The Effect of Adding Silica Elements from Rice Husk Ash on the Mechanical Characteristics of CFRP for Fairing Automotive Vehicle

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Abstract: CFRP (Carbon Fiber Reinforce Polymers) is an alternative automotive component material that has the advantage of being lighter than other materials, making it an option as a substitute for metal. Apart from mechanical strength, lightness, and ease of form, CFRP is also expected to have a high safety value. Research on the mechanical characteristics resulting from efforts to increase the thermal resistance of CFRP will be discussed in this article. Using the experiments method was made CFRP using the hand lay-up (CFRP-HLU) method. By paying attention to the phenomenon caused by the addition of silica gel from rice husk ash, the workpiece is made with 4 variations of silica composition. From this research, the tensile strength and hardness of the material tend to decrease significantly with increasing silica on the matrix composition in CFRP.

Keywords: CFRP; Silika; Hand Lay Up; Fairing Automotive; Rice Hush Ash

1. Introduction

Polymer is a material that is widely used in the manufacturing industry because it is convenience for in the manufacturing process. This trend is predicted to continue to grow along with the development of industrial technology 4.0 in recent years[1,2)]. Apart from having several advantages of being lighter, and easier to manufacture, composites are cheaper compared to using metal in several segments. The ease of the automotive spare parts production process from composites includes the fact that it does not require high temperatures, so manual processes such as using the hand lay-up method, vacuum method, spray lay-up, and technology-based manufacturing such as using molding can be done easily[3-7)]. These conveniences, not only automotive components, use carbon fiber, the frame structure also uses this material. When the use of composite materials becomes more massive, starting from frames, automotive vehicle bodies, and interiors, the effectiveness of fuel use also has an influence[8)]. This was expressed by Sarfras et. al[9)] and Hong et. al[10)], when the percentage of composite material is high, fuel effectiveness also increases, and prices become more competitive because the total costs used can be made more effective. Apart from that, the flexibility of the component production process using composites can reduce the complexity of design concepts when carrying out innovations, especially those related to mold production and mold for spare parts, indirectly also having a positive effect on the industry[11-13)].

CFRP composites are generally used as spare parts for aircraft components and automotive components, however, composites are also widely used as additives or forming hybrid materials. This composition provides the advantage of a material that is lighter than previously obtained[14-16)]. However, the use of molding and the life cycle of materials must still be taken into consideration by designers[17)].

Comprehensively, the mechanical properties of composites are the main factor for automotive components and aeromodelling components, so increasing mechanical properties is carried out by many researchers[18-20)]. According to Nguyen et.al[21,22)], CFRP with a composition of 3% silica gel added has positive performance on Tensile Strength, modulus of elasticity, elongation, and impact strength. In line with efforts to improve composite performance in mechanical properties, research to improve mechanical properties can be carried out using the lamination method. According to Aspinal et.al[23,24)], the thicker the laminate with elements of resistance to heat exposure, the better its thermal resistance properties, as well as an increase in its mechanical properties. However, the impact of adding other elements in composite materials should concern to the effects on the tools used in advanced work such as cutting processes, fastening processes, and assembling. This has also been a topic of research studies where the better the mechanical properties, the more difficult the machine's ability to control. In an effort to improve the mechanical properties of CFRP, it has been researched by Jelinek, Schilp, And Reinhart[25); in] his research, it was stated that the type of carbon fiber used greatly influences the mechanical properties of the material, the higher the fiber used as CFRP reinforcement, the higher the mechanical properties produced. In Liyanage et al. 's (19) research, the electrospinning modification of carbon fiber in the CFRP production process also had an effect on the mechanical properties. The richer the carbon fiber distribution, the more the mechanical properties will increase. In line with Naznin et. al[26)], by using unidirectional type carbon fiber with a microvoids system, the mechanical properties of CFRP can also be improved. This model allows the number of carbon fibers to be compacted so that it becomes more compact. Jadooe et.al[27)], in his research stated that increasing mechanical properties and strengthening heat-damaged RC beams can also be done by diffusion and surface adhesion. This method allows for improving the performance of chemical incompatibility resulting in beam by CFRP.

