THEORETICAL PREDICTION OF RECLAIMED CARBON DUST FILLER ON MECHANICAL PROPERTIES OF SILK FABRIC COMPOSITE

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled “Theoretical Prediction of Reclaimed Carbon Dust Filler on Mechanical Properties of Silk Fabric Composite” is the result of my own research except as cited in references.

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Date : 8 February 2021

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Gentian semula jadi adalah pengganti gentian kejuruteraan yang telah digunakan secara meluas dalam pelbagai aplikasi industri dan komersial kerana gentian itu ada potensi tinggi untuk meningkatkan produk mereka. Ini disebabkan oleh sifat gentian semula jadi seperti rendah kos, ringan, kebaharuan dan mesra alam berbanding dengan gentian sintetik. Di antara gentian semula jadi, sutera adalah gentian semula jadi dari haiwan yang banyak digunakan kerana aplikasinya yang tanpa had dan juga kerana ianya kuat, gentian halus yang panjang dan mempunyai sifat mekanikal yang baik. Di antara masalah yang terdapat dalam kajian ini ialah sangat jarang sutera digunakan sebagai bahan pengukuhan oleh kerana kos yang agak tinggi dan kurang maklumat sifat mekanikal mengenainya. Dalam kajian ini keupayaan serbuk karbon sebagai pengisian terhadap sifat mekanikal sutera komposit disiasat. Gabungan gentian ini dengan pengisi akan menawarkan peluang baru untuk menghasilkan bahan pelbagai fungsi dan struktur untuk aplikasi yang lebih maju. Keupayaan sifat mekanikal ini akan direkodkan menggunakan pengiraan matematik dan simulasi ANSYS. Analisa di antara dua pendekatan ini akan dinilai dan dibandingkan untuk membuat korelasi yang lebih baik dan mengetahui jumlah pemuatan pengisian yang sesuai untuk meningkatkan sifat mekanikal komposit sutera. Hasilnya, melalui pendekatan pengiraan, sifat mekanikal komposit sutera dapat diramal di mana dengan penambahan jumlah pengisi karbon sifat mekanikal meningkat pada 10% dan mula menurun pada 40% dengan sokongan analisis ANSYS. Dalam pendekatan analisis, hasil yang diperoleh sedikit berbeza dari teori namun masih menunjukkan peningkatan sifat mekanikal terhadap komposit. Kesimpulannya, pendekatan teori dan simulasi terhadap penyiasatan potensi sifat mekanikal komposit sutera dengan penambahan serbuk karbon untuk pembangunan produk yang mesra alam menunjukkan sifat mekanikal yang baik.

ABSTRACT

Natural fibre is a substitute for the engineered fibre that have been widely used in various industrials and commercial applications since there are yields with high potential to improve their product. This is due to the inherent properties of natural fibres such as low cost, lightweight, renewability and environmentally friendly compared to synthetic fibres. Among natural fibres, silk is a natural animal fibre that widely used due to its limitless applications since it is strong, filiform fibre and possesses excellent mechanical properties. However, it is rare to use silk as reinforcement due to the high cost and least information on the mechanical properties. This study is about to investigate the performance of reclaimed carbon dust filler on mechanical properties of silk fabric composite. A combination of these fibre and filler will offer a new opportunity to produce multifunctional materials and structures for advanced applications. The performance of the mechanical properties recorded using mathematical and ANSYS approach analysis. The analysis between those two approaches be analyzed and compared to create a better correlation and to know the suitable amount of filler loading that can improve the mechanical properties of silk composite. As a result, it shows that in calculation approach, the mechanical strength of silk reinforced composite can be improved and enhanced by the addition of filler content from 10% to 40% where at 40% the mechanical properties start to decrease and this has been validated by ANSYS simulation. In the analysis approach, the result obtained slightly different from the theoretical but still shows an improvement towards the composite. As a conclusion, the potential mechanical properties of silk composite after being added with carbon dust filler for the development of environmentally friendly products and has shown promising performance in mechanical properties.

DEDICATION

To my beloved father, R Azmi bin Dalgiri,
my beautiful mother, Raja Karbiah binti Raja Salim,
my mischievous yet kind sister and brother, Fana and Aboi,
for giving so endlessly support and encouragement during my years in UTeM,
thank you so much and love you to the moon and back.

To my supervisor,
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for guiding, supervise and support me throughout the whole project.

To all my friends and you know who you are,
for always there and support when I’m at the lowest.

May Allah ease our journey and bless with abundance bless, InshaAllah.

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In the name of Allah, the most gracious, the most merciful with the highest praise to complete this final year project successfully without difficulty.

From this project, I had gain a lot of experiences and new knowledges in engineering field. I am deeply indebted to my respected supervisor, Dr. Zurina bt Shamsudin for her kind supervision, advice and guide as well as meaningful experiences throughout this project. Besides, her supervision and support that gave me truly helps during the period in conducting the final year project.

Next, I would like to dedicate my thankful to panels for their assistance and help in teach me a lot of knowledge to improvise my project study.

Finally, I would like to expand my sincere appreciation to my beloved family and friends for being very understanding and give endlessly support during my ups and downs in completing this project. My appreciation also goes to all those who help me directly and indirectly in completing this report. Thank you very much.

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LIST OF ABBREVIATIONS

ANSYS	-	Analysis System
Ap	-	Antheraea pernyi
ASTM	-	American Society for Testing and Materials
BCE	-	Before Common Era
Bm	-	Bombyx mori
CAD	-	Computer-Aided Design
CATIA	-	Computer Aided Three Dimensional Interactive Application
CFE	-	Crash Force Effiency
CFRP	-	Carbon Fibre Reinforced Composite
FFRP	-	Flax Fibre Reinforced Composite
GFRP	-	Glass Fibre Reinforced Composite
ISO	-	International Organization of Standardization
rCD	-	reclaimed Carbon Dust
ROM	-	Rule of Mixtures
PP	-	Polypropylene
SEM	-	Scanning Electron Microscope
SFRP	-	Silk Fibre Reinforced Composite
TETA	-	Triethylenetetramine
UTM	-	Universal Testing Machine
UTS	-	Ultimate Tensile Strength

LIST OF SYMBOLS

wt.%	-	weight percentage
mm	-	millimeter
g/cm^3	-	gram per cubic centimeter
$MPa/g\ cm^{-3}$	-	Mega Pascal per cubic centimeter
MPa	-	Mega Pascal
GPa	-	Giga Pascal
σ	-	sigma for stress
kJ/mm^2	-	kilo Joule square millimeter
°F	-	degree of Fahrenheit
°C	-	degree of Celsius
J	-	Joule
V	-	Volume fraction

CHAPTER 1

INTRODUCTION

1.1 Background study

For a few decades, natural fibres have been widely used in the industry of various sectors ranging from the packaging of food to automotive industries. They have caught quite an attention to the academic world and industry as an alternative to synthetic fibres. Natural fibres are mainly attractive because of the reasons which are specific properties, price, superior corrosion resistance and recyclability. In this study, the selected natural fibre is silk, a fine continuous protein fibre produced by domesticated silkworms and utilization in the textile industry (Merriam-Webster.com Dictionary, 2020). This single specimen is capable of producing a thick thread over 900 meters long enough to weave material. Silk belongs to one of the most precious and vulnerable parts of Chinese cultural heritage. It existed in years before the middle of the 3rd millennium BCE. They have a long history of silk culture in China been discovered that a large number of valuable silk fabrics in various ancient tombs. Recently, silk seems to be useful because of its physical properties, one of the strongest natural fibres. This natural fibre might be used as a reinforcement with other material because of its characteristics to form a composite with good mechanical and thermal properties. According to Marine *et al.* (2017), several composite materials using silk as a matrix or reinforcement have been prepared for biological applications.

Many researchers evaluated the mechanical properties of their composite by using calculation and simulation not by using machine testing in the lab. With the help of mathematical approach and ANSYS simulation, they can obtain the analysis and result of mechanical properties such as tensile strength, toughness and impact strength. Thus, this study is needed to embark on new knowledge and skills in simulation to gain an understanding of the application of silk reinforced composite on filler loading towards mechanical properties of reinforced composite that may affect the results.

1.2 Problem statement

There are some problem statement needs to be considered by investigating the material used in order to solve the problem of this study. Recently, expanding environmental towards sustainability countries has led to strict policies in concern to persuade industry to produce an eco-friendly product. As stated in the background study, natural fibres can produce many types of reinforcement in composites. Although a range of composites contains silk that has been designed, the mechanical properties achieved for the regenerated silk remain weak because of the reinforcement. Besides, the main concern of this study is to reinforce the silk with filler to improve the properties of the materials. The selected filler is carbon dust from trimming waste which is disposal that can be recycled to be used with reinforced material. Millions of tons of waste are discarded every year in incinerated, recycled or dumped landfills. The researchers found an alternative to the waste because they might be contributing to the production industry by adding value to the products. They have reinforced the natural fibres, silk with filler as it may prove that they can reduce environmental pollution through a combination of biodegradable or recycled filler materials.

Firstly, the silk fabric is rarely used because of the high cost and the least information about material properties. It needs to reinforce silk with selected filler, carbon dust. But there is a problem where need to predict the suitable amount of carbon dust that will be reinforced with silk composite and its involving formula and calculation. By using mathematical approach as the method to solve the problem, the study can determine the suitable weight fraction of filler loading in order to obtain improving mechanical properties of silk composite. According to Youssef K. *et al*. (2018), silk exhibits higher mechanical performance than plant fibres and in some cases comparable specific mechanical properties to glass fibres. By reinforcing the material, the result can achieve more useful material that can be used and help the industry. This type of reinforcement with composite will turn the overall properties such as tensile, impact or even the physical properties of composite material and reduce the cost. Without this study, it is not easy for the industry to create a sustainable product that could negatively affect the environment as it may destroy most of the lands and water to achieve its mission. For example, tensile and impact strength of the mechanical properties of composite because the collected data is only calculated using formula and equation. In order to analyze the relationship between filler loading and silk, it is required to run the analysis by using ANSYS simulation to get a rigid result. From the simulation, the sample can be design followed to our requirement and obtain the results.

Based on the prediction, thus the reinforcement and filler can work well to improve the mechanical properties and solve all of the problems mentioned in this section. Furthermore, it may be another composite material alternative that is low cost to manufacture the product.

1.3 Objective

The objectives of this study are as follows:

1) To predict the influence of carbon dust at different filler loading on the mechanical properties of silk reinforced composite using mathematical approach.
2) To analyze the correlation between the filler loading on performance computing using ANSYS simulation.

1.4 Scope of the study

The scope of the study is listed down to specific scopes that been identified based on objectives. Among the scopes listed is the material with unidirectional fibres in layers of silk fibre and carbon dust used as the primary material because in this study it used longitudinal fibre formula to calculate the mechanical properties using mathematical approach. It is because the fibres are layer in a longitudinal direction. The epoxy resin is under thermosets known as three dimensional crosslinked network. Thermosets have an advantage in incorporating fibres compared to thermoplastics. The research on the amount percentage of the materials needed to generate a composite which resulting in mechanical properties of silk reinforced composite. The samples reinforced with filler loading, carbon dust of different weight fractions (10%, 20%, 30% and 40%). The outcome of this study, to reduce the layers of silk in the composite by replacing it with carbon dust filler. It aims to develop a low-cost composite and has high mechanical properties even though not using entirely silk fibre. The results of the study can clearly state the differences in strength, tensile and also including the interphase and interface of materials by running analysis and compared the results using mathematical approach and simulation to calculate the mechanical properties involved.

CHAPTER 2

LITERATURE REVIEW

2.1 Type of Natural Fibre

According to Sen *et al.* (2016), natural fibre is inexhaustible resources with a few points of interest on them that may help the industry. These materials have outstanding mechanical properties such as it can impart the composite in high specific stiffness, tensile and strength, biodegradable, have attractive fibre aspect to ratio and consistently available from a natural source to be utilized or reap. Natural fibre may lead to advanced advantages compared to synthetic fibres due to their abundance, availability and low cost (Arpitha & Yogesha, 2017). It is because these materials can be used to reinforce both thermoplastic and thermosets matrices in order to enhance their quality and properties. Thermoplastic such as polypropylene, polyethylene and polyolefin while thermosets such as epoxy resins, polyester and polyurethane are commonly used composites because it is required in higher performance applications. These materials can provide sufficient mechanical properties in certain stiffness and strength at low price levels.

There are various types of natural fibres have been found existed nowadays. Mochane *et al*. 2019 stated that natural fibre is extracted from different renewable sources mainly from plant, animals or minerals. Mittal *et al*. 2016 stated that, there are two types of natural fibre from plants. The main is primarily fibre directly obtained from plant root while the other is secondary fibre, which is the by-product from the utilization of the primary fibre. Examples of primary fibres are hemp, kenaf, sisal and cotton while for secondary fibres are wheat straw, pineapple, *etc.* Figure 2.1 shows the classification of different natural fibres.

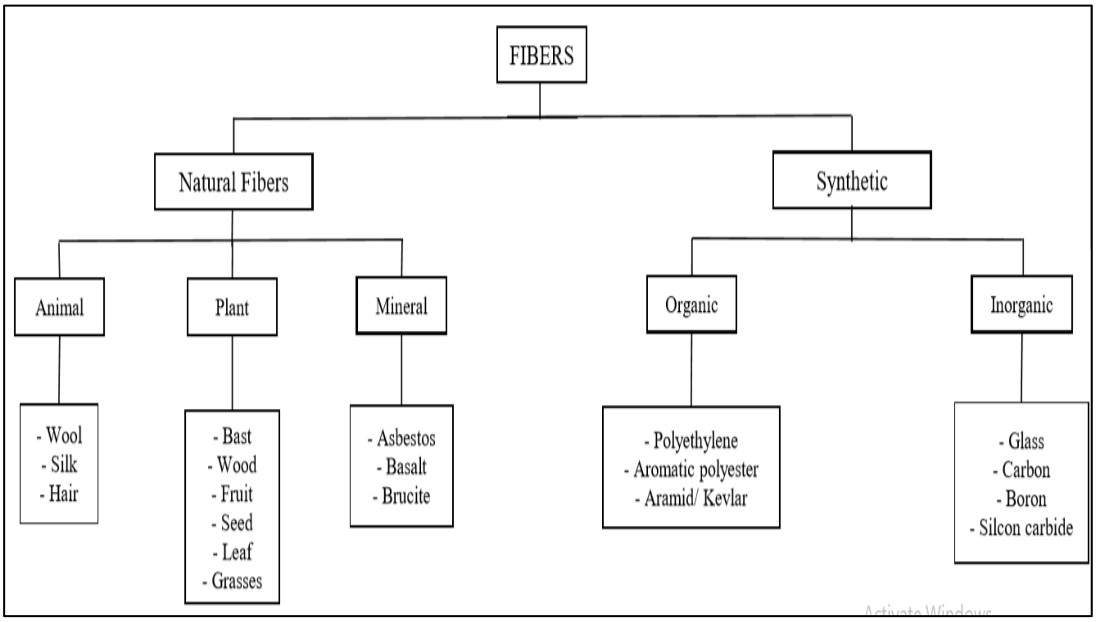


Figure 2.1 The classification of fibres (Mochane *et al*., 2019)

In addition, silk is listed under animal in natural fibres need to be used in this research to achieve the objectives of the study. The table 2.1 shows the natural fibre advantages and disadvantage listed below for further understanding.

Table 2.1 Natural fibre advantages and disadvantages (Mochane *et al*., 2019)

Advantages	Disadvantages
Recyclable	High moisture absorption
Light weight/ Low density	Dimensional instability
High specific mechanical properties than glass	Low strength and thermal resistance than glass fibres
Produce no harmful gasses during handling and irritating skin	Scent aging during degradation

2.1.1 Silk fibre

Silk has occupied a leading position in textile industries because of its luminescence and superb mechanical properties even though there is the least information. Silk yarn is easier to get from the waste of the fabric so the composite can be re-used as a matrix. It is also cost-effective. Silk fibres are removed from silkworms for apparel purposes since old occasions which hundreds of years back until now. Khanam *et al*. 2015 stated that there are many insects produce silk such as mulberry silk moth, *Bombyx mori*, spider, bee and other insects. Still, the only insects that produced silk filament for commercial silk industry are from *Bombyx mori* and mulberry silk moth. Besides, according to Du *et al*. 2016 explained that apart from domestic silkworm silk, there are wild silkworm silk has been evaluated into special research because of their credit to its specific amino acid sequence that might give an advantage to processing material. For example, the pernyi silk has a lower crystallinity, hence a lower strength but superior elasticity and toughness (Zhang *et al*., 2010). Silk is utilized as reinforcement with various polymers to produces a composite that produce great mechanical and thermal properties such as high strength, flame resistance, extensibility and compressibility (Pickering *et al*., 2015; Hamidi *et al*., 2018). Silk exhibits higher mechanical performance than plant fibre. The *Bombyx mori* silkworm consists of a fibrous core protein named fibroin and a group of glue-like proteins named sericin that surround the fibroin thread together (Khanam *et al*., 2015). The compositions of fibroin and sericin proteins for each insect are different. Moreover, the commercial silk fibre *Bombyx mori* has a modulus of about 10 GPa with a strength of 400 MPa. The important strength parameter is fibre diameter, ranging from 20 µm to a few tens of nanometer (Chen, 2011).

In recent years, there are increasing interest in the application of silk fibroin for the development of biotechnological uses, such as biodegradable plastic and medical devices such as ultrasound machine (Shen, 2019). Despite the increasing interest towards which type of silk should be selected, a fundamental understanding on the adhesion between the layers of silk, fibroin and sericin need to be achieved. The understanding could offer inspiration to the design of composite materials with a tremendous interfacial bond between different components and their superior properties.

2.1.2 Physical and mechanical properties of silk fibre

Various trials have been made in developing and produce the reinforcement of the new material which can replace the current materials to produce superior physical and mechanical properties of different applications. Table 2.2 shows the mechanical properties of some natural fibres for further understanding. The properties of each natural fibres are differed due to fibre types as well as growing conditions, harvesting time, extraction treatment and capacity procedures (Pickering *et al*., 2016).

Table 2.2 Mechanical properties of natural and synthetic fibre for comparison (Pickering *et al*., 2016; Darshan *et al*., 2016; Khanam *et al*., 2015)

Natural fibre/ Properties	**Length (mm)**	**Density (g/cm^3)**	**Elongation (%)**	**Tensile strength (MPa)**	**Specific tensile strength ($MPa/g\ cm^{-3}$)**	**Young's modulus (GPa)**
Silk (Animal)	Continuous	1.25 – 1.35	15 – 60	200 – 1800	0.1 – 1.5	5 – 25
Cotton (Seed)	-	7.0 – 8.0	3.0 – 10	287 – 597	0.19 – 0.53	5.5 – 13
Flax (Stem)	25	1.5	1.2 – 1.6	345 – 1035	230 – 1220	18 – 53
Coir (Fruit)	150 – 250	1.2	15 – 40	175	110 – 180	3.3 – 5
Carbon (Synthetic)	-	1.4 – 1.8	1.4 – 1.8	4000	-	230 – 240
E-glass (Synthetic)	Continuous	2.55	2.5	3400	800 - 1400	29

Table 2.2 provides the comparison between animal, plant and synthetic fibre with their mechanical properties based on the three sources stated in the table. Silk represents animal fibre which has advantages over plant-based natural fibre such as uniform fibre properties, continuous fibre type, high toughness and tensile strength, but this silk might be expensive. Next, cotton from seed plant-based natural fibre has an excellent absorbency as cotton represents 46% of world production. Flax from the plant stem has better specific tensile when compared with glass fibre. It also has low density, high strength and stiffness. Other than that, we have coir from the fruit in plant-based natural fibre. They have a great attractiveness because it is more durable than most of the existing natural fibre, free of chemical treatment and strong resistance to saltwater. Lastly, synthetic fibres are carbon and glass represents the replacement of natural fibre-reinforced composite. They also produce a great application in part and production life of a product (Pecas *et al*., 2018).

