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ORIGINAL ARTICLE

Characterization of Glass Fiber/Epoxy with Various Silicone Resin Addition Composite's Compressive and Flexural Strength

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ABSTRACT – Glass fiber/epoxy composite was developed and used widely in many applications. Development on fiber and matrix of composite material was done to improve its properties. Improvement of the composite's matrix can be done/by adding a modifier. Silicone resin is one kind of modifier that can be added to epoxy to improve its properties. Silicone resin will improve the thermal stability of epoxy, but the effect on mechanical properties, especially when combined with glass fiber, has not been done. In this study, a composite of glass fiber/epoxy with 0, 10, 20, and 30 weight-% silicone resin addition was tested by compressive and flexural loading methods. Compressive strength and maximum strain tend to decrease with the increase of silicone resin added. The highest compressive strength and strain were reached by a glass fiber and epoxy composite without any modification at the value 240.63 MPa and 0.5%. Flexural strength will decrease, but maximum strain will increase when more silicone resin is added to the matrix on the flexural test. The biggest flexural strength at 293.73 MPa was possessed by the composite without further modification, and a maximum strain of 5% was owned by the composite with 20% and 30% silicone resin addition.

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INTRODUCTION

Composite materials that use glass fiber as reinforcement are used widely in many applications. It is well known that composite materials have high strength and low density compared to metal [1]. To achieve specific properties, composite materials can be customized by choosing or modifying any elements used in the composites [2]. Synthetic fiber, natural fiber, and combination are used and developed widely worldwide for composite reinforcement, including fiberglass [3]. Various type of thermosetting polymers is used as composite material matrix, including epoxy resin [4].

Epoxy resin has some advantages to be applied as a composite matrix. It has relatively high strength compared to its density and good chemical resistance to be applied in many applications [5]. The curing reaction of the epoxy resin occurs between epoxide and reactive groups, such as the amine group [6]. Modification of epoxy resin can be done by adding substance that have reactive group. Silicone resin with reactive amine group can be added to epoxy resin as modifier [7], [8].

Silicone resin has Si-O-Si chain on its chemical structure that is connected to another functional group [9]. Amine group is one of functional groups that can be connected to Si-O-Si chain so that it can be reacted with epoxy group [10]. Silicone resin can increase the thermal stability of epoxy [10]–[12]. Its effect on the mechanical properties of epoxy also has been studied by Li et al. [13]. However, the mechanical properties of composite material that used epoxy with silicone resin addition as its matrix and glass fiber have not been done [14]–[18].

In this research, compressive and flexural tests were conducted on glass fiber/epoxy composite material with silicone resin addition in different amounts on its matrix. The effect of silicone resin added into the composite's matrix will be studied from compressive and flexural test results.

EXPERIMENTAL METHOD

Materials and Instruments

PRIME™ 27 epoxy resin (≥ 50% bisphenol-A-(epichlorohydrin)) with its slow hardener (25-50% 3-aminomethyl-3,5,5-trimethylcyclohexylamine and 25-50% 2-piperazin-1-ylethylamine) were purchased from Gurit. SILRES® HP 2020 silicone resin (≤ 100% Poly [(2-aminoethyl) aminopropyl] methoxy (diMe) siloxane, polymers with [(2-aminoethyl) aminopropyl]) phenylsilsesquioxane, OH-term) was purchased from Wacker. S-2 glass plain woven fiber was purchased from Pacific Coast Composites. All materials used in this experiment did not undergo additional processes before being mixed into composite. Fourier transform infrared (FTIR) analysis was done using Bruker Alpha II. Compressive and flexural tests were conducted using Tensilon 100kN Universal Testing Machine (UTM).

