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EFFECT OF FIBER ORIENTATION ANGLES ON MECHANICAL BEHAVIOR OF CAR BUMPER COMPOSITE

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ABSTRACT

The present work focused on the effect of glass fiber orientation that reinforced polymeric matrix in car bumper composite to understand the mechanical behavior of these materials during work conditions. Tensile test and bending test were performed and discussed for (0^o, 30^o, 45^o, 60^o, and 90^o) angles of fibers orientation. The finite element method by program (ANSYS V.13 software) was used to study the behavior of these compounds. The results showed that the extension and deflection values were higher at (0^o) and decreased with increasing fiber angle orientation until reached to a lower value at perpendicular state between fibers and applied loads. The study used to improve the mechanical properties of the composite materials depending on the fiber orientation angle.

KEYWORDS: Car bumper; Fiber orientation; Composite materials; Composite mechanical behavior

تأثير زوايا توجيه الألياف على السلوك الميكانيكي لدعامة سيارة من المواد المتراكبة

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الخلاصة

ركزت الدراسة الحالية على تأثير زاوية توجيه الألياف الزجاجية التي تعزز ارضية البوليمر في دعامة السيارة والمصنعة من مواد متراكبة لفهم السلوك الميكانيكي لهذه المواد خلال ظروف العمل. أجري خلال الدراسة اختبار الشد واختبار الانحناء ومناقشة تاثير زاوية انتظام الياف التسليح للزوايا (0، 30، 45، 60 و 90). تم الاستعانة بطريقة العناصر المحددة و برنامج ANSYS V.13 لدراسة سلوك هذه المركبات. أظهرت النتائج أن قيم التشوه والانحراف كانت أعلى عند الزاوية (0) وتتناقص وصولا إلى أقل قيمة في حالة التعامد بين الألياف والأحمال المطبقة. استخدمت الدراسة لتحسين الخواص الميكانيكية للمواد المتراكبة اعتمادا على زاوية اتجاه الألياف.

1. INTRODUCTION

Composite materials are materials made from two or more constituent materials with specific different physical or chemical properties that when combined produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be desired for many reasons, such as stronger, lighter, and less expensive when compared to other materials (Ahmed et al., 2015), and that makes it an important and suitable alternative for multiple uses in order to get a certain mechanical behavior of materials. The multi-types of matrix and fiber reinforcement enables the manufacturers to find a certain materials with special specifications which used in various forms, such as long continuous fibers, discontinuous fibers, chopped fibers, grinded fiber, and oriented or random mat (Broz et al., 2002; Hota et al., 2010; Hashim et al., 2011).

The effect of fiber reinforcement angles were discussed in many previous studies (Hashim et a., 2011). The fibers that are not completely perpendicular to the fracture plane give the greatest toughening while fibers at higher angles oriented showed less toughening, involving the contributions from, breakage, and de-bonding (Norman et al., 2002). Also the damage that is produced in the composites matrix cracking on the lower face was followed by the incorporation of delaminations to be shaped within the reinforcing plies (Davallo, 2010). Also three point bending tests were accomplished out on specimens of $0/90^o$ and $0/45^o$ hand lay-up composites of glass fiber and graphite fiber reinforced laminates which have revealed more flexural strength than orientation $0/90^o$ lay-up composite for the same type of the fiber reinforcement (Rathnakar, 2013). The glass/epoxy with 0^o orientation has higher strength, stiffness, and load carrying capacity than any other orientation (Ahmed, 2013). The experimental of the effect of fiber orientation on the flexural strength results presented the difference in flexural strength in bidirectional glass fibers at $0\text{-}90^o$ and $-45+45^o$, where these results showed that the $-45+45^o$ orientation have higher strength (Sandeep et al., 2013).

The present work investigates the effect of fiber angles orientation in (specific directions) for car bumper composite material and these effects on the mechanical behavior of these materials.

