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SIMULATION ON EFFECT OF FLOW INDUCED FIBER ORIENTATIOIN ON THE MECHANICAL PROPERTIES OF FIBER REINFORCED COMPOSITES

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ABSTRACT

Nowadays, fiber reinforced plastic composites are replacing metals which are being used for many years. This is due to the fact that fiber reinforced plastics have high strength to weigh ratio, low cost compared to metals, and high resistance to corrosion. This paper aims to simulate the effect flow induced fibers orientation on the tensile properties of short glass fiber reinforced nylon composites. Dog-bone shaped tensile testing shapes were simulated using commercial software called ANSYS. For the simulation, the concentration of the glass fiber was varied as 10%, %, 20%, and 30% by weight. First, the orientation state of the fibers during molding were determined experimentally and it was observed that majority of the fibers were aligned to the flow direct in near to the top and bottom mold walls whereas they aligned perpendicular to the few direction in the core region. Structured mesh was constructed with 2623 elements and 2804 nodes. As in input for the simulation, elastic modulus for each composite was obtained by performing tensile test experiment. The simulation results indicated that the yield stress values increased significantly from 13.21 MPa for pure nylon to 56.65 MPa for 30% by weight glass fiber which leads to a conclusion that the higher the percentage of the glass fiber reinforcement, the higher the tensile strength of the composite would be. Moreover, the numerical results showed a decrement in deflection with the increments of fiber content. Hence, this study could assist in decisions regarding the design of reinforced composite products.

Keywords: firefly algorithm, hybridization, modification.

INTRODUCTION

Nowadays, fiber reinforced plastic composites are replacing metals which are being used for many years. This is due to the fact that fiber reinforced plastics have high strength to weigh ratio, low cost compared to metals, and high resistance to corrosion. However, the production of the composites nowadays is very challenging to meet the market requirement. Moreover, the study of the flow of fiber-filled polymers in injection molding process is quite complex due to the fact that the flow of fiber filled thermoplastics in the molten state is modified by the presence of fibers and vice versa, i.e., the fiber motion and rotation are also affected by the flow (Yang, Huang *et al*. 2010, Oumer and Mamat 2012, Mazahir, Vélez-García *et al*. 2015). These add considerable complexities to the flow study of the polymer matrix. Above all, the study of the flow properties of concentrated suspensions in polymer melts remains most challenging.

Effect of flow induced fibers orientation on the tensile properties of injection molded fiber reinforced polymer composites was studied by Mortazavian and Fatemi (Mortazavian and Fatemi 2015). From their experiment, they concluded that tensile strength and elastic modulus significantly reduced from in-flow direction to perpendicular-to-flow direction at all temperatures and strain rates. Linear elastic theories for orthotropic materials and Tsai–Hill criterion accurately predicted off-axis elastic modulus and tensile strength, respectively. A.N. Oumer and D. Bachtiar have investigated effect of natural fiber addition on the tensile properties of High Impact Polystyrene Composites (Oumer and Bachtiar 2014). Their experimental results showed that addition of sugar palm fibers to the high impact polystyrene matrix resulted in a decrease of tensile strength of the final molded part. On the other hand, the stiffness of the SPF-HIPS composite increased by a factor of between 1.3 and 1.35 due to the addition of short sugar palm fibers to the HIPS matrix. According to B. Yang et.al, the longitudinal Young's modulus and in-plane shear modulus of fiber reinforce molded polymer composites appear to increase with increasing aspect ratio, while the transverse Young's modulus , generally decrease (Yang, Ouyang *et al*. 2011).

The mechanical properties of fiber reinforced polymer composites are affected by the weight percentage of the fibers in the composite, as well as the size of the fibers (Karsli and Aytac 2013). According to mechanical test results of Karsli and Aytac, increasing fiber content increases the tensile strength, modulus and hardness values but decreases strain at break values of composites. On the other hand, fiber length at the studied range had no effect on the tensile strength, modulus and hardness values but ascending fiber length increased the strain at break values of composites.

In this study, the tensile properties of glass fiber reinforced nylon composites obtained by means of numerical method are investigated. The experimental observations of the fibers orientation during injecting molding process will be analyzed to use them as an input for the mechanical properties simulation in ANSYS software.

METHODOLOGY

Geometry and fiber orientation

The simulation model considered for this study is a bon-shaped tensile testing part as shown in Figure-1 with dimensions 164 mm x 18 mm x 3 mm. The polymer considered for the simulation is nylon reinforced with glass fiber. The concentration of the glass fiber was varied as 10%, 20%, and 30% by weight.

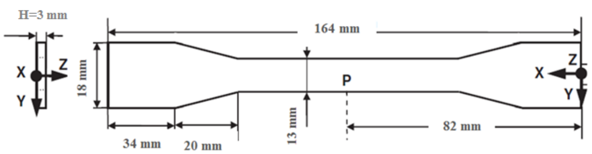

Figure-1. Schematic of the simulation model.

