Behavior of rice husk ash as a filler in polyester-fiberglass bi-panel composites which has the ability to withstand high-speed projectile impact

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Nazarudin Koto[1], Bambang Soegijono[2*] Anne Kusumayati[1], Harun M.Nasution[1], M. Faisol Luchaq.[1]

[1)] Defense Research and Development Agency , Jati No. 1 Pondok Labu South Jakarta 12450, Indonesia
[2)] Department of Physics, FMIPA Universitas Indonesia, Kampus UI Depok, West Java 16424, Indonesia

[*]Corresponding e-mail: bambangsg11@yahoo.com

ABSTRACT – This article discusses the behavior of rice husk ash as a filler in bi-polyester-fiberglass composite panels that have the ability to withstand high-speed projectile impacts. Bi-panel composites consist of unsaturated polyester resin BQTN 157 and reinforced woven S-glass roving with 3, 5, 7, and 9 v% rice husk ash variations. Then it was observed the decrease of panel performance into projectile ballistic impact. Then it was observed the decrease of panel performance into projectile ballistic impact. The structure characterizations of materials were carried out by simultaneous TGA (thermogravimetry) and DSC (differential scanning calorimeter) analysis. The impact tests were carried out with calibre ammunition of 9 mm bullet FN gun. The result showed rice husk additions decreased the panel density. There is an increase in panel decomposition temperature with the addition of rice husk ash. This decomposition temperature, has contributed to the characteristics of the material to be better. Then it also showed significant influence of rice husk ash on the strength of composite panels against the high impact of a bullet.

Keywords: Bi-panel; rice husk ash; polyester; fiberglass; TGA/DSC analysis: ballistic; impact

1. Introduction

For military or police officers who risk their lives in dangerous situations, the potential risk of being impacted by high-speed particles increases. So impact protection equipment for armor materials such as vests, helmets and protective coatings on vehicles becomes a necessity. Thus, the need for ballistic protection as part of safeguarding against threats and terror is increasing. Ballistic protection includes protection from the impact of bullet attacks and from the threat of stabbing or slashing of knives according to the National Institute of Justice Standard (National Institute of Justice, 2000). In ancient kingdoms, nations provided their knights and soldiers with armor and shields to protect the body from enemy attacks. In the medieval period these ballistic devices were generally made of metal..

This study aims to obtain alternative composite materials using bi panels, fiberglass as reinforcing fibers and polyester as a matrix and the use of rice husk ash as bio-filler, how is the behavior of rice husk ash as a filler for ballistic resistance.. We conducted a fiberglass-polyester composite panel by adding rice husk ash filler [8-14]. Rice husk ash as filler aims to increase the performance of the composite and is environmentally friendly. This composite is expected to be used as a protective material for the body. The making of this composite was carried out by hand lay-up with 7 pieces of fixed fiberglass, polyester mixed with rice husk ash filler in a variety of fractions of volumes 3, 5, 7 and 9 wt.% then the ballistic test is carried out according to NIJ Standard [15]. To determine the effect of rice husk ash on the composite bond, the characterization was carried out by using simultaneous TGA (thermogravimetry) and DSC (differential scanning calorimeter) analysis..

2. Experimental Detail

2.1. Materials

The composite was manufactured in the form of panel which consist of 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}as it is. 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. The organic peroxide resin was cured by using methyl ethyl ketone peroxide (MEKP) . The materials were then characterized by means were carried out by simultaneous TGA (thermogravimetry) and DSC (differential scanning calorimeter) analysis..

Rice husk ash supplied from the results of processing themselves. Polyester and fiberglass supplied from PT Justus Sakti (Jakarta, Indonesia). Bullet speed is measured by Chronograph Prochrono Digital brand. The gun used for ballistic testing is the Belgian Fabrique Nationale (FN) 9 mm calibre.

2.2. Fabrication of composite laminates
Panel laminated composites of 20 cm x 20 cm size were used for the ballistic testing. The hand-lay-up method was used to fabricate laminates of woven roving fiberglass and rice husk ash as filler in polyester resin. The samples consisted of 7-layers of woven roving fiberglass in the same direction (0/90^o). 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 mould (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 mould and cured at room temperature for 48 h. The samples with the variation number of ‘1' and ‘2' indicates consisting of one and two panels of double-panel respectively which located in the first and second panels of the configuration when ballistic test, as shown in Figure 1.

