LOW COST FIBREGLASS GO-KART

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"LOW COST FIBERGLASS GO-KART"** was prepared by **ABERDEEN LIM JIAN RONG (07UEB05783)** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechanical Engineering at Universiti Tunku Abdul Rahman.

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In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me useful information and advices when I'm facing stumble upon obstacles throughout this project. Besides, I would like to thank my parents for their moral support and encouragement which contribute to the completion of this project.

LOW COST FIBERGLASS GO-KART

ABSTRACT

This report documents the process and methodology to produce a low cost go-kart chassis by the modelling it with CAD software and a prototype was later built by using locally available fibreglass. The feasibility of the go-kart design was examined through FEA package. The basic characteristic of go-kart is discussed beside the application of composite materials by FEA package in design has also been look into. Some fundamental of FEA is also briefly discussed and its application on the analysis of go-kart chassis, especially the torsional stiffness and bending deflection are also been discussed. Analytical evaluations of different preliminary go–kart designs were then performed by FEA package in effort to determine the best possible design. After the best possible design, is determined, the prototype is been built and an experimental testing is conducting to validate the numerical analysis. The behaviour of bending deflection has also been look into and the torsional stiffness of the go-kart chassis is calculated from the data obtained from FEA package.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

F	Force, N

CAD	Computer Aided Design
FEA	Finite Element Analysis
CIK	Commission Internationale de Karting
FIA	Federation Internationale de l'Automobile
hp	Horsepower
FRP	Fibre-Reinforced Plastic/ Fibre-Reinforced Polymer
FEM	Finite Element Method
1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
PDS	Product Design Specification

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Go–kart or kart is a small single seater, open, four wheeled vehicle without a traditional suspension. Karting is considered a very safe motorsport where risks of injuries are rare and generally non-life-threatening. Karting has always been seen as a gateway in become a professional racer in the higher and more expensive ranks of motorsports.

In Malaysia, karting is starting to gain enormous popularity especially after Malaysia has become a Formula One™ Grand Prix host and recent involvement of Malaysian entities in Formula 1's Lotus racing team. Hence, the demands for karting have increased but it is still restricted to who may afford the relatively high entry cost and equipments cost such the go-kart.

1.2 Problem Statement

Currently, Malaysia does not have local go-karts available which leave local karting fans and karting operators no choice but to import it from abroad. This directly causes the price to soar which turn away some the fans and enthusiasts from involving in this motorsport.

1.3 Aims and Objectives

This project is strives to produce a low cost go-kart chassis by designing with CAD and by using locally available fibreglass. The feasibility of the go-kart design is to be examined through FEA package.

1.4 Schedule

Figure in the following the page is the Gantt chart that shows the schedule of this project that span a period of 28 weeks.

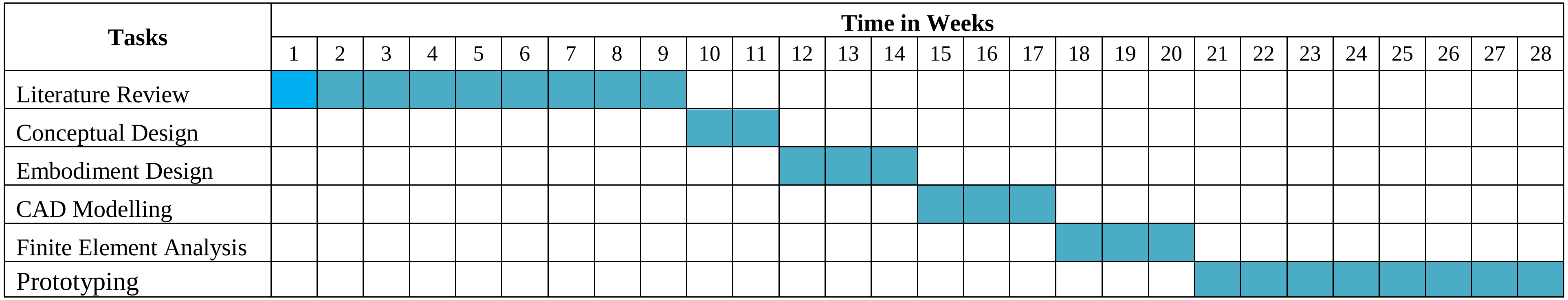

Figure 1.1: Gantt Chart.

CHAPTER 2

LITERATURE REVIEW

2.1 Brief History of Go-Kart

According to Graham Smith (2002), Art Ingels who was a veteran hot rod and race car builder at Kurtis Kraft in California, America invented the first ever go-kart in 1956. Initially, karting is a leisure motorsport enjoyed by airmen during the post-war period. The sport is quickly caught on with Go Kart Manufacturing Co. Inc. Being the first company to manufacture and distribute go-karts after two years. In 1959, McCullough also jump in the bandwagon of the industry, by becoming the first company to manufacture go-kart engines.

Although go-kart originated from United States, it has also gain interests from countries all over the worlds especially Europe. For example, according to Tony Kart's company profile in its website from Italy, they have been producing go-kart since 1958 and emerged as one of the main manufacturer to date.

Today, kart racing is governed by CIK-FIA which was founded in 1962 is the current primary international sanctioning body for kart racing. It is also a part of FIA since 2000 which is a governing body for motorsport across the globe. CIK-FIA plays an important role in regulating kart racing related matters such as technical regulations.

2.2 Main Components of Go-Kart

2.2.1 Chassis

The chassis of a go-kart or also known as the go-kart frame is like a foundation that attached to the axles and holds the engine of the go-kart. It is crucial to have a good design of chassis that will it gives the go-kart better traction for the driver to manoeuvre especially diving in corners at high speeds. Hence, according to Walker (2005), the absence of conventional suspension in go-kart compare to a normal vehicle requires the chassis itself to be flexible as a replacement of the suspensions. Yet, the go-kart chassis has to be rigid enough to withstand the strains it might experience such as weight of the drivers. In addition, a good traction from a proper design will also have less vibration which resulting a longer chassis life span.

For who takes karting seriously, they need a chassis that are able to suit different track conditions. Depending on the conditions of the track, a dry track will require a stiffer chassis; whereas a wet track will require a more flexible chassis. Therefore, there a chassis are designed to have removal stiffening bars on the rear, front, and side of the go-kart that can be removed or added depending on the track conditions.

There are four types of chassis which are caged, open, offset and straight chassis. A caged chassis have a roll cage that surrounds and protect the driver in an event of a roll-over. It usually used for karting on a dirt track where the terrain mostly uneven. As for open, offset and straight chassis, it does not have roll cage. Offset and straight chassis simply differentiate from each other based on the different position of the driver.

2.2.2 Engines

Typical go-kart will have two-stroke and four-stroke engines to choose from. By referring to Vortex's engine specifications, a two-stroke engine usually produces power at range of 8hp single-cylinder unit to 90hp with a twin cylinder unit (Vortex, 2010). Whereas, four-strokes engine from manufacturer such as Aixro which can produces at maximum power up to 45hp (Aixro, 2010). Engine of a kart is also as important as the chassis as it drives the go-kart around the track.

2.2.3 Transmission system

Similar to any other transmission systems, by using gear ratios, it is important in order the conversion of power from engine to prop shaft. It consists of drive train, prop shaft, final drive shafts and whit or without gearbox and clutch, depending on the type of go-kart. However, there is no differential in a go-kart's transmission system compare to conventional transmission especially in Karting World Championship which it is prohibited (CIK-FIA, 2010).

2.2.4 Tyres

Unlike vehicles tyres use on normal road to cater for different road conditions, go-kart has specific tyres for dry or wet track so that drivers can have maximum performances and grips from the tyres. Slick and wet tyres are two main types tyres used in karting.

A slick tyre does not have grooves on the tyre. Slick tyre as shown in Figure 2.1 in the following page is used when the track is dry.

Figure 2.1: Typical go-kart slick tyre. (Sava, 2010)

On the other hand, wet tyres which are grooved are used in order to have more grips when the track is slippery. Hence, for track conditions that are in wet conditions, wet tyre as shown in Figure 2.2 will be employed.

Figure 2.2: Typical go-kart wet tyre. (Sava, 2010)

2.3 Fibreglass

Fibreglass or to be exact, fibre-reinforced polymer (FRP) is a fibrous composite: polymer-matrix composite. As the name indicated, it consists of polymer resin as matrix such as the least expensive polyesters and vinyl esters, reinforced with glass in its fibre form. According Erhard (2006), fibreglass is widely used in aerospace, automotive, marine and construction industries.

2.3.1 Characteristics of fibreglass

Callister (2006) compared glass in fibre form to glass in bulk form and founded that glass in fibre has higher tensile strengths. This is due to the probability of fewer critical surface flaws in fibre than in bulk material. In another context by Jones (1975), he pointed out that in materials that have dislocations, fibre form material experiences fewer dislocations compare to its bulk form.

However, fibre needed matrix as the binder material as a medium for the fibre to take load in the form of a structural element, but the matrix phase only sustains small amount of applied load. In addition, beside the matrix material is ductile; it also protects the individual fibres from mechanical abrasion or chemical reaction with the environment which will cause surface damage. Furthermore, the matrix phase also minimizes the risk of catastrophic failure as it is able to prevent crack propagation.

Besides that, fibreglass usually employs lamination techniques where the orientation of fibre direction of each layer is manipulated in various directions so that the strengths and stiffness are tailored to meet specific design requirements of the structural element. Generally, according to Callister (2006), reinforcement and strength are at their maximum when all fibres are parallel; perpendicular they are a minimum.

2.3.2 Advantages and disadvantages of fibreglass

Fibreglass is becoming increasingly the materials of choice especially in product and applications that require the high strength to weight ratio and high flexural strength. Its flexibility to customize to desired strengths and stiffness also maximised the material usage and minimized wastage. The life spans of fibreglass products are also longer as fibreglass has resistances characteristics against mechanical abrasion or chemical reaction. Directly, fibreglass products have low maintenances and high durability which make it a cost effective material. Last but not least, fibreglass also gives designers greater design freedom as it has fewer constraints on size, shape, colour or finish compared to others common materials such as steel.