2.1.3 Structure of silk fibre

Fibre is a continuous filaments like thread or chopped fibre which has been cut accordingly to the size. According to Kujala *et al*. (2016), silk fibres produced by *Bombyx mori* and other silkworms as revised in subtopic above contain two protein nano-filaments with triangular sections that are 5 – 10 µm wide which named as brins or in easier sentences it is known as one of two filaments of silk combined to form a strand of silk. It is embedded in and held together by a water-soluble sericin protein layer. Sericin is a protein which is removed as it can actuate an inflammatory reaction if silks are used in biological applications. To be exact, it is also being removed in the textile application. The silk cocoons are degummed and it is spun into rovings and yarns then woven into textile fabrics (Hamidi *et al*., 2018). Yang *et al*. (2016) stated that the silk fabric was firmly woven with little porosity between the filaments with dozen of threads in orthogonal directions. Figure 2.2 shows SEM image of plain weave silk fabric. Likewise, the picture shows the shape of silk fibre is uniform despite it not perfectly circular in shape.

Figure 2.2 Image of plain weave silk fabric under SEM (Yang *et al*., 2016)

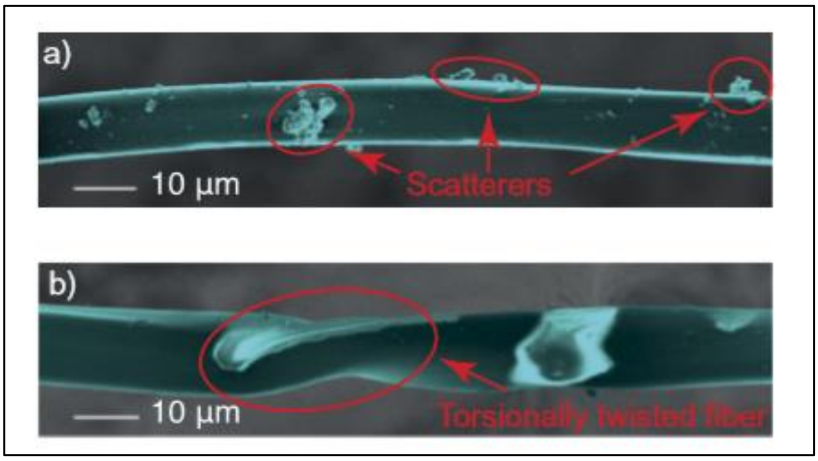


Figure 2.3 Zooming in the shape of silk fibre (Kujala *et al*., 2016)

Moreover, some researchers found out that silk waste from the textile industry can be used as reinforcement material with composite (Hamidi *et al*., 2018). Nowadays, the researchers still doing their study towards the silk reinforced composite and silk itself. As we know, researchers already develop a reinforcement material of silk embedded with polymers such as thermoplastic and thermosets. There are two types of fibre-reinforced phase arrangement which are woven (from silk fabric) and non-woven from natural cocoon walls (Pecas *et al*., 2018; Hamidi *et al*., 2018).

A fibre-reinforced composite depends well on the contribution of additional characteristics such as matrix properties, fibre and matrix ratio, coupling agents and method of processing (Pecas *et al*., 2018). As demonstrated in Yang *et al*. (2017) study explained that they need to incorporate up to 60 vol.% of silk with epoxy resin to get the sample result only partially damaged and resist complete fracture of impact strength. Table 2.3 shows the impact properties of the SFRP with different volume of strength and specific impact strength for further understanding.

Table 2.3 Impact properties of the SFRP with different volume of strength and specific impact strength (Yang *et al*., 2017)

Sample	**Impact strength, σ_i kJ m^{-2}**	**Specific Impact Strength, σ_i/ρ J m^{-2}/kg m^{-3}**
Unreinforced Resin	12.8 ± 0.2	10.7 ± 0.1
30 vol.% *Bm*-SFRP	18.5 ± 1.4	15.0 ± 1.2
60 vol.% *Bm*-SRFP	70.7 ± 1.7	56.1 ± 1.4
30 vol.% *Ap*-SFRP	52.5 ± 3.1	42.7 ± 2.5
60 vol.% *Ap*-SFRP	> 10	> 79.4

Vu *et al*. (2019) stated that a small quantity of silk fibroin solution could make a lot of silk-fibroin nanofibres thus the hydrogen bonds and Van der Waals forces make the interactions between silk nanofibres very strong. These forces lead to expanding the quantity in the composite that will debilitate the end material. Hence, the reinforcement matrix tends not to separate into individual fibres when a high portion of nanomaterial such as silk fibroin nanofibre is used (Vu *et al*., 2019). As for the summary, the studies successfully developed a strong and tough composite through natural silk as reinforcement as it improved the properties of silk reinforcement composite significantly.

2.2 Carbon Waste

This topic will discuss the waste material which is carbon dust act as filler material used to reinforce with the silk composite. The CFRP dust needs to be separated using special techniques to require pure carbon dust to be used in reinforcement composite in this study.

Polymers waste has been a significant constituent's national solid waste every year. Millions of tons of plastic waste end up either in incinerated and dumped in landfills. The authority or certain non-government organization is recycling only the selected waste. Hence, researchers found methods using this waste as value-added to producing products such as fuels, carbon nanotubes, and porous carbons as an alternative. Many types of waste that can be recycled, such as plastic and natural fibre waste. This report will be using carbon dust from excessive Carbon Fibre Reinforced Composite (CFRP) during processing or machining. The CFRP is recognized as the material used to fabricate parts in the aerospace industry. It also contains up to 90% carbon along with additives such as silica, alumina and other minerals. As for information, recycling rates for CFRP are low because the waste will end up in landfills.

Several types of research stated on how to recycle and reuse waste into useful waste that can be used in the manufacturing industry. According to Bazargan *et al*. (2013), another option for plastic waste treatment is to focus on the production of solid and vaporous instead of fluids. Likewise, numerous chemical and physical treatments are recorded to produce porous materials consisting of activated carbon from plastic waste. Other than that, as stated in Khanna R. (2018), carbon waste has several techniques that might help in recycling carbon waste such as pyrolysis, mechanical grinding and so on different approaches. Recycled carbon fibres can be 30% to 40% cheaper than the original carbon fibres, but there might be a problem in the degradation of fibre characteristics during reuse. Reduction of carbon waste in the industry could reduce the carbon footprint and help divert carbonaceous waste from landfills and environmental impact.

2.2.1 Filler loading

The filler is considered as additives which can modify or improve the properties of polymers. Their other contribution also was to lower the cost of materials by replacing the expensive polymer. The addition of fillers requires a balanced formula for optimum processing properties. Hence, there are few conditions to establish such as optimum loading level for the property, optimum formulation for processing and production input and economics of filled formulation (Nura, 2008). The filler loading, carbon dust from excessive Carbon Reinforced Fibre Composite (CFRP) dust to reinforce the filler category. In developing the reinforcing filler, the material modification aims to increase the aspect ratio of particles and improve the interfacial adhesion of the polymer matrix (Xanthos, 2005).

Filler in this research is from particulate filler in the state of powder usually less than 100 µm in size. The dust itself predominantly consists of fibre bundles embedded in epoxy resin due to their adhesive forces. The fibre lengths range from l_f = 10 µm to 1000 µm will affect the process used. These fibres are coated with bonding agent for better interface connectivity where the primary used for textile processing and production of CFRP, the secondary fibres as a recycle of primary fibres. To separate the particles distribution of carbon fibres with the raw material, a classification of length needs to be conducted for better prediction of material properties (Uhlmann and Meier, 2017). The amount of filler loading was measured from 0 g to 20 g, gram as referred to Khan *et al*. (2017) as a guideline.

Table 2.4 shows the fillers and their functions for further understanding. As for information, additional functions of the filler include degradability enhancement, barrier characteristics, anti-aging characteristics, *etc*.

Table 2.4 Fillers and its functions (Xanthos, 2005)

Primary function	**Fillers**	**Additional functions**	**Fillers**
Modification of mechanical properties	**High aspect ratio**: glass fibres, nano-clays, carbon nanotubes, carbon/ aramid/ natural fibres **Low aspect ratio**: talc, $CaCO_3$, wood flour, wollastonite	Control of permeability	**Reduced permeability**: impermeable plate-like fillers: talc, nano-clays, glass flakes
Enhancement of fire retardancy	**Hydrated fillers**: $Al(OH)_3$, $Mg(OH)_2$	Bioactivity	**Bone regeneration**: hydroxyapatite, tricalcium phosphate, silicate glass
Modification of electrical and magnetic properties	**Conductive, non-conductive ferromagnetic**: metals, carbon fibres and nanotubes, carbon black	Degradability	**Organic fillers**: starch, cellulose
Modification of surface properties	**Antiblock, lubricating**: silica, CaCO3, PTFE	Radiation absorption	Metal particles, lead oxide

2.2.2 Reclaimed carbon dust

There are various ways to get carbon dust from CFRP waste. The CFRP needs to undergo a certain method to possess away the polymer that binds together with the CFRP to require the reclaimed fibre of carbon. Nowadays, advance technologies have been discovered which can be classified in mechanical recycling and thermochemical recycling. The first way is by mechanical recycling. This type of recycling involves mechanical disintegration on the composite by crushing, grinding, milling, shredding or other similar processes in order to get the result (Yu *et al*., 2016). The recovered materials can be separated by the filter into powder product which is resin rich powder and fibrous product of different length which is rich fibre. The powdered product can be utilized as a filler integrate with the new composite while the fibrous product can be reuse in composite because of their cost and quality (Khanna, 2018; Yu *et al*., 2016). However, this recycling product is low-value application because it does not recover the individual carbon fibre in this type of recycling. According to Shuaib and Mativenta (2016), in order to obtain fine recycled product is by reducing the screen size. It will result in an increase in energy consumption and processing time. Figure 2.4 shows the example of a machine that undergoes mechanical recycling while figure 2.5 shows the CFRP's recycled fibrous product.

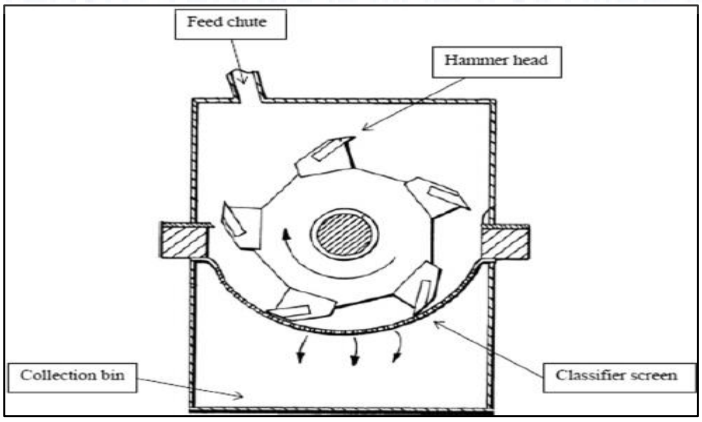


Figure 2.4 Machine used in mechanical recycling (Howarth *et al*., 2014)

Figure 2.5 Recycled fibrous product of CFRP (Milberg, 2018)

Next, the thermochemical recycling techniques are often used to recycle the CFRP because of their efficiency in breaking down the thermoset matrix. It uses heat to break down the composite and the operating temperature is from 450°C to 700°C. It will likely burn the excess composite and leave the fibres (Gopalraj and Karki, 2019). There are many reclamation methods under this type of recycling as an example are the fluidised bed, pyrolysis (heating in the absence of air), and microwave-assisted pyrolysis. The first way is to use a fluidised bed where a fast flow of hot air passed through a bed of silica sand allows the chopped scrap composite to decompose at a low temperature. Typically used a 0.85 mm particle size of fine silica sand to make a bed converted into a fluidised bed that the airflow will pass through in the velocity, 0.4 – 1.0 m/s. The composite scrap is cut to 25 mm in size and will separately pour into the fluidised bed. Inside the bed, the scrap will be separated into fibres and fillers which then will be carried out by the airflow as individual particles (Gopalraj and Karki, 2019). Figure 2.6 shows the fluidised bed process shown below for a further understanding of its process. Even so, this recycling is efficient but it quite has limitations in its ability. The process is capable of retaining only 50% of the tensile strength (Pickering *et al*., 2000).

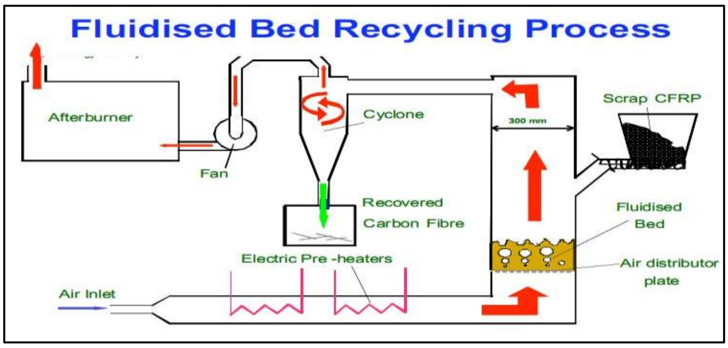


Figure 2.6 Fluidised bed process (Gopalraj and Karki, 2019)

Meanwhile the other process which known as thermochemical recycling is the pyrolysis process where the outcomes are the retention of mechanical properties, recuperation of carbon fibre and the absence of synthetic compounds. When higher amounts of energy depending on the operating temperature applied during pyrolysis, the process does not cause local area contamination (Khanna, 2018). The heating process is undergoing under the absence of air because the decomposing matrix can produce oil and gas along with the outcome products under this condition. The oil and gas can be the chemical feedstock for other processes. Even so, pyrolysis also has limitations where there will be the formation of char possibility occurred on the resulting fibre surface. Figure 2.7 shows how the pyrolysis process undergo.

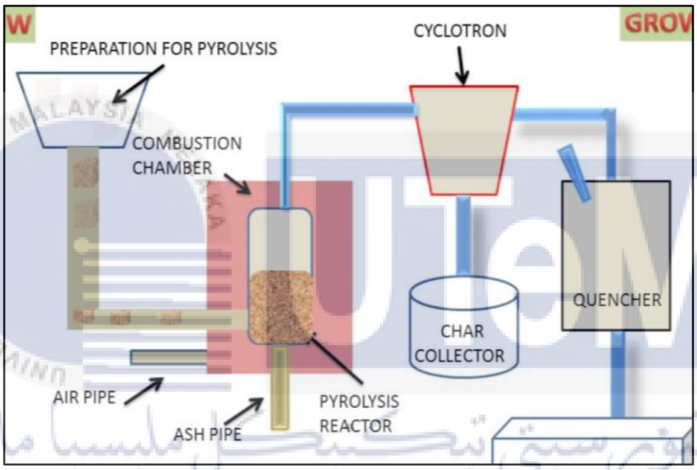


Figure 2.7 Pyrolysis process (Gopalraj and Karki, 2019)

The microwave-assisted pyrolysis is a process where direct heating of material core in the inert atmosphere occurred in thermal transfer and energy savings. The sample of carbon fibre and resin are placed in a microwave then will utilize quartz sand to suspend the sample and glass wool as they have to avoid material loss. Fluidised bed reactor using silica sand to make bed, will dissociate the resin from CFRP matrix. This process is contaminated as well as end of life waste because it does not recover the carbon fibre (Khanna, 2018; Gopalraj and Karki, 2019). Hence, landfilling and incineration are not sustainable approaches to decompose the CFRP waste anymore because of their harmful effect on the environment. Figure 2.8 shows the microwave-assisted process.

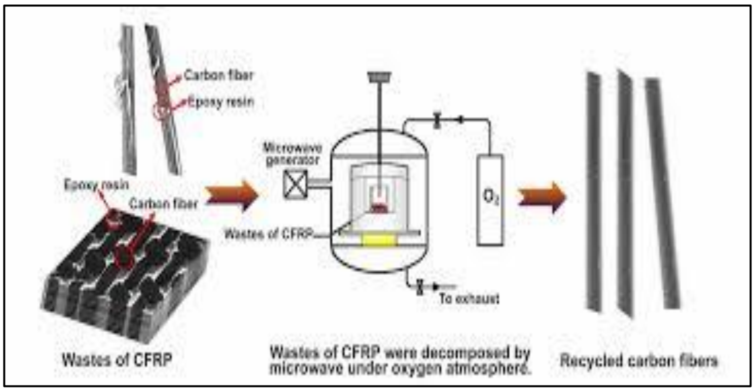


Figure 2.8 Microwave-assisted process (Deng *et al*., 2019)

2.3 Silk reinforced composite

Composites are a material system that made out of at least two or more physical phases which are the combination produces properties that are different from those of its constituents as an example is plastic moulding compounds containing filler or elastic properties mixed with carbon black. This study needs to reinforce silk with the addition of filler loading, reclaimed carbon dust (rCD) and help from thermosets to bind them into the composite. Filler loading which is carbon dust, will be expected to produce an excellent result in miscibility conditions with silk fibroin. The physical and mechanical properties of the composites firmly rely upon the polymer matrix, fibre reinforcement, and their interfacial interactions. Notably, the fibre/matrix interface ensures the stress transfer from the weak matrix to the strong fibre, so the composite performance has mostly relied upon the fibre/ matrix adhesion (Yao *et al*., 2017).

By choosing an appropriate combination of matrix and reinforcement materials, the new material can be made that precisely meets the necessities of an application. There are three types of polymer matrix that can be reinforced with the fibre which is thermoplastic, thermosets and elastomer. Mazumder *et al*. (2018) reported that they are using thermoplastic polypropylene (PP) as matrix material reinforced silk and glass fibre. The result turns out that when the amount of fibre added increases, the contact between fibre and matrix increases and it tends to make the interfacial bonding weaker. But impact strength of composite remains unchanged when there is an increase in fibre loading. Based on the study's result and analysis, composite that contains 10 wt% fibre exhibit good mechanical properties. Also, Li *et al*. (2018) study describing PVA-co-PPE nanofibres reinforced silk films. It is believed that the increasing fibre contain was the result of an improvement of strength and flexibility. This research will use epoxy resin as a matrix that binds together silk and carbon dust to develop material.

The silk cocoons are spun and degummed into roving and yarns then woven into textile before reinforcing in the composite. According to Hamidi *et al*. (2018) study, a linear increase of properties was observed with increasing fibre content from 30% to 70%. The improvement in properties such as tensile, flexural and impact are supported by Yang *et al*. (2016) with the highest fibre content, 70% reinforced to epoxy resin. Above all, supporting this investigation and further understanding of the mechanical properties of silk reinforced composite results.

2.3.1 Thermosets as matrix

Thermoplastic and thermosets are two different polymers matrix which can be differentiated based on behaviour in the presence of heat. The difference between those two matrices is thermoplastic can be re-melted while thermoset remains in the permanent solid state once it is hardened. Pascault *et al*. (2018) explained that thermoplastic is a linear polymer that in solid-state either in semi-crystalline or amorphous so when they are heated in high temperature, the polymer chain will be free to move and flow takes place. While for thermoset, they are cross-linked polymers so their chemical bonds cannot be destroyed at high temperatures. Thermoset is suitable to be used as a matrix because of its properties. The tensile behaviour whereas the temperature increases, the modulus will rapidly fall to T_g section on the graph as the polymer is viscoelastic while at high temperature, the polymer becomes rubbery. Most Young's modulus in thermosets are range from 2 – 4 GPa and even with high crosslink resin, it is possible to achieve modulus at 6 GPa (Mullins *et al*., 2018). Figure 2.9 shows Young's modulus of thermoset.