2.3. Characteristic and Ballistic testing
The characterization was carried out by using STA 6000 Simultaneous Thermal Analyzer. The ballistic impact experiment was conducted using 9 calibres (diameter of 9 mm) fragment simulating projectiles (FSPs) with a weight of approximately 8.1 g. Each sample was impacted according to BA 9000 NIJ standards in 2012 on the requirements of body armour system (Type IIIA in armour level).

3. Results and Discussion

3.1. The TGA/DSC analysis
Figure 1 shows the results of tests and interpretations of TGA / DSC that have been carried out on polyester resin, polyester-fiberglass, and polyester-fiberglass-rice husk ash. The TGA polyester curve shows decomposition starting at about 270 ^oC and finishing at around 425 ^oC. So that the reaction interval is obtained around 155 ^oC. Then the polyester-fiberglass TGA curve shows decomposition starting at 250 ^oC and finishing at 525. Then the reaction interval is 300 ^oC. So polyester-fiberglass shows a reaction temperature temperature that is twice as large as polyester. This means that polyester-fiberglass requires twice the reaction interval of polyester.

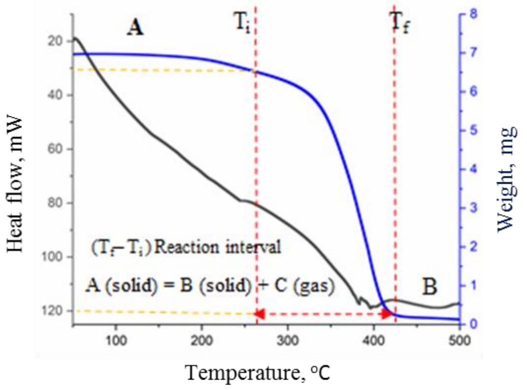


Figure 1. Results of TGA / DSC polyester

Figure 2 shows the TGA curve of polyester-fiberglass-rice husk ash, decomposition starts at 300 ^oC and finishes at around 420 ^oC. So that the reaction interval is around 120 ^oC. So the reaction interval of polyester-fiberglass-rice husk ash is decreased compared to polyester-fiberglass. This means that polyester-fiberglass-rice husk ash absorbs heat energy faster than polyester-fiberglass.

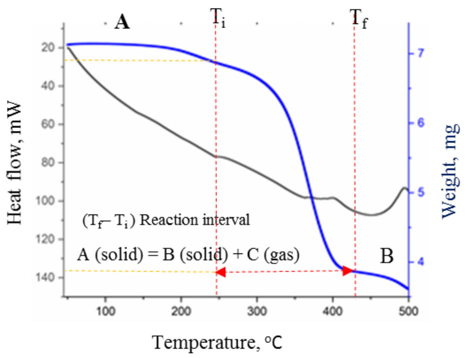


Figure 2. Results of TGA / DSC polyester-fiberglass

Figure 3 shows the results of the analysis of the TGA / DSC curve showing the contribution of rice husk ash as a filler in the bi-panel composite to increase its ballistic ability. This is indicated by the TGA curve of polyester-rice husk ash showing a large reaction interval compared to polyester-fiberglass. This means that polyester-rice husk ash takes longer to complete decomposition than polyester-fiberglass. With a long time this indicates the ability of polyester-rice husk ash to absorb heat longer. So the ability to absorb heat for longer is needed to reduce the heat from the projectile when an impact occurs.