Due to the unique properties of fibreglass (high strength and low elastic modulus compared to steel), it does not offer plasticity that steel has. Besides that, fibreglass also suffers from stress corrosion and lack of ductility (Gdoutos et al., 2000).

2.4 Finite Element Analysis

The finite element analysis (FEA) used numerical method or often known as finite element method (FEM) that can be applied to approximate solution for an engineering problem. The approximate solution is obtained by idealized a product model by splitting it into as many small discrete pieces called finite elements or more commonly known as elements, which are connected by nodes. This dividing process is known as mesh generation. Each of the generated elements has exact equations that define how it reacts to certain load. Hence, accuracy of the solution can be increased by refining the mesh generation. The fundamental of FEM can be found under Appendix B.

2.4.1 Type of finite element

As mentioned in the previous part, finite elements are often just called elements. Basically dimensional (1D), two-dimensional (2D) and three-dimensional (3D) elements are the three most common elements, where the typical general idealization geometry for each type of elements is illustrated in Figure 2.3. Further information regarding each type of finite element can be found under the Appendix A.

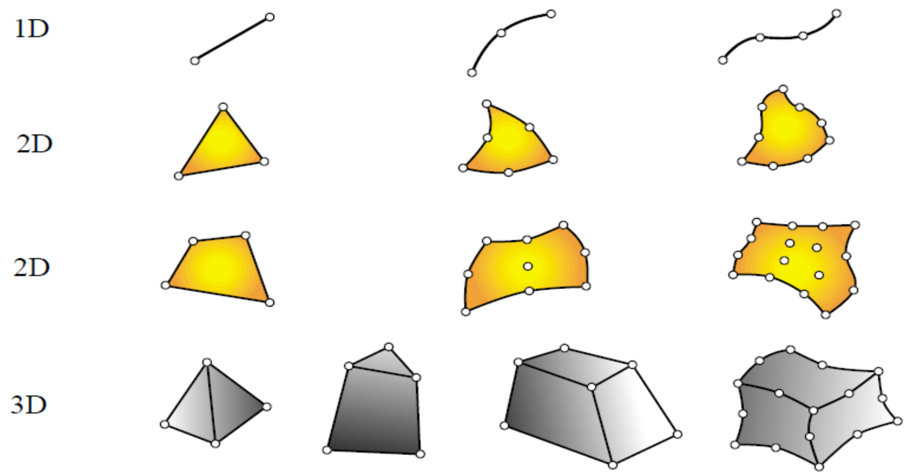

Figure 2.3: Typical finite element geometries in one through three dimensions. (Felippa, 2010)

2.4.2 Type of finite element model

Linear and non-linear are the two basic classifications of model that frequently applied by FEA to tackle static engineering problems. Linear model is simply refers to the geometry and its elements that being analysed are restricted to linear behaviour. On the contrary, non-linear model includes all others static problems that does not cover by linear model.

In many case, however, a non-linear model is favourable compare as linear model differ too much from reality and provide crude or misleading information. As a result, using linear analysis might lead to over-design which increase the overall manufacturing of the products.

2.4.3 Application of FEA on composite materials

A detailed description of the finite element method is beyond the scope of this report since FEA algebraic equations varying from several thousand to several million depending on the model size. Thus, Kollár & Springer (2003) has summarized the application of FEA on composite materials to few major steps which can be found under Appendix C.

The laminate orientation and the generation of FEA models are key factors when performing FEA on composite materials. This can be seen in Solazzi and Matteazzi (2002) study of structural analysis of a frame for go-kart on the usage of different materials (aluminium, titanium and composite materials) where the authors have paid great attention in generation of reliable FEA models. The authors have go the extent of generating couple of FEA models and the final FEA model is chosen based on the accuracy of results (by comparing it to the experimental results). The authors have also defined the orientation of the laminate of composite materials clearly when they simulating the go-kart frame.

Furthermore, FEA on laminate composite materials properties are more likely defined as orthotropic and anisotropic materials. This is due to the fact that isotropic materials are usually unproductive since excess strength and stiffness is unavoidably available some different direction (Jones, 1975). For example, numerous studies like Pavan et al. (2006), Liu and Zheng (2008), Xu et al. (2009), Nanda et al. (2009) all have used orthotropic and anisotropic material properties in their studies. Therefore, it is important to define the type of material properties of laminate composite materials correctly as it affects the accuracy of the results.

In addition, the type of elements used to simulate composite materials is entirely depends on the type of composite materials used. Kollár & Springer (2003) claims that for thick laminates, neither plate (flat shell) or 3D elements (Figure 2.4) is practical. Instead, the authors suggested that thick laminate should be divided into sublaminates where each layer in the sublaminate (Figure2.5) may be monoclinic, orthotropic, transversely isotropic, or isotropic. Hence, to correctly defining the FEA model of composite materials, the mechanical behaviour properties of each layer of laminate composite materials must be indentified first.

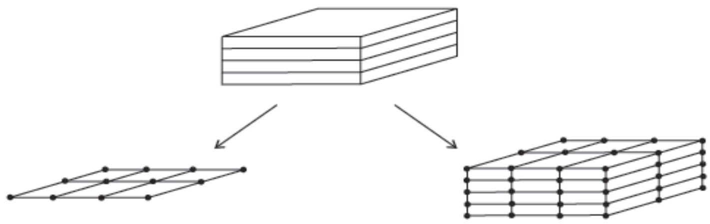

Figure 2.4: Thick laminate (top), analysis with plate elements (left), analysis with three-dimensional elements (right). (Kollár & Springer, 2003)

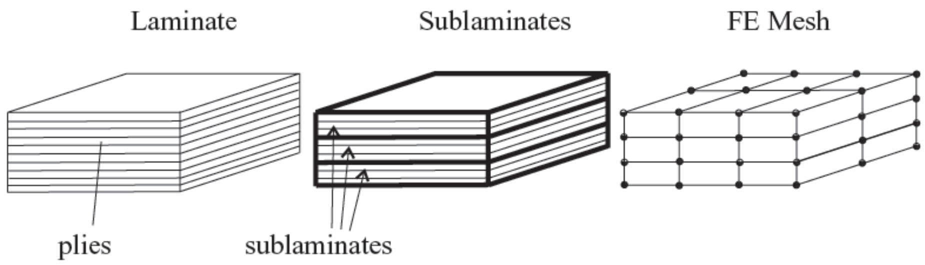

Figure 2.5: Thick laminate (left), sublaminates (middle), and the finite element mesh (right).(Kollár & Springer, 2003)

However, the complexity of the geometries shape of the composite materials structures must also take in considerations. It should be noted that Kollár & Springer’s claims that 3D element is not practical for laminate is not true. Chen et al. (2010), addressed the necessity to generate 3D elements meshes for modelling composite components with complex geometric shapes. Besides that, Elmarakbi et al. (2009) used new modified adaptive cohesive element to simulate delamination growth in composite materials. Thus, it is crucial to understand the geometries of the structures in order to match the correct type of element.

2.4.4 Application of FEA on go kart chassis

The application of FEA on the development of the technical characteristics and dynamics of go kart chassis has only gained momentum in recent years. Before that, the development of go kart, it has always been carried out predominantly on the track through physical testing activities (Muzzupappa et al., 2006). Since go-karts do not have any type of system suspension and differential, its technical characteristics are strongly influenced by the shape and stiffness of the frame (Natoli, 1999).

Hence, a lot of studies have showed that the torsional stiffness of the go-kart chassis is essential as it greatly affects the vehicle global performance. For instance, various studies such as Baudille et al. (2001), Baudille et al. (June 2002), and Solazzi and Matteazzi (2002) all have implement FEA in effort to study the torsional stiffness of the go-kart chassis. Furthermore, in another study by Muzzappa et al. (June 2005), they had defined their go-kart chassis in FEA through shell-type elements. In addition to that, most of the studies had also validated their FEA analysis process by performing physical test (experiment) on a go-kart chassis. Most studies has also looked into the displacement of the chassis through static loading test. Hence, all these suggested that in order to develop a feasible go-kart chassis, the torsional stiffness and bending deflection of the chassis has to be taken in considerations. It also suggested experiment has to be carried whenever possible in order to validate the results of FEA simulations.

2.4.5 FEA/CAD packages

Nowadays, new generation of FEA suites incorporates solvers into CAD software. FEA is important to engineer because it helps engineer understand the possible response of a structure when there is no closed form solution. By using FEA, a product's performance in a virtual environment is able to be simulated. Therefore, it has the advantage to optimize design without producing a prototype over and over again; product cost and development time are reduced.

CHAPTER 3

METHODOLOGY

3.1 Overall methodology

Methodology gives the brief idea to what the method that has been adopted throughout the project. The flow of the whole project is illustrated as in Figure 3.1 in the following page.

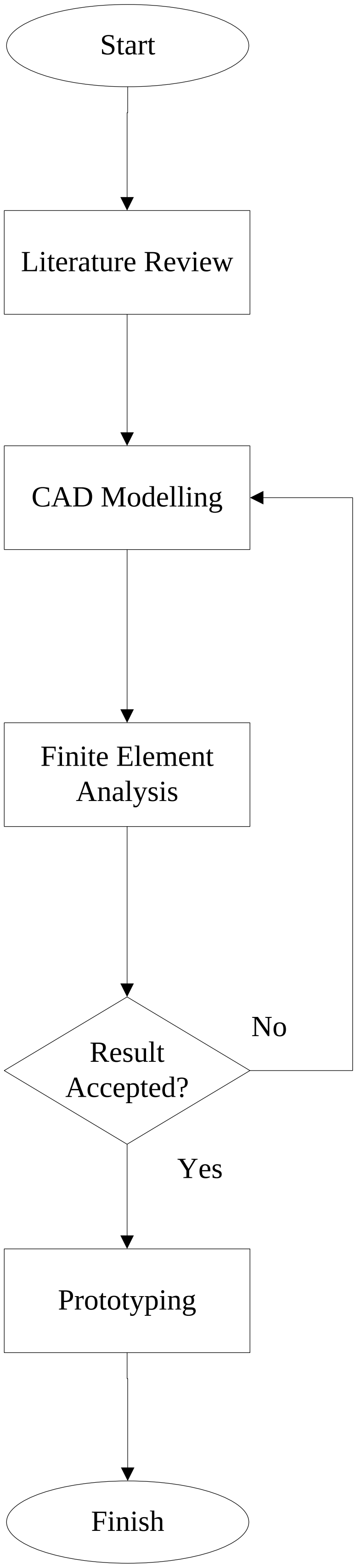

Figure 3.1: Process flow chart.

