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Authors: Sofyan Djamil, NPG Suardana, Agustinus Purna Irawan and IKG Sugita
Corresponding Author: agustinus@untar.ac.id

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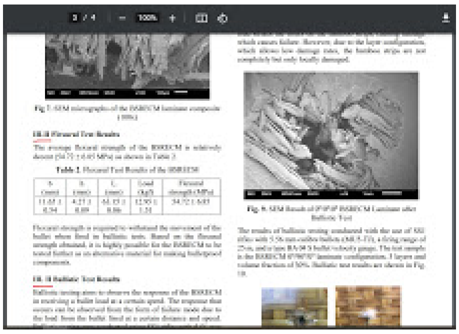

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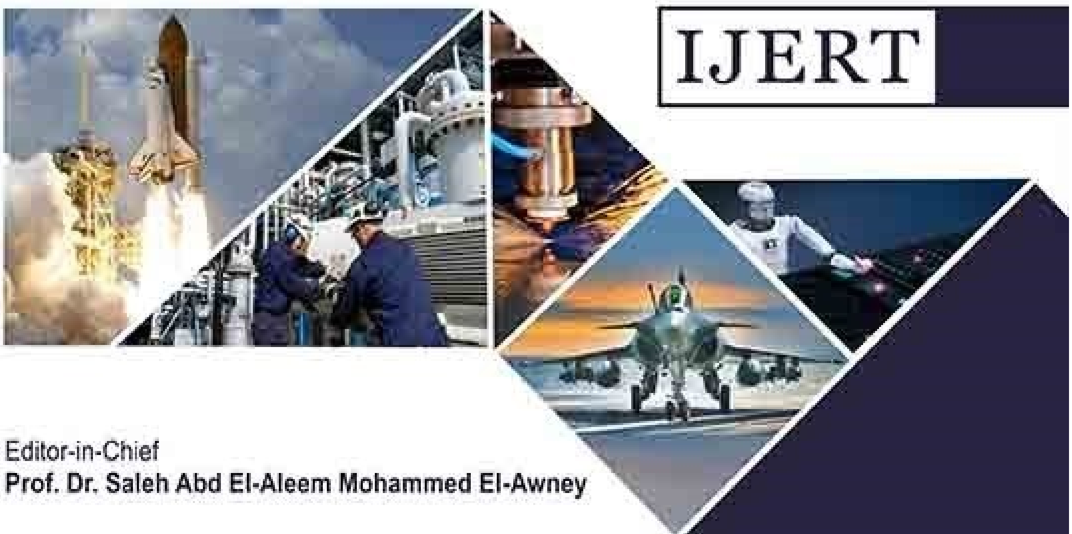

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Contents

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Ballistic Failure Mode of Apus Bamboo Strips Reinforced Epoxy Composite Materials

Sofyan Djamil[1], NPG Suardana[2], Agustinus Purna Irawan[3] and IKG Sugita[4]
[1,3]Mechanical Engineering Department, Universitas Tarumanagara, Indonesia
[1,2,4]Mechanical Engineering Department, Universitas Udayana, Indonesia

