THE EFFECT OF SAMPLE PREPARATION ON THE FLEXURAL STRENGTH OF REINFORCED NYLON 66

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Abstract

Cutting flexural test specimens from molded plaques is commonly used in material testing. The mechanical properties of these cut specimens may be affected by the cutting process as it could introduce extrinsic flaws and thermal residual stress on the cut surfaces. The objective of this experimental research is to determine how band saw cutting affects the flexural strength of 33% short glass fiber reinforced nylon 66. The specimens for the flexural test were obtained by cutting molded plaques using different blade types, blade speeds, feed rates, and levels of polishing. The results were compared with those from uncut specimens. Surface morphology of specimens’ cut edges was observed by using Scanning Electron Microscopy. The results indicate that lowest strength of cut specimens is achieved at the lowest blade speed and highest work piece feed rate.

Introduction

The mechanical testing of polymeric materials in sheet form often involves sample preparation such as cutting, sanding and grinding. The cutting of the samples may introduce extrinsic flaws on the machined surfaces. These defects may cause stress concentrations, which may influence the mechanical test results. In addition, it is well known that polymers are thermally sensitive. Hence the cutting may not only induce defects at the cut surfaces, but the thermal energy resulting from cutting may affect polymer crystallinity or molecular weight. Most of studies on this issue have focused on brittle materials such as ceramics or thermoset composites. The work described in this paper is believed to be one of the first on the effect of cutting on the mechanical properties of thermoplastic polymers reinforced with short glass fibers.

Much of the previous work on the machining of advanced materials has focused on ceramics [1-5]. Despite their many advantages, the strength of brittle ceramics can be significantly reduced by machining. These machining constraints have therefore limited the use of structural ceramics in many applications. The flexural strength of brittle materials is generally influenced by the surface finish, specimen size and shape as well as the testing environment.

One study on the surface integrity of continuously carbon fiber reinforced epoxy composites was found [6]. An experimental study of orthogonal cutting with polycrystalline diamonds tools was conducted on the edge trimming of unidirectional and multi-directional graphite/epoxy composites. This study focused on the fiber orientation effect on the surface integrity. It concluded that machining can affect bulk strength as well as failure initiation and propagation.

The objective of this study was to assess the effect of band saw cutting and surface preparation parameters on the ultimate flexural properties of short glass fiber reinforced nylon 66. The band saw was chosen for this work as it is a relatively rapid method for preparing small mechanical test specimens from injection molded components.

Specimen Preparation

Material

The material used in this study was an injection molding nylon 66 reinforced with 33% short glass fiber [7] provided by Dupont Canada. Rectangular plaques and flexural bars were used in this study. The plaques had dimensions 100.5 mm x 102.5 mm x 3.2 mm and the flexural bars had dimensions 12.8 mm x 135 mm x 3.2 mm. Both parts were injection molded using the same material and similar molding conditions on an Engel 55 ton injection molding machine. The plaque was edge gated along the 100.5 mm x 3.2 mm face using a 2 mm thick film gate. The flexural bar was edge gated along the 3.2 mm x 12.8 mm face using a 3.2 mm thick edge-gate. The molded plaques were subsequently cut into 13 mm x 102.5 mm x 3.2 mm flexural specimens. The cutting procedure used on the plaques is described in the next section.

It is important to note that these flexural specimens were cut parallel to the flow direction. For this reason, the preferential fiber orientation in both the thin cut flexural specimens and in the thin molded flexural bars are along the longest dimension of the part [8]. Although the preferential fiber orientations are in the same direction for the cut specimens and molded bars, the degree of orientation is not expected to be identical. Mold edge
effects in the narrower flexural bar would be expected to cause slightly more fiber orientation in the flow direction.

**Cutting and surface preparation**

Each molded plaque was cut into seven flexural specimens. The two outside specimens each containing an outside, uncut edge were discarded. Two band saws were employed for cutting the plagues. A Heska Model ESU H63 band saw that allowed precise control the work piece feed rate and blade speed was the primary cutting instrument. A laboratory King Industrial KC-1433FX band saw was also used for comparison purposes. This model allowed for limited range of blade speed and only manual control of work piece feed rate.

For a given material, the parameters of blade type, blade speed and work piece feed rate influence cutting quality [9]. For band saws, the blade generally has four major parameters: teeth per unit length (pitch), tooth form, set pattern and width [9]. The blades used in this research are shown schematically in Figure 1.

