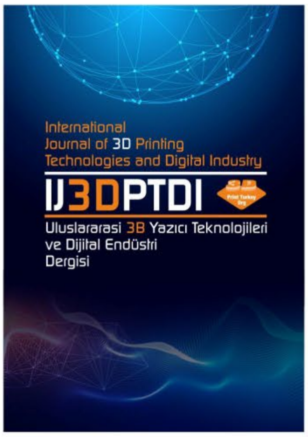

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INFLUENCE OF ABRASIVE WATER JET TURNING OPERATING PARAMETERS ON SURFACE ROUGHNESS OF ABS AND PLA 3D PRINTED PARTS MATERIALS

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ABSTRACT

In this study, PLA and ABS materials produced by 3D printing with 14 mm diameter and 300 mm length were processed by turning with abrasive water jet machining. The effect of processing parameters with abrasive water jet on the surface roughness was investigated. The processing parameters are nozzle feed rate (60-210 mm/min), abrasive flow rate (150-225 g/min), chuck turning speed (75, 125, 175 and 225 RPM) and nozzle distance (3, 5, 7 and 9 mm). Experimental studies have shown that the increase in nozzle feed rate (from 60 to 210 mm/min), abrasive flow rate (from 150 to 225 g/min) and nozzle distance (from 3 to 9 mm) results in average surface roughness values increased by 26%, 35% and 19%, respectively. It was concluded that the increase in the rotation speed of the mirror (from 75 RPM to 225 RPM) resulted in a 17% decrease.

Keywords: Abrasive water jet, Engineering plastics, ABS, PLA, Surface roughness, 3D printing.

1. INTRODUCTION

Polylactic acid (PLA) and acrylonitrile–butadiene–styrene (ABS) are the two most common fused deposition modeling printing materials. Both soften when heated and can be easily remolded and recycled. Thermoplastics are expected to have good mechanical properties, as well as heat and chemical resistance, depending on the conditions in which they are located. Engineering thermoplastics are expected to be suitable for one or more high performance engineering applications. Additive manufacturing is becoming widespread as a production method in which parts with a complex geometry can be obtained very quickly and with less energy consumption. It provides a fast solution in prototype manufacturing and the production of parts that are not possible with conventional methods can be successfully manufactured with this method. The disadvantages of this manufacturing method are that the time that can be considered reasonable for prototype manufacturing takes more time compared to mass production lines where large numbers of production are expected. Deficiencies in repeatability and process stability can also be counted as other disadvantages. On the other hand, although it is not a problem for some products, we see that additive production often cannot meet the expected surface roughness in some sensitive industrial applications. In areas where surface roughness is limited, an additional process is performed to obtain the desired delicate surfaces.

In the literature, 3D printed PLA and ABS samples; There are studies such as determination of optimization parameters [1], determination of structural properties by recycling [2], mechanical properties of graphene filaments [3], determination of tensile and bending behavior [4].

Water jet cutting, unlike other machining processes, is a production method that uses water at high pressure and speed for the cutting process. The water jet processing method is used in a wide range from soft materials such as plastic to hard metals. While no abrasive is needed for soft materials when the water jet contacts the workpiece, abrasive particles are added for hard metals. Thus, the effect of cutting power is increased [5]. Among the important advantages of the water jet processing method are that it can be used in many areas regardless of the hardness of the material, as well as the fact that it does not create a heat-affected zone in the material structure by not creating high heat at the time of cutting due to the cooling effect of water. In addition, not using cutting tools provides an important economic advantage. It provides a reduction in labor costs in terms of keeping the cutting surface clean as a result of the cutting process and not requiring any additional processing. On the other hand, the size and surface tolerances obtained as a result of processing are at an acceptable level for many manufacturing, together with the fact that they do not create any waste harmful to the environment during processing.

