RESEARCH PAPER

The Effect of the Number of Kevlar Layers Impregnated Nano Sic on Ballistic Resistance of Hybrid Laminated Al7075 Composites as Lightweight Material

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Received: Augest 2022 **Revised: February 2023** **Accepted: March 2023**
DOI: 10.22068/ijmse.2910

Abstract: *Materials that are applied to combat vehicles require an innovation as the development of the military world advances. The material innovation in this research is a lightweight hybrid laminated Al7075 composite sample. The main materials used in this research are aluminum 7075 plate, kevlar 29, silicon carbide (SiC) nano powder, and epoxy resin. Initially SiC nano powder was mixed with polyethylene glycol-400 (PEG-400). Then ethanol was added to this mixture so that it became a shear thickening fluid (STF) solution which was used to impregnate kevlar. Laminated composite samples were prepared using the hand lay-up method with epoxy resin as an additive between layers of kevlar and aluminum 7075 plates. The thickness of laminates was related to the number of kevlar layers. The results of this study showed that the composite samples with impregnated kevlar had higher ballistic and impact resistance values compared to the composite to their non-impregnated counterparts. The Fourier Transfer Infrared Spectrometry (FTIR) was used to determine the level of absorbance of the functional groups in the impregnated Kevlar. Scanning Electron Microscopy (SEM) was employed to investigate the distribution of nano SiC fillers in kevlar fiber.*

Keywords: *Hybrid Laminate Composite, Kevlar, SiC Nano Particles, Ballistic Resistance, Impact Strength.*

1. INTRODUCTION

Bullet-resistant combat vehicles are one of the defense equipment that has an important role in military operations, one of which is the tank. Combat vehicle bodies use armor materials that must have high protection against bullets, high hardness, corrosion resistance, and other high performance characteristics [1]. To determine the ballistic resistance performance of the armor material, the parameters can be seen based on the classification in the NIJ standard shown in Table 1, where the higher the level, the better the ballistic resistance of the armor material.

The use of composite materials as lightweight armor material began to be developed because they have low density, high hardness, high stiffness, and strength in compression [2]. In addition, lightweight armor material can increase vehicle efficiency both in terms of mobility and fuel [3]. One type of composite as a lightweight armor material is a hybrid laminated composite. Hybrid laminated composites consist of an array of fiber-fabric type reinforcement with a material matrix [4]. In this study the hybrid laminate laminate composites used kevlar reinforcement which was impregnated by STF solution which is a mixture of SiC nano powders, PEG-400, and ethanol, while the matrix used was Aluminum 7075. STF solution can increase the ability to absorb ballistic energy on Kevlar. This is because STF solutions can undergo a phase transition from low to high viscosity when a shear stress is applied to them [5]. When the applied voltage is greater, the particles in the liquid phase will bind more tightly so that the concentration of STF will be higher.

Generally, combat vehicle armor bodies use RHA (Rolled Homogeneous Armor) material. RHA is able to withstand ballistic attacks up to level III with a plate thickness of 13 mm using 7.62 mm AP projectiles [6]. However, because the density of hybrid laminated composite (4.14 g/cm^3) is much lower than RHA (7.85 g/cm^3) [7]. This is what makes hybrid laminated composites the choice for this study.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

In this study, the materials used to make a hybrid laminate composite were Al 7075 as matrix and nano SiC as reinforcement in the form of STF solution impregnated in kevlar with variations in the number of layers of 8, 16, 24 layers. The sample size used for ballistic testing is 15 cm x 7.5 cm and the sample size used for impact testing refers to the ASTM E23 standard. Several sample tests were carried out by observing the microstructure of Scanning Electron Microscopy (SEM), Fourier Transfer Infrared Spectrometry (FTIR) tests, ballistic tests, impact tests, and taking macro photographs.

2.1.1. Aluminium 7075

Aluminum 7075 is an alloy of the Al-7xxx series which is also called aluminum-zinc alloy because the maximum amount of zinc ranges between 5.1 and 6.1 percent [9]. Al 7075 has good machinability and high tensile strength [10]. Al-7075 has a wide range of applications and therefore needs further strengthening.

