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STATISTICAL ANALYSIS OF THE PERFORMANCE OF YOUNG'S MODULUS OF NATURAL FIBER COMPOSITES AND SYNTHETIC FIBER COMPOSITES

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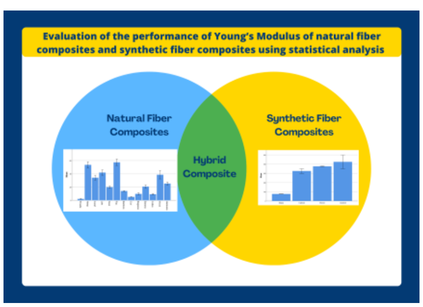
Graphical abstract



Abstract

Fiber-reinforced composites are widely used in a wide range of applications due to their lightweight, low cost, environmentally friendly, and reliable properties. Natural fiber and synthetic fiber are the two main types of fiber. These two fiber groups have distinct features that require a methodical approach for material selection. The distinct properties of both fibers resulted in a wide range of strength that was computed in accordance with the desired performance of material engineers. Synthetic fibers are known to be stronger than natural fibers, however due to sustainability concerns, natural fibers are commonly used with some fiber modifications and hybridization to enhance the strength of natural fiber composites. Statistical analysis is employed in this study to determine Young's modulus of each fiber group. Hypothesis testing was used to confirm the performance of the fiber's Young's modulus. All synthetic fibers have a substantially greater Young's modulus than natural fiber based on the P-value score. Aramid had the highest score for synthetic fibers, while flax fiber had the highest score for natural fiber groups, with 424.8 GPa and 57.3 GPa, respectively. Ultimately, hybridization has the potential to overcome the limitations of both synthetic and natural fibers. This statistical approach may be used to validate the hypothesis about the properties of both fibers.

Keywords: Young's modulus, natural fiber, synthetic fiber, statistical analysis, fiber reinforced composite

Abstrak

Komposit bertetulang gentian digunakan secara meluas dalam pelbagai aplikasi kerana sifatnya yang ringan, kos rendah, mesra alam dan boleh dipercayai. Serat semula jadi dan serat sintetik adalah dua jenis serat utama. Kedua-dua kumpulan gentian ini mempunyai ciri yang berbeza yang memerlukan pendekatan berkaedah untuk pemilihan bahan. Sifat yang berbeza bagi kedua-dua gentian menghasilkan pelbagai kekuatan yang dikira mengikut prestasi yang dikehendaki oleh jurutera bahan. Gentian sintetik diketahui lebih kuat daripada gentian semula jadi, namun disebabkan kebimbangan kemampanan, gentian semula jadi biasanya digunakan dengan beberapa pengubahsuaian gentian dan penghibridan untuk meningkatkan kekuatan komposit gentian semula jadi. Analisis statistik digunakan dalam kajian ini untuk menentukan modulus Young bagi setiap kumpulan gentian. Ujian hipotesis digunakan untuk mengesahkan prestasi modulus Young untuk gentian. Semua gentian sintetik mempunyai modulus Young lebih besar daripada gentian semula jadi berdasarkan skor nilai-P. Aramid mempunyai skor tertinggi untuk gentian sintetik, manakala gentian flaks mempunyai skor tertinggi untuk kumpulan gentian semula jadi, iaitu 424.8 GPa dan 57.3 GPa, masing-masing. Akhirnya, hibridisasi mempunyai potensi untuk mengatasi kekurangan kedua-dua gentian sintetik dan semula jadi. Pendekatan statistik ini boleh digunakan untuk mengesahkan hipotesis tentang sifat kedua-dua gentian.