3.1.1 Literature review

Before the prototype of the fibreglass go-kart is constructed, it is crucial to have a good grasp on the aspects that related to the prototype. Thus, a literature reviews on related materials is conducted by referring information available from the online and offline journals, books and the internet. All the obtained knowledge from literature review is important when it comes to conceptual design.

First and foremost, some basic understanding on the go-kart itself should be done by studying the development of go-kart from the past to the current. Besides that, the main components of a go-kart will also be investigated so that key factors on how each component should perform are known. On top of that, in order to fully utilise the potential of fibreglass, its characteristics must also be learned. Furthermore, adequate understanding toward the fundamentals and concepts of FEA is also important especially regarding the governing equations and applications.

3.1.2 CAD modelling

The fibreglass go-kart will be modelled using CAD software when the go-kart design and its specifications are finalised. The CAD model may need to be remodel if the results of FEA do not meet with the predetermined requirements. In this phase, all the required detailed engineering drawings for manufacturing prototype of the fibreglass go-kart are prepared.

3.1.3 Finite element analysis

The FEA will compromise structural analysis such as torsional stiffness and bending deflection simulations where the behaviours of the designed fibreglass go-kart under different conditions are reviewed. The severity of any undesirable results will be assessed and any necessary modification on the design will be made accordingly.

3.1.4 Prototyping

This is the last phase of this project where the prototype of the fibreglass go-kart is been constructed based on finalized detailed engineering drawings.

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CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Bending deflection

Before the prototype is being constructed, FEA was used in order to determine the best possible design. Several possible designs with various reinforcements had been simulated. The final design was then been built and an experiment was carried out in order to validate the final go-kart design's FEA simulation on the basis of the experimental data.

4.1.1 FEA simulation

4.1.1.1 Preparation of FEA model

In order to carry out the FEA simulation, all the 3D CAD models for each design were prepared using Siemens NX 7. By using NX Nastran solver that bundle with the Siemens NX 7, each design FEA model was solved using the SESTATIC 101 - Single Constraint solution and structural analysis was also used. It was meshed as 2D CQUAD4 thin shell-type elements (4-noded quadrilateral element), where each element size is 10 mm. As a result, an average total of 56556 numbers of CQUAD4 thin shell-type elements and 55168 numbers of nodes per design were meshed. This is crucial since the material used is fibreglass which is formed by several ply of laminate.

Details of how the FEA model material physical properties were defined are discussed in the following sub chapter. The numerical analysis is then solved by linear elimination processor after all the elements, mesh techniques, materials, and boundary conditions of the go-kart chassis model were defined.

4.1.1.2 FEA model material physical properties

The characteristics of the fibreglass used by the FEA model are shown in Table 4.1. It was obtained by inputting all the relevant material properties for matrix material (polyester resin) and fibre material (Chopped Strand Mat, CSM), as guaranteed by manufacturer (please refer to Appendix E and F). By defining the ply materials, the laminate of fibreglass is defined through laminate modeller that comes with the FEA package.

Table 4.1: Material properties of fibreglass laminate defined by laminate modeler

Number of ply	5
Ply thickness	0.7 mm
Young's Modulus	1.033e+007 mN/mm^2(kPa)
Poisson's Ratio	0.295287
Shear Modulus	3.989e+006 mN/mm^2(kPa)

In order to obtain the thickness of each ply, a simple experiment was carried out by laying up a five plies of flat plate (Figure 4.1) where its thickness was been measured and the average thickness for each ply was obtained as Table 4.2 showed in the following page.

Figure 4.1: five plies of fibreglass flat plate

Table 4.2: Average thicknesses of each ply fibreglass lay-up

	5 plies flat plate thickness
1st reading	4.10 mm
2nd reading	4.23 mm
3rd reading	3.33 mm
4th reading	3.55 mm
5th reading	3.41 mm
Average thickness of each ply	$\frac{\left[\frac{(4.10+4.23+3.33+3.55+3.41)}{5}\right]}{5} \cong 0.7mm$

4.1.1.3 FEA model constraints and force components

In order to simulate the bending deflection condition, the FEA model's constraints and by referring to a study by Martin (2011), the standard human mass is 70 kg, as defined as in the Figure 4.2 in the following page shown.

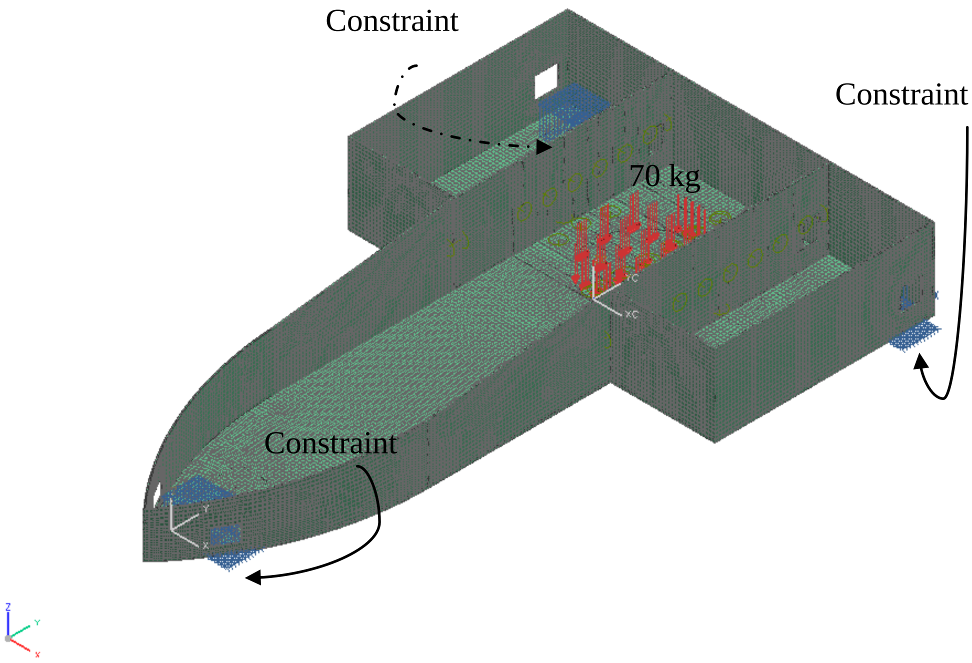


Figure 4.2: Preliminary FEA model constraints and force components for simulation to determine the best possible design

As Figure 4.2 shown, the constraints (simply supported constraint and fixed translation constraint) are defined at the face below the go-kart chassis. The mass of the driver is defined as a force acting on a circular area which presumably similar to the contact area of a human hip when sitting in it.

However, in order to simulate as near as possible the conditions imposed during experiment testing, a different force components has to be redefined; 3 rectangular masses were used instead. The mass of each rectangular mass used during experiment testing is tabulated in Table 4.3 and its designated force components as Figure 4.3 in the following page.

Table 4.3: Mass of rectangular mass

Mass 1, W_1	21.48 kg
Mass 2, W_2	24.98 kg
Mass 3, W_3	24.36 kg

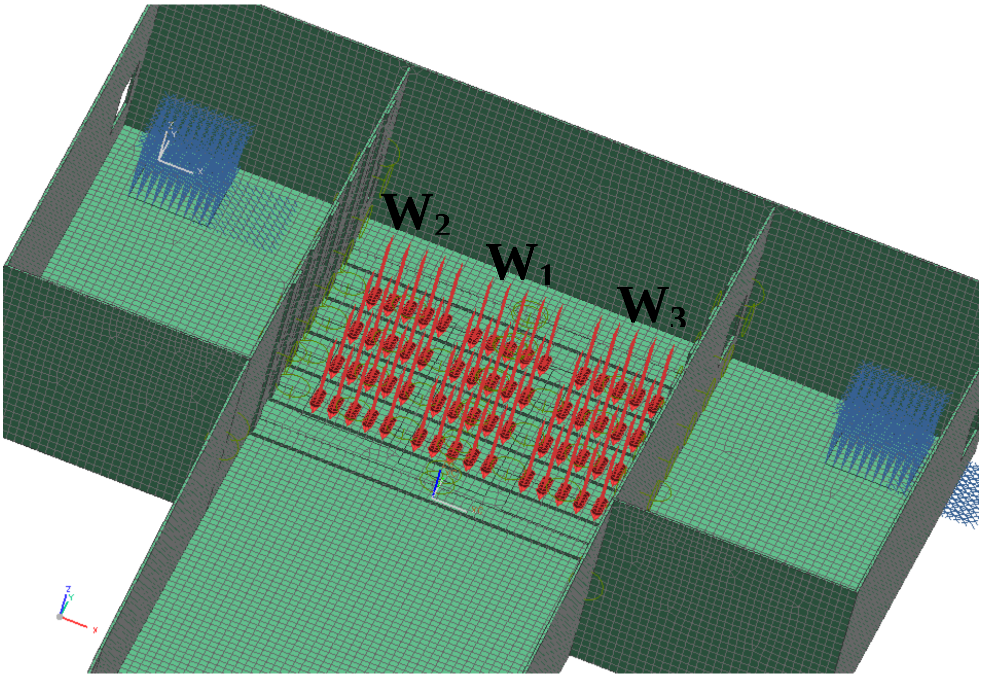


Figure 4.3: matching force components were used to simulate as near as possible the conditions imposed during experiment testing

4.1.2 Experimental Setup

As mentioned previously, an experiment is crucial in order to validate the FEA simulation. Therefore, a static loading test was performed where the setup is as Figure 4.4 shown and the mass of each rectangular mass used is shown Table 4.3 as in previous sub chapter.