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Method and Procedure

The matrix of composite material used in this experiment was prepared in a two-step mixing procedure. The first step was mixing epoxy resin and silicone resin for two minutes with different amounts of silicone resin added. Silicone resin addition variations in this experiment were 10, 20, and 30 wt.-% of epoxy system total weight. Then, slow hardener was added to epoxy resin and silicone resin mixture with a ratio of 28 wt.-% of epoxy resin. The second step was done by three minutes mixing process. All matrix variations and raw materials were analyzed by FTIR. Table 1 shows sample codification in this experiment.

Table 1. Sample codification

Code	Information
GS00	Epoxy system without silicone resin addition
GS10	Epoxy system with 10 wt-% silicone resin addition
GS20	Epoxy system with 20 wt-% silicone resin addition
GS30	Epoxy system with 30 wt-% silicone resin addition

Composite material manufacturing was done by vacuum infusion process. The peel-ply cloth was used to help the manufacturing process. Plies of glass fiber as reinforcement material were stacked on a glass table with peel ply as the first and last layer. The cloth stack was surrounded by tacky tape to stick the vacuum bag. The spiral hose was used as matrix inlet and outlet where the outlet connected to the vacuum pump. After all the systems were ready and there was no leak, the matrix was infused into the system. If the matrix has wetted all the cloth, the matrix inlet could be stopped and waited until fully cured.

The compressive and flexural strength of composite laminate was determined according to ASTM D6641 and D790. The specimen dimension used in the compressive strength test was 25 mm × 2.5 mm × 150 mm with a 25 mm gauge length. On the other hand, the specimen dimension used in the three-point flexural strength test was 13 mm × 2 mm × 120 mm with an 80 mm support span. Compressive strength test was conducted with a strain rate of 1.3 mm/minute, and flexural strength test was conducted with a strain rate of 10 mm/minute.

RESULT AND DISCUSSION

Fourier Transform Infrared (FTIR) Analysis

FTIR testing was carried out to study the reaction between the epoxy system and silicone resin in several variations. Observations on changes in transmittance intensity for the epoxy wavenumber to be one focus as the main reaction that occurs. In addition, the effect of silicon resin addition amount will also be observed through the curve relationship between wave number and transmittance of FTIR test results. The chemical reaction that occurs can also affect the properties of the thermoset matrix when applied to a composite material.

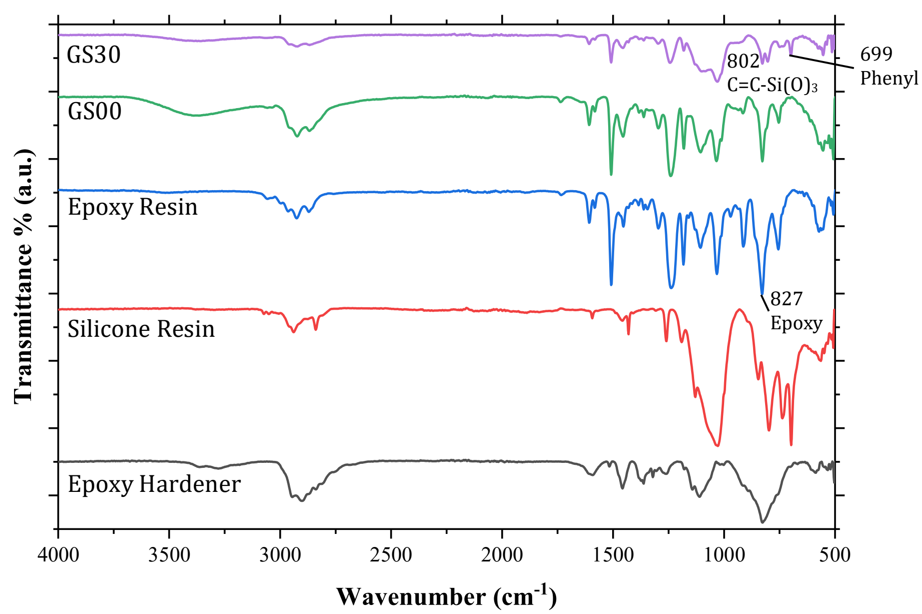

Figure 1. Transmittance curve of GS30, GS00, epoxy resin, silicone resin, and epoxy hardener

