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Effect of Various Cross-Sections on the Flexural Behaviour of Composite Beams

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Abstract

This study investigated the influence of various cross-sections on the flexural properties of composite beams. Within the first stage of the paper, a finite element model represented the standard three-point bending test of a composite beam was developed. The model was correlated by mesh dependency analysis and a three-point bending test. After model correlation was completed, composite beam models with 6 cross-sections were generated as CAD data and imported to the correlated finite element model. As a result of the studies, it has been determined that the F profile is the most unstable profile compared to other sections, and the D profile is the most durable profile.

Keywords: Composite materials, different cross-section, finite element analysis (FEA), three-point bending

1. INTRODUCTION

The rapid progress of technology necessitates the use of new materials with advanced properties as an alternative to classical materials. Thus, studies on composite materials have gained great importance [1, 2].

Glass fiber used in this study is a widely used reinforcing element in polymeric matrix composites. Glass fiber has high tensile strength, high corrosion resistance and very good insulation properties. The disadvantages are low modulus of elasticity, high specific gravity compared to other commercial fibers, low wear resistance, low fatigue strength and high hardness [3].

Mechanical properties define the strength of the material and changes of shape that occur in the material under force. These effects are usually in the form of either deformation or fracture. Objects first deform under increasing external impacts, then they brake by losing their strength. Geometrical change in the cross-section profile of the materials is one of the

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important factors affecting the strength of the material. Esendemir et al. obtained analytical, experimental and numerical maximum deflection values for different beam lengths, widths and loads of a lattice glass-epoxy prepreg composite beam supported on both sides and subjected to a single load from its mid-point. Experimental, analytical and numerical solutions were found to correlate with each other [4]. Vanam et al. made a static analysis of an isotropic rectangular plate with various boundary conditions and various types of load applications. In this paper, finite element analysis has been carried out for an isotropic rectangular plate by considering the master element as a four-noded quadrilateral element. They confirmed the analysis results with the analytical results [5]. Salih et al., in their study, investigated the amount of deflection and bending stresses that occur in beams with different profiles that can be used in steel construction structures. Deflection and bending stress levels for the same dimensions and different cross-section profiles were obtained using ANSYS Workbench, the software. They presented by comparing with theoretical and numerical calculations [6]. Azzam and Li investigated the behavior of a composite laminate structure under a three-point bending load by subjecting two types of stacking sequences of a composite laminate structure by performing a flexural test [7]. Ansari and Cho in their study, they researched the bending and resonance frequencies of rectangular, triangular and step profile microcysts exposed to surface stress with computer -aided structural analysis program [8]. Evran investigated the bending stress in the axial functional-graded layered beams with a built-in-free limit conditions [9].

Present studies are generally emphasizing the influence of cross-section profiles on the mechanical properties of metallic materials as aforementioned. However, to the best of our knowledge, there is no study examining the effect of cross-section profiles load on the flexural properties of composite material. The aim of this study is to observe the effect of cross-sectional change on stress in composite materials. The research mainly presents the results of computational studies. As a part of the study, a glass fiber epoxy composite plate was fabricated using the prepreg compression molding method, and a three-point bending test was performed. The three-point bending test was used to model correlation. In order to reach the force and displacement values obtained as a result of the experiment, mesh dependency analysis was performed. A material correlation was provided as a result of the analysis. 6 various cross-section profiles with the same outer dimensions were designed from the Catia V5 CAD software. Generated models were divided into small parts for the simulation to be carried out in the Hypermesh software. Calculations were made separately for each design in the CAE environment [10].

2. MATERIALS AND METHODS

2.1. Material

Glass fiber-reinforced epoxy composite was used in the experimental section. 5 layers of unidirectional glass fiber reinforced epoxy prepreg were cured via compression molding process to obtain a glass fiber reinforced epoxy plate. The test plate was cut with a water-jet method according to the related test standard to obtain three-point bending test coupons. Three-point bending test coupon was illustrated in Figure 1.

Figure 1 Three-point bending test sample

2.2. Three-Point Bending Test

Three-point bending tests were carried out on the composite test coupons according to the ASTM D790 test standard in order to use in model correlation. Shimadzu universal testing machine with a 250 kN load cell was used. Test rate was determined 1 mm/min. 5 specimen was tested to avoid scattering on the test results. The three-point bending test setup is shown in Figure 2.