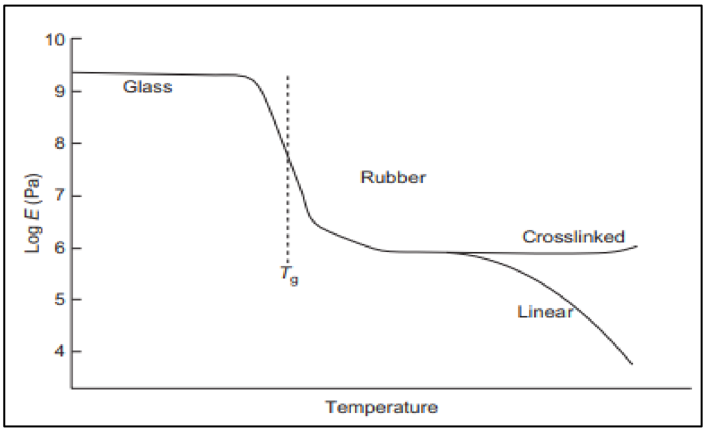


Figure 2.9 Young's modulus curve (Mullins *et al*., 2018)

In this study, the selected thermoset is epoxy resin where it is the versatile monomers that can adapt in various applications. The most common applications are adhesives, coatings, sealers, casting and many other more. The epoxy has good adhesion to metal and reinforcing fibre such as carbon because of their formation in hydroxyl group during curing with hardener (Mullins *et al*., 2018). According to Renjit (2017) stated that the hardener consists of polyamine monomers as example Triethylenetetramine (TETA). When the compounds are mixed together, the amine group will react to form a covalent bond with the epoxy group. The result is polymer formed have a strong cross-linked and therefore becomes stiff and strong. Moreover, epoxy resin is suitable to be used as a matrix because of their high strength and mechanical adhesiveness characteristics. Figure 2.10 below shows example various of epoxy resin widely sold in the market.

Figure 2.10 Example of epoxy resin

2.4 Characterization of silk composite

This section discusses the characterization of silk composite in three main parts which are mechanical testing, morphological using Scanning Electron Microscope (SEM) and its applications. The performance of carbon dust reinforced silk composite depends on many factors such as their fibre ratio, directions of layer, fibre length, etc. In order to achieve the desired result, the reinforced composite needs to undergo specific characterization.

2.4.1 Mechanical testing

In this mechanical testing, there are two methods essential to be tested on the material to know the properties of the composite after being reinforced. The mechanical characterization example is tensile, flexural, impact and hardness. This study covers only on describe tensile and impact strength as it is our aim in this section. The test needs to be carried using the international standard that has been set as examples ASTM and ISO standard. The samples that have been developed using the hand lay-up method with different shapes because of different type of testing that they will undergo has been considered. Figure 2.11 shows hand lay-up method and figure 2.12 shows the shape of the samples.

Figure 2.11 Hand lay-up method (Ramesh and Sudharsan, 2017)

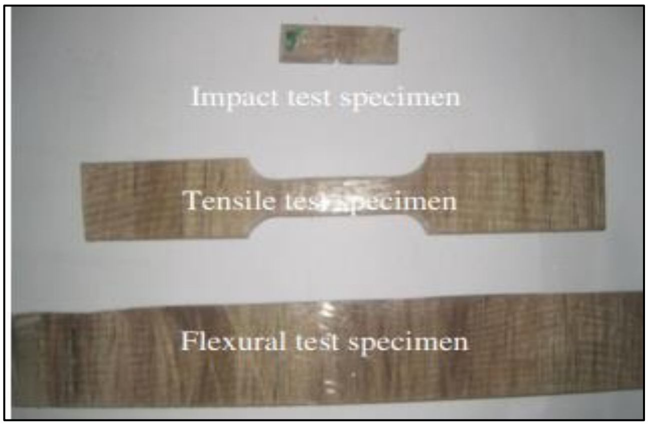


Figure 2.12 Shape of sample with different testing (Ramesh and Sudharsan, 2017)

As for tensile strength, it is the main properties require to run testing when experimenting on a material. Tensile strength is maximum that a material can support without fracture when being stretched (Ramesh and Sudharsan, 2017). The shape of the sample is dog bone-shaped as in the figure. The sample prepared according to the international standard ASTM D638 for plastic and polymeric materials. The deformation of the sample occurred when applied an increasing load along the long axis of the sample using Universal Testing Machine (UTM). The test will require a moving crosshead in mm/min to notice the breakage of the sample occurred. The load at a designated point will be used to calculate the maximum tensile strength in the mathematical approach using the formula given (Mazumder *et al*., 2018; Ramesh and Sudharsan, 2017). Figure 2.13 shows the tensile fracture sample while figure 2.14 is the machine that runs the tensile testing.

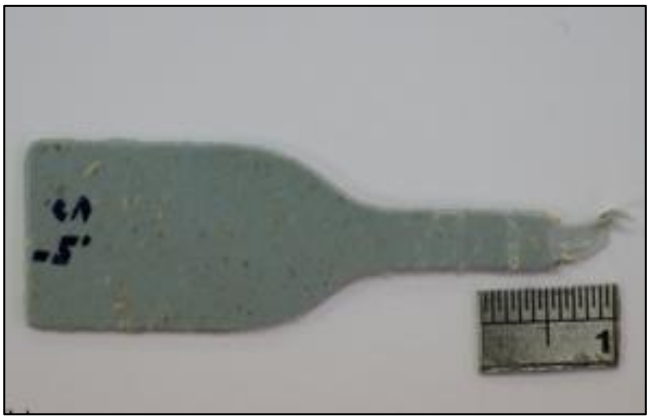


Figure 2.13 Tensile fracture sample (Khanam *et al*., 2015)

Figure 2.14 Universal Testing Machine (UTM)

The fibre used in the study below is silk, flax and glass and it's reinforced with epoxy resin. The result from table 2.5 below can be as a guideline.

Table 2.5 Mechanical properties of silk fibre reinforced composite (SFRP) compared with flax fibre reinforced epoxy resin composite (FFRP) and glass fibre reinforced epoxy resin composite (GFRP) (Yang *et al.*, 2016)

Composite	Fibre volume fraction (%)	Density (kg/cm^3)	Tensile stiffness (GPa)	Tensile ultimate strength (MPa)	Impact strength ($kJ.m^{-2}$)
Nonwoven silk-epoxy	36.2	1.20	5.4 ± 0.2	60 ± 5	16 ± 1
Plain woven silk-epoxy	45.2	1.22	6.5 ± 0.1	111 ± 2	115 ± 7
Nonwoven flax-epoxy	15–35	1.20 – 1.26	5.8 – 9.8	37 – 75	8 – 15
Plain woven flax-epoxy	30–5	1.24 – 1.3	7.3 – 11.2	63 – 89	23 – 36
Nonwoven glass-epoxy	15 - 45	1.36 – 1.80	10.2 – 16.7	123 – 241	73 – 107
Plain woven glass-epoxy	30 - 65	1.58 – 2.09	17.0 – 24.0	350 – 500	165 – 280

Figure 2.15 and 2.16 below, the ultimate tensile strength (UTS) of the composite decreased when there is increasing in fibre loading. The contact between fibre and matrix increases as the amount of fibre added increases in order to make the interfacial bonding weak. As a consequence, the weak interfacial between matrix and fibres increase.

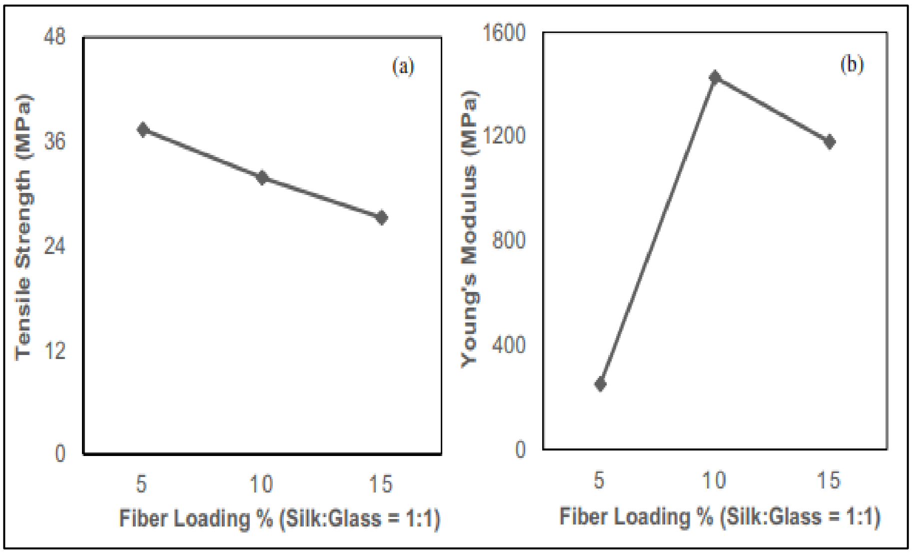


Figure 2.15 (a) Tensile strength and (b) Young's modulus against fibre loading (Mazumder M. R. H. *et al.*, 2018)

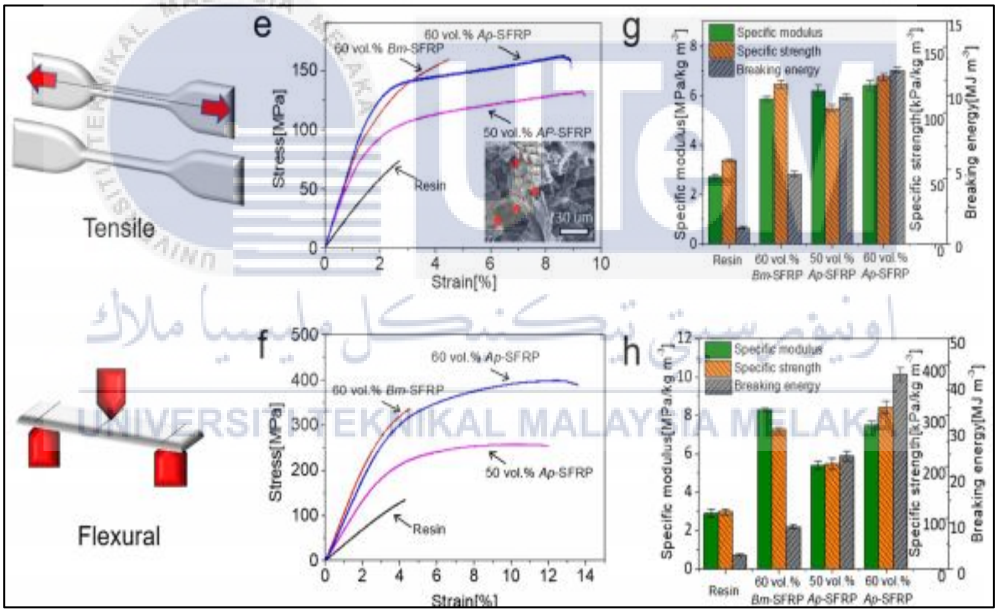


Figure 2.16 (e) Stress strain curve of pure epoxy resin, 60 vol.% Bm and Ap-SFRP and 50 vol.% Ap-SFRP, (f) flexural mode, (g) and (h) breaking energy of the selected Bm and Ap-SFRP (Yang K. *et al.*, 2017)

Next is the impact testing where it used to measure the impact of the materials when a sudden load or force applied onto the sample to see whether the material tough or brittle (Ramesh and Sudharsan, 2017; Khanam *et al.*, 2015). There are Charpy and Izod impact testing to measure the impact energy. In this test, a pendulum with a gigantic striking edge is permitted to hit the sample. The mass and drop stature will decide the vitality of the hammer. Breaking sample is a two advance procedure where it needs the energy to create a crack and more energy to broaden the crack to failure (Khanam *et al*., 2015). The samples prepared for Charpy impact according to ASTM D6110 standard. Figure 2.17 shows the impact tester machine that used to run the impact testing.

Figure 2.17 Impact tester machine

According to Yang K. *et al*. 2017 stated that they similarly investigate the silk fibre with the epoxy resin to know the difference impact strength on the composite. From the result, it can determine the two different silk samples produce a relatively slight different result against each other. These data show the silk fibre reinforcement problem in impact strength can be solved by increasing the fibre volume fraction up to 70 vol.%. It might give a head upon how weak or strong the impact testing be. Table 2.6 below shows the impact properties for the epoxy resin of different type of reinforcement.

Table 2.6 Impact properties of the epoxy resin, *Bm* and *Ap*-SFRP with different volume fraction (Yang, K. *et al.*, 2017)

Sample	**Impact strength, σ_i kJ m^{-2}**	**Specific impact strength, σ_i/ρ J m^{-2} /kg m^{-3}**
Unreinforced resin	12.8 ± 0.2	10.7 ± 0.1
30 vol.% *Bm*-SFRP	18.5 ± 1.4	15.0 ± 1.2
60 vol.% *Bm*-SFRP	70.7 ± 1.7	56.1 ± 1.4

2.4.2 Morphological (Scanning Electron Microscope)

Scanning Electron Microscope (SEM) is used to scan the material surface to analyze the surface roughness, fibre distribution, fracture surface and phase boundaries of the material. The SEM shows the morphology of the composite where the electron bar communicates with the surface and creates auxiliary electrons from the composite. Back dispersing of the electrons are also available. The back disperses electrons is estimated and contrasted with the filter electron shaft. A complexity of picture material will appear on the screen of the machine (Khanam *et al*., 2015). The SEM can observe the differences between the fibre matrix adhesion on unreinforced and reinforced fracture composite. Figure 2.18 below shows the different surface roughness of the silk fibre due to electrospinning speed that increases at a certain time.

Figure 2.18 Different surface roughness of silk fibre under SEM (Zhang *et al.*, 2010)

2.4.3 Applications

Reinforcement material are developed to create a new type of composite that has unique properties. Due to the good mechanical properties acquire by the silk fibre, they can be used in various applications. The silk fibre can be used in biomedical applications where it develops as biomedical suture materials. The one of a kind mechanical properties of these filaments gave a significant clinical fix choice to numerous applications. The report shows that silk proteins give a significant arrangement of polymer materials to be applied in frameworks for tissues, coatings and medication conveyance because of its strength and biocompatibility that possess (Holland *et al*., 2019; Ude *et al*., 2014). Figure 2.19 shows the applications of silk composite.

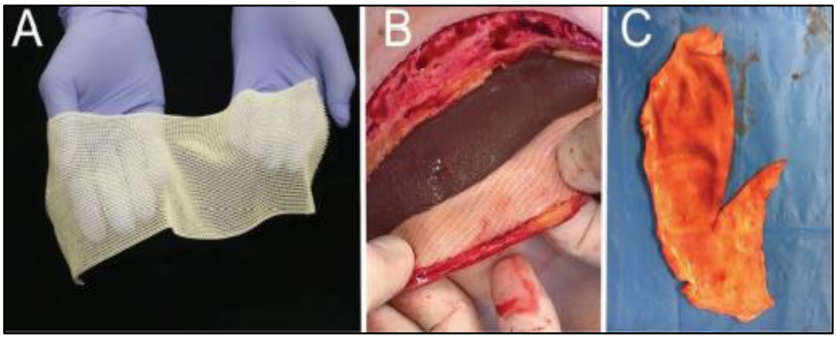


Figure 2.19 Example of surgical scaffold implant loss (a) Silk fibroin surgical mesh, (b) Free lying scaffold on the breast pocket, (c) Retrieved scaffold surrounded with seroma (Holland *et al*., 2019)

Besides, another application is in automotive applications where the silk fibre reinforced with a polymer matrix to improve the crashworthiness characteristics properties. It additionally held a vitality assimilation ability like non-triggered samples. The attachment might trigger the mechanism caused a massive decrease in load conveying limit and energy absorption capability (Khanam *et al*., 2015). According to Ude *et al*. (2014), the parameters measured were the crash force efficiency (CFE) and total absorbed energy (E-total). The industry still researching and try to develop new composite using silk fibre because of their properties. Reinforcing it with filler might give a better outcome to the composite.

2.5 Modeling and simulation

This section described the modeling and simulation of carbon dust reinforced silk composite. Modeling and simulation are to study the behaviour of the composite and predict the properties as it is not easy to run a study under experimental conditions. There will be two approaches in order to create an analysis of mechanical properties reinforced composite.

2.5.1 Mathematical calculation

The first approach is by mathematical calculation where it is essential to calculate the properties of the composite using the collected data such as tensile strength, density, volume of fibre and matrix, etc. To validate the experimental findings, the theoretical prediction which is this approach can optimize the idle time in determine the suitable filler loading that will maximize the properties of the composite (Ramesh and Sudharsan, 2017). In this study, the orientation is a unidirectional fibre composite where it is layer in various orientations. The mechanical properties that will discover are tensile and impact strength. So the formula that will be used for longitudinal fibre. The fibres are the load-carrying the members and tensile force will act along the fibre direction. The sample calculated based on the equation from Ramakrishnan *et al*. (2015) study in the methodology section. Figure 2.20 shows the different orientation of fibre.

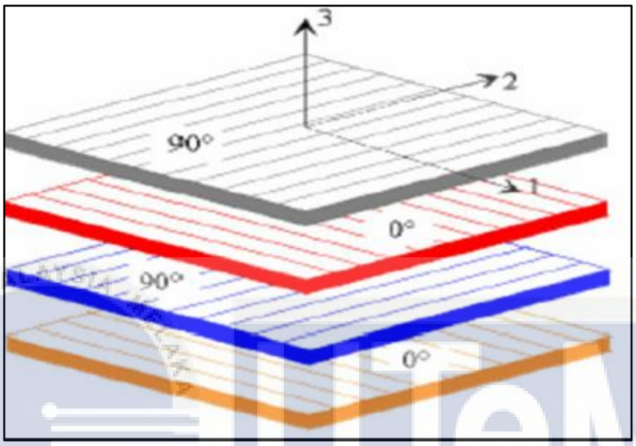


Figure 2.20 Unidirectional layer of fibre

2.5.2 ANSYS simulation

In ANSYS simulation, it is a software used to calculate the mechanical properties of various materials according to a requirement that has been designated. From the mathematical approach, the load applied on the samples can be determined. The unidirectional composite is known as transverse since the properties are equivalent in 2 to 3 directions. First, it is required to design a sample by using CAD software such as CATIA or Solidworks. The sample can design roughly according to the designated size or design a part from a product. Next, analysis of the sample needs to carry out. Then, define the loads and boundaries conditions according to mechanical properties stated. Generate the mesh, choose the properties and run the analysis to obtain the results.

Various types of analysis can be chosen in the simulation. The static analysis is utilized to figure the impact of steady loading conditions while ignoring the effect on damping and inertia. Figure 2.21 and figure 2.22 are examples of the static structural analysis result. Next is the modal analysis where it is a type of dynamic analysis used to determine the natural frequency of part. Lastly is parametric optimization as it is a useful tool to evaluate the design sensitivity from a different level. The input consists of the geometric dimension, material coefficient and boundary condition while the output is reaction force, displacement force and stress (Yeswanth and Andrews, 2017).

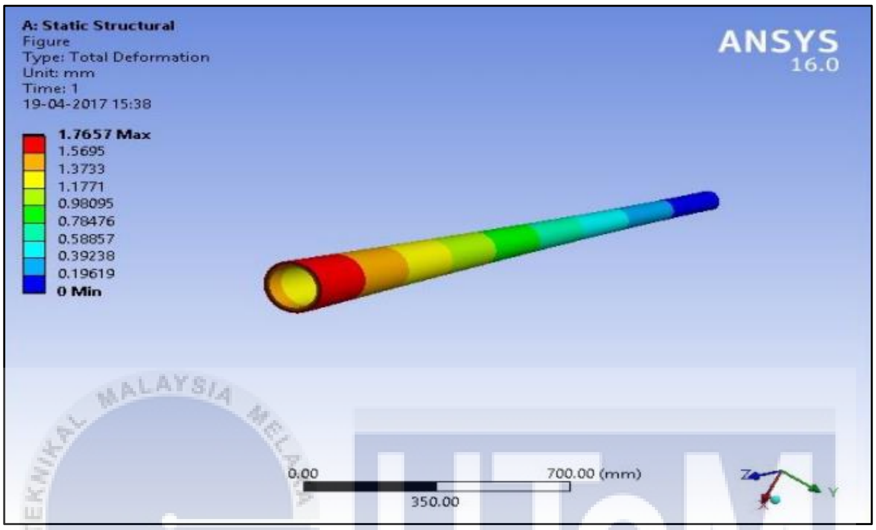


Figure 2.21 Example of static structural analysis result in deformation (Yeswanth and Andrews, 2017)

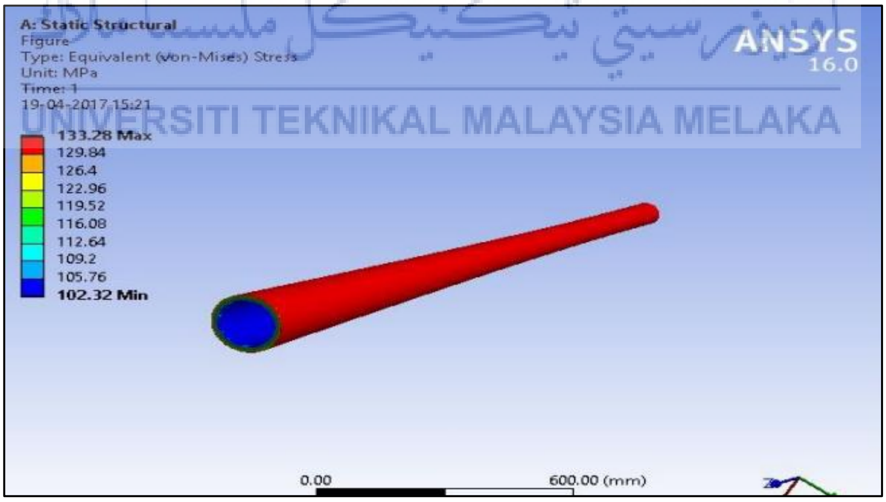


Figure 2.22 Example of static structural analysis result in stress (Yeswanth and Andrews, 2017)

Kim M. J. (2013) study shows that the displacement suitable is from 0.016667 to 0.0333 to ensure the elastic deformation on the sample. Before running the analysis, appropriate loads need to be applied along the nodes. The loads can be in structural load, pressure load, buckling load or fatigue load depends on the properties needed. In this study, will apply structural and pressure loads up to 5kN (Naveen J. *et al*., 2019).

