2044	2.9441	0.6122	2.0935
Minimum	1.6357	0.1924	2.9430	0.4764	1.9653
Maximum	3.3569	0.2454	2.9517	0.8099	3.7964
Coef. of Var.	36.5921	11.9045	0.1381	23.9670	35.2450
Std. Dev.	0.7984	0.0252	0.0041	0.1504	0.8766

5% Aluminium Particulate Composite

Graph 1

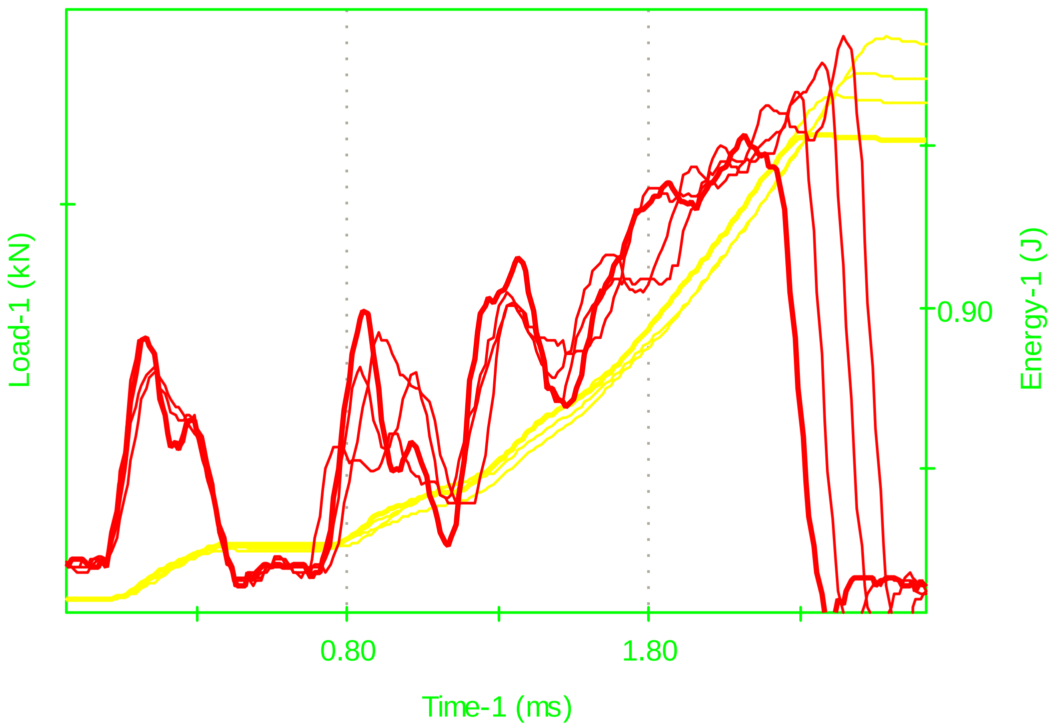


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	1.8066	0.4855	2.9439	1.1205	1.9531
2	2.5024	0.6015	2.9493	2.2938	2.8687
3	4.5410	0.4538	2.9508	3.5622	8.4839
4	1.8921	0.5453	2.9501	1.5833	2.2949
Average	2.6855	0.5215	2.9485	2.1399	3.9001
Median	2.1973	0.5154	2.9497	1.9385	2.5818
Minimum	1.8066	0.4538	2.9439	1.1205	1.9531
Maximum	4.5410	0.6015	2.9508	3.5622	8.4839
Coef. of Var.	47.4835	12.5521	0.1056	49.7157	78.9479
Std. Dev.	1.2752	0.0655	0.0031	1.0639	3.0791