Abstract

Indonesia has abundant natural fibre potential to be developed into engineering materials with good strength. One of the potential natural strips in Indonesia is bamboo fibre. This study aims to determine the tensile strength, flexural and ballistic failure mode of Apus Bamboo Strips Reinforced Epoxy Composites Materials (BSRECM) as an alternative material for making bulletproof products. The research was carried out by making epoxy bamboo fibre composites with laminate configurations of $0^0/0^0/0^0$ and $0^0/90^0/0^0$, thickness of 4.5 mm, 3 layers, and volume fraction of 30%. Bamboo strips were soaked in 5% NaOH, for 72 hours, and dried for 48 hours at room temperature. Following that process, bamboo strips are heated in an oven at 40^0C for 2 hours, then woven and laminated using epoxy resin. The tests carried out were tensile, flexural and ballistic tests. Ballistic testing was carried out with a firing range of 25 m and bullet speed of 900 ± 30 m/s with an Indonesian SS1 rifle. Based on the tests results, it was obtained that the average tensile strength was 50.49 ± 3.77 MPa, the average strain was 5.5 ± 0.8%, the average flexural strength was 54.72 ± 6.85 MPa. The ballistic failure mode of epoxy bamboo fibre composites with laminate of $0^0/0^0/0^0$ configuration in the form of partial penetration failure mode and has a complete penetration mode for specimens with $0^0/90^0/0^0$ laminate configuration. SEM observations with $0^0/0^0/0^0$ laminate configuration shows that the bamboo strips are not completely but only locally damaged, the laminate configuration $0^0/90^0/0^0$ damage that occurs on the front surface, the level of damage tends to widen due to the high impact load of the bullet projectiles. The results of this study will be able to be used as a reference for further.

Keywords: Bamboo Strips, Tensile Strength, Flexural Strength, Ballistic Test, Failure Mode

I. INTRODUCTION

The development of natural fibre composites continues to increase in proportion with the need for products that are environmentally friendly, recyclable and abundant. One of the natural fibres that is potential to be developed as a technical material with various uses is the Apus bamboo fibre. Apus bamboo fibre is feasible to be developed because it has several advantages such as environmentally friendly, cheaper manufacturing costs and materials, abundant, and can be replanted for sustainability [1], [2], [3], [4], [5].

This study aims to determine the ability of bamboo strips composite with an epoxy matrix as an alternative material for making bullet-proof products. This is in proportion with the increasing need for using bullet-proof protective materials. In making bulletproof materials, it is necessary to design a material that is lightweight and has a high level of protection [6], [7]. Bamboo strips composite is one alternative for making body armour from sharp weapons and bullet shots. Body armours can prevent penetration and the occurrence of defects or damage to the human body [6], [8], [9]. The characteristics of a human body armour can be measured in terms of the interaction between the armour and the human body. Effectively as a protector of the human body, there must be no penetration inside of the human body when receiving external loads such as bullets and sharp weapons.

II. MATERIAL AND METHOD

II.I Bamboo Strips Preparation

The bamboo strips used in this study were Apus Bamboo (Giganchtoloa Apus), taken from Pebasiran village, Parung Panjang, West Java, Indonesia. The bamboo is cut manually using a strip knife with a thickness of 0.5 - 0.7 mm and a width of 5 - 7 mm. The bamboo strips were soaked in 5% NaOH for 72 hours and dried for 48 hours at room temperature (Fig. 1). The bamboo fibres are then heated in an oven at a temperature of 40^0 C for 2 hours to remove the moisture content in the fibre and are made woven (Fig. 2)

Fig. 1. Bamboo Strips Preparation

Fig. 2. Bamboo Strips Drying Process at a Temperature of 40^0C

II.II Fabrication of Laminate Composites

The manufacturing process of bamboo strips composite is carried out by hand layup method using a mould of 200 x 200 mm steel plate made in 3 layers and 4.5 mm thickness. The matrix used is epoxy resin of diglyceryl ether of bisphenol type A with a density of 1.15 x 103 kg/m^3 and working temperature of 120^{0}C. The epoxy has the characteristics of having high strength, good dimensional stability, low shrinkage, and a high level of adhesive. Two types of the test samples were made with the orientations of 0^0/0^0/0^0 and 0^0/90^0/0^0 (Fig. 3)

