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Analysis of Tensile Strength on Various Layer Stack Sequence of Fiber Reinforced Polymer (FRP)

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Abstract

This paper presents the analysis of tensile strength on various layer stack sequence of Fiber Reinforced Polymer (FRP). FRP is a composite material which made of hardened or room temperature treated resin as medium. The FRP is composed with particular reinforcement materials in order to evaluate the strength. The specimens or samples were made from different combination of FRP materials which involved resin, tissue mat, chopped strand mat, woven roving, resin, catalyst, and colour pigment. The Tensile Test is carried out based on the Axial Stress Test for the same size specimen in five different combination of materials. This study has identified that the combination of Specimen 3, which combined woven roving, resin and colour pigment as the FRP materials has acquired the highest tensile strength.

Keywords: Tensile, Fibre-Reinforced Polymer, stack sequence, laminate, composite

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1. Introduction

The strength of a structure is important to avoid cracking and damaging. In an effective composite, there must be an adequate attachment between the related fiber and matrix and this attachment may be either physical or chemical. The main function of the matrix material is to hold the fiber in the correct position so that they can carry the stress applied to the composite as well as to provide adequate stringency. At the same time, the matrix protects the fiber from any surface damage and environmental menace. The main advantages of composite materials include, high-strength, robust and diminutive density (Aleksendrić & Carlone, 2015).

The strength design is prepared to ensure that the stress at any point of the element does not exceed the permissible value of the material that will be utilised. Most composites are widely exploited in the diminutive commercial vessels and recreational craft industries but yet, it is also growing rapidly in the offshore structure building industry (Yaacob, Zakaria, Zarina, Koto, & Kidd, 2015).

Fiber Reinforced Polymer (FRP) can be used as an alternative material in the construction of floating structures. FRP can provide a solution in terms of better strength capacity, less maintenance during service and anti-corrosion.
Composites are able to meet diverse design required with consequential weight, preserving, as well as high strength-to-weight ratio compared to conventional materials (Rubino, Nisticò, Tucci, & Carlone, 2020). The proportion of shear and compressive strength to principal strength is significantly less for most orthotropic composite laminates than steel or aluminum plate.

This research concentrates on the FRP which is laminated with epoxy resin. The FRP material is a kind of E-glass fiber which includes a chopped strand mat 450 (CSM) and woven roving mat 600 (WRM). The woven roving mat glass fiber is in the orientation of crossed ply 0° & 90° whereas both chopped strand mat and tissue are in the unidirectional glass orientation. Figure 1 shows the sequence of the research methodology.

