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# Evaluation of tensile strength and flexural strength of GFRP composites in different types of matrix polymers

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## ABSTRACT

**Purpose:** Resin selection has a crucial role in determining the properties and performance of GFRP composites; this study aims to investigate the effects of different resin types, specifically epoxy, bisphenol, ripoxy, and polyester, on the mechanical strength of GFRP composites.

**Design/methodology/approach:** The composites were fabricated using the conventional method of hand lay-up technique with a fiber to matrix ratio of 60:40 wt%. The glass fibre laminate arrangement consists of 4 layers, two layers of Woven Roving Mat (WRM) fibres (0°/90°) and 2 layers on the outer side of the Chopped Strand Mat (CSM). The composite specimens were molded using the ASTM D-838 tensile test standard and ASTM D-790 for the bending test.

**Findings:** The research results found that the maximum tensile strength was obtained by GFRP composite with ripoxy matrix type of 181.6 MPa, strain of 0.028%, and flexural strength of 1387 MPa. Composites using polyester matrices can generally be classified as splitting in multiple areas where failure occurs in various areas, but the composite has very high strength.

**Research limitations/implications:** Material experiments conducted on a scientific laboratory scale may not fully reflect the behaviour of composites in actual conditions. Furthermore, aspects such as environmental influences, sustained stresses, or fatigue effects may need to be considered in further research. This evaluation also does not consider the effects of long-term exposures or ageing on the mechanical properties of GFRP composites. Investigating the behaviour of materials over long periods can provide important insights into their durability and reliability in practical applications.

**Practical implications:** In GFRP composites, the application of resin to the fibres is critical. The performance and mechanical characteristics of GFRP composites are largely determined by the polymer matrix. Composites with epoxy, polyester, or bisphenol matrices can be compared to composites with the most equivalent tensile strength values, but composites with ripoxy matrices can be suggested. However, the GFRP composite with bisphenol matrix has an excellent bending strength value. As a result, numerous applications exist for implementing matrix selection in producing GFRP composites.

**Originality/value:** The reliability of the tensile properties of GFRP composites was obtained using the ripoxy matrix type. Furthermore, the reliability of the flexural properties of the composites was obtained using the bisphenol matrix type.

**Keywords:** Composite, GFRP, Tensile strength, Flexural strength, Polymer, Matrix, Top of form

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PROPERTIES

# 1. Introduction

Composite polymers, such as glass fibre-reinforced polymers (GFRP), have revolutionized various industries due to their exceptional strength-to-weight ratios and versatility in applications ranging from construction and automotive to aerospace and sports equipment [1]. The materials consist of a matrix, typically made of thermosetting polymers like epoxy or polyester resins, reinforced with strong, stiff fibres such as glass or carbon fibres [2]. In the construction industry, GFRP composites are increasingly being used for various applications, such as reinforcement in concrete structures, bridge decks, and marine structures [3,4]. The composites offer significant advantages over traditional materials like steel, including corrosion resistance, increased durability, and reduced maintenance costs [5].

Various factors, including the type and orientation of the reinforcement fibres, the matrix material, and the manufacturing process influence the strength of composites. Furthermore, the adhesion between the reinforcement and matrix, as well as the interfacial bonding, also play a crucial role in determining the overall strength and performance of the composite material [6,7]. The choice of polymer matrix can significantly influence the strength, stiffness, durability, and other mechanical properties of composites [8]. Different types of polymer matrices, such as epoxy, polyester, vinyl ester, and others, have been used in GFRP composite manufacturing depending on the specific application requirements and performance goals [7].

