

THE EFFECT OF NANO TiC IMPREGNATION ON KEVLARS AND THE NUMBER OF LAYERS ON BALLISTIC PROPERTIES OF LAMINATE HYBRID COMPOSITE

Firdaus Agustha and Anne Zulfia Syahril*

Received: February 10, 2021; Revised: April 03, 2021; Accepted: April 12, 2021

Abstract

The remarkably advanced military technology allows innovation in new lighter materials for combat vehicles, such as laminate composite, which is fabricated from AA2024 metal sheet and Kevlar smeared with epoxy resin. This research identified the effect of the addition of ceramic nano-powder on its ability to absorb ballistic energy from projectiles. The powder used, TiC, was mixed with PEG-400 to form Solid Thickening Fluid (STF), which later was impregnated on the Kevlar sheet. The ability of STF-impregnated composite to absorb energy was compared with the non-impregnated one, with variations in the number of layers of 10, 20, and 30 Kevlar sheets. To obtain the exact level of absorbed energy, there were two tests conducted; ballistic test with NIJ 0108.01 Type II standard using P1 handgun with 10 m range, and impact test with ASTM E23 standard using 300-joule pendulum. Furthermore, the SEM test was conducted on the composite to identify the distribution of nano ceramic powder on Kevlar as well as macro photos to determine the type of failure after ballistic and impact tests. The addition of TiC and the number of Kevlar sheets on sample results showed an acceptable result on ballistic, and impact tests.

Keywords: Composite, TiC, Kevlar, ballistic, impact

Introduction

One of the weapons systems commonly used by many countries to protect their nation, especially in the ground warfare, is a bullet-proof combat vehicle, or commonly called a tank. The bodies of these vehicles are mostly made of steel which has a relatively large density. Although steel in general has good decent mechanical and chemical properties, due to its density value, the tank will subsequently have a large mass. This large mass would be a disadvantage to the use of these combat

vehicles, specifically in the mobility of the vehicle itself (Vemuri *et al.*, 2011).

This problem could be reduced by replacing the basic material (steel) with other materials. The new material must have low density so it has a lower mass. However, this material must be equipped sufficient ballistic resistance (Rusnaldy *et al.*, 2019). One of the compatible materials to replace steel as the base material for a combat vehicle body is a composite, a combination of two or more materials

Department of Metallurgy and Material Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI, Depok 16424, West Java, Indonesia. Tel.: +62-812-901-7857. E-mail: zulfiaanne@gmail.com; anne@metal.ui.ac.id

* Corresponding author

that have different mechanical properties and characteristics from its constituent materials (Suhdi *et al.*, 2016).

Hybrid composite with laminate structure is a type of composite that could replace steel in combat vehicles. The base material of this composite is plate-shaped Aluminum which has a low density and the reinforcing material used are Kevlar fabrics that are impregnated with Shear Thickening Fluid (STF). After that, Aluminum plates and Kevlar fabrics impregnated by STF will be arranged in layers using epoxy resin and hardener by hand lay-up method. After finished, the sample will be tested for the ballistic test, impact test, and SEM visualization.

Material and Experimental Procedure

Materials

This study used Al 2024 plate as a matrix and Kevlar 29 as reinforcement for the hybrid composite. Later on, Kevlar fabrics will be impregnated by shear thickening fluid (STF), which consisted of TiC nano-powder and Polyethylene glycol (PEG-400). To combine these materials, Bakelite® EPR 174 is used as an epoxy resin, and Bakelite® EPH 555 as a hardener with a mixture ratio of 2:1.

Sample Preparation

The process began with preparing the required materials. Firstly, the aluminum plates were cut into 2 types for each test (7.5 cm × 1.5 cm for the ballistic test and 5.5 cm × 1 cm for the impact test). Afterwards, each aluminum surface was grinded by SiC emery paper and was also cleansed by ethanol.

