Analysis of Damage Area of Fiberglass/Polyester Bi-Panel with Rice Husk Ash as a Filler Caused by the Impact of High-Speed Particles

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Abstract. Analysis of the damaged area of the composite bi-panel fiberglass/polyester with the addition of rice husk ash as a filler have been presented in this paper. The area of damage is caused by the impact of high-speed particles. Bi-panel composites were made by hand lay-up of S-glass and unsaturated polyester resin BTQN 157 ex with variations of 3, 5, 7, 9 %v rice husk ash as a filler. The impact test were carried out using a 9 mm caliber FN gun in accordance with NIJ level IIIA standards. The results show the area of damage caused by a projectile decrease with the increasing amount of Rice husk %v. There is a significant effect with the addition of rice husk ash filler on the composite of bi-panel fiberglass/polyester to the impact of high-speed particles. The rice husk ash could be used as an alternative for filler in Polyester/Fiberglass composite for body armor application.

Keywords: bi-panel, fiberglass/polyester, rice husk ash, impact,

1. Introduction
Some previous studies have reported the use of metal, ceramic, polymer, natural fiber or composite as body armor materials. But the researches on this material are still ongoing on searching the lightest, the cheapest, environmentally friendly and also the geometry and the number of layer [1]. Tasdemirci et al. (2012) reported the results of research on testing aluminum foam and Teflon composites without inserts and which were inserted by 3 rubber which was carried out using AP Projectile type M61 at a shooting distance of 15 m, experiencing an increase in kinetic energy that was almost the same [2]. Composites given inserts cause delayed kinetic energy that arises and drastically reduces kinetic energy in both models [3-5]. Ritonga (2014) reported that the addition of Hollow Glass Microsphere (HGM) volume fraction of 16% in epoxy showed a maximum toughness value of 21.54 x 10-3 J / mm3 [6]. Maples et al. (2014), reported that the compressive and tensile properties that occur in carbon fiber reduced significantly at 120 °C due to the presence of softened polystyrene interleaves. The results of the flexural strength test at 20°C indicate that there is a need for improved adhesion between polystyrene and fiber-carbon with epoxy [7]. It has also been investigated that the average absorption of epoxy matrix kinetic energy with HGM epoxy reinforcement for vehicle front bumper is 86.39% [8]. Meanwhile, the use of ballistic devices with a thickness of 20 mm, capable of absorbing bullet energy is smaller than 170 Joules [9-10].
The existing body armor is still developing to enhance its performance. In addition to the reliability of the body armor such as opaque and capable of providing protection from projectile impact, there are problems that arise when applied to objects that move like a soldier and his combat vehicle. To answer the issue of this body armor, research needs to be done. The material chosen for this composite body armor is a matrix using polyester because it is lightweight, economical and environmentally friendly. Furthermore, the reinforcement uses fiberglass because it increases mechanical strength and is more economical than fiber-kevlar or other aramid fibers which have always been used for making body armor composites.

This objective of this study is to obtain alternative materials other than Kevlar fiber or other aramid fibers which are relatively expensive and imported from abroad. For this reason, it is necessary to try the use of fiberglass as reinforcing fiber and polyester as a matrix and the use of rice husk ash filler to obtain an armored body where all the materials have been produced in Indonesia.

2. Experimental procedures

2.1. Materials
Polyester and fiberglass supplied from PT Justus Sakti in Jakarta Indonesia. Rice husk ash was manually prepared using a table loom. The density of the rice husk ash is 1.40 g/m$^3$. The parameters of rice husk ash are provided. The resin used in this study is unsaturated polyester BQTN 157 with a density of 1.08 g/m$^3$.

2.2. Fabrication of composite laminates
The composite was manufactured in the form panel with fiberglass, rice husk ash as a filler and polyester resin as a matrix. The constant fraction volume of fiberglass used in this study was a woven roving S-Glass denier 800 g/cm$^2$, which was taken from the supplier’s data sheet. The resin was cured using methyl ethyl ketone peroxide (MEKP) is an organic peroxide. Rice husk ash supplied from the results of processing themselves. Panel laminated composites of (20 x 20 x 0.4) cm size were used for ballistic testing. The hand-lay-up method was used to fabricate laminates of woven roving fiberglass and rice husk ash as a filler in polyester resin. The samples consisted of 7-layers of woven roving fiberglass in the same direction (0/90$^\circ$). The woven roving fiberglass fabrics were hand laid-up with the polyester + rice husk ash matrix by mixing resin and MEKP catalyst in the ratio of 5%. Two thick mild steel plates were used as a mold (20 cm x 20 cm) in the fabrication process. The composites were cured by applying compression pressure using load which is equal 150 Kg on the top of the mold and cured at room temperature for 2 days.