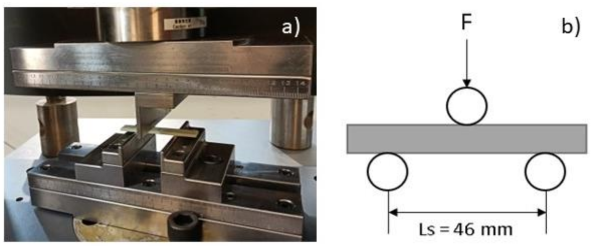

Figure 2 a) Three-point bending test set-up, b) schematical view of the test setup.

2.3. Design of Cross-Section Profiles

Three-point bending test setup and schematical view of the test setup are given in Figure 2. The sample dimensions are 14.9 x 2.84 x 90 mm.

Test sample and 6 various cross-section profiles with the same dimensions were designed from the Catia V5 solid model design program shown in Figure 3.

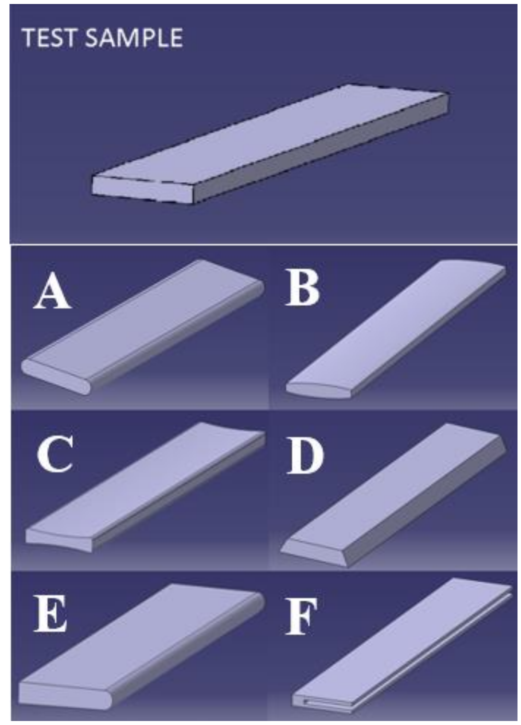

Figure 3 Design of various cross-section profiles

3. RESULT AND DISCUSSION

3.1. Model Correlation

Three-point bending test results were utilized for model correlation. The force-displacement curve of a specimen was shown in Figure 4 as a representative illustration.

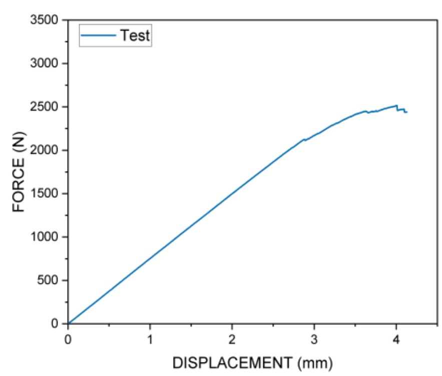

Figure 4 Force-displacement curves of three-point bending test sample

During the three-point bending test, deflection in the middle of the sample is measured as the function of force (F). Deflection values were measured at the midpoint of the sample where the highest deflection and bending moment occur for the entire sample. The image of the damaged sample as a result of the experiment is given in Figure 5. The maximum bending stress occurs at the bottom of the sample (Fig. 6).
Maximum deflection measured from the three-point bending tests was imported to the finite element model and stress distribution on the composite beam was obtained shown in Figure 7.