On the other hand, the Kevlar fabrics were also cut into the same size with the aluminum (7.5 cm × 15 cm for the ballistic test and 5.5 cm × 1 cm for the impact test). There were two types of Kevlar used, namely plain Kevlar and STF-impregnated Kevlar. For later one, the ratio of 1.25 gr TiC: 2.5 mL PEG: 2.5 mL ethanol was used for impregnating 1 layer of 7.5×15 cm sized Kevlar and 0.06 gr TiC: 0.12 mL PEG: 0.12 mL ethanol for impregnating 1 layer of 5.5 cm × 1 cm sized Kevlar.

With regards to producing STF, the process was initiated with stirring the materials using a magnetic 1,200 rpm stirrer in a room temperature for 3 h. Then, the ethanol was added and the mixture was again stirred using the same equipment and the same conditions for 2 h. Consequently, the STF (in a liquid form) was ready to use. Afterwards, Kevlar layers were immersed into the STF liquid, followed by drying the Kevlar fabrics for 72 h at room

temperature until the ethanol had completely evaporated.

After Kevlar fabrics had entirely impregnated, the next stage was to combine the hybrid laminate composite. During the preparation, adhesive substance was applied to the surface of each Kevlar fabric (Al 2024) using the Hand Lay-up method. This was a mixture of epoxy resin and hardener with a mixing ratio of 2:1. The composite structure was depicted in Figure 1. Finally, the laminate composite was pressed by hydraulic pressure of 1,600 Pa for 24 h at room temperature.

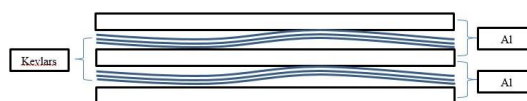


Figure 1. Structure of the laminate composite

After being arranged according to the configuration in Figure 1, the laminate composite was pressed using hydraulic pressure with a pressure of 1,600 Pa for 24 h under room temperature conditions.

Experimental Testing

In this research, there were three tests conducted, namely ballistic test, impact test and SEM test. First, the ballistic test (with NIJ 0108.01 Type II standard and P1 handgun with 10 m range-shooting) was performed to observe the ballistic behaviour of the composites. Next, the impact test was demonstrated to obtain the exact level of absorbed energy. This test also referred to the ASTM E23 standard with 300-joule pendulum. Finally, the SEM test was carried out on the composites to identify the distribution of nano ceramic powder of Kevlar surfaces. Besides that, TiC nano-powder were also tested using SEM-EDS and XRD to find several characterization.

Results and Discussion

Characterization of TiC Nano-Powder Using SEM-EDS and XRD

After conducting SEM-EDS test in the TiC nano-powder, we obtained the result in the material characteristics, specifically the size and the purity of the powder. The SEM result is shown in Figure 2.

The picture was taken with 10000x magnification. It is seen that the TiC powder in the form of agglomeration. The size of nano-powder in ranged of 400-600 nm. With regards to the purity of TiC nano-powder then we were analysed by EDS

and XRD. During the EDS measurement, several areas were focused and the corresponding peaks are shown in Figure 3 and the wt% of the elements are shown in Table 1.

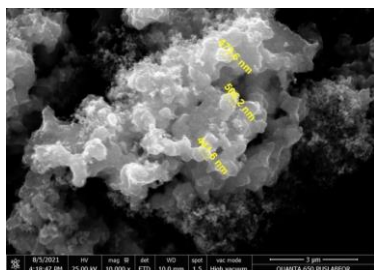


Figure 2. SEM Visualization of TiC Nano-Powder

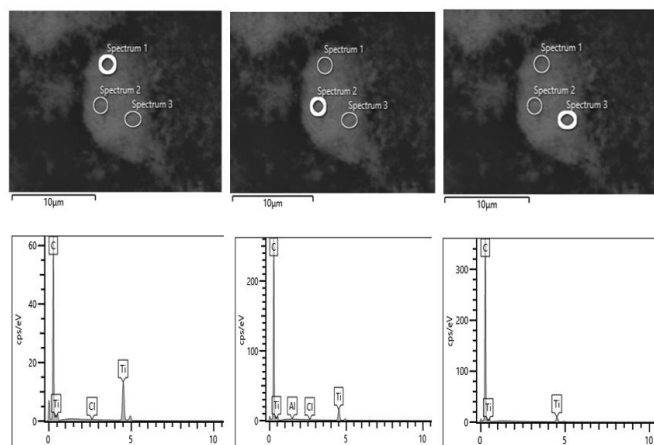


Figure 3. Enlarge of TiC nano-powder from Figure 2 and EDS showed the elements content in TiC

