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An Investigation on Composites Reinforced with Multi-Layer Carbon Fiber and Silicone Rubber Against Impact test and Shoot Strength

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Abstract. The aim of this study is to examine the durability of composite materials reinforced with carbon fiber and the effects of silicone rubber on the composites' tensile strength, bending, firing, impact, and density. The silicon fiber was mixed with resin using a magnetic stirrer at 250 rpm, with a temperature of 40o C for 30 minutes. Furthermore, the composite production process was carried out using a vacuum infusion method with carbon fiber sheet variations of 6, 8, and 10. Tensile strength shows a proportional increase with the number of carbon fiber layers. Flexural strength indicates the opposite. The impact test was conducted in accordance with the ASTM E 23 standard, the firing test was performed using a 9x19 mm caliber bullet with a distance of 10 m, and the density was found by employing ASTM 792-13. The greatest density was 1,274 grams/cm3, and it was gotten from the sample with 10 fiber layers. Following this, the results of the impact test (Izod) showed that the specimen with 6 layers of carbon fiber had the highest impact strength of 0.040 Joule/mm. While the shoot test results indicated that the composite with 6 layers of carbon had smaller shot holes. There was no significant absorption in the water absorption test.

Keywords. Carbon Fiber, Silicon Rubber, Composite, Impact, Shoote Strength.

1. Introduction

Body armor was known to protect limbs from ballistic penetration and this armor coating can be made of ceramic and composite composition materials [1]. Ceramic body armor has a hard surface but can be brittle and heavy [2]. Composites, which are lightweight, can serve as an alternative to body armor but these materials still have poor ballistic qualities. In this regard, a multi-layer Kevlar fiber-reinforced composite and fique fabric were used for high-speed ballistic testing of 7.62 calibers [3].

The shield was made of a multi-layer fabric and high-strength fiber Kevlar, twaron, and metallic or ceramic plates inserted between the layers, which are used as part of the body armor materials. Furthermore, the Multi-layer Armor System (MAS) was developed for front-coated vests using hard and brittle ceramic as the reflected compressive shock wave and is expected to absorb 50% of thrust. The second layer was made of lightweight synthetic laminate panels while the third comprises ductile metal sheets evaluated with NIJ standards [4]. In the last decade, various methods have been applied to improve flexibility in order to obtain a thin ballistic shield [5].

Lightweight materials that were widely used as reinforcement in body armor include Kevlar, Carbon, Twaron, and Dynama fibers. Following this, the ballistic resistance fiber's level of energy absorption has been investigated experimentally using analytical methods [6]. From the perspective of energy transfer, it is seen that when the projectile hits the fabric, its energy was lost as a result of the mechanisms in the thread or fiber such as primary stress, fabric deformation, projectile-thread friction energy, and yarn breakdown[7,8].

The addition of 5% silicone rubber to polypropilene (PP) increases flexural strength, impact, and Heat Deflection Temperature (HDT). Increasing the volume fraction of silicon rubber in epoxy will increase impact strength, heat resistance, and impact. But the addition of more than 30% silicon will reduce the tensile strength of the composite. [9].

T

he addition of this material to graphite-reinforced composites made it possible for the composite to absorb impact shock [10]. Meanwhile, the addition of silicon carbon was able to reduce heat, improve mechanics, and increase hydrophobic properties in composites reinforced with nanodiamonds [11]. By incorporating silicon rubber into this composite, it is expected to be able to dampen impacts, collisions, and heat conductivity. Addition of silicone rubber to CF-epoxy but increases impact and toughness. Mechanisms and events are dominated by ballistic properties, materials, friction between the two, and the shape of the projectile. [12,13].

The impact on the composite and its mechanical behavior in the presence of failure modes on the strength of the matrix were also investigated [14]. It has been found that epoxy carbon reinforced composites present a high energy ratio during impact, almost matching vinyl ester based laminates.[15]. Sandwich and laminated composites provide a high strength-to-weight ratio, in both tensile and flexural strength.[16]. Grapevin and carbon are a laminated composition that is widely used in nanomaterials for military and aerospace applications. [17]. Carbon fiber has advantages such as flexibility, strength to weight ratio, and fracture toughness.[18]. Thus in this study, carbon fiber and silicon rubber, which incorporated epoxy as an alternative material for body armor with a standard firing test NIJ 1010.04, density, tensile, flexural strength, water absorption, and impact strength were tested. The aim of this study was to evaluate composites reinforced with carbon fiber and silicon rubber with several SEM tests and observations for use as fire-resistant materials.