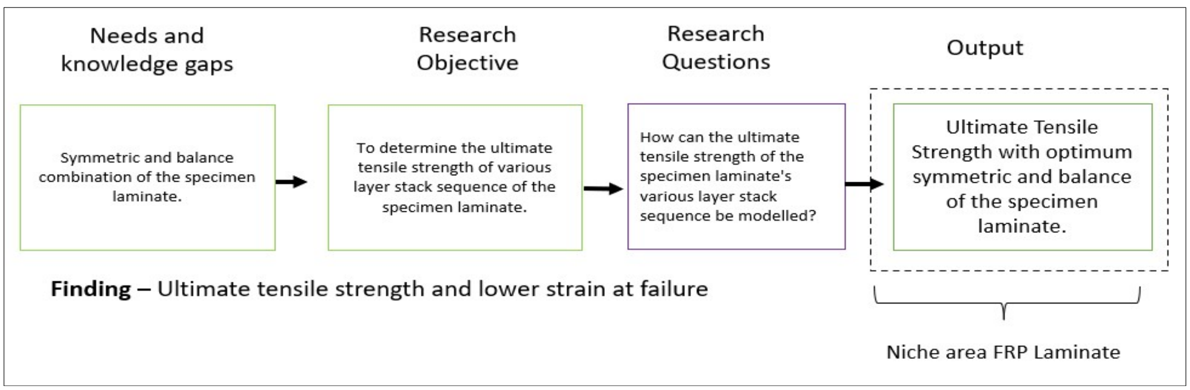


Figure 1. The sequence of the research methodology

2. Literature Review

Tensile properties are the reaction of composite materials to resist when forces are applied with pressure. (Rahman & Zhafer Firdaus Syed Putra, 2019). The tensile properties consist of the modulus of elasticity, elastic limit, elongation, proportional limit, tensile strength, yield strength, and other tensile properties. Tensile properties are determined by the Tensile Test which produces the load versus elongation curve. The curve is then converted into stress-strain curve. The Tensile Test procedure is based on the American Society for Testing and Materials (ASTM) standard which is D3039 (ASTM International, 2000). The ASTM D3039 is the standard test method for polymer matrix composite materials. The standard specimen for a Tensile Test is a dog-bone shaped rectangular without the coupon tab type of specimen. The example of stress-strain graph of polymer matrix composite is shown in Figure 2.

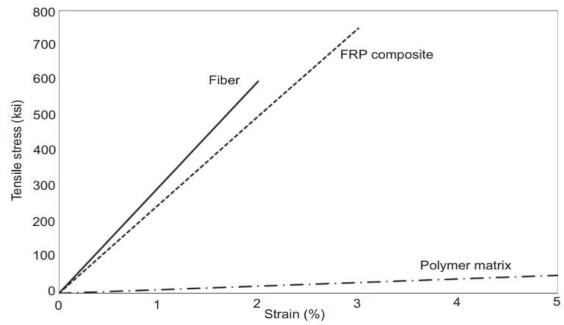


Figure 2. Example of Stress-strain Graph of FRP composite (Rahman, 2019)

The FRP composite is a combination of two or more materials. These FRP composite materials possess a unique characteristic that is utterly different from the individual material added (Abbood, Odaa, Hasan, & Jasim, 2021). The FRP composite materials consist of fibre, resin and additive.

There are four types of fiber which include, fiberglass, carbon, aramid, and basalt. The fiberglass is a commonly used E-glass in this field. The thermoset resin types include the epoxy, polyester, vinyl ester and polyurethane. Among the polymer types, the epoxy resin is mostly used due to its low viscosity at room temperature which is found excellent (Frigione & Lettieri, 2018). The additive is exploited to improve both physical and mechanical properties and enhance the workability of the composites.

The process of the FRP composite is termed laminate. Laminate composite material has two or more lamina layers which are attached to each other. The lamina layer is a flat position of the unidirectional fibers or woven fabrics in a matrix (Nurfaizey Abdul Hamid, 2010). The unidirectional and woven roving are continuous matrices which consist of unidirectional 0° and woven roving 0°/90°. Lamination process enables the attachment of the composite materials according to their required strength and endurance to achieve the preferred designs.

In a complete laminate process, the Tensile Test is exploited to investigate the tensile properties for each specimen and it is operated by a Universal Testing Machine (UTM). The FRP composite acquired higher tensile properties than the natural FRP composite (Rahman & Zhafer Firdaus Syed Putra, 2019). The continuous type of 0°/90° has a higher tensile strength (Hossain, Islam, Van Vuure, & Ignaas, 2012).

3. Methodology

Fiber Reinforced Polymer (FRP) is a composite material which is made of a heat-hardening or room temperature curing resin as the medium. The curing resin is composed with reinforcement materials such as, particle reinforced, fiber reinforced and structural.

There are three main groups of the most common man-made composites which include, Fiber Reinforced Polymer (FRP), Ceramic Matrix Composite (CMC) and Metal Matrix Composite (MMC). This test procedure determines the tensile properties in-plane of polymer matrix composite materials which reinforced with high modulus fibers. Composite forms are restricted to continuous fibers or fiber-reinforced discontinuous composites in which the laminate is balanced and symmetrical in respect to the test direction (ASTM International, 2000).

