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Mechanical, Morphological, and Fire Behaviors of Sugar Palm/ Glass Fiber Reinforced Epoxy Hybrid Composites

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ABSTRACT

This research aims to investigate using sugar palm fiber (SPF) and glass fiber (GF) in an epoxy matrix to develop composite materials with improved mechanical, morphological, and flammability properties. The mechanical and flammability properties are examined per ASTM standards, while the morphological study examines the fractured surfaces of the samples. Using the hand lay-up technique, the hybrid composite comprises 15% SPF, 15% GF, and 70% epoxy resin. Three treatments are applied to the SPF: untreated, alkaline treated, and benzoyl chloride treated, which enables research into the effect of fiber treatment on mechanical properties and flammability. The morphological investigation reveals that both treated SPF/GF/EP composites exhibit lower tensile strength than the untreated SPF/GF/EP composite due to inadequate mechanical interlocking at the fiber-matrix interface. However, the alkaline-treated SPF/GF/EP composite demonstrates a 24.8% improvement in flexural strength, a 1.52% increase in impact strength, and a 9.76% enhancement in flammability. Similarly, the benzoyl chloride-treated SPF/GF/EP composite improves flexural strength, impact strength, and flammability by 24.6%, 0.51%, and 5.66%, respectively. These results highlight the potential of fiber treatment to improve composite materials' mechanical and flammability properties.

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INTRODUCTION

Researchers are now paying attention to natural fiber-reinforced composites, and materials have shown significant demand

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from numerous sectors to be employed in diverse goods such as furniture, packaging, automotive components, and construction (Ilyas, Sapuan, Atikah, et al., 2020; Tarique et al., 2022). Natural fiber sources such as rice straw, roselle, sugar palm, jute, bamboo, kenaf, and others are easily accessible, and natural fiber is utilized as an alternative filler or reinforcement for synthetic fibers and fillers (Ilyas et al., 2021). Furthermore, the usage of petroleum-based polymers in human everyday activities is expanding. Plastic disposal is one of the environmental contamination concerns (Sapuan et al., 2018). As a result, increasing awareness activities in society is one strategy for minimizing the environmental effect (Azammi et al., 2019). As a result, one solution to this issue is to utilize natural fibers. These natural sources are affordable in cost, low in density, simple to recycle, biodegradable, environmentally friendly, and long-lasting (Harussani et al., 2021). Advanced composites are frequently employed in engineering applications because of their superior strength-to-weight and particular stiffness-to-weight ratios (Ibrahim et al., 2012; Lau et al., 2018). These composites are suitable for various industries since they provide higher mechanical performance while lightweight. Researchers are investigating natural fibers as potential reinforcements in composite materials due to the need for environmentally acceptable and sustainable products.

Sugar palm fiber (SPF, Arenga pinnata Wurmb. Merr) is one of these natural fibers and offers much promise as Malaysia's most abundant natural resource. SPF has numerous benefits, including low cost, biodegradability, non-toxicity, low density, and high mechanical strength (Huzaifah et al., 2016). Sugar palm fibers are utilized in various industries (Sapuan et al., 2018). These fibers are also used to make brushes, brooms, roofing materials, thatching materials, fishing equipment, traditional prayer headgear, and other small commodities (Bachtiar et al., 2008; Tarique et al., 2021). The SPF is safe for humans and the environment as it is a natural source of *Arenga Pinnata*, which is degradable and will not harm the environment as synthetic fibers do. Thus, this is one of the factors that researchers have been eager to use natural fibers as reinforcement to the fiber composite. Glass fiber (GF) is a synthetic fiber, which has been commonly used as reinforcement in composites to enhance mechanical properties. Unfortunately, touching the glass fiber with bare hands will irritate the skin. Tsunoda et al. (2014) state that skin irritation is called "*Dermatitis,*" in which the glass stimulates the skin mechanically but not chemically. However, it can be safely touched once it has been bound with resin, as it will not be exposed. Epoxy resin is a thermosetting plastic that exhibits huge smoke once ignited and burnt. These smokes are harmful to the environment as well as air pollution. Saba et al. (2016) claim that petroleum-based resin is highly flammable and produces huge amounts of smoke when burned. Despite its environmental issues, epoxy is a good thermosetting plastic that can be a matrix of composite that gives good mechanical properties.

Recent research on SPF/GF/EP composites has shown promising property improvement, fabrication, and characterization results. Researchers have made significant progress in improving the mechanical, thermal, and physical properties of SPF/GF/EP composites. Adding glass fibers to sugar palm fiber composites has increased tensile strength by up to 55.7% (Saba et al., 2016). In addition, the addition of nanofillers in the phenolic resin has shown outstanding multifunctional properties compared to traditional polymeric composites (Kamaruddin et al., 2022). Hybrid composites of SPF/GF have been shown to enhance the characteristics of SPF composites, overcoming the weakness of SPF (Huzaifah et al., 2019). However, there are still challenges and limitations to using these composites, such as their higher cost and limited availability of raw materials. Further research is needed to fully understand the potential benefits and limitations of SPF/GF/EP composites compared to traditional materials. The research on SPF/GF/EP composites is still in its early stages, and more work is needed to understand these materials' potential benefits and limitations fully.

This research has developed a composite material with natural sugar palm fiber and synthetic glass fiber as reinforcement. Sugar palm fiber's main constituents are cellulose (43.88 wt.%), hemicelluloses (7.24 wt.%), lignin (33.24 wt.%), and ash (1.01 wt.%) (Ilyas, Sapuan, Kadier, et al., 2020). E-glass fiber has been widely used as a reinforcement in polymer composites due to its excellent mechanical properties and low cost. The matrix for the hybrid composite is taken to be epoxy. Table 1 lists the mechanical characteristics of the hybrid material inputs. The developed hybrid composite's combination of good strength and fire retardancy will widen the opportunity for industries to produce various potential products.