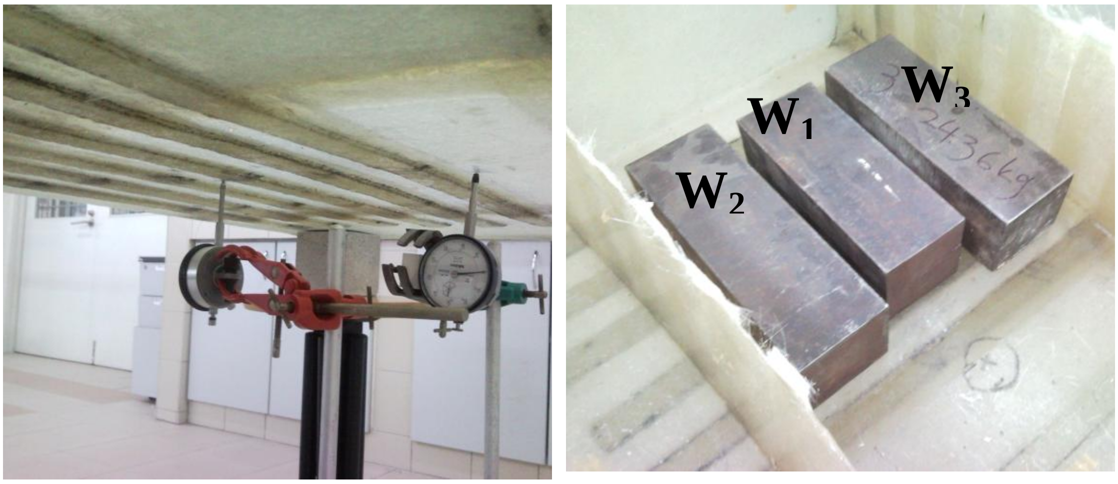


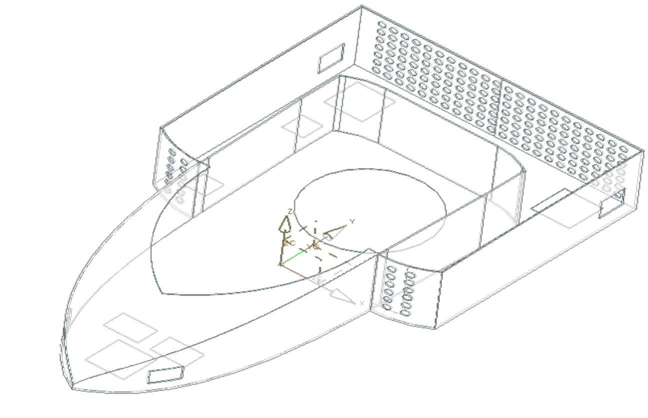
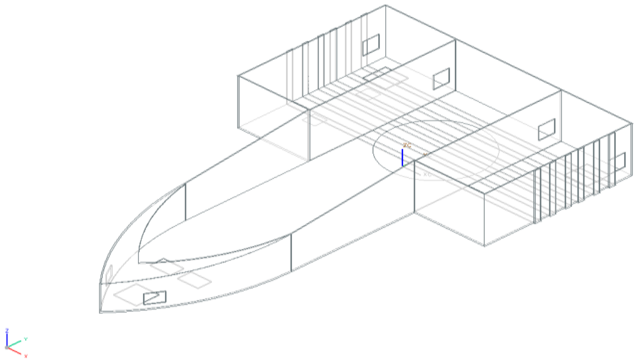
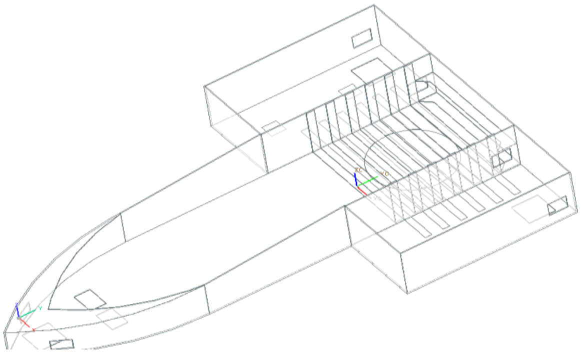
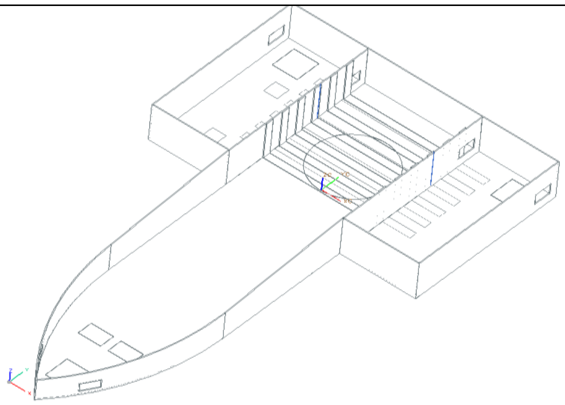
Figure 4.4: (left) The strain gauge setup; (right) rectangular mass

4.1.3 FEA Simulation Results

4.1.3.1 FEA simulation results for determining the best possible design

A total of four possible design with different design variations such different design of reinforced were been simulated before the final best design is been “translated” into a real prototype. The result of each variation is tabulated in Table 4.4 in the following page and the best FEA result for the best possible design is shown in Figure 4.5 in the following page after Table 4.4.

Table 4.4: FEA Simulation results for determining the best possible design

Design viariation	Maximum displacement
	22.990 mm
	14.700 mm
	6.344 mm
	6.817 mm (Chosen best possible design)

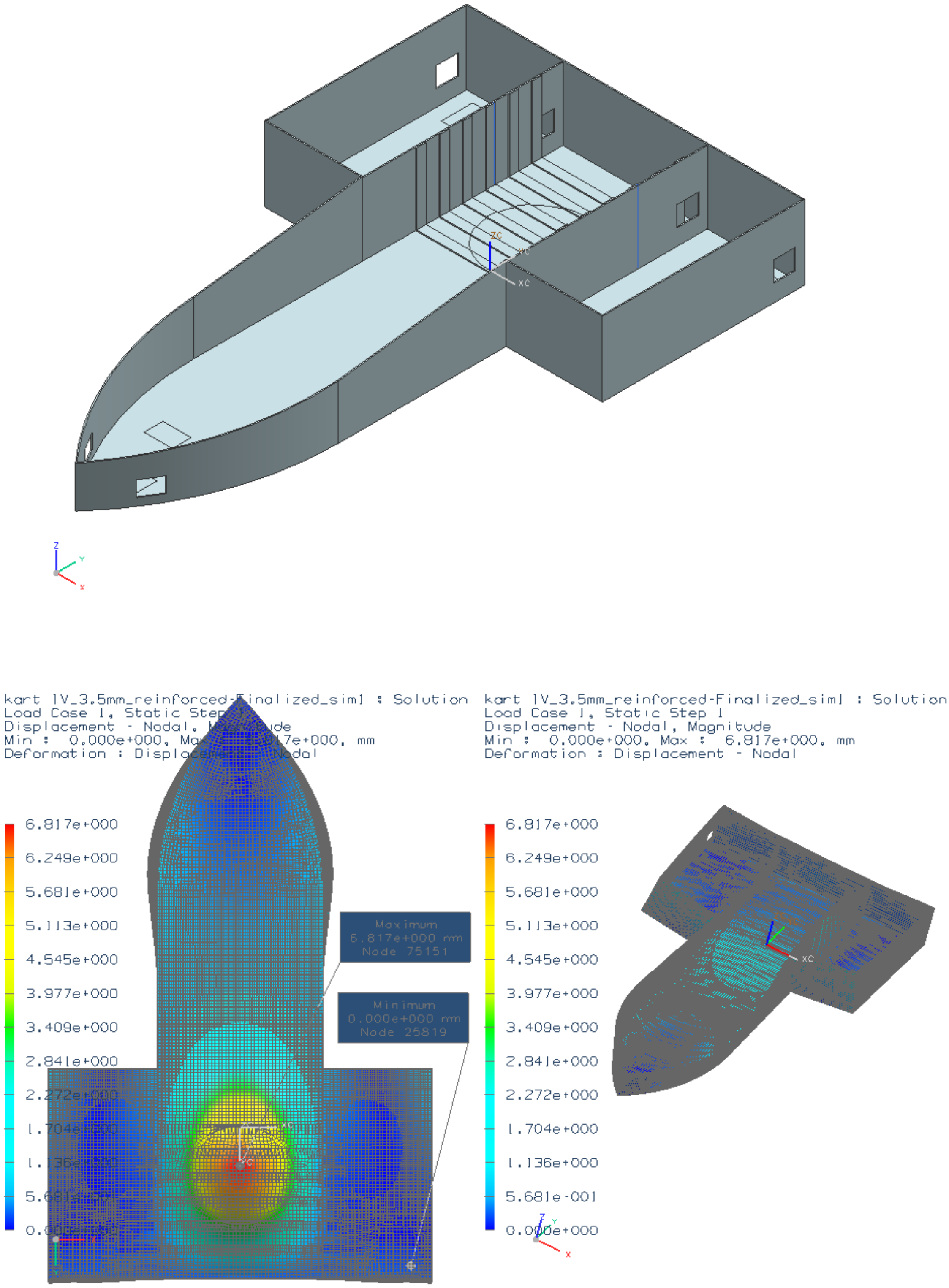


Figure 4.5: FEA result for the best possible design

4.1.4 Validation of FEA results

Figure 4.6 indicates the result for FEA model that been simulate to match as close as the experiment setup; whereas the following Table 4.5 is the difference between experimental testing results and FEA simulation result. The results will be only discussed later under the discussion chapter (chapter 4.3).

