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DIGITAL IMAGE CORRELATION OF E-GLASS/BECK GP 189 RESIN SOLUTION

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ABSTRACT

The focus of this research is to develop reliable techniques to enable using digital image correlation in characterizing the mechanical properties of fiberglass composite. This composite is comprised of eight E-glass Chopped Strand layers and seven E-glass Woven Roving layers of orientations -45°, 45°, 90° and 0°. The BECK GP 189 resin solution, manufactured by Jiangyin Beck Composite Material Co. Ltd, is hardened by Methyl Ethyl Ketone Peroxide catalyst in a ratio of 2%, which may not be suited for most speckling techniques when polymerized. Therefore, this work investigates the fracture properties of specimens. For this purpose, fiberglass specimens are fabricated as per ASTM D6272 – 17e1 and ASTM D790-17 standards. Accordingly, strain rates are calculated based on the ASTM standards for the four-point and three-point bending tests using Instron 5585H load frame. GOM Correlate software is used for digital image correlation (DIC) and 3D motion analysis of the specimens during testing to determine flexural strength, strain and modulus.

1 INTRODUCTION

Fiber-reinforced polymer composites are known for their high specific tensile and compressive strength, controllable electrical conductivity, low coefficient of thermal expansion, good fatigue resistance and suitability for producing complex shape materials. Consequently, they are used as an alternative to conventional structural materials such as steel, wood, or metals in various applications such as car industry and aircraft fabrication [1]. A fiber-reinforced composite consists of a network of reinforcing fibers embedded in a matrix of resin and other materials such as fillers and pigments may also be added [2]. Among composites, E-glass Chopped Strand and E-glass Woven Roving are emerging as promising materials. Chopped strand mat is a non-woven reinforcement material made from randomly distributed chopped glass fibers held together with a binder where the fibers in chopped strand mat are usually short and typically oriented in a random fashion. On the other hand, Woven roving is a high-strength fabric made by weaving continuous glass fibers in a crisscross pattern having a uniform appearance with fibers running in both the warp and weft directions, providing strength in both directions. Various other methods of fabricating the polymer matrix composites are hand lay-up, resin transfer molding, filament winding and compression molding. Among the techniques mentioned above, the Hand lay-up technique is used in this study owing to the fact that it is effective, economical and results in a relatively good surface finish [1]. Since laminated composite structures such as plates and shells are often required to resist a bending load, it is desirable to establish their behavior and properties, usually using beam flexure tests. Accordingly, the focus of this research is to develop reliable techniques to enable using digital image correlation (DIC) in characterizing the flexural properties of fiberglass composite, such as flexural strength, strain, and modulus, under four-point and three-point bending tests and the strength differences between both tests is investigated. Flexural Strength is often referred to as transverse rupture strength, modulus of rupture, and bent strength. It is a material property that is characterized as the tension in a material just before yielding in a bend test [3]. Four-point and three-point bending assess mechanical performance under dominant normal and shear stresses, respectively. DIC algorithms require the sample surface to have random intensity variations as a carrier of deformation information. Thus, a random speckle pattern must be artificially created where the accuracy of the DIC results is highly dependent on the quality of the speckle pattern [4]. Standard speckling techniques are not applicable for all resin types due to their absorption of the applied speckling pattern, resulting in decorrelation and inaccurate strain measurements. As a result, producing an adequate speckling pattern that meets the requirements for the composite is a challenging task that is tackled in this study.

2 SPECIMEN PREPARATION

Twelve rectangular specimens were fabricated with their dimensions shown in Table 1, where six specimens used for four-point bending tests are denoted by 4PB-X, and the remaining six specimens used for three-point bending tests are identified by 3PB-X. The specimens are made of eight 1.5oz E-glass Chopped Strand layers with a density of 450 g/m^2 and seven 24oz E-glass Woven Roving layers stacking sequence with a density of 800 g/m^2 with a staking sequence of [//-45//45//90//0//90//45//-45//], where // denotes a chopped strand layer, using hand lay-up method. The BECK GP 189 resin solution, manufactured by Jiangyin Beck Composite Material Co. Ltd, is hardened by Methyl Ethyl Ketone Peroxide catalyst in a ratio of 2%.

Table 1: Specimen geometry.