Studies have shown that mechanical properties, such as tensile strength, flexural strength, and impact resistance, can vary significantly depending on the type of polymer matrix used in GFRP composites [7]. For example, epoxy resin matrices are known for their high strength and stiffness, making them suitable for applications requiring high mechanical performance [9]. On the other hand, polyester matrices are more cost-effective and offer good resistance to corrosion, making them suitable for certain applications [10,11]. Another factor that can impact the mechanical properties of GFRP composites is the curing process of the polymer matrix [12]. The curing process can affect the degree of crosslinking and the bond strength between the matrix and the glass fibres, thus influencing the overall mechanical performance of the composites. In addition to the mechanical properties, the choice of polymer matrix can also affect other factors such as thermal stability, chemical resistance, and moisture absorption of GFRP composites [13]. Therefore, it is important to carefully select the polymer matrix based on the specific requirements and environmental conditions of the intended application. Overall, the choice of polymer matrix plays a vital role in determining the mechanical properties and performance of GFRP composites. The mechanical properties of GFRP composites can be significantly influenced by the type of polymer matrix used.

Different resin types, such as epoxy, bisphenol, ripoxy, and polyester, have been widely used in producing GFRP composites. However, the impact of resin type on the mechanical strength of GFRP composites has not been widely investigated. Understanding the interrelation between resin type and mechanical strength is critical to optimizing the performance and durability of GFRP composites. This study aims to investigate the effects of different resin types, specifically epoxy, bisphenol, ripoxy, and polyester, on the mechanical strength of GFRP composites. The findings from this study will provide valuable insight into the suitability of different resin types for GFRP composites, allowing the industry to make informed decisions regarding manufacturing processes, material selection, and product design to achieve the desired mechanical properties and performance.

# 2. Material and method

## 2.1. Material

PT Justus Kimiaraya, Surabaya, Indonesia, supplied E-glass fibre and polymer matrix materials. The e-glass fibre uses Woven Roving Mat 200 (WRM) 0°/90° and Chopped Strand Mat 300 (CSM), as shown in Table 1 and Figure 1. The mechanical properties of the polymer matrix can be seen in Table 2.

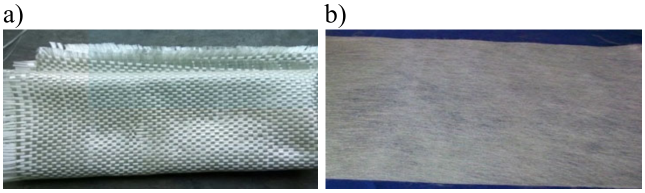

Fig. 1. a) Woven roving mat, b) chopped strand mat

Table 1.
Mechanical properties glass fiber

| Tensile strength | Young's modulus | Elongation | Density |
|---|---|---|---|
| 3400 MPa | 72 GPa | 4.7% | 2.54 g/cm$^2$ |

Table 2.
Mechanical properties polymer resin

| Properties | Tensile strength, MPa | Flexural strength, MPa | Modulus elastisity, MPa |
|---|---|---|---|
| Polyester | 56.87 | 92.18 | 2941 |
| Epoxy | 40.20 | 76.49 | 79.43 |
| Ripoxy | 69 | 120 | 3200 |
| Bisphenol | 88 | 153 | 2700 |

## 2.2. Composite fabrication

Composites were fabricated using an easy and conventional hand lay-up technique. The glass fibre laminate arrangement consists of 4 layers: 2 inner layers of Woven Roving Mat 200 (WRM) 0°/90° and two layers on the outer side using Chopped Strand Mat 300 (CSM) fibres. The composition ratio of matrix and reinforcement is 60:40, according to equations 1-4. The parameters for the use of resins and catalysts or hardeners according to the manufacturer's recommendations can be shown in Table 3.

Table 3.
Resin composition/100 g

| Resins | Catalyst | | |
|---|---|---|---|
| | MEXPO | Cobalt | Hardener |
| Polyester | 1 g | - | - |
| Epoxy | - | - | 100 g |
| Ripoxy | 3 g | 0.6 g | - |
| Bisphenol | 0.4 g | 0.8 g | - |

The composites were moulded according to the standard dimensions of ASTM D638-01 tensile test samples and ASTM D-790 for bending tests. After the moulding process was completed, the composites were cleaned and cured at room temperature (25ºC) for seven days. Sample preparation for testing can be seen in Figure 2.