FTIR analysis results of raw materials, matrix with silicone resin addition, and matrix without silicone resin addition are shown in Figure 1. The curing reaction of epoxy resin is mainly shown by transmittance change at 827 cm^{-1}, which is the transmittance of the oxirane group. Furthermore, new transmittance can be observed at 802 cm^{-1} on the sample with silicon resin addition. That wavenumber showed the presence of C=C-Si(O)$_3$ bond from silicone resin [14]. Another transmittance that showed silicone resin existence in the matrix was at 699 cm$^{-1,}$ which indicates the phenyl bond of silicone resin used in this experiment [19].

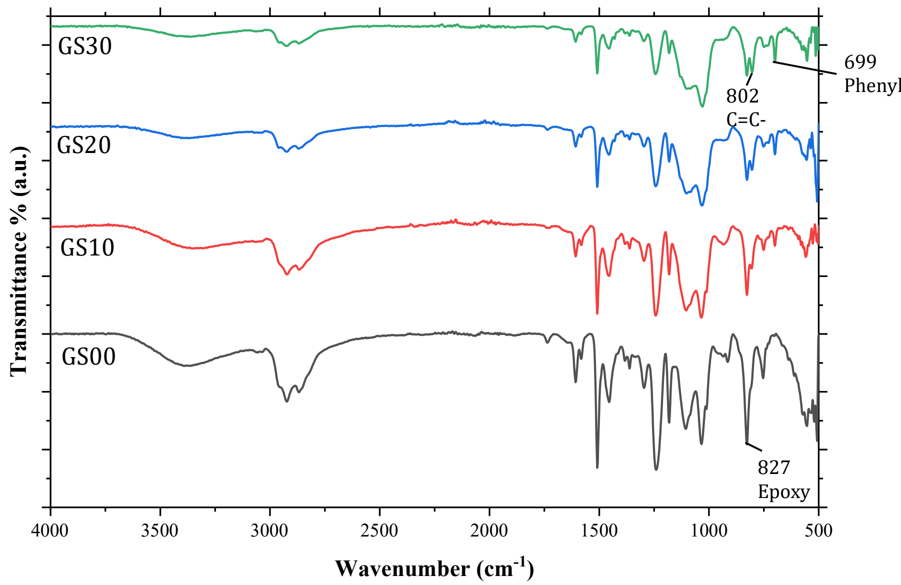

Figure 2. Transmittance curve of GS30, GS20, GS10, and GS00

Figure 2 shows the FTIR analysis results of the epoxy system with various silicone resin addition. Transmittance of phenyl and C=C-Si(O)$_3$ bonds tend to decrease with more silicone resin added into the epoxy system. The lower transmittance intensity indicates more chemical bonds of a functional group in the substance based on Beer's Law [20]. Increasing the epoxy bond's transmittance indicated less epoxy bond in the sample with more silicone resin added. The epoxy bond will be opened when reacting with the amine group owned by hardener and silicone resin [21].

Compressive Strength

Compressive test results of fiberglass composite materials with an epoxy matrix that has been treated with and without silicone resin are shown in Figure 3. Composite material with unmodified matrix has higher maximum stress with a value of 240.63 MPa compared to the GS 30 sample with a value of 140.52 MPa. The maximum strain of the GS00 sample is also higher than the GS30 sample. GS30 reached a value of 0.5%-gauge length, whereas the GS00 sample reached 0.4%-gauge length strain.