2. Materials And Research Methods

The carbon fiber used in this study, which was obtained from PT Perdana Chemindo Jakarta Indonesia, has a density, tensile strength, and elastic modulus of elasticity of 1.72 gram/cm3, 5423 MPa, and 273 GPa respectively. Furthermore, silicon rubber was obtained from the PT Sigma Aldrich Jakarta Indonesia wit a density 1.08 grams/cm3. The epoxy with type cycom 5320, which has a density of 1.292, and a catalyst (methyl ethyl ketone peroxide (Mekpo) were obtained from PT Kimia Jaya Abadi Semarang Indonesia.

The silicon rubber and epoxy were mixed using a magnetic stirrer with a ratio of 1:4. The mixing process was carried out with parameter a rotating speed of 250 rpm, at a temperature of 40o C, for 30 minutes, and then methyl ethyl ketone peroxide was added as a catalyst [19,20]. Furthermore, composite molding was performed by preparing carbon fiber in a vacuum infusion mold, in accordance with the number of sheets, namely 6, 8, and 10. The matrix mixture that has been mixed with silicon rubber and catalyst was then placed in a container. Following this, the vacuum pump was used to suck the matrix into the mold,and then the composite from the mold was removed and cured in the oven for 6h at 60o C. Composites were prepared to make specimens according to needs tests. Density specimens, tensile strength, flexural strength, impact specimens, shot specimens, and water absorption specimensThe number of samples for each is 5 specimens for all testers.

Fig. 1 : Magnetic Stirrer

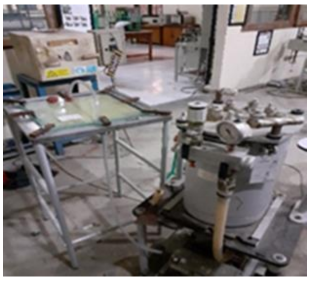

Fig. 2: Composite Molding

The addition of catalyst to silicon composites is limited, because the addition of too much catalyst results in a higher amount of heat generated during the curing process and a faster curing process. The limit on the amount of catalyst or crosslinker will depend on the reaction temperature; if it was too high it can cause degradation of the silicone rubber, so that the final product will have lower mechanical properties than desired. The resulting temperature profile also depends on the thickness of the final product.

2.2. Composite Density

The composite density test was conducted using the ASTM 792-13, 2013 method. This method involves the use of a Precisa XT 220 A balance (Indonetwork, Jakarta Indonesia) to compare the composite weight in liquid and air using the formula :

$$\text{Density}(g/cm^3) = \frac{a}{b+a} x.\delta.f \qquad (1)$$

Where :
a = specific gravity (g/cm^3) in the air
b = specific gravity (g/cm^3) in fluida .
The tests were performed at room temperature using biodiesel with a density of 0.867 g/cm^3.

2.3. Tensile Strength and Flexural Strength

The tensile strength of the composite was tested by ASTM D638-02 with a maximum load of 2 kN, while the crosshead used a speed of 500 mm/min, at a measuring length of 50 mm. while the flexural test was conducted using ASTM D-790-03. Both tests were carried out at the integrated MIPA Laboratory, Malang State University, Malang Indonesia.

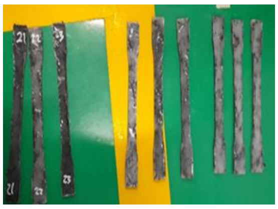

Fig. 3.a Sampel Tensile strength

Fig. 3.b. Flexural Strength

2.4. Impact Test

The impact test was carried out at the Mechanical Engineering Laboratory, Gajah Mada University, Yogyakarta Indonesia using a standard E 23 with a notch at 28 mm from one end and a length of 75 mm. The formula used for impact testing was as follows:

$$W_1 = G\lambda(1 - cos\alpha) \qquad (2)$$

Where:
W1 = Effort (Kg.m)
G = Pendulum weight (Kg)
λ = Swinger arm distance (m)
cos λ = The initial angle of the pendulum

Sample and impact tested process as shown in Figure 4.