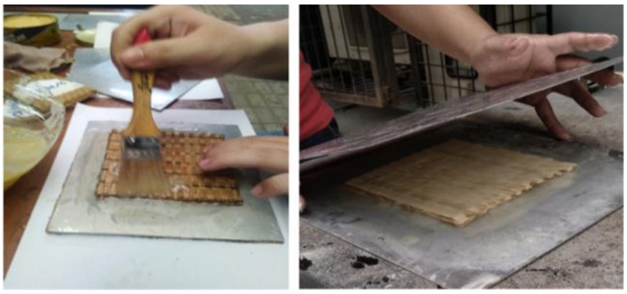

Fig. 3. Fabrication of the BSRECM

II.III Tensile Strength Test

In reference to the ASTM D 3039 standard, tensile testing was conducted by using the Universal Testing Machine in a room temperature of 22^{0}C and relative humidity of 63%. The crosshead speed for tensile testing was 2 mm/min. The dimensions of the specimens for tensile testing were 250 x 25 x 4 mm (length x width x thickness). Six samples were tested for tensile testing. The average values were reported including the standard deviations. The Universal Testing Machine and the process of tensile testing are shown in Fig. 4. Each sample was loaded to failure. Based on tensile testing will be obtained for tensile strength and Young's Modulus of the BSRECM [10].

Fig. 4. Tensile Specimen Test of the BSRECM

II.IV Flexural Strength Test

In reference to the ASTM D 790-03 standard, flexural testing was conducted by using the Universal Testing Machine with a testing room temperature of 22.5^{0}C and relative humidity of 63.5%. The load was applied midway between the supports with a crosshead speed of 1.7 mm/min (Fig. 5). Each sample was loaded to failure. The dimensions of the specimens for flexural testing were 120 x 10 x 4 mm (length x width x thickness). Six samples were tested for flexural testing. The average values were reported including the standard deviations [10].

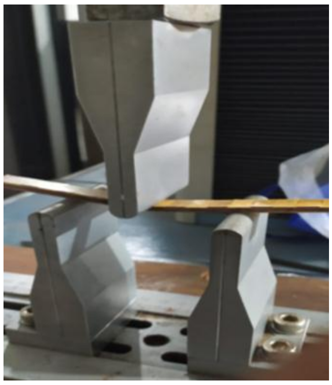

Fig. 5. Flexural Specimen Test of the BSRECM

II.V Ballistic Test

Ballistic testing was carried out at the ballistic testing laboratory of the Indonesian Army Research and Development Agency (Dislitbangad), Bandung, Indonesia, as in Figure 6. This test was conducted by the use of 5.56 mm bullets (MU5-TJ) with an Indonesian-made SS1 gun by the serial number of JaT 97045854, bullet speed 900 ± 30 m/s, firing range of 25 m. Observations on ballistic test results focused on the failure mode that occurred in the BSRECM.

Fig. 6. Ballistic Testing Process of the BSRECM

III. RESULT AND DISCUSSION

III.I Tensile Test Results

Based on the results of tensile test on the test sample of the BSRECM, the average tensile strength is obtained as follows (Table 1).

Table 1. Tensile Test Results of the BSRECM

Load (kgf)	Area (mm^2)	Strain (%)	Ultimate tensile strength (MPa)
265 ± 24.4	53.8 ± 3.7	5.5 ± 0.8	50.49 ± 3.77

The average tensile strength of the BSRECM resulting from this test is relatively decent. Based on the obtained tensile strength, the BSRECM was assessed further in ballistic testing to obtain alternative materials for making bullet-proof components. The results of the tensile strength are also supported by the results of observations using SEM on the tensile test sample. Based on the SEM test, the interface between the strips and the matrix is satisfactory, no voids and delamination are seen (Fig. 7).

