Analysis of Damage Area of Fiberglass/Polyester Bi-Panel Composite With Tapioca Starch Filler Through a Ballistic Test

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Abstract. Analysis of the damaged area due to ballistic impact was carried out on fiberglass/polyester bi-panel composites with tapioca starch as a filler. The Bi-Panel composite consists of two panels with a thickness of 4 mm each. Each panel consists of unsaturated polyester resin BQTN 157 and reinforced with constant volume of woven roving S-glass and variation of tapioca starch of 40% and 50% vol. as a filler. The characterization has been done by means of Fourier-transform infrared (FTIR) spectroscopy, x-ray diffractometer (XRD) and impact test with calibre ammunition of 9 mm bullet FN gun. The results showed the influence of tapioca starch on the strength of composite panels against the high impact of a bullet.

1. Introduction

Fiberglass reinforced polyester laminates are widely employed in the fighter aircraft as well as navy naval and army ground-transport industries owing to the good mechanical properties, low manufacturing costs, and stealth. Although these kinds of laminates are not designed as body armor, they could be subjected to high-velocity impacts of low-mass fragments, and this requires fuller knowledge of their response to impacts of this type. The impact damage could significantly diminish their strength although this may not be visually detectable [1]. This is one of the main reasons of the use of laminate-type composite materials is limited [2].

Some parameter that could be used to calculate the strength of a laminate against perforation is the ballistic limit. This can be defined as the maximum velocity at which a particular projectile is expected to fail consistently to penetrate the specimen [3]. Another important parameter is the damaged area, which is directly related to the residual strength of the specimen after the impact. It has been observed that in ballistic impacts on S-glass composites the damage generated is quite widespread, and therefore it is considered a critical parameter in structural design [4]. The behavior of a multi-panel laminate is not the same as that of a single panel laminate. In the literature, there are many separate studies, either of multi-panel laminates or of single panel laminates. For comparisons of their ballistic behavior, the laminates must be target specimen to the same impact conditions while also maintaining the other parameters (material, geometry, etc.) under the same conditions.
In this study, the effect of adding tapioca starch as a filler to the strength of arrest a bullet with a speed of 380 m/s would be investigated. Tapioca is the name given to processed products from cassava roots. Analysis of the typical cassava root identifies levels 70% of water, 24% of starch, 2% of fiber, 1% of protein and 3% of other components. In addition, tapioca starch is also an environmentally friendly material. In reference presented rice flour steamed into cassava flour with the tensile strength of 20.65 MPa, elongated breakage of 4.7% and Young modulus of 1138 MPa [5]. The composition of tapioca starch can be seen in the previous study [5-9]. The choice of 40 and 50% were based on previous research (unpublished) that the use of tapioca starch with a volume fraction of 10 to 30% gave an unsatisfactory yet impact strength, with a tendency to increase the volume fraction of tapioca starch increasing its impact strength. Therefore, in this study, tapioca starch fraction was increased that such an increase can reduce panel weight, which is one of the research objectives.

2. Experimental Methods

2.1. Materials
The composite was manufactured in the form panel with fiberglass, tapioca starch as a filler with different volume fractions (40 and 50%) and the polyester resin as a matrix. The fraction volume of fiberglass used was a woven roving S-Glass denier 800 g/cm², which was taken from the supplier’s data sheet. Tapioca starch was manually prepared using a table loom. Unsaturated polyester resin BQTN 157 with a density of 1.08 g/m³ was used as resin. The resin was cured using methyl ethyl ketone peroxide (MEKP). The materials were characterized through XRD Pan Analytical brand, type: E’xpert Pro and FTIR spectrometer Perkin Elmer Spectrum 100 FTIR. Tapioca starch was supplied from UD. Bumi Kencana Flour in Tangerang, Indonesia. Polyester and fiberglass were supplied from PT. Justus Sakti in Jakarta, Indonesia. Bullet speed was measured by Chronograph Prochrono Digital brand. The Belgian Fabrique Nationale (FN) of 9 mm caliber was used as the gun for ballistic testing.

2.2. Fabrication of composite laminates
Figures 1 and 2 showed panel laminated composites of 20 cm × 20 cm in size were used for the ballistic testing. The hand-lay-up method was used to fabricate laminates of woven roving fiberglass and tapioca starch as a filler in polyester resin. It is known that the direction of the fibre affects the strength of the composite panel. Therefore, in this research, the direction of the fibre is arranged similarly so that the contribution of the effect of fibre is the same in all experimental units. The samples were consisted of 7-layers of woven roving fiberglass in the same direction (0/90°). The woven roving fiberglass fabrics were hand laid-up with the polyester/tapioca starch as a matrix by mixing resin and MEKP catalyst in the ratio of 5%. Two thick mild steel plates were used as a mold (20 cm × 20 cm) in the fabrication process. The composites were cured by applying compression pressure using dead weights on the top of the mold and cured at room temperature for 2 days. The samples with the label '1' and '2' indications consisted of one and two panels of double-panel, respectively, were located in the first and second panels of the configuration when the ballistic test was conducted as shown in figure 1.

![Panel 1](image1.png)

![Panel 2](image2.png)

Figure 1. Variation 1, polyester-  Figure 2. Variation 2, polyester-
2.3. **Ballistic testing**

The ballistic impact experiments were conducted using 9 calibers (diameter of 9 mm) Full Metal Jacket (FMJ) with the weight of approximately 8.1 gram. 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 3.