2.1.2. Kevlar 29

Kevlar is a kind of man-made synthetic fiber of high modulus para aramid. It is an organic fiber in the aromatic polyamide family [11]. Kevlar 29 has a light density and high tensile strength. In addition, kevlar 29 has a high elongation length compared to kevlar grades 49 and 149 which shows that kevlar 29 has better toughness properties [12].

2.1.3. SiC nanopowders

Silicon carbide is a non-oxide ceramic consisting of a combination of carbon and silicon particles. SiC acts as a nano filler for the kevlar fiber which fills the gaps in the kevlar fiber. The addition of SiC to kevlar increases the tensile strength and resistance of kevlar during ballistic testing [10].

2.1.4. PEG-400

PEG-400 is used to disperse nano SiC into kevlar. PEG-400 was chosen because of its low volatility so it can produce the desired thermal stability for various applications.

2.1.5. Epoxy Resin & Hardener

Epoxy resin acts as an adhesive which is suitable for bonding kevlar fibers and aluminum plates. The use of adhesive serves to form a bond or interaction between the matrix and the reinforcement. Epoxy resin requires a catalyst to harden which is commonly called a hardener or *curing agent*.

2.2. Methods of Sample Preparation

The process of making hybrid laminated composites begins with cutting Al 7075 plates into predetermined sizes for ballistic testing and impact testing. Then, the surface of the Al 7075 plate is cleaned using ethanol. Next, the kevlar is cut according to the size of the Al 7075 plate. The kevlar that has been cut will be impregnated with STF solution.

The STF solution consists of a mixture of nano SiC, PEG-400, and ethanol. Preparation of the STF solution begins by weighing the nano SiC powder and measuring the volume of PEG-400 and ethanol with a ratio of 1:2:2. Then, the SiC nano powder and PEG-400 were mixed using a magnetic stirrer at 1200 rpm for 2 hours at room temperature [13].

After that, ethanol was added to the mixture for 1 hour at room temperature. The mixed STF solution will be impregnated on kevlar and then the impregnated kevlar will be dried for 72 hours at room temperature.

Table 1. Ballistic resistance performance according to NIJ Standard 0108.01 01 01 [8].

Level of ballistic protection	Ammunition type	Nominal mass (g)	Barrel length (cm)	Projectile velocity (m/s)	Kinetic Energy (J)	Shots per panel
I	.22 LRHV Lead	2.6	15-16.5	320 ± 12 m/s	133.12	5
	.38 Special RN Lead	10.2	15-16.5	259 ± 15 m/s	342.12	
II-A	9 mm FMJ	10.2	10-12	381 ± 12 m/s	440.09	5
	.357 Mag JSP	8.0	10-12	332 ± 12 m/s	740	
II	9 mm FMJ	10.2	15-16.5	425 ± 15 m/s	512.66	5
	.357 Mag JSP	8.0	10-12	358 ± 12 m/s	921	
III-A	44 Magnum Lead SWC	15.55	14-16	426 ± 15 m/s	725.9	5
	9 mm FMJ	8.0	24-26	426 ± 15 m/s	1406	
III	7.62 x 51 FJNB	9.7	56	838 ± 15 m/s	3405	5
	308 Winchester FMJ					
IV	30-06 AP	10.8	56	868 ± 15 m/s	4068.5	1

[DOI: 10.22068/ijmse.2910]

The next step is to assemble impregnated kevlar with Al 7075 to form a hybrid laminate composite with the configuration shown in Figure 1.Impregnated kevlar and Al 7075 are bonded and assembled using an adhesive which is a mixture of epoxy resin and hardener in a ratio of 2:1 using the hand-lay up method. Then, the finished laminated composite is dried and pressed with a 2 kg heavy object.

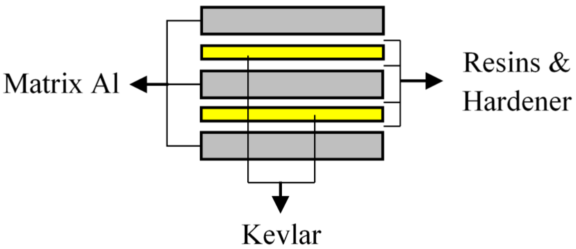

Fig. 1. Hybrid laminate composite configuration.