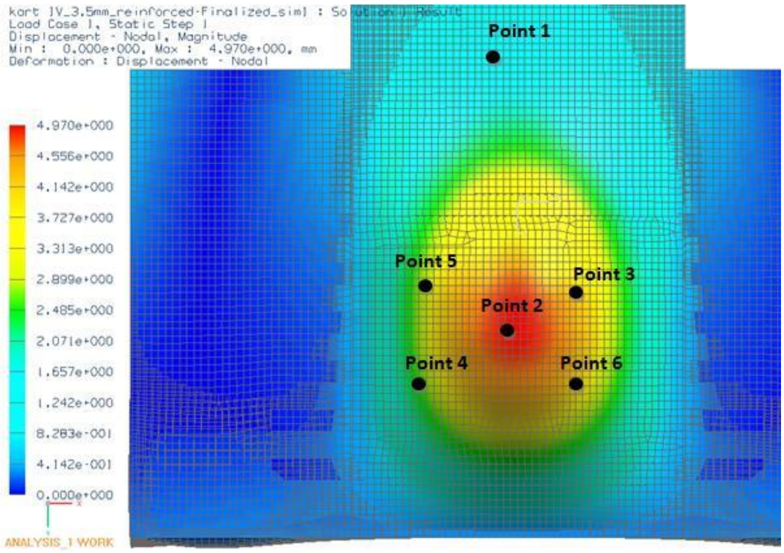


Figure 4.6: FEA result for the validation

Table 4.5: The Difference Between Experimental Testing and FEA Simulation Result.

	Displacement (experimental), mm	Displacement (simulation), mm	Difference, mm	Percentage of Difference, %
Point 1	5.93	1.657	4.273	257.88
Point 2	6.21	4.970	1.240	24.95
Point 3	5.49	4.142	1.348	32.54
Point 4	3.97	2.899	1.071	36.94
Point 5	4.44	3.313	1.127	34.02
Point 6	4.66	3.727	0.933	25.03

In addition, as Figure 4.8 in the following page shown, it is the setup how the bending deflection is been monitor. As in Figure 4.7, the figure on the right, the wall of the go-kart has actually deflected inward slightly. Therefore this verified that the bending deflection behaviour of the simulation and the experiment behaved similarly.

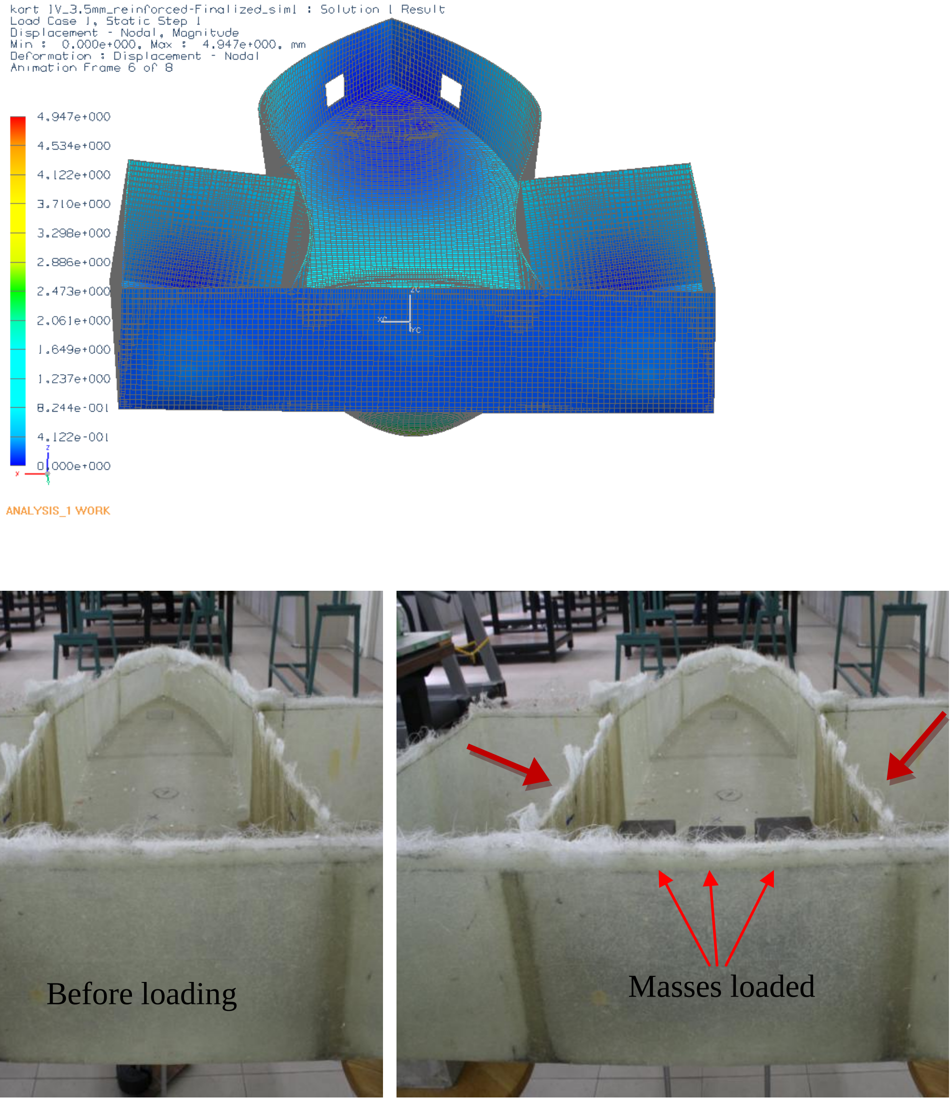


Figure 4.7: Similarity in the bending deflection behaviour between experimental and FEA simulation

Figure 4.8: Setup for observations of bending deflections

4.2 Torsional stiffness

As previously discuss the torsional stiffness is equally important in the development of go-kart chassis. Hence a FEA analysis of different load is simulated accordingly as the following.

4.2.1 FEA Model

4.2.1.1 Preparation of FEA model

In order to carry out the FEA simulation for torsional stiffness, all the elements, mesh techniques, materials, and boundary conditions of the go-kart chassis model were defined similar for the study of bending deflection. The main differences are FEA model constraints and its force components which are defined as Figure 4.9 shown in the following page.

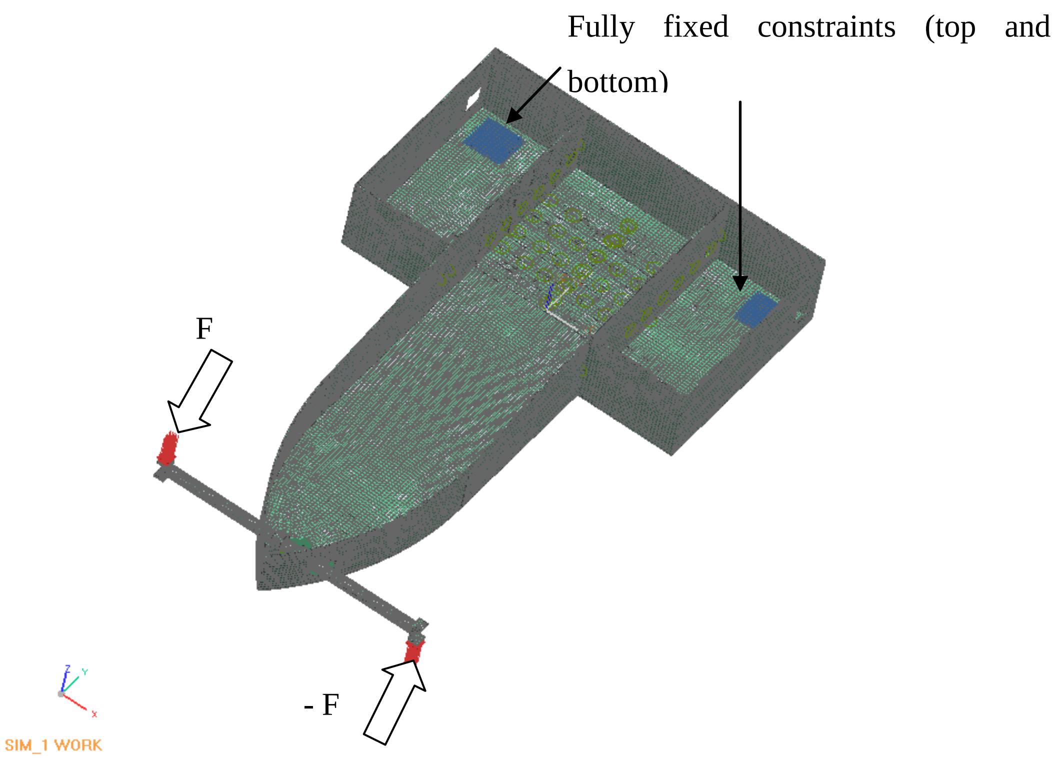


Figure 4.9: FEA model constraints and force components for the study of torsional stiffness

4.2.2 FEA Simulation Results

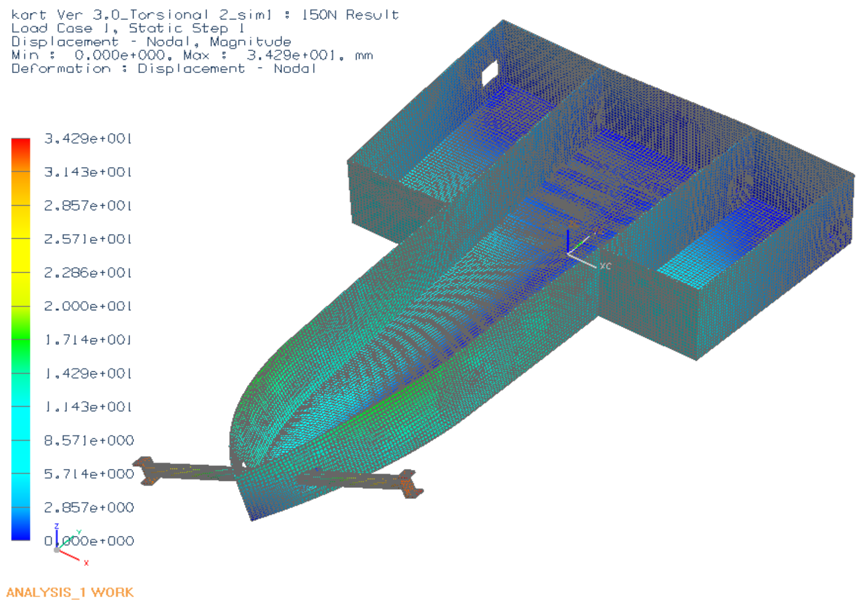


Figure 4.10: FEA simulation results for the study of torsional stiffness at maximum displacement of 34.29 mm where F = 150N