In this study, glass fiber (GF) and sugar palm (SPF) fiber (*Arenga pinnata (wurmb) merr*) fiber were combined in an epoxy matrix to produce composite materials. Unlike earlier research, this novel hybrid technique intends to capitalize on the synergistic effects

Table 1
Mechanical properties of used materials and others

Material	Density (g/cm^3)	Strength (MPa)	Modulus (GPa)	Elongation at break (%)	Reference
Sugar Palm Fiber	1.2-1.3	15.5	4.189	-	Sherwani et al., 2021
Sugar palm frond fiber	-	421.4	10.4	9.8	Sahari et al., 2012
Sugar palm bunch fiber	-	365.1	8.6	12.5	Sahari et al., 2012
Sugar palm trunk fiber	-	198.3	3.1	29.7	Sahari et al., 2012
ijuk	-	276.6	5.9	22.3	Sahari et al., 2012
Glass	2.5	1.	70	2.5	Davoodi et al., 2010
Epoxy	1.1-1.4	35-100	3-6	1-6	Davoodi et al., 2010
Carbon	1.8	4900	230	-	Dong & Davies, 2015
S-glass	2.5	4700 (@25^{o}C)	85	-	Jones & Huff, 2018
A-glass	2.46	3100(@25^{o}C)	72	-	Jones & Huff, 2018

of SPF and GF, potentially resulting in improved mechanical and flammability features. Investigating several SPF treatments (alkaline and benzoyl chloride) adds to the originality, providing insights into maximizing composite performance. The research focuses on sustainability, employing SPF as Malaysia's renewable and abundant resource. This study addresses crucial factors generally missed in similar studies by analyzing mechanical, flammability, and morphological qualities, paving the path for creative applications in various industries.

MATERIALS AND METHODS

Materials

The SPF was collected from a sugar palm tree at Kampung Kuala Jempol, Negeri Sembilan, Malaysia. Sodium hydroxide (NaOH), Benzoyl Chloride with reagent 99.9%, and ethanol for the fiber treatments were supplied by Evergreen Engineering and Services, Taman Semenyih Sentral, Selangor, Malaysia. Lastly, chopped E-glass fiber, epoxy resin, and hardener were Zeegen brand with a ratio of 3:1, were supplied by Mecha Solve Engineering, Petaling Jaya, Selangor, Malaysia, and used for the SPF/GF/EP composites.

Fiber Treatments

Alkaline Treatment of SPF. SPF was alkaline treated to remove impurities of surface and hemicelluloses within fibers. Thus, in this study, SPF proceeded with an alkaline treatment where the fibers were immersed in 6% NaOH for 1000 mL for 1 hour at room temperature (RT). After that, the soaked SPF was then moved to an acetic acid solution until it hit a neutral pH value and rinsed with distilled water. Lastly, SPF was dried in the oven for 24 hours at 60°C.

Benzoyl Chloride Treatment of SPF. 50g of SPF was first soaked in an 18% concentration of NaOH solutions and then rinsed with water to rinse off the NaOH. The next step was immersing the fibers in a mixed solution of 50 ml benzoyl chloride and 10% NaOH solution for 15 minutes. For the period of immersing the fibers, it was found that 15 minutes of soaked fiber showed the best performance in Izwan et al. (2022). Lastly, the fibers were removed and soaked in ethanol for 60 minutes before being cleaned and dried in the oven at 60 for 24 hours.

Fabrication of SPF/GF/Epoxy Hybrid Composites Testing Samples

According to Syaqira et al. (2020), the best performance of the composite was achieved at 20% SPF with short-cut fibers (0.1 to 0.5 cm). For epoxy mixing, by following Ahmed (2013), the ratio of epoxy and hardener in the study was 4:1, and treated and untreated

SPF will be mixed with epoxy for 5 minutes at RT. However, Zeegen brand epoxy resin and its hardener require a ratio of 3:1 to cure properly; thus, a ratio of 3:1 was used for the curing process. Table 2 describes the hybrid composite formulation to ensure the sugar palm and chopped E-glass fibers and epoxy were mixed properly to develop a high-quality and durable composite plate. After that, the mold-releasing agent was applied to the open mold, and the mixture of resin and fibers was poured and spread evenly using the hand-layout technique. The mold was left to be fully hardened for 24 hours and removed after being cured. The composites were developed into sheets, which were then cut into test samples as per the ASTM standard for tensile, flexural, impact, and flammability tests, namely, ASTM D638-10, ASTM D790, ASTM D256-10, and ASTM D635, respectively.

Table 2
Formulations of treated and untreated hybrid composites

Composite	Matrix as Epoxy (wt.%)	Reinforcement		
		Sugar Palm Fiber		Glass Fiber
		Treatment	wt.%	
USPF/GF/EP	70	-	30	-
ASPF/GF/EP	70	6% NaOH	15	15
BSPF/GF/EP	70	Benzoyl chloride	15	15

Note. USPF: Untreated SPF; ASPF: Alkaline treated SPF; BSPF: Benzoyl chloride

Characterization

Tensile Test. The tensile test was performed using an Instron 3366 universal testing machine (Instron, Norwood, MA, USA) following ASTM D638-10 (ASTM D638-10, 2015). With a 5kN load cell, the gauge length for hybrid composites follows the ASTM standard D638-10, where the gauge length was 33 mm, and the crosshead velocity was set to 2 mm/min. Five samples were prepared for the tensile testing with dimensions of 115 mm × 19 mm × 3 mm. The average value was taken from among the results taken from five specimens.

Flexural Test. The flexural properties of treated and untreated composites were evaluated using an Instron 3365 columns tabletop Universal Testing Machine with a span length of 50 mm as well as a crosshead speed of 12 mm/min, as specified by the ASTM D790 (3-point bending) standard (ASTM D790, 2017). Composite plates produced five composite samples measuring 127 mm × 12.7 mm × 3 mm. The results were calculated using the average of five specimens.

Impact Test. The five specimens, kept separate from the composite plate for the Izod impact test, were 65 mm × 15 mm × 3 mm in size and adhered to ASTM D256-10 (ASTM D256-10, 2015). Five identical specimens of each composite type were positioned tightly vertically and hit with a pendulum at a force of 10 J in the instrument's center. The averages of the five specimens were used to measure the impact's energy and velocity, which were 2.75 J and 3.46 m/s, respectively.

Scanning Electron Microscopy (SEM). Adhesion of fibers with polymer matrix of treated and untreated fiber composite was observed under the scanning electron microscope, SEM (Coxem-EM-30AX +), at 5 kV of an acceleration voltage. Specimens were mounted on the aluminum stubs using double-sided adhesive tape. In order to stop charging, specimens were covered in a thin layer of gold (0.01-0.1 m).