The result calculated from the mathematical calculation and ANSYS simulation compared in a table. The study can obtain and differentiate a better correlation between those two approaches. The result will be shown where there is an improvement or not by using the two methods and the analysis of the mechanical properties can be created. As an example, the result of tensile strength from the mathematical approach is slightly higher than the result from ANSYS simulation (Ramakrishnan *et al*., 2015). Figure 2.23, figure 2.24 and figure 2.25 below show the example graph resulting from different natural fibre using a different approach.

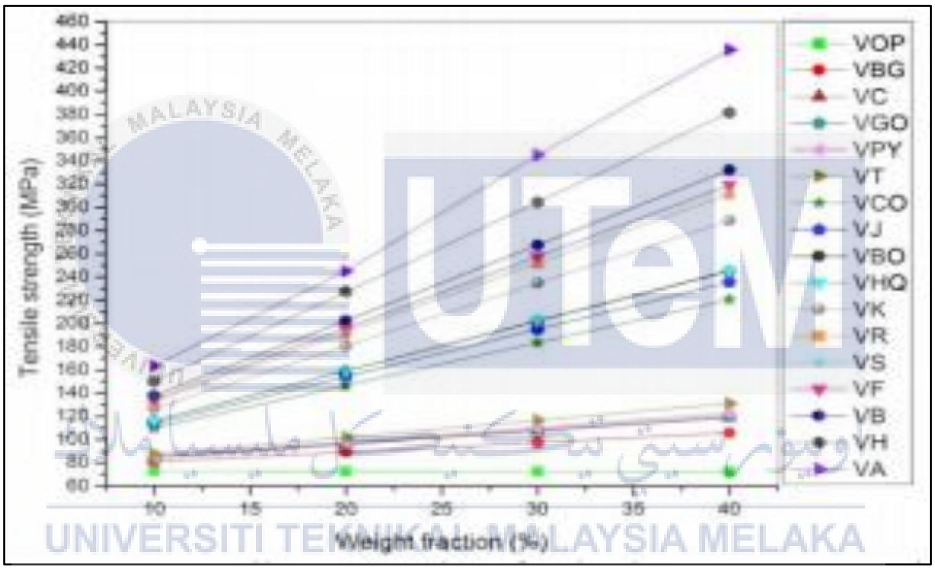


Figure 2.23 Tensile strength vs weight fraction graph of different natural fibre using mathematical approach (Ramakrishnan *et al*., 2015)

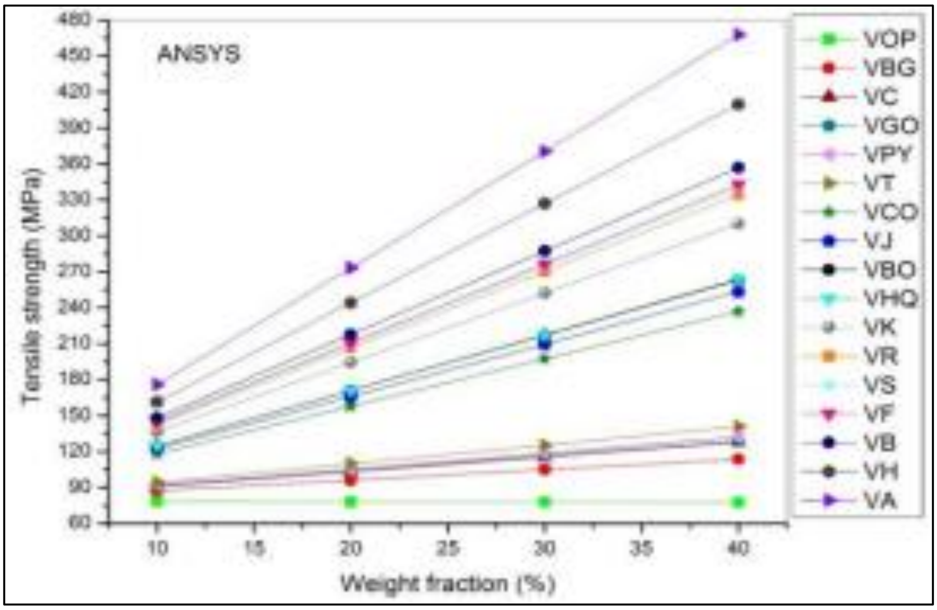


Figure 2.24 Tensile strength vs weight fraction graph of different natural fibre using ANSYS simulation (Ramakrishnan *et al.*, 2015)

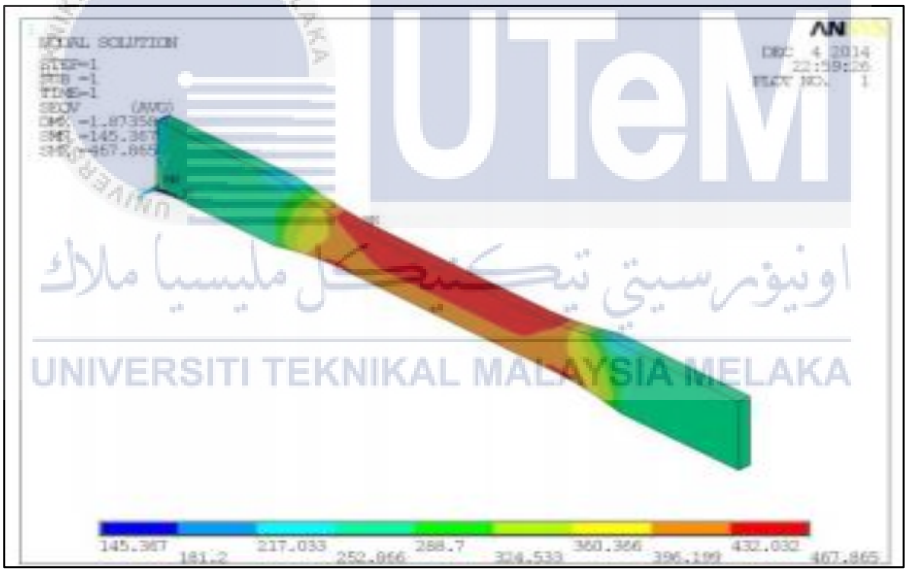


Figure 2.25 Example of stress value of sample run in analysis of ANSYS simulation (Ramakrishnan *et al.*, 2015)

CHAPTER 3

METHODOLOGY

This section consists of the research methodology that has been used in Final Year Project II. It comprises three main parts which is the collection of data, mathematical approach and simulation using ANSYS. The data collection and analysis using various methods show the output at the end of the study aligned with the objectives stated in the introduction chapter. Figure 3.1 presents the flowchart of study methodology as per further understanding. It shows all the sequence and step took place during developing of the study such as the proposed title, literature review, data collection and analysis.

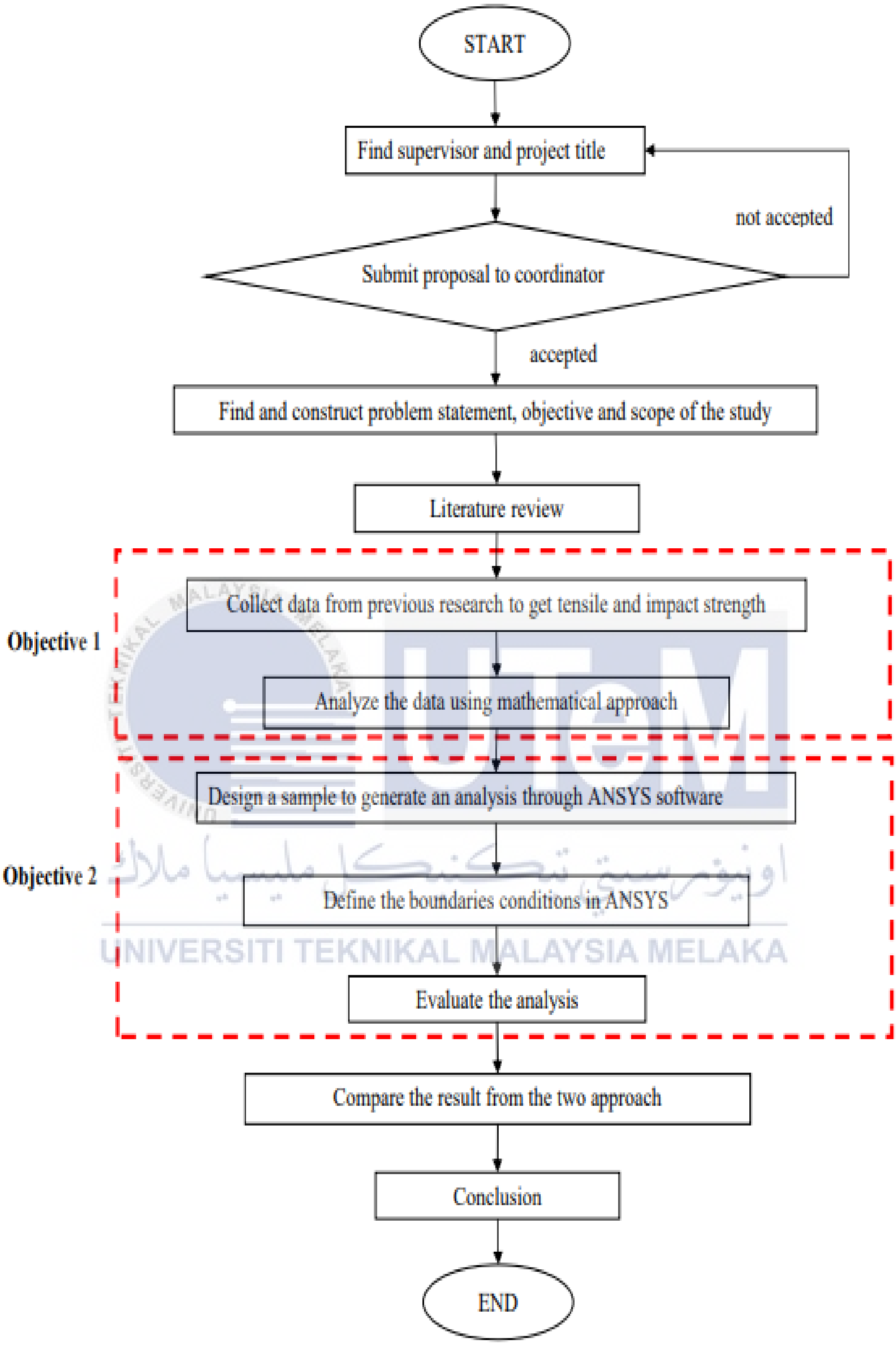


Figure 3.1 Flow chart of the study

3.1 Materials

There are three main materials that used in this study. First is silk fibres that are used in this study as reinforcement materials. Original silk fibres are obtained to do the experiment analysis. The silk type used is from the animal fibre which is *Bombyx mori*/ *Bm* silk, the common natural silks used in the textile industry. The density of silk fibre is 1.25 – 1.35 @ 1.3 g/cm^3 (Darshan *et al*., 2016). The tensile strength and ultimate strain, ε_t is 200 - 1800 MPa and 2.7 - 2.9%. Other than that, Young's modulus of *Bombyx mori* silk is 10 GPa and it elongates up to 18 – 20% with an impact strength of 12.5 – 13.0 kJ.m^{-2} (Ude *et al*., 2014 and Yang *et al*., 2016).

The second material used is the epoxy resin in the thermosetting polymer group. In this study, a commercial epoxy resin as epoxy matrix system binds the materials together to form a sample. Based on Correia *et al*. (2013) and Yang *et al*. (2016), the selected epoxy resin density is 1.20 g/cm^3, while the tensile strength and modulus of selected epoxy resin are 73 – 78 MPa and 3 GPa.

The last material is reclaimed carbon dust which is from carbon group. The main material carbon dust used in the experiment is from the excess of Carbon Fibre Reinforced Composite (CFRP). Even though the material and the properties are still the same. The density of carbon fibre is 1.70 - 1.80 g/cm^3 and the tensile strength is 2550 - 4000 MPa while Young's modulus is 230 - 250 GPa based on Smitthipong *et al*. (2016) and Sanjay *et al*. (2017). The amount of filler loading that used in this study is 10%, 20%, 30% and 40%. By using these manufacturing methods, a samples size 160 x 20 x 3 mm of carbon dust reinforced silk/ epoxy laminates were fabricated. All of the data were collected from the journals and articles of the researches as it might give us the guidelines or references in doing the analysis using simulation.

3.2 Data collection

This section listed the samples' collected data from the researcher's studies before running its own analysis. The dimension composite of samples is taken as 160 x 20x 3 mm as followed the ASTM D638-1 standard for tensile. The data collected from the researcher's journals in order to do the mathematical approach and ANSYS simulation. There are four different samples with different weight fraction of carbon dust. The sample run twice to get the average result. The length, height, and sample thickness are same (160 x 20 x 3 mm). Below is the example of the table result by using the two approaches for better comparison.

Table 3.1 Tensile and impact strength analysis results

Weight fractions (%)	**Mathematical approach**		**ANSYS simulation (static structural)**		**ANSYS simulation (explicit dynamic)**	
	Tensile strength (GPa)	**Impact strength (J/mm^2)**	**Deformation (m)**	**Stress (MPa)**	**Deformation (m)**	**Stress (MPa)**
10						
20						
30						
40						

3.3 Mathematical approach

Fibre composite is made up from phases through fibre and matrix. Their mechanical behaviour determines the properties of fibre and matrix. The importance in determining the mechanical properties such as fibre shape, fibre array and volume fractions of fibre. After obtained the results, it is time to run the analysis using the collected data in a calculation and simulation.

3.3.1 Density

The density of the samples measured followed according to ASTM D792 Standard and calculated using the equation below (Patil *et al*., 2017):

$$\text{Density, } \rho_c = \rho_f v_f + \rho_r v_r + \rho_m v_m \qquad (1)$$

where, ρ_c – density of composite

ρ_f – density of fibre

v_f – volume fraction of fibre

ρ_r – density of reinforcement

v_r – volume fraction of reinforcement

ρ_m – density of matrix

v_m – volume fraction of matrix

3.3.2 Tensile properties

The tensile strength testing determines the sample while applying axial load stretching until the sample fails. The fibre content on each sample (10%, 20%, 30% and 40%) undergo this tensile test but in the aspect of calculation and simulation. The data were calculated using Universal Testing Machine (UTM) followed the ASTM D638 Standard for plastic and polymeric materials. The sample must be in dog-bone shape as for tensile testing. Example of the tensile result as in table 2.5 and the graph can be created as refer in figure 2.16.

3.3.3 Impact properties

The impact testing followed according to the standard. This standard for the unnotched sample is loaded in a flat condition with a hammer for calculating using mathematical and car crash simulation using ANSYS. The impact testing is done by dropping the hammer from a height of 500 m to impact the samples at a velocity of 20 m/s. Below will describe the formula and calculation involved in this study to find specific parameters and predicting the performance of the properties. The main equation in this calculation is The Rule of Mixture (ROM) applicable to unidirectional continuous fibre. In the unidirectional composite structure, the fibres are the main load to carry the tensile force that acts along the direction of the fibre. Figure 3.2 shows the different orientation of fibre.

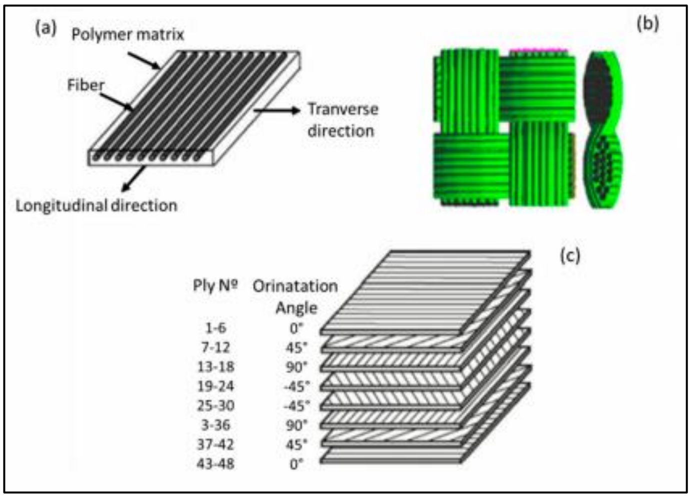


Figure 3.2 (a) Unidirectional fibre orientation, (b) Bidirectional fibre orientation (woven), (c) Multiorientation laminate (0°, 45°, 90°, -45°) (Muzel *et al*., 2020)

The main equation in this calculation namely is the Rule of Mixtures (Ramakrishnan *et al*., 2015). The equation covers from equation 2 until equation 7:

$$E_c = E_f V_f + E_r V_r + E_m V_m \qquad (2)$$

where,

E_c – Tensile modulus of composite (GPa)

E_f – Tensile modulus of fibre (GPa)

E_r – Tensile modulus of reinforcement (GPa)

E_m – Tensile modulus of matrix (GPa)

V_f – Volume fraction of fibre

V_r – Volume fraction of reinforcement

V_m – Volume fraction of matrix

The tensile strength of composite can develop from the ROM relate the matrix stress, σ_m which at the fracture strain of the fibre rather than the ultimate tensile strength (UTS). Equation 3 shows the tensile modulus of composite:

$$(\sigma_c) = (\sigma_f)_{ult} V_f + (\sigma_r)_{ult} V_r + (\sigma_m)_{ult} V_m \qquad (3)$$

where,

σ_c – Tensile strength of composite (MPa)

$(\sigma_f)_{ult}$ – Ultimate tensile strength of fibre (MPa)

$(\sigma_r)_{ult}$ – Ultimate tensile strength of reinforcement (MPa)

$(\sigma_m)_{ult}$ – Ultimate tensile strength of matrix (MPa)

V_f – Volume fraction of fibre

V_r – Volume fraction of reinforcement

V_m – Volume fraction of matrix

If the fibre has a uniform cross-section, the area fraction will be equal to the volume fraction as in equation 4:

$$A_c = t_c h \tag{4}$$

where,

t_c – Thickness of the sample (mm)

h – Height of the sample (mm)

The ultimate strain of fibre in equation 5:

$$(\varepsilon_f) = (\sigma_f)_{ult} / E_f \tag{5}$$

where,

ε_f – Strain of fibre

$(\sigma_f)_{ult}$ – Ultimate tensile strength of fibre (MPa)

E_f – Tensile modulus of fibre (GPa)

The ultimate strain of reinforcement in equation 6:

$$(\varepsilon_r) = (\sigma_r)_{ult} / E_f \tag{6}$$

where,

ε_r – Strain of reinforcement

$(\sigma_r)_{ult}$ – Ultimate tensile strength of reinforcement (MPa)

E_r – Tensile modulus of fibre(GPa)

The ultimate strain of matrix in equation 7:

$$(\varepsilon_m) = (\sigma_m)_{ult} / E_f \tag{7}$$

where,

ε_m – Strain of matrix

$(\sigma_m)_{ult}$ – Ultimate tensile strength of matrix (MPa)

E_r – Tensile modulus of fibre (GPa)

The potential energy in equation 10:

$$U_c = E = mg(h_1\text{-}h_2) \tag{8}$$

where,

U_c, E – Potential energy (J)

m – Mass (kg)

g – Gravity (m/s^{-2})

h – Height (m)

The impact strength in equation 11:

$$G_c = U_c/A \tag{9}$$

where,

G_c – Impact strength (J/mm^2)

U_c, E – Potential energy (J)

A – Area (mm^2)

The ultimate tensile strength of the composite, ultimate strain of fibre, matrix, and composites is determined by applying the formula above. Same as the tensile modulus, toughness, impact strength are calculated from the prepared composite equation.