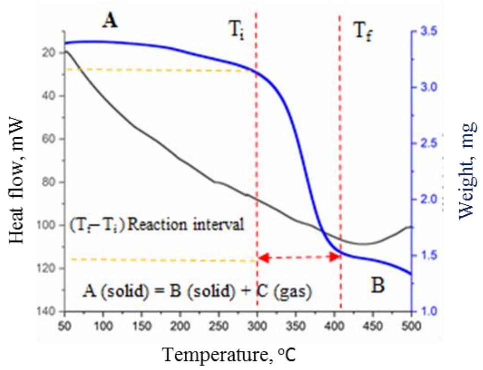


Figure 3. Results of TGA / DSC polyester-fiberglass-rice husk ash

Figure 4 shows the interpretation of DSC test results that have been carried out on polyester resin, polyester-fiberglass, polyester-fiberglass-rice husk ash, and polyester-tapioca starch. At intervals of 270-500 °C, there was a shift in the transition peak. In this area glass transition can occur because the temperature of the amorphous solid increases. This transition appears as a first step or basis for recorded DSC signals. This is due to the sample experiencing a change in heat capacity but no phase change occurs. As the temperature rises, the amorphous solid becomes less viscous which causes that at some points the molecules can still turn into crystals.

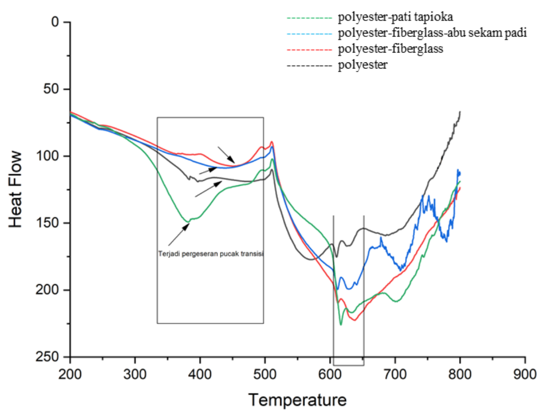


Figure 4. Interpretation of TGA / DSC polyester-fiberglass-rice husk ash

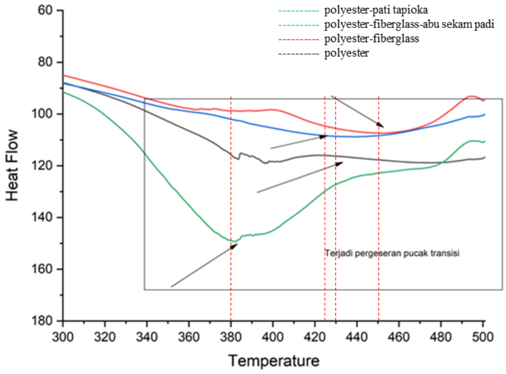


Figure 5. Interpretation of TGA / DSC polyester-fiberglass-rice husk ash

Figure 5 shows the shifting peak transition region of the DSC results that have been carried out on the following samples: polyester resin, polyester-fiberglass, and polyester-fiberglass-rice husk ash. On the DSC curve visible peak polyester resin at 430 oC. Then by combining polyester with fiberglass the peaks are shifted from the polyester peaks at 450 oC. Also observed with the addition of rice husk ash as a filler, the transition peak shifted at 425 oC. There is an increase in the panel decomposition point with the addition of fiberglass, rice husk ash. Of course, the shifting of the decomposition point contributes to the characteristics of the material to be better as desired.

This transition shift indicates the addition of energy to the endothermic process (if the heat flow exo is up), exothermic (if the heat flow exi down). This can happen because of a shift in transition. Composite panels with tapioca starch as fillers produce a wide transition peak because the heat process of fiberglass and polyester at these temperatures overlaps with the tapioca heating process.

The decomposition point is defined as a state in which there is a balance between the solid phase and other phases in a material. Decomposition temperature is the temperature at which a material precisely reposes from the solid phase to the next solid and gas phase. This situation is different when the panel material is met with a hot projectile, then there is an adjustment condition towards the balance between the panel and projectile. Panels that have a higher decomposition point certainly have a long enough time to reach balance until a new phase changes. Judging from the results of the above interpretation it is indicated that the panel which gets additional filler has a higher decomposition point.

3.4. Ballistic Test Results

Figure 5 shows a picture of ballistic impact from panel 2 of variation 1 (see figure 1a). The fracture area decreases with increasing filler. But there is an anomaly when fillers are 5 and 9%, the panels are piercing. However, there was an effect with the increasing the fraction volume of rice husk ash, the performance of the composite double-panel increased which was marked by a reduced damage area of the matrix.