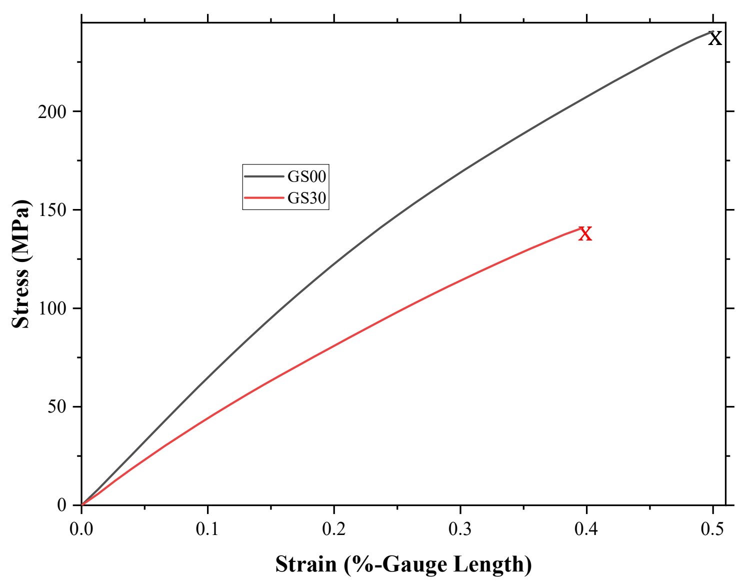

Figure 3. Stress-strain curve of GS00 and GS30 from compressive test

The composite of glass fiber/epoxy with various silicone resin addition's compressive strength is shown in Figure 4. The compressive strength of the material in this experiment decreased with the increasing silicone resin addition. 10 wt-% silicone addition dropped compressive strength for about 40 MPa compared to composite material without any modification on its matrix. Further silicone resin addition caused about 35 MPa compressive strength reduction. The sample with 30 wt-% silicone resin addition on its matrix has the lowest compressive strength, which is 140.52 MPa.

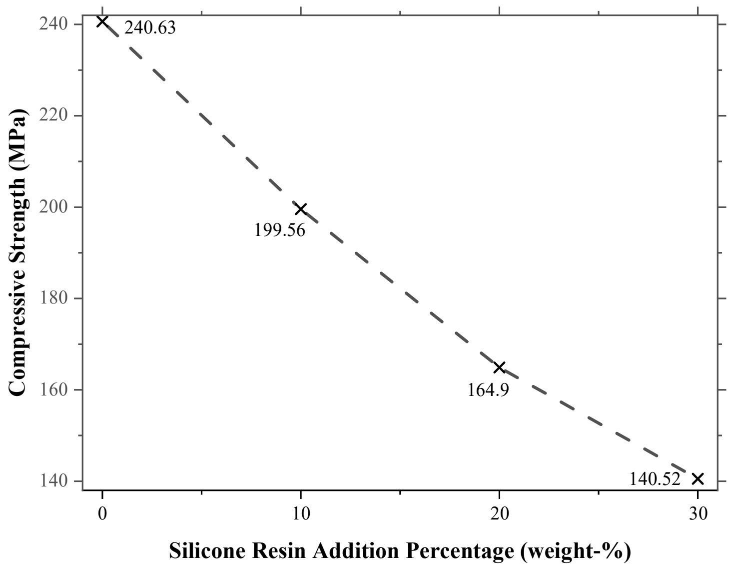

Figure 4. Relationship between compressive strength and silicone resin addition

Figure 5 shows the maximum strain of glass fiber/epoxy with various silicone resin addition composites from compressive test results. The biggest value of maximum strain was owned by the composite without any modification on its matrix, which is 0.5%. The maximum strain of glass fiber/epoxy with 30 weight-% silicone resin addition was the lowest maximum strain between all variations, which is 0.4%. The maximum strain of material will decrease with the increase of silicone resin added into the matrix.