3. RESULTS & DISCUSSION

3.1. Microstructure of Kevlar in SEM & FTIR

SEM testing was carried out on non-impregnated kevlar and impregnated kevlar with SiC nanoparticles. The SEM test aims to determine the distribution of SiC nano filler on impregnated kevlar, so that the penetration rate of the filler that enters the kevlar fiber gap can be observed.

In Figure 2. (a) and (b) shows that non-impregnated kevlar still has void spaces which can be seen as gaps between the kevlar fibers. If non-impregnated kevlar is used for the hybrid laminated composite, the voids in the gaps between the kevlar fibers will be filled with epoxy resin. Therefore, non-impregnated kevlar has a weaker energy absorption capability than impregnated kevlar, so that non-impregnated kevlar is less effective in resisting bullets during ballistic testing [14].

In Figure 2. (c) and (d) shows the impregnated kevlar where it can be seen that the void spaces in the gap between the kevlar fibers has been filled with nano SiC from STF solution. The even distribution of SiC nano filler on kevlar makes the ballistic energy absorption rate better, thereby minimizing damage caused by ballistics. However, some kevlar fibers show agglomeration. This is because nanoparticles have a high specific surface energy that makes them easy to agglomerate [15]. Therefore, PEG is used as a dispersant in the process of mixing STF solution with nano SiC, this is because the chain molecules can form a steric barrier effect by absorbing and wrapping the surface of the particles, thereby inhibiting agglomeration [15].

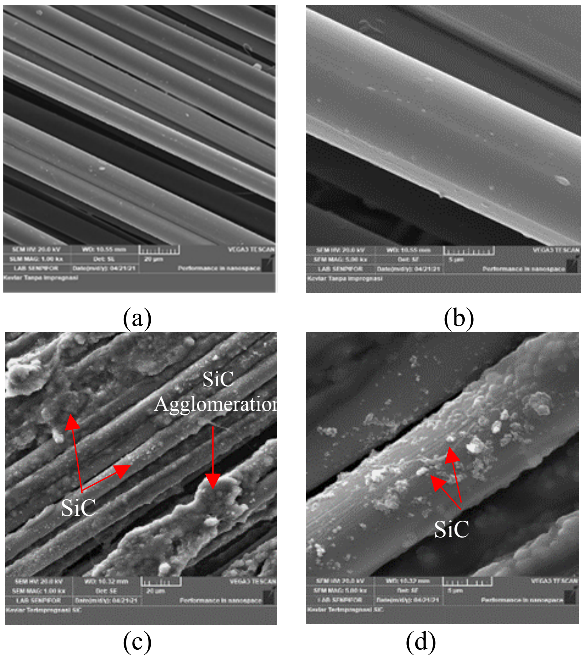

Fig. 2. SEM test results on non-impregnated kevlar in (a) 1000x magnification, (b) 1000x magnification, and SiC impregnated kevlar (c) 5000x magnification, (d) 5000x magnification.

To ensure the presence of SiC content in kevlar can be seen at the wavelength of the results of the FTIR test with the standard wavelength range shown in Table 2. Figure 3 shows the O-H functional group from the ethanol content at peak 3005.86 cm-1 in the wavelength range of 3000-3700 cm^{-1}. At the peak of 794.86 cm^{-1}, the presence of the Si-C functional group was detected in the wavelength range of 737-815 cm^{-1}. In addition, PEG contains the C-O functional group which was detected at a peak of 1060.88 cm^{-1} in the wavelength range of 1000-1300 cm^{-1} and the CH_2 functional group at a peak of 2865.96 cm^{-1} in the wavelength range of 2850-3040 cm^{-1} [16].

It can be concluded that impregnated kevlar can absorb STF solutions well based on the presence of functional groups from alcohol, SiC, and PEG. The SiC absorption peak looks quite large and steep which indicates that the SiC content absorbed by kevlar is quite high. The peak of ethanol absorption on kevlar was not too high because prior to this test the kevlar had been dried, so that the ethanol content evaporated.

[DOI: 10.22068/ijmse.2910]

Table 2. FTIR spectrum data [17].