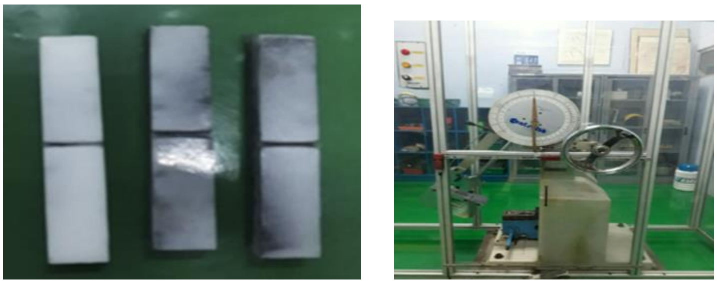

Fig. 4 : Sample and Impact Test Process

2.5. Shoot Balistic Test

The shooting test was performed at the Mako Brimob Pekalongan field by testing 9 specimens using an HS-930 G2 SS pistol made in Croatia with 9x19 mm PMC caliber bullets. The shooting distance was 10 m from the specimen, which had a size of 150 mmx150 mmx10 mm (thick).

Fig.5 : Gunshot, Proyectil, Shoot Process

Furthermore, the firing test was conducted in accordance with the NIH (National Institute of Justice) standard using type III – A NIJ 0101.04. The mass of the bullet, minimum speed, and firing range were 8.1 grams, 376 m/s, and 10 m respectively.

2.6. Water Absorption

The composite is tested for water absorption to determine the ability of the composite to absorb water under certain conditions. Water absorption in the composite results in an increase in the volume, weight, and adhesive strength of the composite. Water absorption was carried out for 10 days by soaked in distilled water and weighing every 24 hours. Water absorption as shown in Figure 6.

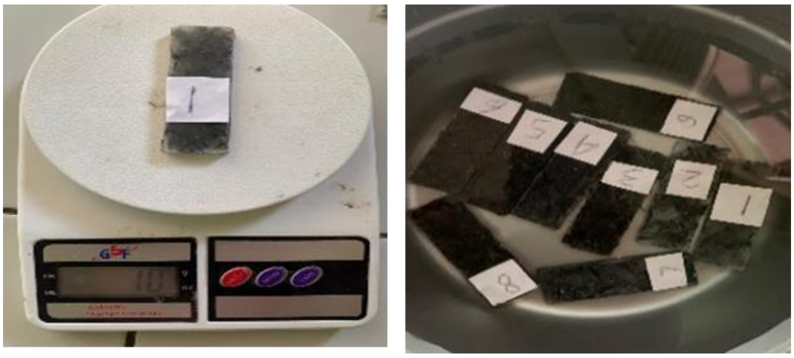

Fig.6 : Composite weigh and immersion

The water absorption capacity of the composite was tested using ASTM D5229 by formula :

$$\text{Water absorption} = \frac{W - D}{D} x100\% \qquad (3)$$

W = Wet weight (gram)
D = Dry weight (gram)
3. Results, Test, and Analysis

3.1. Density Test Results

The results obtained from testing the reinforced composite's density with carbon fiber and silicon rubber are shown in Table 1.

Table 1. Density Result Test

Nu	Code	Description	Density (g/cm^3)
1	6 L	Composite 6 layers carbon fiber	1.309±0,06
2	8 L	Composite 8 layer carbon fiber	1.347±0.07
3	10 L	Composite 10 layer carbon fiber	1.374±0.05

The results show that the more carbon fiber, the higher the density of the composite, this is because the density of carbon fiber is higher than that of the matrix and silicon rubber. Composites reinforced with carbon fiber and SiC have a density of 1.23 grams/cm3, [21,22]. While those that are made of silicon rubber and carbon non filler have a density of 1.31. grams/cm3, [23]. Furthermore, the composite's density was not excessively hefty, hence, it was very light when applied to the protective tube The composite with a carbon fiber and epoxy volume of 40 %, and 60% respectively produced a density value between 1.32 and 1.54 g/cm3. [24,25].

The operational standard of armor and bulletproof has a density of 3.75 g/cm3 for the Alotec 96 SB, 3.80 g/cm3 for the Alotec 98 SB, 3.87 g/cm3 for the Alotec 99 SB, and 3.1 g/cm3 for the Cisadur FC models [26]. The density above shows that the composite made is still lower in density, hence, it is lighter. Admittedly, increasing the density of the composite, in general, can increase the strength and flexibility of the material. The low density makes it possible to use body armor because the weight of the material used was lighter, however, it must be balanced with the strength of the composite [5]. The amount of SR exceeds 30%, the interfacial bond between the matrix and SR decreases, so that the strength is lower, even though the density is smaller [27]. The use of bullet-proof helmets and body armor requires composite materials with low density and high strength to be able to withstand bullet projectiles.

3.2. Tensile and Flexural Strength Test Result

The tensile strength was tested using the ASTM D638-02 and flexural strength test was conducted using ASTM D-790-03, The results of the tensile strength test for composite materials reinforced with silicon rubber and carbon fiber are shown in Table 2.