Flammability Test. The flammability test determines the fire resistance of composites when burnt by taking the total time taken for the specimen to be fully burnt and calculating the burning rate. A UL-94 horizontal burning test conducted the flammability test of untreated and treated biocomposite samples according to the ASTM D635 (2022) standard. For specimens with dimensions of 125 mm × 13 mm × 3 mm, were 2 marks made on the specimen where 25 mm was measured from each side. The purpose of the one end was to burn first to test whether the specimen was flammable, and once the fire passed through the first mark, the time was recorded for it to burn until the fire reached the second mark. Therefore, the length between the 2 marks was 75 mm, divided by the total minutes taken for the specimen to be burnt to calculate the burning rate. Finally, the burning rate of biocomposite samples was calculated as follows:

$$V = 60L/t$$

Where V, L, and t represent the burning rates (mm/min), burned length (mm), and burning time (s), respectively.

Statistical Analysis. SPSS software analyzed variance (ANOVA) on the experimentally collected data. Duncan's test compared means at a 5% significance level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Tensile Test

Figure 1 shows the average value of the tensile strength tested in agreement with the ASTM standards of D638-04. The USPF/GF/Epoxy exhibited the highest tensile strength value compared to the ones with fiber treatment, which showed 47.17 MPa. Meanwhile, the ASPF/GF/Epoxy showed 42.43 MPa in its tensile strength, which is slightly higher than the BSPF/GF/Epoxy with a value of 40.67 MPa. It has clearly shown that the untreated fiber hybrid composite has the best performance as it was 10.05% higher than ASPF/GF/Epoxy and 13.8% better than the BSPF/GF/Epoxy.

However, as stated by Izwan et al. (2022), the higher treated Kenaf Fiber ratio exhibited the best mechanical properties, with the highest tensile (19.4 MPa), impact (1.2 J/m^2), and flexural values (18.4 MPa). Furthermore, the benzoyl chloride-treated fiber composite was ranked the lowest for its tensile performance. Sherwani et al. (2021) report a similar case in which the benzoyl-treated SPF with glass fiber-reinforced PLA was the weakest, with the lowest slope among the alkaline-treated and untreated fiber composites. Furthermore, according to Table 3, the treated specimens were heavier than the untreated specimens, whereas results showed that untreated specimens had the highest tensile strength. Thus, the adhesion of fibers and polymer will be the major concern in this case.

Even though alkaline-treated fiber composites have degraded tensile properties, several studies found that alkaline-treated fibers showed improved and enhanced mechanical properties. In a study conducted by Bachtiar et al. (2011), the application of alkali treatment to sugar palm fibers increased the composites' strength, surpassing the tensile strength of neat, high-impact polystyrene. In another study conducted by Ibrahim et al. (2010) on kenaf fiber, it was found that the alkaline treatment enhanced its composite tensile

Table 3
The mass for each tensile test specimen

Sample	Specimen	Mass (g)
USPF/GF/EP	1	8.34
	2	8.21
	3	8.45
	4	8.41
	5	8.36
ASPF/GF/EP	1	8.48
	2	8.43
	3	8.51
	4	8.78
	5	8.82
BSPF/GF/EP	1	8.41
	2	8.39
	3	8.46
	4	8.76
	5	8.79

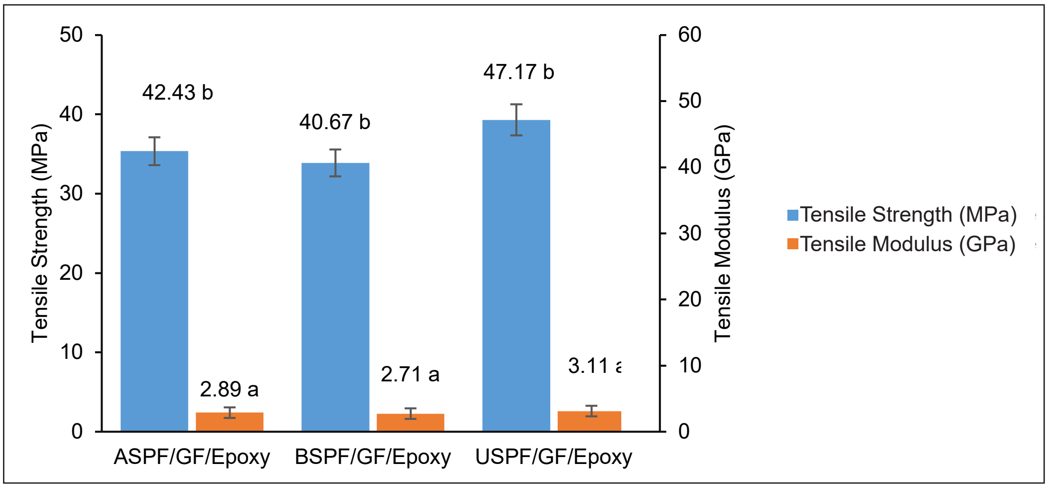


Figure 1. Tensile strength of hybrid composite samples. Values with different letters in the figures are significantly different ($p < 0.05$)

strength. However, at a higher concentration, the tensile strength later dropped due to the degradation of lignocellulose on the fiber surface. The study further explained that the alkaline treatment facilitates the removal of impurities and the protective waxy layer from the outer surface of fibers, leaving a rough surface after treatment, which enhances adhesion between fibers and the matrix. The experiment improved the mechanical properties of flax fiber-reinforced epoxy composites with the alkaline treatment, especially with an increment of the solution concentration up to 3%. On the other hand, a similar case to the degraded tensile strength result was found in the study of Orue et al. (2016). The tensile strengths of alkaline-treated sisal fibers dropped and were lower than untreated sisal fibers, which was explained by the removal of non-cellulosic compounds, which created voids in the fibers and led to weaker mechanical properties.

Flexural Test

The flexural stress of the composites with different treatments has been evaluated by taking an average value out of five specimens tested. Figure 2 clearly shows that the treated fiber composites have much higher flexural stress in their capability to resist deflection while against the force applied. The highest flexural stress found is 131.69 MPa ($p < 0.05$) on ASPF/GF/Epoxy, while the second highest is 122.42 MPa on BSPF/GF/Epoxy. The alkaline-treated fiber composite (ASPF/GF/Epoxy) improved its performance by at least 24.8% higher than the untreated fiber composite. Meanwhile, the BSPF/GF/Epoxy is 24% higher than untreated and was, however, 7% lower than the ASPF/GF/Epoxy.