For the tensile simulation analysis, the orientation states of the fibers in the final product should be known first. This is to decide the orientation angle in ANSYS. Therefore, the orientation state of the fibers was determined both experimentally for 20% by weight glass reinforced nylon composite. For the experiment, small sections were cut out from the final molded specimens at three different positions along its length to examine the orientation states of the fibers. The three positions considered are near the mold inlet (10 mm from inlet), at the middle section of the specimen (82 mm from inlet) and far from inlet (150 mm from inlet). Then the fibers distribution on the cut surfaces were examined by taking pictures using a Scanning Electron Microscope (SEM).

Figure-2 shows the fiber orientation distribution across the sample thickness at the cut out position 150 mm fron inlet. As can be clearly seen from the SEM image, two different regions (or three layers of orientation structures) across the thickness of the sample part can be found: a shell region which is near to the top and bottom mold cavity walls, and a core region at the middle of the cross section. The image shows that there are more grooves than holes (circular sections) visible in the shell region, which indicates that majority of the fibers are oriented in the flow direction (x-direction). On the other hand, in the core region, circular sections are dominant indicating that most of the fibers are predominantly oriented perpendicular to the flow direction.

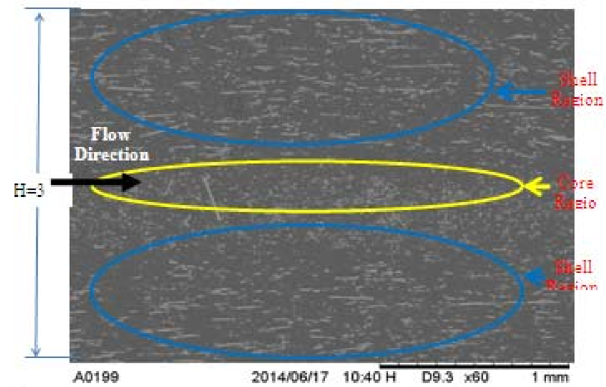

Figure-2. SEM micrograph of cut out at position 150 mm from inlet in the molded dog-bone shaped sample.

Therefore, for tensile testing simulation it can be assumed that the composite is made of three laminates. The top and bottom layers have fibers oriented to the direction of the tensile force, on other hand, the middle layer has fibers oriented in the perpendicular direction to the applied force.

Numerical simulation

ANSYS software was used to numerically calculate the tensile properties of the model. Specific properties for both nylon polymer and glass fibers were inserted in the database of ANSYS, as well as standard shape of samples, and applied different amount of loads to make a theoretical emulation to experimental tensile tests. After conducting mesh independent test, structured mesh with 2623 elements and 2804 nodes were selected to be the optimum mesh size for the simulation as shown in Figure-3. The elastic modulus and tensile stress values of the composite which are used as in input value for the simulation were obtained from experimental observations.

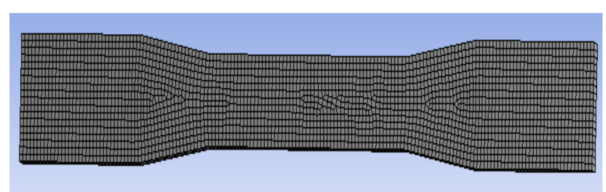

Figure-3. Mesh used in the simulation.

RESULTS AND DISCUSSIONS

The experimental results of elastic modulus obtained from the tensile testing at various glass fiber loadings are shown in Figure-4. The results will be used as an input for ANSYS simulation. It can be clearly seen from Figure-4 that the Young’s Modulus increased with the increment of glass fiber contents. The first type was Pure PA-6 which contained zero percent of glass fiber and has a Young’s Modulus value of 1.026 GPa. As the fiber concentration increases, the elastic modulus values also increased linearly. For instance, with 10 percent of glass fiber content in PA-6 the Young’s Modulus value is 1.785

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which is 74% increment compared to pure nylon. Moreover, addition of 20 percent and 30 percent fiber contents to the nylon polymer resulted to elastic modulus values of 4.021 GPa and 5.661 GPa, respectively. As can be clearly seen in the results, addition of glass fiber in pure nylon increased the elastic modulus significantly. Significant increment in elastic modulus is obtained due to the fact that majority of the fibers were aligned to the flow direction as shown in Figure-2.

Figure-5 shows contour of simulated equivalent (von-Mises) stress for the deformed 30% by weight reinforced nylon composite. The contours shows that higher stresses are occurred around the neck region with stress values of 49.4 MPa. On the other hand, near to the region where the force is applied, the equivalent stress values is smaller (with stress value of 35.65 MPa) compared to the neck region.

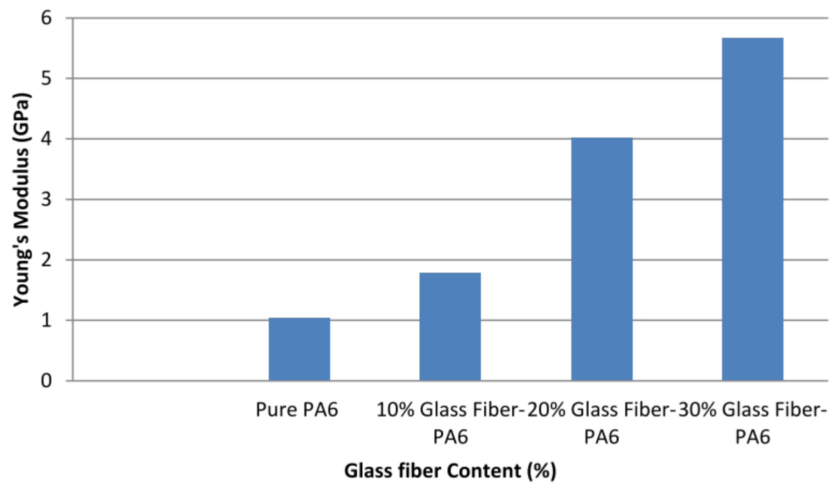

Figure-4. Variation of experimental elastic modulus for polyamaide (PA6) with different fiber contents.

