# Machinability Of Unsaturated Polyester Composite And AISI 1050 In Turning

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***Abstract*— Cutting parameters were selected according to ISO 3685 as depth of cut (2.5 mm), cutting speed (100 m/min), and three feed rate (0.24, 0.32 and 0.40 mm/rev). To make a comparison with a material whose machining characteristics were well known, AISI 1050 steel was machined under the same cutting conditions of Unsaturated Polyester Composite samples. Tool wear tests were conducted over 15 minutes. Tool wear was examined by using the loss in weight method and a scanning electron microscope. Two cutting forces ($F_c$ and $F_v$) were measured using the biaxial dynamometer integrated computer by data logger and A/D convertor. It is observed that in comparison to the cut forces generated during the operation of AISI 1050 (between 270 and 1383 N), the cut forces generated during the operation of UPC are significantly smaller (between 2 and 40 N). According to the SEM studies of the sets, while no abrasion mechanisms were detected in the set processing the UPC samples, it was observed that in the set processing, the AISI 1050 samples had a crater abrasion mechanism. It is detected that according to the weight loss tests and SEM results, UPC samples are puddled against the set surface during the processing.**

***Keywords*—Machinability;composites; dynamometer; wear.**

## I. Introduction

Glass Fiber Reinforced Polymer materials (GFRP) are widely used in many sectors of the industry owing to their superior features such as high endurance in comparison to weight, high fracture toughness, and almost perfect corrosion resistance. Machining is inevitable for ultimate dimensioning for end use. For this reason, the processability of GFRP composite materials are of utmost importance [1–4]. The factors affecting the machining of a material are closely related to the material's processability. Processability, on the other hand, is a relative concept and varies from study to study. While the amount of required force for machining in a study may be important, it might be neglected in another. Additionally, cut forces, set abrasion, and surface smoothness are the most important parameters for processability in machining.

The variety of matrix (polyester, epoxy, polyethertherketone, polyamide, vinylester) and support elements (glass fiber, carbon fiber, alumina, SiC), which are widely used in GFRP materials, makes it possible to obtain composite materials of many types and features. Furthermore, the fact that there are many processing methods (turning, milling, penetration) in machining and that every method has many unique variables makes it essential that many studies should be conducted on the processability of composite materials with polymer matrix.

In the previous turning studies, mostly GFRP materials [5–8] with epoxy matrix were used, but also studies with polyester [9,10], polyamide [11,12], PEEK [13,15], vinylester [16,17], and carbon [18,19] matrices were conducted. It is noticeable that glass fiber [5,6,8–17,19] was more widely used as a support element than carbon fiber [7,13,14,18]. In those studies, the researchers focused on cut forces [11], surface smoothness [8,14], set abrasion [6,7,18], and set temperature [19] generated during turning. As can be seen from the literature studies, there are few studies conducted on polyester and other matrix materials in turning research. UPC materials are obtained through the polymerization starting with the addition of the catalyst and the hardening agent to the unsaturated polyester resin and following curing. The ratios of catalyst and hardening agents play an important part in the endurance of the material [20,21]. Many types of UPC materials with mechanic features can be obtained with support elements added before the curating starts [22–26].

UPC was used in this study is because it is the first phase of a large study, whereby the malleability of the materials “fiber weave (FW)”, “quartz particle (QP)”, and “short particle fiber-reinforced (SPF)” which are among the reinforced composites, can be used as products in industry. In this study, UPC is a composite made up of main matrix polyester resin and catalyzers having no filling material (or, to use another expression, material for reinforcement) in its content. UPC is the working piece material in this study. Therefore, the first aim of the study was to determine the sawdust levitation force in the process of turning of this composite. Another published study in the literature about UPC, which was used in this study, has not been encountered. Hence the cutting forces in the turning activity are unknown. AISI 1050 on the other hand is a material that is widely used in industry and a material whose properties are well known. The reason for the use of AISI 1050 in this study is that it is a reference pursuant to the force values of the UPC composite, and better interpretation has been aimed at by the use of this well-known material. The results of the experimental studies on the malleability of the other three reinforced composite types (FW, QP, and SPF) are planned to be announced in further studies.