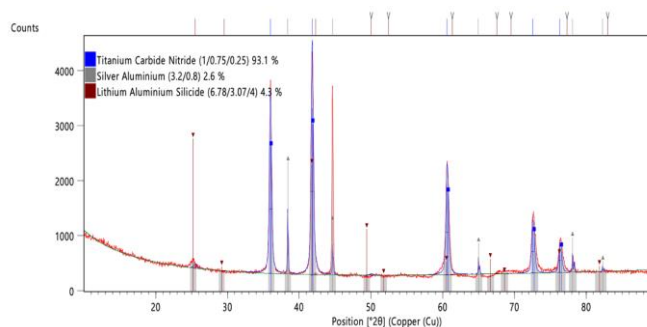


Figure 4. XRD of TiC Nano-Powder

Table 1. EDS Weight percentage of TiC Nano-Powder from 3 spectrum

TiC Nano-Powder	Titanium Weight (%)	Carbon Weight (%)	Other Elements Weight (%)
Spectrum 1	17.8	82.1	0.1
Spectrum 2	7.2	92.7	0.2
Spectrum 3	3.7	96.3	0

TiC and other elements were identified in the sample with EDS Spectrum. In spectrum 1, the quantity of Ti, C, and other elements were 17.8%, 82.1%, and 0.1%, respectively, while in spectrum 2, the wt% values were 7.2%, 92.7%, and 0.2%. For the last spectrum, Ti and C accounted for 3.7% and 96.3% respectively.

After identifying the purity of TiC nano-powder, the result of EDS were confirmed by doing XRD test. This test were performed and the result are shown at Figure 4.

According to Figure 4, the powder was mostly made of Titanium Carbide Nitride phase, accounted for 93.1%, while the rest was Aluminium phases, specifically Silver Aluminium 2.6% and Lithium Aluminium Silicide 4.3%. Since the EDS analysis

showed the dominant elements are C and Ti, others element can be neglected due to the very low amount. It seems that the purity of TiC content of nitride was analysed by XRD, but it was undetectable in EDS. The dominance of TiC phase demonstrated its potential ability to play a huge role in the ballistic resistance of composite, considering that TiC phase is equipped with a relatively decent level of strength in absorbing energy.

Analysis of Impregnated Kevlar in STF Containing TiC Nano-powder

Figure 5 shows the results of the Scanning Electron Microscopic (SEM) evaluation of the impregnation of the Kevlar fabrics with and without TiC nano-powder.

Figure 5(a) depicts the SEM result of plain Kevlar. It shows empty spaces between knits from different directions and between the fibers, showed by yellow arrows. The empty spaces in the Kevlar would only be filled with epoxy resin, which was less effective at absorbing energy from the bullet.

Meanwhile, Figure 5(b) shows the SEM results of the Kevlar that were impregnated by STF. It is noticeable that the empty spaces in Kevlar were filled with TiC nano-powder, showed by yellow circles. TiC nano-powder provided more strength in receiving energy given from ballistics. Also, the presence of STF increased the friction force between Kevlar. This certainly strengthened the ability of Kevlar to energy from ballistics and reduced the possibility of Kevlar's delamination and fiber pull-out (Haro *et al.*, 2016).

Analysis of Ballistic Properties

From this research, the resulting data were the size of the perforation diameter, depth of penetration, and deformation that occurred after the test. The result were shown in Figure 6.