10% Aluminium Particulate Composite

Graph 1

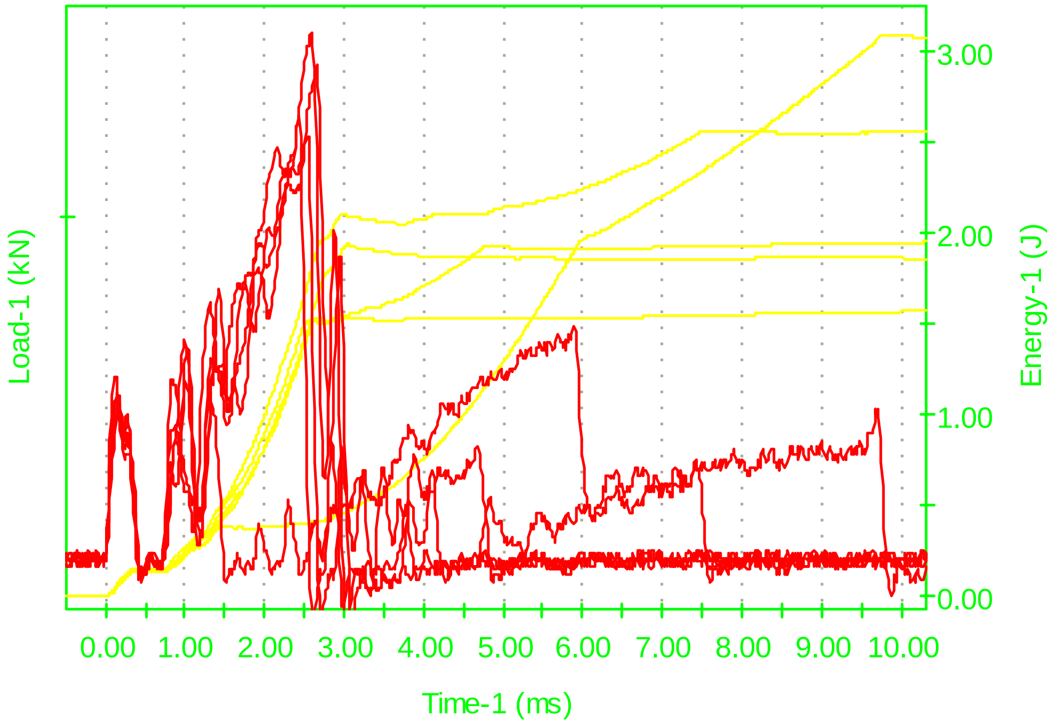


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	2.4414	0.5842	2.9487	1.7348	2.5879
2	2.3682	0.5563	2.9504	1.6247	2.5146
3	2.2827	0.5224	2.9482	1.5538	2.4292
4	2.1118	0.4750	2.9488	1.4356	2.3560
Average	2.3010	0.5345	2.9490	1.5872	2.4719
Median	2.3254	0.5393	2.9487	1.5893	2.4719
Minimum	2.1118	0.4750	2.9482	1.4356	2.3560
Maximum	2.4414	0.5842	2.9504	1.7348	2.5879
Coef. of Var.	6.1639	8.7950	0.0321	7.9121	4.0822
Std. Dev.	0.1418	0.0470	0.0009	0.1256	0.1009