## II. EXPERIMENTAL PROCEDURE

Unsaturated Polyester Composite (UPC) consists of polyester, methyl ethyl ketone peroxide (MEKP) and cobalt octoate (CoO). The unsaturated polyester resin is catalyzed with MEKP and CoO in a mold and after a curing process, UPC is produced. UPC work pieces used in the turning tests were prepared with this process. The compressive strength tests of UPC samples that have different polyester, MEKP (5 groups), and CoO (5 groups) compositions were performed to obtain the optimum percentage of polyester, MEKP and CoO of UPC. These percentages of polyester, MEKP, and CoO were determined as 98.5%, 1%, and 0.5%, respectively. The compressive strength of UPC on the optimum compositions was established as 133.747 MPa. The details of this optimization study was given following references [20,21]. The dimensions of length and diameter of UPC and AISI 1050 samples machined in turning tests were 109 and 43.25 mm, respectively. The chemical composition and mechanical properties of the AISI 1050 sample is given Table 1 and Table 2, respectively.

TABLE I. CHEMICAL PROPERTIES OF AISI 1050

| Component | Fe | C | Mn | Si | P | S | Cr |
|---|---|---|---|---|---|---|---|
| Percentage | 98.221 | 0.528 | 0.842 | 0.216 | 0.010 | 0.057 | 0.017 |
| Component | Ni | Cu | Mo | Co | Nb | V | W |
| Percentage | 0.035 | 0.053 | 0.003 | 0.011 | <0.002 | 0.003 | <0.002 |

TABLE II. MECHANICAL PROPERTIES OF AISI 1050

| Yield Strentgh (MPa) | Tensile Strentgh (MPa) | Rupture Strentgh (MPa) | Hardness (BHN) |
|---|---|---|---|
| 462 | 702 | 649 | 215 |

UPC has an unreinforced structure that contains no filling material. The components of UPC in the process of its production are liquids and there is a procedure of vibration in the process until the start of gelling. The composite in its current condition is a solid at room temperature. UPC has the same structural properties on all sides and it is homogeneous. The product with its components of the amounts that were specified attained a brittle and firm structure. This fact was detected after the smashed material was analyzed after the compression experiment. It was observed that the smashed material can have sharp edges and they have been smashed into pieces of a variety of sizes, from large scale to the scale of dust.

Tool wears and cutting forces were selected machinability parameters. Thus, two experimental tests groups were arranged. Cutting forces and tool wears tests were carried out in the first and second group, respectively. Cutting parameters for each group were selected according to ISO 3685 and are presented in Table 3.

All machining experiments were performed on the lathe (Tezsan-SN45C) with 5.5 kW power and maximum speed of 2000 rpm. A triangular carbide insert (TPGN-160308) coated with TiCN-Al2O3-TiN and a tool holder (CTGPR-2525M-16) were used. The tool geometry on the tool holder was as follows: clearance angle 5°, rake angle 6°, and cutting edge inclination angle 0°. The approach angle of the cutting edge on the tool holder of 75° was kept constant. A biaxial strain gauge based dynamometer which was integrated to PC by data logger (TESTBOX1001) and A/D convertor was used to measure the two cutting forces, namely, cutting force (Fc) and feed force (Fv). With the appropriate software (TESTLAB BASIC) installed on the PC, cut forces could be monitored and recorded while the processing occurred. The schematic drawing of the experiment assembly is shown in Figure 1. The dynamometer used in the experiments consists of a single piece and can make force measurements (cut force and proceeding force) on two axes [21,27,28].

In all cut force experiments, the turning table and the integrated system were initially run idly for 30 minutes. Then, to dimension the piece at turning, UPC and AISI 1050 samples were processed to a diameter of 42 mm. Finally, the turning table was set up in the desired cut parameters to execute the turning process. Whenever cut forces stabilized on a value on the screen of the software, they were recorded for 15 seconds. For each experiment, repeated thrice at room temperature, a new carbide set was used.