Kata kunci: Modulus Young, gentian asli, gentian sintetik, analisis statistik

1.0 INTRODUCTION

Recent studies on composite materials have been extensively found in applications such as automotive components design, customer product design, food packaging, defense technology, and medical instruments. Composites have attracted manufacturers in many type of product applications due to their low cost in production, availability, and good for sustainability. They are also known for their advantages in solving contradictions in design requirements where they are lightweight but have good strength. Moreover, past researchers have selected composites in the materials selection process where the materials satisfied several selection requirements that focus on the technical performance. Ke *et al.,* (2019) had reviewed the past studies regarding the material selection of leaf springs where carbon/epoxy composite resulted as the most suitable material [1]. They also found that the composite leaf springs showed better performance than steel leaf springs. Hagnell *et al.,* (2020) had suggested applying composite materials in the aviation and automotive industry, where the composite could lessen the weight and manufacturing cost of structural design [2]. *Mastura et al.,* (2017) conducted a study on the material selection of hybrid fiber composite to be applied to design automotive anti-roll bar [3]. In the study, hybrid sugar palm fiber composite could satisfy the lightweight and high strength requirements using integrated approach of Quality Functional Deployment for Environment (QFDE)/ Analytic Hierarchy Process (AHP). Therefore, extensive study on the composites should be conducted to explore the unprecedented characteristics of the materials. There are several types of composites that are commercially found in the market. These composites can be divided into two main categories, which are synthetic fiber composites and natural fiber composites. These two types of composites have their benefits and can be blended as hybrid composites. The hybridization of the composites consists the employment of natural fiber and synthetic fibers as reinforced materials for polymer. The purpose of hybridization is to obtain superior properties and lessen the cost of composites [4]. The material engineers have used this technique in producing a promising material that could satisfy the general needs of product design. Many researchers have shown the fibers' unique and wide range of material properties that make it difficult for design engineers to decide on the most suitable materials. Generally, the main purpose of the application of composite is to enhance the properties of the dominant materials at the lower cost of production. Application of natural fiber in polymer based composites is purposely to enhance the environmental impact by reducing the quantity of polymer that could give negative impact towards the environment. Reinforcement of synthetic fiber in the composite as the initial selection purposely substitutes the traditional materials made by 100% polymer. Synthetic fiber exhibits excellent strength compared to natural fiber. However, considering the demand for environmentally friendly materials and lower cost of production, natural fibers are chosen as a alternative for synthetic fibers in composites. In comparison with synthetic fibers, natural fibers have moderate mechanical properties, are easier to process, lower cost of production, and are biodegradable. In product design, to keep up the strength of the design part that uses alternative materials like natural fiber composite, it is suggested to add the reinforced design element such as ribs or change to the appropriate geometry of the design part [5]. As presented in Mastura *et al*., (2017) study, the development activities of composite anti-roll bar should be performed concurrently [6]. The material selections process should also consider design requirements to save time, cost, and design failure could be avoided in an earlier stage. Here, they suggested that to satisfy the design requirements of the anti-roll bar, the new design of composite anti-roll bar should be reinforced with ribs, and the size of the bar should be increased. Therefore, material selection is a crucial task that needs to be performed adequately to avoid damage later. The decision-maker must decide which type of fiber could satisfy the selection requirements. Selecting the type of fiber, either synthetic or natural fiber, is not easy when both materials have their advantages. In general, Young's modulus (YM) is significantly included in selection criteria where it exhibits the mechanical performance of the materials and important criteria to determine the reliability of the materials. Moreover, YM can be used as an indicator to measure the stiffness of the material where the behavior of the material to respond under load and deform before breaking point [7]. A comparison study between the synthetic fiber and natural fiber regarding their YM should be conducted to assist decision-makers in obtaining a general idea on selection between synthetic and natural fiber. If YM of natural fiber composite is comparable with synthetic fiber composites, natural fiber composites are highly recommended, which could satisfy the government policy on sustainability. Therefore, in this study, a comparison of YM of natural fiber composites and synthetic fiber composites is performed to evaluate the capability of the natural fiber to replace synthetic fiber in terms of mechanical properties. As the highlight of this study, a statistical approach using descriptive statistical measurements gives basic information about the performance between these two materials. The comparisons between several natural and synthetics fibers using hypothesis testing can confirm the characteristic of the YM of them. In the end, the conclusion toward natural and synthetic fiber was finalized from the sample data set in this study. The distribution of YM of both materials was also discussed.

2.0 LITERATURE REVIEW

2.1 Natural Fiber Composites

The natural fiber is obtained from various natural resources such as plants, animals, and minerals. Categorization of natural fiber is illustrated as in Figure 1 [8]. Amongst the three types of natural fibers, plant-based fibers are the most found in various applications for composites. Plants produce hair-like cellulose fibers obtained from the bast, fruit, seed, leaf, and stalk. Plant-based natural fiber is renewable material where the plant can be replanted and sustainably managed. In general, this type of fiber consists of three chemical compositions: hemicellulose, cellulose, and lignin. Each of the parts exhibits the fiber's material properties and influences the material performance of the fiber-reinforced composites. Cellulose as a basic structure of all plant fibers aligned along the fiber's length, exhibits tensile and flexural strength, and implies the rigidity of the fibers. It consists with of a long chain of duplicating units of D-anhydro glucose $C_6H_{11}O_5$ and b-1,4 glycoside linkages that are interconnected together as microfibrils [9]. Hemicelluloses are short and branched chains that consist of polysaccharides that influenced the behavior of plant-based fiber as hydrophilic. This behavior affects the strength of the fiber-reinforced composite, creating active conditions for water absorption. Consequently, the polymer molecules could not adhere firmly with the fiber cell wall due to the existence of hydrogen bond to create good interfacial bonding strength. Therefore, hemicellulose positively correlated with mechanical properties, for example, Young's modulus, and specific strength of the natural fiber. Lignin is three-dimensional hydrocarbon polymer that contributes to rigidity of the woody stem and improves bonding of distinct cell of the fibers. Moreover, lignin is positively correlated with the failure strain of the natural fiber but negatively correlated with tensile strength and YM of natural fiber. These three chemical compositions of plant fibers are found in the primary and secondary cell wall. The other chemical composition found in the plant fibers is pectin and waxes that sometimes their amounts are not significant and negligible. The most common plant fibers found in various applications are flax, jute, coir, pineapple leaf, hemp, bamboo, sisal, kenaf and ramie. These fibers are commercially available in composite form reinforced with polymer matrix such as polyurethane, polyethylene (high and low density), polypropylene, and polylactide acid. Plant-based fibers are desirable as reinforced fiber in composites due to several advantages: easy to process, cheap, renewable, abundantly available, available in mass production, and sustainable.