Fig. 2. Tensile and flexural tests of composite specimens

The fibre fraction in GFRP composites can be calculated using the following mathematical equation 1.

$$v_f = \frac{v_c - \left[\frac{M_c - M_f}{Q_M}\right]}{v_c} \quad (1)$$

where $v_f$ is the volume fraction, $v_c$ the composite volume, $M_c$ the composite mass (kg), $M_f$ the fibre mass (kg) and $Q_M$ the matrix density (g/cm$^3$). If the weight of the fibre and matrix are known, the mass and volume fractions of the composite can be calculated using the following equations 2 and 3.

$$v_f = \frac{\frac{W_f}{\rho_f}}{\frac{W_f}{\rho_f} + \frac{W_M}{V_M}} \quad (2)$$

$$W_f = \frac{\rho_f v_f}{\rho_f v_f + \rho_M v_M} \quad (3)$$

where $V_M$ is the matrix volume fraction $W_f$, fibre mass $W_M$ matrix mass, $W_c$ composite mass, $\rho_f$ fibre density (g/cm$^3$) and $\rho_M$is matrix density (g/cm$^3$). From equation (3) above, it can be simplified as in the following equation

$$W_f = \frac{W_f}{W_c} \quad (4)$$

## 2.3. Evaluation of tensile and flexural strength

Tensile testing on GFRP composites is carried out to determine the mechanical properties of composites that have been fabricated with ASTM standard test specimens. Composite testing uses a Hydraulic Servo Pulser tensile testing machine with a capacity of 30 kN and a speed of 0.2 mm/s. The tensile test results were analysed with mathematical equations 5-7. Meanwhile, the flexural strength value is calculated based on equation 8.

$$\sigma = \frac{P}{A} \tag{5}$$

where the stress (σ) in the composite can be calculated by comparing the load (*P*) with the cross-sectional area (*A*) in N/mm$^2$ (MPa).

$$\varepsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0} \tag{6}$$

The stress value ($\varepsilon$) is calculated by comparing the difference of length increase ($\Delta l$) divided by the length before the experiment ($l_0$) in mm.

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{7}$$

where the modulus of elasticity of the composite (*E*) is calculated using equation 7. Where the stress (σ) is compared to the strain (ε).

The bending testing process was carried out using the three-point bending method. The maximum bending stress was calculated based on equation 8 where Ϭ is the bending strength (MPa), *P* is the load (N), *L* is the span length (mm), *b* is the width of the test specimen (mm), and *d* is the thickness (mm).

$$6 = \frac{3.P.L}{2.b.d2} \tag{8}$$

### 2.4. Fracture analysis

A fracture composite investigation was used to observe the visual morphology of each composite variation. Observations were made using a Canon EOS R50 digital camera. The visual images obtained were then analyzed using ImageJ software. The images created from ImageJ were focused on confirming the qualitative observations of the tensile test fractures.

## 3. Results and discussion

### 3.1. Tensile strength

The tensile properties of GFRP composites with different types of matrices are illustrated through the stress-strain diagram, as shown in Figure 3.

Figure 3 shows the stress and strain graph of GFRP composites with various synthetic matrices. After analysing the stress and strain graphs of the various resins in the GFRP composites, it was that riboxy resin performed at the optimum level in achieving maximum stress and strain. The data showed that ripoxy resin had a significantly higher tensile strength than the other resins tested. In addition, the elasticity of the GFRP composites also reached an optimal level when using Ripoxy resin. These results indicate that Ripoxy resin has the potential to be a superior choice in improving the mechanical performance of GFRP composites.