In set abrasion experiments, an experiment assembly, generally used for cut force measuring, was used. UPC and AISI 1050 samples were first processed to a dimension of 42 mm for dimensioning. Then, the table was set to the desired parameters and the samples were processed for 15 minutes. Since the experiment duration was long, the processing continued until all samples were down to 19.6 mm from 42 mm, and cycle numbers changed on the necessary cutting depths so that the cut speed was between 60 to 85 m/min. At each cutting depth, a lengthways turning of 40 mm was made. To complete the abrasion duration, 10 samples of every material were used. The experiment was terminated; the total amount of time reached 900 seconds (15 minutes) at the last sample. During the abrasion experiments, cut and proceeding forces at 0, 5, 10, and 15 minutes were measured to investigate the effect of set abrasion on cut and proceeding forces. After the abrasion experiments, all sets were studied with SEM (Carl Zeiss AG-EVO 40) in order to determine the abrasion mechanisms and types of the sets. Before and after the abrasion experiments, the sets were weighed with 0.0001 g precision digital scales (AND 200) and the changes in their weight were measured. The plaques that were used in the experimental study were cleaned with compressed air before and after they were removed from the tool-holder. The plaques that were removed from the tool-holder were sprayed with alcohol and dried with compressed air. No procedure of cleaning other than these procedures was applied to the plaques. The objective was to observe the condition of the plaque's cutting edges that came into contact with the material and the forms of contact of the particles of steel or composite that remained on the plaque.

TABLE III. CUTTING PARAMETERS USED IN THE GROUPS

| Group | Material | Feed (mm/rev) | Cutting speed (m/min) | Depth of cut (mm) | Time (min) | Cutting force (N) | Feed force (N) | Tool weight (g) |
|---|---|---|---|---|---|---|---|---|
| 1 | AISI 1050 | 0.24 | 100 | 2.5 | - | 897.077 | 270.973 | - |
| 1 | AISI 1050 | 0.32 | 100 | 2.5 | - | 1165.026 | 335.210 | - |
| 1 | AISI 1050 | 0.4 | 100 | 2.5 | - | 1383.346 | 362.748 | - |
| 1 | UPC | 0.24 | 100 | 2.5 | - | 3.567 | 1.765 | - |
| 1 | UPC | 0.32 | 100 | 2.5 | - | 16.781 | 4.534 | - |
| 1 | UPC | 0.4 | 100 | 2.5 | - | 19.121 | 6.457 | - |
| 2 | AISI 1050 | 0.16 | 60-85* | 1.6 | at the start | 881.273 | 267.434 | 4.3530 |
| 2 | AISI 1050 | 0.16 | 60-85* | 1.6 | 5 | 957.823 | 387.356 | - |
| 2 | AISI 1050 | 0.16 | 60-85* | 1.6 | 10 | 880.748 | 206.273 | - |
| 2 | AISI 1050 | 0.16 | 60-85* | 1.6 | 15 | 954.355 | 283.720 | 4.3531 |
| 2 | UPC | 0.16 | 60-85* | 1.6 | at the start | 3.456 | 1.340 | 4.3379 |
| 2 | UPC | 0.16 | 60-85* | 1.6 | 5 | 12.340 | 2.450 | - |
| 2 | UPC | 0.16 | 60-85* | 1.6 | 10 | 10.730 | 3.560 | - |
| 2 | UPC | 0.16 | 60-85* | 1.6 | 15 | 10.320 | 4.560 | 4.3381 |

*Cutting Speed was adjusted in this interval owing to change of diameter of the workpiece during the tool wears tests.

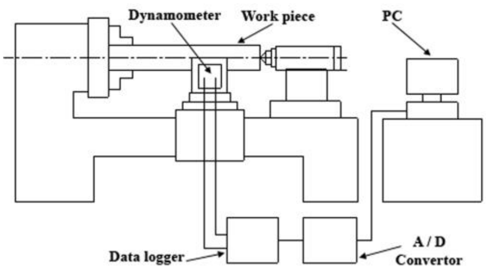


Fig. 1. *Experiment assembly*

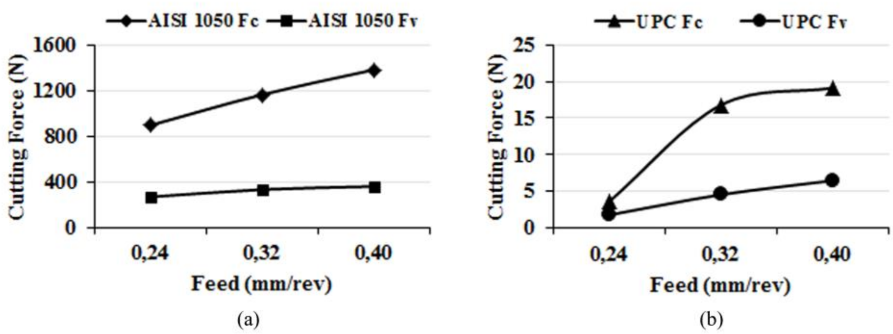


Fig. 2. *The cut and proceeding force/proceeding relationship for (a) AISI 1050 and (b) UPC material*