2. EXPERIMENTAL WORK

The present work focused on the mechanical behavior of composite material for front car bumper with different fibers orientation angles. Some of laboratory tests were correlated to understand the mechanical behavior of these materials under certain conditions. The fibers orientation angles (0^o, 30^o, 45^o, 60^o, and 90^o) were discussed.

The composite material included materials, such as unsaturated polyester resin Saudi Arabia, Tapaz 1110TP (pale yellow insoluble in waster, 1.2 g/cm3, 100oC flash point) (Sika Products), catalyst material (1% - 3%), cobalt octoate, and glass fibers in one direction as shown in Fig. 1 that were tested in specific angles. Some of laboratory tests were performed, such as tensile test, according to ASTM D 638 plastic that used for testing materials for thickness up to 14 mm (thick sheet) and less than 1 mm (thin sheet). ASTM D 3039 is used to determine the properties of tensile for polymer matrix composite materials that is reinforced by fibers with high modulus, and this was used in the present work with volume fraction (12%) for each sample.

a) (0^o)

b) (30^0**)**

c) (45^o)

d) (60^0**)**

e) (90^o)

Fig. 1. Glass fiber Orientation

Figs. 2 and 3 illustrate tensile test computerize machine with piston stroke 600mm, double acting piston with low-friction, capacity range; 400kN-800kN, with Accuracy 0.001mm that was calibrated by standardization and quality control organization- Baghdad. The test rates V_o=5 mm/min; V_1=10 mm/min.

Fig. 2. Tensile test computerized machine

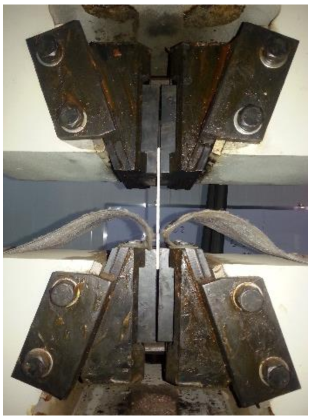


Fig. 3. Tensile test grips

At least five test specimens from each sample type (angle) should be tested then the average results was taken. The tensile test specimens were preparing at standard laboratory atmosphere conditions (23 ± 3 °C and 50 ± 10 % relative humidity). The test specimen is shown in Fig. 4 and tested according to ASTM D3039.

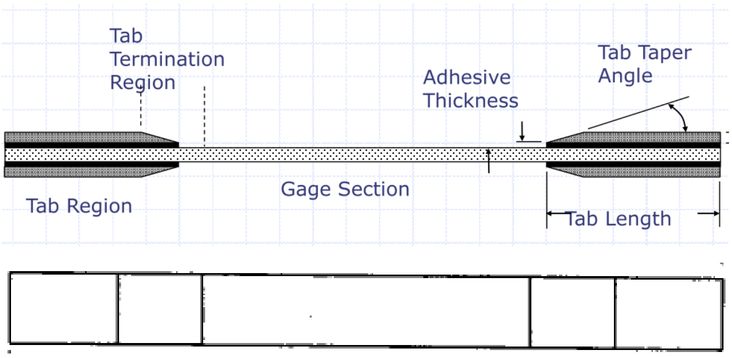


Fig. 4. Tensile test specimen

Also, Fig. 5 shows the bending test in the same machine that was executed based on ASTM D790-07e1 using a three point bending test technique to calculate deflection and stress resulting for a rectangular cross-section until failure occurs. Five test specimens from each sample type (angle) should be tested, and the average results was taken.

Fig. 5. 3-Points bending test

3. FINITE ELEMENT INVESTIGATION

FEM requires the solution of large systems of equations and powered by fast solvers; ANSYS V.13 makes it possible for designers to quickly check the integrity of their designs and search for the optimum solution (Moghaddam, 2011). Cars bumper must be aerodynamic, light weight, and aesthetically pleasing to the consumer and made of polypropylene, polyurethane, or polycarbonate (Uddandapu, 2013). Shell91 may be used for nonlinear behavior. A free mesh has no restrictions in terms of element shapes and has no specified pattern applied to it (Bagherpour, 2012).

