Mekanika: Majalah Ilmiah Mekanika

Comparative Analysis of the Size of Glass Fiber Woven Roving based on a Polyester Matrix on the Impact Strength of Composite Materials

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Abstract
Laminated Glass Fiber Reinforced Polymer (GFRP) composites are widely used in various industries, such as boat building, car bodies, water tanks and pipelines, which in their use sometimes have the potential to be exposed to impact loads, especially in transportation equipment. Therefore, it is necessary to perform an impact test to determine the toughness value of a composite material against impact loads. This study aims to investigate the characteristics of fibreglass Woven Roving (WR)/polyester composites produced by the compression moulding process to determine the toughness of the composite material concerning changes in weave size. This research uses variations of glass fibre woven roving in sizes of 200 gsm, 400 gsm, 600 gsm. The impact test was conducted following the American Society for Testing Materials (ASTM) D6110-10. The impact test result showed that the lowest impact strength is found in a composite with a woven size of 200 gsm, which is 0.145 J/mm^2, and the highest impact strength is found in composite with a woven size of 600 gsm, which is 0.280 J/mm^2.

1 Introduction

Currently, the manufacturing industries are experiencing numerous changes, including energy conservation. Therefore, reducing structural load is essential in conserving energy for several sectors. This is particularly true in using composite materials in multiple engineering fields, including construction, automotive, marine industries, and so forth [1]. Composite laminates have attracted the attention of many users in several engineering and other disciplines as structural members is because of the unlimited possibilities of deriving any characteristic material behaviour [2]. A composite material comprises a combination of two or more materials that result in better properties than individual ones [3]. There are two types of composite materials, natural and synthetic matrices and the Matrix is divided into polymer, ceramic, and metal. The composite material also has fibre, sheet, and particle reinforcement [4].

Laminated composite materials such as glass, Kevlar, and carbon fibre are increasingly used in engineering applications because of their excellent strength and stiffness-to-weight ratio and superior corrosion resistance compared to other materials such as steel and aluminium [5]. Typically, metals and polymers are used as matrix materials because it is desirable to have some ductility. Polymers are as a matrix in most composite applications due to their properties, making manufacturing the composite easier [6]. The properties of the composite are a function of the properties of its constituents and the geometry of

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the reinforcement layers, which comprise the shape, size, quantity, distribution and orientation of fibres or particles [7]. Laminated composite materials are a combination of laminated sheets made of fabric and resin arranged in a single piece [8]. The matrix gives composite material's structure, secures the fibres load distribution and protects their surfaces. The ease of processing (architectural flexibility), together with its low density (and chemical resistance), cause the composite polymer-matrix materials to that have a greater range of applications and are subject to further development [7]. While these composite materials offer attractive properties, their use is often limited because they are susceptible to lateral impact [9]. Especially on high-speed vessels, the weight savings of composite construction are most advantageous, but also on other structures and vessels, such as fishing vessels, where collisions between the fishing gear and the hull are common [10].

Polymer composites commonly used to manufacture composite materials are glass fibre reinforced composites. The matrix consists of organic, polyester, vinyl ester, phenolic and epoxy resins [11]. The mechanical properties of composite materials depend on the properties of the fibres, the strength and chemical stability of the matrix, and the effectiveness of the bond between the matrix and the fibres in transferring stress [12]. Fibreglass can be used as a composite material in making boats, water tanks, cars, pipes, roofs and others. The advantages of fibreglass are high strength, low cost, high chemical resistance and sound insulation properties [13]. In cases such as driving a land vehicle, where a sudden load occurs due to the impact of rocks or holes on the road, the effect of vibrations generated by the engine, and the possibility of an accident, as well as in a water vehicle, where there is a possibility of collisions between ships or with reefs. Therefore, it is necessary to perform an impact test to determine the toughness value of a composite material against impact loads [14].

