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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Comparison of Hole Quality of Polyamide Materials Produced by Traditional and Additive Manufacturing

Geleneksel ve Eklemeli İmalat ile Üretilen Poliamid Malzemelerin Delik Kalitesinin Karşılaştırılması

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Abstract

Polyamide, commonly used in engineering plastics, has wear resistance and high strength. In this study, polyamide, which is produced with casting and three-dimensional printer, has been drilled and reamed in numerical controlled machine. Thus, the effect of production technique, machining allowance and tool feed rate on hole surface and dimensional accuracy was investigated. In general, the surface quality of the holes in the polyamide material produced by the two production techniques was directly affected by the machining allowance and the increased feed rate. In addition, the size of the holes created with the three-dimensional printer has reached the desired level after reaming process.

Keywords: Polyamide, Additive Manufacturing, Surface quality, Dimensional Accuracy, Hole quality, Reaming

Öz

Yaygın olarak kullanılan mühendislik plastiklerinden polyamid, yüksek aşınma direnci ve yüksek mukavemete sahiptir. Bu çalışmada, döküm ve üç boyutlu yazıcı ile üretilen polyamide malzemeye, nümerik kontrollü tezgâhta delik delme ve raybalama işlemi yapılmıştır. Böylelikle, üretim tekniğinin, işleme payının ve takım ilerleme hızının delik yüzeyi ve boyut kalitesine etkisi incelenmiştir. Genel olarak her iki üretim tekniğiyle üretilen polyamid malzemedeki deliklerin yüzey kalitesi, işleme payından ve artan ilerleme hızından doğrudan etkilenmektedir. Ayrıca üç boyutlu yazıcı ile oluşturulan deliklerin boyut kalitesi raybalama işlemi sonrası istenilen seviyeye ulaşmıştır.

Anahtar Kelimeler: Polyamid, Eklemeli İmalat, Yüzey kalitesi, Boyutsal doğruluk, Delik kalitesi, Raybalama

I. INTRODUCTION

Additive manufacturing (AM) is described in ASTM as a production process in which the layers are deposited or added to the final shape of the material or the closest to it. In the definition made by ASTM, additive manufacturing is the production technique of adding layer by layer material based on 3D model data. Many materials such as polymers, ceramics, metals and alloys are used by the AM technique [1] The advantages of this method include features such as reducing the weight of parts, design flexibility and contribution to the manufacture of spare parts [2] However, there are advantages as well as disadvantages. In particular, defects in surface quality and dimension tolerance directly affect the quality of the product. In addition, high financial costs, operating costs and materials for AM machines are the biggest challenges to the acceptance of AM [3]. AM is complete opposite with subtractive manufacturing (i.e. grinding, milling, drilling, cutting, etc.) in which the material is cut out to get the final part. Traditional manufacturers, such as machine designer, have recognized the advantages of additive manufacturing as a major obstacle, although they know the advantages of AM [4]. Therefore, the Computer Numerical Control (CNC) process is still a way of overcoming the obstacles in the additive manufacturing process. However, although high flexibility, great precision, high speed and similar features are presented with modern CNC technology, the flexibility of final production reached in CNC machining is relatively low in parallel to the AM process [5].

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Polyamide (PA) is one of the most valuable and most chiefly used engineering plastics. It can be produced by casting and injection production as well as additive manufacturing. Various polyamides are produced under various trade names, nylon 6 and nylon 66 are the most produced polyamides. The melting range of Nylon 6 is between 215-228℃ and nylon 66 between 250-265℃. Polyamides have excellent abrasion resistance and high strength [6]. Due to these properties, polyamide composites are generally used in various engineering areas such as machines, aircraft, automobiles, and robots.

In this paper, traditional-additive manufacturing involves two or more subsequent disconnected processes (e.g. additive manufacturing + drilling/reaming) employed to accomplish the final part properties. This paper focus on the better understanding of the machinability of PA6G with reaming. The effect of production techniques, machinability allowances for reaming and feed rates on surface and dimensional accuracy were investigated.

When the literature is examined, there is no study comparing the surface quality and size tolerance of casting polyamide materials produced by three dimensional printers. For this reason, the literature has been examined under the titles of polyamide processing.