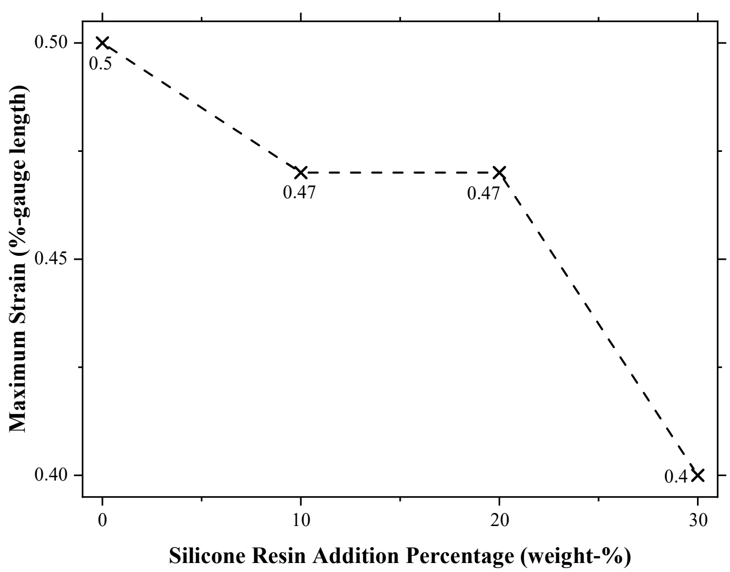

Figure 5. Relationship between maximum strain and silicone resin addition from compressive test

The addition of silicone resin to the epoxy matrix can affect the compressive strength of the composite material. Silicone chain in silicone resin has more flexibility than epoxy chain. This silicone chain weakens the stiffness of the epoxy chain and cross-linking network after curing [14]. This mechanism causes the decrease in compressive strength of composite material with the increase of silicone resin addition. Decreasing of compressive strength was caused by more $C=C-Si(O)_3$ bond with more silicone resin added. This phenomenon can be seen from the FTIR result in Figure 2.

Flexural Strength

Flexural test results of glass fiber/epoxy with and without silicone resin addition composite materials are shown in Figure 6. Composite material with unmodified epoxy reached higher maximum stress of 293.73 MPa compared to the GS 30 sample with a value of 212.9 MPa. However, the maximum strain of the GS00 sample was lower than GS30 sample. The GS30 sample has a value of 5% strain, and the GS00 sample has 3.91 % strain.

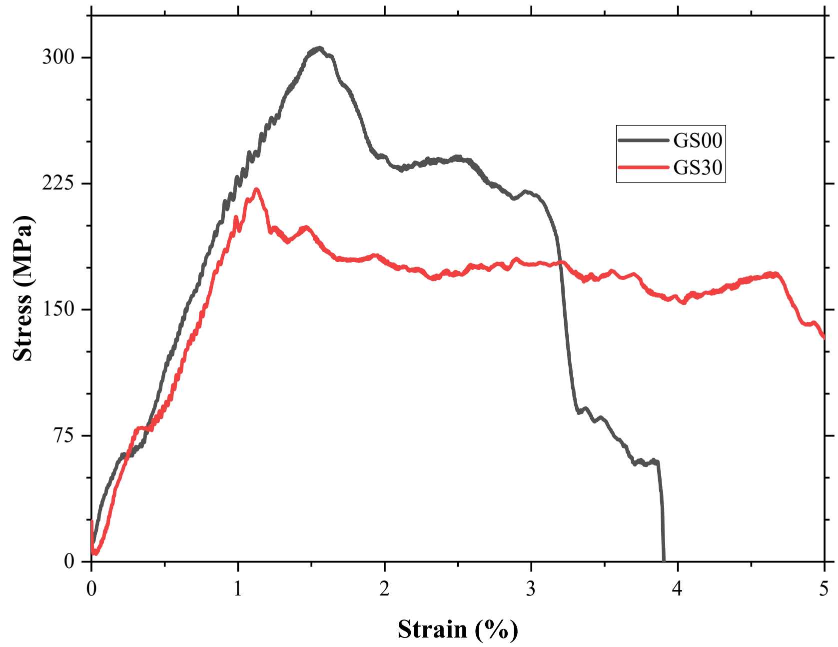

Figure 6. Stress-strain curve of GS00 and GS30 from flexural test

The flexural strength of glass fiber/epoxy with various silicone resin addition is shown in Figure 7. The flexural strength of the material in this experiment decreased with the increasing silicone resin addition. 10% and 20% addition of silicone resin lowered the flexural strength of the composite material for about 7 MPa and 4 MPa. Silicone resin addition at the value of 30% dropped the flexural strength quite significant for about 70 MPa.