3.1. Combination of material

Most fibers possess 30% - 70% of matrix volume in the composites. The fibers can be chopped, stitched, knitted, and or braided. The most commonly recognized types of fiber which are exploited as advanced composites for structural applications include, fiberglass, carbon and aramid. Fiberglass type is the least expensive while carbon type is the most expensive type of fiber. The glass fiber is divided into three particular categories which include, C-glass, E-glass and S-glass. The C-glass fiber is for high corrosion resistance and it is uncommon for civil engineering applications. The E-glass fiber is designed for electrical use and the S-glass fiber is for high strength use. Table 1 shows the typical properties of E-glass and S-glass. These typical properties show the difference between E-glass and S-glass. The experimental testing purposed to estimate the properties of the E-glass fibre. The E-glass fiber used in this experiment is woven roving 600.

Table 1. Typical properties of E-glass and S-glass (Bai & Jin, 2015)

Typical Properties	**E-Glass**	**S-Glass**
Density (g/cm^3)	2.60	2.50
Young's Modulus (GPA)	72	89
Tensile Strength (GPa)	1.72	2.53
Tensile Elongation (%)	2.4	2.9

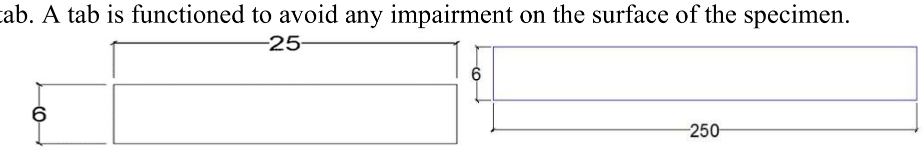
Resin is another significant component of a composite. It is divided into thermoplastics and thermosets where thermoplastic resin remains solid at room temperature, dissolves when heated and hardens when chilled. The long-chain polymers do not chemically cross-linked. The epoxies utilised as part of glycidyl ethers and amines. Epoxies are generally found in marine, electrical, automotive and appliances (Bagherpour, 2012; Dholakiya, 2012; Naik, Meduri, & Chandrasekher, 2001). The high viscosity in epoxy resin limits its use to certain processes such as hand lay-up, molding and filament winding.

A variety of added substances or call additives are utilised as part of the composites to improve the material properties, aesthetics, manufacturing process, and performance. The combination of material which utilised the colour pigment or gel coat (Polycor GP-H) were impregnated with epoxy resin (3554A) with 1% methyl ethyl ketone peroxide (MEKP) as a catalyst. The mixture of colour pigment and resin were based on the designed configurations.

3.2. Specimen preparation

Each test sample requires at least five specimens for each test condition unless useable result can be acquired through the use of less specimen. The test sample in this research exploits the FRP. The standard tensile specimens based on the American Society for Testing and Materials (ASTM International, 2000) were prepared to acquire both measurement and lenience for five different combinations of materials. The samples were made of different combination of FRP materials such as, tissue mat (T), chopped strand mat 450 (CSM), woven roving 600 (WR), resin (R), catalyst (C), and colour pigment (CP).

Each specimen is in the shape of a coupon without tab with similar thickness, 250mm x 25mm x 6mm as shown in Figure 3. However, each specimen was combined differently as shown in Table 2. The specimen is a flat bar without a tab. A tab is functioned to avoid any impairment on the surface of the specimen.



(a) (b)

Figure 3. (a) Front view; (b) side view of the specimen

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Table 2. Combination of material for each specimen

Specimen Label	Material (Fiber Reinforced Polymer)
1	T + R +C + CP
2	CSM + R +C + CP
3	WR + R +C + CP
4	2 T + 4 CSM + 1 WR + R +C + CP
5	2 T +3 CSM + 3 WR + R +C + CP

Specimen 1 up to Specimen 5 utilised the colour pigment or gel coat (Polycor GP-H) which were impregnated with epoxy resin (3554A) with 1% methyl ethyl ketone peroxide (MEKP) as catalysts. The mixture of the colour pigment and resin were based on the designed configurations. Then, one plate of glass was utilised to provide a pleasant decorative surface. Prior to the process, Mirror Glaze® mold release wax was applied onto the glass to prevent the unwanted attachment between the materials and the glass surface. The coated sample was cured at room temperature for 24 hours.