Mechanical properties are the main factor in selecting automotive materials and aircraft components. However, the use of components made from CFRP is often associated with heat. For example, spare parts are used to cover machine parts or other electronic components. When a composite is applied to a part that has the potential for high-temperature changes, the component has the potential to change and decrease its mechanical properties so that one day it will change shape, and the mechanical strength of this component will be lost[28-30)]. According to Nguyen et al. research[21)], in his research, when composite materials are heated from 20 to 600 C, the mechanical properties ranging from Failure force decrease by up to 80%, ultimate strength decreases by up to 70%, Young's modulus decreases by 20%, and retained stress ratio decreases by up to 90% so that no again makes good material. To improve the thermal and mechanical properties of composites, many researchers have tried adding other elements to CFRP composites. One element to increase thermal conductivity is adding a ceramic coating to the CFRP composite[31-33)]. Apart from that, there are also other elements in the form of nano silica RHA and bentonite, which provide a positive effect on CFRP. Based on research, if the addition of RHA nano-silica elements is increased, then the thermal properties by thermogravimetric analysis and the material's modulus of rupture also increase[34)].

Silica is known as an element that has a high fire point, so it is known as a fire retardant which is used to slow down the rate of combustion. Pure silica, also known as polysilicon, has been widely used as the main material in semiconductor manufacturing, especially in the MEMS industry. Polysilicon in crystal form has a high melting point. However, the failure of this material construction is still highly dependent on the dimensions of the parts or components. This is due to the yield strength and brittle properties of polysilicon crystals which are optimal when the volume and surface area are small[35,36)].

Silica also has the property of being easy to mix with other elements, making it possible to use it as a material additive to modify the desired material properties[36)]. Silica available on the market has various forms, ranging from crystals, powders, to gels. Each form has a different interfacial bonding value, which ultimately affects the mechanical properties of the material. In addition, the aspect ratio also plays an important role; the larger the aspect ratio or form of the material with large particles, the less suitable it is for use as a reinforcement, but more suitable as a filler material. However, according to Zhang et.al[37)], the composition of the filler and base material must have uniform chemical properties, because it will form a non-Gaussian effect between materials that impact the properties of the material. In his research, the reinforcement effect is directly related to the effective volume effect of the material being formed[35,37)].

Starting with the ease of obtaining silica from nature, rice husk ash also provides the opportunity to be used as a raw material for making silica. Rice husk ash silica (RHA Silica) has been proven to increase the fire resistance of certain materials, be it fabric or carbon fiber such as CFRP. Indirectly, increasing thermal resistance means reducing the danger of fire. such as when CFRP is used for heat protection on firefighter motorcycles[38-42)]. However, until now, there is no data showing the effect on the mechanical properties of using silica from rice husk ash, which is generally silica from rice husk ash used as a material to increase the thermal resistance of CFRP. From the description above, research on the impact of the mechanical properties of CFRP on the use of silica from rice husk ash needs to be conducted.

2. Material and method

This research uses experimental methods. The base material used as a specimen is CFRP, which is modified by adding silica elements up to a certain percentage. To obtain data about the properties of silica coating on CFRP, the research steps are conducted using material preparation and mechanical testing methods.

2.1 Material preparation

The silica used is silica obtained from rice husk ash which is processed by heating and adding a liquid solvent that is conditioned to have a normal acid-base level. This aims to reduce other effects when the acid-base balance of silica affects the CFRP matrix. In this phase, the silica produced from the extraction of rice husk ash is in gel form, so that it has a viscosity similar to resin as a matrix for making CFRP. The composition and material of CFRP as shown in Table 1 below

Table 1. CFRP Specifications.

CFRP Specifications	
Silica type	RHA silica
Matrix type	Epoxy Resin Isophthalic
Amplifier Type	Woven type Carbon Fiber
Drying method	Normal Temperature, 4 x 24 hours
Number of reinforcing layers	5 layers
Epoxy Resin Hardness Number	31 BHN
Tensile-strength epoxy resin	75,9 (MPa)

From the table above, each specimen was produced using the hand lay-up (HLU) method with a total of 3 samples. The silica element composition was compared between CFRP without silica elements and CFRP which had 5%, 10%, 20%, and 30% silica elements from rice husk ash. The composition between matrix and reinforcement is 75%:25% which is measured by the mass of each composition.