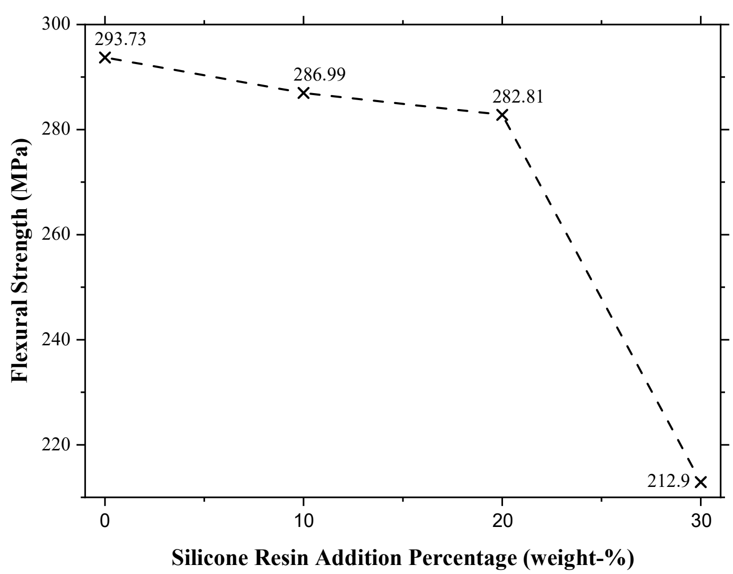

Figure 7. Relationship between flexural strength and silicone resin addition

Figure 8 shows the maximum strain of glass fiber/epoxy with various silicone resin addition from flexural test results. 5% maximum strain was the failure criteria from ASTM D790 for the flexural test's strain. The value was reached by composite material with 20% and 30% silicone resin addition. Maximum strain from flexural test tends to increase with the increase of silicone resin amount added into the composite matrix.

The changes in stress and strain concerning the amount of silicon resin added in the flexural test differed from the results of the composite material compression test. The maximum stress drop that the composite material can withstand can be caused by the presence of groups with straight chains owned by silicon resin. This phenomenon is also in line with other studies that have been conducted. In a study by Li et al., a significant decrease occurred in epoxy treated with silicone resin addition [14]. C=C-Si(O)$_3$ bond increased when more silicone resin was added to the epoxy system. It is proved by transmittance change at the wavelength 802 cm^{-1}, as seen in Figure 2. The increase in maximum strain can occur in composite materials because of an increase in the matrix and glass fiber interfacial strength [16].