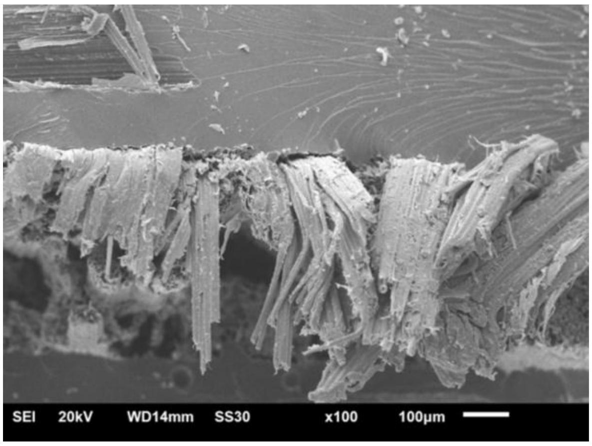

Fig 7. SEM micrographs of the BSRECM laminate composite (100x)

III.II Flexural Test Results

The average flexural strength of the BSRECM is relatively decent (54.72 ± 6.85 MPa) as shown in Table 2.

Table 2. Flexural Test Results of the BSRECM

b (mm)	h (mm)	L (mm)	Load (kgf)	Flexural strength (MPa)
11.65 ± 0.54	4.27 ± 0.09	63.15 ± 0.06	12.95 ± 1.51	54.72 ± 6.85

Flexural strength is required to withstand the movement of the bullet when fired in ballistic tests. Based on the flexural strength obtained, it is highly possible for the BSRECM to be tested further as an alternative material for making bulletproof components.

III. III Ballistic Test Results

Ballistic testing aims to observe the response of the BSRECM in receiving a bullet load at a certain speed. The response that occurs can be observed from the form of failure mode due to the load from the bullet fired at a certain distance and speed. Ballistic testing was conducted using SS1 rifles with 5.56 mm calibre bullets (MU5-TJ), a firing range of 25 m, and a BA 04 S type bullet velocity gauge. The test sample was a $0^0/0^0/0^0$ laminate configuration, 3 layers and volume fraction of 30 %. Ballistic test results are shown in Fig. 8.

a. Bullets b. Front View c. Rear View

Fig. 8. Ballistic Test Results of the BSRECM $0^0/0^0/0^0$ Laminate

Fig. 8 shows the ballistic test results of the BSRECM $0^0/0^0/0^0$ laminate configuration and bullet velocity of 894.2 m/s. The front and back views of the specimens show the partial penetration failure mode in the form of small deformations around the area of damage. In Fig. 9, the SEM observations on the front surface of the ballistic test specimens with the BSRECM $0^0/0^0/0^0$ laminate configuration show the fracture area of the front surface as a result of the initial impact load, which occurs in the front surface of the BSRECM. Most of the load strikes the fibres on the bamboo strips, causing damage which causes failure. However, due to the layer configuration, which allows low damage rates, the bamboo strips are not completely but only locally damaged.

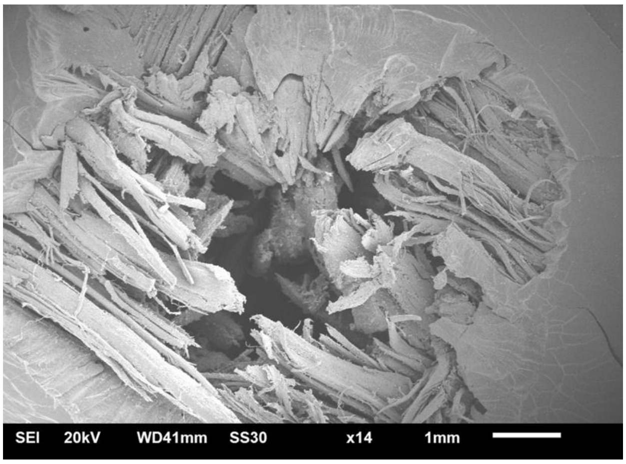

Fig. 9. SEM Result of $0^0/0^0/0^0$ BSRECM Laminate after Ballistic Test

The results of ballistic testing conducted with the use of SS1 rifles with 5.56 mm calibre bullets (MU5-TJ), a firing range of 25 m, and a type BA 04 S bullet velocity gauge. The test sample is the BSRECM $0^0/90^0/0^0$ laminate configuration, 3 layers and volume fraction of 30%. Ballistic test results are shown in Fig. 10.