Figure 6 shows photograph of the ballistic impact of panel 1 variation 2 (see figure 1b). The fracture area decreases with increasing filler. There was an effect of filler with the increasing fraction volume of rice husk ash, the performance of the composite double panel increased which was marked by the damaged area of the matrix to be reduced. The ability of this panel is quite good as indicated by the absence of piercing panels and projectiles stuck in panel 1.

Figure 6 shows the area of damage that occurs in the bi-panel specimen 1 filler 3% on panel 1 and filler 3% on panel 2. On panel 1 the front shows a hole and is not translucent due to projectile impact with a width of 9 mm. The back of panel 1 shows visible damage to the matrix and fiberglass is almost broken with a width of 30 mm, as shown in Figure 6b. Furthermore panel 2 shows the area of fiberglass damage and the front view matrix with a slight 10 mm wide basin and the rear panel 2 there is a slight damage to the matrix crack with the pattern shown in Figure 6d.

The ability of specimen 1 is better than the previous specimen. There is an effect of rice husk ash filler and bi-panel arrangement on the ability to withstand impact.

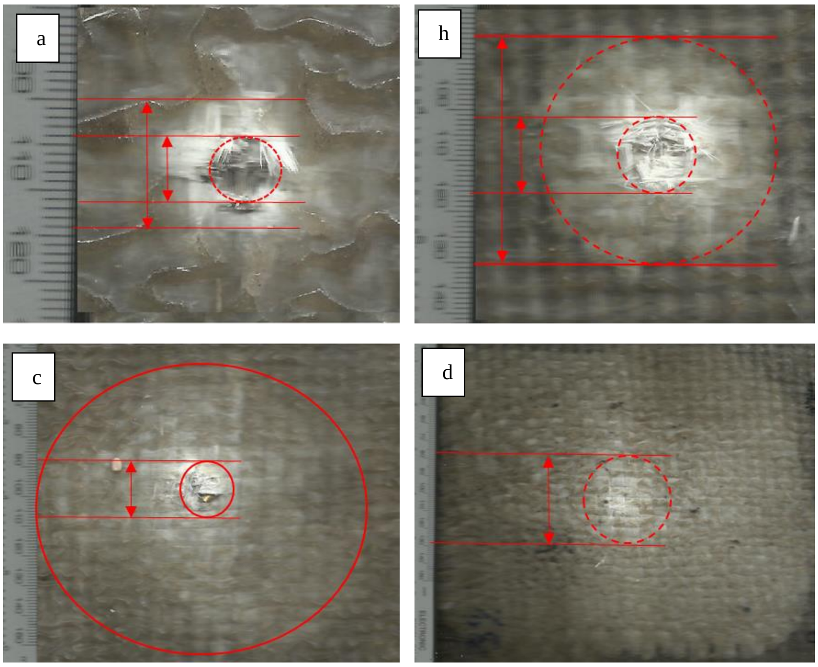
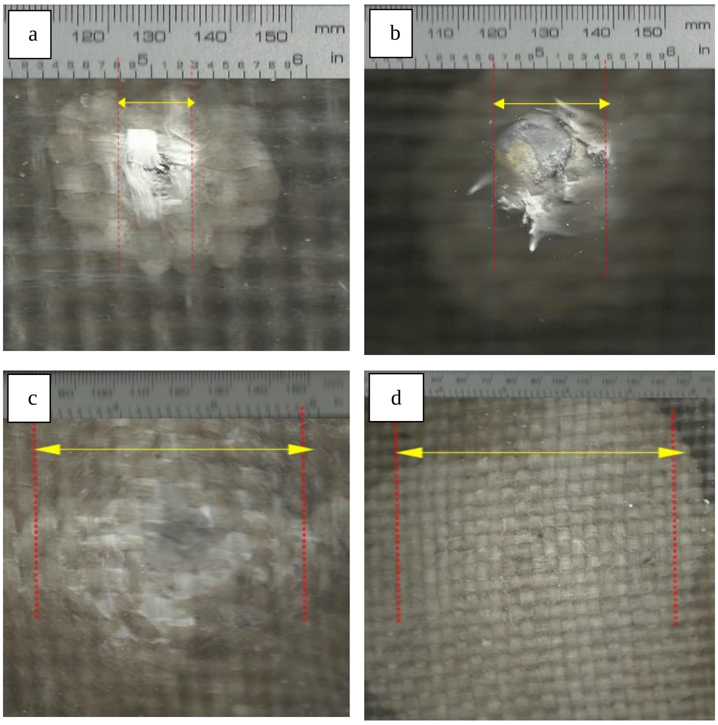