To ensure that the manufacture of CFRP using hand lay-up is in accordance with the CFRP generally on the market, the author first made CFRP without RHA silica concentration which was then compared with CFRP on the market for its mechanical properties. From the results of the comparison between the CFRP made and the CFRP on the market, as shown in Table 2 below.

Table 2. comparison of CFRP HLU to general CFRP on the market.

Component	CFRP HLU	CFRP
Max force parameter (N)	5896,88	5921,11
Tensile strength (N/mm^2)	270,45	272,86
Elastics 10-100 N (N/mm^2)	4414,90	4502,01
Break Strain	6,23	4,10

2.2 Mechanical properties testing

Mechanical properties testing using a 10 kN universal tensile testing machine and using a Vickers hardness testing machine. This method uses a diamond pyramid indenter with a square base. Where hardness is determined by the average diagonal of the indenter to the workpiece by this formula:

$$HV = 0{,}1891\, x\, (\frac{F}{d^2}) \qquad (1)$$

$$\boldsymbol{d} = \frac{d1+d2}{2} \qquad (2)$$

while HV = Vickers Hardness

F = force (N)

d = average diagonal length

$d1$ = 1st diagonal length

$d2$ = 2nd diagonal length

whereas for tensile test specimens are prepared as follows (Fig. 1).

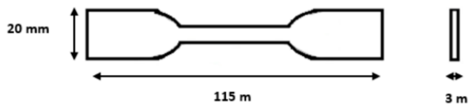


Fig. 1: Tensile test specimens.

From Fig. 1. The thickness of the specimen made is 3mm, following the matrix and reinforcement composition of 75%: 25%. Meanwhile, the model is adjusted to Tensile testing standards. Each of the specimens, from 75% of the matrix composition, will be inserted with a percentage of RHA silica to meet the specified specimen variations. For each hardness test and tensile test were done 3 specimens. Then, we will look at the trend and average value of each specimen. Meanwhile, to ensure that the production results using the hand lay-up method have material cohesiveness, each material is photographed using a microscope with 100X magnification; the U-view and V-view photo models are shown in Fig. 2.

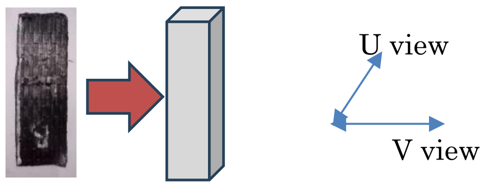


Fig. 2: Microscope view of specimen.

After the material is prepared according to mechanical testing requirements, 3 specimens are provided for each sample. Then the Vickers hardness test results, using the test equipment as in Fig. 3, were analyzed on each of the 3 specimens to obtain the average hardness of the samples provided. Meanwhile, to get Ultimate Tensile Strength, use the tool as shown in Fig. 4. This method takes a static load that is applied slowly or quickly to produce a reaction of stress and strain. The tensile stress can be calculated from the force applied to the unit cross-sectional area of the workpiece. As in the following formula:

$$\sigma_y = P_y / A_0 \qquad (3)$$

while σ_y = tensile stress (kN/ mm^2)

P_y = force (kN)

A_0 = cross-sectional area (mm^2)

Fig. 3: Vickers Hardness Tester.

Fig. 4: Universal Testing Machine.

3. Result and discussion

3.1 Experimental data result

Based on experimental data, microscope view, and hardness value advance based on the average Vickers number for 3 tests, CFRP, which contains silica elements, has a trend of increasing hardness value (see Table 3.). CFRP without silica has the lowest hardness value with a value of 9,8 on the Vickers scale, while the addition of 10% RHA silica has the effect of increasing the Vickers hardness value up to 5 on the Vickers scale. Meanwhile, with the addition of 20% silica, there was a significant increase to 10,2 Vickers' number. while for 30% silica, the hardness value was found to be 26,1 Vickers number. This data as shown in Fig. 5.