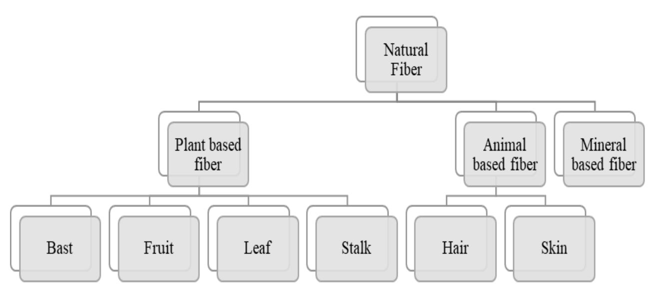


Figure 1 Classification of natural fiber

Past researchers have conducted experimental studies to characterize the behavior of the natural fiber composite, especially under load conditions. The engineers need to identify the characteristics of the materials before the application. Jiménez *et al.*, (2017) have conducted a study in investigating the YM of sugarcane bagasse composites experimentally and theoretically [10]. The study found that sugarcane bagasse (with fiber modification) has a potential to substitute glass fiber as reinforced material in polypropylene composites by exhibits 3.4 - 3.6 GPa of YM and the theory of Tsai and Pagano model and Halpin and Tsai equations could be used to predict the YM of sugarcane bagasse reinforced polymer composites. Another study conducted by Jariwala and Jain [11] found that the diameter of the fibers significantly influenced the YM of the fibers where it is unproportionally related to each other. However, increasing fiber length would increase the value of YM until the length reached 30 mm as the optimum value. In composite materials, the YM depends on the amount of fibers where it is found that the YM is increasing proportionally to fiber loading [12]. Sisal fiber is found to have YM of 7 GPa to 22 GPa with the increasing amount of volume fraction. Banana fiber has 320% of YM with an increasing fiber loading of up to 48% [11]. Moreover, Patil *et al*., (2018) found that the YM of natural fiber composites is greatly influenced by the chemical composition of the fibers and the fiber loading [13]. In their study, YM of epoxy/sweet lime composite increased from 743.90 MPa to 1013.25 MPa with the fiber loading of peel particles from 10% to 30%. For epoxy/lemon composite, the YM is increased from 999.64 MPa to 1358.30 MPa, increasing the fiber loading of peel particles from 10% to 30%. Due to the undesirable chemical composition of natural fibers, it is suggested to have fiber modifications to enhance the properties of the natural fibers composite, such as mechanical and water resistance. Removal of impurities and hemicellulose to reduce the hydrophilicity and increase fiber and matrix's interfacial bonding strength can be conducted using chemical, physical or biological treatment. A study has been conducted by Siakeng *et al*., (2019) found numerous studies in fiber modification that improve the mechanical properties of the natural fiber composites [14]. Alkali-treated sisal fiber-reinforced soy protein resin-based bio-composites have improved the rigidity of the bio-composites by 36.2% in a study conducted by Kim and Netravali [15]. Silane treatment has improved the YM of PLA/spruce wood flour up to 3.73 + 0.247 GPa in Gregorova *et al*., (2011) study [16]. Alaaeddin *et al*., (2019), in their study, had shown a relationship between physical properties and mechanical properties of the natural fibers where it is found that fiber morphology has influenced the value of YM [17]. On average, their study shows that the YM of short sugar palm fiber nanocomposites is 2243.8 MPa. Moreover, they agreed that the aspects ratio is the most influential parameter in determining the mechanical properties of natural fiber composites. Data on the YM of natural fiber composites have been collected from past studies for further comparative analysis with synthetic fiber composites. The summary of the data collection is presented in the next section. Polypropylene is chosen as the polymer matrix as it is the most common polymer matrix compounded with fibers.