The disadvantages of this method are the high initial setup costs, the necessity of using abrasives in the processing of hard metals, and the longer time compared to cutting using tools. For this reason, the number of production per unit time is lower than conventional methods [6]. In the processing of thick-walled materials, due to the decrease in the effect of water jet, sometimes there are situations where the cutting process cannot be performed with the desired precision throughout the thickness.
In the literature, in the field of abrasive water jet (AWJ), machinability of multi-directional CFRP laminates [7], hybrid composites [8], parameter optimization of aluminum/tungsten carbide composites [9], kerf width and surface quality definition of metal-composite materials [10], carbon fiber reinforced polymers There are studies such as fluid-structure interaction modeling of abrasive waterjet puncture [11] and experimental investigation and optimization of abrasive waterjet processing parameters for GFRP composites [12] using metaphor-free algorithms. There is no study in the existing literature on the surface roughness to be obtained by processing 3D printed PLA and ABS materials with abrasive water jet.

In this study, cylindrical parts made of PLA and ABS printing material are processed with AWJ without any thermal effect [13]. It has been determined how different machining parameters affect the average surface roughness. Nonlinear regression analysis and logarithmic transformation were used for experimental data.

2. MATERIAL AND METHODS
2.1. Materials
The work piece material produced with open source 3D printing machine, the materials properties of ABS and PLA (Table 1). The diameter of the test sample is 28 mm and its height is 150 mm. (Figure 1).

Table 1. PLA and ABS filament materials properties

Item	Units	ABS	PLA
Density	kg/m^3	1.01	1.20-1.25
Melt Point	°C	220-260	190-220
Tensile Yield Strength	MPa	40.96	62.63
Elongation at Break	%	20.86	4.43
Flexural Strength	MPa	45.44	65.02
Flexural Modulus	MPa	1948.45	2504.4
Impact Strength	kJ/m^2	22.11	4.28

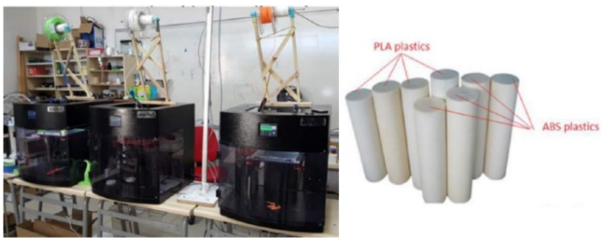


Figure 1. 3D printing machines used in the production of cylindrical parts

2.2. Experimental Layout
Experimental studies were carried out on a CNC abrasive water jet processing machine. This machine is max. It can produce a pump pressure of 415 MPa. The test sample was determined by calculating the arithmetic mean by making

several roughness measurements on the symmetry axis. A new turning mechanism was developed by removing the negativities in the water jet turning mechanisms available in the literature. While existing turning arrangements are made open air, loud noise and water abrasive particles are scattered around. In this study, by means of submerged working, on the one hand, it was possible to prevent water splashing during contact with the workpiece, and on the other hand, it was possible to reduce the noise level during machining. The structure of the specially developed underwater turning experimental setup, in which the defects that occurred in the previous studies were eliminated (Figure 2). During the processing with submerged abrasive water jet, sound level measurement is observed (Figure 3).

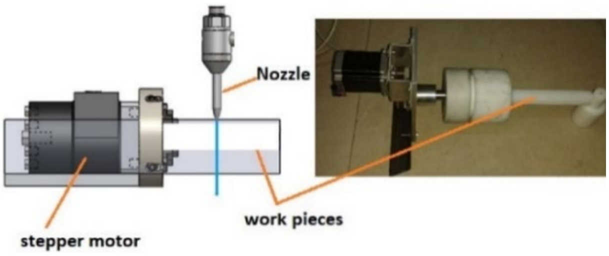


Figure 2. Technical design and fabricated views of the newly designed AWJ system.