while related to the CFRP microstructure due to the addition of silica, microstructural observations from side to side have significant differences. As shown in Table 3, column 3 (V view) shows the CFRP surface morphology. while column 4 (U view) is the microstructure of the cut results which are the thickness of the workpiece. from this table it can be seen that on the surface of CFRP (v view), the addition of silica results in more crystals covering the carbon fiber as a reinforcement. where the higher the percentage of silica, the surface of the photo results are shinier and brighter. this significant difference is seen when CFRP without silica is compared to CFRP 30% silica.

while the observation of the microstructure from the thickness of the workpiece (U view), the addition of silica has an impact on the density and air cavities produced in CFRP. from this table it can be seen that the greater the percentage of silica, the air cavities and density between carbon fibers are reduced. Significant differences are seen between CFRP without silica and CFRP with a percentage of 30% silica. where, the surface looks uniform matrix on each layer of carbon fiber. while for the percentage of 30% silica as seen in column 4 of Table 3, between carbon fiber layers looks hollow which indicates that between fibers do not have a uniform matrix volume.

From the picture above, the hardness value of CFRP has the highest percentage when adding the RHA silica element at 10% to 20%. Specimens with 20% silica elements, the hardness value increased by up to 80% compared to the previous specimen. Meanwhile, adding up to 30% of the RHA silica element experienced an increase of 10%.

Meanwhile, research data regarding Tensile tests using a 10 kN universal machine as shown in Table 4 below.

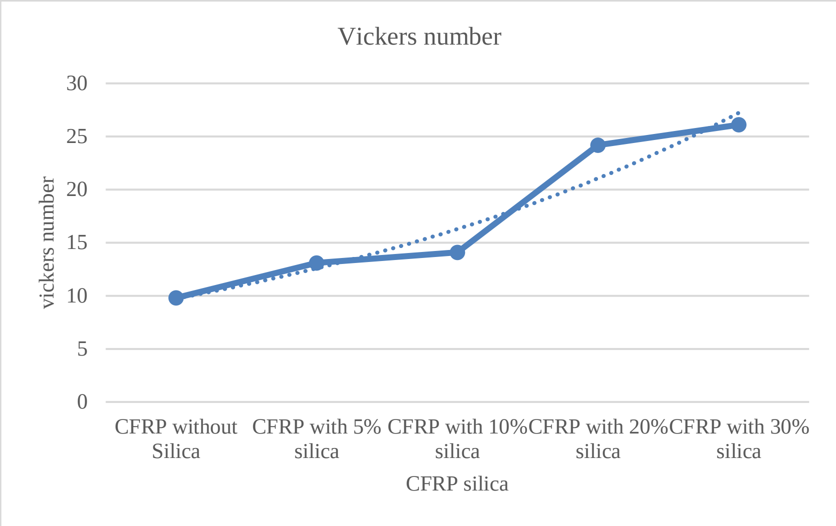
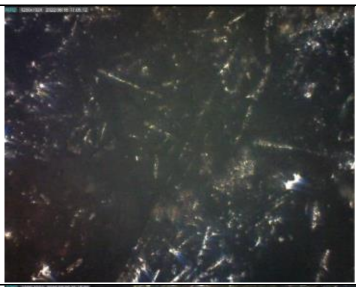
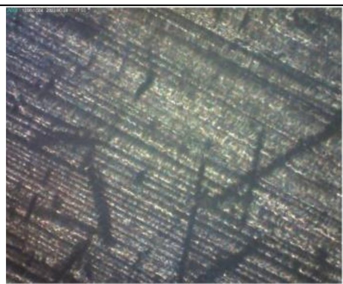
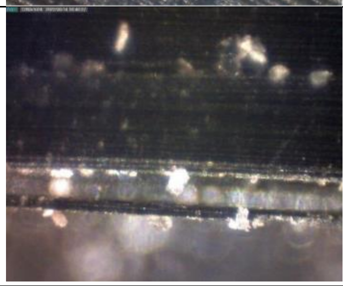
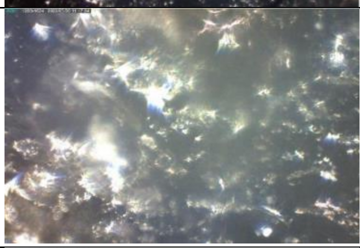
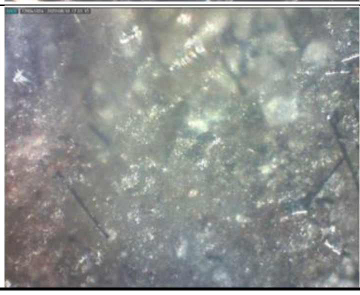


Fig. 5: Hardness value of CFRP with RHA silica.