For the study involving the Heska band saw, the effect of the pitch (120 and 240 teeth/m), blade speed (1200 m/min and 200 m/min) and work piece feed rate (7.9 m/min and 0.09 m/min) were studied using skip tooth blades with a straight set. The width of the blade was 12.5 mm. These cut flexural specimens were tested without any further surface preparation.

The laboratory band saw was used to examine the effect of blade tooth shape. A 10 mm wide, 160 teeth/m saw blade that had a hook tooth and raker set (Figure 1) was used on this machine. The blade speed and work piece feed rate were set to approximate as close as possible the high blade speed and low feed rates of the larger Heska machine: 660 m/min and 0.1 m/min respectively. The effect of post-cutting surface preparation was examined using samples cut on the lab machine. One set of cut flexural specimen was polished using 240, 320, 400 and 600 grit sandpaper in order to remove any surface asperities prior to mechanical testing.

The mechanical results from cut samples were compared with those of directly molded bars. Although the glass fiber orientation of the molded bars was similar to that of the cut specimen, it was expected that the glass fibers in the these samples would be more oriented due to molding edge effects absent in the cut specimens. In order to isolate this potential orientation effect from cutting effects, the edges of some of the molded bars were also cut using the lab scale saw and the cutting conditions described previously.

**Evaluation Procedure**

Three-point bending test

In order to assess whether a relationship existed between the flexural strength of Nylon 66 and various cutting and treating parameters, three-point bending tests were conducted on all specimens. The first flexural test followed ASTM D790. The molded bar and cut specimens rested flat on two supports 60 mm (L) apart and were loaded at 2 mm/min by means of a loading nose midway between the supports. The flexural stress ($\sigma_{\text{max}}$) is calculated using equation 1 where $F$ is the applied load and $b$ and $h$ are the width and thickness respectively.

$$\sigma_{\text{max}} = \frac{3FL}{2bh^2}$$

In order to focus the tensile and compressive stresses on cut surfaces, a modified flexural test was developed. In this test method, the molded bar or cut specimen was oriented such that the smaller 3.2 mm edge contacted the test fixture. In order to prevent the molded bar or cut specimen from slipping during testing, two copper guides were employed on each support as shown in Figure 2.

For both the standard and modified test, a minimum of six specimens was tested for each cutting/surface preparation condition.

Microscopy of edge surfaces

The edge surfaces resulting from different cutting/surface preparations were examined using scanning electron microscopy (SEM). An SEM magnification of 25 was chosen to view the surface roughness.

Results and discussion

The results from the cutting study performed using the Heska saw are shown in Table 1. The results of the modified technique are observed to be consistently lower than those from the standard test method. This is most likely due to higher shear stresses occurring in the modified technique caused by the higher thickness/span ratio.

Interestingly, over a wide range of teeth per unit length (highest/lowest=2), blade speeds (highest/lowest=6) and work piece feed rates (highest/lowest=90), the results are all within 10% of each other suggesting that the cutting technique used did not greatly affect the flexural strength of 33% glass reinforced nylon 66. Although nylon 66 might be expected to be more sensitive to these notches given its high glass transition temperature, the relatively slow test speed may have allowed the polymer to yield locally. High speed impact testing is currently planned.
A closer inspection of the results suggests that the combination of low blade speeds and high work piece feeds leads to lower strengths. This is shown in Figures 3 and 4 for the 120 teeth/m blade.
Figure 5 shows micrographs of parts cut with low and high work piece feed rates for the 120 teeth/m blade at a blade speed of 200 m/min. The higher feed rate appears to leave fewer but more pronounced ridges. The distance between ridges is proportional to the volume of material cut per tooth. If this large distance between ridges is related to the lower mechanical properties, it should therefore be possible to collapse the data for all cutting conditions onto a master curve.

If $T$ is the number of teeth per meter, and $v$ the blade speed in m/min, then the time ($t$) between teeth on the same side of the blade passing a given position on one work piece is:

$$ t = \frac{2}{Tv} $$

(2)

The 2 appears in the equation because only every second tooth contacts a given work piece on the straight set blade. If $F$ is the work piece feed in m/min, then the distance ($d$) that the work piece travels during that time is:

$$ d = \frac{2F}{Tv} $$

(3)

d represents the spacing between cut marks on the cut specimen. Figure 6 shows a plot of flexural strength versus $d$ for all feed rates, cutting speeds and teeth per meter used in this research. It shows that as $d$ is increased the strength drops off. The results would therefore suggest that, ideally, it is desirable to use low work piece feed rates along with high blade speeds and large number of teeth per meter to minimize the material removed per tooth.