Zhang et al. in 2020 studied the mechanical behaviour of hybrid composites made of carbon/glass reinforcements, and the processing method used is 'wet lay-up', which is not a best practice for obtaining high-quality laminates. Adding hard reinforcements such as silicon carbide, alumina, and titanium carbide improves the composites hardness, strength and wear resistance [15]. Jaganantha et al. in 2015 studied the influence of glass fibre and carbon fibre reinforced epoxy polymer matrix on mechanical properties. The hybrid composites were developed by varying the reinforcements from 15%, 30%, 45% and 60% of glass fibre and carbon fibre in a 40% epoxy matrix under a vacuum bag process. The hardness and tensile properties were studied per the ASTM standards [16].

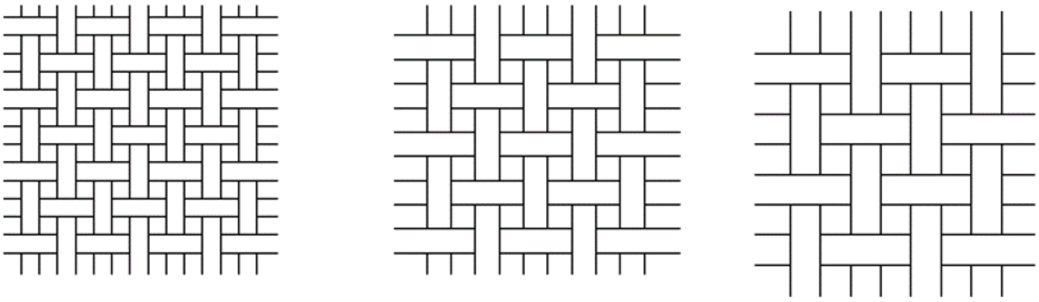
This research will analyse the comparison of the size of woven fibreglass roving on the impact strength value. Fibreglass composites are commonly used as the basic material for making the body of vehicles such as fast boats and cars that often experience impact loads such as accidents and collisions. Thus, the results of this research are expected to minimise the impact caused by accidents and collisions often experienced by vehicles.

2 Experimental Methods

2.1 Materials and instruments

1. Fiberglass Woven Roving

   This research uses a fibreglass woven roving materials with three variant sizes, that is, 200 gsm, 400 gsm, and 600 gsm. Woven roving is a fabric composed of continuous roving woven in two perpendicular directions. Woven roving provides bidirectional properties that depend on the woven model and the number of fibres in the longitudinal and transverse directions [17]. Fiberglass woven roving is shown in Figure 1.



(a) (b) (c)

Figure 1. Fiberglass woven roving (a) 200 gsm, (b) 400 gsm, (c) 600 gsm

2. Polyester Resins

   Polyester is a thermoset polymer matrix. Polyester is a liquid resin with a low viscosity value and can be hardened at room temperature using a catalyst without producing gas. This research uses a polyester resin type 108.

Figure 2. Polyester resins type 108

3. C Clamps

   Figure 3 is the C clamp used to press the specimen mould. The C clamp has a size of 3 inches.

Figure 3. C clamps 3 inches

4. Impact Testing Machine

   Figure 4 shows an impact testing machine from the State Polytechnic of Malang. The machine has a pendulum weighing 8.3 kg and a length of 0.62 m.

Figure 4. Impact testing machine

2.2 Fabrication

Compression moulding is a method of forming composite materials by applying high pressure to the moulded parts [18]. The combination of three moulds, namely the bottom, centre, and top, is used to perform the pressing of acrylic material used to form composite products. The glass fibres are cut to the mould size following ASTM D6110-10 [19]. Mix the hardener with the polyester resin by stirring until evenly mixed. Weigh the glass fibre according to the specified volume fraction. Place the composite materials, reinforcement and matrix in the mould. Press for three hours. Remove the composite and cure at room temperature to obtain the final composite results [20]. Figure 5 shows a compression moulding process.