Table 3. U, V view Of CFRP And Vickers Number Result test.

No	Specimen	V-views	U-Views	Hardness (VN)
1	CFRP Without silica			9,8
2	CRFP with 5% Silica			13,1
2	CFRP with 10% silica			14,1
3	CFRP with 20% silica			24,2

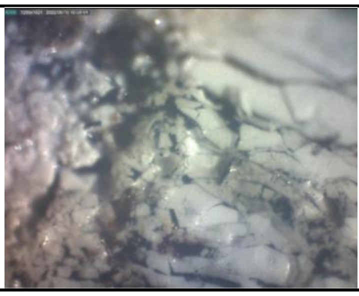
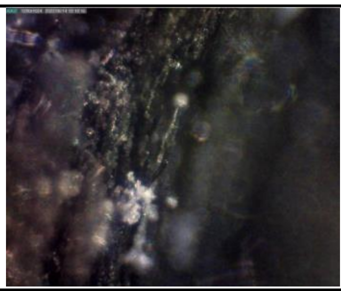
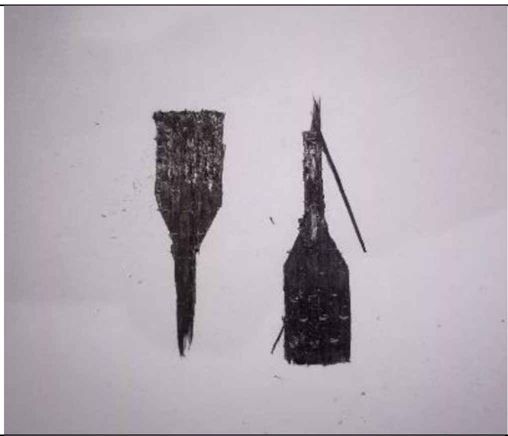
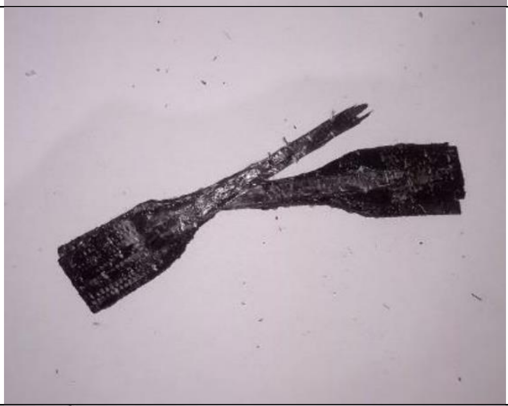
4	CFRP with 30% silica			26,1

Table 4. Universal Testing Result.

No	Specimen	Universal testing result	Max_Force Parameter (N)	Tensile Strength (N/mm^2)	Break Strain
1	CFRP without Silica		5896,88	270,45	4414,9
2	CFRP with 5% Silica		6529,69	291,3	4566,4

3	CFRP with 10% silica		5837,5	322,22	4617,08
4	CFRP with 20% silica		5614,06	177,9	2688,56
5	CFRP with 30% silica		6067,19	129,08	2239,08

From the table above, the addition of silica from 10% to 30% gives a negative trend in tensile strength; in CFRP without silica, the tensile strength reaches 270,45 N/mm^2, whereas when the silica percentage is added to the matrix by 5%, the tensile strength decreases, but returns. increases when 10% silica in the CFRP matrix tensile strength increases to 322,22 N/mm^2. When the percentage was added to 20% RHA silica and 30% RHA silica, tensile strength actually decreased to 129,08 N/mm^2.