Specimen 1 utilised a tissue mat with FRP impregnated with epoxy resin (3554A) with 1% methyl ethyl ketone peroxide (MEKP) as catalysts. The ratio of resin to fiber is fixed at approximately 2:1. The laminated composites were preserved at room temperature for 24 hours. Finally, the laminates were cut according to the specimen size using a Tenoning and Squaring Machine as shown in Figure 4. The prepared specimen size is 250mm x 25mm x 6mm. Figure 5 (a) shows the sample of Specimen 1.

Figure 4. Specimen cutting process using Tenoning and Squaring Machine

(a) T + R +C + CP (b) CSM + R +C + CP (c) WR + R +C + CP

Figure 5. (a) Specimen 1-Tissue Mat; (b) Specimen 2 – CSM 450; (c) Specimen 3-Woven roving

Specimen 2 and Specimen 3 exploited the chopped strand mat (KCM 450A) and woven roving (XD-600) of E-glass fiber impregnated with resin (3554A) with 1% methyl ethyl ketone peroxide (MEKP) as catalysts.

The fiber and resin were laminated layer by layer. Figure 5 (b) and Figure 5 (c) show a preserved samples of specimen 2 and specimen 3.

Specimen 4 exploited a tissue mat, chopped strand mat (KCM 450A) and woven roving (XD-600) impregnated with resin (3554A) with 1% methyl ethyl ketone peroxide (MEKP) as catalyst. The fiber and resin were laminated layer by layer exploiting a tissue mat as the first and the final layers. The following laminated composites contained two chopped strand mat, one woven roving and followed by two chopped strand mats as shown in Figure 6 (a).

(a) 2 T + 4 CSM + 1 WR + R +C + CP

(b) 2 T +3 CSM + 3 WR + R +C + CP

Figure 6. (a) Specimen 4 mixed; (b) Specimen 5 Mixed

Specimen 5 exploited a tissue mat, chopped strand mat (KCM 450A) and woven roving (XD-600) impregnated with resin (3554A) with 1% methyl ethyl ketone peroxide (MEKP) as catalyst as shown in Figure 6 (b). The ratio of resin and fiber is fixed at approximately 2:1. The fiber and resin were laminated layer by layer with tissue mat as the first and the final layers. The following was layered with one chopped strand mat, one woven roving and the similar process was repeated twice. Each specimen was made one at a time according to the laminate sequence and orientation. The stacking sequence and orientation are shown in Table 3.

Table 3. Stacking sequence and orientation (Symmetric & Balance)

Specimen Label	Stacking sequence	Reinforced Types
1	Tissue Mat (T)	Continuous
2	Chopped Strand Mat 450 (CSM)	Discontinuous 0°/90°
3	Woven Roving 600 (WR)	Continuous
4	T+2CSM+W/R+2CSM+T	Continuous + Discontinuous 0°/90°
5	T+CSM+W/R+CSM+W/R+CSM+W/R+T	Continuous + Discontinuous 0°/90°

3.3. Tensile Test

Galdabini Quasar 100 is a Universal Testing Machine (UTM) which is exploited in this research to acquire data. This testing machine is designed with two-column rigid system with 100 kN maximum capacity and suitable for metals, plastics, composites, and other materials. The machine is flexible and it has a modular design for an easy future expansion. The significant technical advantages of the machine include, high resolution of load and troke readings, minimum test speed of 0,0005mm/min for the highest performance and provide the most accurate results.

The Tensile Test was conducted at Material Laboratory in University of Kuala Lumpur Malaysian Spanish Institute (UniKL-MSI) by using Galdabini Qausar 100 as shown in Figure 7.