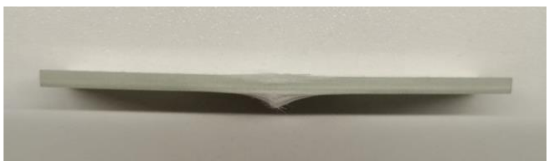

Figure 5 As a result of the bending test, the sample

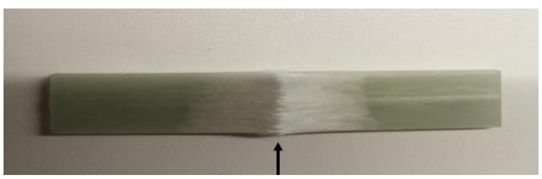

Figure 6 Maximum bending stress region of the specimen

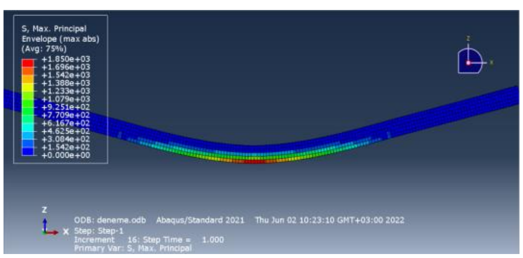

Figure 7 Maximum bending stress of the part when maximum deflection is applied

In order to converge to the force and displacement values obtained as a result of the three-point bending test with finite element model mesh dependence analysis was used. Finite element models were generated with various mesh sizes to find optimum meshing.

Figure 8 shows the 1st mesh iteration into the rectangular sample. The dimensions of the mesh are given. As a result of the analysis, it is seen in Figure 9 that the model is not correlated with the test results.

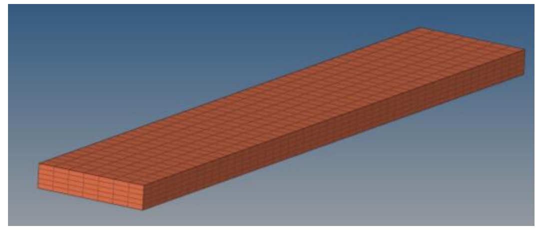

Figure 8 1st Mesh image (2.13mm-0.57mm-1.8mm)

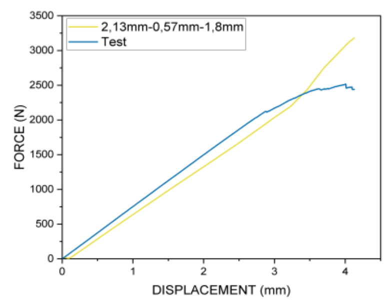

Figure 9 1st Mesh Force-displacement curves (2.13mm-0.57mm-1.8mm)

Figure 10 shows the 2nd meshing iteration. Mesh dimensions are 0.99mm-0.57mm-1mm. The results converged as the mesh size was reduced, as shown in Figure 11.

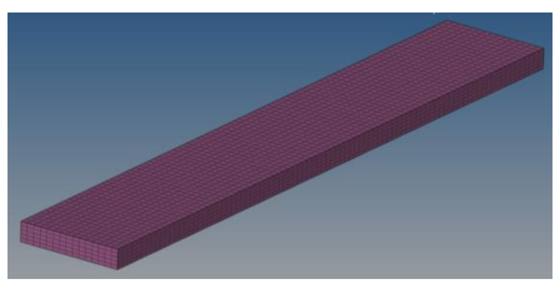

Figure 10 2nd Mesh image (0.99mm-0.57mm-1mm)

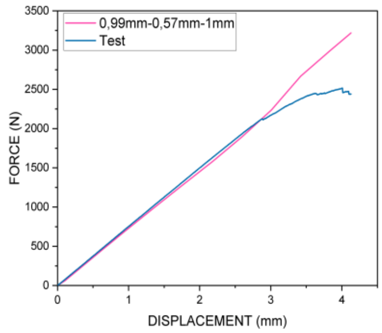

Figure 11 2nd Mesh force-displacement curves (0.99 mm-0.57mm-1mm)

The model with a mesh size of 0.99mm-0.57mm-1mm, it is aimed to improve the results by reducing the mesh sizes one step further (Figure 12). Mesh dimensions have been updated to 0.49mm-0.57mm-0.5mm. Force-displacement curves for dimensions 0.49mm-0.57mm-0.5mm are shown in Figure 13.