For the maximum force data on universal machines (see Fig. 6), CFRP without RHA silica has a maximum force of 5614 N; the force used increases when CFRP adds silica elements to the matrix. At 5% RHA silica element, the maximum force required for this material is 5021,18 N. This condition increases from an additional 5% silica element to 30% silica element in the matrix. This as shown in Fig. 7. Tensile strength of CFRP.

In this condition, increasing the silica element does not completely increase the force required for CFRP tension. For the tensile strength trend, an increase occurs with the addition of RHA silica at 5% to 10%, while the subsequent addition of silica elements starts from 20% to 30%; the tensile strength actually decreases significantly. At a concentration of 20% silica, the tensile strength is ar below that of CFRP without RHA silica. An image of the trend of decreasing tensile strength mechanical properties as shown in Fig. 8 below.

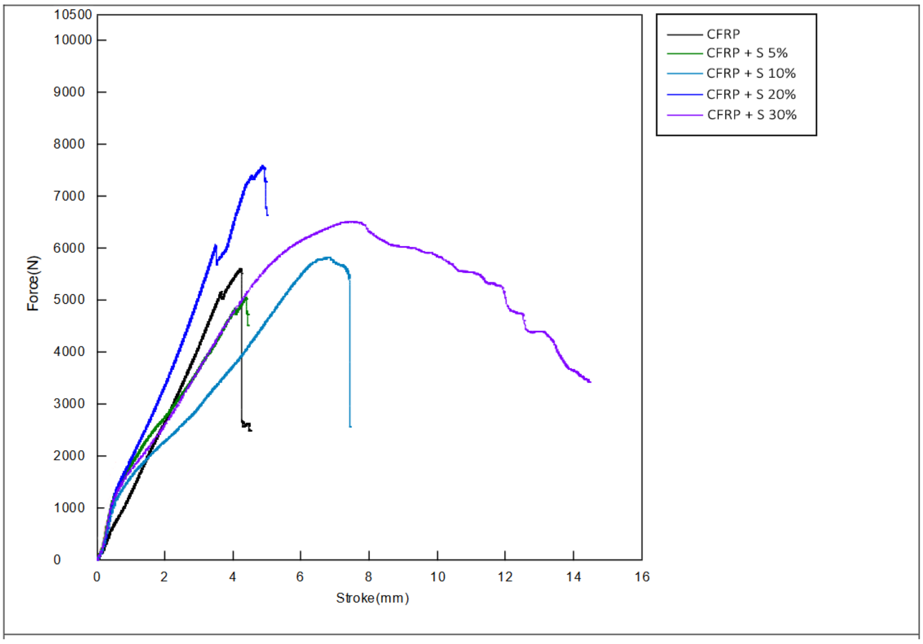


Fig. 6: Max Force (N) of CFRP with silica.