Figure 6(a) illustrates that each of the laminate composites, whether using impregnated or non-impregnated Kevlar, had a smaller perforation diameter as the number of Kevlar layers increased, because many fibers were dislocated due to ballistic

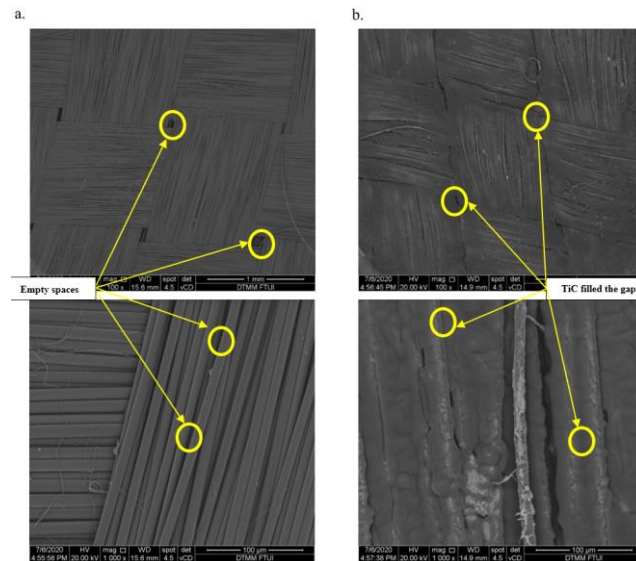


Figure 5. SEM Visualization of (a) Plain Kevlar; (b) Kevlar with STF with 100x and 1000x magnification

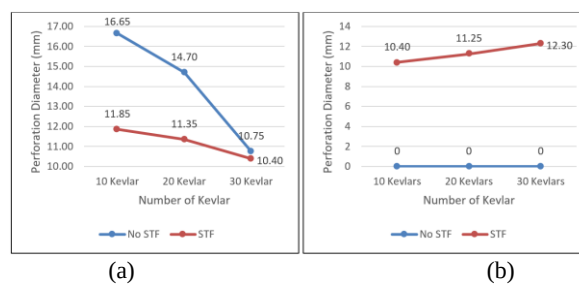


Figure 6. (a) Perforation diameter; (b) Penetration Depth of composites after ballistic tests

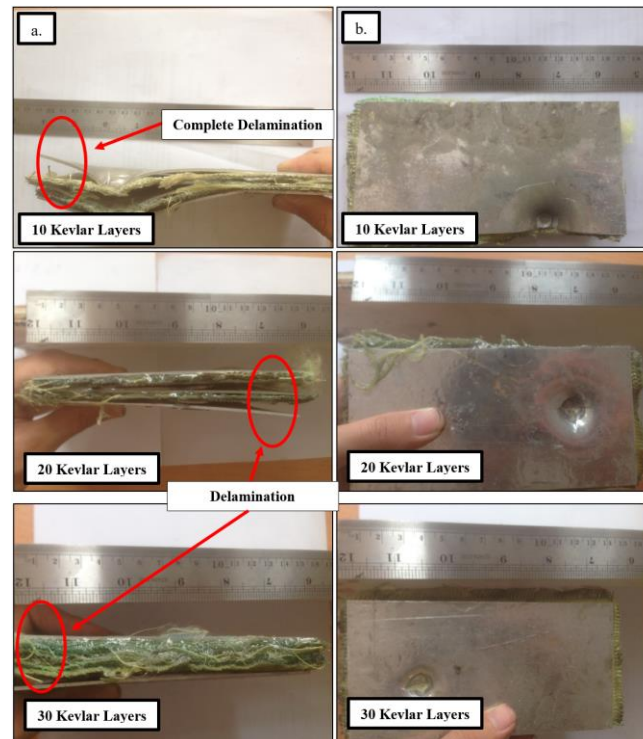


Figure 7. (a) Side view; (b) Top view of Composites (without STF) Visualization after ballistic test

impact so the energy from ballistics was well-absorbed (Liu *et al.*, 2018). From the same graph, composites with impregnated Kevlar had a smaller perforation diameter than composites with plain Kevlar for each number of layers since with regards to STF impregnated Kevlar, TiC nano-powder filled the space between the Kevlar threads so TiC assisted Kevlar to absorb ballistic energy and improved the ballistic performance of the material (Haro *et al.*, 2016).