Functional Group	Wavenumber cm^{-1}
- OH	3700 - 3000
C - H	3040 - 2850
C = O	1725 - 1650
C - N	1360 - 1180
C - O	1300 - 1000
Si - C	815 -737
C - C	480 - 430

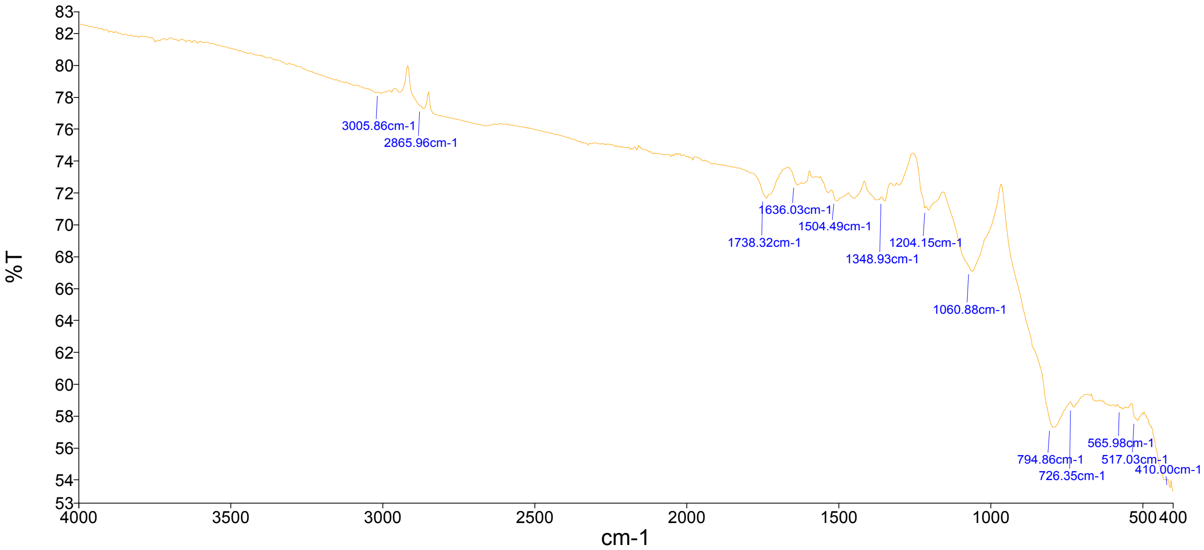

Fig. 3. FTIR test results on SiC impregnated kevlar.

3.2. Ballistic Performance on Laminated Composite

Ballistic testing is carried out by firing projectiles at laminated composites for ballistic resistance at level II and level III. Each ballistic level has a different type of ammunition, weight, range and projectile speed according to the ballistic level. Projectiles fired at laminated composites will leave traces of projectiles in the form of penetration holes.

Figure 4 (a-c) shows the projectile traces of level II and level III ballistics on non-impregnated laminate composites with 8, 16, and 24 layers of kevlar. The results of projectile trail does not form deep holes on the composite surface, this indicates that the non-impregnated laminate composite is still capable of withstanding ballistic loads. Figure 5 (a-c) shows the projectile traces of level II and level III ballistics on SiC impregnated laminate composites with 8, 16, and 24 layers of kevlar. The projectile trail from level II ballistics is indicated by a larger hole shape than level III, this is due to the different size of the projectiles. From the side view, it can be seen that the laminated composites shown in Figure 4 (d-f) and Figure 5 (d-f) both suffered damage such as delamination and deformation due to the impact of the projectiles and the weak bond between the adhesive and Kevlar.

How deep the projectile penetrated and the damage caused by ballistic testing in the SiC impregnated laminate composite can be seen in the macro photo of the cross section of the laminate composite shown in Figure 6. Fiber damage occurred in all SiC impregnated laminate composites with 8, 16, and 24 layers of kevlar, in both level II and level III ballistic testing samples (Figure 6). Fiber damage is a kevlar fiber that comes out when kevlar receives a high projectile energy. The kevlar fiber that comes out is called a pull-out fiber. The difference in damage from level II and III ballistic tests can be seen in how much the laminate composite can withstand projectiles.

Figure 6 (a-c) shows that all laminated composites with level II ballistics experience bending damage which indicates that the laminated composites can withstand projectiles.