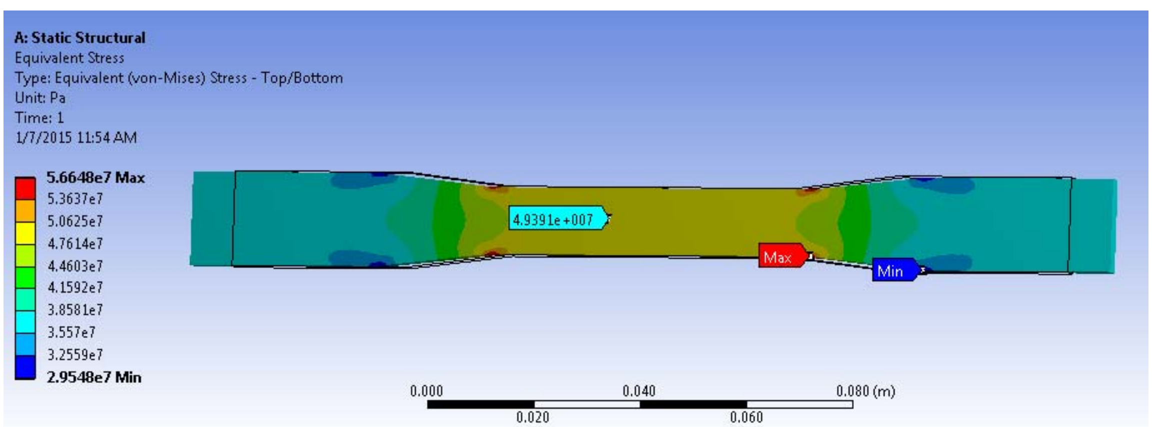

Figure-5. Contour of equivalent stress for deformed 30% by weight glass reinforced nylon composite (the solid line shows the undeformed geometry).

Comparison of the simulated equivalent stress results and those obtained for the tensile testing experiment at various glass fiber loadings are tabulated in Table-1. It can be clearly seen from the table that the tensile stress values increased linearly from 13.201 MPa for pure to 56.65 MPa for 30% by weight glass fiber content. From the results, it can be concluded that the higher the percentage of the glass fiber reinforcement, the higher the tensile strength of the composite would be. On the other hand, the tensile modulus of the composite increases as the concentration of the sand decreases, and vice versa. For instance, the tensile moduli obtained for 5% and 30% wt sand-pp composites are 2.7 GPa and 1.3 GPa, respectively. The trend of the results is not uniform as its value decreased to 1.7 GPa for 10% wt and increased again to 1.84 GPa for 15%.

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Table-1. Tensile stress results for various glass fiber loadings.

Glass fiber weight percentage	Tensile stress at yield load [MPa]	
	Experiment	Simulation (Max)
0%	12.54	13.201
10%	21.035	22.169
20%	33.968	35.79
30%	53.74	56.65

Similarly, the simulation results for the total deformation due to tensile forces at various fiber loadings are shown in Table-2. From the table, it can be clearly seen that the total deformation tends to decrease from 0.78 mm for pure nylon to 0.75 mm and 0.54 mm for 10% and 20% by weight fiber contents, respectively. Then the total deformation rose back to 0.61 for 30% fiber content. This discrepancy might be due to the reason that the material properties used in the simulation for 30% are obtained from the supplier's data base while the others were obtained from literature.

Table-2. Total deformation results for various glass fiber loadings.

Glass fiber weight percentage	Total deformation (mm)
0%	0.78
10%	0.75
20%	0.54
30%	0.61

CONCLUSIONS

In this paper the numerical result of effects of fibers orientation and concentration on the mechanical properties of dog-bone shaped glass fiber reinforced injection molded nylon composites has been presented. The orientation state of the fibers in the sample were determeined experimentally. The experimental results have showed that three layer fiber orientation structures (two shell regions and one core region) formed during mold filling. In the shell region, almost all fibers were aligned to the flow (force) directioin whereas they are aligned normal to the flow (force) direction in the core reionn. From the simulation results it can be concluded that (since the flow is parallel to the length of the specimen) the final dog-bone shaped product can withstand both tensile and compression force. The shell layer which has high probability of fibers alignment in the flow direction is strong along the length whereas the core region is strong across the length. Moreover, it was observed that as the fiber content increased the tensile strength of the molded product will also increase. In general, the results of this study could assist in decisions regarding the short fiber reinforced polymer composites.

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