In the present investigation a free mesh was used to treat car bumper model. The meshing process for car bumper is illustrated in Fig. 7, and the element type was Shell91 that has six degrees of freedom at each node; the translations are in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes (ANSYS Software).

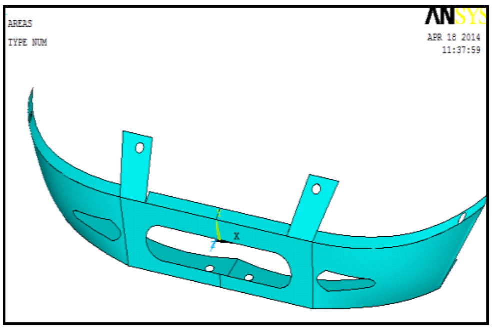


Fig. 6. Schematic configuration of car bumper

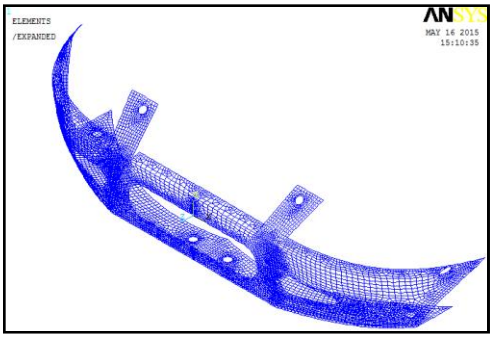


Fig. 7. Meshing of car bumper

4. RESULTS AND DISCUSSION

Tensile strength (TS_c) of fiber reinforced polymer composites depends on the linkage between the fibers and the matrix. Where, the rule of mixtures used to estimate the tensile strength (Bagherpour, 2012):

$$TS_c = f_m \sigma_m + f_f\, TS_f \tag{1}$$

Flexural strength was calculated according to:

$$\sigma_m = \frac{3\,FL}{2\,bd^2} \tag{2}$$

The maximum value of tensile strain was calculated from:

$$\varepsilon = \frac{6\,Dd}{L^2} \tag{3}$$

Figs. 8 and 9 described the mechanical behavior of polymeric composite material.