15% Aluminium Particulate Composite

Graph 1

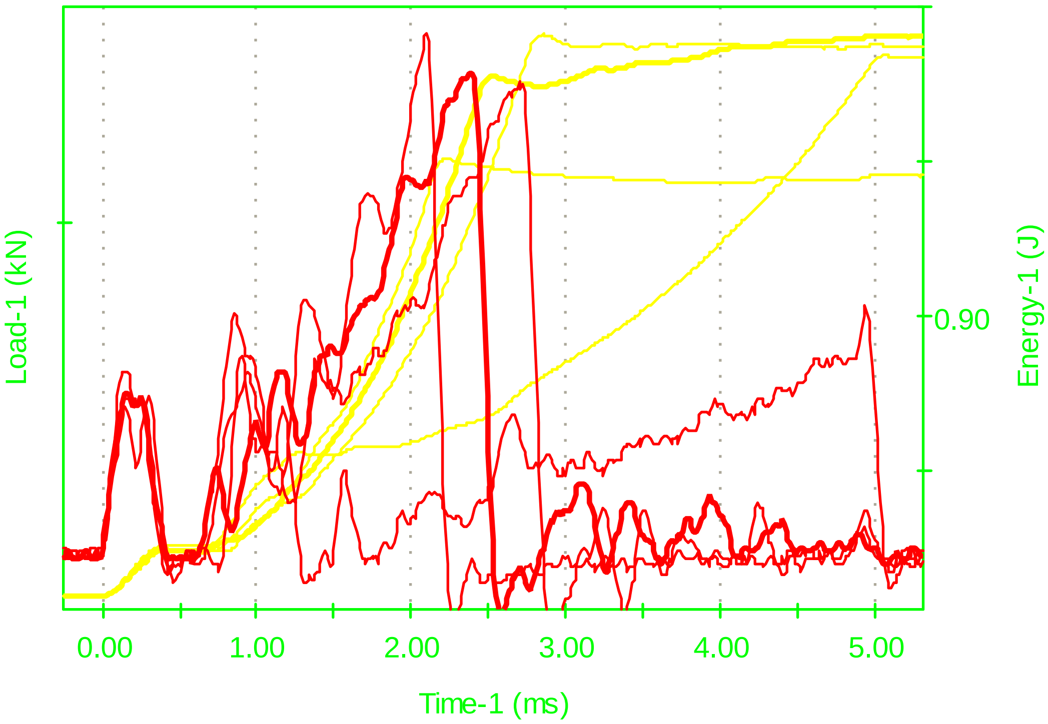


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	2.5269	0.4944	2.9505	1.5291	2.6733
2	2.6489	0.5760	2.9497	1.9347	3.0518
3	5.8716	0.2735	2.9523	3.0966	9.8267
4	2.5879	0.6144	2.9481	2.1027	2.9907
5	2.4292	0.5187	2.9489	1.5188	2.5635
Average	3.2129	0.4954	2.9499	2.0364	4.2212
Median	2.5879	0.5187	2.9497	1.9347	2.9907
Minimum	2.4292	0.2735	2.9481	1.5188	2.5635
Maximum	5.8716	0.6144	2.9523	3.0966	9.8267
Coef. of Var.	46.3280	26.7906	0.0546	31.6739	74.3945
Std. Dev.	1.4885	0.1327	0.0016	0.6450	3.1403

20% Aluminium Particulate Composite

Graph 1



Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (kN)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	2.0996	0.6294	2.9481	1.4089	2.2339
2	2.3804	0.5805	2.9465	1.6734	2.5391
3	4.9438	0.3026	2.9499	1.7419	5.0659
4	2.6978	0.5718	2.9490	1.8091	2.8564
Average	3.0304	0.5211	2.9484	1.6583	3.1738
Median	2.5391	0.5762	2.9486	1.7077	2.6978
Minimum	2.0996	0.3026	2.9465	1.4089	2.2339
Maximum	4.9438	0.6294	2.9499	1.8091	5.0659
Coef. of Var.	42.8599	28.3782	0.0501	10.5676	40.5424
Std. Dev.	1.2988	0.1479	0.0015	0.1752	1.2867

Appendix C Creep Results

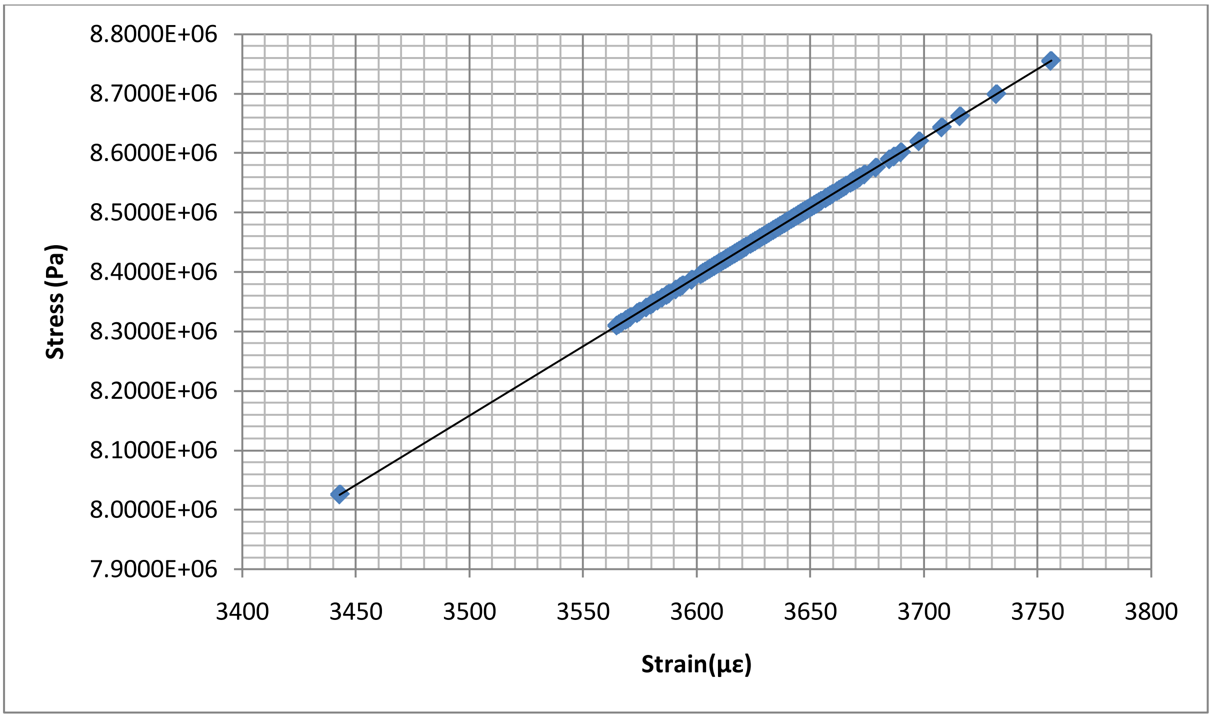
Time(30min intervals)	Strain	Time (hours)	Days	Stress
0	3443	0		8.0256E+06
30	3756	0.5		8.7552E+06
60	3732	1		8.6993E+06
90	3716	1.5		8.6620E+06
120	3708	2		8.6433E+06
150	3698	2.5		8.6200E+06
180	3690	3		8.6014E+06
210	3687	3.5		8.5944E+06
240	3685	4		8.5897E+06
270	3679	4.5		8.5757E+06
300	3674	5		8.5641E+06
330	3669	5.5		8.5524E+06
360	3664	6		8.5408E+06
390	3658	6.5		8.5268E+06
420	3653	7		8.5151E+06
450	3647	7.5		8.5012E+06
480	3643	8		8.4918E+06
510	3639	8.5		8.4825E+06
540	3634	9		8.4709E+06
570	3630	9.5		8.4615E+06
600	3627	10		8.4545E+06
630	3624	10.5		8.4475E+06
660	3621	11		8.4406E+06
690	3618	11.5		8.4336E+06
720	3615	12		8.4266E+06
750	3613	12.5		8.4219E+06
780	3610	13		8.4149E+06
810	3610	13.5		8.4149E+06
840	3608	14		8.4102E+06
870	3606	14.5		8.4056E+06
900	3604	15		8.4009E+06
930	3603	15.5		8.3986E+06
960	3608	16		8.4102E+06
990	3611	16.5		8.4172E+06
1020	3615	17		8.4266E+06
1050	3617	17.5		8.4312E+06
1080	3619	18		8.4359E+06
1110	3619	18.5		8.4359E+06
1140	3622	19		8.4429E+06