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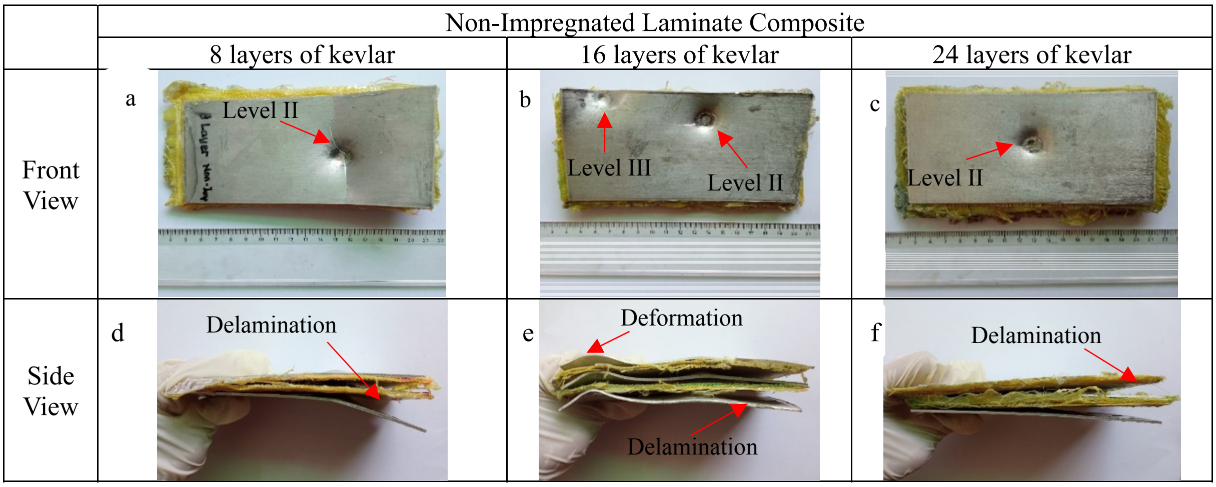

Fig. 4. Ballistic tests at level II and level III on non-impregnated laminate composite (a) front view of 8 kevlar layers, (b) front view of 16 kevlar layers, (c) front view of 24 kevlar layers, (d) side view of 8 kevlar layers, (e) side view of 16 kevlar layers, (f) side view of 24 kevlar layers.

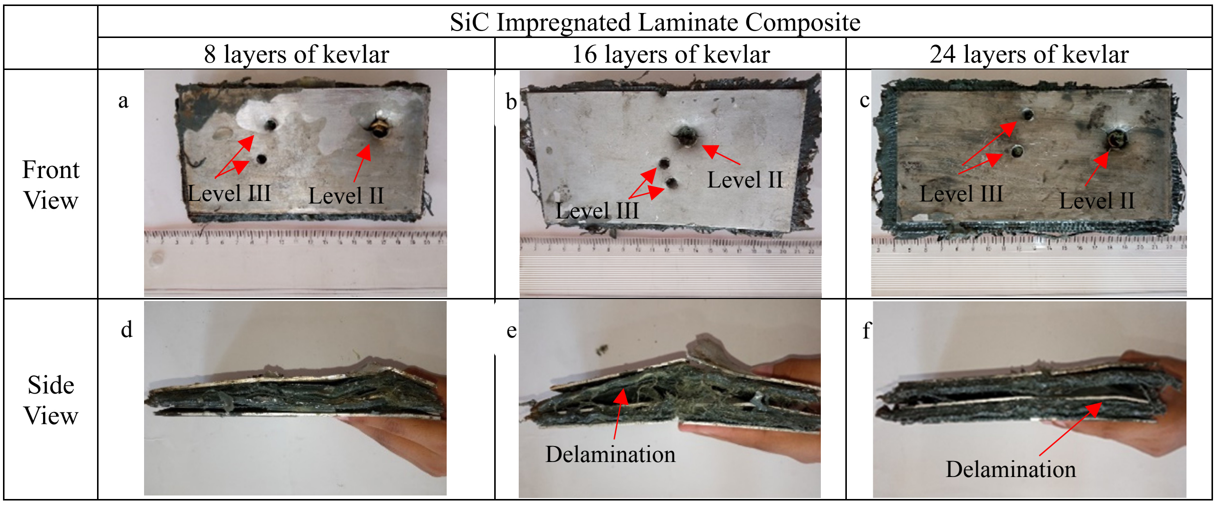

Fig. 5. Ballistic tests at level II and level III on SiC impregnated laminate composite (a) front view of 8 kevlar layers, (b) front view of 16 kevlar layers, (c) front view of 24 kevlar layers, (d) side view of 8 kevlar layers, (e) side view of 16 kevlar layers, (f) side view of 24 kevlar layers.