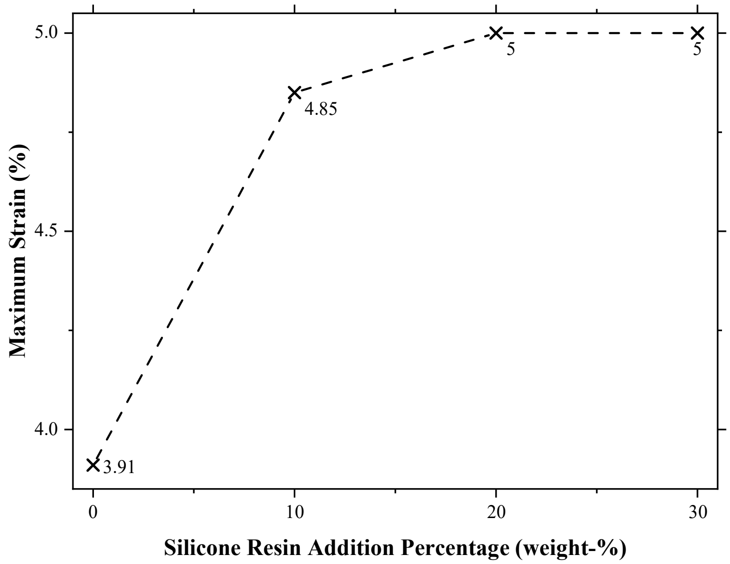

Figure 8. Relationship between maximum strain and silicone resin addition from the flexural test

CONCLUSION

The study on compressive and flexural strength of glass fiber/epoxy composite with silicone resin addition on its matrix at different amounts is described in this research. From the results, some phenomena can be concluded. Compressive test results revealed several phenomena of glass fiber/epoxy composite with modification on its matrix using silicone resin. The biggest compressive strength was reached by composite material without silicone resin addition into its matrix at the compressive strength of 240.63 MPa. The composite's compressive strength tends to decrease when more silicone resin is added to the matrix. A similar trend can be observed on maximum strain from compressive test results with maximum strain possessed by material without any modification at the value of 0.5%.

The flexural test result showed slightly different trend from the compressive test. The highest flexural strength was possessed by composite material without silicone resin addition into its matrix at the flexural strength 293.73 MPa. The flexural strength of the material in this experiment decreased with the increasing silicone resin addition. On the other hand, the maximum strain from the flexural test became greater with more silicone resin added to the matrix. The maximum strain of 5 % was reached by material with 20% and 30% silicone resin addition.

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REFERENCES

[1] K. Diharjo, K. Priyanto, A. Purwanto, N. S. Suharty, B. H. Jihad, S. J. A. Nasiri, D. Widianto, and Suyitno. "Study of flexural strength on hybrid composite of glass/carbon-bisphenol for developing car body of electrical vehicle," *in 2013 Joint International Conference on Rural Information & Communication Technology and Electric-Vehicle Technology (rICT & ICeV-T)*, IEEE, 2013, pp. 1–4

[2] M. Y. Mahmoud Zaghloul, M. M. Yousry Zaghloul, and M. M. Yousry Zaghloul, "Physical analysis and statistical investigation of tensile and fatigue behaviors of glass fiber-reinforced polyester via novel fibers arrangement." *Journal of Composite Materials*, vol. 57, no. 1, pp. 147–166, 2023.

[3] N. Sapiai, A. Jumahat, N. A. Shamshulizam, and M. Chalid. "Effect of angle orientation and fibre hybridization on impact behaviour of glass, basalt and arenga pinnata composites." *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, vol. 13, no. 13, pp. 1–13, 2022.

[4] B. N. V. S. Ganesh Gupta K, M. M. Hiremath, B. C. Ray, and R. K. Prusty. “Improved mechanical responses of GFRP composites with epoxy-vinyl ester interpenetrating polymer network.” *Polymer Testing*, vol. 93, p. 107008, 2021.

[5] L. Joseph, P. S. Kumar, B. D. S. Deeraj, K. Joseph, K. Jayanarayanan, and K. M. Mini. “Modification of epoxy binder with multi walled carbon nanotubes in hybrid fiber systems used for retrofitting of concrete structures: evaluation of strength characteristics.” *Heliyon*, vol. 8, no. 6, p. e09609, 2022.

[6] Y. Yang, D. -Y. Wang, R. -K. Jian, Z. Liu, and G. Huang. “Chemical structure construction of DOPO-containing compounds for flame retardancy of epoxy resin: A review.” *Progress in Organic Coatings*, vol. 175, p. 107316, 2023.