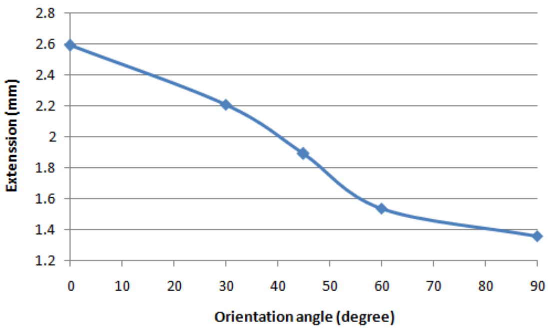


Fig.8. Max. extension vs. orientation angle

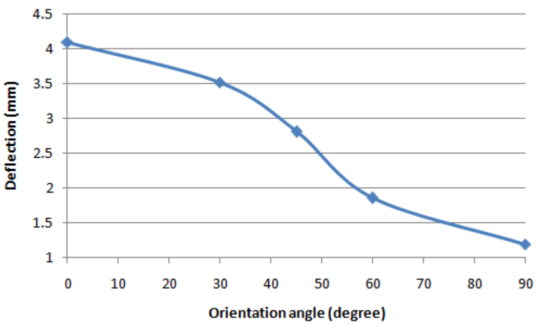


Fig.9. Max. deflection vs. orientation angle

From a review of the results, it seems clearly the ability of composite material to bear the stresses, but this ability begins to decrease with increasing the amount of fiber orientation angle. Fig. 8 shows the extension value at 0^o was 2.59 mm, while the extension value at 90^o was 1.36 mm. Fig. 9 shows the deflection value at 0^o was 4.1 mm, while the deflection value at 90^o was 1.2 mm. These results may be related to the ability of fibers to withstand against affective loads, and with increasing the orientation angle the fiber carried out less effective loads and through that polymeric matrix being to carry out these loads until carry overall loads at perpendicular direction of loads on fibers. That leads to occurrence of separation between polymeric matrix and reinforcement fibers as a result to detach bonding between matrix and fibers, where the forces stretched the matrix and causing the material to shear at the interface between matrix and fibers and this lead to failure. The bonding between the fiber and matrix affect on the tensile strength of fiber reinforced (Bagherpour, 2012). The present results may be related to the concentration of the fibers, shape, and geometrical size of fiber, aspect ratio of fiber, and adhesion between fiber and the matrix, and all these may be affected on the mechanical behavior of the composite material. Finally, some of the environmental factors like humidity and weathering cause to aging of the specimens, and the flexibility may be decreased slightly. in the current study cannot tested the car bumper completely and will be treated in the analytical side.

Table 1 shows a comparison between experimental and numerical results of tensile test for a composite material containing of polyester resin reinforced by glass fiber. The test was performed with different angles (0^o, 30^o, 45^o, 60^o, and 90^o).

Table 1. Experimental (tensile) results

Orientation angle (deg.)	Exp. Maximum Extension (mm)	Theo. Maximum Extension (mm)	Error (%)
0	2.59	2.70	4.24
30	2.21	2.30	4.07
45	1.89	1.96	3.17
60	1.54	1.67	8.44
90	1.36	1.47	8.08

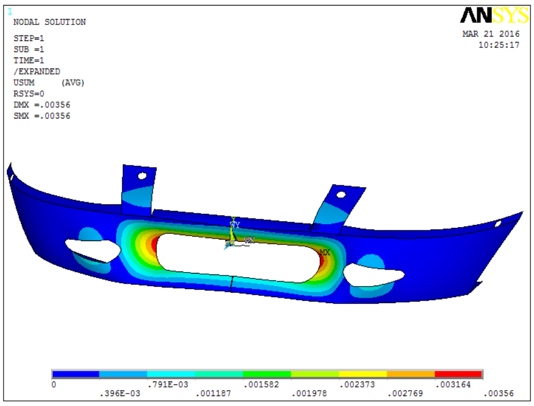
Also, Table 2 shows a comparison between experimental and numerical results of bending test for a composite material containing of polyester resin reinforced by glass fiber. The test was performed for same angles mentioned previously.

Table 2. Numerical (bending) results

Orientation angle (deg.)	Exp. Maximum Deflection (mm)	Theo. Maximum Deflection (mm)	Error (%)
0	4.10	4.37	6.580
30	3.30	3.52	6.670
45	3.70	3.81	2.970
60	1.86	2.14	15.05
90	1.22	1.43	17.20

All the analytical results showed same behavior in tensile and bending tests. Also, the analytical results seem to be increased slightly compared with the experimental results, and these increases may be related to idealistic the analytical solution where there is no defects or cracks. Also, several factors that affected the mechanical behavior of the composite material that mentioned previously were neglected during the analytical solution, and that may be lead to the discrepancy between experimental and analytical results. The difference between experimental and theoretical results was found to be no more than (8.44%) for extension in tensile test, and no more than (17.2%) for deflection in bending test.

For fully car bumper structure, the analytical solution introduced excellent results for displacement distribution and stress according to von misses theory for (0^{o}, 30^{o}, 45^{o}, 60^{o} and 90^{o}) angles of fibers orientation and by using ANSYS V.13. Figs. 10-14 show displacement distribution and Figs. 15-19 show stress distribution.