It can be seen that there is no sign of the projectile penetrating the laminate composite. This means that the presence of SiC nanoparticles plays a role in increasing the load distribution received by the composite. Figure 6 (d-f) shows that all laminate composites with level III ballistics experienced petalling damage. Petalling occurs when the bullet energy spreads in all directions on kevlar, so petalling will be shaped like a flower at the point of maximum energy absorption [18]. In addition, petalling damage caused by projectiles penetrating the laminate composite can be seen in level III ballistic laminate composites with 8 and 16 layers of kevlar (Figure 6 d-e). This is because level III projectiles have greater penetrating power than level II projectiles. However, in Figure 6 (f) it can be seen that the SiC impregnated laminate composite with 24 layers of kevlar at level III ballistics can still withstand projectiles even though it suffers a little petalling due to the high projectile thrust.

Traces of projectiles in the form of holes caused by bullets penetrating the laminated composite affect the diameter of the perforation and depth of penetration produced. The perforation diameter and penetration depth play an important role in ballistic performance. The graph for measuring the perforation diameter in Figure 7 (a) shows that the greater the number of layers of kevlar, the smaller the diameter of the perforation produced.

[DOI: 10.22068/ijmse.2910]

The diameter of the perforation will differ according to the size of the projectile at each ballistic level. The SiC impregnated laminate composite had a smaller perforation diameter than the non-impregnated composite. This is because impregnated kevlar has a greater thickness due to the presence of nano SiC filler which fills the empty space in the kevlar fiber gap which increases the ability to absorb projectile energy, so that the resulting projectile footprint is smaller. Penetration depth has a role to determine whether the projectile penetrates well into the composite and how deep the projectile penetrates when it enters the composite. The penetration depth measurement graph in Figure 7 (b) shows that the SiC impregnated laminate composite has a deeper projectile penetration rate than the non-impregnated laminate composite as the number of kevlar layers increases. This is in accordance with the literature where the thicker the kevlar layer on the composite, the greater the projectile energy that can be absorbed, resulting in a deeper level of bullet penetration in the composite [19].

The application of shear thickening fluid (STF) into kevlar will increase the viscosity in the event of a projectile impact so that the rigidity of kevlar will increase dramatically. This will increase the energy absorption rate of the composite when the projectile is fired. The deformation caused by the firing also affects the depth of penetration that the projectile can penetrate. The more homogeneous the distribution of SiC nanoparticles as reinforcement, the easier the load is transferred to the existing matrix and fibers. The level of homogeneity of SiC nanoparticles also affects the adhesion between resin and kevlar.

From the explanation it can be concluded that impregnated laminated composites have higher ballistic resistance properties than non-impregnated composites.