Natural fibers have a limitation that requires fiber modification and additives during the compounding process. There are physical impurities and hydroxyl groups on the fiber surface that can affect the structural integrity of the natural fiber [18]. Natural fibers rich with cellulose make the fiber behave as hydrophilic and cause resin incompatibility and poor surface adhesion [19]. Consequently, natural fibers composites exhibit low elastic modulus, high water absorption, attract insects and encourage fungal growth, lack of durability in an alkaline environment, and contain a wide range of carbohydrates [20]. Moreover, the employment of natural fibers is restricted to several applications that require moderate mechanical properties. In construction applications, the natural fiber composites are more likely to cause wall crack due to the swelling and volume change. The wide range of characteristics of natural fibers is mainly because of their inconsistent physical properties that may vary due to several factors. The variations are dependent on the harvesting process, type of soil, locality, maturity of the plant during the extraction process, fiber treatment, and manufacturing process of the fibers [21]. Therefore, a wide range of material properties are considered during the selection of the material as shown in several studies [3], [22, 23, 24, 25, 26]. In the material selection process, all the elements that influence the performance of the natural fibers are considered by evaluating the relationship between the material characteristics and selection requirements. According to its application, the natural fiber that satisfied all the requirements by obtaining the highest scores is chosen as the most suitable natural fiber. Natural fiber has a limitation for thermal properties when it needs to be processed under high temperatures, which is 2000°C and above. A study has shown that when the temperature reaches 2000°C and above, the natural fiber will degrade and shrink due to low thermal stability. A suitable manufacturing process must be determined initially to avoid material degradation that could cause damage to the resultant composites. Two parameters, processing temperature and processing time are essential in determining the suitable manufacturing process of the natural fiber composites [27]. However, this type of composites have shown low fire-retardant properties in several studies [28]. Hence, several modifications are required to ensure the compatibility of the natural fibers with the desired applications and improve the durability of the composites. Moreover, overdesigned is necessary for the product that will replace traditional materials with more environmentally friendly materials such as natural fiber composites [29].

2.2 Synthetic Fiber Composites

Synthetic fiber is a man-made fiber derived from raw non-renewable materials such as petroleum or petrochemical that purposely prepared with high strength and stiffness. Glass fibers, carbon fibers, nylon fibers and aramid fibers have been developed and studied by many researchers to potentially commercialized in many product design applications. Glass fibers are commonly used as reinforcement material for polymeric resin. Different types of glass fibers are specifically manufactured for various applications. E-glass fibers are the first reinforcement synthetic fiber for a composite that developed for electrical insulation applications. Compared with high strength (HS)- glass fibers, E-glass fibers are relatively low elastic moduli and prone to rupture. HS-glass is stronger, stiffer and better resistance to fatigue and creep than E-glass [30]. Glass fibers mainly consist of silica, alumina, calcium and boron where the composition could be changed to exhibit different material properties that make this type of fiber very versatile. Generally, carbon fiber is derived from non-renewable petroleum, which is polyacrylonitrile (PAN). This material takes 50% of the manufacturing cost, which makes carbon fiber an expensive material. There is a growing interest in bio-based carbon fiber where it is derived from lignin. Lignin is a natural resource found in plant cell walls and can be an alternative precursor for carbon fiber at a lower cost [31]. Carbon fibers are classified according to their precursors, which are PAN-based, pitch-based and rayon-based [32]. Inagaki [33] classified carbon fibers into four categories: PAN-based, isotropic pitch-based, mesophase pitch-based, and hydrocarbon gases. He also presented the classification of carbon fiber according to its mechanical properties: high strain-high strength type, high strength type, medium modulus type, high modulus type, and ultrahigh modulus type. Aramid fiber, also known as Kevlar fiber, is an organic synthetic fiber mainly applied in defense and ballistic technology. The fibers are derived from long-chain synthetic aromatic polyamide. Boron fiber is made by chemical evaporation deposition of boron trichloride and hydrogen onto continuous tungsten or carbon filament heated by electric current. This type of fiber is primarily found as reinforced fiber for polymer matrix composites for restricted application. The complexity of the manufacturing process of boron fibers caused the fiber to be expensive and applied primarily in military aviation and space [34]. Generally, the long and continuous synthetic fibers are prepared by polymerization and extruded in a manufacturing stage. There are several methods of the manufacturing process of synthetic fibers, such as melt spinning and heat-setting process. The melt spinning process is a conventional fabrication process of synthetic fibers derived from polymers with low melting temperatures. The molten polymers are extruded from a spinneret and quenched with cold air. Later, the extruded polymer is solidified into filaments. The heat-setting process is a heat treatment process where the polymers are going to be subjected to high temperature for a short time where structural and chemical modifications are occurred. This process will bring changes in the material properties of the fibers such as strength, stretchability, and softness.