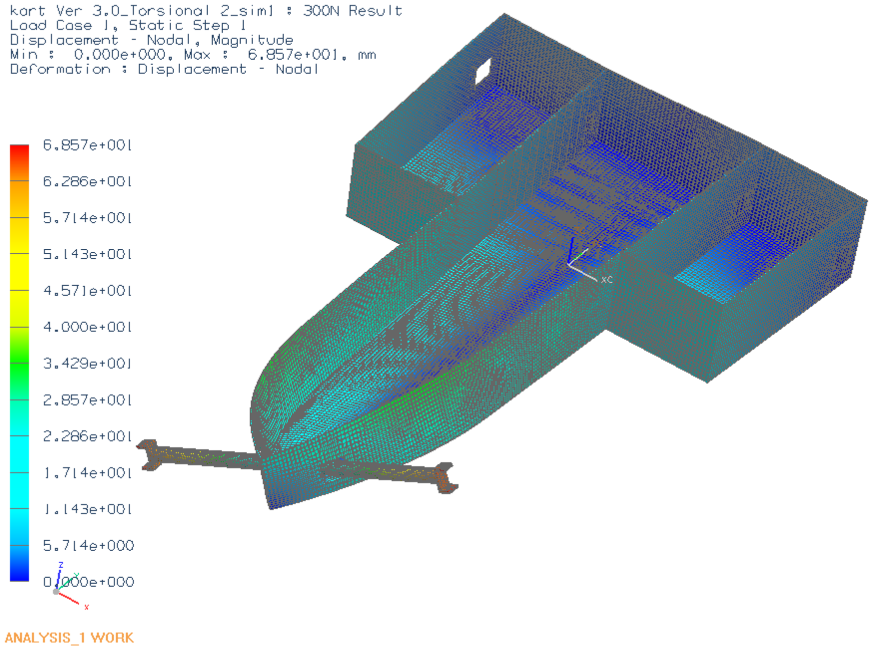


Figure 4.11: FEA simulation results for the study of torsional stiffness at maximum displacement of 68.57 mm where F = 300N

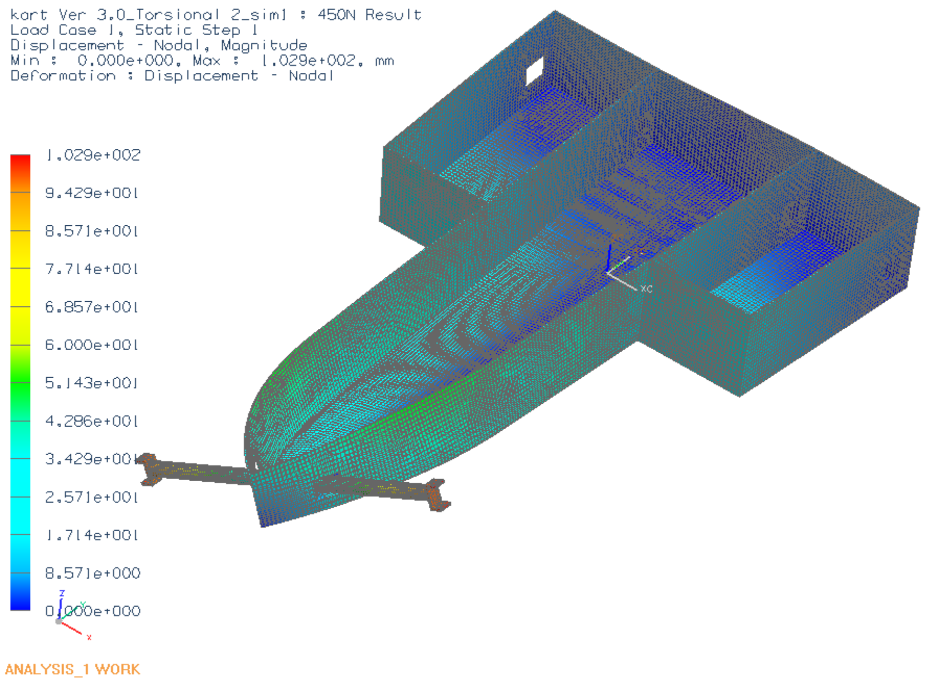


Figure 4.12: FEA simulation results for the study of torsional stiffness at maximum displacement of 102.9 mm where F = 450N

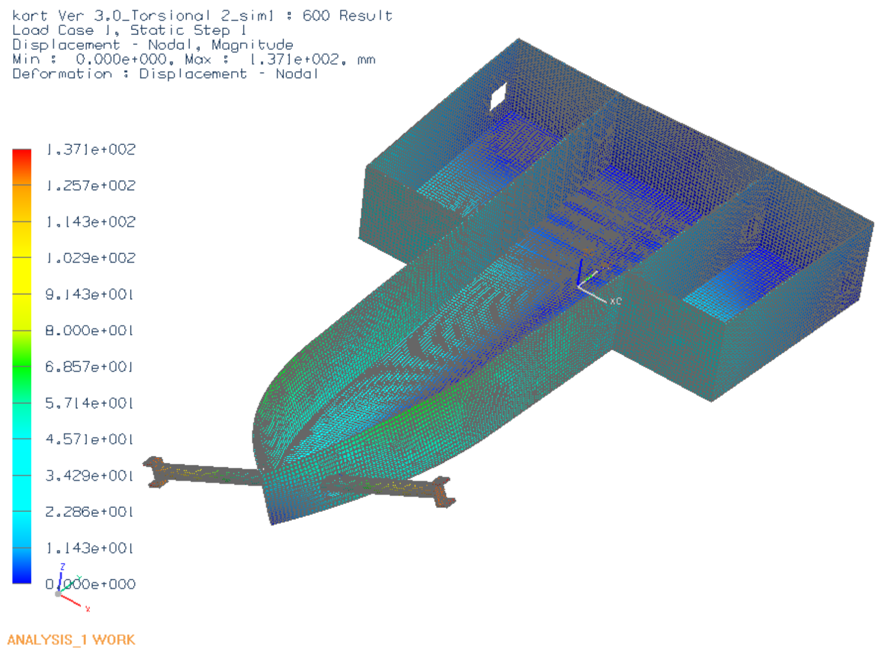


Figure 4.13: FEA simulation results for the study of torsional stiffness at maximum displacement of 137.1 mm where F = 600N

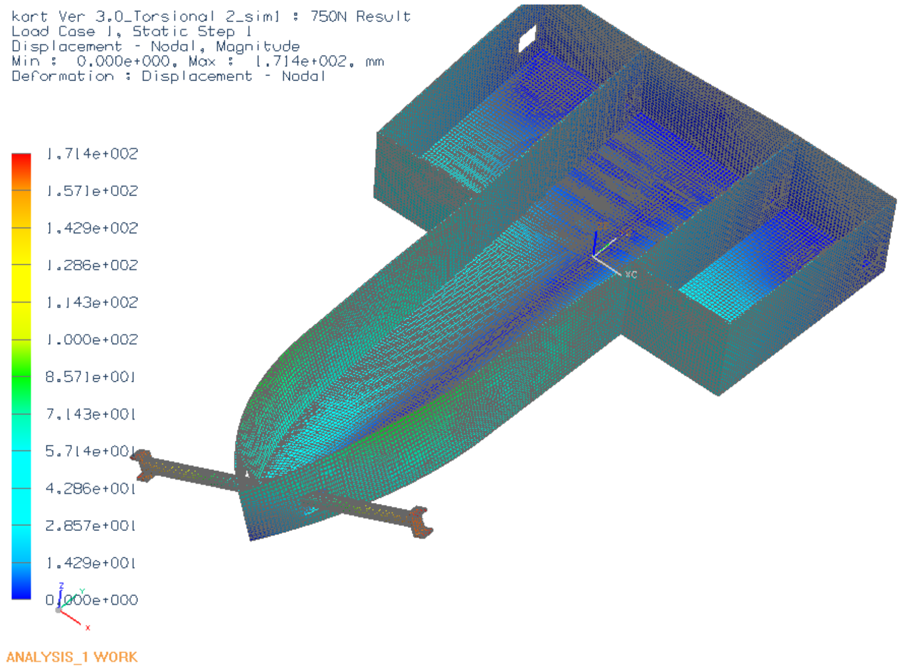


Figure 4.14: FEA simulation results for the study of torsional stiffness at maximum displacement of 171.4 mm where F = 750N

4.3 Discussion

4.3.1 Bending deflection

4.3.1.1 Validation of FEA results

The comparison between the FEA model and the experimental test show a relative fair results correspondence in terms of displacements measured at the reference point. It is worth to note that, the discrete point 1 has an extremely high difference of 257.88%. In contrast to FEA conducted by others such as Biancolini et al. (June 2002) and Maurizio et al. (2006), they are able to validate with experimental within 95% accuracy. Directly this suggested that, this suggested that there are the possibilities such as the prototype was not built exactly the same to the FEA model (such as dimensions and ply thickness) are possible. In addition, the prototpype might also experience shrinkage since polyester resin was used as suggested by van der Woude and Lawton (2010).

However, the average results difference is 25% to 36% for the other five points. This most likely cause by error in FEA models itself. As Dr Grieve from University of Plymouth addressed that errors associated with FEA can arises from the element size itself. Throughout the FEA simulation, although finer element has smaller the discretisation error, the FEA model element size used is 10 mm as the smaller the element size (the finer the mesh), the higher the computation time and resources needed. M. Vable from Michigan Technological University has also held that error can also originate from the description of the boundary value problem.

4.3.2 Torsional stiffness

4.3.2.1 Analysis and Calculation of torsional stiffness

As suggested by the study by Matrangolo et al. (2004), the torsional stiffness of the frame is evaluated by evaluating how it is distributed along its length, which can be obtained by analysing the data retrieved from simulation of the FEA model.