a. Front view b. rear view

Fig. 10. Ballistic Test Results of the BSRECM $0^0/90^0/0^0$ Laminate

The greatest degree of deformation at the front surface occurs in the BSRECM with the laminate configuration of $0^0/90^0/0^0$. The failure mode describes the occurrence of surface deformation in the front and rear-view specimens caused by the projectile energy. This indicates a complex penetration failure mode. A bullet that is fired into the target area of the specimen results in penetration of the deformed front surface. The type of laminate configuration and the velocity of each projectile can affect the damage and performance of the test specimen [6], [8], [9]. This has been demonstrated by previous researchers who found that the area of damage increases when the impact load increases [11].

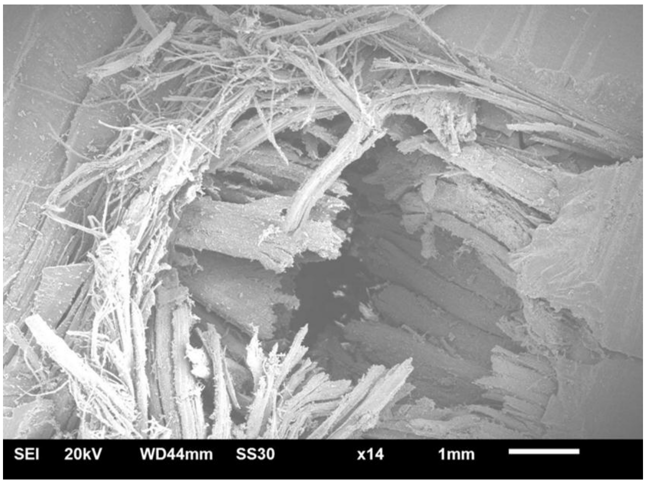

Fig. 11. SEM Result of the BSRECM $0^0/90^0/0^0$ Laminate after Ballistic Test

Fig. 11 shows SEM observations with a laminate configuration of $0^0/90^0/0^0$ and the damage to the front view surface, due to impact loads. Part of the load strikes the bamboo strips, causing surface damage. The damage occurs on the front surface with the level of damage tends to widen. This is due to the factor of velocity and laminate configuration. The bamboo strips were broken randomly and spread outward from the area of damage. From the condition of the impact load, it is clearly visible on the front surface that the fibre is damaged on the bamboo strip due to the high impact load of the bullet projectiles. The different layers show that the fibre breaks randomly along at its weakest point [12]. The damage that occurs is usually confined to the zone near the impact and is limited by the velocity of the bullet and the impact load. The magnitude of the impact load is one of the factors that contribute to the fibre breakdown [10], [12], [13]. The fibres on the surface which are subjected to impact loads, have been observed to appear with a smooth surface between the laminate boundaries [12], [13]. The results of this study indicate that the BSRECM is exceptionally potential to be further developed as an alternative component for bullet-proof materials. More testing is needed with various angles of fire, ballistic speeds and ranges of fire. These data are very useful for the further design of epoxy bamboo fibre composites as a bullet-proof material.

IV. CONCLUSION

Research and ballistic testing have been carried out on epoxy bamboo fibre composites. The observation focus is the failure mode of the composite material against the impact load of a bullet fired at a 25 m radius. Based on this research, it can be concluded that specimens with a $0^0/0^0/0^0$ laminate configuration have a partial penetration failure mode and the specimen with a $0^0/90^0/0^0$ laminate configuration has a complex penetration mode of failure. SEM observations with $0^0/0^0/0^0$ laminate configurations showed that the bamboo strips were not completely but only locally damaged. Furthermore, the results of the $0^0/90^0/0^0$ laminate configuration indicate damages to the front surface, with the degree of damage tending to expand. From the perspective of the impact load, the bamboo strips were damaged on the front surface due to the high impact loads of the bullet projectiles. The results of this study will be able to be used as a reference for further development.

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