As shown by the results, it has been proven that the fiber treatment has significantly improved the mechanical properties of the composites by bringing them better adhesion with polymers. According to Siakeng et al. (2019), natural fiber itself has a significant disadvantage when it comes to the choice of synthetic fiber or natural fiber, which is the hydrophilic nature that causes poor adhesion between the fibers and the polymer in composites. Therefore, with the treatment, the natural fibers will overcome the problem by improving their adhesion with the matrix by removing substances like lignin, waxes, and oil-based layers. Moreover, in both work done by Kabir et al. (2012) and Safri et al. (2018), the results have proven that benzoyl treatment brought improvement to the fibers in terms of the mechanical

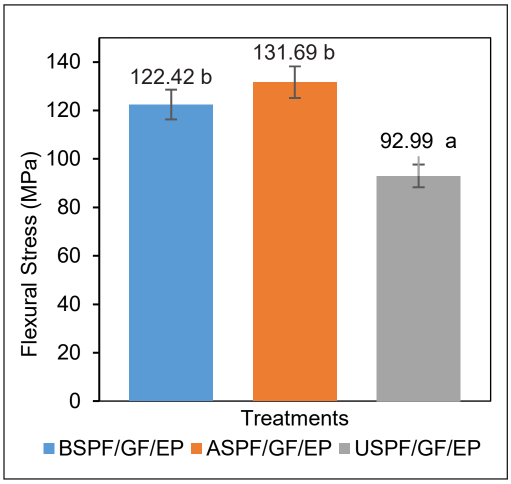
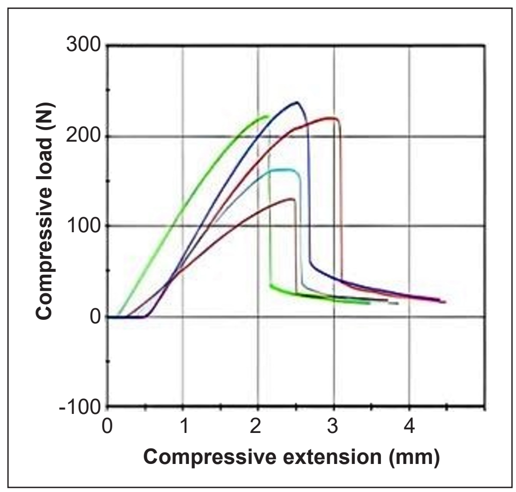


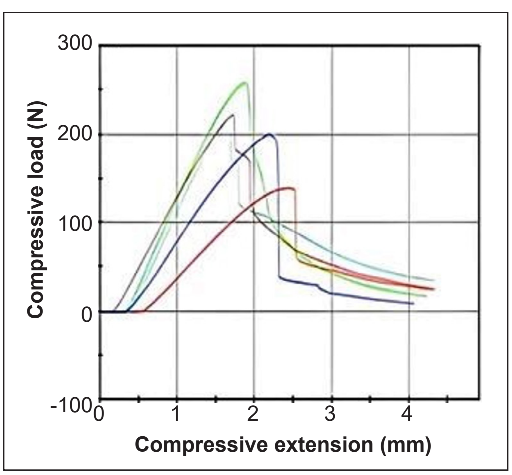
Figure 2. Flexural stress of the hybrid composites with different treatments. Values with different letters in the figures are significantly different ($p < 0.05$)

strength, adhesion with the matrix, and reduction in water absorption by reducing hydrophilic nature of natural fiber itself.

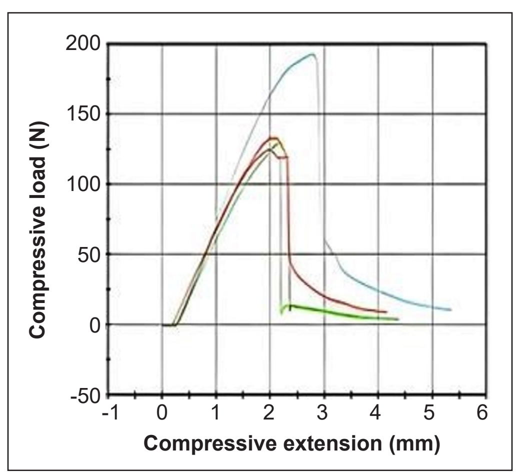
According to Figure 3, the graph shown was in compressive load (N) against the compressive extension (mm). It was, however, to be used for flexural testing on compression software due to the breakdown of the flexural testing machine. Apart from that, by referring to the behavior of the graphs based on these composites with various treatments, it was found that the ASPF/GF/EP exhibited the highest slope in the curves, while the BSPF/GF/EP had second highest among the curves, and yet the USPF/GF/EP has the lowest slope as compared to the other two. Moreover, the result was obvious that three of these composites showed similar extensions. The results highlight the importance of fiber treatment in influencing the mechanical performance of the composites. The distinct slopes and responses of the curves suggest that the treatments impact the interfacial adhesion between the fibers and the epoxy matrix, influencing the overall composite strength and stiffness. Notably, despite the differences in slope and stiffness, all three composites exhibited similar extensions, indicating a consistent level of ductility. This finding indicates that the chosen treatments did not compromise the ability of the composites to withstand deformation before failure.



(a)



(b)



(c)

Figure 3. The compressive load (N) versus compressive extension (mm) of the composites: (a) BSPF/GF/EP; (b) ASPF/GF/EP; and (c) USPF/GF/EP

Overall, these results provide valuable insights into the significance of fiber treatments in enhancing the mechanical properties of the composites. The findings offer new possibilities for tailoring the mechanical behavior of natural fiber-reinforced composites through appropriate treatment approaches by providing a more detailed result, in which each composite's strain has been calculated, as shown in Table 4. The highest strain was shown in ASPF/GF/EP with a value of 0.033, whereas the other two composites showed similar results to the ASPF/GF/EP with values of 0.031 and 0.032 for BSPF/GF/EP and USPF/GF/EP, respectively. Based on the behavior of the composites that reacted towards the flexural testing, one major factor may be due to the brittleness of the epoxy itself, as thermoset matrices are known for their extreme brittleness as compared to thermoplastic materials (Turk et al., 2017).