## III. RESULTS AND DISCUSSION

Cut forces and set weights obtained as a result of experiments are shown in Table 3. In Figure 2, graphics of cut forces generated in different proceeding conditions of AISI 1050 and UPC materials are presented. It is seen in Figure 2 that both cut forces rise with the increase of procession for both material groups. According to the graphics, in comparison to AISI 1050 material, UPC material can be processed with very little cut forces under the same cut conditions.

In Figure 3, SEM pictures of the carbide set machining the surface gap surface abraded with the processing of AISI 1050 for 15 minutes are presented. After 15 minutes, acceptable crater abrasion on the set's machining surface is seen. The crater's width and length respectively are 0.354 and 1.675 mm. An insignificant amount of shaving around the crater is seen. Although there was no abrasion observed on the gap surface of the set, starter indications of typical flank wear was seen at the end of the 15 minutes. The duration of 15 minutes was not sufficient to produce a negative effect as a bandwidth towards the lower levels of gap surface.

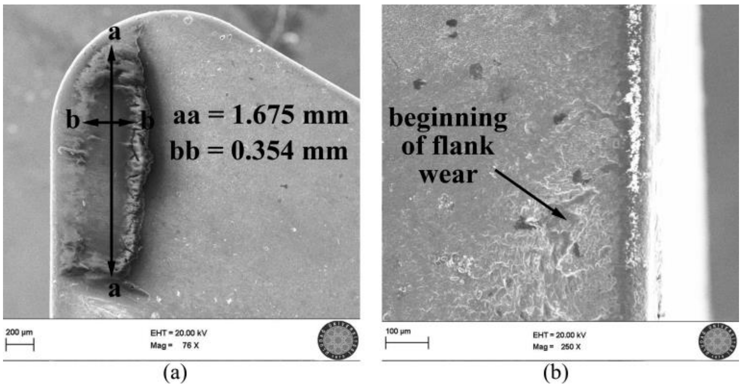


Fig. 3. *The machining of AISI 1050, tool surface (a) and gap surface (b)*

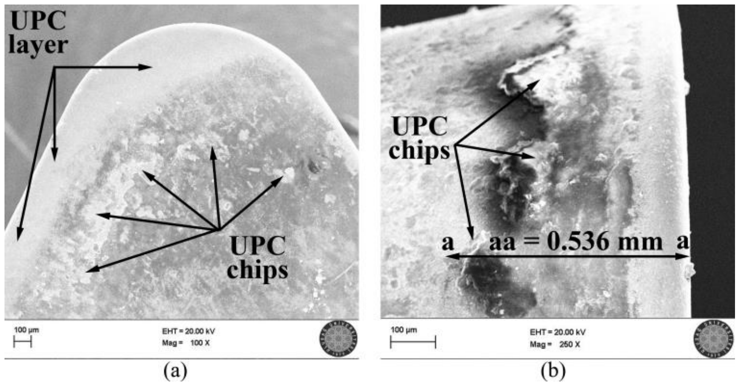


Fig. 4. *The machining of UPC, tool surface (a) and (b) gap surface*

In Figure 4, SEM pictures of carbide set machining surface gap surface abraded with the processing of UPC material for 15 minutes are presented. There were no indications of crater abrasion on the machining surface of the set at the end of 15 minutes. The processed material is melted by heat and then the chip, the tool contact surfaces were covered. On the gap surface of the set at the end of 15 minutes, a similar state to the state of machining surface occurs. On the surfaces where contact decreases and opens, regional accumulations as masses occur.