Table 2. Tensil Strength Result

Nu	Code	Tensile Strenght (MPa)	E(Modulus) (GPa)	Elongasi (%)
1	L 6	435,89	16,59	1,11
2	L 8	457,39	21,78	1,21
3	L 10	510,47	24,09	1,31

The addition of a carbon fiber layer increased the tensile strength due to the greater amount of reinforcement. This increase in strength is proportional to the increase in density in the composite. Likewise, the inclusion of a substantial amount of carbon fiber led to an increase in tensile strength, flexural strength, and impact strength by up to 60% in PP/HDPE and carbon fiber composites [28]. Carbon fiber as a composite reinforcement will greatly increase when tows and woven are formed, and this in turn increases the tensile strength [29,30]. Carbon fiber as a reinforcement was made of 0o orientation, and 45o chopped models. The results showed that the greatest tensile strength, which is 566 MPa, was obtained by using 0o oriented carbon fiber, while the chopped model decreased by 44% [31]. Increasing the tensile strength of carbon fiber can be achieved by grafting a rigid dendritic polymer onto the surface of the carbon fiber with branch density that can be adjusted based on reaction time. [32] This treatment can increase the tensile strength of carbon fiber reinforced composites by 20 %. Following this, the elastic modulus test shows results that are comparable with that of the tensile strength, and this is in accordance with the findings of the study [33]. Penambahan silicon rubber dapat meningkatkan konduktifitas termal, ketahanan, benturan, ketahanan panas, dan mengurangi densitas komposit. [27] The results of the flexural test of the composites reinforced with multi-layer carbon fiber and silicon rubber are shown in Table 3.

Table 3. Flexural strength result

Nu	Code	Flexural Strength (MPa)	E (Modulus) (GPa)	Elongasi (%)
1	L 6	387,19	12,59	1,04
2	L 8	417,23	17,78	1,12
3	L 10	421,47	19,09	1,25

These results indicated that there was an increase in proportion to the number of layers of carbon fiber as a composite reinforcement. Flexural strength increases with the number of layers, but not significantly. Carbon fiber has high tensile strength, but the flexural strength is rather brittle [34]. The flexural strength of carbon fiber is lower than that of glass fiber (FG)[35]. The flexural strength of copped carbon fiber in composites is lower than that of aramid. [36]. This shows that the flexural strength of carbon fiber is lower when compared to glass and aramid fiber [20]. But the addition of carbon fiber and sial to the compost can increase the stability of the mat [37]. The addition of silicon rubber to the composite has good elasticity, damping and toughness properties in the composite, but the addition of silicon rubber above 30% can reduce the flexural strength of the composite.[32].

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3.3. Impact Test Result

The impact test was carried out on 9 specimens, 3 specimens per time with the Izod model, and the results of this test are contained in Table 4.

Table 4. The results of the impact test are

Nu	Code	Angle	Energy	Angle	Energy	Area	Impact
		α (°)	(J)	β (°)	(J)	(mm)	J/mm^2
1	L 6	30	21	27.25	3.67	92.53	0.04
2	L 8	30	21	27.91	2.80	91.67	0.031
3	L 10	30	21	27.91	2.81	93.00	0.03

The results of the impact test show the failure method of specimens with broken nutmeg L 6 and L 8. It also revealed higher deamination accompanied by specimen and fiber damage, as well as matrix breakage. Delamination usually occurs by debonding the fibers and the epoxy propagated due to shear stress. Furthermore, these results indicated that the more layers of carbon in the composite the lower the impact obtained and this is due to the carbon fiber's high tensile strength. The impact strength, however, increased when the temperature of the composite was increased to 60o C.[38]. Increasing the number of carbon fibers shows a decrease in damage strength in several research results. The addition of silicon rubber to the composite can increase the impact strength. The higher the silicon rubber in the composite, the higher the impact strength, but this can lead to a decrease in tensile strength and flexural strength. [39]. The results of the impact test are shown in Fig 7,8 and 9.

Fig. 7 Impact L 6

Fig.8 Impact L 8

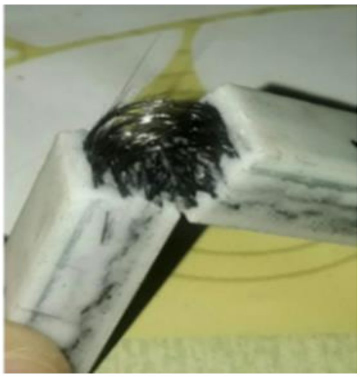


Fig.9 Impact L 10

Following this, fiber splitting occurred in the notch region and this was due to tensile stress [40]. Delamination is the main cause of failure with loose fibers and matrix. In the L10 composite, there was damage to the matrix and some separation between the matrix and fiber. Specimens with increased fiber fraction had some delamination, as well as fiber breakage and exit. Similar types of behaviors were reported by Nazrin [41] and Gay-our [42]. Addition of silicone rubber to CF-epoxy decreases tensile strength but increases impact and toughness. [43].