Table 4
The average values of mechanical properties out of five specimens

Sample	Tensile (MPa)	Tensile Modulus (GPa)	Flexural (MPa)	Strain (mm/mm)	Impact (kJ/m²)
USPF/GF/EP	47.17 ± 0.7 [b]	3.112± 0.09 [a]	92.99 ± 0.3 [a]	0.032	19.4 ± 0.4 [a]
ASPF/GF/EP	42.43± 0.8 [b]	2.886 ± 0.08 [a]	131.69 ± 0.9 [b]	0.033	19.7± 0.3 [a]
BSPF/GF/EP	40.67± 0.6 [b]	2.707 ± 0.04 [a]	122.41± 0.7 [b]	0.031	19.5± 0.5 [a]

Note. Data are expressed as the mean value of replication (n) ± SD; for the same column, the different letter indicates a significant difference ($p < 0.05$)

Impact Test

The impact test of this study has been summarized in Figure 4. As it can be seen from the graph shown in Figure 4, ASPF/GF/EP has the highest impact strength at 19.7 kJ/m² and yet the BSPF/GF/EP is ranked as second in the impact test at 19.5 kJ/m² while USPF/GF/EP has the lowest with a slightly lower value at 19.4 kJ/m² as compared with the two samples. There are no significant changes. During the impact test, all the specimens, after being hit by the heavy blow, appeared to be hinge broken.

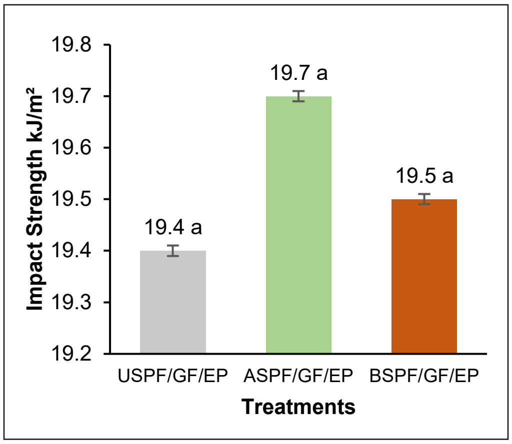


Figure 4. Impact strength of composite samples with various treatments

With the results given, it has been proven that the benefits gained by having fiber treatment that removes the outer layers of fibers, such as lignin, hemicelluloses, and pectin, have significantly improved adhesion between fibers and the polymer and thus an improvement in mechanical properties as an output. For the contribution of such improved results, it has been shown that the engagement of fibers with the epoxy as the matrix of composites was in good condition, and yet it allowed for the optimal absorption of the energy that was crushed towards the specimen. Furthermore, Swain and Biswas (2017) find that benzoyl chloride-treated jute fiber-reinforced epoxy significantly improves its impact strength compared to untreated.

According to Cartie and Irving (2002), the resin toughness is still the most important factor in influencing impact strength, rather than the strength of the fibers as well as their stiffness. Epoxy was the matrix of the tested composites, which is well known for its excellent mechanical strength despite its brittleness. In comparing the thermoset plastic with thermoplastics such as PLA, in the study of Sherwani et al. (2021), the same composition of the reinforcement with 15 wt.% of SPF, GF, and PLA as the matrix, the highest impact strength that was exhibited was 3.10 kJ/m². As a result, there is a large gap between the thermoset plastic and the thermoplastic.

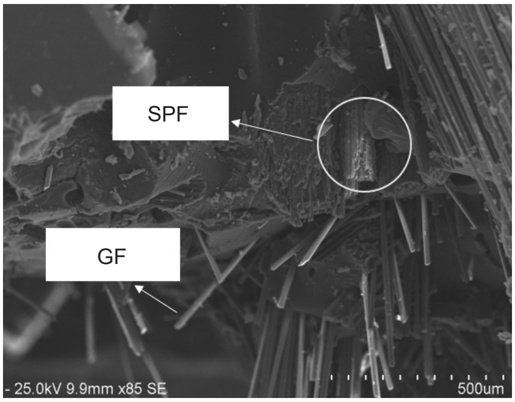
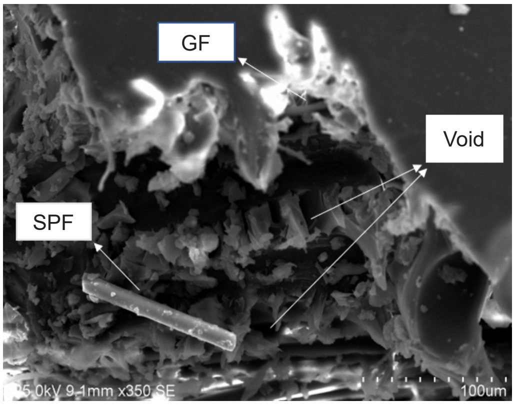
Scanning Electron Microscopy (SEM)

Throughout the mechanical tests, it was found that all the treated SPF/GF/EP composite have improved properties except for the tensile test, where the untreated SPF/GF/EP has the best outcome. By referring to the studies done by Bachtiar et al. (2008), Ibrahim et al. (2010), Swain and Biswas (2017), and Sherwani et al. (2021), all alkaline-treated fibers showed a significant improvement in improving mechanical properties of the composite, especially in tensile strength and flexural strength. However, the ASPF/GF/EP was somehow gotten with a lower tensile strength than the USPF/GF/EP. Therefore, the morphological observation will be focused on the ASPF/GF/EP and USPF/GF/EP.

According to Table 5, both SEM analyses of USPF/GF/EP and ASPF/GF/EP have been shown. For USPF/GF/EP, the breakage of the SPF can be seen, which indicates a good interlocking of fibers with the matrix, as it shows that more energy was absorbed when the specimen was being pulled during the tensile test. In contrast, the ASPF/GF/EP fiber was shown in a pulled-out condition instead of broken due to the tension applied. Ishak et al. (2009) found a similar result: the SPF was also pulled out with holes remaining, but this time with untreated SPF. That being said, this indicates poor interfacial bonding owing to poor adhesion between fibers and matrix. Moreover, based on SEM analysis of ASPF/GF/EP, many voids can be seen, and these voids have guaranteed poor mechanical performances due to poor adhesion. However, one explanation from Swain and Biswas (2017) states that the presence of the holes can be either air entrapments or voids. Air entrapments are mostly known to be a common problem for epoxy resins. The gassy issue happens when the temperature rises during the curing process and gets trapped.