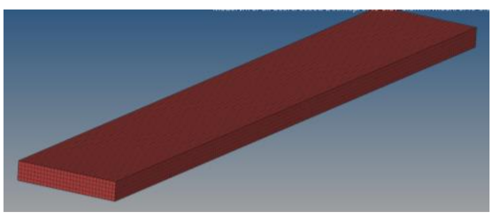

Figure 12 3rd Mesh image (0.49mm-0.57mm-0.5mm)

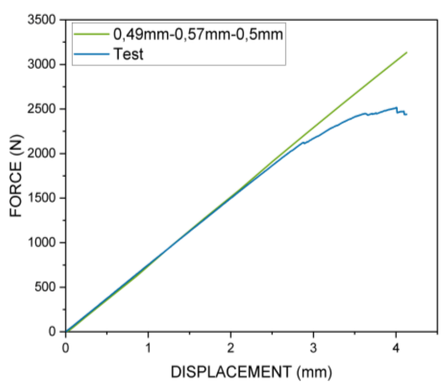

Figure 13 3rd Mesh force-displacement curves (0.49mm-0.57mm-0.5mm)

In Figure 14, while the mesh sizes are 0.99mm-0.57mm-1mm and the mesh sizes are 0.49mm-0.57mm-0.5mm, there are minor differences between them. The results are shown when the mesh size is 0.49mm-0.57mm-0.5mm was observed to converge better.

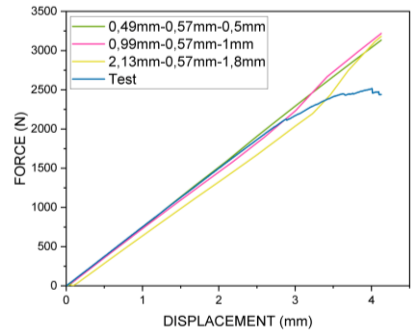

Figure 14 Force-displacement curves

As a result of the analysis, it was determined that the optimum mesh size was 0.49mm-0.57mm-0.5mm in the analysis in correlation with test results.

3.2. Analysis Results and Discussions

In this study, the stress and deflection levels that occur on different cross-section profiles were analyzed by the computer-aided structural analysis software Abaqus. For the finite element model, the mesh sizes are 0.49-0.57-0.5mm and the mesh type is Hexa Dominant. A load of 1000 N was applied to each section profile to be analyzed. The running parts are shown in Figures 15, 16, 17, 18, 19, 20, and 21.