Meanwhile Figure 6(b) illustrates that the more Kevlar layers were used, the deeper the penetration caused by the projectile because the thicker the composite absorbed more energy (Nguyen *et al.*, 2015). Also, the deeper penetration on the laminate composite caused by the bullet, the less defect found on the Al plate because of the dominant role of Kevlar in absorbing energy during the shear plugging process so the rest of the absorption ran into the bulging process (Goode *et al.*, 2019). That said, the Al plate mainly resisted the energy with regards to the structural aspect of composite.

Meanwhile, the laminates without impregnation had more swallow depth of penetration since the bullet bounced off after hitting the tested laminate composite. This process delaminated the composites as shown in the red

circles in Figure 7. This is caused by the adhesive layer from a mixture of epoxy resin with hardener was more brittle than aluminum and Kevlar so the adhesive layer presented in the laminate composite would be the highest energy absorbent from the bullet and crack easily (Grujicic *et al.*, 2012). Therefore, the penetration depth of the three laminate composites could not be calculated.

Figure 8(a) is a visualization of ballistic testing samples from the side view. There was petalling on the first layer of the Al plate as well as fiber damage on Kevlar fabrics for every composite. Also, there was a piece of Al plate in each composite that was pushed into those due to the trajectory of the bullet known as plugging. Meanwhile, Figure 8(b) shows the composites' top view that describes the perforation made after the ballistic test.

Since all existing laminate composites did not experience penetration by bullets, it was unlikely to identify the maximum absorbable energy for each laminate composite. However, we can find out the energy absorbed in this ballistic test using the calculation shown in the equation below. Because of using a pistol named P1, we could conclude that the initial velocity was 380 m/s and the final speed was 0 m/s because the bullets did not experience penetration by a projectile. The projectile used for the ballistic testing was a bullet with a caliber of

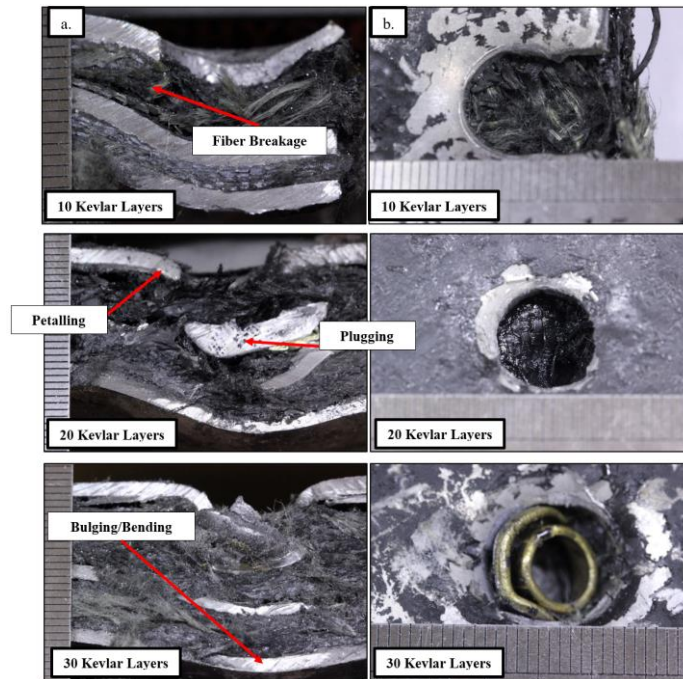


Figure 8. (a) (a) Side view; (b) Top view of Composites Visualization after ballistic test

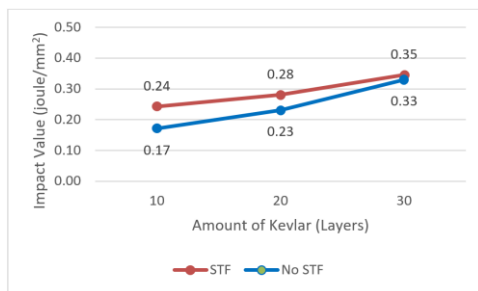


Figure 9. Impact value of composites after impact tests

9×19 mm with a mass of 8 grams (Scataglini *et al.*, 2019). The formula is shown below and the result is about 577.6 joules.

$$\text{Energy absorbed or dissipated}(J) = \frac{1}{2}mV_i^2 - \frac{1}{2}mV_r^2 \dots (1)$$

where

m = Mass of the bullet used (kg)

V_i = Initial velocity of the bullet (m/s)

V_r = Final velocity of the bullet after pass through the composite (m/s)

Results and Analysis of Impact Testing

This research resulted in the impact value of material after the test. The result are shown on Figure 9.