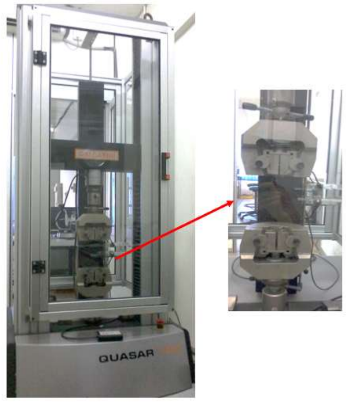

Figure 7. Universal Testing Machine (UTM)

Before the experiment was carried out, the thickness and the instrument length of each specimen was measured and numbered for appropriate identification as shows in Figure 8. Specimen which has been placed accurately was applied with vertical load of maximum 100kN load capacity. The related data and observation were recorded.

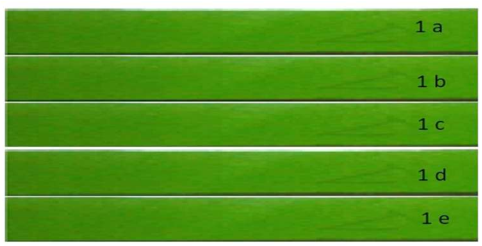

Figure 8. Example of numbered identification for Specimen 1

4. Results and Discussion of Findings

The specimen stacking sequence and orientation exploits either a tissue, a chopped strain mat or a woven roving fiber glass with [0°/90°] orientation infused with epoxy (3554A) and catalyst. The detailed result for each specimen is shown in Table 3. The example of the Tensile Test failure occurrence is shown in Figure 9. The failure type which occurred was an explosion in the middle of the specimen, however, the grip was not affected. According to ASTM D3039 (2000), the grip shall not cause any damage to the specimen surface. The Tensile Test failure occurrence is shown in Figure 9.

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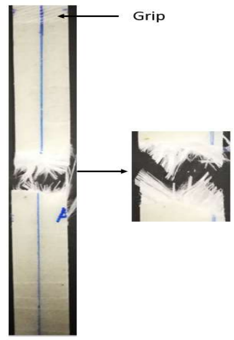

Figure 9. Tensile Test Failure

The level of strength achieved by the specimen is in the range of 44 MPa to 270 MPa. Specimen 3 is the specimen that achieved the highest strength which is 269.59 MPa compared to all five specimens. The specimen that attained the lowest ultimate strength is specimen 1 which only accomplish 44.51 MPa. The following specimens were in the average strength which involved Specimen 2, 93.80 Mpa, Specimen 4, 111.56 Mpa and Specimen 5, 106.82 Mpa.

The capacity of the Tensile Test result shows that Specimen 3 has the maximum load which is 40437.83 N with the maximum strain, 0.078 ε. The Specimen 1 has the minimum load which is 6676.00 N and the minimum strain, 0.032. The following Specimen 2 acquired 0.052 ε, Specimen 4, 0.053 ε and Specimen 5, 0.055 ε which are all the average level. The result for the Tensile Test is shown in Table 4.

Table 4. Result of Tensile Test

Specimen Label	**Load (N)**	**Stress σ (MPa)**	**Strain ε**
1	6676.00	44.51	0.032
2	14071.00	93.80	0.052
3	40437.83	269.59	0.078
4	16734.17	111.56	0.053
5	16022.83	106.82	0.055

The average graph results of the stress versus strain show a liner elastic behaviour to failure, no yielding, ultimate strength, and lower strain at failure as shown Figure 10. Figure 10 shows the curve is slightly linear for the stress vs strain of Specimen 1 – Specimen 5.

The Specimen 1 has a linear graph without the curve, which the Specimen 1 was flexible fracture. As for Specimen 2, the curve starts to deviate in the strain range of 0.006 – 0.017%, which the fracture within weak fiber strands orientated to load direction and the straight line until the failures. Specimen 3 has started to deviate in strain 0.009 – 0.017%, which the material is hard, strong and obstinate with the higher stress up to 269.59MPa. Specimen 4 started to deviate in strain 0.011 – 0.017%, which the material is hard, strong, and obstinate with stress 111.56MPa. The Specimen 5 has started to deviate in strain 0.003 – 0.024%, which the material is hard, strong, and obstinate with stress 106.82MPa.