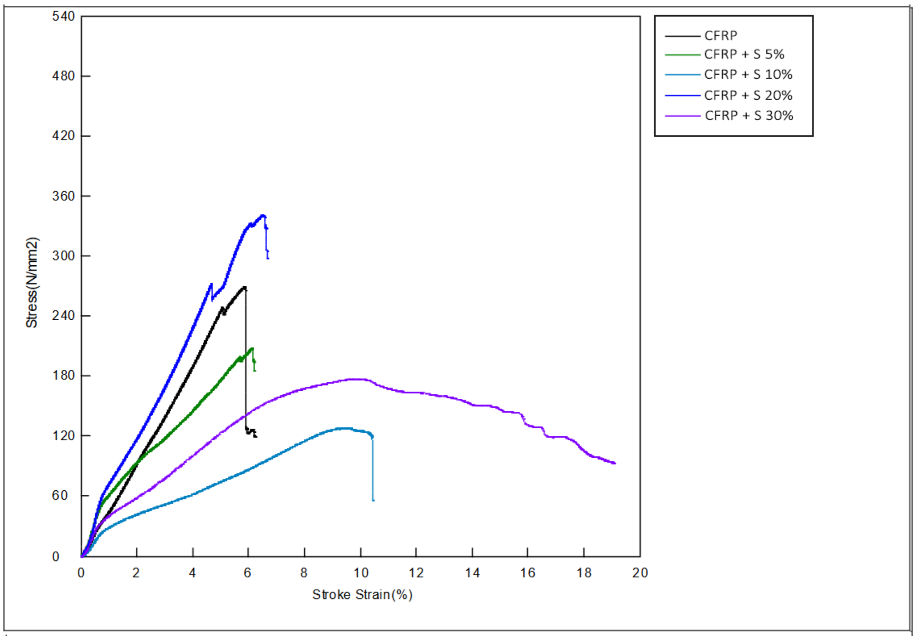


Fig. 7: Tensile strength (N/mm^2) of CFRP with RHA silica.

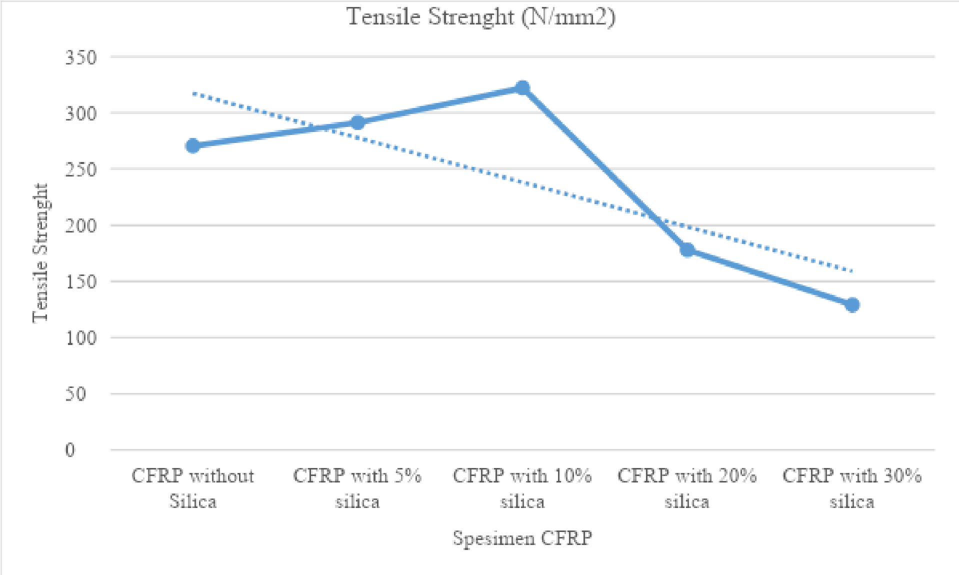


Fig. 8: Tensile Strength Trend Result.

From the data that has been collected, increasing silica concentration in CFRP is not always accompanied by increasing mechanical properties of the material. This is caused by the decreasing resin composition in CFRP. This can be proven from Table 1, where in the images of 20% and 30% CFRP, it can be seen that the homogeneity of the resin is decreasing. In this condition, it is possible for Carbon's attachment to the matrix to weaken and the compactness of this material to decrease.

3.2 Discussion

Starting from the limited information on the effectiveness of adding silica to the mechanical properties of CFRP, the volume of silica to the resin turned out to have a significant impact. However, this did not occur in all sample variations. Optimal mechanical properties when the addition of 10% silica elements was applied to the manufacture of CFRP. When the percentage was increased, the data found a decrease in tensile strength even though the hardness experienced a positive trend.

This is in accordance with the findings of several previous studies but does not correspond to the author's hypothesis that every increase in the percentage of silica will always increase the mechanical properties of CFRP.

To help find a decrease in mechanical properties, especially in the tensile strength of CFRP material, microscopic visual observation found that increasing the percentage of silica in the matrix mixture increased the crystallization of the CFRP surface but increased the cavities between layers in the carbon fibers in CFRP. The condition of increasing surface crystallization will be related to an increase in surface hardness, while the increase in cavities which can be interpreted as reducing the adhesive strength between layers reduces the tensile strength of CFRP. Where the physical conditions of the results of microscopic observations have been discussed in the previous sub-chapter.

The increase in cavities can come from changes in the silica phase from the gel form that dries to form crystals along with the hardening of the resin. The greater the percentage of silica, the greater the percentage of gel that dries, so this influences the bond between the carbon fibers used in making CFRP from the resin matrix and RHA silica.