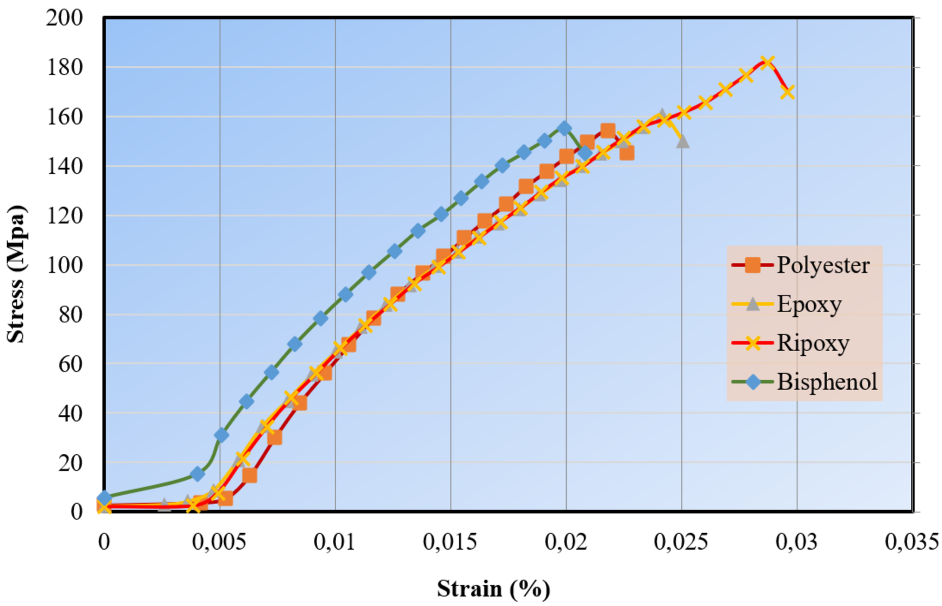


Fig. 3. Stress-strain diagram composite GFRP

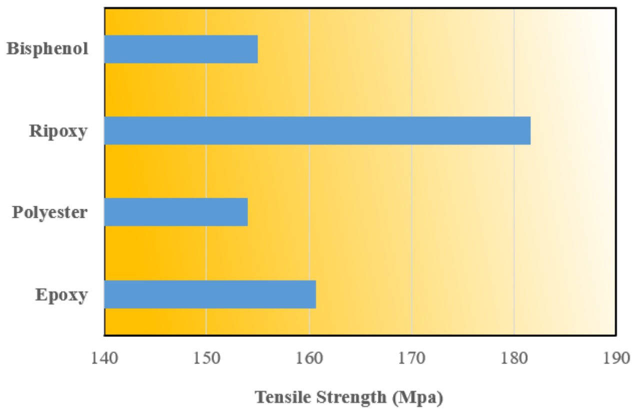


Fig. 4. Tensile strength GFRP composite

More details of the tensile strength values of composites with variations of various types of matrices can be seen in Figure 4. Where GFRP composites with polyester resin have a value of 154 MPa, Bisphenol resin 155 MPa, Epoxy resin 160 MPa and Ripoxy resin 181 MPa.

The tensile strength of GFRP composites with epoxy resin is higher than that of polyester resin. This finding is similar to previous research, where using natural fibre-epoxy has superior mechanical properties compared to polyester-matric composites [14]. It can occur because the hand lay-up technique can oxidise the polyester used during the composite manufacturing process. In addition, using more MEXPO catalysts can affect the zelling time of the composite, making it faster and the composite more brittle. In addition, research shows that oxidised polyester resin used in the composite matrix increases the capacity of reinforced concrete beams [15]. The results align with the mechanical behaviour of abaca fibre composite materials. In addition, the stress-strain behaviour of the resin also showed similar performance. The initial stiffness of epoxy resin-based matrix composites is higher than that of polyester resin-based matrix composites. However, the stress-strain curves of epoxy and polyester resin-based matrix composites are linear, while the stress-strain curves of ripoxy and bisphenol resin-based matrix composites are bilinear.