Applications of synthetic fibers in lightweight parts can be found in various areas such as automotive, aircraft, construction, and medical. Since synthetic fibers are human-made fibers produced by desired material properties, the applications are specific and depend upon the desired material characteristics. Besides lightweight, which has been the main criteria in applying synthetic fiber composites, excellent mechanical properties such as tensile modulus are among the main criteria in substituting traditional materials with synthetic fiber composite materials. Meola *et al*., (2017) characterized the mechanical properties of carbon and glass fiber reinforced thermoplastic composites [34]. They concluded that the material could offer good tensile and flexural properties for high-performance structural part design. Hybridization of natural fibers with synthetic fibers for polymer composites has been applied widely to overcome the drawbacks of both types of fibers. It is not only improvised the primary material properties, but it is also a method to reduce the cost of the raw materials. Methods of hybridization involve stacking, intermingling, interplay, selective placement, and selective orientation [35]. Makeev *et al*., (2019) had found that hybrid carbon fiber composites had increased the compression strength [36]. Prabhu *et al*., (2019) studied the effects of glass/jute/tea leaf fiber reinforced hybrid composites [37]. They found that this hybrid composite produced the optimum mechanical properties and can be an alternative material for 100% glass fiber reinforced polymer composite. In their study, Sanjay and Yogesha [38] found that the hybridization of glass with jute/kenaf composite had gained significant improvement in tensile and flexural properties of natural fiber reinforced epoxy composite. Employment of synthetic fibers can be found in various applications and hybridization of this type of fiber could extend the variety of applications.

As a man-made fiber, synthetic fiber has a deficiency regarding environmental impact. The recyclability rate of synthetic fiber is lower than natural fiber. Many manufacturers would prefer to choose natural fiber in their application due to cost, availability, and impact on the environment [39]. However, synthetic fibers are preferable when it comes to structural design applications that require excellent mechanical properties of the material. Hydrophilic behavior of natural fibers caused incompatible adhesion between the fibers and polymer matrix. This behavior could not be found in synthetic fibers. Therefore, synthetic fibers composite exhibits excellent mechanical properties and have been chosen in high structural application. A study from [40] had shown the comparable results of Young's modulus of the bleached pine fiber and glass fiber composites. The study concluded that natural fibers could be used as substitute fiber for glass fiber. Dehrooyeh *et al*., (2021) performed a study on the hybrid carbon/glass composites [41].

They found that the material could exhibit superior mechanical properties up to 300 MPa of tensile strength and 24.9 GPa of Young's modulus. Deb *et al.*, (2020) had found that synthetic fiber composite exhibited good ductility compared with natural fiber composite [42]. However, higher strength of jute fiber composite was shown compared with the synthetic fiber composite in their study. Therefore, there is a need to study the mechanical properties of these two types of fibers as demonstrated in the next section.

2.3 Future Perspective on Natural Fiber and Synthetic Fiber Composite

Properties, performance, cost and environmental benefits of natural fiber and synthetic fiber are an important factor that increase both industrial applications and fundamental research studies regarding these materials in recent years [43]. These materials believe can optimize the cost of manufacturing and raw materials, improved performance and increase the environmental impact when mixed with a polymer as composite. In the past two-decade studies toward the effect of hybridization of natural and synthetic fiber-reinforced polymer composites had reviewed from year 2001 until 2020 by Gupta et. al. [44]. This study summarized the different properties of mechanical, thermal, water absorption, tribological behaviour and morphological characteristic between natural fiber and synthetic fiber as a reinforcement agent in the composite. To improve the performance of the composite, natural fiber and synthetic fiber are modified with different treatments. Moreover, the polymer also contributes to improve the properties of the composite. For example, polypropylene can modify using maleic anhydride through grafting process.

3.0 METHODOLOGY

In this study, previous studies are used to collect the mechanical properties of natural fiber and synthetic fiber composite. Descriptive statistic measurements are used to explain the distribution of the mechanical properties of natural and synthetic fiber composites. Moreover, the inferential statistic hypothesis testing is explained in detail certain claims or situations about the mechanical properties of natural and synthetic fiber composites reported in a recent study. Finally, the performance of natural and synthetic fiber composite of YM is finalized.

3.1 Measurements of Mechanical Properties of Natural and Synthetic Fiber Composites

The characteristic of natural fiber that has diverse physical, mechanical, chemical, and thermal properties make these properties always reported in range. Multiple measurements were reported in more than 10 years. Tensile properties were the most measured mechanical properties, as shown in Table 1 from the previous studies. The properties of natural and synthetic fiber are collected from different sources and represented them as a range. The types of natural plant fibers are not specified as the range will be wider and more data could be obtained. In this study, statistical analysis is used to describe and explain the variation of YM for natural and synthetic fiber. By using simple random sampling, 30 measurements of YM are used to further analysis.