Based on the experimental data, the hardness and tensile strength of CFRP specimens with varying silica content were evaluated. The addition of silica from rice husk ash showed a trend of increasing hardness but decreasing tensile strength.

For the Vickers hardness test results indicated that adding silica increased the hardness value of CFRP. The hardness value increased significantly with 10% to 20% silica addition but showed a marginal increase at 30% silica. The highest hardness value was observed at 20% silica. And also, for tensile test results showed that adding silica initially increased the tensile strength at 5% and 10% concentrations. However, further increasing the silica content to 20% and 30% resulted in a significant decrease in tensile strength. This trend suggests that while silica improves hardness, it may weaken the composite's tensile properties due to reduced resin homogeneity.

The addition of silica particles can lead to inhomogeneous dispersion within the CFRP matrix. At higher concentrations (20% and 30%), the silica particles may not be uniformly distributed, creating stress concentration zones. These zones can act as weak points where the material is more prone to failure under tensile stress, thereby reducing the overall tensile strength of the composite. Then, The interaction between the silica particles and the resin matrix is crucial for the mechanical properties of the composite. At higher silica concentrations, the interfacial bonding between the silica particles and the resin matrix may weaken. This poor interfacial bonding can result in a higher likelihood of particle debonding under stress, which further reduces the tensile strength of the composite.

Silica has different properties than the resin matrix, such as a higher modulus of elasticity. When silica is added at high concentrations, the bond between the silica and the resin matrix can become weaker. This is due to the difference in modulus of elasticity between silica and resin, which can cause cracks or weaknesses in the carbon bonds.

4. Conclusion

From the findings in this study, the increase in the mechanical properties of silica derived from rice husk ash is worthy of being used as an alternative advanced material based on waste materials. This will also help to increase the economic value of rice husks which were originally considered as waste. However, the increase in the percentage of silica must be further investigated against the quantitative value of the effective percentage of silica. Because a large percentage of silica will reduce the bond between carbon fibers which can have an impact on reducing mechanical properties, especially tensile strength. The addition of RHA silica up to 10% in the CFRP matrix can significantly increase the tensile strength. However, the addition of silica more than 10% to 30% actually causes a sharp decrease in tensile strength, reaching a decrease of about 52% compared to CFRP without silica. Although the addition of RHA silica increases the maximum force required, especially at levels of 10% to 30%, excessive increase in silica content has a negative impact on the mechanical properties of CFRP, especially in terms of tensile strength.

From the data above, the mechanical properties of CFRP with the addition of silica elements from rice husk ash from 5% to 30%, increase the hardness value. The percentage increase in hardness value is at a rate of 10% to 20% silica. Meanwhile, increasing the silica element to 30% of the matrix does not have a significant impact. Meanwhile, for the mechanical properties of tensile strength, the addition of RHA silica elements ranging from 5% to 30% does not have a positive impact; increasing the silica element up to 30% actually reduces the tensile strength of this material. This study highlights that silica derived from rice husk ash (RHA) can effectively enhance the mechanical properties of CFRP when used in moderate amounts, specifically up to 10% by weight in the matrix. This level of RHA silica addition significantly improves tensile strength and hardness, making it a viable alternative material that adds economic value to what is otherwise considered agricultural waste. However, increasing the silica content beyond 10% results in a substantial decrease in tensile strength, indicating that excessive silica can weaken the bond between carbon fibers and reduce overall mechanical performance.

For applications such as automotive and aerospace components, the modified CFRP with RHA silica is best suited for applications in high-temperature environments, where improved hardness is beneficial. However, due to the reduction in tensile strength at higher silica levels, its use may be limited in applications where mechanical strength is critical. For comprehensive results, future research should focus on identifying the optimal balance between resin and silica content to maximize both hardness and tensile strength. Additionally, exploring alternative materials or modifying the silica particles to enhance compatibility with the CFRP matrix could lead to better overall performance. Investigations into the effects of increased silica content on heat resistance and manufacturability are also recommended to broaden the practical applications of this material.

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