Figure 6 Specimen analysis. 1 after the ballistic impact. Panel 1 front (a) and rear (b). Panel 2 front (c) and rear (d)

Figure 7 shows the area of damage that occurred in the 5% filler 1-specimen bi-panel in panel 1 and 5% filler in panel 2. On panel 1 the front showed a hole and was not translucent due to projectile impact with a width of 12 mm. The back of panel 1 shows visible damage to the matrix and fiberglass is almost broken with a width of 20 mm and cracked matrix width of 5 mm, as shown in Figure 7b. Furthermore panel 2 shows the area of damage to the front view matrix with slight concavations and a 70 mm wide matrix crack and panel 2 to the back there is a slight damage to the matrix crack with the pattern shown in Figure 7d.

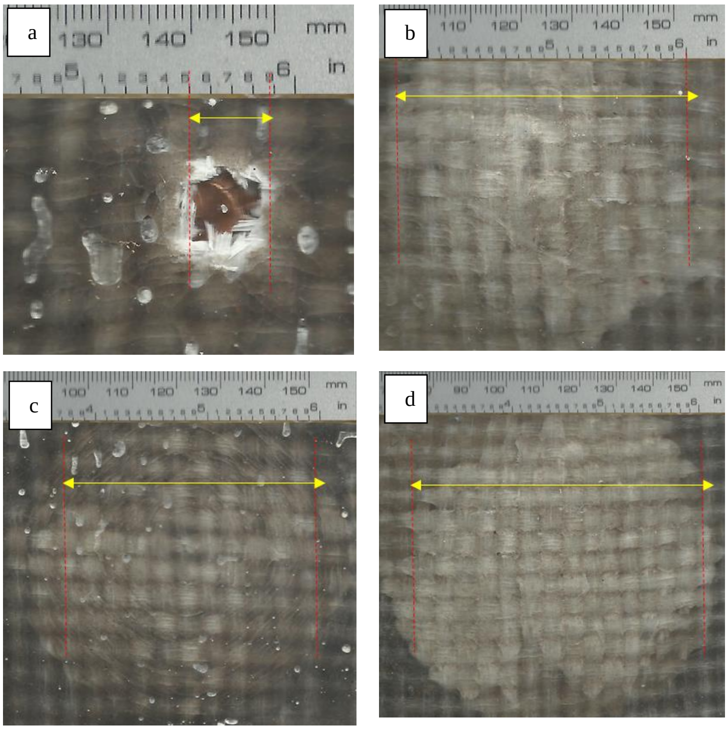
The ability of specimen 2 is better than the previous specimen. There is an effect of rice husk ash filler and bi-panel arrangement on the ability to withstand impact.



a) Panel 1 is front view. (b) Panel 1 looks behind. (c) Panel 2 front view. (d) Panel 2 looks behind

Figure 7 Analysis of damage area of specimen 2 bi-panel filler ash of rice husk panel 1 (5%) and panel 2 (5%)