Suppose the alkaline treated SPF would have a better adhesion with the matrix due to its rougher fibers' outer surface. Benyahia and Merrouche (2014) reported that the removal of the lignins, pectin, hemicelluloses, and others of Alfa fibers after alkaline treatment caused the outer surface of the fiber itself to be rougher than untreated, and thus, the rough surface helps in the adhesion between fibers as well as polymer due to exposure of hydroxyl groups to the matrix. Therefore, by considering the factor for the result that untreated has higher tensile strength, the factor could be either the chemical treatment that leads to degradation in the fiber structure or the air entrapments during the curing process.

Table 5
The morphological investigation of fractured tensile samples for untreated and alkaline-treated

Sample	Tensile Test
USPF/GF/EP	
ASPF/GF/EP	

Flammability Test

The flammability test determines the fire resistance of composites when burnt by taking the total time for the specimen to be fully burnt and calculating the burning rate (Sherwani et al., 2021; Suriani et al., 2021).

The five specimens of each sample were tested with the burning test in accordance with the standard of the UL-94 horizontal burning test. Based on Table 6, the average time taken for the specimens to finish burning the marked parts has been calculated based on the time recorded for five specimens of each. It was found that the treated fiber composites took a longer time to burn than the untreated fiber composites. Based on Figure 5, it is noticeable that ASPF/GF/EP has the lowest burning rate at 17.01 mm/min as compared to the other two samples. However, BSPF/GF/EP has a lower burning rate at 18.03 mm/min compared with the USPF/GF/EP, where the burning rate is the highest among the tested samples at 18.85 mm/min. Such a result may be attributed to the main factor, which belongs to the treatments done on the fibers for benzoyl chloride and alkaline. As Izwan et al. (2022) stated, benzoylation-treated fibers improved fire retardancy. Moreover, Shukor et al. (2014) claim that the alkaline-treated kenaf fiber showed a 5% improvement in its fire retardancy after removing lignin after being alkali-treated.

By observing the burning behaviors of all samples, it was observed that the flames on all samples were high flame, and high smoke was produced. For such a phenomenon, the high flame and high smoke produced are due to the matrix of the composites, as the composite itself has 70 wt.% of the epoxy resin as a petroleum-based polymer. Saba et al. (2016) state that petroleum-based polymers are mostly known to be extremely flammable as epoxies dissipate heat and produce smoke when they are burnt. Apart from that, after being burnt, all the samples showed the same results where char was formed, and no dripping happened throughout the burning process. Char formation could be caused by the high content of fibers, which account for up to 30 wt.% of composites. Comparable observations have been reported by Chee et al. (2020). The fibers were up to 40%, and the cohesive char formed after the burning test.

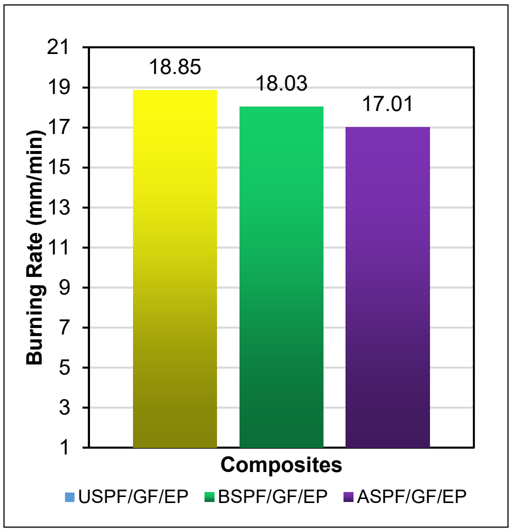


Figure 5. The burning rate of the composite samples

Table 6
The time recorded for the samples to be burnt and the burning behavior of various samples

Sample	Time taken to burn (minute)	Burning Behaviour
USPF/GF/EP	4.09	Fully burnt, high flame, high smoke production, no dripping, and char formed.
BSPF/GF/EP	4.27	Fully burnt, high flame, high smoke production, no dripping, and char formed.
ASPF/GF/EP	4.53	Fully burnt, high flame, produces high smoke, no dripping, and char formed.

CONCLUSION

This novel composite material was successfully fabricated and tested for mechanical, morphological, and flammability properties. The flexural and impact strength of SPF hybrid composites treated with alkaline and benzoyl chloride improved by 24.8%, 1.52%, 24%, and 0.51%, respectively. However, both treated SPF hybrid composites exhibited weaker tensile strength compared to the untreated SPF hybrid composite due to poor mechanical interlocking at the fiber-matrix interface. For flammability, alkaline-treated, as well as benzoyl chloride-treated SPF hybrid composites showed improvements of 9.76% and 5.66%, respectively, in lowering the burning rate, owing to the reduction of lignin content in SPF after treatment. Based on the findings, it can be concluded that the fabrication of SPF/GF/EP hybrid composites offers promise for various industrial applications, including automotive components, aerospace structures, marine applications, and lightweight construction materials for vehicles, aircraft, and ships. These composites provide superior mechanical performance and lightweight construction. In addition, SPF, a readily available, renewable, biodegradable material with excellent tensile properties, can substantially impact and contribute to environmental sustainability. Further research, including thermal loading studies, should be conducted on such hybrid composites to explore their full potential.

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REFERENCES

Ahmed, Q. I. (2013). Fracture toughness of sugar palm fiber reinforced epoxy composites. *International Journal of Science and Research*, *2*(12), 273–279.

ASTM D635. (2022). *Standard test method for rate of burning and/or extent and time of burning of plastics in a horizontal position*. ASTM International. https://www.astm.org/d0635-18.html

ASTM D790. (2017). *Standard test method for flexural properties ofunreinforced and reinforced plastics and electrical insulation materials*. ASTM International. https://www.astm.org/d0790-03.html

ASTM D256-10. (2015). *Determining the izod pendulum impact resistance of plastic*. ASTM International. https://www.astm.org/d0256-23e01.html

ASTM D638-10. (2015). *Standard test method for tensile properties of plastics*. ASTM International. https://www.astm.org/d0638-10.html

Azammi, A. M. N., Ilyas, R. A., Sapuan, S. M., Ibrahim, R., Atikah, M. S. N., Asrofi, M., & Atiqah, A. (2019). Characterization studies of biopolymeric matrix and cellulose fibres based composites related to functionalized fibre-matrix interface. In K. L. Goh, M. K. Aswathi, R. T. De Silva & S. Thomas (Eds.)