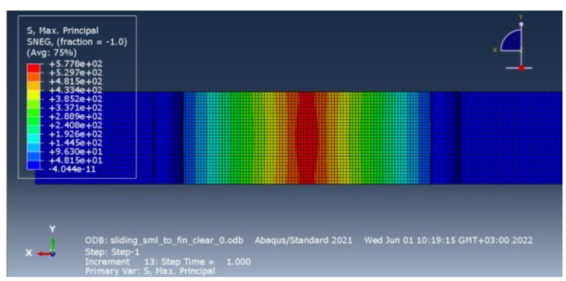

Figure 15 Bending stress resolved for rectangular profile

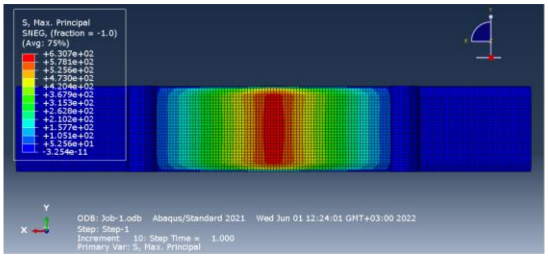

Figure 16 Bending stress resolved for A profile

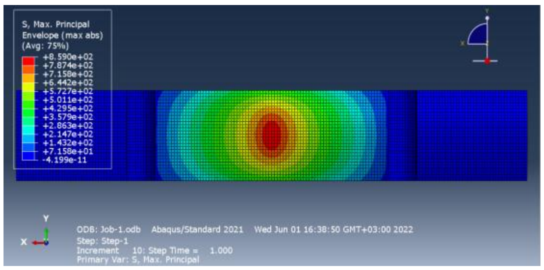

Figure 17 Bending stress resolved for B profile

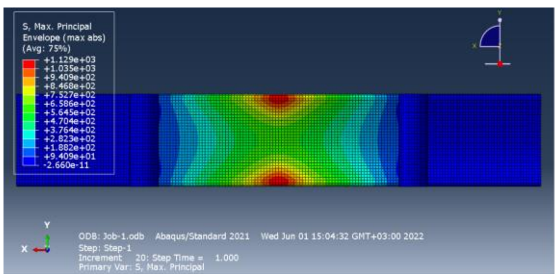

Figure 18 Bending stress resolved for C profile

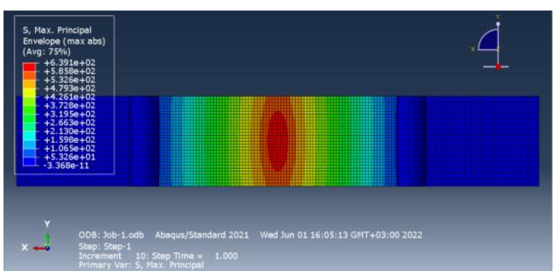

Figure 19 Bending stress resolved for D profile

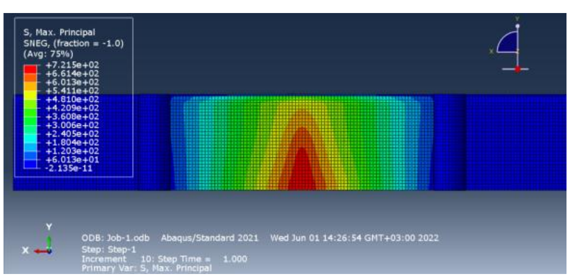

Figure 20 Bending stress resolved for E profile

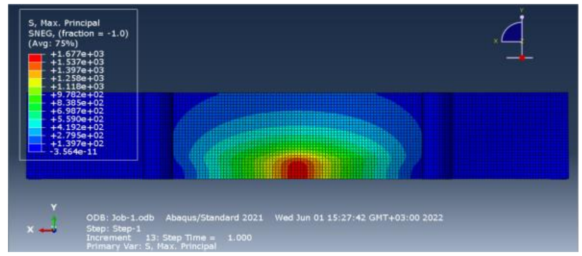

Figure 21 Bending stress resolved for F profile

The deflection and maximum bending stresses given in Table 1 have been examined section concerning the rectangular sample.

Table 1 Deflection and bending stresses determined with the help of numerical calculations of different section profiles

Section Profile	***Cross-Sectional Area***	***Maximum Bending Stress***	***Force***	***Deflection***
	(mm^2)	(σ-MPa)	(N)	(mm)
Rectangle (Test Sample)	42.32	577.8	1000	1.22444
A	40.24	630.7	1000	1.33772
B	36.33	859	1000	1.84013
C	33.98	1129	1000	2.55304
D	37.66	639.1	1000	1.39696
E	39.55	721.5	1000	1.5832
F	29.94	1677	1000	3.37653

When the rectangular section profile is excluded, Table 1 shows that the profile section with the least deflection behavior is the A profile with 1.337 mm, and the section profile with the highest deflection behavior is the F profile with 3.376 mm. When examined in terms of maximum bending stress, the minimum stress belongs to the A profile with 630.7, and the highest bending stress belongs to the F profile with 1677 MPa. Profiles showing the least deflection behavior were calculated as A profile, E profile, D profile, B profile, C profile, and F profile, respectively. The profiles with the least bending stress were found as the A profile, D profile, E profile, B profile, C profile, and F profile, respectively.

Table 2 Results of different section profiles according to rectangular section (%)

Section Profile	***Cross-Sectional Area***	***Maximum Bending Stress***
	Decreasing (%)	Increasing (%)
A	5	9
B	14	49
C	20	95
D	11	11
E	7	25
F	29	190

4. CONCLUSION

For the A-section, the cross-sectional area decreased by 5%, while the maximum bending stress increased by 9%. For the B section, the cross-sectional area decreased by 14%, while the maximum bending stress increased by 49%. For the C section, while the cross-sectional area decreased by 20%, the maximum bending stress increased by 95%. The reason for the stress of the C section to be excessive is the local stress concentrations that occur due to the loading conditions. For the D section, the cross-sectional area decreased by 11%, while the maximum bending stress increased by 11%. For the E section, while the cross-sectional area decreased by 7%, the maximum bending stress increased by 25%. For the F section, the cross-sectional area decreased by 29%, while the maximum bending stress increased by 190% (Table 2). This shows that the F profile is the weakest compared to other sections. In terms of area reduction and stress increase, it was determined that the best result was the D section profile. D section profile may be preferred for materials to be produced from composite in the future. In this way, while there is no loss in material strength, cost savings are achieved as the area is reduced.

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Authors' Contribution

The authors contributed equally to the study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification of the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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