1170	3626	19.5		8.4522E+06
1200	3630	20		8.4615E+06
1230	3632	20.5		8.4662E+06
1260	3633	21		8.4685E+06
1290	3637	21.5		8.4778E+06
1320	3639	22		8.4825E+06
1350	3640	22.5		8.4848E+06
1380	3641	23		8.4872E+06
1410	3639	23.5		8.4825E+06
1440	3640	24	1day	8.4848E+06
1470	3640	24.5		8.4848E+06
1500	3639	25		8.4825E+06
1530	3637	25.5		8.4778E+06
1560	3634	26		8.4709E+06
1590	3632	26.5		8.4662E+06
1620	3632	27		8.4662E+06
1650	3626	27.5		8.4522E+06
1680	3622	28		8.4429E+06
1710	3617	28.5		8.4312E+06
1740	3613	29		8.4219E+06
1770	3611	29.5		8.4172E+06
1800	3608	30		8.4102E+06
1830	3606	30.5		8.4056E+06
1860	3602	31		8.3963E+06
1890	3598	31.5		8.3869E+06
1920	3594	32		8.3776E+06
1950	3591	32.5		8.3706E+06
1980	3588	33		8.3636E+06
2010	3585	33.5		8.3566E+06
2040	3583	34		8.3520E+06
2070	3580	34.5		8.3450E+06
2100	3578	35		8.3403E+06
2130	3575	35.5		8.3333E+06
2160	3574	36		8.3310E+06
2190	3571	36.5		8.3240E+06
2220	3570	37		8.3217E+06
2250	3569	37.5		8.3193E+06
2280	3567	38		8.3147E+06
2310	3566	38.5		8.3123E+06
2340	3565	39		8.3100E+06
2370	3567	39.5		8.3147E+06
2400	3574	40		8.3310E+06
2430	3581	40.5		8.3473E+06
2460	3587	41		8.3613E+06

2490	3593	41.5		8.3753E+06
2520	3598	42		8.3869E+06
2550	3603	42.5		8.3986E+06
2580	3610	43		8.4149E+06
2610	3628	43.5		8.4569E+06
2640	3646	44		8.4988E+06
2670	3660	44.5		8.5315E+06
2700	3659	45		8.5291E+06
2730	3655	45.5		8.5198E+06
2760	3652	46		8.5128E+06
2790	3653	46.5		8.5151E+06
2820	3650	47		8.5082E+06
2850	3648	47.5		8.5035E+06
2880	3647	48	2days	8.5012E+06
2910	3649	48.5		8.5058E+06
2940	3648	49		8.5035E+06
2970	3648	49.5		8.5035E+06
3000	3646	50		8.4988E+06
3030	3646	50.5		8.4988E+06
3060	3645	51		8.4965E+06
3090	3644	51.5		8.4942E+06
3120	3642	52		8.4895E+06
3150	3640	52.5		8.4848E+06
3180	3637	53		8.4778E+06
3210	3636	53.5		8.4755E+06
3240	3634	54		8.4709E+06
3270	3631	54.5		8.4639E+06
3300	3628	55		8.4569E+06
3330	3626	55.5		8.4522E+06
3360	3624	56		8.4475E+06
3390	3622	56.5		8.4429E+06
3420	3620	57		8.4382E+06
3450	3618	57.5		8.4336E+06
3480	3616	58		8.4289E+06
3510	3614	58.5		8.4242E+06
3540	3612	59		8.4196E+06
3570	3610	59.5		8.4149E+06
3600	3609	60		8.4126E+06
3630	3607	60.5		8.4079E+06
3660	3606	61		8.4056E+06
3690	3605	61.5		8.4033E+06
3720	3604	62		8.4009E+06
3750	3603	62.5		8.3986E+06
3780	3603	63		8.3986E+06