3.4 Simulation using ANSYS

The sample modeled and analyzed for mechanical properties with finite element method software called ANSYS to study the elastic behaviour of composites and predict the mechanical properties. It is a software used to simulate computer models of structures or machine components for analyzing strength, toughness, elasticity and other features. Specific properties of the samples are given as inputs for the ANSYS program and the results for the given data obtained after running the software. The properties can be obtained by experimentation, but it is not easy to study the behaviour under experimental and current conditions. Hence, the need for FEA simulation is essential. First, the result needs to be calculated using mathematical calculation, the load applied on the samples is valued carbon dust reinforced silk at various weight fractions (10%, 20%, 30% and 40%). The results from mathematical calculation compared with ANSYS simulation. Two different results from two different approaches existed to prove that there are improvements in composite or vice versa.

3.4.1 Boundaries conditions

There are few boundaries conditions need to be defined when using ANSYS simulation for analysis. The boundaries conditions for the composite determine by the constraint and load condition applied to the samples. The samples also need to define the fixed support and need to apply the small displacement for testing. In this study, the boundaries conditions consist of displacement and load. Before running the analysis, appropriate boundaries conditions stated above need to be defined. The suitable displacement utilized in this study ranges from 0.01 to 0.05 while the load ranges from 5kN to 30kN. Figure 3.3 below shows the result of the sample with a fixed end as it might be applied in this study.

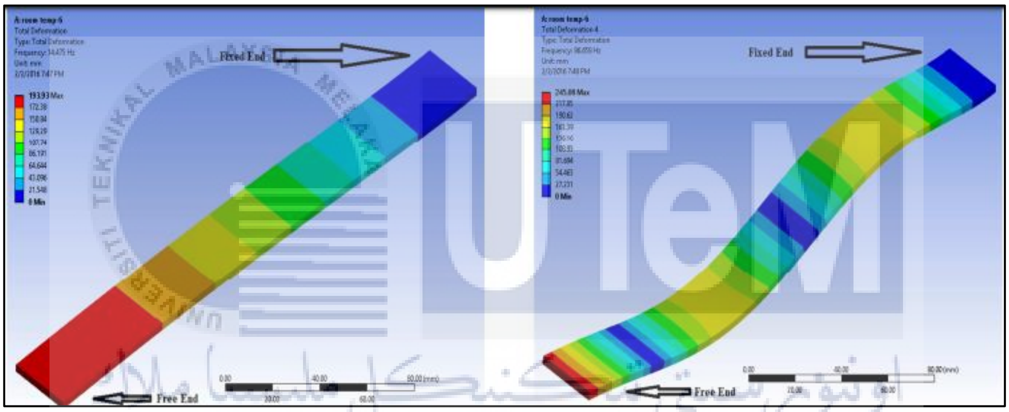


Figure 3.3 Example of sample with boundary condition is fixed end (Dodiya and Venkatachalam, 2016)

Calculated results in ANSYS simulation are shown in Figure 3.4 below with the requirements that have been set before running the analysis.

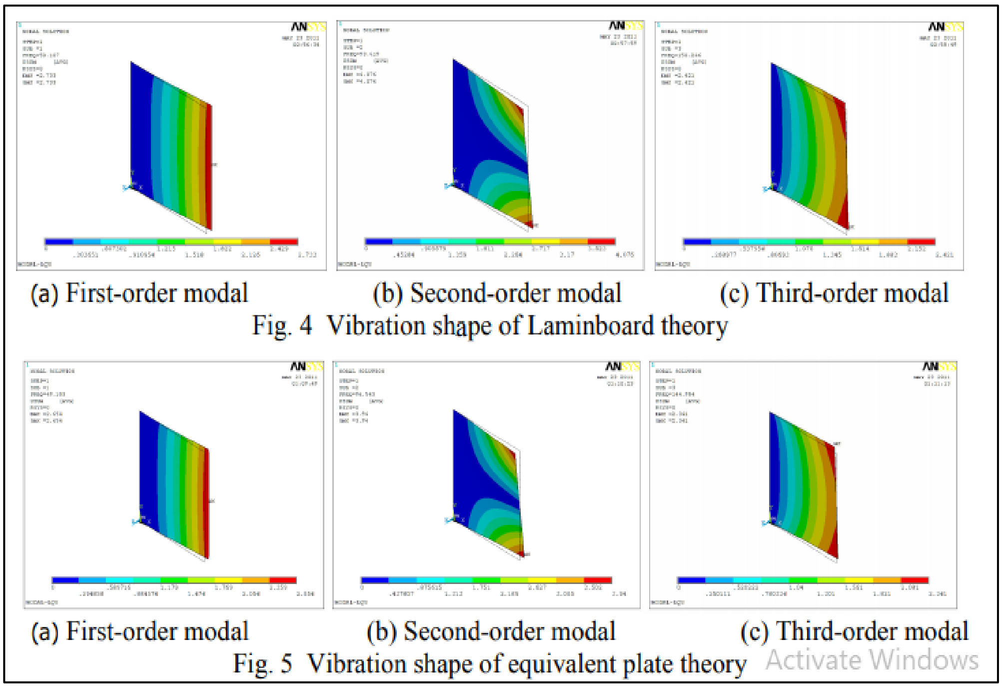


Figure 3.4 Example of the calculated result of models with two different sample (Yang *et al*., 2012)

After getting the analysis from both approaches, the result needed to compare by followed the properties that have been highlight such as plotting tensile modulus (GPa) vs weight fraction (%) and impact strength (J/mm^2) vs weight fraction (%) graph. Figure 3.5 is the result of different fibre that has been run in ANSYS simulation.

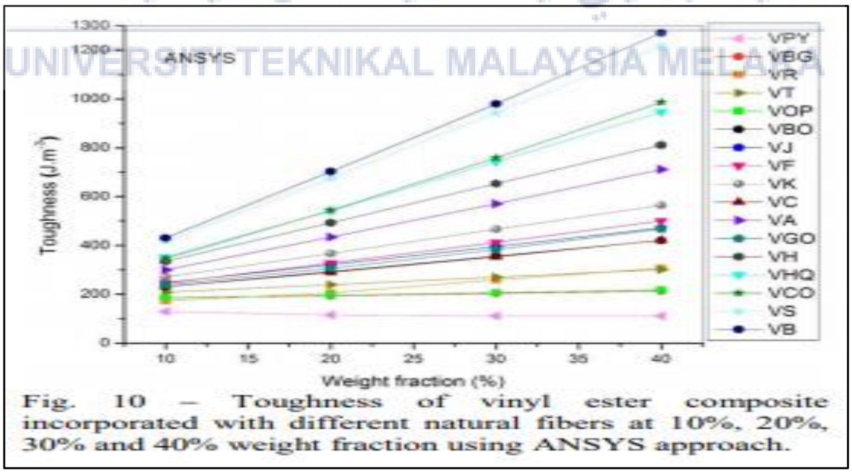


Figure 3.5 Example of graph with different natural fibre and weight fraction (Ramakrishnan *et al*., 2015)

The data collected can prove that the incorporation of increasing weight fraction of carbon dust can improve the mechanical properties or vice versa.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter represented and discussed the result of mechanical properties obtained in the study of dog bone sample by using mathematical calculation and ANSYS simulation. Those two approaches, theoretical and simulation compared after the results to know which one proves in increasing of mechanical properties in tensile and impact strength of the silk reinforced carbon dust.

4.1 Data collection material properties of silk fibre reinforced composite

In this section shows the collection data of materials used in this study to calculate and observe the improvement of mechanical properties of the composite. The process undergoes two approaches which is the mathematical calculation and ANSYS simulation. The data listed were collected from other research studies to be used in order to develop the analysis of calculation and simulation. Below listed the data of each material.

4.1.1 Data collected of each material properties

Below is the data collected from other research studies before doing the theoretical calculation of mechanical properties. The data need to be collected and filtered from other researchers' papers to get accurate data of material properties. Table 4.1 shows each material's data properties which is silk fibre, carbon dust and epoxy resin.

Table 4.1 Properties of silk fibre

Material	Density (g/cm^3)	Tensile strength (MPa)	Young's Modulus (GPa)	References
Silk fibre	1.25 – 1.35 @ 1.3	200 – 1800	-	Darshan, S. M. *et al.* (2016)
	1.3	100 – 1500	5 – 25	Pickering, K. L. *et al.* (2016).
	1.3	200 – 1800	10	Shah, D. U. *et al.* (2014)
	1.25 – 1.35 @ 1.3	300 – 600	5 – 15	Smitthipong, W. *et al.* (2016)
Reclaimed Carbon dust	1.81	3800	228	Atiyeh, M. *et al.* (2020)
	1.82	2550 – 4000	-	Sanjay, M. *et al.* (2017)
	1.70 – 1.80 @ 1.75	3000 – 4000	230 – 250	Smitthipong, W. *et al.* (2016)
	1.70 – 2.00 @ 1.85	3500	230	Zhu, J. H. *et al.* (2019)
Epoxy resin	1.20 – 1.30 @ 1.25	60 – 80	2.0 – 3.0	Correia, J. R., (2013)
	1.15	60 – 75	2.7 – 3.2	Shah, D. U. *et al.* (2014)
	1.20	73 - 78	3.0 – 3.2	Yang, K. *et al.* (2016)

Above is the table properties of each material that have been filtered and selected from other studies. The selection of data is based on the latest studies to get accurate and identical data. Based on the range of silk fibre data, data for density is 1.3 g/cm^3, tensile strength, σ is 200 – 1800 MPa and Young's modulus, E is 10 GPa. The data are selected because it is proven by Darshan *et al.* (2016) and Shah *et al.* (2014). They stated that this type of silk *Bombyx Mori* fibre has strong fibre than other silk fibre types. Next, for reclaimed carbon dust, data for density is 1.8 g/cm^3, tensile strength, σ is 230 MPa and Young's modulus, E is 2550 – 4000 MPa supported by Atiyeh *et al.* (2020), Sanjay *et al.* (2017) and Zhu *et al.* (2019) based on their studies since carbon dust is from the excess of carbon fibre that has a strong strength and toughness in their properties. Last material epoxy resin, data for density is 1.20 g/cm^3, tensile strength, σ is 78 MPa and Young's modulus is 3.0 GPa supported by the authors in Table 4.1 epoxy resin. Based on Yang *et al.* (2016), even though the epoxy resin is in the liquid state, it can help bind the materials to create a composite. All this data will be used to calculate the mechanical properties of composite which is tensile strength and impact using the formula equation in the subtopic 3.3 mathematical approach in Chapter 3. Before that, it is required to identify the percentage of fibre, filler and matrix because stated in objective the volume percentage of filler loading which is reclaimed carbon dust that used in this study is 10%, 20%, 30% and 40% to determine the mechanical properties of composite either it improved in strength and impact. Table 4.2 below shows the volume fraction of each material.

Table 4.2 Volume fraction of fibre, reinforcement and matrix

Reclaimed carbon dust (filler loading)	**Silk fibre (fibre)**	**Epoxy resin (matrix)**
10% = 0.10	70% = 0.70	20% = 0.20
20% = 0.20	60% = 0.60	20% = 0.20
30% = 0.30	50% = 0.50	20% = 0.20
40% = 0.40	40% = 0.40	20% = 0.20

4.1.1.1 Density

The percentage of each material was substituted in the equation to determine the composite density using the formula stated in subtopic in Chapter 3.

Table 4.3 Result density of the composite

Volume fraction of filler loading	**Density of composite (g/cm^3)**
At 10% = 0.10 content	1.33
At 20% = 0.20 content	1.38
At 30% = 0.30 content	1.43
At 40% = 0.40 content	1.48

At 10% = 0.10 reinforcement content:

$$\rho_c = \rho_f v_f + \rho_r v_r + \rho_m v_m$$

$$= [(1.3\ g/cm^3)(0.70)] + [(1.80\ g/cm^3)(0.10)] + [(1.20\ g/cm^3)(0.20)]$$

$$\rho_c = 1.33\ g/cm^3$$

Table 4.3 above shows the result of density composite which is the total density of fibre, filler and matrix are multiply each by volume fraction of each material. Also, above shows the example of density calculation for review. From the result density composite of each volume fraction filler, shows that increasing density of composite because of the increasing volume of filler loading in the structure. According to Salman and Leman (2018), the higher volume of weight fraction filler results in better mechanical properties of the composite. The dispersion of carbon dust on the composite can prove that the composite could withstand high pressure and crashworthiness when applied. The 40% of volume fraction filler were dispersed equally on the composite structure to avoid porosity in a large area that could affect composite uses (Mishurov and Murashov, 2016). It gives an advantage and disadvantage on both sides when density increasing.

4.1.1.2 Rule of Mixtures (ROM)

The ROM was used in this study to predict the elastic modulus of composite, E_m with given modulus and volume fraction of reinforcing fibre, filler and matrix. Table 4.4 shows the overall result of elastic modulus composite, E_c based on the equation (2) mentioned previously in Chapter 3.

Table 4.4 Result ROM of composite

Volume fraction of filler loading	**Elastic modulus composite, E_c (GPa)**
At 10% = 0.10 content	30.6
At 20% = 0.20 content	52.6
At 30% = 0.30 content	74.6
At 40% = 0.40 content	96.6

Table 4.4 shows the result of elastic modulus, E_c increase when there is an increasing volume fraction of filler loading which is reclaimed carbon dust which is in a good agreement with the works done by Song *et al*. (2012), Young's modulus increase rapidly with an increase in the volume fraction of filler. Adding filler 10% in each sample has increased 22% improvement of the elastic modulus in the mechanical properties of silk reinforced composite than usual. It is supported by Masouras *et al*. (2008) where the combination of the small and varied size of filler allows a more compact packing in the composite structure. It improves the strength of material because the stiffness of composite has been increasing significantly. The silk reinforced composite can withstand from deformation and crack propagation happen too fast during composite functioning.

4.1.1.3 Tensile strength

The tensile strength is the maximum load that a material can support without fracture when it is being stretched. The equation as in subtopic in Chapter 3 was used to find the tensile strength of this composite.

Table 4.5 Result tensile strength of composite

Volume fraction of filler loading	Tensile strength of composite, σ_c (MPa)
At 10% = 0.10 content	1676
At 20% = 0.20 content	1896
At 30% = 0.30 content	2116
At 40% = 0.40 content	2336

From the table 4.5 it shows the result of tensile strength composite increasing when adding filler into the structure matrix. This result shows that the silk fibre reinforced composite can withstand up to 2336 MPa during the composite being stretched elastically. This material began to fail when it exceeds the maximum tensile strength thus, it leads to fracture. Increasing 10% of filler content separately makes the composite escalate up 220% improvement in tensile strength. This result is supported by Hamidi *et al*. (2018) where the result share that the unique and remarkable improvements in silk reinforced composite can be achieved when fibre contents were 60% and higher as a low or moderate fibre content did not yield extensive improvement in mechanical properties. Also, supported by Song *et al*. (2012), adding a higher volume fraction of filler in the composite can increase tensile strength. In this study, using less amount of silk fibre and replaced it with carbon dust was to reduce the cost as known silk fibre is an expensive material. According to Nwanonenyi *et al*. (2013), the authors highlighted that the mechanical properties increased with increase in filler content but decreased the filler particle size. This study is compatible with Nwanonenyi *et al*. (2013) study because reclaimed carbon dust is in the smallest size of particle thus, it can improve in the mechanical properties of silk reinforced composite.

4.1.1.4 Area

The formula for area shown in subtopic Chapter 3 to determine the area of the dog bone sample. The result for area of the composite is 480 mm^2. The dog bone dimension is

160 mm x 20 mm x 3 mm designed using SOLIDWORK software following the ASTM D638 standard for tensile testing.

4.1.1.5 Ultimate strain fibre, filler and matrix

The ultimate strain that corresponds to the maximum stress point on the strain curve and material will fail it function after reaching the point limit

Table 4.6 Result ultimate strain of fibre, filler and matrix

Properties	Result
Ultimate strain of fibre	0.18
Ultimate strain of reinforcement	0.40
Ultimate strain of matrix	0.0078

Table 4.6 shows the results of ultimate strain using the equation (5), (6) and (7) stated at previous chapter which representing the fibre, reinforcement and matrix. Mentioned properties observed that the ultimate stress of materials was divided with Young's modulus of fibre. The value shown is the maximum stress-strain occurs before it fails its function. Cracks propagation will occur afterwards and the sample broke into two. The ultimate strain matrix has the lowest strain since the ultimate stress is only 78 MPa than the other two material. Epoxy resin is in the liquid state, low viscosity and in elastic properties. This material can only act as a binder to combine the materials into one composite so it cannot work alone to improve the composite's mechanical properties. The value of ultimate strain reinforcement is the highest since it is from the carbon group where the highest value of ultimate strength has. It proves that this study of composite could improve the mechanical properties in strength and impact.

4.1.1.6 Impact strength

In this study, using the Izod impact test to determine the amount of energy that material can withstand when applying load. The formula equation in finding the value of impact strength is stated in subtopic in Chapter 3. Figure 4.1 below shows the schematic diagram of impact test.

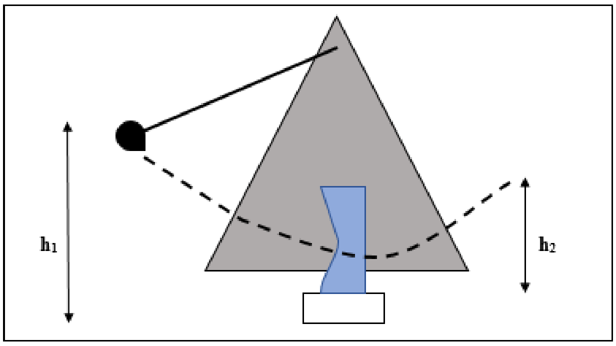


Figure 4.1 Schematic diagram of Izod impact test

The load applied in this study is from 5 kN to 50 kN to make this reinforced composite applicable in an automotive and aerospace application. The value proves that the composite material can withstand up to that value before it breaks. Table 4.7 below shows the result of impact strength where the masses are convert from Newton to kilogram unit.

Table 4.7 Result of impact energy

Mass (kg)	**Potential energy (kJ)**	**Impact strength (J/mm^2)**
509.86	1000.35	0.40
1019.72	2001.04	0.81
1529.57	3001.02	1.21
2039.43	4001.36	1.61
2549.29	5001.71	2.02
3059.15	6002.05	2.42

From the table above it shows that the impact energy increase when the mass that applied also increased. The potential energy also increases when mass is increased. It is supported by Song *et al*. (2012), where the interaction between fibre, reinforcement and matrix in the analysis and crack propagation behaviour determine the impact strength of the composite. The higher amount of filler loading can withstand the impact on the composite longer than usual volume fraction of filler loading. It resulted in the silk reinforced composite with low interfacial bonding strength between layers with higher energy absorption due to longer debonding length (Song *et al*., 2012).

4.2 Design modeling using ANSYS simulation

This section shows the result and discussion of mechanical properties improvement using ANSYS simulation. The data were collected from many research studies are used in running the analysis in ANSYS. The results were compared at the end of the analysis to know the correlation between these two approaches.