2.3. Ballistic testing
The experiment consists of 2 variations where each variation consist of two panels as shown in Figure 1. Each variation consists of 4 composite bi-panel specimens. These bi-panel specimens are stacked together without adhesives. The front panel is panel 1 and the back is panel 2. For variation 1 the front part is panel 1 with the composition without filler, and the rear part is panel 2 with the filler of 3, 5, 7, and 9 %v rice husk ash. Whereas variation 2 is the opposite of variation 1, the front is panel 1 with fillers of 3, 5, 7, and 9 %v rice husk ash and the back is panel 2 without filler. The composite bi-panel the configuration is shown in Figure 1.

The ballistic impact experiment was conducted using 9 calibers (diameter of 9 mm) fragment simulating projectiles (FSPs) with a weight of about 8.1 g. Each sample was impacted according to BA 9000 NIJ standards in 2012 on the requirements of body armor system (Type IIIA in armor level). The ballistic testing setup used is shown in Figure 1. Bullet speed is measured by Chronograph Prochrono Digital brand. The gun used for ballistic testing was the Belgian Fabrique Nationale (FN) 9 mm.
3. Results and discussion

Table 1 shows the results of ballistic tests on variations 1 and 2. Variation 1 in specimens 1b and 3b show that the composite bi-panel is not punching until panel 2. However, specimens 2b and 4b penetrate until panel 2. In variation 2 for specimens 1a, 2a, 3a, and 4a show the restrained projectile in panel 1, and panel 2 only shows the matrix crack. So variation 2 shows good results for holding the impact of bullet projectiles. Panel 1 without filler did not show a low performance for the body armor panel because all panels were punching, this was proven in variation 1. Although in variation 2, panel 2 without filler was not punching but panel 1 showed a significant area of damage. The rice husk ash as a filler has an influence on the performance of bi-panels composite on the impact of bullet projectiles.

Table 1. Ballistic test results of composite bi-panel specimens on variations 1 and 2

| Variation | Specimen codes | Arrangements of bi-panel with and without filler | Condition after the impact of the projectile |
|-----------|----------------|-----------------------------------------------|---------------------------------------------|
|           |                | Panel 1 | Panel 2 | Panel 1 | Panel 2 |
| 1         | 1b             | 0 %v    | 3 %v    | punch   | restrained |
|           | 2b             | 0 %v    | 5 %v    | punch   | punch v_f: 250 m/s |
|           | 3b             | 0 %v    | 7 %v    | restrained | matrix crack |
|           | 4b             | 0 %v    | 9 %v    | punch   | punch v_f: 230 m/s |
| 2         | 1a             | 3 %v    | 0 %v    | restrained | matrix crack |
|           | 2a             | 5 %v    | 0 %v    | restrained | matrix crack |
|           | 3a             | 7 %v    | 0 %v    | restrained | matrix crack |
|           | 4a             | 9 %v    | 0 %v    | restrained | matrix crack |

3.1. The density of the composite

Figure 2 shows the composite with the addition of the fraction of the volume of rice husk ash will reduce the weight of the composite panel. The polyester-fiberglass composite panel shows the density of 1.613 g/cm\(^3\). With the addition of filler 3 %v of rice husk ash, the density of composite panel mass decrease to 1.610 g/cm\(^3\). Likewise, with the addition of 5 %v, the density is 1.609 g/cm\(^3\). Furthermore, the addition of 7 %v of rice husk ash, the density decreased again to 1.606 gram/cm\(^3\). Then in the volume fraction of 9 %v, the rice husk ash tends to decrease to 1.604 g/cm\(^3\). It turns out that in general the density decreases compared to the panel without filler that is visible. The ballistic test was a double-panel composite with 9 %v filler shows the most amazing performance. It turns out that by increasing the fraction of the volume of rice husk ash as a filler can improve the higher performance of the double-panel composite for the body armor function.
3.2. The ballistic test of variation 1

Figure 3 shows the deformation of the projectile after impact. The projectile with an original diameter of 9 mm became flat after the test (diameter of 20 mm). Based on projectile data it will break and break if it hits a hard surface. Based on the fact that the projectile was held in panel 2 after penetrating panel 1.

Figure 4 shows the area of damage that occurs in the bi-panel composite specimen 1b. The specimen 1b arrangement is the first panel without filler and the second panel 3 %v filler. In panel 1 in the front, the former projectile hole is 10 mm wide. The back of the panel 1 break fiber with a hole due to the impact of a 20 mm wide projectile. Then the projectile is held in panel 2 by showing the area of the matrix damage to be wide with a width of 70 mm, and the back of panel 2 is not damaged. The bullet projectile penetrates panel 1 and is then held in panel 2. Panel 1 with filler 3 %v has not been able to hold the projectile. It turns out that panel 2 has a contribution to holding back the rate of projectiles that have experienced a slowdown in panel 1.