3810	3608	63.5		8.4102E+06
3840	3613	64		8.4219E+06
3870	3617	64.5		8.4312E+06
3900	3621	65		8.4406E+06
3930	3625	65.5		8.4499E+06
3960	3629	66		8.4592E+06
3990	3632	66.5		8.4662E+06
4020	3635	67		8.4732E+06
4050	3639	67.5		8.4825E+06
4080	3642	68		8.4895E+06
4110	3645	68.5		8.4965E+06
4140	3648	69		8.5035E+06
4170	3650	69.5		8.5082E+06
4200	3651	70		8.5105E+06
4230	3652	70.5		8.5128E+06
4260	3652	71		8.5128E+06
4290	3653	71.5		8.5151E+06
4320	3653	72	3days	8.5151E+06
4350	3653	72.5		8.5151E+06
4380	3653	73		8.5151E+06
4410	3653	73.5		8.5151E+06
4440	3654	74		8.5175E+06
4470	3654	74.5		8.5175E+06
4500	3657	75		8.5245E+06
4530	3657	75.5		8.5245E+06
4560	3657	76		8.5245E+06
4590	3654	76.5		8.5175E+06
4620	3652	77		8.5128E+06
4650	3649	77.5		8.5058E+06
4680	3647	78		8.5012E+06
4710	3645	78.5		8.4965E+06
4740	3645	79		8.4965E+06
4770	3643	79.5		8.4918E+06
4800	3640	80		8.4848E+06
4830	3638	80.5		8.4802E+06
4860	3634	81		8.4709E+06
4890	3631	81.5		8.4639E+06
4920	3628	82		8.4569E+06
4950	3626	82.5		8.4522E+06
4980	3624	83		8.4475E+06
5010	3622	83.5		8.4429E+06
5040	3621	84		8.4406E+06
5070	3620	84.5		8.4382E+06
5100	3618	85		8.4336E+06

5130	3617	85.5		8.4312E+06
5160	3615	86		8.4266E+06
5190	3614	86.5		8.4242E+06
5220	3614	87		8.4242E+06
5250	3619	87.5		8.4359E+06
5280	3625	88		8.4499E+06
5310	3628	88.5		8.4569E+06
5340	3631	89		8.4639E+06
5370	3635	89.5		8.4732E+06
5400	3639	90		8.4825E+06
5430	3643	90.5		8.4918E+06
5460	3646	91		8.4988E+06
5490	3651	91.5		8.5105E+06
5520	3655	92		8.5198E+06
5550	3659	92.5		8.5291E+06
5580	3663	93		8.5385E+06
5610	3665	93.5		8.5431E+06
5640	3669	94		8.5524E+06
5670	3670	94.5		8.5548E+06
5700	3671	95		8.5571E+06
5730	3671	95.5		8.5571E+06
5760	3672	96	4days	8.5594E+06
5790	3672	96.5		8.5594E+06
5820	3671	97		8.5571E+06
5850	3670	97.5		8.5548E+06
5880	3669	98		8.5524E+06
5910	3669	98.5		8.5524E+06
5940	3668	99		8.5501E+06
5970	3666	99.5		8.5454E+06
6000	3663	100		8.5385E+06
6030	3662	100.5		8.5361E+06
6060	3660	101		8.5315E+06
6090	3659	101.5		8.5291E+06
6120	3657	102		8.5245E+06
6150	3655	102.5		8.5198E+06
6180	3653	103		8.5151E+06
6210	3651	103.5		8.5105E+06
6240	3648	104		8.5035E+06
6270	3647	104.5		8.5012E+06
6300	3645	105		8.4965E+06
6330	3643	105.5		8.4918E+06