4.2.1 Boundaries conditions

Before running the sample analysis, it is crucial to set the boundaries condition of each sample. The force and support were calibrated in order to get the result of the sample. The first boundary is the support of the sample. The support was fixed end only at one part of the body sample. Figure 4.2 shows the diagram of the fixed end that applied. The support was applied at the end because this testing analysis was to calculate the tensile strength of the sample. The ANSYS analysis was apply accordingly same procedure with the Universal Testing Machine (UTM). In the tensile test using Universal Testing Machine (UTM), the sample is placed between two fixtures called grips, which clamped the sample. The sample gripped at one end while the other is fixed when the machine started to apply the load.

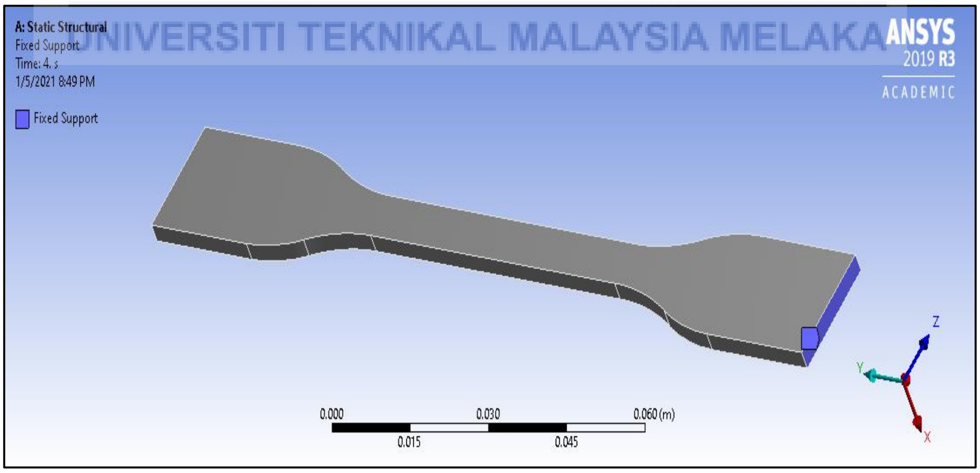


Figure 4.2 Fixed end support

The second boundary condition is the force that applied to the sample adding some force. Supported by Ali *et al.* (2020), these two boundary conditions were applied to make the deformation and analyze the shear stress, normal stress, and many other properties. The result obtained shown below. Figure 4.3 shows the amount of force applied to the sample. The amount of force applied was stated in Chapter 3.

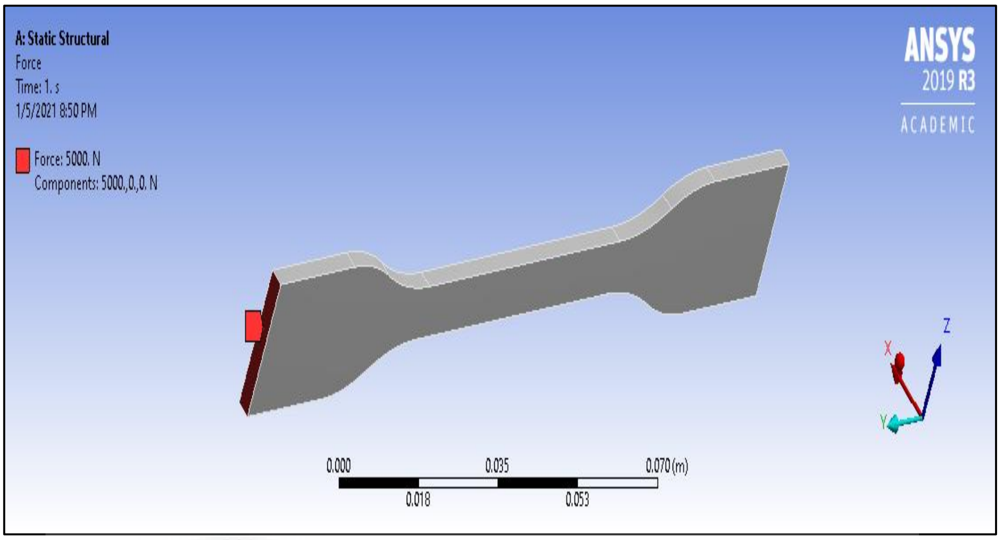


Figure 4.3 Force applied

4.2.2 Analysis of silk fibre-reinforced composite on tensile strength

This section elaborated the analysis of composite in mechanical properties, which is tensile strength. It is crucial to know that the maximum and minimum value deformation occurs when generating the sample because the simulation was run according to the lab's real machining test. The sample of different weight fractions undergoes analysis one by one to get the results so that it can be compared with other samples. The boundaries condition have been applied according to the desired data collected.

4.2.2.1 Analysis on 10% volume fraction of filler loading

Analysis on static structural that has been observed in the simulation was total deformation used to obtain displacement from stress. This analysis gave the overall deformation of the sample because it has been set in the simulation. This analysis is important to know the maximum and minimum deform because force from 5kN to 30kN applied at the end of the sample. Figure 4.4 below shows the deformation of 10% volume fraction of filler takes place.

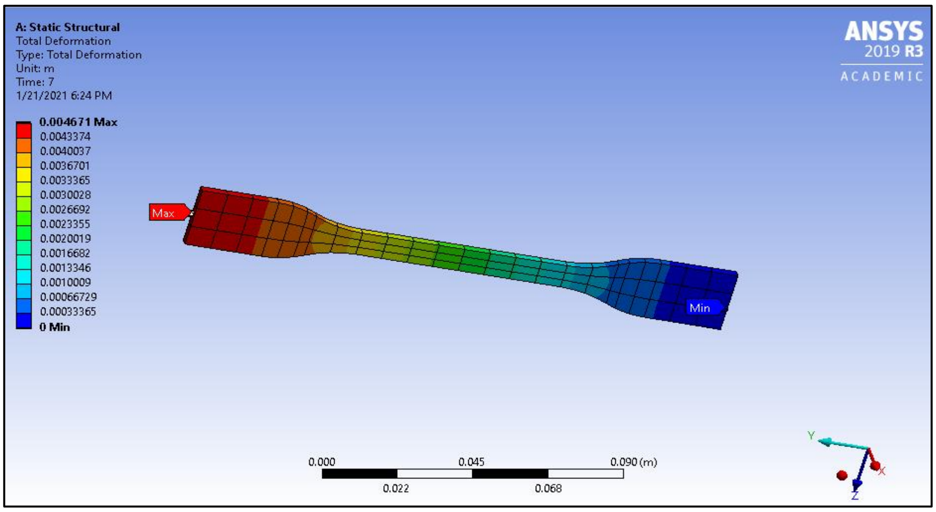
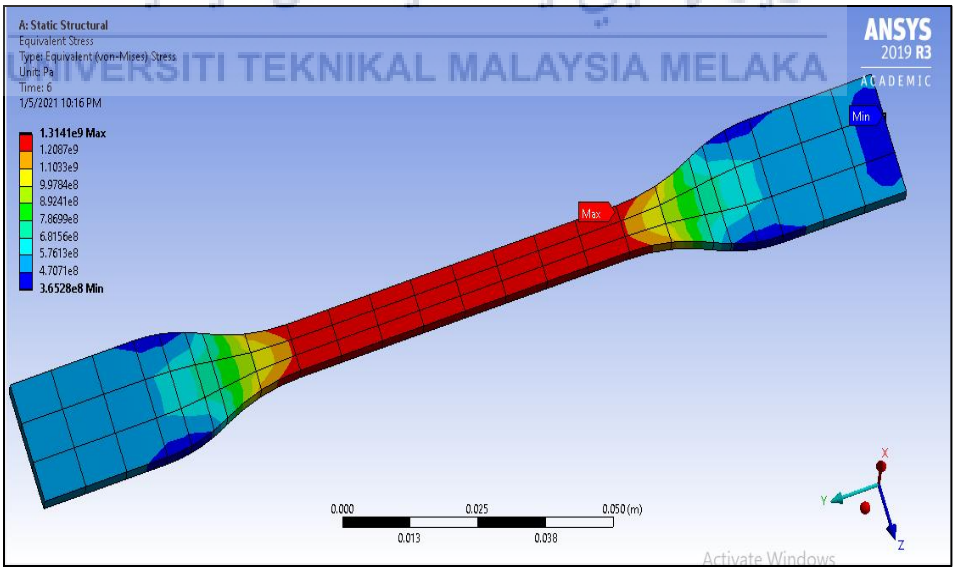


Figure 4.4 Total deformation of 10% volume fraction filler

Figure 4.4 shows the analysis of total deformation of the sample when the force applied at the end of it, just like tensile testing takes place. The red region was when the maximum deformation occurred as the force was applied at 30kN, resulting in a 0.004671 m. The blue region was the minimum deformation since it was located at the fixed support part of the analysis. The deformation in 10% content filler does not give any significant result to the analysis of this silk reinforced composite.



(a)

(b)

	Steps	Time [s]	✔ Equivalent Elastic Strain (Max) [m/m]	✔ [C] Equivalent Stress (Max) [Pa]
1	1	1.	0.	0.
2	2	2.	7.1414	2.1902e+008
3	3	3.	14.283	4.3804e+008
4	4	4.	21.424	6.5706e+008
5	5	5.	28.566	8.7608e+008
6	6	6.	35.707	1.0951e+009
7	7	7.	42.849	1.3141e+009

(c)

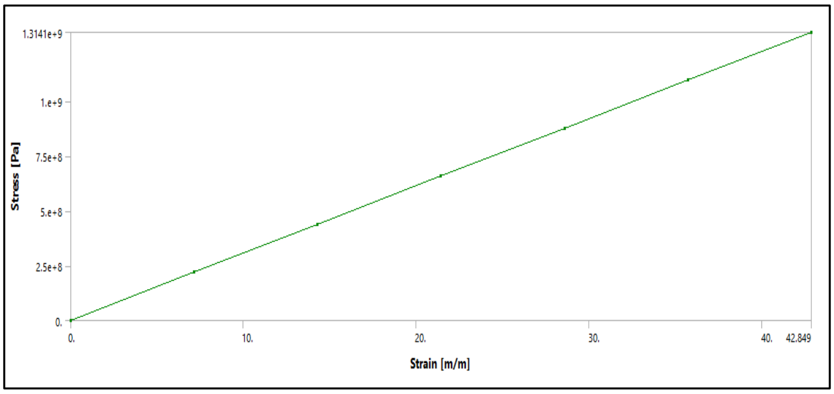


Figure 4.5 (a) Stress of 10% volume fraction filler sample, (b) Table data of stress and strain, (c) Stress-strain graph (MPa/mm)

Figure 4.5 (a) shows the analysis equivalent stress of 10% volume fraction sample. The red region was at the center of the sample stretched by force applied to it. The maximum value of stress, 1314.1 MPa of sample's necking area, while the minimum value is 219.02 MPa located at the dark blue region. According to ASM International (2004), plastic deformation where the stress has been applied to the sample, and the sample will elongate until it reaches failure, it will not recover back to its shape. The stress value increases aligned with the strain value. The force applied was based on applying the composite in aerospace and automotive to produce the composite that can be used in the heavy industries. Below is figure 4.6 of total deformation volume fraction 20% filler.

4.2.2.2 Analysis on 20% volume fraction of filler loading

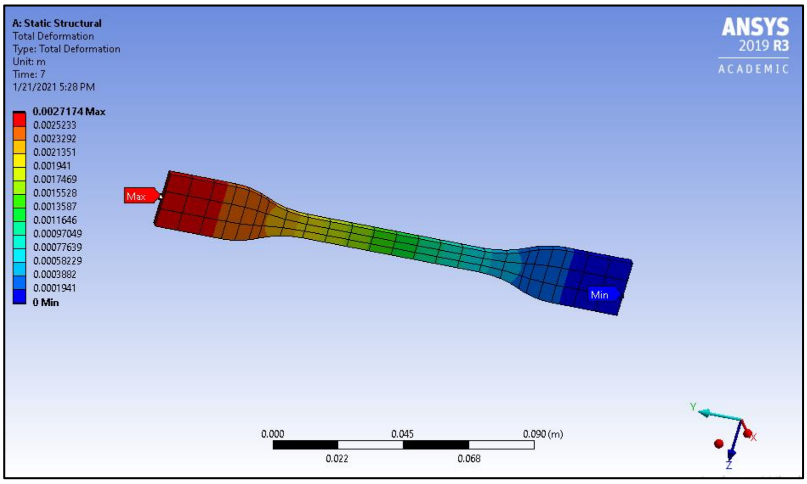
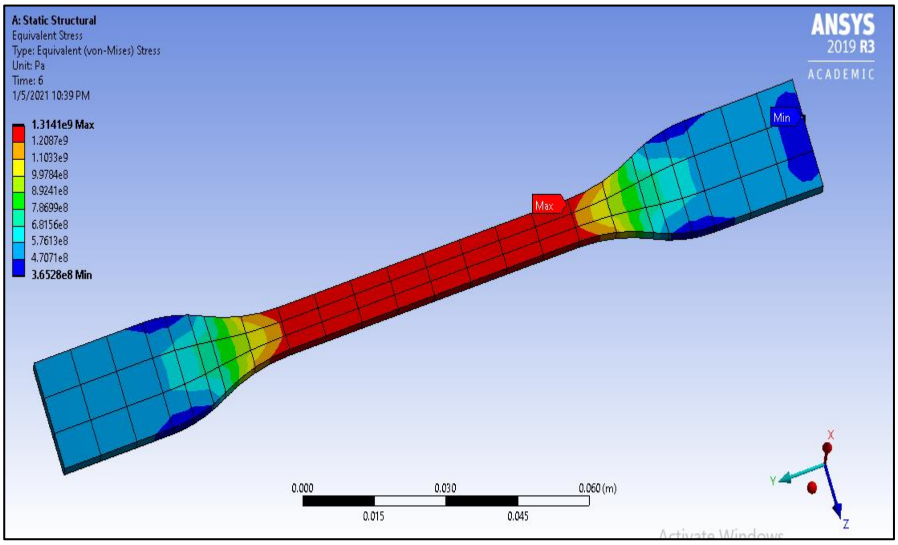


Figure 4.6 Total deformation of 20% volume faction filler

Figure 4.6 shows the analysis result from the total deformation of 20% volume fraction. This 20% content filler analysis resulted about 0.0027174 m displacement a little bit lower than 10% content filler because of the increasing value in density, tensile strength, and Young’s modulus. Simultaneously, the minimum value is 0.001941 m, where it is when low force, 5kN applied, so the sample only slightly elongates as it near the fixed support. According to Khan *et al.* (2017), carbon filler can enhance the composite’s strength with the matrix's epoxy usage. The higher dispersion of carbon dust particles contributes to the deformation and strength of the composite.



(a)

(b)

Tabular Data

	Steps	Time [s]	Equivalent Elastic Strain (Max) [m/m]	[C] Equivalent Stress (Max) [Pa]
1	1	1.	0.	0.
2	2	2.	4.164	2.1902e+008
3	3	3.	8.3281	4.3804e+008
4	4	4.	12.492	6.5706e+008
5	5	5.	16.656	8.7608e+008
6	6	6.	20.82	1.0951e+009
7	7	7.	24.984	1.3141e+009

(c)

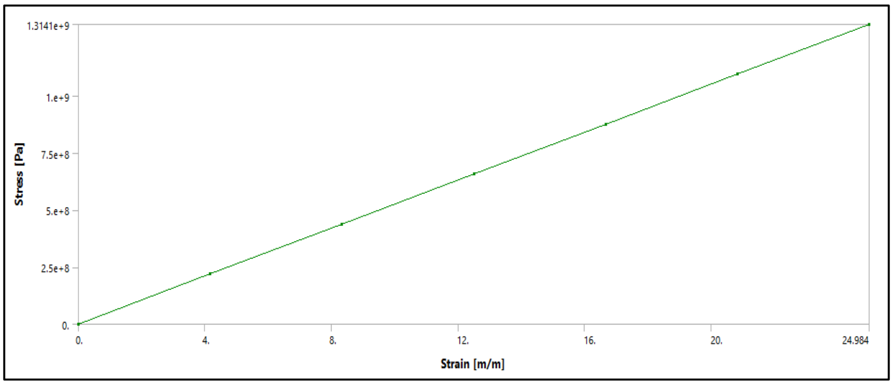


Figure 4.7 (a) Stress of 20% volume fraction filler sample, (b), Table data of stress-strain, (c) Stress-strain graph (MPa/m)

Figure 4.7 shows the sample of 20% volume fraction filler that undergoes equivalent stress analysis under some force applied to it. The maximum value stated is 1314.1 MPa, same as stress at volume fraction 10% of filler. It does not show any differences in the analysis because the additional filler content is too little to make changes. The values only presented the reinforcement was enhanced by the silk and epoxy. The table shows the difference value between strain 10% and 20%, but the stress value is the same. The dark blue region with the lowest value was less than the light blue region because its forces are smaller in that region. Simultaneously, the red region amount was in the necking area where a high plastic deformation and stresses occur. Based on Masouras *et al.* (2007), stresses tend to develop and improves because of the small and varied size filler that allows a more dense packing in the resin matrix composite.

4.2.2.3 Analysis on 30% volume fraction of filler loading

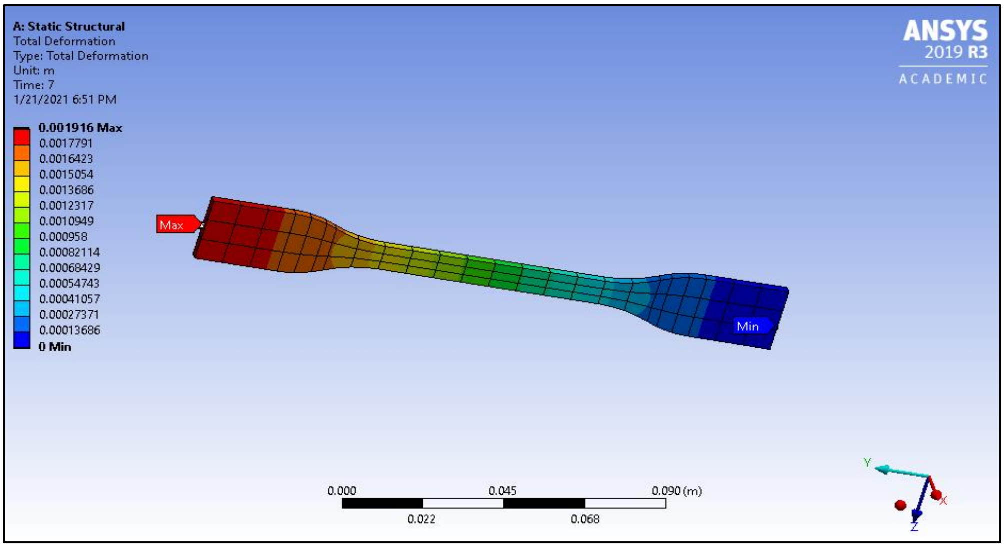
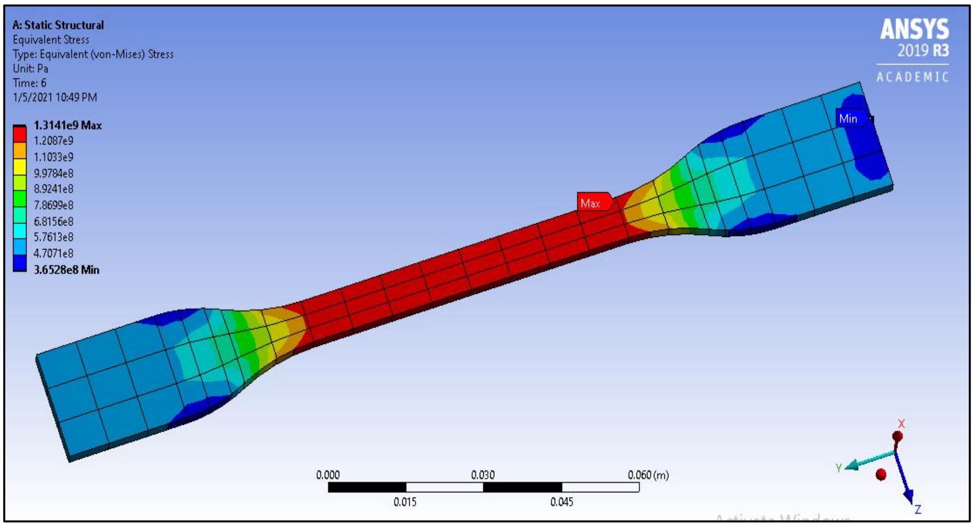


Figure 4.8 Total deformation of 30% volume fraction filler

Figure 4.8 shows the total deformation volume fraction of 30% filler content where the maximum value is 0.001916 m, slightly decreasing from another 10% and 20% filler content. It may be because the amount of carbon dust increases in the composite to withstand the deformation longer than the previous sample value. The even dispersion of carbon dust becomes more on the composite because of the increasing value of content filler and proving that the sample can withstand more deformation occurs even though with the presence of silk.