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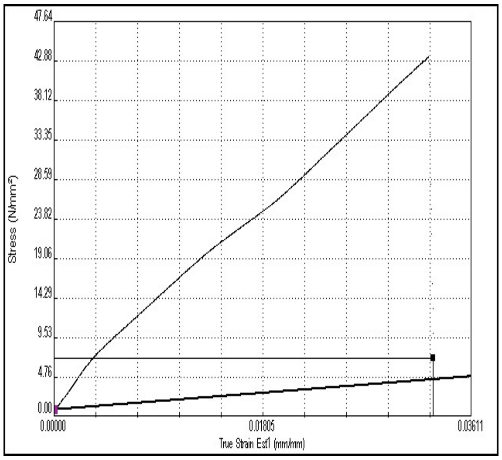
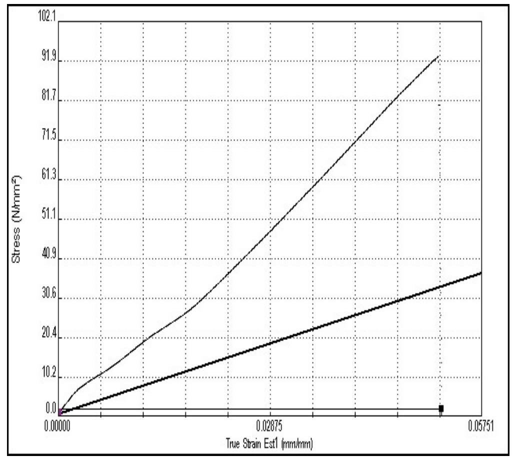
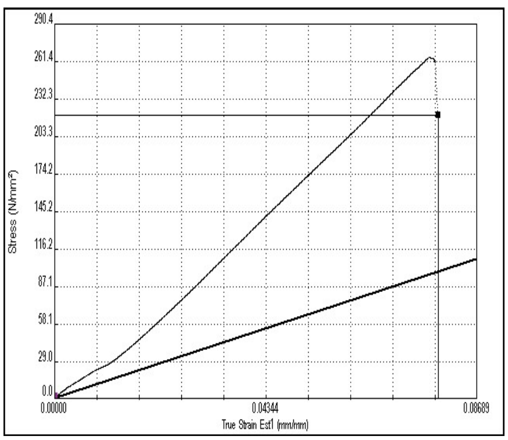


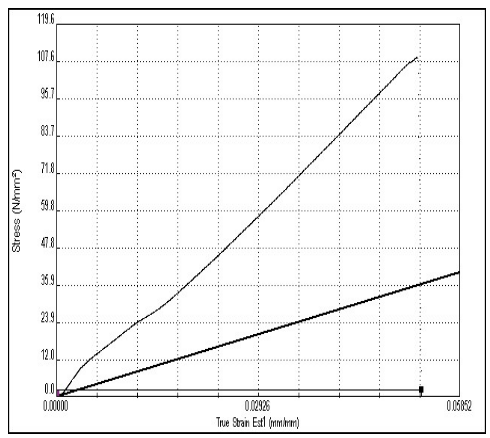
(a) Specimen 1



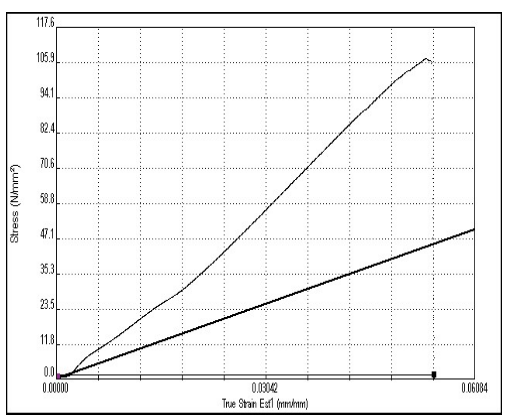
(b) Specimen 2



(c) Specimen 3



(d) Specimen 4



(e) Specimen 5

Figure 10. Stress Strain graph of the average results.