Table 1 Mechanical properties of Natural Fiber and Synthetic Fiber Composites [45]–[54]

Type	Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Reference
Natural	Roselle	150-400	1.5-2.76	[49], [54]
	Hemp	550-1110	30-70	[48]
	Kenaf	930	20-53	[46]
	Jute	200-770	20-55	[46]
	Sisal	100-800	9-28	[46]
	Flax	350-1830	28-80	[50]
	Bamboo	140-230	11-17	[51]
	Coir	131-220	4-6	[52]
	Bagasse	20-290	2.7-17	[52]
	Banana	36-54	7.7-32	[47]
	Cotton	290-800	5-13	[53]
	Wood	90-180	10-70	[53]
	Harakeke	440-990	14-33	[45]
Synthetic	Glass	2000-3800	72-79	[48]
	Carbon	2200-4900	230-440	[41]
	Boron	3600	350-400	[43]
	Aramid	2900-3800	78-800	[43]

3.2 Descriptive Statistic of Natural and Synthetic Fiber Composites

The data collected are described by descriptive statistics such as the mean and standard deviation (SD) of 30 samples for each of the materials in this study. Mean is the best measurement used to estimate the variation of the mechanical properties with the standard deviation rather than the value of range normally reported for the value of natural and synthetic fiber composites [46], [55]. The basic information is gain from the first screening of descriptive statistics is beneficial to the researcher in a statistical framework for material selection application proposed by Noryani *et al.*, (2018) [22].

3.3 Inferential Statistic of Natural Fiber Composites and Synthetic Fiber Composites

Hypothesis testing is one of the inferential statistics that can be used to conclude the population based on a sample [56]. In this study, hypothesis testing is used to verify the performance of YM of the fiber. There are five command steps in hypothesis testing, which are: write the null and alternative hypothesis, perform the statistics testing, find the critical point, and decide the region, finalize the decision making and, lastly, make a conclusion. Then, the confidence interval is more relevant when used for natural and synthetic fiber composites with diverse properties. All the calculations and conclusions in this study are based on α=0.05 (5% standard error) significant value and 95% confidence interval. z-test statistics are used in hypothesis testing and confidence interval because the sample data is equal to 30. Equations (1) and (2) are used to perform the hypothesis testing and confidence interval.

$$z = \frac{\left(\bar{x}_{YMsf} - \bar{x}_{YMnf}\right) - \left(\mu_{YMsf} - \mu_{YMnf}\right)}{s_{YMsf} - s_{YMnf}} \quad (1)$$

$$s_{sf-nf} = \sqrt{\frac{s^2_{YMsf}}{n_{YMsf}} + \frac{s^2_{YMnf}}{n_{YMnf}}} \quad (2)$$

Where:

$\bar{x}_{YMnf}$ = sample mean of YM_{nf} properties

$\bar{x}_{YMsf}$ = sample mean of YM_{sf} properties

μ_{YMnf} = population mean of YM_{nf} properties

μ_{YMsf} = population mean of YM_{sf} properties

s_{YMnf} = standard deviation of YM_{nf}

s_{YMsf} = standard deviation of YM_{sf}

n_{YMnf} = number of samples for YM_{nf}

n_{YMsf} = number of samples for YM_{sf}

4.0 RESULTS AND DISCUSSION

4.1 Descriptive Statistic of Natural and Synthetic Fiber Composites

Descriptive statistics can give basic information about natural and synthetic fiber data such as minimum, maximum, average, and standard deviations of the data set. These values also can highlight any potential relationship between the variables. All the measurements also can display and discuss using a graphical approach that has more representatives. Based on Table 2, the basic information such as minimum, maximum, mean, and standard deviation are the measurements that can explain the variation of the natural and synthetic fiber. Time and cost are the limitations of natural and synthetic fiber composites for physical, mechanical, and chemical testing [57, 58]. A simple random sampling approach is used to prepare the 30 measurements of YM of the materials.

Table 2 shows that flax composites have a maximum YM which is 77 MPa. Many studies showed the performance of this fiber in many fields, such as the automotive and aircraft industry. Flax fiber is the most potential natural fiber that can achieve maximum residual tensile properties because of the high cellulose content of the fiber [59]. Flax fiber also was the highest rank in the material selection of natural fiber for a composite automotive component using analytical hierarchy process and analytic network process where the tensile properties is the significant criteria reported by Mastura *et al.*, (2019)[60]. The minimum YM was roselle fiber with 1 MPa. Even though roselle fibers have a minimum value of YM, treated roselle fiber with vinyl ester can improve the tensile properties [61]. The alkalization treatment also enhances the thermal stability of the fiber because the lignin and hemicellulose in the fiber structure are removed [62].