(a)

(b)

	Steps	Time [s]	Equivalent Elastic Strain (Max) [m/m]	[C] Equivalent Stress (Max) [Pa]
1	1	1.	0.	0.
2	2	2.	2.936	2.1902e+008
3	3	3.	5.8721	4.3804e+008
4	4	4.	8.8081	6.5706e+008
5	5	5.	11.744	8.7608e+008
6	6	6.	14.68	1.0951e+009
7	7	7.	17.616	1.3141e+009

(c)

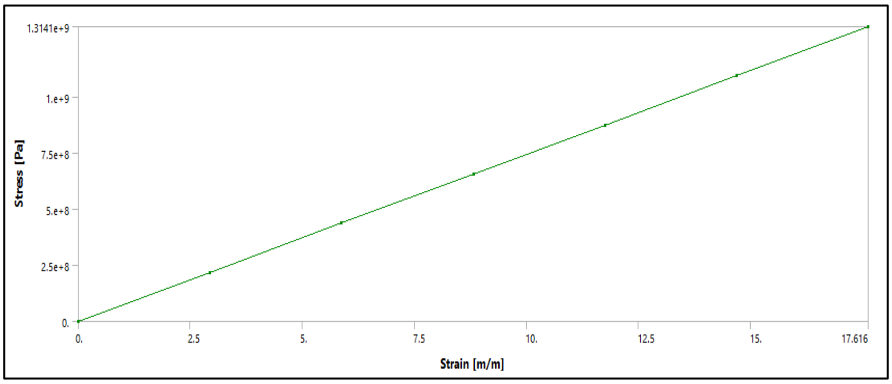


Figure 4.9 (a) Stress of 30% volume fraction filler sample, (b) Table data of stress-strain, (c) Stress-strain graph (MPa/m)

Figure 4.9 shows the equivalent stress of 30% volume fraction filler where the value of stress is still the same with another filler content maximum value (the green line) is 1314.1 MPa at 30kN. The stress analysis value was not changed because the value of force and area was the same for all the samples. Supported by Rice University, 2021 website article as stress is defined as force per unit area, so all of the samples have the same stress value. Graph (c) shows increasing stress aligned with strain.

4.2.2.4 Analysis on 40% volume fraction of filler loading

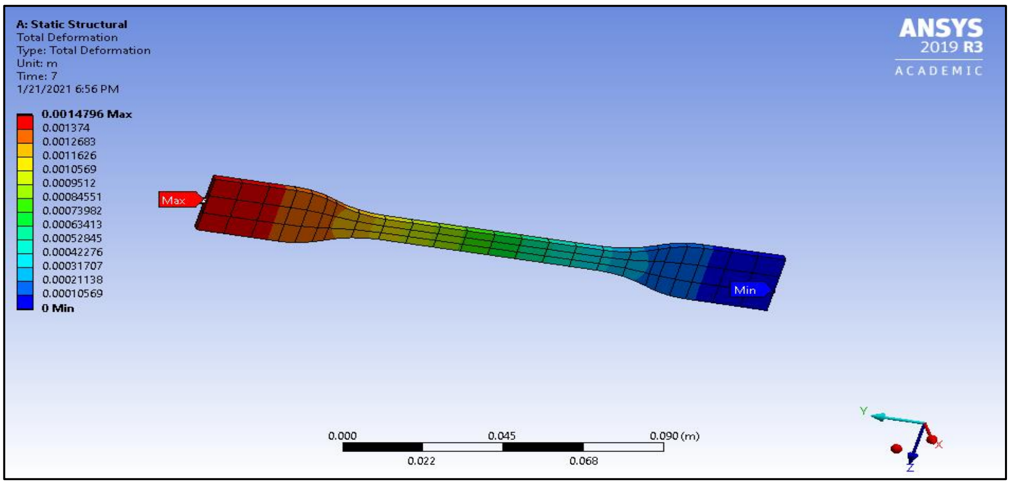
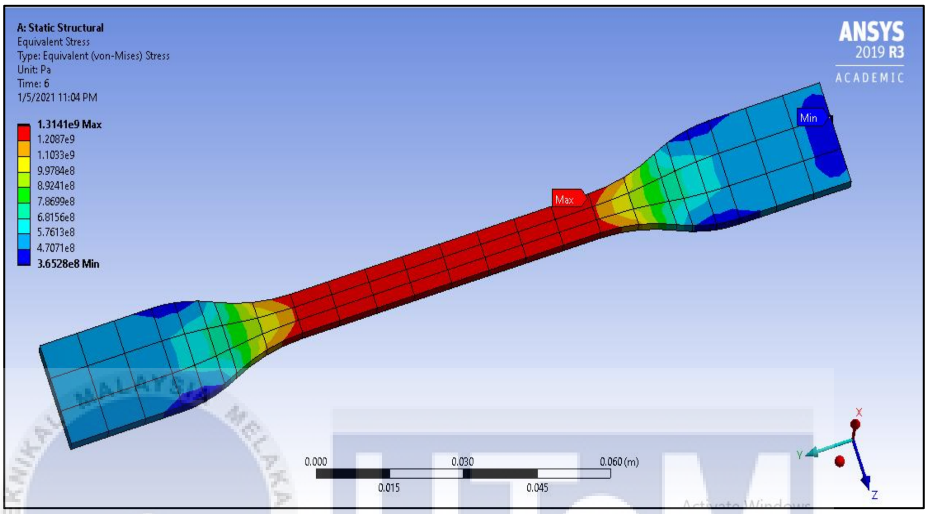


Figure 4.10 Total deformation of 40% volume fraction filler sample

Figure 4.10 shows the total deformation of the highest volume fraction filler, which is 40% in this analysis. The maximum value of this total deformation analysis is 0.0014796 m, a slightly decrease from the previous analysis sample because of the increasing filler loading content. The dispersion of particle filler loading in this composite sample has been more significant than the previous sample, resulting in lower deformation.

(a)



(b)

	Steps	Time [s]	✔ Equivalent Elastic Strain (Max) [m/m]	✔ [C] Equivalent Stress (Max) [Pa]
1	1	1.	0.	0.
2	2	2.	2.2674	2.1902e+008
3	3	3.	4.5347	4.3804e+008
4	4	4.	6.8021	6.5706e+008
5	5	5.	9.0695	8.7608e+008
6	6	6.	11.337	1.0951e+009
7	7	7.	13.604	1.3141e+009

(c)

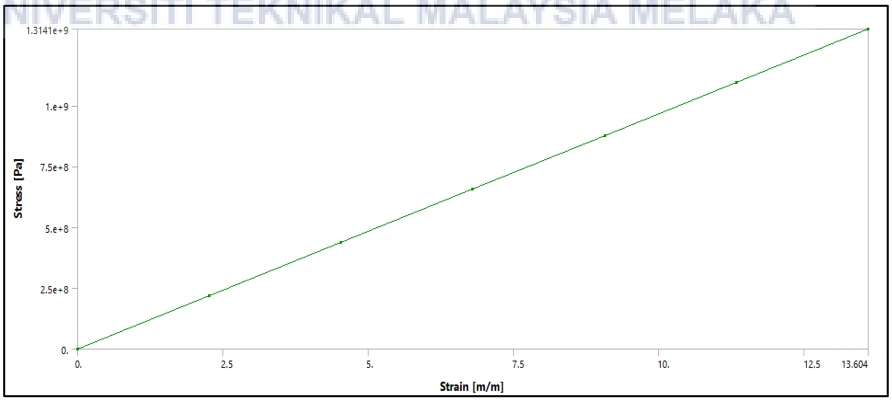


Figure 4.11 (a) Stress of 40% volume fraction filler sample, (b) Table data of stress-strain, (c) Stress-strain graph (MPa/m)

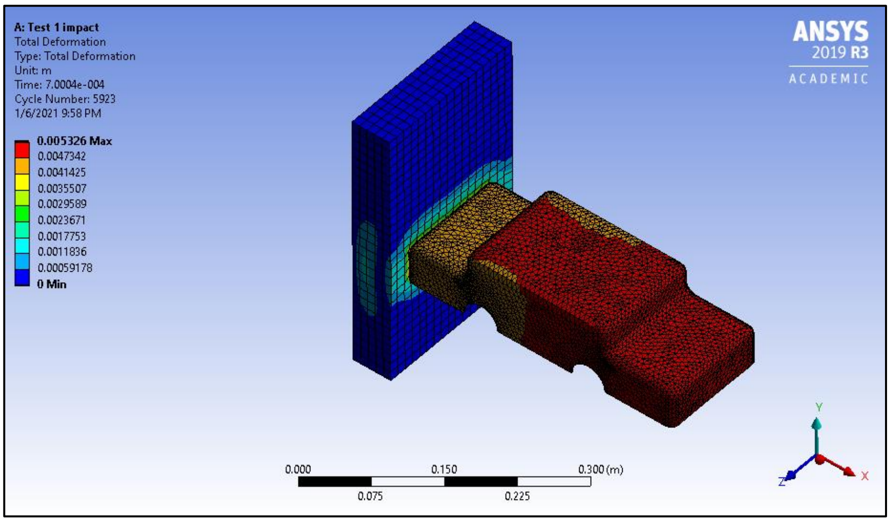
Figure 4.11 above shows the stress occurs on 40% volume fraction of filler loading where it is the highest content of filler but still no improvement in the composite's analysis stress. The maximum and minimum values are the same as the previous analysis because of the sample's forces and area.

4.2.3 Analysis of silk fibre-reinforced composite on impact strength

This section elaborated the analysis of composite in mechanical properties, which is impact strength. It is crucial to know the maximum and minimum value deformation occur and stresses when generating the sample. The simulation was run according to the real machining test in the lab. The sample of different weight fractions undergoes analysis one by one to get the results to be compared with other samples. The boundaries condition have been applied according to the desired data collected. This mechanical property is to know the crashworthiness value when impact occurs in high technology such as the automotive industry.

4.2.3.1 Analysis on 10% volume fraction of filler loading

Analysis of explicit dynamics that have been observed in the simulation was total deformation and stress. This analysis gave the overall deformation and stress impact of the car simulation as set in the simulation. Figure 4.12 below shows the deformation of 10% volume fraction of filler takes place.



(a)

(b)

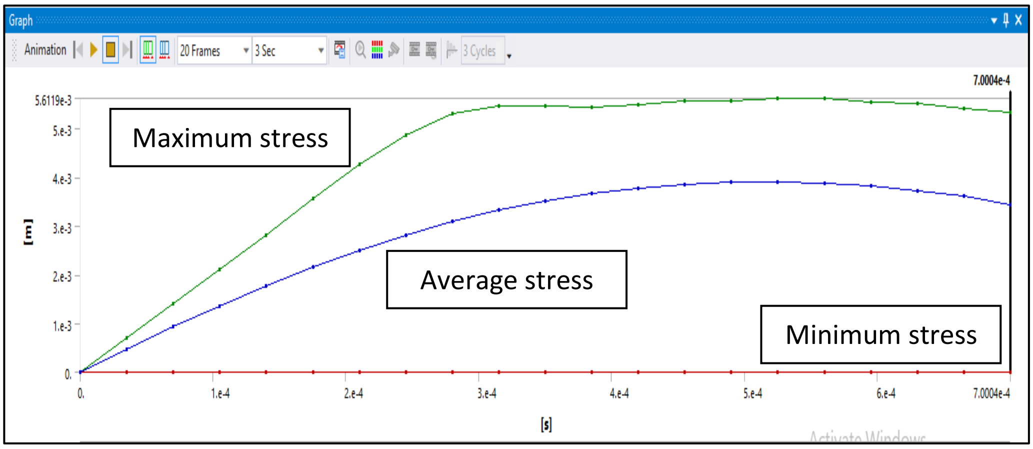
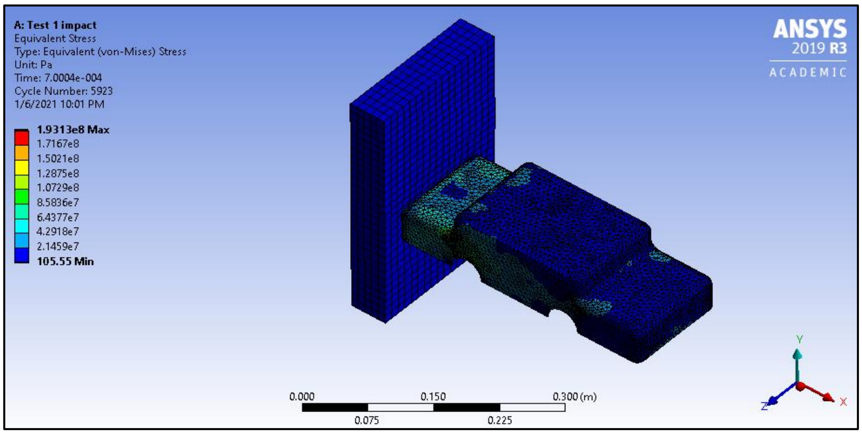


Figure 4.12 (a) Total deformation impact of 10% volume fraction, (b) Graph total deformation (m/s)

Figure 4.12 shows the total deformation of the impact test with filler loading 10%, where it is the lowest value of filler. The figure shows the car impact that occurs in the simulation to calculate the value of deformation and stress. The wall in front of the car is made of concrete and the car front is from silk reinforced composite. The velocity applied in this simulation is only 20 m/s to show a small impact of the car and concrete wall. When crash occurs, the front area hits first, but the red region was at the back area of the car. The maximum value in red region is 0.005326 m, and the graph showing an increased value of deformation, and then it is constant for the time being and finally failure. The green line in the graph shows the maximum value of stress, the blue line shows the average value and red line shows minimum value. This analysis only focusing on the maximum value of the graph which is the green line.

(a)



(b)

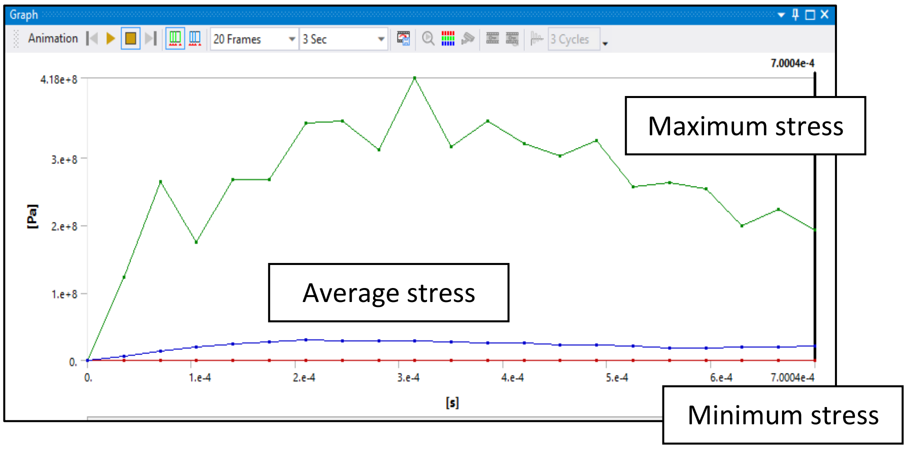
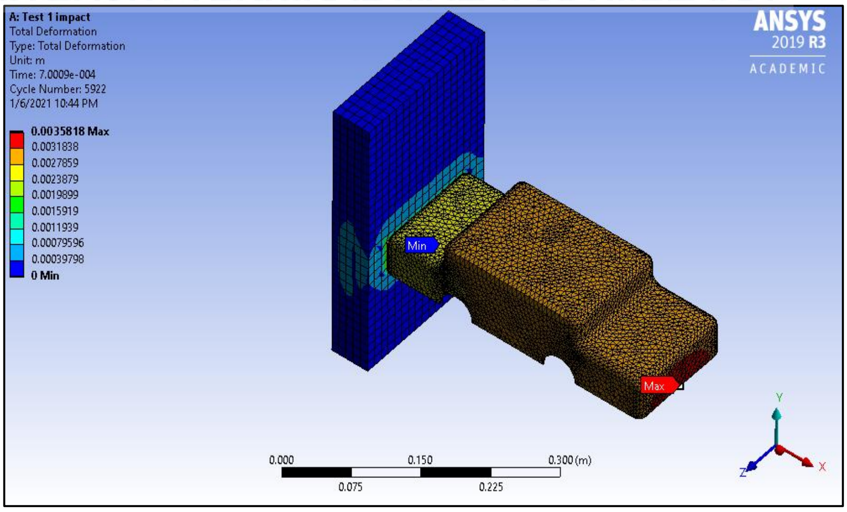


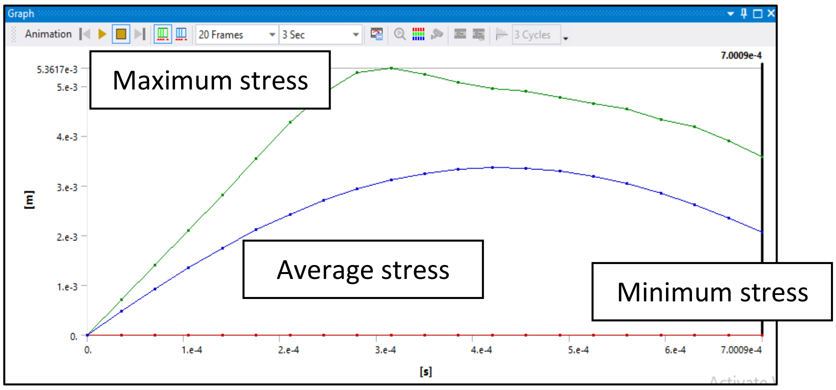
Figure 4.13 (a) Equivalent stress impact of 10% volume fraction, (b) Graph equivalent stress (Pa/s)

Figure 4.13 shows the stress of impact on 10% usage of filler loading. Figure (a) the stress occurs was small because all of the car analysis is in the dark blue region. The red region stress was small at the front bumper, where the part hit the wall concrete first. The highest value of stress is 418 MPa, where shown in the graph. In the animated simulation, the car hit the wall and then bounce back. Thus, it explained the increases and decreases in the chart until the car stop.

4.2.3.2 Analysis on 20% volume fraction of filler loading

(a)

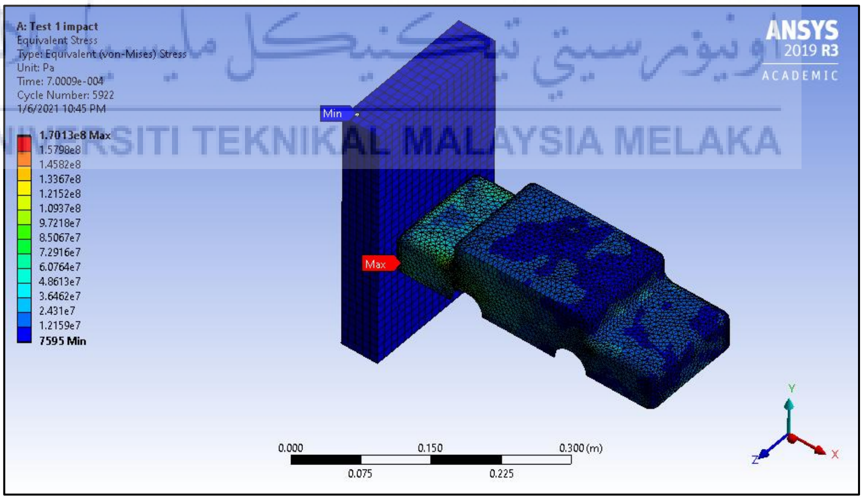




(b)

Figure 4.14 (a) Total deformation impact of 20% volume fraction, (b) Graph total deformation (m/s)

Based on figure 4.14 shows the total deformation for 20% filler loading, slightly increase than previous content. It offers the impact analysis when using 20% filler loading, resulting in decreasing deformation of the impact because of increasing value in properties of silk reinforced composite. A decreased value of about 0.001808 m differences between those two filler content. It proves that growing filler usage loading can withstand a little deform when impact occurs. The graph also shows that increasing deformation data and then decreasing as time goes by shows that the car stops after crushing the wall.