The smaller laboratory band saw was used to examine the effect of using a hook tooth, raker set blade. The value of $d$ used with this saw was small (0.002 mm) in order to maximize properties. The results with the hook tooth, raker set blade are shown on Figure 6 to be statistically equal to the results obtained under similar cutting conditions with the skip tooth, straight set blade.

The cut edges of parts made with smaller laboratory saw were also polished using 240, 320, 400 and 600 grit sandpaper to remove any asperities. The results compared with the unsanded specimens are given in Figure 7. It shows that, for these materials and cutting conditions, sanding had no significant effect on flexural strength.

The flexural strength of the molded bar using the standard test method was found to be 287 MPa with a standard deviation of 2 MPa. The test result using the modified method was observed to be 280 MPa with a standard deviation of 3 MPa. Again the modified method yielded slightly lower results due to shear stresses caused by higher thickness to span ratios.

The flexural strength results from the molded bar were, on average, 10% higher than those obtained on cut specimens. Although this may be partly due to the smoother edge surface shown in Figure 8, one must recall that the glass fibers in the molded bar are more highly oriented in the test direction due to edge effects during filling. In order to assess the effect of cutting given this glass fiber orientation difference, 0.5 mm of each 3.2 mm edge of the molded bar were cut off with the laboratory scale band saw using the conditions described above. This would introduce surface roughness comparable to that on the cut specimens described previously. The results (Figure 9) show that cutting had a small but statistically insignificant effect on the strength of these bars. This again confirms that, under the correct conditions, band saw cutting has little effect on the average flexural properties of 33% glass reinforced nylon 66. It should be noted however, that the standard deviations were generally higher for the cut specimens.

**Conclusions**

The flexural strength of glass reinforced nylon 66 samples cut on a band saw can be maximized by cutting under conditions of high blade speed and a low work piece feed rate. Under these optimized cutting conditions, polishing the cut surface does not significantly improve the flexural strength.

Molded bars were observed to have higher flexural strengths than cut specimens of the same dimensions. This is believed to be due to differences in glass fiber orientation. Cutting the edges off the molded bars, thereby inducing possible notches, did not significantly affect the molded bar’s average flexural strength although the property variability did increase.

Given that polishing cut specimens and cutting the edges off molded bars did not significantly affect the average flexural strength of these parts, it can be concluded that cutting, under the correct conditions, does not significantly affect the average flexural strength of 33% glass fiber reinforced nylon 66. More work is underway to assess the effect of cutting on impact properties.

**Acknowledgements**

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6. References:


Table 1 – Strength using standard and modified test methods as a function of cutting parameters. The values in round brackets represent measurement standard deviations.

<table>
<thead>
<tr>
<th>Teeth [teeth/m]</th>
<th>Blade speed [m/min]</th>
<th>Feed rate [m/min]</th>
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<th>Modified test method</th>
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<td>200</td>
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Figure 2 – Side and front view of the modified flexural testing fixture used to test molded bars and cut specimens on their small 3.2 mm face.

Figure 1 – Schematic representation of the different band saw set patterns and tooth forms used in this research.
Figure 3 - Flexural strength as a function of blade speed and workpiece feed rate using the Heska saw with 120 teeth/m. Standard flexural test method used.

Figure 4 - Flexural strength as a function of blade speed and workpiece feed rate using the Heska saw with 120 teeth/m. Modified flexural test method used.
Figure 5 - SEM micrographs of specimens cut at low (left) and high (right) work piece feed rates at a blade speed of 200 m/min using a 120 teeth/m blade.

Figure 6 - Flexural strength as a function of the distance between cuts for standard and modified test fixtures on the Heska and laboratory band saws. The lines are drawn to show trends for the standard and modified flexural test method.
Figure 7 - Flexural strength of specimens cut using the laboratory band saw. One specimen had no further surface preparation and the second was sanded.

Figure 8 - SEM micrograph of the edge of a molded flexural bar.
Figure 9 - Flexural strength of molded bars as molded and with 0.5 mm shaved off of each edge using the laboratory band saw using both standard and modified flexural test methods.