In Figure 5, it is clear that the various types of matrices greatly affect the values of elastic modulus and elongation of GFRP composites. Ripoxy composites have an elastic modulus of 6325 MPa, followed by Epoxy 6650 MPa, Polyester 7051 MPa and Bisphenol 7781 MPa. Mathematically, elastic modulus (E) is defined as the ratio of stress to strain in the elastic phase of the stress-strain curve (equation 7) [16]. A high modulus of elasticity indicates the ability of the material to undergo elastic deformation in the elastic phase before undergoing plastic deformation [17].

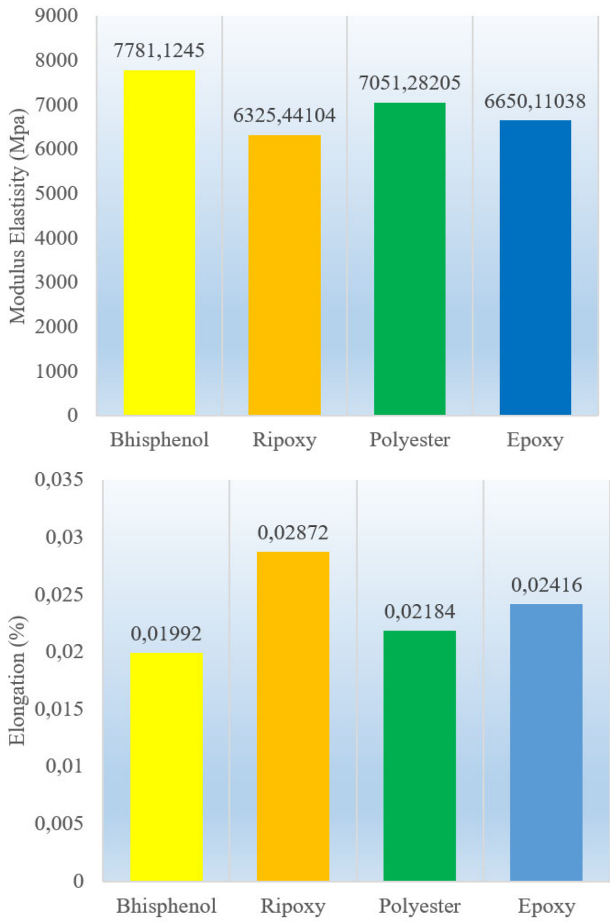


Fig. 5. Modulus elasticity and elongation GFRP composite

In other words, the composite can stretch significantly without undergoing permanent changes in its internal structure. The advantage of a high elastic modulus in bhisphenol composites is resistance to permanent deformation and recovery of the initial shape after the tensile load is removed [18]. Therefore, high elastic modulus resistance is therefore often desirable in applications such as structures and various mechanical components that require toughness and elastic deformation resistance [12,19,20].

## 3.2. Flexural strength

The flexural strength of GFRP composites with various synthetic resins is shown in Figure 6 and Table 2. The load-displacement diagram shows the amount of force required to press the composite until displacement occurs. Where the force required to press the Polyester, Ripoxy, Epoxy and Bisphenol matric composites is 284.7 N, 291.81 N, 427.29 N and 597.36 N, respectively. The results confirm the tensile