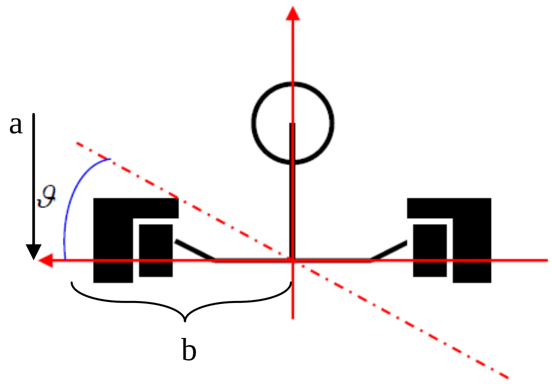
Hence, by using the fundamental of torsional stiffness, torque per angle of twist, Table 4.6 is tabulated by using the following equation (Muzzuppa et al., 2006). By taking the FEA simulation result for torsional stiffness when force is at 150 N the a = 34.29 mm (Figure 4.10):

$$\tan\theta = \frac{a}{b}$$

$$\tan\theta = \frac{34.29}{400}$$

$$\theta = 0.085725$$

$$\theta = \tan^{-1} 0.085725$$



$$K = \frac{Tb}{\theta}$$

$$K = \frac{150 \times 400}{\tan^{-1} 0.085725}$$

$$K = 12.25\ Nmm/^{\circ}$$

Figure 4.15: Sample calculation of torsional stiffness when force is at 150 N the *a* = 34.29 mm

Table 4.6: Torsional stiffness and angle of twist for each force.

Force, F(N)	Angle of Twist, θ (°)	Torsional Stiffness, K (Nmm/°)
150	4.8997	12.25
300	9.7274	12.34
450	14.4265	12.48
600	18.9192	12.68
750	23.1951	12.93

As a result, the relationship between force and torsional stiffness and force and angle of twist were plotted as Figure 4.16 and Figure 4.17 respectively.

From both of the graph, it suggests that the force is proportional to the torsional stiffness where angle of twist also increases proportionally. In addition, it also fit with the increment deflection from 150N to 750N (Figure 4.10 – Figure 4.14) behaviour demonstrated by the animation of FEA simulation.

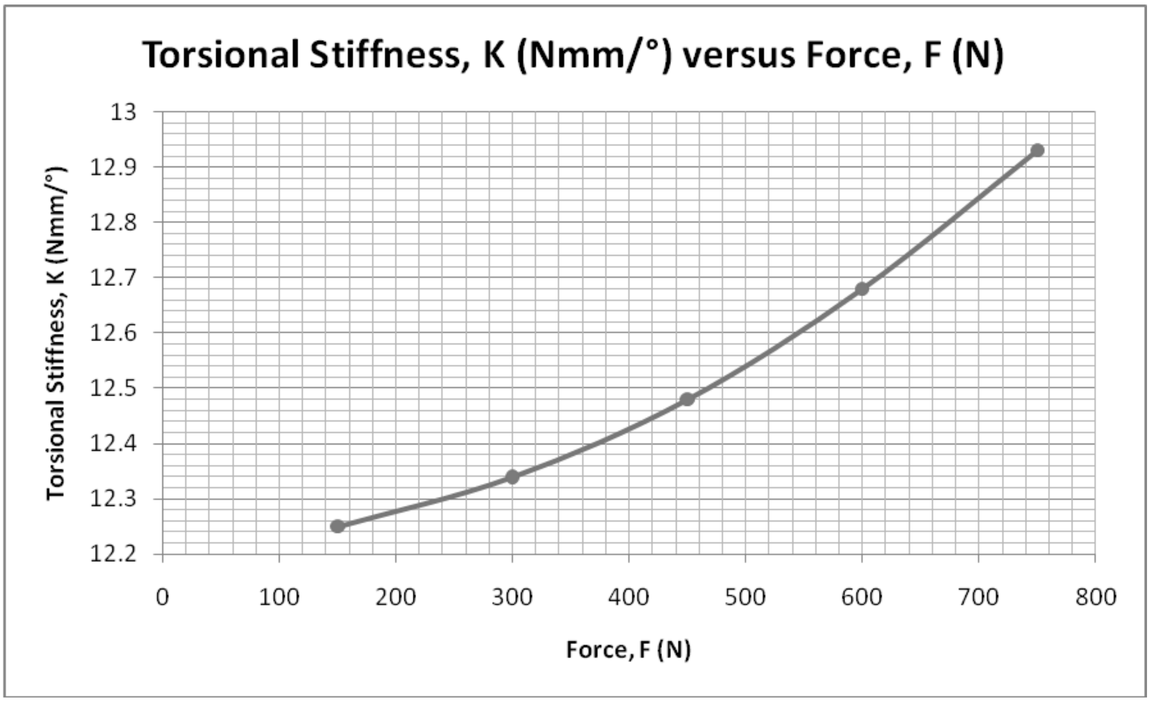


Figure 4.16: Torsional Stiffness, K (Nmm/°) versus Force, F (N) Graph

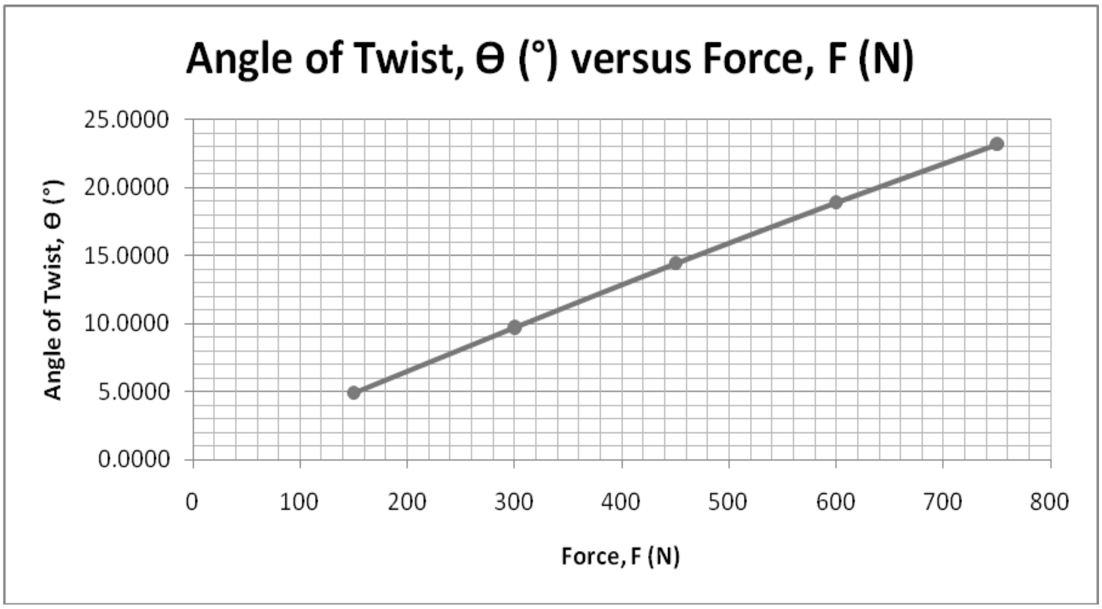


Figure 4.17: Angle of Twist, Θ (°) versus Force, F (N) Graph

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the result obtained, the objective of the project is achieved and complete within the planned time frame. A low cost go-kart chassis was designed with CAD and a prototype has been built by using locally available fibreglass. The feasibility of the go-kart design was been examined through FEA package which later is validate through experimental analysis of the fibreglass go-kart prototype. The torsional stiffness of the fibreglass go-kart has also been study beside the bending deflection behaviour of the go-kart.

However, the advantage and the application of FEA package is not fully maximize. This was due to several reasons. One of the major causes is the lack of necessary understanding of the FEA package that been used throughout this project. Thus, due that reasoning, it more or less contributes to the errors occurred. Besides that, there are is still lack of methodology and baseline data that can be use as a yard stick when it comes to the analysis of go-kart chassis. For instance, the data obtained from go-kart when it been drive around the track is still not common and available for the study of the public.

5.2 Recommendations

The methodology of FEA has to be further developed such as validating the FEA analysis through dynamic experimental test. This is crucial in providing the basis for the future developments regarding the optimisation process of the vehicle performance. Besides that, instead using one FEA package, analysis conducted by several FEA package on the same analysis might also be able to be done in order to provide better validation. Besides that, the possibility and potential of using composite materials instead of fibreglass alone is also worth to explore.

In future, experimental analysis of conventional go-kart chassis maybe carried out by analysing the go kart chassis while it is out on the track. These data are essential and important. This is because by understanding how a go-kart actually or should perform when on the track, a go-kart that are road worthiness can only be built. This proven where, in motorsport, the driver feedback is always one of the major key aspects in building a race wining vehicles.