3. **Results and Discussion**

3.1. **XRD analysis**

Figure 4 shows the X-ray diffraction pattern of Polyester-fiberglass panel bi-panel composites and Polyester-fiberglass bi-panel composites with tapioca starch 40%. According to the XRD pattern, it shows an amorphous pattern. The fraction of amorphous decreased when fiberglass bi-panel composites with tapioca starch. The presence of filler in polyester resin matrix leads to partly chemical reaction. The vibration of the molecule in the matrix which corresponds with each peak in the pattern seems to decrease in the number. This chemical reaction probably induces the degree of crystallinity of the matrix as shown in figure 4. When the samples are exposed to high energy impact, reducing the amorphous part will favour to a homogeneous propagation of energy.

3.2. **FTIR analysis**

Figure 5 shows the FTIR pattern of the polyester-fiberglass bi-panel composites and Polyester-fiberglass bi-panel composites with tapioca starch 40%. The transmittance increased when fiberglass and tapioca starch mixed in polyester resin. FTIR spectrum of bi-panel composite shows the effect of tapioca starch on the polyester resin which is characterized by the shifting in wavenumbers in the O-H bonding functional group and the formation of peaks in the wavenumber range of 3550-3250 cm⁻¹.
Furthermore, in the wavenumber range 2980-2850 cm\(^{-1}\), there is a shift in the peak between polyester-fiberglass bi-panel composites with Polyester-fiberglass bi-panel composites on the C-H bond function group. However, the ratio of the spectrum both is not very noticeable in the bond carbon-hydrogen but new peaks appear in polyester-tapioca starch.

At wave number 1493 cm\(^{-1}\) there is an aromatic bond C-H for all spectrums of polyester-fiberglass bi-panel composites and Polyester-fiberglass bi-panel composites with tapioca starch 40%. Then at wavenumbers 1780-1720 cm\(^{-1}\) there is an ester double bond C - O for all spectrums of polyester and polyester-tapioca starch.

At wavenumbers 1290-1180 cm\(^{-1}\) there is a double bond C-O-C for all spectrums of polyester-fiberglass bi-panel composites and Polyester-fiberglass bi-panel composites with tapioca starch 40%.

**Figure 4.** XRD polyester-fiberglass panel bi-panel composites (a) without and (b) with tapioca starch 40%. (b).

**Figure 5.** FTIR spectroscopy of the polyester-fiberglass bi-panel composites (a) and polyester-fiberglass bi-panel composites with tapioca starch 40%. (b).

**Figure 6.** Variation 1: Damage area view front and back panel 2 with filler 40%.

**Figure 7.** Variation 2: Damage area view front and back panel 1 with filler 50%.
Then the double bond C= C at wavenumber 979 cm$^{-1}$ and other aromatic bonds C - H at wavenumber 697 cm$^{-1}$ for all three samples. The intensity of O-H is greater in the polyester-fiberglass-tapioca starch bi-panel composites because of the increase in O-H concentration due to the combination with tapioca.

Figure 6 shows the results of the ballistic test on the composite bi-panel with a filler of 40% wt. Visible damage to fibre breaks and cracked matrix by projectile occurs on the front surface of panel 1 and no piercing. The damage area occurred on the front surface of panel 1 with about the size of a projectile. Then the cracking of the damage area matrix is about 625 mm$^2$ with a damaged length of 25 mm. In panel 2 there is no damage to the front and back surfaces of the panel. The matrix damage area of the back face of the panel 1 is wider than the front face is about 900 mm$^2$. This damage has no buckling. The panel surface is still relatively flat.

This can be seen in figure 7. The ballistic test in Table 1 shows the comparison of the results. Through increasing the filler volume fraction could increase the ballistic ability. Damage to bi-composite panels with 50% filler occurs on the front surface of panel 1 with projectile size. The damage area of the matrix is around 400 mm$^2$ with the damage length is 20 mm. In panel 2 there is no damage to the front and rear surfaces of the panel. The matrix damage area on the back side of panel 1 is larger than the front face of around 2500 mm$^2$.

There is a difference in the damaged area between 40 and 50% filler bi-panel composites. With the addition of a higher filler, the performance of the bi-panel increases in the bullet projectile impact. This is an indication from the damaged area decline in the front face of panel 1 and the damaged area increase on the back face of panel 1, due to the increase in the volume of tapioca starch filler. The difference in this area of damage indicates the presence of absorption power in the form of even distribution of kinetic energy when projectiles are inside the panel.

The presence of tapioca starch makes the composite softer, according to XRD pattern that only 1 diffraction peak was observed. It shows that the material is not crystalline and also not amorphous.

4. Conclusions
With the addition of tapioca starch as filler, the composite becomes less amorphous. There is a chemical reaction, based on FTIR results. The existence of chemical reaction, there is a bond between the filler and the matrix. The FTIR spectrum shows a C= C bond at wavenumber 979 cm$^{-1}$ and other aromatic bonds C-H at wavenumber 697 cm$^{-1}$ on the composites. Addition of tapioca is very helpful in reducing kinetic energy from bullets.

The composite panel with the addition of tapioca starch as a filler could stop the rate of bullet projectile based on the combination of double panel composites with tapioca starch as a filler. It is possible to obtain energy absorption of panel laminates through the appropriate design of double panel composites for body armour. With the increase in tapioca starch content, the impact ballistic properties of the double panel composites were increased. The arrangement of composite panels was also found
to significantly affect the ballistic performance of double panel composites. It was also found that the thick panel composites with woven fiberglass 7 layers performed better in terms of ballistic properties.

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