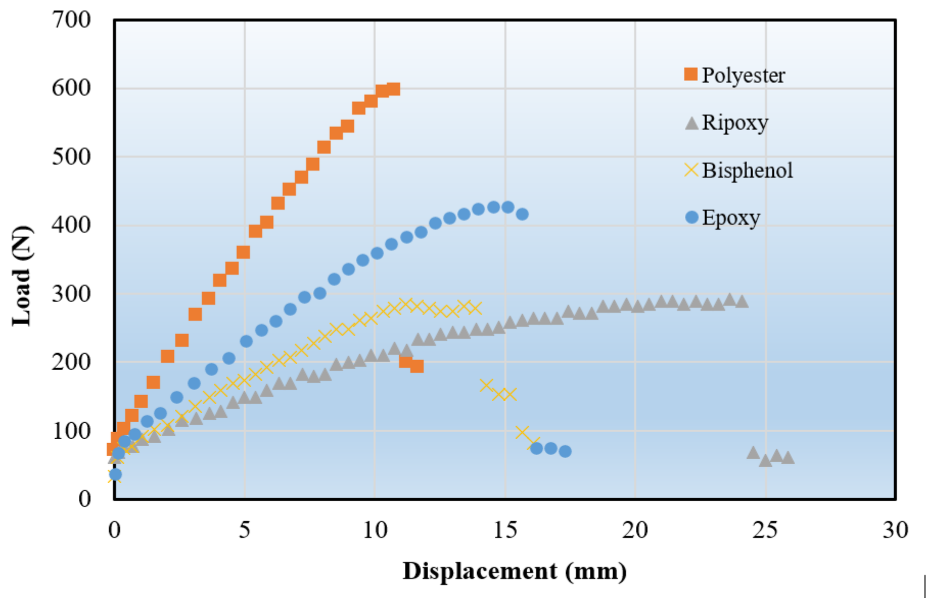


Fig. 6. Load-displacement

testing in Figure 3. where the high tensile strength of GFRP composites is directly proportional to the force response obtained from the flexural testing results.

Table 4. shows the flexural test data of all the samples in the study. Overall, using several matrices with the same reinforcement has very different strengths. GFRP composites with bisphenol matrix had the highest flexural strength value of 413.40 MPa compared to composites with polyester matrix 197.02 MPa, Ripoxy 201.94 MPa, and epoxy 295.70 MPa. The difference in strength can be possible due to the compatibility of the matrix with the different fibres [21-23]. It can also be influenced by the density value of each composite [24]. It is proven that bisphenol resin has a higher density value of 1.17 g/cm$^3$ when compared to epoxy resin, which is 1.2 g/cm$^3$ [25]. The higher the density value, the lower the porosity value of the composite, so the bending strength of the GFRP composite is better. The same thing was also reported in previous research, which showed that density affects the mechanical strength properties of GFRP composites [24].

Table 4.
Flexural strength of composite GFRP

| Matrix | Load, N | Displacement, mm | Flexural strength, MPa |
|---|---|---|---|
| Polyester | 284.7 | 11.19 | 197.02 |
| Ripoxy | 291.81 | 23.64 | 201.94 |
| Epoxy | 427.29 | 15.07 | 295.70 |
| Bisphenol | 597.36 | 10.76 | 413.40 |

### 3.3. Fracture of composite under tensile test load

Figure 7 shows the final fracture results of the composite specimens after the tensile test. The composites using Ripoxy matrix can generally be classified as splitting in multiple areas where failure occurs in different areas, but the composites have very high strength. The fracture cross-section showed a minimum of debonding brittle, and the fibers pull-out before fracture. Composites with splitting in multiple areas usually have very high strength [26].

The failure of composites with epoxy and bisphenol matrices is also clear in several areas, but when compared to the fractures in polyester composites, the areas in composites with epoxy and bisphenol matrices are significantly reduced. The cross-section still shows the pull-out of fibres and debonding [27]. This may also be due to the interlayer composition of the GFRP composites. An unbalanced interlayer arrangement can lead to strength reduction mechanisms and random fractures [28]. The polyester matric composites have brittle fractures. It could be possible due to the excessive addition of MEXPO catalyst, which causes high composite shrinkage and reduced elasticity. It also occurs in polyester glass laminate composites with the addition of 30% filler, which has a low fracture strain and poor dynamic load resistance [29]. The fibre pull-out failure behaviour is no longer visible in composites using an epoxy matrix. The fracture looks neater, and the area is narrowed, almost said to be a single fracture [30,31].