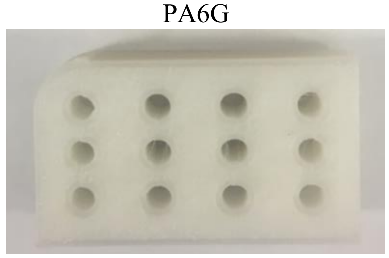
In Kuram's study, PA6 and glass-fibre reinforced PA6 were produced by injection moulding to investigate their ability to micro process. Burr formation, surface roughness, cutting force and tool wear were investigated during micro milling of the material [7]. Rubio et al, used the glass reinforced polyamide to determine the best drilling properties. PA6 and PA66GF30 composites were used to analyse the effects of spindle speed, tool geometry, and feed rate factors on the circularity error, hole mean diameter, and thrust force by using three drill bits with various geometries on composites [8]. Bozdemir, in terms of formation of mean surface roughness values of the casting PA6G samples, the properties such as cutting speed, depth of cut, and feed rate were examined under the same cutting conditions. They also considered the condition of the material to be dry and humidity [9]. Davim et al. investigated the ability of PA66 polyamide to be processed with 30% glass fibre reinforced and untreated. They used four different tool materials by precision turning at different feed rates [10]. Bozdemir and Aykut investigated the surface roughness quality of the Castamide holes prepared in the dry and wet forms processed using the comparable parameters. Artificial neural network modeling technique was advanced with the results acquired from the experiments. In this model, cutting depth, cutting speed and material type parameters are used [11]. As known from the literature, additively manufactured pieces almost require post-processing to improve surface quality features and relieve residual stresses. There are several studies on this subject. Reviews have been launched empathizing on hybrid manufacturing processes [12], [13]. Lorenz et al. [14] greatly focused and propose alternative additive manufacturing processes [15].

II. MATERIALS AND METHODS

Polyamide is a significant thermoplastic which is generally used in injection moulded components, with powerful economic benefits due to its low manufacturing cost. Polyamide has superior wear resistance related to other engineering polymers due to its ability to form a thin and uniform transfer film while sliding against steel parts.

In this study, polyamide material produced by three-dimensional printer and casting PA6G were used. The surface and dimensional qualities of these materials, which were produced by different production techniques, were examined by drilling the holes (Figure 1). The polyamide, which is produced by casting technique, is supplied in plate form. However, 3D printed PA holes was firstly designed on computer. The part designed on the computer was transferred to the 3D printer and the production was completed.

PA6G

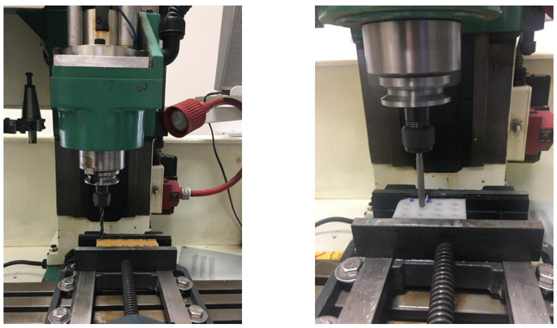


3D Printed PA

Figure 1. Experimental test samples

Test samples were manufactured by the Zmorph 3D printer. This machine can manufacture a model with size of 250x235x165mm with positioning accuracy of 14μm for X and Y axes and 0,625μm for Z axis. Uniquely processed 3D printing codes are used to fabrication parts so that the entire sample can be produced at 0-90°angles respectively. The test specimens are printed one by one in the centre of the bed so that all values can be fabricated as similar as possible. For test specimen, 3 shells were used around the part and 100% filler was used at the printing edges specified for the inside of it. The PA material was extruded at 245 °C on a 100 °C heated printing bed at a speed of 2400 mm/min and a layer thickness of 0.2 mm. Production was 5 hours and 23 meters filaments were used.

Triac Denford was used to process holes with a numerically controlled machine (Figure 2). The Triac is a versatile three axes CNC milling machine. The spindle speed was 1592 rpm. The cutting speed was planned as 30 m/min and the feed rate was planned as 0.1, 0.2 and 0.3 mm/rev. Ø5.8, Ø5.9 and Ø6 HSS drilling tools were used. In addition, reaming was done with Ø6H7 HSS reamer.