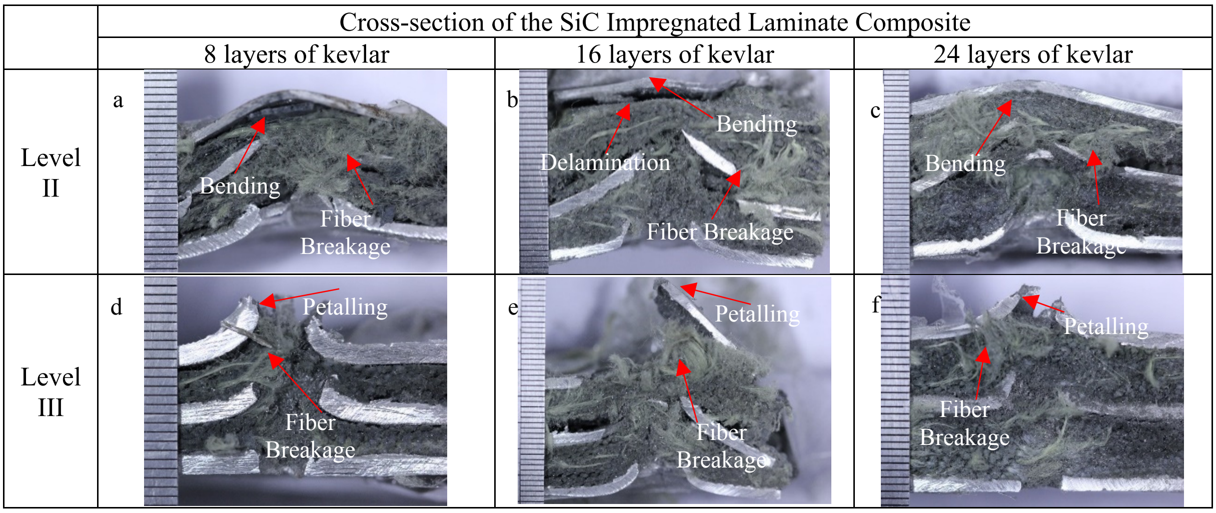

Fig. 6. Cross-section view of SiC impregnated laminate composites at ballistic level II with (a) 8 layers of kevlar, (b) 16 layers of kevlar, (c) 24 layers of kevlar, and at level III ballistic with (d) 8 layers of kevlar, (e) 16 layers of kevlar, (f) 24 layers of kevlar.

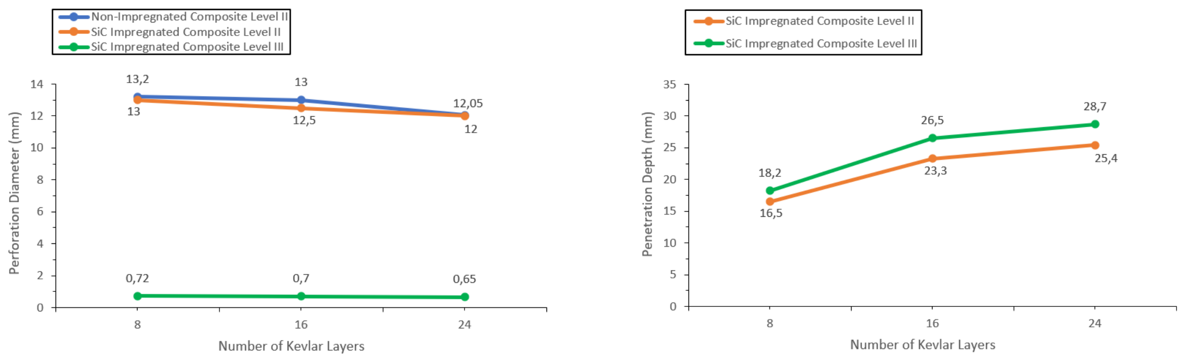

Fig. 7. Graph of laminate composite for each ballistic level with respect to (a) perforation diameter and (b) penetration depth.

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Overall, the SiC impregnated laminate composite with 24 layers of kevlar showed the best ballistic performance which could withstand the ballistic rate of level III projectiles. Ballistic resistance at level III is also shown by RHA material [6]. In addition, the development of armor materials must have maximum ballistic resistance along with low density so that the movement of vehicles on the battlefield becomes easier. Therefore, SiC impregnated laminated composites can be an alternative choice as an armor material because it has good ballistic resistance and low density, so it can replace RHA steel as a conventional armor material.

3.3. Impact Strength on Laminate Composite

Impact testing is carried out to determine the impact resistance ability of a material when given a high shock load or suddenly. In this test, an impact test was performed with 9 samples of the SiC impregnated composite and non-impregnated laminate composite which was divided into 3 samples for each 8, 16, and 24 layers of kevlar. Of the 18 composite samples for impact testing, the average impact value for each number of kevlar layers will be sought.