Interfaces in particle and fibre reinforced composites- From macro to nano scales (pp.1–68). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-102665-6.00003-0

Bachtiar, D., Salit, M. S., Zainuddin, E., Abdan, K., & Dahlan, K. Z. H. M. (2011). Effects of alkaline treatment and a compatibilizing agent on tensile properties of sugar palm fibre-reinforced high impact polystyrene composites. *BioResources*,*6*(4), 4815-4823.

Bachtiar, D., Sapuan, S. M., & Hamdan, M. M. (2008). The effect of alkaline treatment on tensile properties of sugar palm fibre reinforced epoxy composites. *Materials & Design*, *29*(7), 1285–1290. https://doi.org/10.1016/j.matdes.2007.09.006

Benyahia, A., & Merrouche, A. (2014). Effect of chemical surface modifications on the properties of alfa fiber-polyester composites. *Polymer-Plastics Technology and Engineering*, *53*(4), 403–410. https://doi.org/10.1080/03602559.2013.844828

Cartié, D. D. R., & Irving, P. E. (2002). Effect of resin and fibre properties on impact and compression after impact performance of CFRP. *Composites Part A: Applied Science and Manufacturing*, *33*(4), 483–493. https://doi.org/10.1016/S1359-835X(01)00141-5

Chee, S. S., Jawaid, M., Alothman, O. Y., & Yahaya, R. (2020). Thermo-oxidative stability and flammability properties of bamboo/kenaf/nanoclay/epoxy hybrid nanocomposites. *RSC Advances*, *10*(37), 21686–21697. https://doi.org/10.1039/D0RA02126A

Davoodi, M. M., Sapuan, S. M., Ahmad, D., Ali, A., Khalina, A., & Jonoobi, M. (2010). Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam. *Materials and Design*, *31*(10), 4927–4932. https://doi.org/10.1016/j.matdes.2010.05.021

Dong, C., & Davies, I. J. (2015). Flexural strength of bidirectional hybrid epoxy composites reinforced by E glass and T700S carbon fibres. *Composites Part B: Engineering*, *72*, 65–71. https://doi.org/10.1016/j.compositesb.2014.11.031

Harussani, M. M., Sapuan, S. M., Khalina, A., Rashid, U., & Tarique, J. (2021, April 7-9). *Slow pyrolysis of disinfected COVID-19 non-woven polypropylene (PP) waste*. [Paper presentation]. International Symposium on Applied Sciences and Engineering (ISASE), Erzurum, Turkey.

Huzaifah, M. R. M., Sapuan, S. M., Leman, Z., & Ishak, M. R. (2019). Effect of soil burial on physical, mechanical and thermal properties of sugar palm fibre reinforced vinyl ester composites. *Fibers and Polymers*, *20*(9), 1893–1899. https://doi.org/10.1007/s12221-019-9159-6

Huzaifah, M. R. M., Sapuan, S. M., Leman, Z., & Ishak, M. R. (2016, Month date PLEASE PROVIDE THE INFORMATION). *A review on sugar palm (Arenga Pinnata): Characterization of sugar palm fibre*. [Paper presentation]. Proceedings of the 5th Postgraduate Seminar on Natural Fiber Composites, Selangor, Malaysia.

Ibrahim, M. S., Sapuan, S. M., & Faieza, A. A. (2012). Mechanical and thermal properties of composites from unsaturated polyester filled with oil palm ash. *Journal of Mechanical Engineering and Sciences*, *2*, 133-147. https://doi.org/10.15282/jmes.2.2012.1.0012

Ibrahim, N. A., Hadithon, K. A., & Abdan, K. (2010). Effect of Fiber Treatment on Mechanical Properties of Kenaf Fiber-Ecoflex Composites. *Journal of Reinforced Plastics and Composites*, *29*(14), 2192–2198. https://doi.org/10.1177/0731684409347592

Ilyas, R. A, Sapuan, S. M., Kirubaanand, W., Zahfiq, Z. M., Atikah, M. S. N., Ibrahim, R., Radzi, A. M., Nadlene, R., Asyraf, M. R. M., Hazrol, M. D., Sherwani, S. F. K., Harussani, M. M., Tarique, J., Nazrin, A., & Syafiq, R. (2021). Roselle: Production, product development, and composites. In S. M. Sapuan & A. M. Radzi (Eds.) *Roselle* (pp.1–23). Academic Press. https://doi.org/10.1016/B978-0-323-85213-5.00009-3

Ilyas, R. A., Sapuan, S. M., Atikah, M. S. N., Ibrahim, R., Hazrol, M. D., Sherwani, S. F. K., Jamal, T., Nazrin, A., & Syafiq, R. (2020, November Date PLEASE PROVIDE THE INFORMATION). *Natural fibre : A promising source for the production of nanocellulose*. [Paper presentation]. 7th Postgraduate Seminar On Natural Fibre Reinforced Polymer Composites, Selangor, Malaysia.

Ilyas, R. A., Sapuan, S. M., Kadier, A., Krishnan, S., Atikah, M. S. N., Ibrahim, R., Nazrin, A., Syafiq, R., Misri, S., Huzaifah, M. R. M., & Hazrol, M. D. (2020). Mechanical testing of sugar palm fiber reinforced sugar palm biopolymer composites. *Advanced Processing, Properties, and Applications of Starch and Other Bio-Based Polymers, 2020,* 89-110. https://doi.org/10.1016/b978-0-12-819661-8.00007-x

Ishak, M. R., Leman, Z., Sapuan, S. M., Salleh, M. Y., & Misri, S. (2009). The effect of sea water treatment on the impact and flexural strength of sugar palm fibre reinforced epoxy composites. *International Journal of Mechanical and Materials Engineering*, *4*(3), 316–320.