It is seen on the SEM pictures of sets abraded for 15 minutes in both groups that while AISI 1050 material shows an expected abrasion mechanism in the carbide set, the carbide set of UPC material does not create a significant abrasion, but just puddled on the set surface due to the heat. In an evaluation conducted considering both of the groups' cut forces experiments result values, these abrasion results are logical. This is because UPC material can be processed with smaller cut forces in comparison with AISI 1050 material. It is a well-known fact that cut forces have a significant impact on abrasion mechanisms. Therefore it is not a surprise that the little cut forces do not cause abrasion on the set during the processing of UPC material. Furthermore, one can claim that aside from the translucent puddling of the UPC material against the set, no chemical abrasion mechanism developed.

Before and after the abrasion experiments, the sets were weighed with 1/10,000 g precision digital scales and the weight changes were measured. An increase of 0.0002 g on the UPC material and a 0.0001 g increase on the AISI material occurred. When the SEM pictures are studied, it seems there is no abrasion on the UPC material. Additionally, matrix material adhering can again be seen from the SEM pictures. For this reason, the increase on UPC material on abraded sets may have resulted from this adhering matrix material. When SEM pictures of AISI 1050 material are studied, it can be seen that a crater abrasion has recently begun. It is obvious that this causes a decrease in set weight. However, it is observed on the SEM pictures that matrices and shavings adhere to the abraded set, even if in small amounts. It can be said that matrix and shavings adhering to the abraded set in AISI 1050 material balances out the weight losses, or maybe even transcends it.

Table 3 shows the results of the cut force applied on 0, 5, 10, and 15 minutes to determine whether there is a change in the cut forces coming to the set during the abrasion experiments. Figure 5 shows the graphics of cut forces measured on 0, 5, 10, and 15 minutes during the abrasion experiments of AISI 1050 and UPC materials. The graphics show that the crater abrasion that occurred on the set processing AISI 1050 material began to affect the cut force at the end of 15 minutes. There was not a significant change in the proceeding force. These results are normal when evaluated with set SEM pictures. This is due to the fact that no abrasion mechanism developed on the flank surface that would change the proceeding force and it is normal for the force not to change in this duration. The graphic demonstrates that because no abrasion mechanism occurred on the set processing the UPC material, no significant change on the cut forces after 15 minutes occurred.

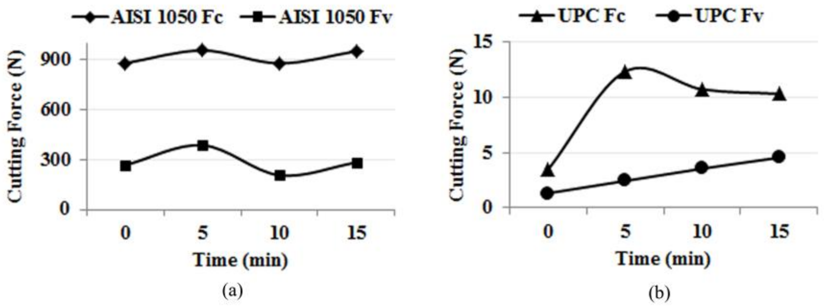


Fig. 5. *The cut and proceeding force/time relationship for (a) AISI 1050 and (b) UPC sample processing.*

## IV. CONCLUSIONS

In this study, with the aim of determining the processability of UPC material on the turning table, cut forces, and set abrasions were researched in comparison with AISI 1050 steel. The experiments produced the results below.

* While cut forces generated during the UPC material turning are between 1.8 and 19.1 N, this range in AISI 1050 steel is 270.1 - 1383.3 N. In terms of cut forces, UPC materials' processability is quite good.

* After 15-minute abrasion experiments, while a usual crater abrasion took place on the machining surface of the set processing AISI 1050 material, no indication of abrasion on the set processing UPC material was seen. Furthermore, UPC material, affected by the heat generated during processing, puddles formed against the machining and side surfaces of the set.

* Weight measurements conducted both before and after the abrasion experiments show that set processing materials did not lose weight, but on the contrary, it was determined that there was an increase in their weights. The increase in the set processing UPC material was determined to be caused by the UPC shavings puddling against and adhering to this set. It was determined that the shavings adhering to the side surfaces of the set of AISI material balance out and transcend the crater abrasion.

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