Table 2 Descriptive statistic of natural fiber polypropylene composites

Type	Fiber	Min	Max	Mean	SD
	Roselle	1	3	2.10	0.803
	Hemp	30	70	53.47	12.376
Natural	Kenaf	20	53	34.13	9.475
	Jute	20	55	41.83	10.389
	Sisal	10	28	19.97	4.923
	Flax	35	77	57.30	12.852
	Bamboo	11	17	14.00	1.948
	Coir	4	6	5.17	0.834
	Bagasse	4	17	9.70	3.825
	Banana	8	32	20.70	7.159
	Cotton	5	13	9.17	2.890
	Wood	13	70	38.63	17.032
	Harakeke	14	33	25.27	5.502
Synthetic	Glass	72	79	76.17	2.306
	Carbon	230	436	325.50	66.334
	Boron	350	400	376.47	15.458
	Aramid	125	783	424.80	201.122

* All value in unit of GPa

Another study found the hybrid composite of roselle and sisal can increase the mechanical properties compared to single roselle fiber by chemical treatment [63]. The highest average YM, which is 57.3MPa was flax fiber and the smaller YM is roselle with 2.1MPa in this study. Figure 2 shows the error bar based on a 95% confidence interval for each natural fiber. This error bar also can describe the dispersion of the data set base on the standard deviation. The standard error considers 2.5% each on the right and left of normal distribution tails.

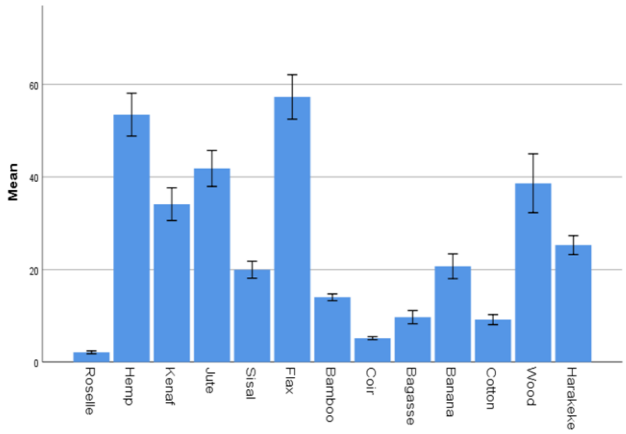


Figure 2 The Young's Modulus of Natural Fibers/PP Composites

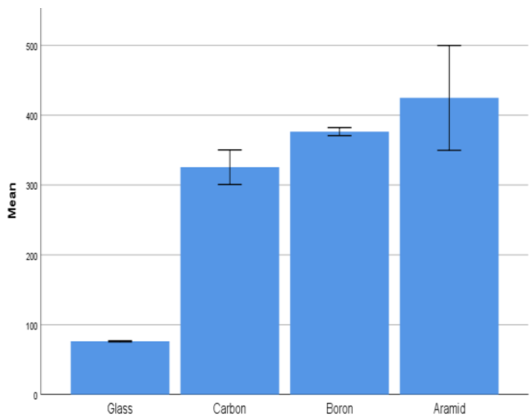


Figure 3 The Young's Modulus of Synthetic Fibers/PP Composites

This study has four synthetic fibers; YM is significantly different in general by referring to the mean. Aramid fiber scores the highest YM compared to carbon, boron, and glass, 424.8 MPa. This high-performance aramid is the preferred material in body armor application [64]. But the standard deviation of aramid is significant because of the large range present in the data set in Table 1. Moreover, aramid has a few types, such as Kevlar, Nomex and Conex that have twenty-time higher performance compared to other polyamide fibers [65]. Aramid also is an established material that can replace the steel wire in radial tires in automotive applications [66]. Figure 3 shows the performance of YM of each synthetic fiber in this study. Hypothesis testing is used to confirm the claim that synthetic fiber is higher in YM than natural fiber reported by most previous studies in composites material.

4.2 Hypothesis Testing of Natural and Synthetic Fiber Composites

Table 3 showed the five steps involved to perform the hypothesis testing between two independent sample mean of materials. The general alternative hypothesis in Table 3 is synthetic fiber (A) is greater than natural fiber (B). The standard deviation of two samples is calculated as S_{A-B} . Test-statistics used in this study are z-test; the z-distribution is referred to decide on rejecting the null-hypothesis. The natural fiber of flax and hemp are used to compared with glass, boron, carbon, and aramid in this analysis. The null hypothesis is rejected when the P-value is less than 0.05 or the value of the z-test is more than the critical point from the z-distribution table.