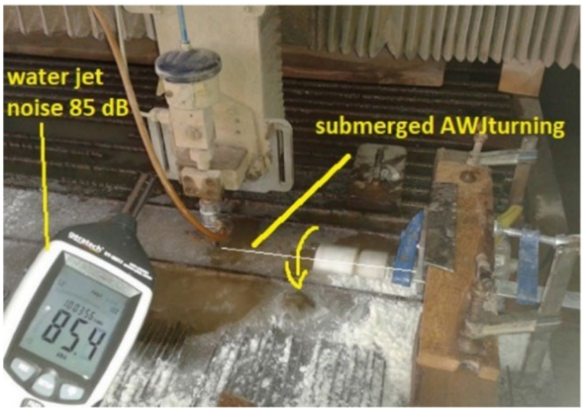


Figure 3. PLA and ABS cylindrical parts turning with submerged AWJ

2.3. Test Parameters and Measurement

The parameters were determined based on the experiences obtained from the preliminary experiments and literature survey [14-18] (Table 2). Experiments were carried out at 350 MPa pump pressure. Output parameters were measured with the Mitutoyo sj-201 surface roughness measuring device in the same direction as the water jet.

Table 2. AWJ Processing levels and parameters

Parameters	Units	Levels			
Nozzle feed rate (NFR)	mm/min	60	110	160	210
Abrasive flow rate (AFR)	g/min	160	185	210	235
Chuck Turning speed (CRS)	RPM	85	135	185	235
Nozzle distance (ND)	mm	3	5	7	9

3. RESULTS AND DISCUSSION

Graphs and estimation equations were obtained by making nonlinear regression analysis on average surface roughness values obtained from the surfaces of processed plastic parts. The correlation between surface roughness and spindle speed in AWJ machining of ABS and PLA materials can be seen in Figure 4 and Figure 5. The average surface roughness value (5.80 µm to 4.96 µm to 17%) decreased as the lathe speed increased for PLA plastic material. High turnover speed has resulted in good macro surface quality. Similarly, for ABS material, when the rotation speed is increased from 85 rpm to 235 rpm, the average surface roughness value decreases from 5.80 µm to 4.96 µm and decreases by 14%.

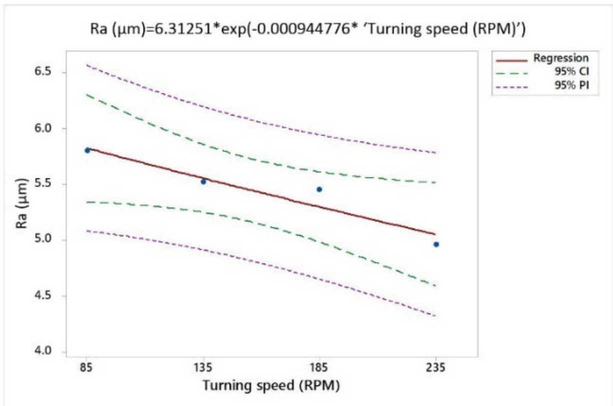


Figure 4. Influence of rotation speed on roughness when machining PLA material.

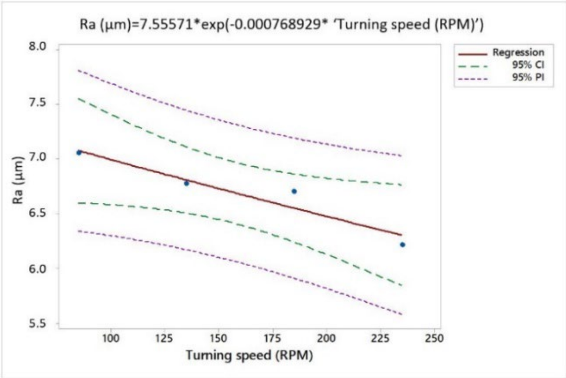


Figure 5. Influence of rotation speed on roughness when machining ABS material.