Specimen	Width	Thickness
4PB-1	26.51	12.64
4PB-2	25.87	12.86
4PB-3	25.91	12.78
4PB-4	25.77	12.65
4PB-5	25.98	12.66
4PB-6	25.82	12.51
3PB-1	25.78	12.80
3PB-2	25.88	12.65
3PB-3	26.35	12.53
3PB-4	25.69	12.51
3PB-5	25.59	12.11
3PB-6	25.96	12.98

3 FLEXURAL TESTING SETUP

The specimens were rested on two supports and loaded at two points by means of two loading noses, each an equal distance from the adjacent support point, as illustrated in Figure 1a. According to ASTM D6272 – 17e1 [5], support span-to-depth ratio of 16:1 was used. An electromechanical load frame, namely, Instron 5585H with a maximum loading capacity of 250 kN, was used to apply load with the strain rate calculated using equation *1,* obtained from ASTM D6272 – 17e1 standard:

$$R = 0.185ZL^2/d \tag{1}$$

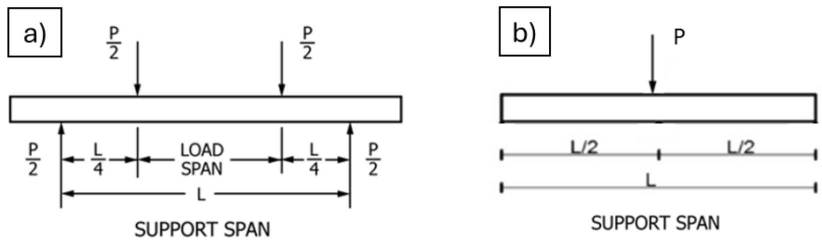

Figure 1. a) Four-point bending test diagram, b) Three-point bending test diagram (ASTM D6272) [5][6].

Where *R* is the rate of crosshead motion (mm/min), *L* is the support span (mm), *d* is the depth of the beam (mm), and *Z* is the rate of straining of the outer fibers (mm/mm) where it is usually equal to 0.01.
The load frame was equipped with a 3D digital image correlation (DIC) stereo system focused on capturing strain measurements in the y-direction. The DIC system used consisted of two Mega Speed highspeed cameras model MS 130K and LED lights working in sync to capture full-field strain data. The sensor pixel size of the identical cameras is 12 µm. The 40 mm lenses were used to provide excellent focus on the specimens. The intention behind this setup is to imitate the capabilities of the human vision system. By doing so, we aim to not only measure the strain in a specific direction but also to capture the entire test as a 3D model. This approach provides a more complete understanding of the material's behavior under bending and enables a comprehensive analysis of its mechanical response. The 3D DIC system was calibrated using GOM correlate standard coded panel MV 55x44. The 3D version of GOM correlate software 2017© was used for the analysis [7]. Figure 2 shows the load frame with the stereo camera system. For all tests, the thickness of the specimen and the radius of supports and loading noses were kept constant.
When the composite is polymerized, the speckling paint is absorbed, introducing errors when defining and verifying the speckle pattern. Consequently, a thin base layer of clear paint was carefully applied to all samples before the standard speckling process. This clear paint layer acted as a protective barrier, preventing the absorption of the subsequent spray paint used for speckling. The clear paint layer was allowed to dry thoroughly before proceeding with the normal speckling process. Subsequently, the specimens were speckled using black and white paint by layering one colour on top of the other until the required density was achieved.
Similar procedures were used for the three-point bending tests. However, the specimens were loaded at one point by means of one loading nose, as displayed in Figure 1b. The strain rate is calculated using equation *2* obtained from ASTM 790-17 [8]:

$$R = ZL^2/6d \tag{2}$$

Figure 2. Instron 5585H load frame with high-speed stereo system for 3D digital image correlation (3D-DIC) test setup.

4 FLEXURAL TESTING RESULTS

Full-field strain measurements just before the final fracture under the four-point bending test and three-point bending test are shown in Figures 3a and 3b, respectively. The chief objective of the proposed work is to analytically predict the Flexural behavior of E-GLASS/BECK GP 189 RESIN. Accordingly, Flexural Strength (*S*), Flexural Strain (ε) and Flexural Modulus (*M*) were calculated for four-point bending tests using equations (*3), (4)* and (*5)* [5][6], respectively:

$$S_{4PB} = \frac{PL}{bd^2} \tag{3}$$

$$\varepsilon_{4PB} = \frac{4.36Dd}{L^2} \tag{4}$$

$$M_{4PB} = \frac{11PL^3}{64bd^3D} \tag{5}$$

Where *P* is the load at a given point on the load-deflection curve (N), *L* is the support span (mm), *b* is the width (mm), and *d* is the depth (mm), and *D* is the deflection due to the load *P* applied at the middle of the specimen.