Table 3 The hypothesis testing between natural and synthetic fibers

A	*B*	s_{A-B}	z-test	*P*-value	Decision
Aramid	Flax	36.795	9.988	0.000	Reject null hypothesis
Boron	Flax	3.670	86.757	0.000	Reject null hypothesis
Carbon	Flax	12.336	21.741	0.000	Reject null hypothesis
Glass	Flax	2.384	7.915	0.001	Reject null hypothesis
Aramid	Hemp	36.790	10.093	0.000	Reject null hypothesis
Boron	Hemp	3.615	89.347	0.000	Reject null hypothesis
Carbon	Hemp	12.320	22.081	0.000	Reject null hypothesis
Glass	Hemp	2.30	9.878	0.000	Reject null hypothesis

Based on the decision and *P*-values in Table 3, the YM of all synthetic fiber is significantly greater than the natural fiber of flax and hemp. There is enough evidence to prove the YM of aramid, boron, carbon, and glass fibers is higher than flax and hemp fibers. All the z-test values in Table 3 are more than the critical value in z-distribution which is 1.645 (based on 5% standard error). Comprehensive comparisons about the structure of synthetic fiber were done by Chung [67]. Although synthetic fiber has a higher YM, many studies proposed hybrid composite that can give a green effect to the environment in the long term. The impact energy absorbed and hardness of the kenaf composite increases when the weight of percentage of Kevlar is increased [68]. Another study concludes kenaf/glass epoxy composite can increase mechanical properties such as tensile strength, YM, flexural strength, and flexural modulus but the impact properties are still low for car bumper application [69]. A study on the effect of layering the hybrid composite of kenaf and Kevlar was done by Yahaya *et al.*, (2015) [64]. This study concludes there is an effect of hybrid kenaf-Kevlar composite as a skin layer that improved the tensile, flexural, and impact properties. Combining natural and synthetics fibers into the polymer matrix can give many applications that performed the best environmentally friendly and economic properties.

4.3 The Distributions of Natural and Synthetic Fiber Composites

The scatter plot of fiber can describe the distribution of the data sets. Figure 4 shows the large distribution of synthetics fibers compared to natural fibers. This finding is also mentioned in the previous analysis by looking at the standard deviation value of each fiber. In addition, the data set of natural fiber is more fit and precise for estimation purposes than synthetic fiber.

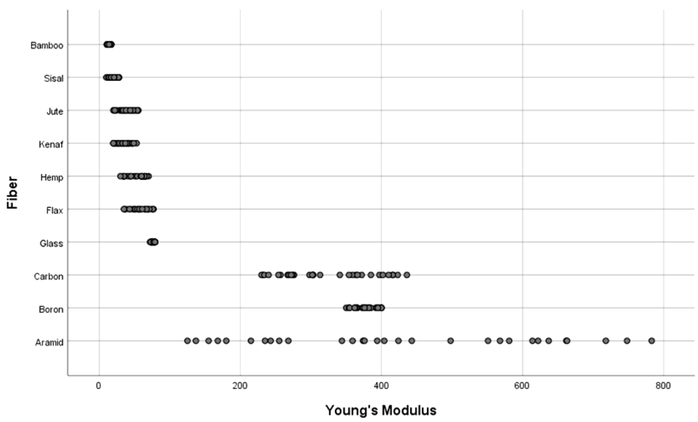


Figure 4 The scatter plot of Young's modulus of natural and synthetic fibers

To increase the accuracy of hypothesis testing about natural and synthetic fiber, the data on hybrid composites that consist of both natural fiber and synthetic fiber with a particular polymer may consider. The data analysis on this type of data is more meaningful and can give an informative idea and concept that can be tested and compared with experimental work. This is because the natural fiber structure gives different values of mechanical properties [53]. There are three types of fiber which are bast, leaf, and seed. Flax, jute, hemp, roselle, and wood are classified as bast fiber, while banana and sisal are leaf fiber and coir are an example of seed fiber. As mentioned in the previous section, the performance of mechanical properties of synthetic fibers are superior to the natural fibers as the properties could be tailored as per desired. Several factors could influence the properties of natural fibers. Specifically, mechanical properties such as Youngs' modulus is influenced by the composition of the fibers which is by the percentage of cellulose on the fibers. Properties of the fibers also exhibited through the percentage of the hemicellulose, pectin, and lignin. As per expected in this study, natural fibers exhibit lower value of YM and need to hybridize with the synthetic fibers to obtain better mechanical performance of the composites.

5.0 CONCLUSION

A random sample of 30 fibers, both natural and synthetic, was taken based on the YM range mentioned in the previous studies. The performance of the mechanical characteristics of both materials is evaluated using descriptive statistical measures. The average YM of synthetic fiber is greater than that of natural fiber. Aramid had the highest score for synthetic fiber on YM, with a mean of 424.8MPa, whereas flax received the highest score for natural fiber, 57.3MPa. By using hypothesis testing in this study, there is enough evidence to reject the null hypothesis and conclude that the YM of four synthetic fibers is superior to flax and hemp. The z-test score is more than the critical threshold according to the z-distribution table, and the P-value is less than 0.05. The hybrid composite of natural and synthetic fibers is recommended to achieve the desired YM that yet can deliver the benefits of natural fiber such as renewable, affordable, biodegradable, and inexpensive in the future study.

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