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APPENDICES

APPENDIX A: Type of finite element

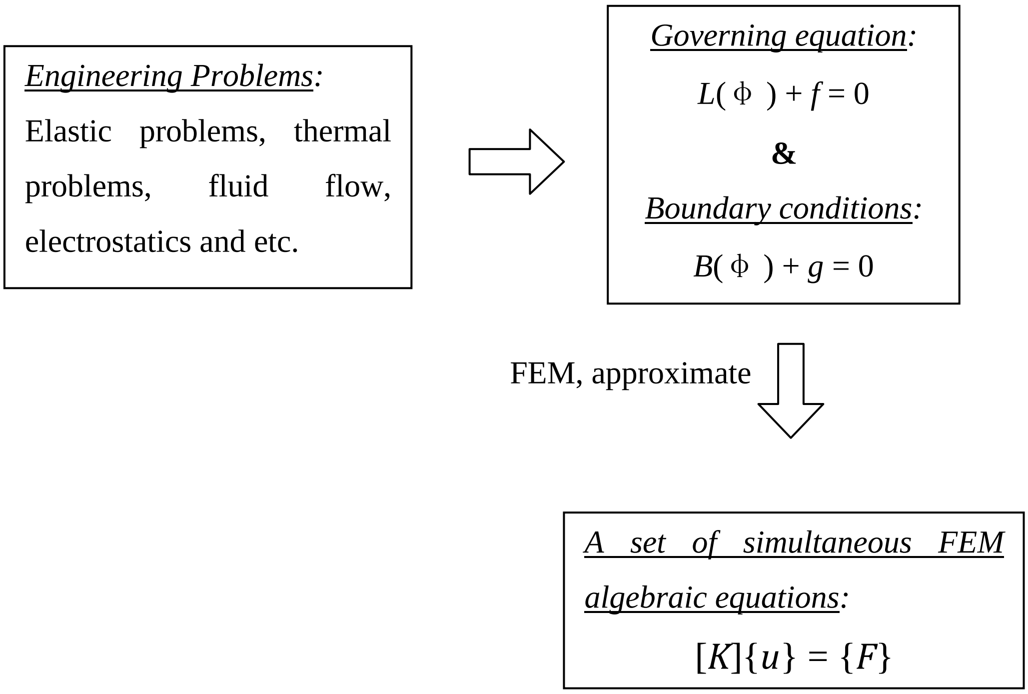
Although in the real world, all geometry is in 3D, it would be costly and time consuming to solve every engineering problem in 3D. Hence, in some of the cases, a 3D geometry can be idealized or simplified into the simplest form which is the 1D element (a line or a curve), where the field variable varies in only one direction. Two-node linear elements and two-node quadratic elements are the commonly used 1D element. 1D element is usually used to study rods, trusses and beams design.

On the other hand, 2D can be modelled when the field variable is constant in the direction normal to a plane but varies within the plane. Hence, the geometry of the elements is a 2D planar region of constant thickness. The most frequently used 2D elements are three-node triangular elements and four-node quadrilateral elements. In addition, plane stress and plane strain problems are few engineering problems that adopt 2D element in FEA.

Nevertheless, some engineering problems field variable differs in all directions. Therefore, that particular problem cannot be modelled as 1D or 2D element. Instead, it will be modelled as 3D elements such as four-node tetrahedral elements and eight-node hexahedral elements. 3D structural problems are the problem that most likely will employ 3D elements.

APPENDIX B: The fundamental of FEM

The fundamental of FEM is based on the concept of piecewise polynomial interpolation. In other words, engineering problem such as elasticity, thermal, fluid flow and many more can be described by governing equations and boundary conditions. However, there will be too many equations to be solved manually. Therefore, this where FEM come in where it approximate a solution through a set of simultaneous algebraic equations.



Fundamental of FEM with governing equations.

As above figure shown, approximation by FEM will give out the following set of simultaneous FEM algebraic equations (fundamental FEA equation) where the behaviour of the desired engineering problem can be obtained.

$$[K]\{u\} = \{F\}$$

$$\{u\} = [K]^{-1}\{F\}$$

where

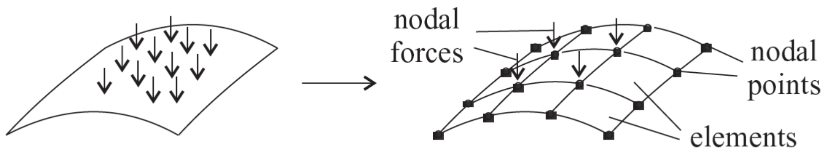
K = *known stiffness matrix* (represent property such as stiffness and conductivity)

u = *unknown vector of nodal displacements*(represent behaviour such as displacement and velocity)

F = *known vector of nodal loads* (represent action such as force and heat source)

APPENDIX C: Applications of FEA on Composite Materials

The major general steps involved in FEA for structures made of either isotropic or composite materials consist as the following:



Structure and its finite element mesh.

Preprocessing Phase

1. A mesh for the structure is generated as shown in above figure.
2. For each element, the element stiffness matrix [k] is determined.
3. Then, the element stiffness matrices are assembled in order to determine the stiffness matrix [K] of the structure.
4. A corresponding force system is used to replace the load applied to the structure.

Solution Phase

5. The displacements of the nodal points, u are solved by

$$[K]\, u = F \tag{0.1}$$

where

K = *stiffness matrix* of the structure

u = *displacement of nodal displacements*

f = *force loads* (representing the equivalent applied nodal forces; above figure)

6. Each subvectors, δ representing the displacement of the nodal point of a particular element is obtained by subdiving the vector u.
7. The displacements at a point inside the element are solved by

$$u = [N]\ \delta \tag{0.2}$$

where

u	=	*displacement of nodal displacements*
N	=	*matrix of the shape vectors*
δ	=	*subvectors*

8. The strain (equation 0.3) and stress (equation 0.4) at a point inside the element are solved by

$$\varepsilon = [B]\ \delta \tag{0.3}$$

$$\sigma = [E]\ \varepsilon \tag{0.4}$$

where

ε	=	*strain at the point inside the element*
σ	=	*stress at the point inside the element*
B	=	*strain-displacement matrix*
E	=	*stiffness matrix characterizing the material*
δ	=	*subvectors*

In addtion, the element stiffness matrix from step 2 is defined as:

$$[k]\ \delta = f_e \tag{0.5}$$

where

k	=	*the element stiffness matrix*
f_e		*the forces acting at the nodal points of the element*

Besides that, according to Kollár & Springer (2003), the element stiffness matrix is

$$[k] = \int_{(V)} [B]^T [E][B]\, dV \tag{0.6}$$

where

V = *volume of the element*

Postprocessing Phase

9. This is the last phase of FEA where the validity of the analysis is checked, the values of primary quantities such as displacements and stresses are examined. In some cases, additional quantities such as specialized stresses and error indicators are also derived and examined.

Although the above steps apply to structures made of either isotropic or composite materials, it is worth to note that the material stiffness matrix $[E]$ is the only factors that differentiate between isotropic and composite structures.

APPENDIX D: Properties of Different Optimization used for Composite Lay-up Design

Table 1
Properties of different optimization methods used for composite lay-up design.

Method name	Method	Global	Continuous	Discrete	Constrained	Derivative	Deterministic	Relative convergence rate
Vanishing the function gradient	D0		X			2	X	
Steepest descent	SD		X			1	X	
Conjugate gradient								
Linear conjugate gradient	LCG		X			1	X	SD+*/in *n* steps
Powell's method	CG-P		X				X	SD+/in *n* steps
Fletcher–Reeves	CG-FR		X			1	X	Aprx. in *n* steps
Polak–Ribiere	CG-PR		X			1	X	CG-FR+
Quasi-Newton								
Broyden–Fletcher–Goldfarb–Shanno	BFGS		X			1	X	Super linear
Davidon–Fletcher–Powell	DFP		X			1	X	Super linear
Method of feasible directions	MFD				X	1	X	
Modified feasible direction (Topal)	MFD		X		X	1	X	MFD+
Conlin's approximation method	Colin		X		X	1	X	
Method of moving asymptotes	MMA		X		X	1	X	
Globally convergent MMA	GCMMA		X		X	1	X	
Globally convergent MMA-2	GCMMA2		X		X	2	X	GCMMA+
Generalized MMA	GMMA		X		X	1	X	GCMMA+
Method of diagonal quadratic approximation	MDQA		X		X	2	X	GCMMA+
Enumeration search	ES	X		X	X		X	
Partitioning methods							X	
Golden section	GS		X		X		X	
Simplex method								
Nelder–Mead simplex	NM		X				X	
Random search	RS	X		X	X			~ES**
Monte Carlo	MC	X		X	X			RS+
Improving hit and run	IHR	X	X	X	X			~MC
Greedy search	GRS		X	X	X		X	RS+
Greedy randomized adaptive search procedure	GRASP	X	X	X	X			~GRS
Simulated annealing	SA	X	X	X	X			~GRS
Improved SA	ISA	X	X		X	1		~SLP/SA+
Genetic algorithm	GA	X		X	X			
GA + local improvements	GA+L	X		X	X			GA+
GA + special operators	GA+O	X		X	X			GA+
Scatter search	SS	X	X	X	X			~GA
Tabu search	TS		X	X	X			
Particle swarm optimization	PSO	X	X	X				
Ant colony optimization	ACO	X	X	X				
Knowledge-based methods	KBM		X	X	X		X	

* Having a better convergence rate.
** Having almost a similar convergence rate.

APPENDIX E: Material Properties of Chopped Strand Mat (CSM)

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TECHNICAL DATA SHEET

产品名称： 短切原丝毡 Products Name & Code： *Chopped Strand Mat EMC450-1040/2080*		*Chopped Strand Mat EMC300-1040/2080*
检验项目 Test Item	标准值 Standard Value	标准值 Standard Value
单位面积质量 Mass per Unit Area (g/m²)	450 ±7%	300 ±7%
碱金属含量 R_2O Content, %	≤0.8	≤0.8
含水率 Moisture Content, %	≤0.2	≤0.2
可燃物含量 Loss of Ignition, %	3.0±1.0	3.5±1.0
拉伸断裂强度 TensileStrength,N/150x200mm	≥100	≥80
树脂浸透速率 Resin Wet-out Rate, s	≤50	≤50
Coupling agent	Silane	Silane
Width	1040/2080	1040/2080
Binder type	Powder	Powder
Compatible resin	Polyester	Polyester

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APPENDIX F: Material Properties of Polyester resin

Typical Properties of the Cured Resin

Properties	**Method**	**Non- Reinforcement**	**Laminate with CSM (30%)**
Tensile Strength, Kg/m ㎡	ASTM D638	6.0	11
Tensile Modulus, Kg/m ㎡	ASTM D638	250~300	NA
Tensile Elongation %	ASTM D638	2.0	2.0
Flexural Strength, Kg/m ㎡	ASTM D790	10	20
Flexural Modulus, Kg/m ㎡	ASTMD790	350	850
Impact Strength, Kg-cm/cm	ASTMD638	3.0	60
HDT 25°C	ASTMD648	85~95	NA
Shrinkage %	ASTM D2566	7.0~9.0	NA
Barcol Hardness	ASTM D2583	45	50