The Ra values obtained from experiments performed for ABS and PLA plastics using four different NFR's (Figure 6 and Figure 7). Ra increased by 26% (5.45 µm to 7.37 µm) when the NFR for PLA was increased from 60 mm/min to 210 mm/min. Ra increased 22% (6.70 µm to 8.62 µm) when the NFR for ABS was increased from 60 mm/min to 210 mm/min. The increase in roughness is due both to the heterogeneity of the jet's effect on the surface and to less processing time. The abrasive particles included in the water jet are not homogeneous in size. As the nozzle feed rate (NFR) increases, the number of particles contacting the surface of the treated material will be reduced. For this reason, the particles which are not homogeneous and have less contact with the surface will not be able to provide a homogenous plastic deformation. This causes deterioration of surface quality, the findings present a good fit with the literature [19-21].

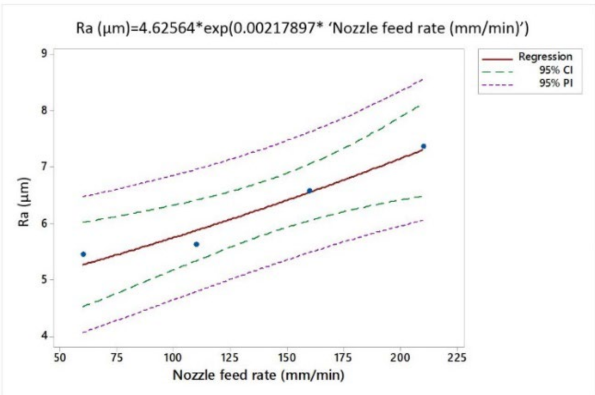


Figure 6. Influence of NRF on roughness when processing PLA material.

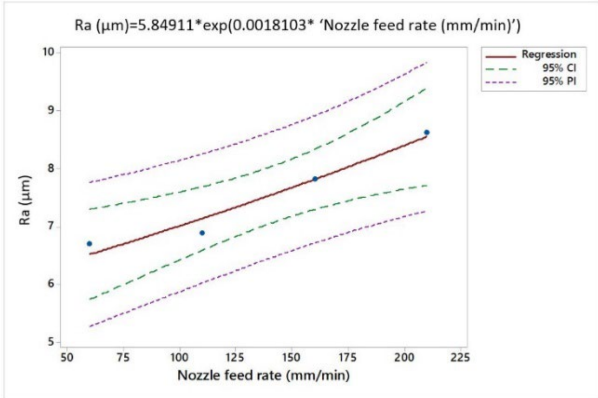


Figure 7. Influence of NRF on roughness when processing ABS material.

The variation of the abrasive flow rate (AFR) in the AWJ turning method with the variation of the surface roughness values of PLA and ABS (Figure 8 and 9 Figure). AFR increased from 160 g/min to 235 g/min average 35% surface roughness on PLA (6.58 µm - 4.85 µm) and ABS (7.82 µm - 6.11 µm) provided improvement. The higher AFR improved the Ra values by providing a more stable cutting process. The increase in the AFR will allow more abrasive particles to be contacted on the surface per unit time. The surface quality of the treated material has increased since this situation provides homogenization at the particle contacting surface. In addition, the increase in the amount of particles in the water jet provides the more rigid behavior of the jet. As the speed increases with increasing speed, more stable cutting will be expected.

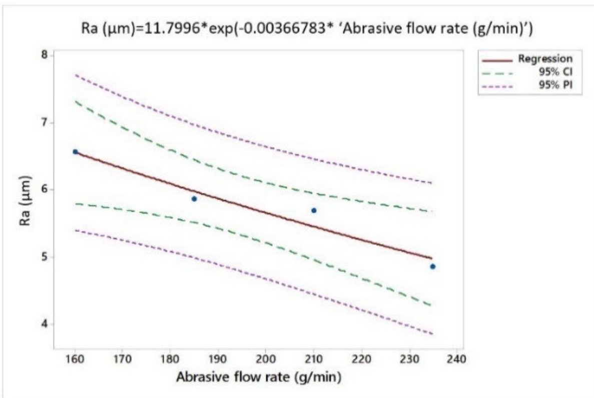


Figure 8. The effect of abrasive flow rate on the Ra when machining PLA material.