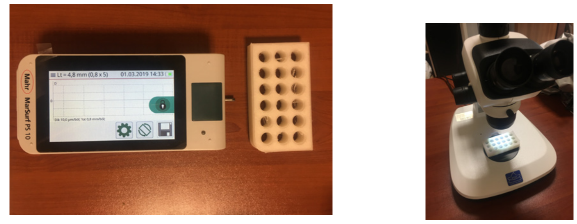
Drilling of PA6G Reaming of 3D Printed PA

Figure 2. Drilling/reaming of PA/PA6G materials

The milling process is as follows: Firstly, holes of 5.8, 5.9 and 6 mm diameter were drilled in three different feed rates (0.1, 0.2 and 0.3 mm/rev) on the plate produced with the casting. Then all these holes are reamed. In manufacturing with three-dimensional printer, holes are created in the design, sent to the printer. In other words, a material with holes of various diameters has been manufactured. This 3D Printed PA material is only reamed. Each procedure was repeated at least 3 times and the results were determined using the mean values. At the final of the tests, all holes are done Ø6H7.

Surface roughness values were measured at least 3 times before and after reaming. In addition, the post-production and reaming dimensions of the 5.8 and 5.9 mm holes produced by the three-dimensional printer were measured with a stereo microscope. In surface roughness measurements, the device named MAHR (MahrSurf PS-10) was used (Figure 3a). Measured parameters for surface roughness evaluation include Ra, Rz and RSm. The measurement results were displayed on an LCD screen and recorded on the computer. During the operation, the device measured 4 mm in length, the measurement speed was 0.5 mm/sec and the cut off was 0.8 mm.

The dimensions of the holes were measured using the SOIF SZ780-B2/L Trinocular Stereo Zoom Microscope (Figure 3b) The M-SHOT 5.0 MP CMOS microscope image integrated with this microscope was taken from the surfaces examined by the transfer camera and software.



a. Surface quality **b.** Dimensional accuracy

Figure 3. Equipment used for holes quality.

III. RESULTS AND DISCUSSIONS

Figure 4 illustrates the changes in the roughness of the surfaces, which are produced by the casting technique, on the reamed surfaces after drilling the holes in various diameters (Ø5.8, Ø 5.9, Ø 6 and Ø 6 without reaming). In the case of 0.1 mm/rev feed rate, the best surface quality is listed as Ø 5.8, Ø 5.9, Ø 6 and Ø 6 without reaming respectively. This order is the same for 0.2 mm/rev. At 0.2 mm/rev, there is a serious improvement in the surface quality of the drill hole with diameters of 5.8 and 6 mm without reaming in particular.

It is known that surface quality decreases with increasing feed rate in drilling operations. It should be noted that although the results obtained in Figure 4. When literature is reviewed for reaming process after hole drilling, for hole quality, higher feed rates are usually recommended for reaming than for drilling operations. When Figure 4 are evaluated in this way, the results of reaming after hole drilling are consistent with the literature [16,17]. It should be noted that there are many variables in this more complex machining process. This processes is linked to the dynamic stability of the drilling-reaming process rather than to increasing or decreasing feed rate, spindle speed, cutting speed or cutting depth. Furthermore, the selection of the correct reaming parameters depending on the reaming material also affects the quality of the reamed surface [18]. These effects should be considered for Figure 4, Figure5 and Figure 6.

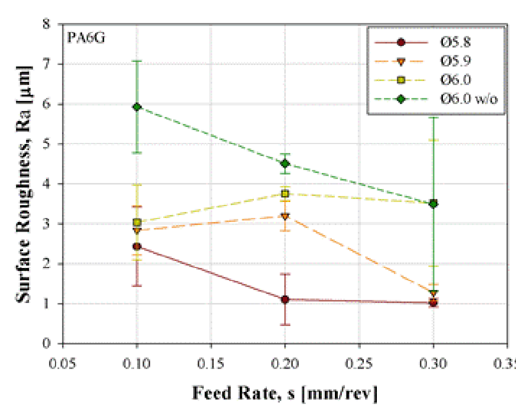


Figure 4. Surface roughness of PA6G

With increasing feed rate (s = 0.3 mm/rev), the surface quality of all hole treatments has increased. At this feed rate, after the reaming of the holes with diameters of 5.8 and 5.9 mm, the surface roughness values which are very close to each other were obtained. A similar situation is also possible for a 6 mm diameter reamed hole. The surface quality of the non-reaming hole with a diameter of 6 mm and the surface quality of the reamed hole of 6 mm diameter are the same with the increasing of feed rates in the polyamide produced by the casting technique. This result indicates that the results obtained from the experimental study support each other. When the surface quality of the holes with different diameters in the polyamide material produced by the casting technique is reamed to the same hole diameter, it is understood that the machining allowance for the reamer affects the surface quality at low feed rates. It is observed that the increasing of the feed rates, machining allowance for reaming has no effect.