Stress vs strain 10%

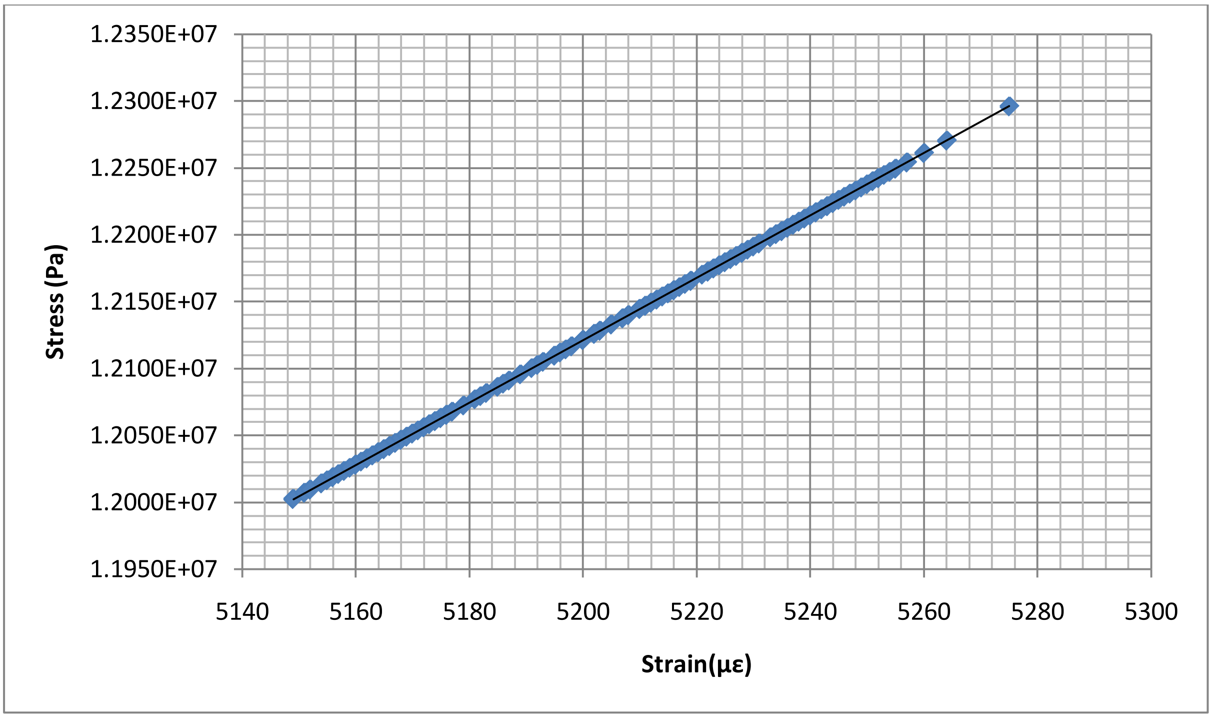
Time(30min intervals)	Strain	Time (hours)	Days	Stress
0	5275	0		1.2296E+07
30	5264	0.5		1.2270E+07
60	5260	1		1.2261E+07
90	5257	1.5		1.2254E+07
120	5257	2		1.2254E+07
150	5252	2.5		1.2242E+07
180	5250	3		1.2238E+07
210	5249	3.5		1.2235E+07
240	5252	4		1.2242E+07
270	5252	4.5		1.2242E+07
300	5249	5		1.2235E+07
330	5247	5.5		1.2231E+07
360	5245	6		1.2226E+07
390	5244	6.5		1.2224E+07
420	5243	7		1.2221E+07
450	5242	7.5		1.2219E+07
480	5242	8		1.2219E+07
510	5241	8.5		1.2217E+07
540	5240	9		1.2214E+07
570	5240	9.5		1.2214E+07
600	5239	10		1.2212E+07
630	5238	10.5		1.2210E+07
660	5235	11		1.2203E+07
690	5233	11.5		1.2198E+07
720	5231	12		1.2193E+07
750	5229	12.5		1.2189E+07
780	5227	13		1.2184E+07
810	5226	13.5		1.2182E+07
840	5225	14		1.2179E+07
870	5224	14.5		1.2177E+07
900	5223	15		1.2175E+07
930	5223	15.5		1.2175E+07
960	5222	16		1.2172E+07
990	5222	16.5		1.2172E+07
1020	5222	17		1.2172E+07
1050	5222	17.5		1.2172E+07
1080	5225	18		1.2179E+07
1110	5226	18.5		1.2182E+07
1140	5228	19		1.2186E+07
1170	5230	19.5		1.2191E+07
1200	5233	20		1.2198E+07
1230	5235	20.5		1.2203E+07
1260	5236	21		1.2205E+07