Figure 5. Compression moulding

2.3 Testing method

The Charpy impact test is a dynamic three-point bending test of an unnotched beam. The impact test is performed following ASTM D6110-10 [19]. The test setup consists of a specimen, an anvil on which the specimen is supported, and a pendulum with a given mass attached to an arm on the machine body that can rotate. During the test, the pendulum falls along a circular trajectory and strikes the specimen at the mid-span length, transferring kinetic energy to the pendulum [21]. This study ignores energy loss due to bearing friction and air resistance because it makes a small contribution to the energy balance. The energy absorbed by the specimen (Equations 1 and 2) when it receives an impact from a pendulum hammer is equal to the difference between the potential energy of the hammer before and after the impact [22].

$$E_f = m \cdot g \cdot R\,(\cos\beta - \cos\alpha) \quad (1)$$

$$IS = E_f / A \quad (2)$$

Definition:
E_f = absorbed energy (J)
m = mass of the pendulum (kg)
g = gravity acceleration (m/s^2) = 9.81 m/s^2
R = pendulum length (m)
α = initial swing angle (^{o})
β = pendulum swing angle after breaking the specimen (^{o})
IS = impact strength (J/mm^2)
A = area (mm^2)

3 Results and Discussion

Figure 6 shows the results of fibreglass woven roving composite specimens with woven sizes of 200 gsm, 400 gsm and 600 gsm, respectively. It can also be seen in the specimens tested for impact, showing that the specimens did not experience fractures because the fibreglass woven roving composites bind each other between the roving so that they can maintain the woven shape of the load perpendicular to the fibre direction.

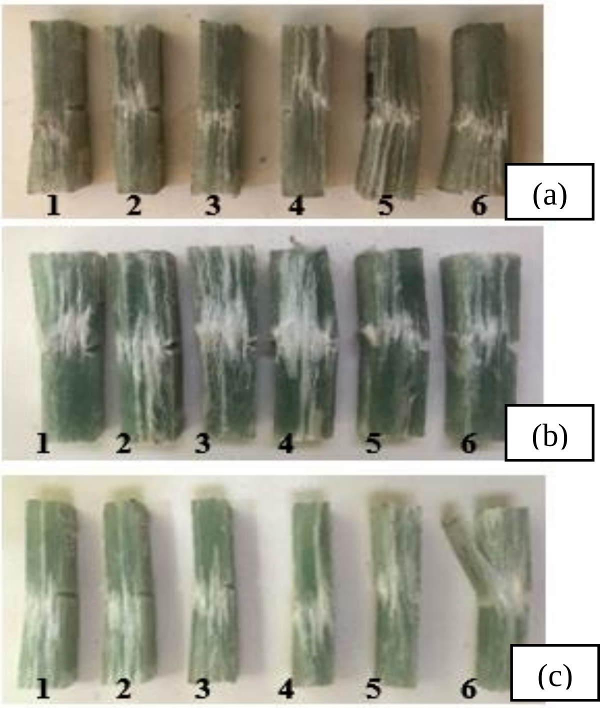


Figure 6. Impact testing result specimen: (a) 200 gsm, (b) 400 gsm, (c) 600 gsm

The impact strength of the fibreglass woven roving composite can be seen in Table 1 and Figure 7. Table 1 shows that the impact strength value of a fibreglass woven roving composite with a woven size of 200 gsm has the lowest value of 0.145 J/mm^2, while the fibreglass woven roving composite with a woven size of 400 gsm has an impact strength value of 0.202 J/mm^2. The highest impact strength value is obtained in the fibreglass woven roving composite with a woven size of 600 gsm of 0.280 J/mm^2.

Table 1. Impact strength of fiberglass woven roving composite

Woven Size	Impact Strength (J/mm²)						Average (J/mm²)
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	
200 gsm	0.131	0.152	0.141	0.192	0.190	0.066	0.145
400 gsm	0.146	0.210	0.248	0.257	0.204	0.150	0.202
600 gsm	0.264	0.284	0.294	0.248	0.268	0.324	0.280