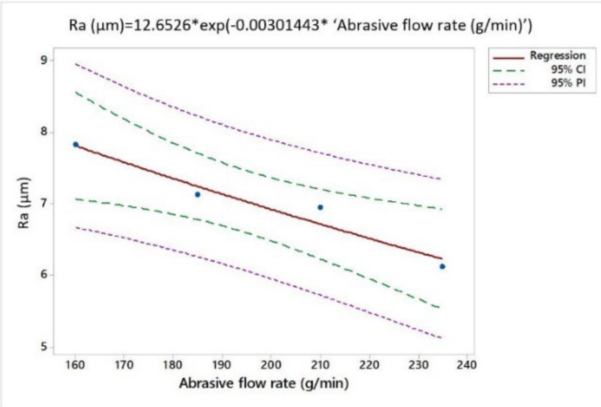


Figure 9. The effect of abrasive flow rate on the Ra when machining ABS material.

The Ra values obtained from experiments performed at four different nozzle distances (2, 4, 6 and 8 mm) for PLA and ABS plastics (Figure 10 and Figure 11). Increasing the ND parameter worsened the mean Ra value. This can be explained by the nature of the jet produced by the nozzle. Degradation of the jet core results in the formation of rougher surfaces due to a larger and inhomogeneous impact. When the nozzle distance (ND) from PLA plastic material was increased from 3 mm to 9 mm, the average surface roughness values increased by 19% (5.07 3µm- 6.24 µm). When the distance between the material and the nozzle was increased from 3 mm to 9 mm during machining, the average surface roughness value increased by 19 %5.07 3µm-6.24 µm for PLA material and 16% (6.17 3µm-7.35 µm) for ABS material.

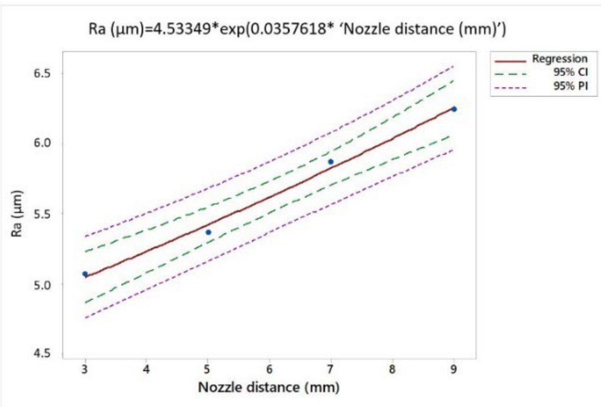


Figure 10. Surface roughness obtained in PLA material due to ND change.

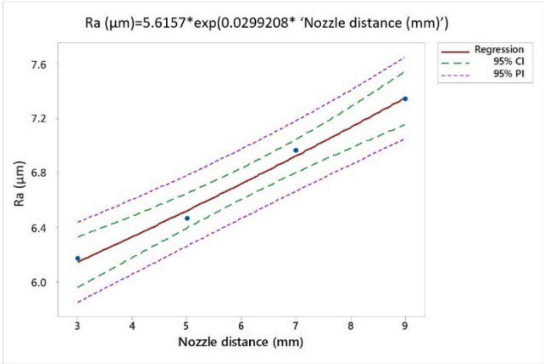
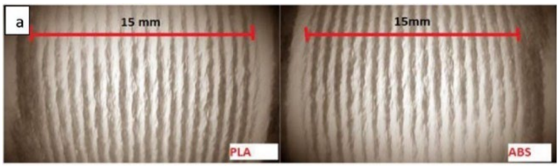


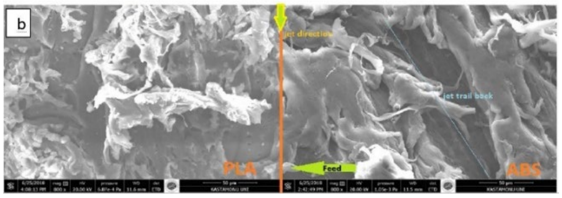
Figure 11. Surface roughness obtained in ABS material due to ND change.