(a)

(b)

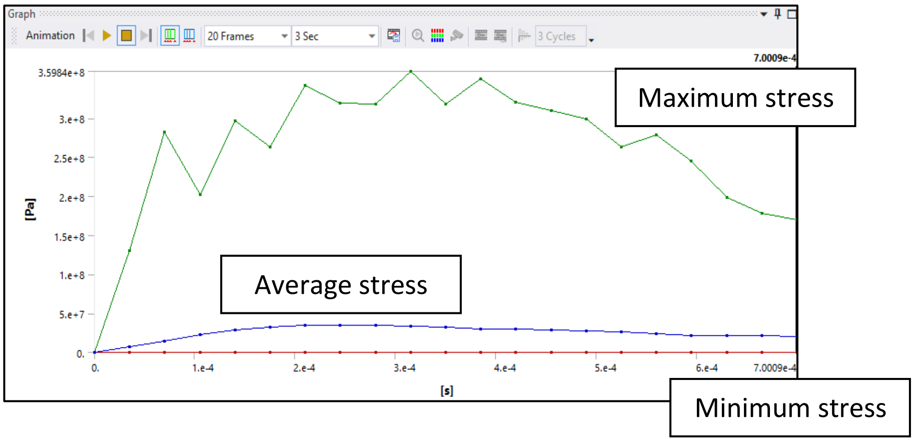


Figure 4.15 (a) Equivalent stress impact of 20% volume fraction, (b) Graph equivalent stress (Pa/s)

Figure 4.15 shows the maximum and minimum value of stress impact of 20% filler loading. The increased value of filler loading resulting in a decreased value of stress in this analysis. The difference value between 20% and 10% filler loading is about 23 MPa where in this section, the maximum value is 170 MPa slightly decreased. The maximum stress is the red region in figure 4.15 (a) where the front part car hits the wall first. The front part of the car is in bad condition of impact in simulation, also in reality. According to Mazumder *et al.* (2018), the impact strength remains unchanged even though there is increased filler loading value. The impact strength of composite depends on the nature of the fibre, matrix and fibre-matrix interfacial. In these cases, the value of stresses keeps changing when increasing the amount of filler loading due to the distribution of the carbon dust with the silk and epoxy. This might contributed to the potential of carbon dust acting as stress concentration due to the carbon dust becoming clustering.

4.2.3.3 Analysis on 30% volume fraction of filler loading

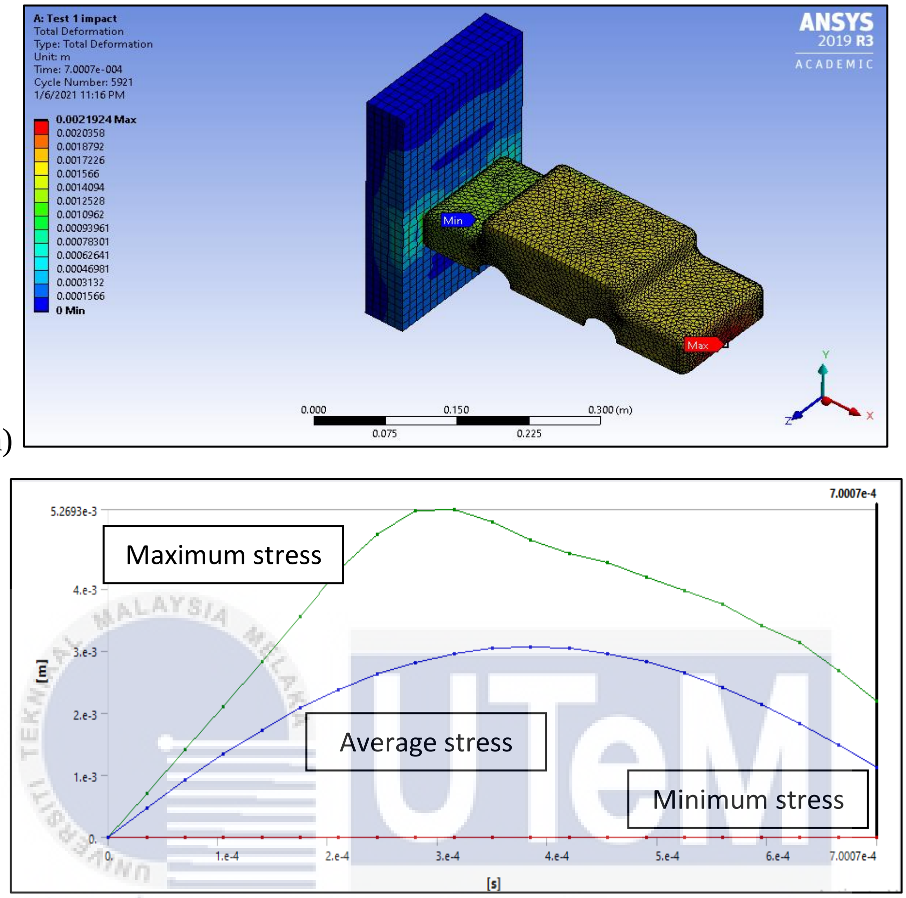
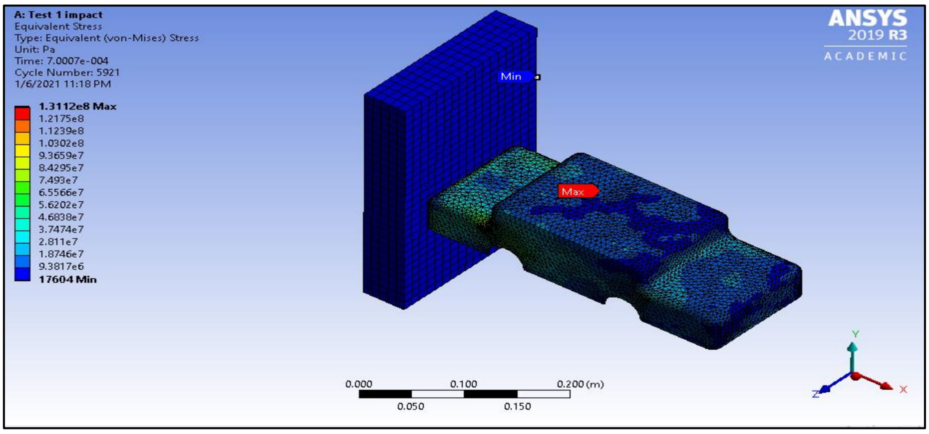
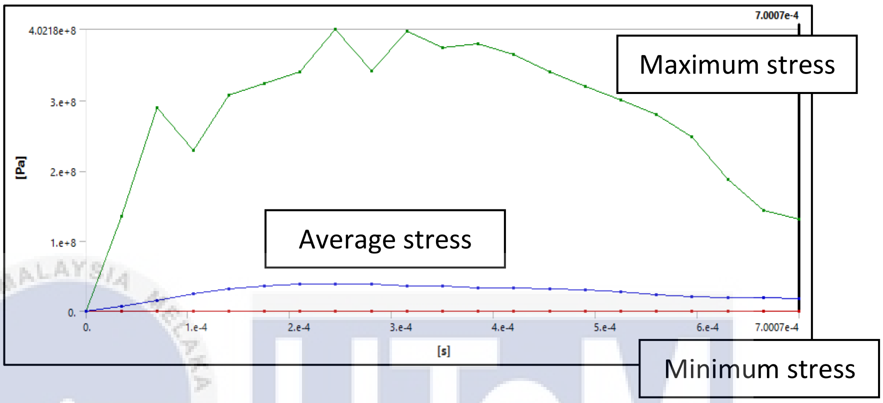
(a)
(b)


Figure 4.16 (a) Total deformation impact of 30% volume fraction, (b) Graph total deformation (m/s)

Figure 4.16 shows the total deformation of 30% filler loading, where it is resulting in a decreasing value of deformation between the previous analysis. Also, the analysis showed the color region of the car where it started to change to yellow. Yellow region concludes that reducing deform occurs during impact testing. The high content of filler loading helps in reducing the impact of propagation. Based on Onuoha *et al*. (2017) stated that the filler is added to the polymer to increase the rigidity and make it stronger. The higher the filler corporate, the stronger the composite. The high amount of filler can make the filler agglomeration in the composite. Thus, the stresses and deformation become lower.



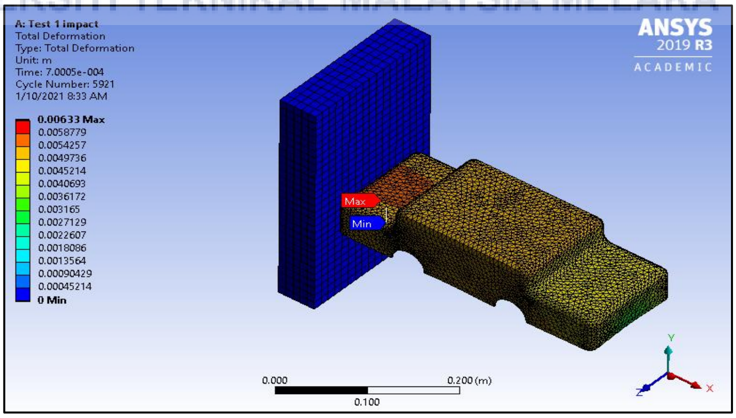
(a)



(b)

Figure 4.17 (a) Equivalent stress impact of 30% volume fraction, (b) Graph equivalent stress (Pa/s)

4.2.3.4 Analysis on 40% volume fraction of filler loading



(a)

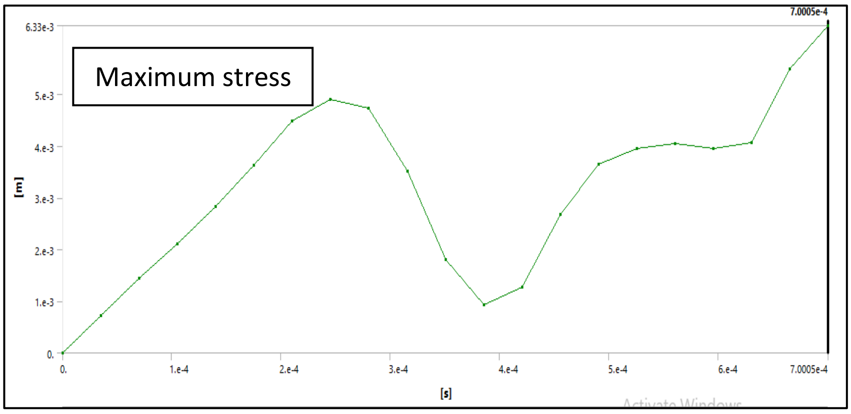
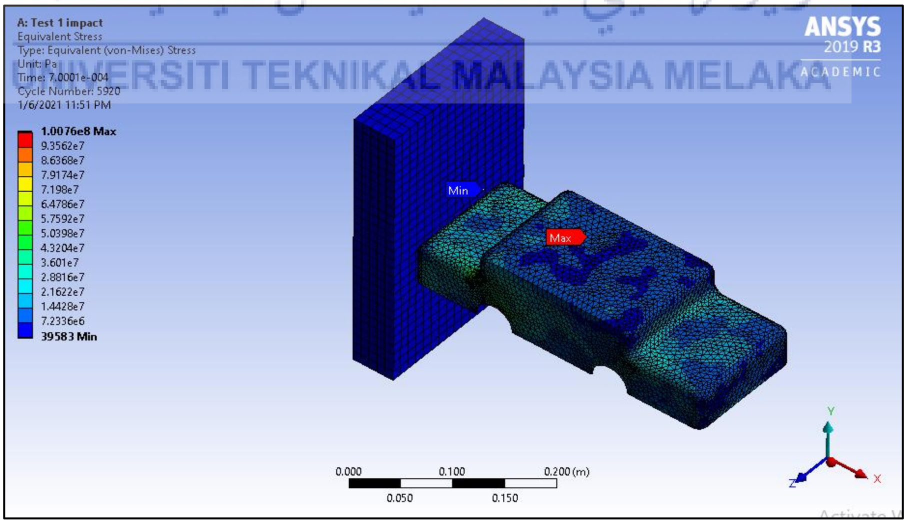
(b) 

Figure 4.18 (a) Total deformation impact of 40% volume fraction, (b) Graph total deformation (m/s)

Figure 4.18 illustrates the total deformation of 40% filler content where the result between the previous analysis slightly changed. The difference between the two data is 0.02077 m/s, which slightly decreases as it shows. Also, the impact of car analysis in figure (a) slowly shows the green region where less deformation occurs than the previous analysis. Chandrasekar *et al.* (2008) supported that 40% of filler loading shows optimal impact properties with less composite breakage, pull-out, and debonding. The difference content in failure mechanism delivered a significant role in interfacial bonding between silk, carbon dust, and epoxy resin.

(a) 

(b)

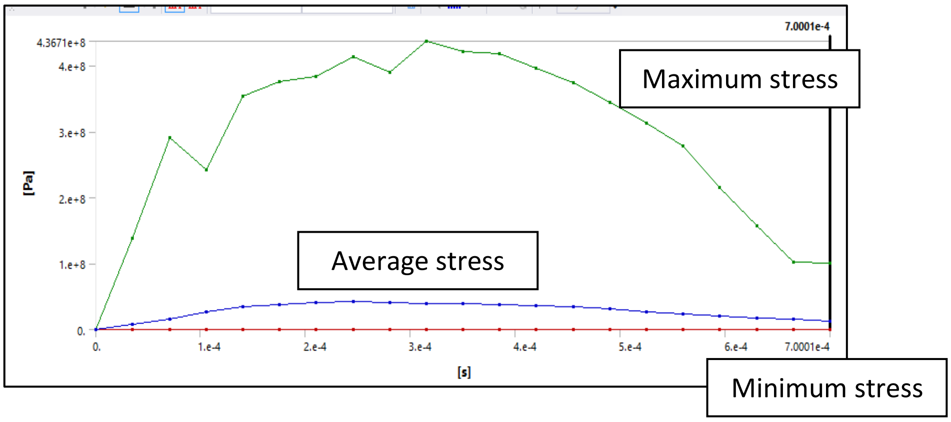


Figure 4.19 (a) Equivalent stress impact of 40% volume fraction, (b) Graph equivalent stress (Pa/s)

Figure 4.19 shows the stress impact of 40% filler loading, which is the highest value of loading in this analysis. It shows that the value of stress keeps decreasing from 10% of filler loading. The differences between the 40% and 30% filler loading were quite huge for about 30 MPa. According to Yang *et al*. (2017) stated in the study, the impact strength will increase with the increasing volume fraction of fibre. In this study, the increasing volume is the reinforcement, not the fibre, yet the stresses decreased. This study aims to reduce the amount of silk fibre and replace it with reclaimed carbon dust. The graph shows the less amount of point that hit a peak higher than other value. The point value was significantly fewer different from other points. Based on Mallick (2012) stated that both the front and back rails of automobiles need to be designed for crashworthiness to absorb energy when impact occurs. Carbon is one of the reinforced composites that have higher energy absorption.

4.3 Comparison of result analysis between mathematical approach and ANSYS simulation

This section discussed the comparison between those two approaches that have been undergoing through the result analysis of each percentage filler loading in tensile and impact strength of the study. The discussion of each analysis above shows a slight difference between those two approaches wherein theoretical prediction shows an increasing value of all properties. The properties such as density, elastic modulus, tensile strength and impact strength of the composite showed increasing value when the amount of filler loading added each sample is increased. Increasing elastic modulus also gives an advantage to the composite where the addition of filler increases the composite's stiffness, making the elongation at break become lower (Salmah *et al*., 2011). Besides, according to Fairuz *et al*. (2016) stated that when the percentage of filler increase, the tensile strength also increase followed the addition of filler loading. The increase of filler tends to make the composite withstand with any strength that acts on it. Thus, it can make a great composite in the future. Table 4.8 and 4.9 shows the summary results of all properties that undergo mathematical calculation and ANSYS analysis respectively.

Table 4.8 Summary result of mathematical calculation

Volume fraction of filler loading (%)	**Density (g/cm^3)**	**Elastic modulus (GPa)**	**Tensile strength (MPa)**
10	1.33	30.6	1676
20	1.38	52.6	1896
30	1.43	74.6	2116
40	1.48	96.6	2336

Apart from the mathematical calculation discussion, the ANSYS simulation results show a little different from the first approach. It shows the decreasing value of deformation and stress. In ANSYS analysis, the tensile strength value cannot be determined because lack of information on ANSYS simulation. The value of deformation in static structural analysis decreases when the amount of filler loading increases, which shows that the sample can withstand more high pressure longer and did not deform easily. Also, the deformation value in explicit dynamic decrease resulting that the front bumper can withstand high impact and did not deform so much rather than usual matrix composite. Poor filler matrix adhesion might weaken the composite and filler will not behave as reinforcement but as a defect in the matrix. 40% carbon dust silk reinforced composite has absorbed the energy during impact force which expected lead so the deformation and stress value is lower.

Table 4.9 Summary results of ANSYS analysis

Volume fraction of filler loading (%)	**ANSYS analysis (Static structural)**		**ANSYS analysis (Explicit dynamic)**	
	Total deformation (m)	**Equivalent stress (MPa)**	**Total deformation (m)**	**Equivalent stress (MPa)**
10	0.004671	1314	0.005326	193
20	0.002717	1314	0.003582	170
30	0.001916	1314	0.002192	131
40	0.001479	1314	0.000633	101

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the project that has been carried out, the conclusion drawn in this overall study is the achievement of the objectives. The prediction of carbon dust's influence with different volume fractions on mechanical properties of silk reinforced composite using a mathematical approach has been discussed and achieved in the study. It shows a great improvement among the properties calculated, such as density, tensile strength, Young's modulus and ultimate strain of each material. From the mathematical approach, each properties' value shows huge differences against each other when the filler content increases. Thus, dispersion of reclaimed carbon dust on the sample composite were expected to be as alternative reinforcement and became an excellent opportunity to create the material in the future.

Next, to analyze the correlation between the filler loading on performance computing using ANSYS simulation, all of the sample analysis was run in the simulation, resulting in deformation and stress. The mechanical properties that have been highlight are only strength and impact. The ANSYS simulation was constructive for the study and the results needed in this study can be used as future reference for improvement.

5.2 Sustainability

The sustainability is the use of reclaimed carbon dust virtually in this study by using calculation and simulation. The reclaimed carbon dust is from the excess waste of carbon fibre that cannot be used to save the waste. This silk reinforced composite has been utilized to reduce the amount of silk fibre usage as it is expensive. Carbon fibre is commonly known because it has greater mechanical properties. Using recycled material can embark on potential waste via this study in calculation and modeling.

5.3 Long-life learning

The long-life learning applied in this study is that the prediction of the potential waste in high technology application requires a long time by learning how to use the ANSYS simulation. This software is so comprehensive and has various features and analysis that can be discovered one by one. It is a new time experience to use ANSYS simulation as this software learning does not include these manufacturing courses. New skills, experiences, and knowledge in learning this software would be helpful in the future.

5.4 Complexity

The complexity that can be highlighted in this study is using two approaches (mathematical calculation and ANSYS simulation) to determine whether the mechanical properties' results had an improvement or vice versa. This study has utilized specific engineering knowledge in ANSYS which is software need to self-learn and explore starting from designing until run the simulation. Those two approaches require many data and trial tests in order to get the desired results in mechanical properties.

5.5 Recommendation

Many aspects need to be improved in this study. Firstly, the ANSYS simulation could include another analysis such as safety factor and strain. Also, this software is broad and has many features that cannot be discovered quickly. The tensile strength can be run in the ANSYS software, but it takes time to explore the software. The comparison between those two approaches was not completed because of insufficient data on simulation and lack of knowledge in learning ANSYS. To get accurate data on silk reinforced composite, it is encouraging to experiment on this composite to get better results to support this study. Hence, the ability of this new type of composite can be more useful to the industries.

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