1290	5237	21.5		1.2207E+07
1320	5234	22		1.2200E+07
1350	5235	22.5		1.2203E+07
1380	5235	23		1.2203E+07
1410	5237	23.5		1.2207E+07
1440	5241	24	1day	1.2217E+07
1470	5241	24.5		1.2217E+07
1500	5238	25		1.2210E+07
1530	5239	25.5		1.2212E+07
1560	5240	26		1.2214E+07
1590	5240	26.5		1.2214E+07
1620	5241	27		1.2217E+07
1650	5245	27.5		1.2226E+07
1680	5246	28		1.2228E+07
1710	5243	28.5		1.2221E+07
1740	5243	29		1.2221E+07
1770	5242	29.5		1.2219E+07
1800	5243	30		1.2221E+07
1830	5244	30.5		1.2224E+07
1860	5244	31		1.2224E+07
1890	5248	31.5		1.2233E+07
1920	5251	32		1.2240E+07
1950	5252	32.5		1.2242E+07
1980	5253	33		1.2245E+07
2010	5254	33.5		1.2247E+07
2040	5255	34		1.2249E+07
2070	5255	34.5		1.2249E+07
2100	5255	35		1.2249E+07
2130	5251	35.5		1.2240E+07
2160	5247	36		1.2231E+07
2190	5244	36.5		1.2224E+07
2220	5241	37		1.2217E+07
2250	5237	37.5		1.2207E+07
2280	5234	38		1.2200E+07
2310	5231	38.5		1.2193E+07
2340	5228	39		1.2186E+07
2370	5224	39.5		1.2177E+07
2400	5222	40		1.2172E+07
2430	5228	40.5		1.2186E+07
2460	5227	41		1.2184E+07
2490	5223	41.5		1.2175E+07
2520	5221	42		1.2170E+07
2550	5219	42.5		1.2165E+07
2580	5219	43		1.2165E+07

2610	5217	43.5		1.2161E+07
2640	5218	44		1.2163E+07
2670	5216	44.5		1.2158E+07
2700	5215	45		1.2156E+07
2730	5216	45.5		1.2158E+07
2760	5215	46		1.2156E+07
2790	5214	46.5		1.2154E+07
2820	5213	47		1.2152E+07
2850	5211	47.5		1.2147E+07
2880	5208	48	2days	1.2140E+07
2910	5207	48.5		1.2138E+07
2940	5205	49		1.2133E+07
2970	5203	49.5		1.2128E+07
3000	5202	50		1.2126E+07
3030	5200	50.5		1.2121E+07
3060	5198	51		1.2117E+07
3090	5196	51.5		1.2112E+07
3120	5195	52		1.2110E+07
3150	5192	52.5		1.2103E+07
3180	5191	53		1.2100E+07
3210	5189	53.5		1.2096E+07
3240	5187	54		1.2091E+07
3270	5185	54.5		1.2086E+07
3300	5183	55		1.2082E+07
3330	5181	55.5		1.2077E+07
3360	5179	56		1.2072E+07
3390	5177	56.5		1.2068E+07
3420	5176	57		1.2065E+07
3450	5174	57.5		1.2061E+07
3480	5172	58		1.2056E+07
3510	5170	58.5		1.2051E+07
3540	5168	59		1.2047E+07
3570	5166	59.5		1.2042E+07
3600	5164	60		1.2037E+07
3630	5162	60.5		1.2033E+07
3660	5160	61		1.2028E+07
3690	5158	61.5		1.2023E+07
3720	5156	62		1.2019E+07
3750	5154	62.5		1.2014E+07
3780	5151	63		1.2007E+07
3810	5149	63.5		1.2002E+07
3840	5149	64		1.2002E+07
3870	5156	64.5		1.2019E+07
3900	5160	65		1.2028E+07

3930	5162	65.5		1.2033E+07
3960	5163	66		1.2035E+07
3990	5163	66.5		1.2035E+07
4020	5163	67		1.2035E+07
4050	5164	67.5		1.2037E+07
4080	5165	68		1.2040E+07
4110	5167	68.5		1.2044E+07
4140	5169	69		1.2049E+07
4170	5172	69.5		1.2056E+07
4200	5174	70		1.2061E+07
4230	5175	70.5		1.2063E+07
4260	5176	71		1.2065E+07
4290	5176	71.5		1.2065E+07
4320	5175	72	3days	1.2063E+07
4350	5175	72.5		1.2063E+07
4380	5175	73		1.2063E+07
4410	5175	73.5		1.2063E+07
4440	5175	74		1.2063E+07
4470	5176	74.5		1.2065E+07
4500	5175	75		1.2063E+07
4530	5175	75.5		1.2063E+07
4560	5174	76		1.2061E+07
4590	5173	76.5		1.2058E+07
4620	5172	77		1.2056E+07
4650	5171	77.5		1.2054E+07
4680	5170	78		1.2051E+07
4710	5169	78.5		1.2049E+07
4740	5168	79		1.2047E+07
4770	5168	79.5		1.2047E+07
4800	5167	80		1.2044E+07
4830	5166	80.5		1.2042E+07
4860	5166	81		1.2042E+07
4890	5165	81.5		1.2040E+07
4920	5164	82		1.2037E+07
4950	5164	82.5		1.2037E+07
4980	5163	83		1.2035E+07
5010	5161	83.5		1.2030E+07
5040	5160	84		1.2028E+07
5070	5160	84.5		1.2028E+07
5100	5158	85		1.2023E+07
5130	5157	85.5		1.2021E+07
5160	5155	86		1.2016E+07
5190	5154	86.5		1.2014E+07
5220	5152	87		1.2009E+07