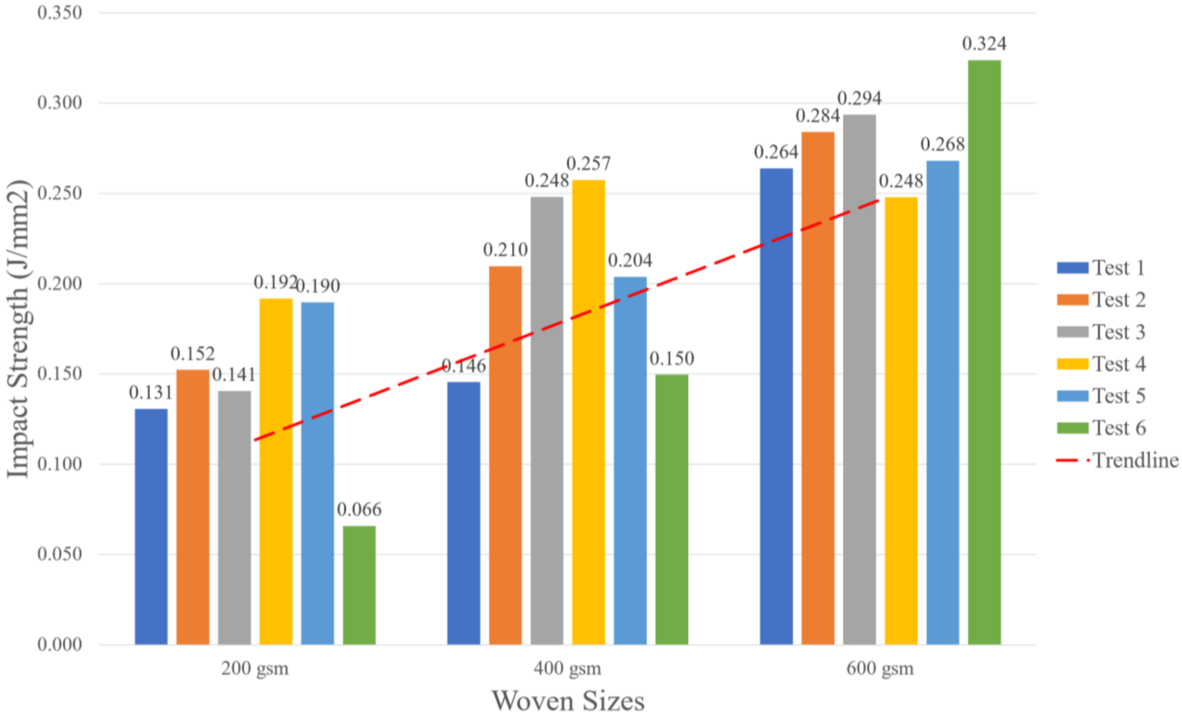


Figure 7. Impact strength of fiberglass woven roving composite

Figure 7 shows the variation of impact strength values in each specimen with variations in woven size of 200 gsm, 400 gsm and 600 gsm. The lowest average impact strength value is in the 200-gsm woven size variation of 0.145 J/mm^2, and the highest impact strength value is in the 600-gsm woven size variation of 0.28 J/mm^2. So, increasing the size of the woven fibreglass composite can increase the impact strength value. It is because the number of fibres in the roving has a greater number in the woven size of 600 gsm compared to 200 gsm so that when the composite receives a shock load, it will be able to reduce the effect that occurs because the bond between the fibres also become more robust than the smaller number of fibres in the woven size of 200 gsm.

In Figure 7, it can be seen that some specimens have lower values than other specimens of the same size. It is an anomaly that occurs in each experiment. Figure 8 shows the anomaly in fibreglass composite specimens with a woven roving size of 200 gsm. In comparison, the anomaly that occurs in composite specimens with a woven roving size of 400 gsm is shown in Figure 9. The anomaly in fibreglass composite specimens with a woven roving size of 600 gsm is shown in Figure 10. The anomaly is a model of the damage in fibreglass woven roving composites due to the impact tests performed.