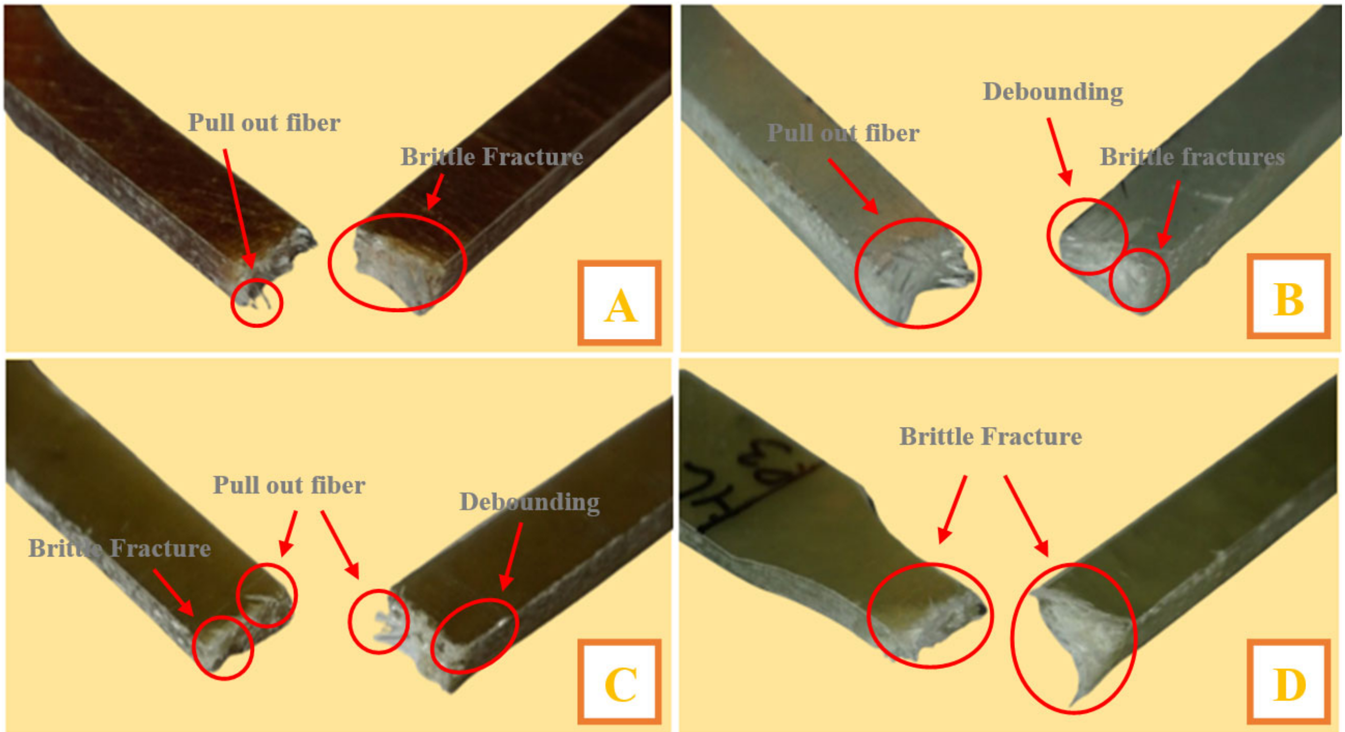


Fig. 7. Fracture composite: a) Bisphenol, b) Epoxy, c) Ripoxy, d) Polyester

## 4. Conclusions

From the results, it can be concluded that using resin on fibres in GFRP composites is very important. The polymer matrix has a significant role in determining the mechanical properties and performance of GFRP composites. Composites with Ripoxy matrices can be recommended in terms of tensile properties of the composites, with the highest tensile strength value of 181.6 MPa and strain of 0.028% compared to composites with polyester, bisphenol or epoxy matrices. However, in terms of bending strength, the GFRP composite with bisphenol matric has a very high value of 413.40 MPa.

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## Authors contribution

Aris Budi Sulistyo: Investigation, data curation, project administration, curation, funding acquisition.

Willy Artha Wirawan: conceptualization, resources, writing, validation, formal analysis, methodology, software, supervision.

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