According to Figure 10, the modulus of elasticity can be directly calculated. The formula of modulus for elasticity is *Stress* divide by *Strain* (**σ/ε**). Figure 11 shows a graph of the modulus of elasticity for all specimens. Specimen 3 attained the highest modulus of elasticity which is 3456.28MPa compared to all the five specimens. Specimen 1 is the specimen that acquired the lowest modulus of elasticity which only 1390.94 MPa. The following specimens with average modulus of elasticity include Specimen 2, 1803.85MPa, Specimen 4, 2104.91MPa and Specimen 5, 1942.18MPa.

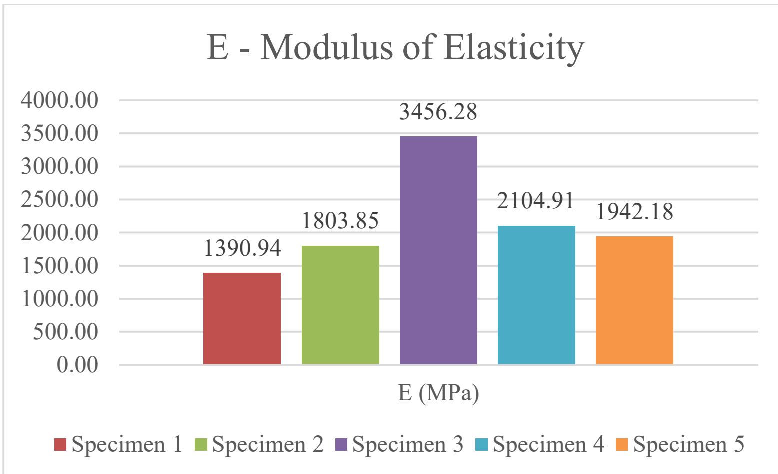


Figure 11. The modulus of elasticity

The result from the experiment has proven that the change in woven roving orientation angle and combination of material has significantly improved the tensile strength of Specimen 3 with the highest tensile strength in average of 269.59 MMa and with the maximum load of 40.44 kN. The modulus and strength of laminate in this form of orientation for all sequences preferred is observed to be less when compared with similar successive layer fibre orientation woven roving (0°/90°). The result provides evidence that the combined effect of collective aligned orientation is beneficial since the direction of load applied and the direction of alignment of fiber orientation are similar (Srivathsan, Vijayaram, Ramesh, & Gokuldass, 2017).

5. Conclusion

According to ASTM D3039, FRP Fabric Properties is tested by Tensile Test which the result for stress versus strain shows a liner elastic behaviour to failure, no yielding, ultimate strength, and lower strain at failure. The results of the experiment showed that the behaviour of Fiber Reinforced Polymer (FRP) combination is capable to sustain the carrying capacity to the highest tensile strength for specimens 3 (woven roving + Resin + Colour Pigment) with was 269.59 MPa. This study has identified that the combination of specimens 3 has the highest tensile strength result of the Tensile Test. Generally, Fiber has a higher strength and arduousness, whereas matrix has a higher degree of elongation (Rahman & Zhafer Firdaus Syed Putra, 2019). The combination of these two or three constituents in the FRP composite has increased the tensile properties as the result of Specimen 4 and Specimen 5. These two specimens are added with chopped strand mat and woven roving. The experimental work has proved that the result of the experiment is within the range of theory of calculation to identify the highest tensile strength. Based on the international standard of the American Bureau Shipping (ABS) section 4.4.2 (Bureau, 1992), the theory of calculations has identified that the minimum tensile strength was 124.106MPa.

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