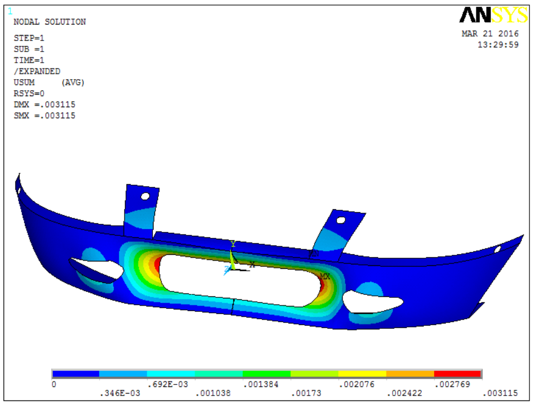
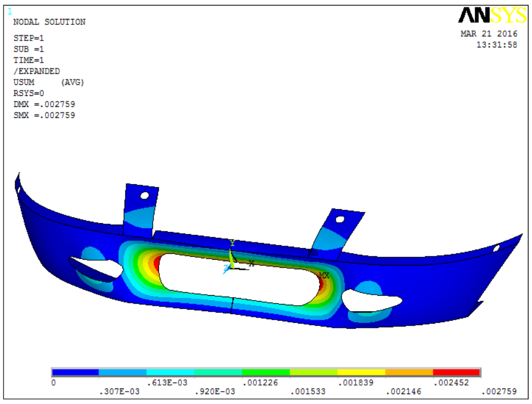


Fig. 10. Displacement distribution at (0^{o})

Fig. 11. Displacement distribution at (30^{o})



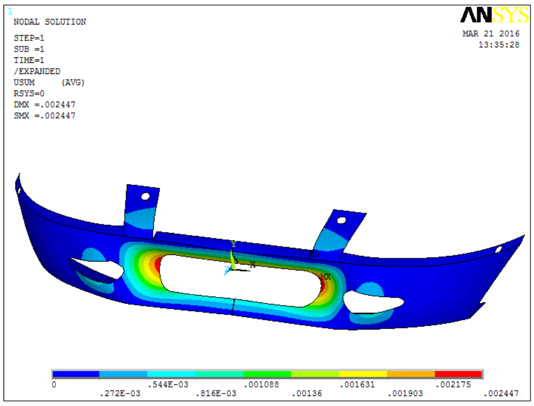


Fig. 12. Displacement distribution at (45^{o})

Fig. 13. Displacement distribution at (60^{o})