The surface roughness values were statistically significant. The variation of the input parameter and the variation of the surface roughness values and the estimation interval vary in the 95% confidence interval. Furthermore, the fact that the values change with the low differences along the linear axis in the center of the figure proves that the experimental results have a high regression coefficient (relation rate). It can be argued that the variation of the surface roughness values with the change of each parameter can be modeled as nonlinear regression (obtaining empirical equations) in the mathematical modeling stage. The macro surface view obtained at the NFR 225 mm/min (Figure 12.a).

There are jet grooves and spiral cavities formed here. The cavities formed depending on the feed rate of the nozzle were obtained at 225 mm/min. This value can be said to be high for the processing of plastic materials. The Scanning Electron Microscope (SEM) image of the machined ABS and PLA plastic material work piece, (Figure 12.b), because of the lower density of PLA material, it is more easily processed than ABS material and jet lines are not visible in the area processed behind the nozzle. One reason for this may be related to the density and mechanical properties of the material. PLA is more easily broken and hard surface. It is more likely to break when bent. The 3D models produced by PLA can be cut, grinded, painted and bonded with strong adhesives. 3D models manufactured with ABS are stronger and more impact resistant. Therefore, it is recommended to use in mechanical parts and against variable weather conditions. When plastic materials are tried to be processed with traditional methods, since heat is applied above the melting temperature (Tm) of plastics, it is not possible to process such materials because the material undergoes deformation. For this reason, plastic materials are produced by molding technique and used in industry with a limitation that does not allow processing. However, since the heat generated in the material during turning with water jet is transferred by means of water, high heat does not occur. Thus, it is possible to keep the plastic material below the glass transition temperature (Tg) value at which it will start to deform.



(a)



(b)

Figure 12. Machined ABS and PLA plastic parts

4. CONCLUSIONS

The machinability of ABS and PLA materials was investigated by turning with abrasive water jet. The input parameters considered are ND, AFR, NFR and CRS. The input parameters are determined as four levels and the surface roughness (output parameter- Ra) values are changed depending on the change of the levels. The following results were obtained from the studies carried out with the newly designed and developed experimental system.

The increase in flow rate (from 160 g/min to 235 g/min) and chuck speed (from 85 rpm to 235 rpm) resulted in a 35% and 26% decrease in the average surface roughness value, respectively. The increase in ND resulted in a 19% increase in the surface roughness value. Thus, it has been determined that the increase in flow rate and chuck speed improves the surface roughness, while the increase in ND worsens it. The most important problem in front of the processing of thermoplastics by removing sawdust is the melting and deformation of the part due to the high heat generated during processing. It can be said that an effective solution has been presented by overcoming this problem with the abrasive water jet turning method. It has been determined that this method, which eliminates all the costs such as tool supply, coating and renewing them as they wear, is a very economical method during the manufacturing process.

But the three major disadvantages of the process should not be ignored. The first is the difficulty of loom installation and sealing problems. The second element is that it is difficult to obtain adequate and desired surface quality. For this reason, roughing process is more effective in turning with abrasive water jet. The minimum surface roughness value obtained in the processing of ABS and PLA material is 4.86 µm. This value is high even for roughing. For this reason, considering the industry expectations, the abrasive water jet turning method is difficult to use as final processing. The third factor is ergonomic factors. Due to the excessive noise of the water jet machine, operators need protective equipment. In this study, submerged turning operation was also carried out successful submerged, resulting in a lower noise level in the open atmosphere (85 dB). In order to remove the mentioned disadvantages, further research is needed on the subject of abrasive water jet and submerged turning.

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