5250	5151	87.5		1.2007E+07
5280	5152	88		1.2009E+07
5310	5159	88.5		1.2026E+07
5340	5165	89		1.2040E+07
5370	5170	89.5		1.2051E+07
5400	5173	90		1.2058E+07
5430	5177	90.5		1.2068E+07
5460	5182	91		1.2079E+07
5490	5186	91.5		1.2089E+07
5520	5193	92		1.2105E+07
5550	5202	92.5		1.2126E+07
5580	5207	93		1.2138E+07
5610	5210	93.5		1.2145E+07
5640	5211	94		1.2147E+07
5670	5208	94.5		1.2140E+07
5700	5211	95		1.2147E+07
5730	5212	95.5		1.2149E+07
5760	5210	96	4days	1.2145E+07
5790	5213	96.5		1.2152E+07
5820	5212	97		1.2149E+07
5850	5211	97.5		1.2147E+07
5880	5211	98		1.2147E+07
5910	5210	98.5		1.2145E+07
5940	5216	99		1.2158E+07
5970	5219	99.5		1.2165E+07
6000	5219	100		1.2165E+07
6030	5219	100.5		1.2165E+07
6060	5214	101		1.2154E+07
6090	5210	101.5		1.2145E+07
6120	5207	102		1.2138E+07
6150	5205	102.5		1.2133E+07
6180	5203	103		1.2128E+07
6210	5202	103.5		1.2126E+07
6240	5200	104		1.2121E+07
6270	5198	104.5		1.2117E+07
6300	5197	105		1.2114E+07
6330	5195	105.5		1.2110E+07



Stress vs strain 25%

Appendix C

SWP 001

FACULTY OF ENGINEERING & SURVEYING

WORK PERMIT

Permit No: 1055

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: Buddhi Nuwan Lanka Assiriyage

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

Work Area / Location: Z104 Z106

(Work area staff must be consulted BEFORE using any facilities)

Equipment / Process: Test sample preparation & testing of sample

Relevant SWPs: ____________ For Unit / Project: ____________

From (Start): ____________ AM/PM Date: 11/3/10

To (Permit Expires): ____________ AM/PM Date: 24/3/10

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: BNL Assiriyage **Date :** 11/3/2010

APPROVAL

(To be completed by Work Area Manager/Supervisor)

Special Precautions/Instructions: use MSDS before using any chemicals use chem gloves, eye protection, respiratory, cover foot wear & other protective equip. as require

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: M. Jacobs **Date:** 11/3/10

Position : Sr. Tech Off. **Signature:** [signature]

THIS PERMIT MAY BE REVOKED AT ANY TIME.

CENTRE OF EXCELLENCE IN ENGINEERED FIBRE COMPOSITES

STANDARD WORK PROCEDURE

ceefc CENTRE OF EXCELLENCE IN ENGINEERED FIBRE COMPOSITES

USQ AUSTRALIA

WORK PERMIT (SWP001)

Permit No: ______________________

This form is to be used where a Standard Work or Operating Procedure (SWP/SOP) indicates that a permit is required to use CEEFC work areas.

APPLICATION

Name of Applicant: Buddhi NL Assiriyage Student/Employee No: 0050034949

Work Area / Location: P9 / P11

(Work area staff must be consulted BEFORE using any facilities)

Relevant Equipment and SWP's refer to Equipment/Process List on the following page.

For Unit / Project: Aluminium filler composite impact testing

I certify that:

1. I have read and understand the requirements of the Standard Work Procedure applicable to this permit.
2. I have been instructed on the correct operating and safety procedures applicable to this process or equipment.
3. I agree to comply with the SWP/SOP requirements and, follow the correct operating and safety procedures and comply with any special precautions and/or instructions listed below.

Signature: BNL Assiriyage **Date :** 01/04/2010

APPROVAL

To be completed by Work Area Manager/Supervisor

Special Precautions/Instructions: ______________________

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 in the note below.

Name: ATUL SAKHIYA **Date:** 1/4/2010

Position : ______________________ **Signature:** Atul

NOTE: ***General CEEFC Staff*** – permits are valid for duration of 2 years, unless equipment has been modified or permit revoked. ***Students and External Staff*** – permits are valid for duration of 1 year unless equipment has been modified or permit revoked.

THIS PERMIT MAY BE REVOKED AT ANY TIME.

This form is to be completed by the job initiator in consultation with the relevant Work Area Manager.

C:\Documents and Settings\sakhiya\Desktop\CEEFC SWP's\Student Version of SWPs.docx