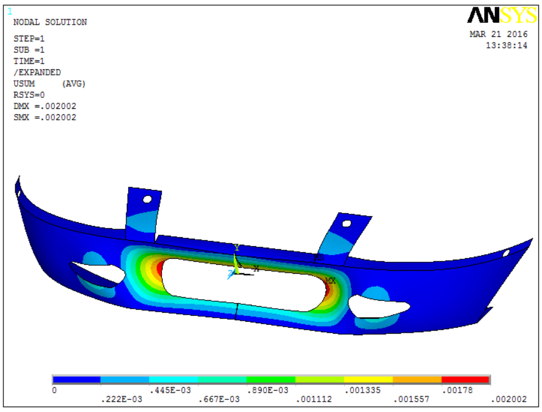


Fig. 14. Displacement distribution at (90^o) angle

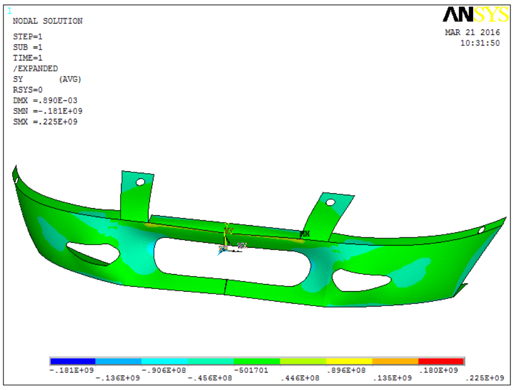


Fig. 15. Stress distribution at (0^o) angle

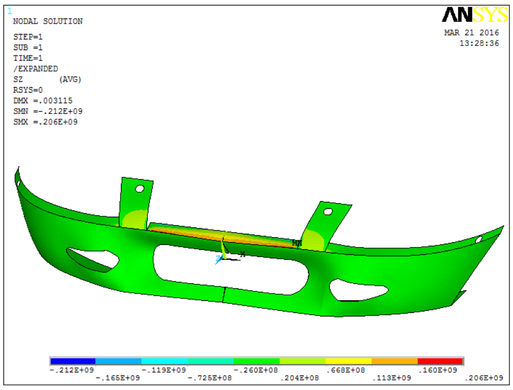


Fig. 16. Stress distribution at (30^o) angle

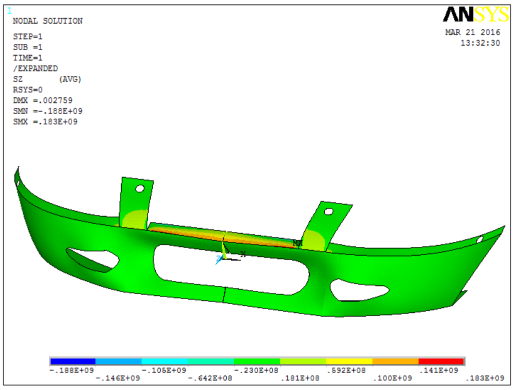


Fig.17. Stress distribution at (45^o) angle

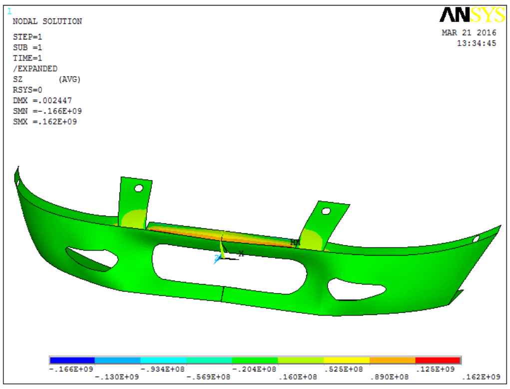


Fig.18. Stress distribution at (60^o) angle

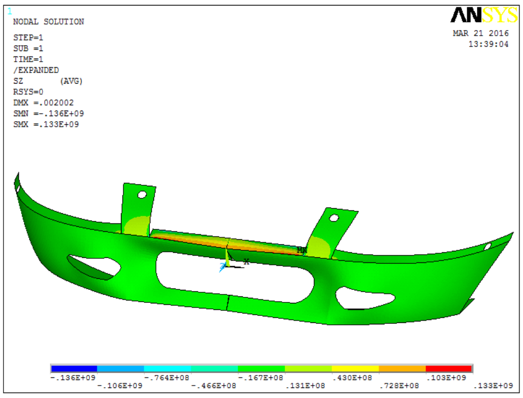


Fig. 19. Stress distribution at (90°) angle

Table 3 below illustrates the maximum value of displacement and stress distribution verity with orientation angle of fibers on the fully design of car bumper composite.

Table 3. Numerical results (displacement and stress distribution)

Orientation angle (deg.)	Maximum Displacement (mm)	Maximum Stress (MPa)
0	3.560	225
30	3.110	206
45	2.750	183
60	2.440	162
90	2.002	133

5. CONCLUSIONS

The present work extracted to durable dependency between the strength of composite material and fibers orientation:

1. The best results were loads in the direction of fiber orientation at (0°), and this may be due to the ability of composite material to carry out loads in direction with reinforcement fibers, and this ability decreases with increasing of fiber orientation angle at (90°).
2. The bending test gives best results at fiber orientation at (0°), and this may be due to viability of composite materials to withstand applied stresses where reinforcement fiber is working to rise most of those loads, and this ability decreases with increasing fibers orientation angle at (90°).
3. The analytical results showed similar behavior at tensile and bending tests, but these results increased slightly due to ideal condition of composite material during this solution.
4. Fully car bumper structure shows similar mechanical behavior for displacement and stress distribution, for same fiber orientation angle.

6. ACKNOWLEDGEMENT

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8. ABBREVIATIONS AND NOMENCLATURE

f_m: Weight fraction of matrix.

f_f: Weight fraction of fiber.

σ_f: Stress of fiber.

σ_m: Stress of matrix.

σ_c: Stress of composite.

TS_f: Tensile strength of fiber.

TS_c: Tensile strength of composite.

F: Applied central load (N).

L: Support span (mm).

b: Width of the specimen (mm).

d: Thickness of the specimen (mm)

D: the deflection beam at a given point on the load –deflection data.