Figure 5 shows the results of the ballistic test in specimen 2b with a filler composed of 5 %v of rice husk ash. The specimen 2b arrangement is the first panel without filler and the second panel 5 %v filler. After the ballistic test shows the entire panel on this bi-panel composite were punched by the bullet projectiles. The projectile speed after penetrating both panels is 250 m/Sec from 380 m/Sec. (Table 1). The damage pattern is shown as in Figure 5, with the damaged area of panel 1 in the form of a used projectile hole and there is a small matrix damage. This indicates very little energy distribution to all fiberglass. Likewise, the same thing was shown by fiberglass panel 2 as reinforced which did not respond to kinetic energy. In this case, the filler distributed in the panel is less than optimal for preventing projectile impact.
Figure 4  Specimen 1b showing the damaged area in bi-panel composite consists of panel 1 without filler and panel 2 with 3 %v rice husk ash. Front view (a) and back view (b) of panel 1. Front view (c) and back view (d) of panel 2.

Figure 5  Specimen 2b showing the damaged area in bi-panel composite consists of panel 1 without filler and panel 2 with 5 %v rice husk ash. Front view (a) and back view (b) of panel 1. Front view (c) and back view (d) of panel 2.

Figure 6 shows the damaged area that occurred in bi-panel specimens 3b with a filler composed of 7 %v of rice husk ash. The specimen 3b arrangement is the first panel without filler and the second panel 7 %v filler. In panel 1 in the front, there was a 9 mm wide projectile hole. The back of panel 1 is a damaged matrix of 27 mm wide and punching in Figure 6b. Next panel 2 shows the front the damaged area of the matrix with a width of 18 mm and the rear panel 2 punching with a width of 13 mm in Figure 6d. The ability of panels 1 and 2 to impact bullet projectiles is not good. This is caused by the percentage of filler is smaller and there is a wider distance (space) between panels 1 and 2 than recommended (below 1 mm). It is estimated that there are production defects when making composites. After the ballistic test shows the 1st panel is not penetrated by the bullet projectile and is held in the panel. Next panel 2 shows the basin due to the impact of deformed projectiles as shown in Figure 6.

Figure 7 shows the damaged area that occurs in the bi-panel composite specimen 4a without filler in panel 1 and 9 %v filler in panel 2. In panel 1 in the front, there is a 10 mm wide projectile hole. The back of the panel 1 breaks fiber with a hole due to the impact of a 20 mm wide projectile. Then the projectile is held in panel 2 by showing the area of the matrix damage to be wide with a width of 70 mm, and the back of panel 2 is not damaged. Figure 7 shows the damaged area that occurred in bi-panel 4B specimens of 0 %v filler in panel 1 and 9 %v filler in panel 2. In panel 1 in the front, there is a 9 mm wide projectile hole. The back of the panel 1 is a 27 mm wide and translucent matrix damage as shown in Figure 7b. Next, panel 2 shows the area of front-facing matrix damage with a width of 18 mm. The back panel 2 is punching with broken fiberglass broken matrix with a width of 13 mm in Figure 7d.
Figure 6 Specimen 3b showing the damaged area in bi-panel composite consist of panel 1 without filler and panel 2 with 7%v rice husk ash. Front view (a) and back view (b) of panel 1. Front view (c) and back view (d) of panel 2.

Figure 7 Specimen 4b showing the damaged area in bi-panel composite consists of panel 1 without filler and panel 2 with 9%v rice husk ash. Front view (a) and back view (b) of panel 1. Front view (c) and back view (d) of panel 2.

This specimen 4b has the ability to resist projectile impact. There is an effect of 9%v rice husk ash filler on impact ability. The bi-panel composition also affects the panel's impact ability. The wider area of the matrix damage indicates kinetic energy is distributed evenly throughout the direction and layer of the fiber. Specimen 4b shows that the impact ability is not as good as the specimen 3b. This was caused by defects in production when manufacturing composites. There is a larger space than the bi-panel recommendation. It is suspected that there is a defect in the laminate in the form of uneven resin on the entire surface of the fiberglass and the presence of air bubbles trapped inside the panel laminate. The uneven mixture of polyester resin with rice husk ash filler. The overall capability of panel 1 is still below panel 2 because there are still production defects.