For three-point bending tests, equations (*6*), (7) and (*8*) were used to determine the Flexural Strength (*S*), Flexural Strain (ε) and Flexural Modulus (*M*) [6][8]:

$$S_{3PB} = \frac{3PL}{2bd^2} \tag{6}$$

$$\varepsilon_{3PB} = \frac{6Dd}{L^2} \tag{7}$$

$$M_{3PB} = \frac{PL^3}{4bd^3D} \tag{8}$$

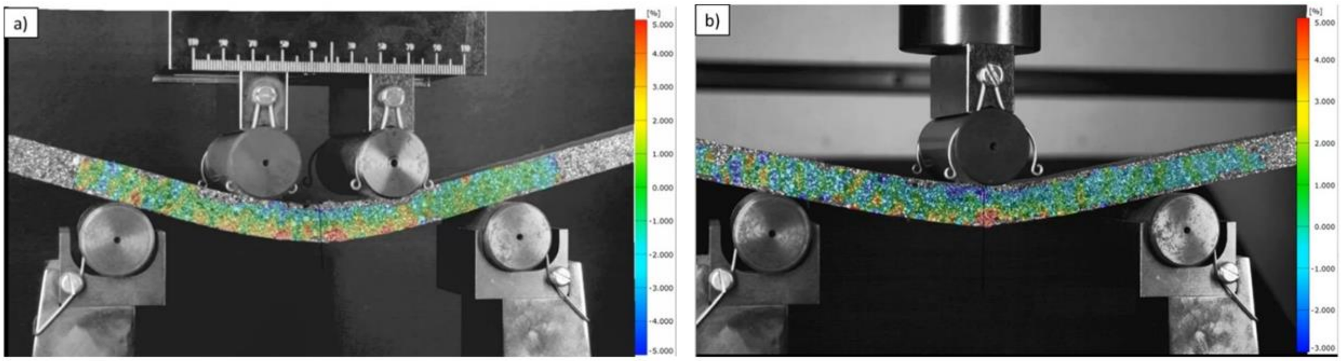

Figure 3. a) Full-field strain of composite specimen under four-point bending test just before failure, b) Full-field strain of composite specimen under three-point bending test just before failure.

Load values, *P,* were obtained from the Instron 5585H load cell, while displacement measurements, *D*, were attained using the GOM software. Tables 2 and 3 summarize the flexural properties, including the composite specimens' flexural strength, strain, and modulus under the four-point and three-point bending tests, calculated using equations *(3)* to *(8)*.

Table 2: Summary of four-point bending flexural tests.

Specimen	Flexural Strength [MPa]	Flexural Strain [mm/mm]	Flexural Modulus [GPa]
4PB-1	179.4	0.038	4.92
4PB-2	206.8	0.040	4.71
4PB-3	192.6	0.034	4.86
4PB-4	162.6	0.046	3.25
4PB-5	147.2	0.039	3.52
4PB-6	159.2	0.036	3.90
Mean	174.6	0.039	4.19
Standard Deviation	22.43	0.004	0.73

Table 3: Summary of three-point bending flexural tests.

Specimen	Flexural Strength [MPa]	Flexural Strain [mm/mm]	Flexural Modulus [GPa]
3PB-1	194.0	0.046	5.28
3PB-2	196.6	0.033	6.25
3PB-3	198.3	0.029	6.83
3PB-4	181.5	0.033	5.62
3PB-5	177.7	0.035	5.20
3PB-6	176.0	0.030	5.81
Mean	187.35	0.034	5.83
Standard Deviation	10.06	0.006	0.62

As demonstrated in Tables 2 and 3, the four-point bending test resulted in a mean flexural strength of 174.6 MPa, a mean flexural strain of 0.039 mm/mm and a mean flexural modulus of 4.19 GPa. On the other hand, the three-point bending test resulted in a mean flexural strength of 187.4 MPa, a mean flexural strain of 0.034 mm/mm, and a mean modulus of 5.83 GPa. Evidently, a significantly higher flexural strength and modulus with the three-point bending test was observed in comparison with the four-point bending test.

5 CONCLUSION

The focus of this research is to develop reliable techniques to enable using digital image correlation in characterizing the flexural properties of E-glass/BECK GP 189 resin under both three-point bending and four-point bending tests. Specimens were fabricated via hand lay-up technique, and testing was done according to ASTM D790 – 17 and ASTM D6272 – 17e1 using Instron 5585H. GOM Correlate software was used for digital image correlation (DIC) and 3D motion analysis of the specimens to extract full-field strain measurements. Challenges while speckling the composite were detected due to their absorbent property; thus, a thin base of clear paint layer was added as a protective barrier preventing the absorption of the subsequent spray paint used for speckling. The flexural strength, flexural strain, and flexural modulus were found from the experimentations and appropriate formulas. It can be concluded that the three-point bending tests resulted in higher flexural strength and modulus for the E-glass/BECK GP 189 RESIN composite than the four-point bending tests.

6 REFERENCES

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