Jones, F. R., & Huff, N. T. (2018). The structure and properties of glass fibers. In A. R. Bunsell (Ed.) *Handbook of properties of textile and technical fibres* (pp.757–803). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-101272-7.00019-5

Kabir, M. M., Wang, H., Lau, K. T., & Cardona, F. (2012). Composites : Part B Chemical treatments on plant-based natural fibre reinforced polymer composites : An overview. *Composites Part B*, *43*(7), 2883–2892. https://doi.org/10.1016/j.compositesb.2012.04.053

Kamaruddin, Z. H., Jumaidin, R., Ilyas, R. A., Selamat, M. Z., Alamjuri, R. H., & Yusof, F. A. M. (2022). Influence of alkali treatment on the mechanical, thermal, water absorption, and biodegradation properties of cymbopogan citratus fiber-reinforced, thermoplastic cassava starch–palm wax composites. *Polymers*, *14*(14), 2769. https://doi.org/10.3390/polym14142769

Lau, K., Hung, P., Zhu, M. H., & Hui, D. (2018). Properties of natural fibre composites for structural engineering applications. *Composites Part B: Engineering*, *136*, 222–233. https://doi.org/10.1016/j.compositesb.2017.10.038

Izwan, S. M., Sapuan, S. M., Zuhri, M. Y. M., & Muhamed, A. R. (2022). Effect of benzoyl treatment on the performance of sugar palm/kenaf fiber-reinforced polypropylene hybrid composites. *Textile Research Journal*, *92*(5–6), 706–716. https://doi.org/10.1177/00405175211043248

Orue, A., Jauregi, A., Unsuain, U., Labidi, J., Eceiza, A., & Arbelaiz, A. (2016). The effect of alkaline and silane treatments on mechanical properties and breakage of sisal fibers and poly(lactic acid)/sisal fiber composites. *Composites Part A: Applied Science and Manufacturing*, *84*, 186–195. https://doi.org/10.1016/j.compositesa.2016.01.021

Saba, N., Jawaid, M., Alothman, O. Y., Paridah, M. T., & Hassan, A. (2016). Recent advances in epoxy resin, natural fiber-reinforced epoxy composites and their applications. *Journal of Reinforced Plastics and Composites*, *35*(6), 447–470. https://doi.org/10.1177/0731684415618459

Safri, S. N. A., Sultan, M. T. H., Saba, N., & Jawaid, M. (2018). Effect of benzoyl treatment on flexural and compressive properties of sugar palm/glass fibres/epoxy hybrid composites. *Polymer Testing*, *71*, 362–369. https://doi.org/10.1016/j.polymertesting.2018.09.017

Sahari, J., Sapuan, S. M., Ismarrubie, Z. N., & Rahman, M. Z. (2012). Physical and chemical properties of different morphological parts of sugar palm fibres. *Fibres and Textiles in Eastern Europe*, *91*(2), 21–24.

Sapuan, S. M., Ilyas, R. A., Ishak, M. R., Leman, Z., Huzaifah, M. R. M., Ammar, I. M., & Atikah, M. S. N. (2018). Development of sugar palm–based products: A community project. In S. M. Sapuan, J. Sahari, M. R. & Ishak, M. L. Sanyang. *Sugar palm biofibers, biopolymers, and biocomposites* (pp. 245–266). CRC Press. https://doi.org/10.1201/9780429443923-12

Sherwani, S. F. K., Zainudin, E. S., Sapuan, S. M., Leman, Z., & Abdan, K. (2021). Mechanical properties of sugar palm (Arenga pinnata Wurmb. Merr)/glass fiber-reinforced poly(lactic acid) hybrid composites for potential use in motorcycle components. *Polymers*, *13*(18), 3061. https://doi.org/10.3390/polym13183061

Shukor, F., Hassan, A., Saiful Islam, M., Mokhtar, M., & Hasan, M. (2014). Effect of ammonium polyphosphate on flame retardancy, thermal stability and mechanical properties of alkali treated kenaf fiber filled PLA biocomposites. *Materials & Design (1980-2015)*, *54*, 425–429. https://doi.org/10.1016/j.matdes.2013.07.095

Siakeng, R., Jawaid, M., Ariffin, H., & Sapuan, S. M. (2019). Mechanical, dynamic, and thermomechanical properties of coir/pineapple leaf fiber reinforced polylactic acid hybrid biocomposites. *Polymer Composites*, *40*(5), 2000–2011. https://doi.org/10.1002/pc.24978

Suriani, M. J., Radzi, F. S. M., Ilyas, R. A., Petrů, M., Sapuan, S. M., & Ruzaidi, C. M. (2021). Flammability, tensile, and morphological properties of oil palm empty fruit bunches fiber/pet yarn-reinforced epoxy fire retardant hybrid polymer composites. *Polymers*, *13*(8), 1282. https://doi.org/10.3390/polym13081282

Swain, P. T. R., & Biswas, S. (2017). Influence of fiber surface treatments on physico-mechanical behaviour of jute/epoxy composites impregnated with aluminium oxide filler. *Journal of Composite Materials*, *51*(28), 3909–3922. https://doi.org/10.1177/0021998317695420

Syaqira S, S. N., Leman, Z., Sapuan, S. M., Dele-Afolabi, T. T., Azmah Hanim, M. A., & Budati, S. (2020). Tensile strength and moisture absorption of sugar palm-polyvinyl butyral laminated composites. *Polymers*, *12*(9). https://doi.org/10.3390/POLYM12091923

Tarique, J., Sapuan, S. M., Khalina, A., Sherwani, S. F. K., Yusuf, J., & Ilyas, R. A. (2021). Recent developments in sustainable arrowroot (Maranta arundinacea Linn) starch biopolymers, fibres, biopolymer composites and their potential industrial applications: A review. *Journal of Materials Research and Technology*, *13*, 1191–1219. https://doi.org/10.1016/j.jmrt.2021.05.047

Tarique, J., Zainudin, E. S., Sapuan, S. M., Ilyas, R. A., & Khalina, A. (2022). Physical, mechanical, and morphological performances of arrowroot (Maranta arundinacea) Fiber reinforced arrowroot starch biopolymer composites. *Polymers*, *14*(3), 388. https://doi.org/10.3390/polym14030388

Tsunoda, M., Kido, T., Mogi, S., Sugiura, Y., Miyajima, E., Kudo, Y., Kumazawa, T., & Aizawa, Y. (2014). Skin irritation to glass wool or continuous glass filaments as observed by a patch test among human Japanese volunteers. *Industrial Health*, *52*(5), 439–444. https://doi.org/10.2486/indhealth.2012-0222

Turk, M., Hamerton, I., & Ivanov, D. S. (2017). Ductility potential of brittle epoxies: Thermomechanical behaviour of plastically-deformed fully-cured composite resins. *Polymer*, *120*, 43–51. https://doi.org/10.1016/j.polymer.2017.05.052