3.3. The ballistic test of variation 2
Ballistic test results in specimens 1a in panel 1 composition with 3%v rice husk ash filler and panel 2 without filler. The test results showed panel 1 succeeded in holding the bullet projectile and was stuck on the panel. Panel 2 does not suffer significant damage, only the matrix breaks. Overall the results of the ballistic test and the damage that occur can be seen in Figure 8. The damage area that occurs in bi-panel specimens 1a 3%v filler in panel 1 and 0%v filler in panel 2. In panel 1 the front is visible due to projectile impact 9 mm wide. The back of panel 1 damage the matrix with a width of 17 mm, there are some broken fiberglass parts and the panel has not penetrated as shown in Figure 8b. Furthermore, panel 2 shows the frontal matrix damage area with a width of 18 mm and the rear panel 2 there is no fiberglass damage but there are matrix cracks with the width of 40 mm in Figure 8d. The ability of specimens 1a is better than previous specimens. There is a filler effect of rice husk ash and a bi-panel arrangement of the ability to resist impact. Bi-panel capability increases by changing the position of the panel arrangement as in specimen 1b.

Figure 9 shows the area of damage that occurs in bi-panel specimens 2a 5%v filler in panel 1 and without filler in panel 2. In panel 1 the front is visible hole due to the impact of projectiles with a width of 9 mm. The back of panel 1 damage the matrix with a width of 60 mm, there are several broken fiberglass parts and the panel has not penetrated. Next panel 2 shows the front area matrix damage area with a slight width of 10 mm and the rear panel 2 there is no fiberglass damage but there are matrix cracks with the pattern as in Figure 9d. The area of damage in panels 1 and 2. fiberglass is
unable to hold projectiles and breaks. The holes that occur to the rear surface of panel 1 with a diameter of 9 mm and the back of 15 mm. In panel 1, the more dominant damage is broken fiberglass breaks and fewer matrix cracks, this indicates the panel does not work better and there is no kinetic energy distribution in this panel. Likewise in panel 2, the same thing is shown as in panel 1 with fewer matrix damage areas and broken fiberglass by forming a hole in panel 2.

Figure 8 Specimen 1a showing the damaged area in bi-panel composite consists of panel 1 with filler 3% wt rice husk ash and panel 2 without filler Front view (a) and back view (b) of panel 1. Front view (c) and back view (d) of panel 1.

Figure 9 Specimen 2a showing the damaged area in bi-panel composite consists of panel 1 with filler 5% wt rice husk ash and panel 2 without filler. Front view (a) and back view (b) of panel 1. Front view (c) and back view (d) of panel 1.

Figure 10 is the result of ballistic tests on specimens 3a with a filler composition of 7 %v of rice husk ash. The first-panel arrangement with 7 %v filler and second panel without filler. The ballistic test results showed panel 1 was successful in holding the bullet projectile and was stuck on the panel. Panel 2 does not suffer significant damage, only the matrix breaks. The area of damage that occurs in bi-panel specimens 3a in panel 1 of the front is visible holes due to the impact of projectiles with a width of 9 mm. The back of panel 1 damage the matrix with a width of 60 mm, there are several broken fiberglass parts and the panel has not penetrated as shown in Figure 11b. Furthermore, panel 2 shows the front area matrix damage area with a little width of 10 mm and the rear panel 2 does not have fiberglass damage but there is a matrix with the pattern as shown in Figure 11d.

Figure 11 is the result of ballistic tests on specimens 4a with a filler composition of 9 %v of rice husk ash. The first-panel arrangement with 9 %v filler and the second panel without filler. After the ballistic test, the bullet projectiles were embedded in the first panel and the second panel only cracked the matrix. The area of damage that occurs in bi-panel specimens 4a is in panel 1 the front is visible hole due to the impact of projectiles with a width of 9 mm. The back of panel 1 damage the matrix with a width of 60 mm, there are several broken fiberglass parts and the panel has not penetrated as shown in Figure 11b. Next panel 2 shows the front area matrix damage area with a little width of 10 mm and the rear panel 2 there is no fiberglass damage but there are matrix cracks with the pattern as in Figure 11d. The ability of specimens 4a to resist the impact is better than previous specimens. There is a filler effect of rice husk ash and a bi-panel arrangement of the ability to resist impact. Bi-panel capability in resisting the impact increases by changing the position of the panel arrangement as in the specimen 4b.
4. Conclusion

Based on variations in rice husk ash fillers in bi-panel composites, the density becomes decrease with an increase in volume fraction. The damaged area in variation 1 indicates the effect of rice husk ash as a filler can resist the impact of projectiles. The damaged area gets smaller with the increase of filler volume fraction. In variation 2, the filler volume fraction increases become the performance of the composite bi-panel against projectile impact increase. The rice husk ash can affect the performance of bi-panel composites to be better as a body protector.

5. References

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**Acknowledgment**

The authors would like to show their appreciation Research and Development, Ministry of Defence and University of Indonesia for supporting this research activity.