From Figure 9, it can be seen that there was an increase in the impact value of each increase in the

amount of Kevlar. This was happened due to the resistance of each layer, which helped the material to absorb energy from the pendulum (Malingam *et al.*, 2016).

The impregnated Kevlar constantly had greater impact value than composites with plain Kevlar as the TiC nano-powder filled the space between the impregnated Kevlar fibers. Thus, the presence of TiC boosted the Kevlar's ability to absorb energy. Also, TiC nano-powder also strengthened the Kevlar's structure so its fibers would be unlikely to undergo shear stress, considering it would cost more energy to create fiber pull-out (Haro *et al.*, 2016).

Conclusions

- The addition of STF to Kevlar had appropriate effects on the composites after ballistics and impact testing. This is because the presence of STF in Kevlar can increase the performance of composites in absorbing energy.

- The additional Kevlar layer to a laminate composite also results in positive impacts on the ability of the laminate composite to absorb energy, both in the ballistic and the impact testing, due to the more Kevlar used, the greater capacity of the composite to absorb energy. Even though the high number of Kevlar results in the higher penetration depth, the failure caused by the ballistic test was the lowest, and did not significantly create any changes

into the composite.

- The addition of STF to Kevlar greatly affects the microstructure of the Kevlar surface itself. In the Kevlar with STF, it can be seen that the Kevlar spaces are filled with STF.

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 KRUPT Grant with contract number: NKB-5/UN2.RST/HKP.05.00/2020

References

- Goode, T., Shoemaker, G., Schultz, S., Peters, K., and Pankow, M. (2019). Soft body armor time-dependent back face deformation (bfd) with ballistics gel backing. *Comp. Struct.*, 220:687-698.
- Grujicic, M., Pandurangan, B., and d'Entremont, B. (2012). The role of adhesive in the ballistic/structural performance of ceramic/polymer-matrix composite hybrid armor. *Mat. Design.*, 41:380-393.
- Haro, E., Odeshi, A.G., and Szpunar, J. (2016). The energy absorption behavior of hybrid composite laminates containing nano-fillers under ballistic impact. *Int. J. Impact Eng.*, p. 11-22.
- Liu, L., Zhao, Z., Chen, W., and Luo, G. (2018). Influence of pre-tension on ballistic impact performance of multi-layer Kevlar 49 woven fabrics for gas turbine engine containment systems. *Chinese J. Aeronau.*, 31(6):1,273-1,286.
- Malingam, S.D., Subramaniam, K., Selamat, M., Said, M., and Subramonian, S. (2016). A study on impact behaviour of a novel oil palm fibre reinforced metal laminate system. *ARPN J. Eng. Appl. Sci.*, 11(4):2,483-2,488.
- Nguyen, L., Ryan, S., Cimpoeru, S., Mouritz, A., and Orifici, A. (2015). The effect of target thickness on the ballistic performance of ultra high molecular weight polyethylene composite. *Int. J. Impact Eng.*, 75:174-183.
- Rusnaldy, R., Nugroho, S., Haryanto, I., Herlangga, H., Anastasia, J., and Arifin, F. (2019). Pembuatan Pelat Baja untuk Material Tahan Peluru untuk Kendaraan Tempur. *ROTASI*, 21(4):264-270.
- Scataglini, S. and Paul, G. (2019). *DHM and posturography*. San Diego: Elsevier Science Publishing.
- Suhdi, S., Mahardika, S., and Rosa, F. (2016). Analisa Kekuatan Mekanik Komposit Seratsabut Kelapa (Cocos Nucifera). *J. Teknik Mesin.*, 2:29-36.
- Vemuri, M. and Bhat, T. (2011). Armour protection and affordable protection for futuristic combat vehicles. *Def. Sci. J.*, 61:394-402.