[7] M. Yu, T. Zhang, J. Li, J. Tan, and X. Zhu. “Enhancing toughness, flame retardant, hydrophobic and dielectric properties of epoxy resin by incorporating multifunctional additive containing phosphorus/silicon.” *Materials & Design*, vol. 225, p. 111529, 2023.

[8] C. Robeyns, L. Picard, and F. Ganachaud. “Synthesis, characterization and modification of silicone resins: An ‘Augmented Review.’” *Progress in Organic Coatings*, vol. 125, pp. 287–315, 2018.

[9] R. G. Jones, W. Ando, and J. Chojnowski, Eds., *Silicon-Containing Polymers: the Science and Technology of Their Synthesis and Applications*. Dordrecht: Springer Netherlands, 2013.

[10] Wacker, (2020, Jul. 01). *SILRES® HP 2020 Technical Data Shee*t [Online]. Available: https://www.wacker.com/h/en-us/medias/SILRES-HP-2020-en-2020.07.01.pdf

[11] C. -Y. Hsu, W. -G. Han, S. -J. Chiang, W. -C. Su, and Y. -L. Liu. “Multi-functional branched polysiloxanes polymers for high refractive index and flame retardant LED encapsulants.” *RSC Adv.*, vol. 6, pp. 4377–4381, 2016

[12] R. Wen, J. Huo, J. Lv, Z. Liu, and Y. Yu. “Effect of silicone resin modification on the performance of epoxy materials for LED encapsulation.” J. Mater. Sci.: Mater. Electron, vol. 28, pp. 14522–14535, 2017.

[13] Y. Liu, X. Luan, Y. Feng, X. Tan, Y. Han, and X. Sun. “Self-adhesive epoxy modified silicone materials for light emitting diode encapsulation.” *Polym. Adv. Technol.*, vol. 28, no. 11, pp. 1473–1479, 2017.

[14] R. Li, C. Zhou, Y. Chen, H. Zou, M. Liang, and Y. Li. “Preparation, characterization, and properties of organic silicone intermediate-modified epoxy resin copolymers.” *High Performance Polymers*, vol. 29, no. 1, pp. 36–45, 2017.

[15] Q. Wu, J. Jiang, F. Xie, C. Cui, Z. Hua, L. Liu, and Y. Huang. “Novel hybrid silicone resin composites with excellent low dielectric and high temperature mechanical properties.” *Composites Communications*, vol. 35, p. 101288, 2022.

[16] W. Shen, R. Ma, A. Du, X. Cao, H. Hu, Z, Wu, X. Zhao, Y. Fan, and X. Cao. “Effect of carbon nanotubes and octa-aminopropyl polyhedral oligomeric silsesquioxane on the surface behaviors of carbon fibers and mechanical performance of composites.” *Applied Surface Science*, vol. 447, pp. 894–901, 2018.

[17] T. Zhang, J. Yang, B. Jiang, and Y. Huang. “Study on the interfacial properties of the dual-activity silicone resin/carbon fibers composites.” *Composites Science and Technology*, vol. 165, pp. 347–354, 2018.

[18] Y. Li, T. Zhang, B. Jiang, L. Zhao, H. Liu, J. Zhang, J. Fan, Z. Guo, and Y. Huang. “Interfacially reinforced carbon fiber silicone resin via constructing functional nano-structural silver.” *Composites Science and Technology*, vol. 181, p. 107689, 2019.

[19] Wacker, “SILRES® HP 2020 Safety Data Sheet,” Nov. 04, 2021.

[20] P. R. Griffiths and J. A. de Haseth, Eds., *Fourier transform infrared spectrometry, 2nd ed*. Hoboken, N.J: Wiley-Interscience, 2007.

[21] X. Chen, J. Bao, C. Shen, B. Zhang, Y. Xu, and Z. Shen. “Polymer Matrix Materials,” in *Composite Materials Engineering, Volume 1*, X. -S. Yi, S. Du, and L. Zhang, Eds., Singapore: Springer Singapore, 2018, pp. 151–352.