Figure 8 shows a graph of the impact value of the SiC impregnated laminate composite having a higher impact value compared to the non-impregnated composite as the number of kevlar layers increases. This is because nano SiC has filled the empty space in the kevlar fiber gap, so that the kevlar fiber becomes denser and the strength of the composite increases because the kevlar fiber does not slide easily. This is in accordance with the literature where the thicker the composite, the higher the energy absorption [20]. Therefore, the impact resistance ability of the composite is increased.

The high impact on the laminated composite caused some damage. Damage due to the impact test can be identified visually. Figure 9 (a) shows that the composite does not delaminate, but only experiences bending due to impact, while Figure 9 (b-c) shows that the laminated composite is damaged by delamination. This is due to the adhesive not covering the surface of the kevlar evenly so that the bond between the kevlar fiber and the adhesive is weak. In addition, it can also be caused by voids that appear due to agglomeration in the kevlar fiber. Voids appeared during the pasting process, so the layers were easily peeled off. In Figure 9 (d-f) all laminated composites have delamination damage. This should have been minimized because the STF solution had been impregnated with kevlar, so that the toughness had increased. However, this can occur due to voids during the gluing process. For this reason, it is necessary to pay attention to the ratio of the use of epoxy resin and hardener as adhesive.

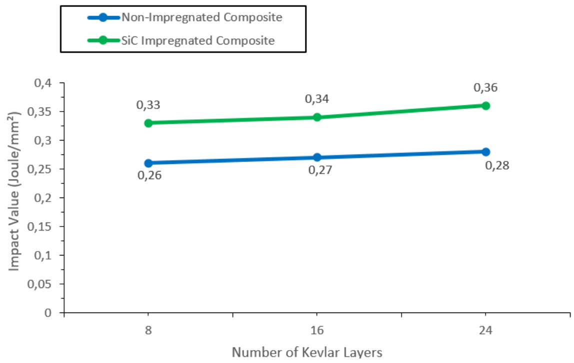

Fig. 8. Impact Strength on Laminated Composite.

None of the impact samples experienced fractures, this is because kevlar has flexible properties so that it can withstand excess deformation (Figures 9). In addition, it can be concluded that the impact strength of the SiC impregnated composite is higher than the non-impregnated composite. This is in accordance with the literature where the large number of layers of kevlar and the impregnation of STF solutions on kevlar affect the mechanical properties of laminate composites due to the presence of nano SiC which can fill the kevlar fiber gaps and increase the energy absorption capability.

4. CONCLUSIONS

The role of SiC nano-size filler particles in the hybrid laminated composite samples made of aluminum alloy 7075, kevlar, and epoxy resin was studied in this work. Microstructural results on SiC impregnated kevlar showed that SiC nanoparticles were able to fill the empty space between the kevlar fiber gaps. This caused the SiC impregnated composite samples to have a higher projectile energy absorption than the non-impregnated counterparts. In addition, increasing the number of kevlar layers also affected the ballistic and impact resistance of laminate composites.

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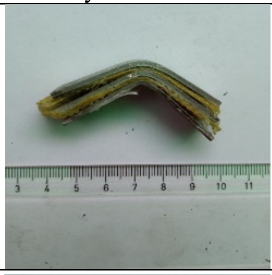
	Visual of Impact Test Results		
	8 layers of kevlar	16 layers of kevlar	24 layers of kevlar
Non-Impregnated Kevlar	a 	b 	c 
SiC Impregnated Kelar	d 	e 	f 

Fig. 9. Impact test results on non-impregnated composites with (a) 8 layers of kevlar, (b) 16 layers of kevlar, (c) 24 layers of kevlar and SiC impregnated composites with (d) 8 layers of kevlar, (e) 16 layers of kevlar, (f) 24 layers of kevlar.

This was seen from the decrease in the diameter of the perforation and the increase in the depth of penetration in the laminated composite with the increase in the number of kevlar layers. Better performance was observed in the SiC impregnated laminate composite with 24 layers of kevlar which was able to withstand projectiles up to level III, especially with lower mass and cost in comparison to the RHA armor material.

ACKNOWLEDGEMENTS

Authors would like to thank The Deputy for Research Strengthening and Development, Ministry of Research and Technology/National Research and Innovation Agency for financial support under PDUPT Grant with contract number: NKB- 189/UN2.RST/HKP.05.00/2021.

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[DOI: 10.22068/ijmse.2910]