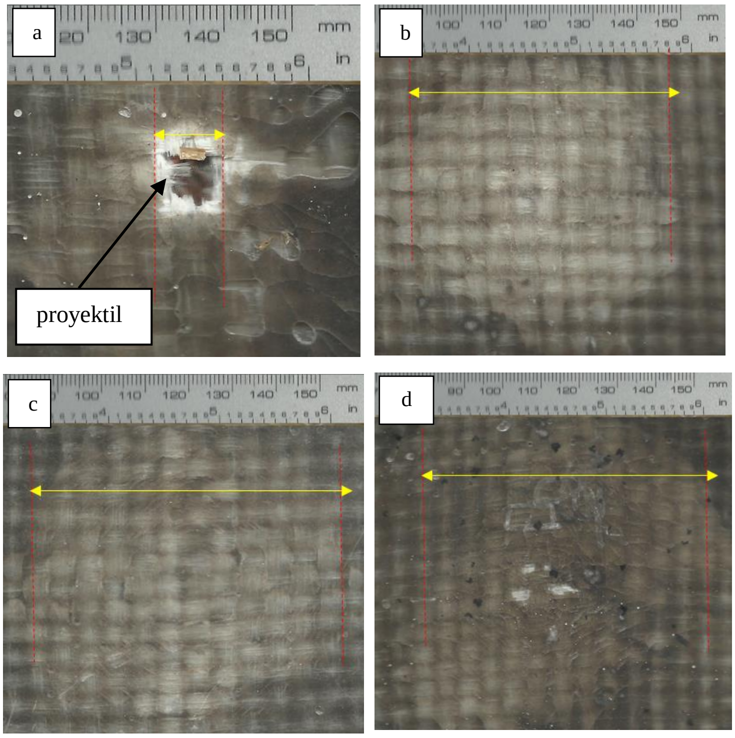
Figure 8 shows the area of damage that occurs in the 7% filler 3-specimen bi-panel in panel 1 and 7% filler in panel 2. On panel 1 the front shows a hole and is not translucent due to a 9 mm wide projectile impact. The back of panel 1 damage matrix with a width of 60 mm as shown in Figure 8b. Furthermore panel 2 shows the area of damage to the front view matrix with a width of 70 mm and panel 2 to the back there is no fiberglass damage but there is a cracked matrix with a pattern like in Figure 8d. The ability of specimen 3 is better than the previous specimen. There is an effect of rice husk ash filler and bi-panel arrangement on the ability to withstand impact.



(a) Panel 1 front view. (b) Panel 1 looks behind. (c) Panel 2 front view. (d) Panel 2 looks behind

Figure 8 Analysis of damage area of specimen 3 bi-panel filler ash of rice husk panel 1 (7%) and panel 2 (7%)

Figure 9 shows the area of damage that occurred in specimen 4 bi-panel with panel 1 and panel 2 each 9% v. rice husk ash as a filler. On panel 1 the front looks visible and is not penetrated by the impact of a projectile bullet, but the front surface of the panel shows a broken part with a width of 10 mm and the projectile is stuck. The back of panel 1 has a 70 mm wide matrix damage, as shown in Figure 9b. Furthermore panel 2 shows the area of damage to the matrix slightly wider, ie 80 mm and panel 2 to the back there is no damage, but there is very little matrix cracking defect with the pattern as in Figure 9d. The ability of specimen 4 is the best compared to previous specimens. It turned out that the contribution of rice husk ash as a filler and the composition of the bi-panel composition became a determining factor towards increasing ballistic ability to withstand impact.



(a) Panel 1 front view. (b) Panel 1 looks behind. (c) Panel 2 front view. (d) Panel 2 looks behind

Figure 9 Analysis of damage area of specimen 4 bi-panel filler ash of rice husk panel 1 (9%) and panel 2 (9%)

Type-3 composite specimens with each panel consists of 7 layers of WR 800 fiberglass which is an advanced stage of type-2 composites. Based on the results of the evaluation and analysis, it was found that the bi-panel arrangement was the best result because the technical specifications were met, found in Table 1.

Table 1 Composition of rice husk ash after ballistic impact.

Specimen code	Composition of Rice husk ash		Result after impact of projectile	
	Panel 1	Panel 2	Panel 1	Panel 2
1	3%	3%	restrained projectile	matrix crack
2	5%	5%	restrained projectile	matrix crack
3	7%	7%	restrained projectile	matrix crack
4	9%	9%	restrained projectile	no matrix crack

4. Conclusion

Based on variations in rice husk ash fillers in double panel composites, the density becomes lighter with an increase in volume fraction. Also, this rice husk ash can increase the crystalline fraction that was previously predominantly amorphous which can affect the performance of double-panel composites to be better as a body protector. The ability of the new SiO_3 bond derived from rice husk ash also increases composite performance in holding the rate of bullet projectiles.

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