3.4. Shoot Balistic Test

The front of the composite material, which is made of silicon rubber and multilayer carbon fiber, was penetrated by the projectile structure damage, and the pressure in the fragmented area was felt in the rear. The rear surface became tense, impact forces occurred, and then the structure cracked [49]. Six layers of carbon fiber absorbed the energy from the bullet projectile after it had struck the target, thus causing it to deform. However, the composite could not withstand the velocity of the bullet, so it penetrated with a starting hole of 11.3 mm and a rear hole of 24.9 mm (average). Ballistic testing with the Croatian HS-930 G2 SS gun using the 9 x 19 mm caliber projectile shown in Figure 10.

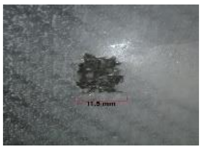
Specification	Front hole	Rear hole
Composite L6		
Composite L8		
Composite L 10		

Fig.10 : Result from Composite treatment projectile test

The bullet projected towards the 8-layered carbon fiber target deformed the composite and penetrated the front with a 12.5 mm hole and the rear with 25.8 mm (on average). The projectile also penetrated the composite with 10 layers of zinc fiber with 12.7 holes and 26.6 rear holes (average). It has been found that carbon fiber composites are very brittle in the transverse position when projectiles penetrate them. Therefore composites with layered carbon fiber must be parallel to the impact projectile [44]. Therefore, it can be concluded that the number of carbon fiber layers has little effect on the tear width of the projectile in resisting deformation and projectile velocity. This is because increasing the amount of carbon fiber increases the tensile strength, but decreases the flexural strength, impact, and resistance to projectile impact. Laminates with a flexible matrix perform much better at absorbing energy, but have a greater degree of deformation than laminates with a rigid matrix. The matrix plays an important role in limiting the propagation of transverse deformations, and therefore affects the local strain and impact resistance of composites.[45]

3.6. Water Absorption

The results of the water absorption test for composites reinforced with carbon fiber and silicon rubber are as shown in Figure 11.

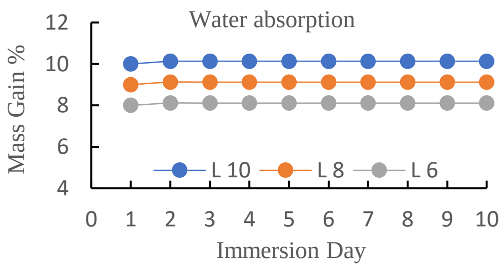


Fig. 11: Water absoption test

The water absorption test showed a slight addition on the first and second days, then there was no significant addition of water absorption to the composite after immersion. Non-Fickian absorption has been reported. Water absorption can be caused by the presence of voids in the composite and wetting of the carbon fiber. The water absorption behavior was carried out on the carbo/epoxy composite. Absorption behavior shows very little non-Fickian absorption [46,47]. Carbon fiber with a very narrow pore size between 0.65 – 0.70 nm per unit surface area and coated with a matrix is very difficult for water absorption [48]. Water absorption research on epoxy carbon fiber composites does not absorb water, its resistance remains unchanged when soaked. Water absorption greatly affects the mechanical strength of the composite. The high air absorption strength of the composite is proportional to the decrease in the mechanical strength of the composite.[49]. Water absorption in composites can affect mechanical properties such as tensile strength, bending, impact, and composite microstructure.[50]

4. Conclusion

In conclusion, the more carbon fiber, the higher the density, the tensile strength increases, and the flexural strength is not proportional to the number of layers. Carbon fiber is impervious to impacts and projectiles. The multiple layers of carbon fiber had a lower impact but the composite did not wear down quickly. This was because of the ductility caused by the presence of silicone rubber in the composite. Lastly, ballistic tests led to more extensive cracks in the layer-reinforced composite. The addition of silicon rubber to the composite reduces the interfacial bond between the fiber and the matrix, but is able to increase impact strength, bending and toughness. This happened because the binding ability of carbon fiber was more functional, thus, providing greater tensile strength. There was no significant absorption in the water absorption test.

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