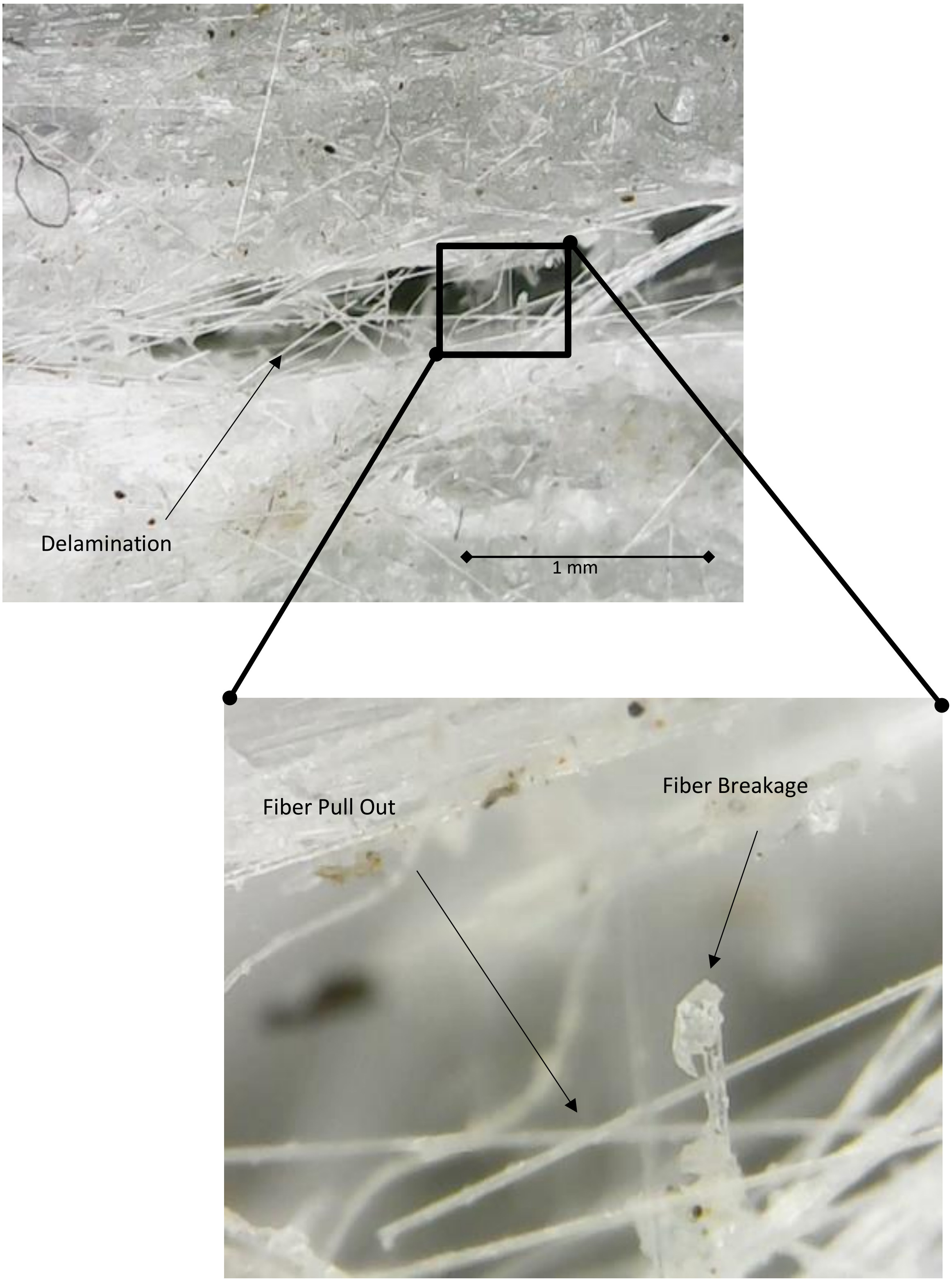


Figure 8. Composite fracture observation 200 gsm – Specimen 6

Figure 8 shows the anomaly in the sixth specimen with a woven size of 200 gsm. The presence of extensive delamination and fibre damage, as well as fibre pull-out, causes the composite to be unable to withstand perfectly the load that occurs so that the impact strength value is lower than the other specimens. This anomaly may be due to errors in the manufacturing process of the glass fibre roving composite specimens, one of which is the lack of compression so that the resins cannot spread evenly throughout the composite.

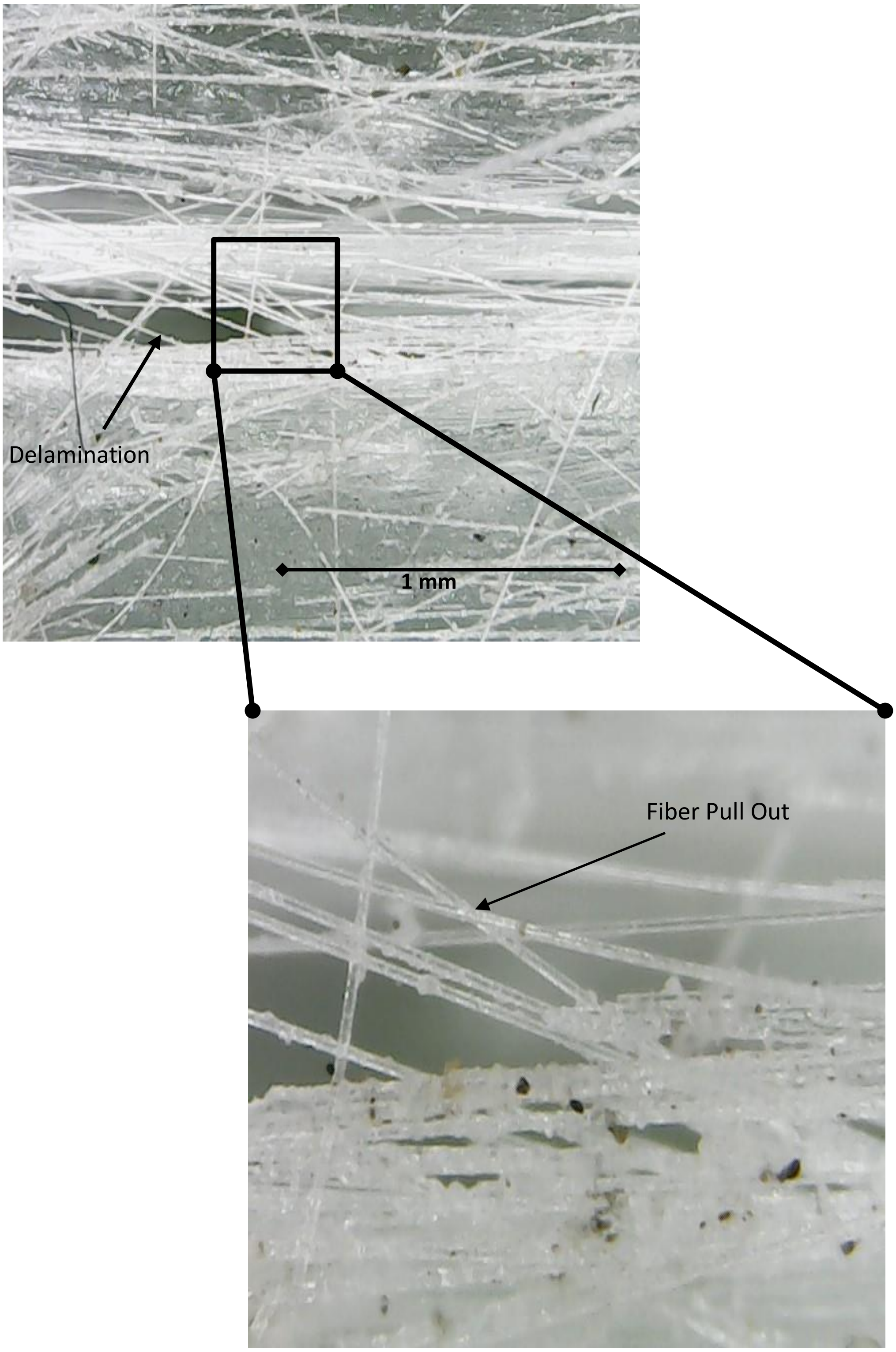


Figure 9. Composite fracture observation 400 gsm – Specimen 1

Figure 9 shows the anomaly in the first specimen with a woven size of 400 gsm. The presence of large delamination and fibre pull-out, causes the composite to be unable to withstand the load perfectly, so the impact strength value is lower than the other specimens. Figure 10 shows the anomaly in the fourth specimen with a woven size of 400 gsm. The presence of large delamination, fibre breakage, and fibre pull-out causes the composite to be unable to perfectly withstand the load that occurs so that the impact strength value is lower than the other specimens.

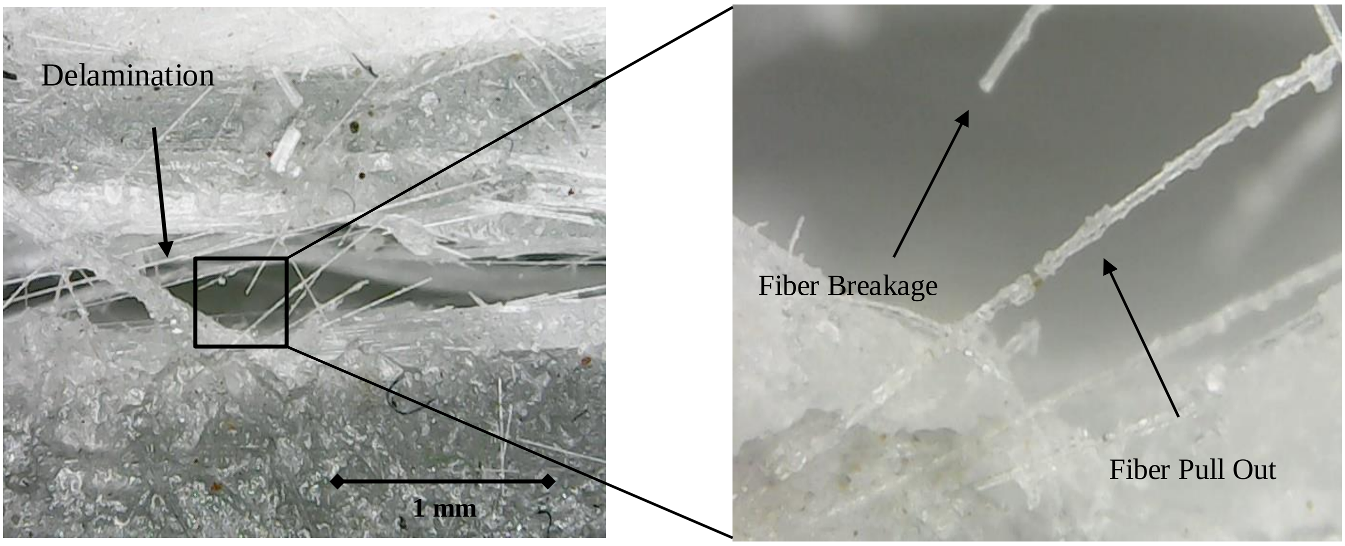


Figure 10. Composite fracture observation 600 gsm – Specimen 4

4 Conclusions

Impact tests with different woven size variations of 200 gsm, 400 gsm and 600 gsm result in a different impact strength of the specimen composites made of fibreglass. This study also found that in each woven size variation, there is one specimen whose impact strength value is far below the distribution of other specimen data, such as specimen 6 in the 200-gsm woven size variation, specimen 1 in the 400-gsm woven size variation and specimen 4 in the 600-gsm woven size variation. It happens because some variables cannot be controlled, so there are air bubbles in the specimen that the human eye cannot detect. However, the average impact strength for 600 gsm woven size has a high value of 0.28 J/mm^2. It proves that the composition of 600 gsm woven size from specimen composites can increase the average impact strength value and reduce specimen damage after being subjected to an impact load. The target is to prove that the effect of woven size variations of fibreglass composites with their impact strength has succeeded.

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