After the reaming of the holes in the polyamide material produced by the three-dimensional printer, the surface roughness values obtained according to the feed rate are given in Figure 5. At 0.1 mm/rev feed rate, the best surface quality is achieved by reaming the hole with a diameter of 5.9, while a 0.2 mm/rev feed rate is at Ø5.8. With the increasing in feed rate (s = 0.30 mm/rev), all surface qualities are close to each other. In polyamide materials produced by three-dimensional printers, the effect of raised feed rate on the surface roughness is almost non-existent. However, at low feed rates, machining allowance for the reamer increases the surface quality.

Figure 6 presents surface roughness values after Ø6H7 reaming applied to holes of different diameters (Ø5.8, Ø5.9, Ø6) In various feed rates, the effect of the allowance for the reaming process on the surface roughness is evident. In general, the surface quality obtained by reaming the holes in the plate produced by the casting technique is better than the surface after the reaming process applied to the perforated plate produced by the three-dimensional printer. In a three-dimensional printer, high surface quality is achieved by producing the hole with the desired diameter and reaming in high feed rate.

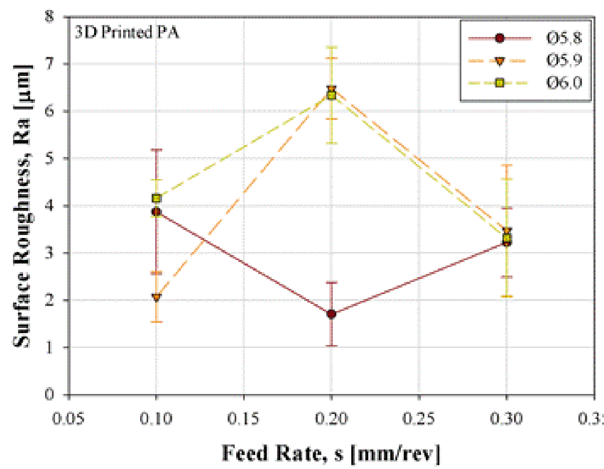


Figure 5. Surface roughness of 3D Printed PA

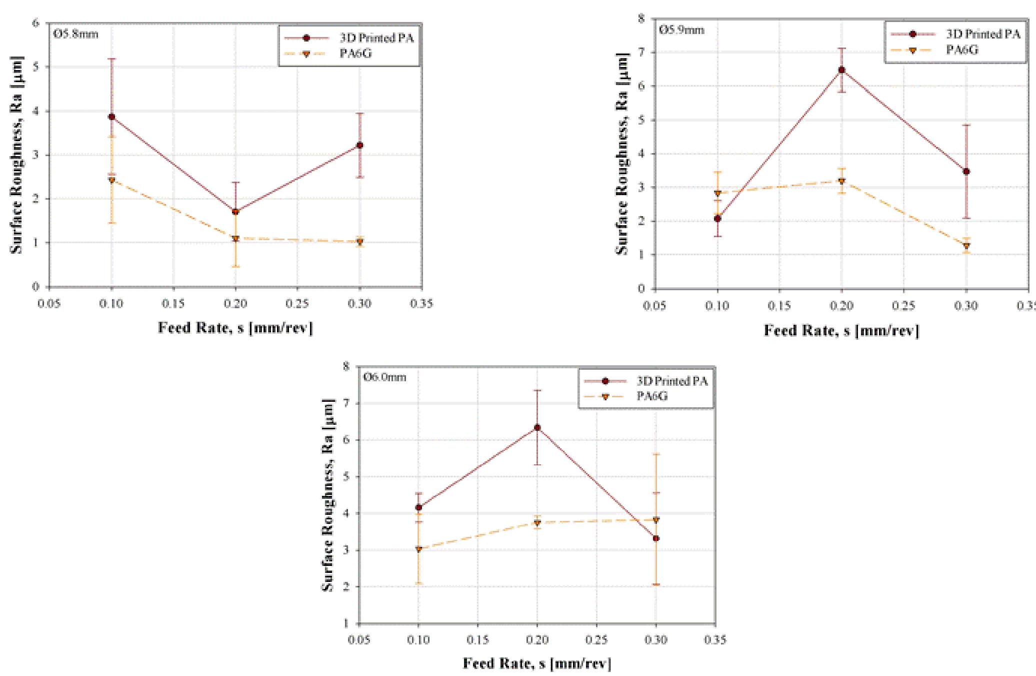
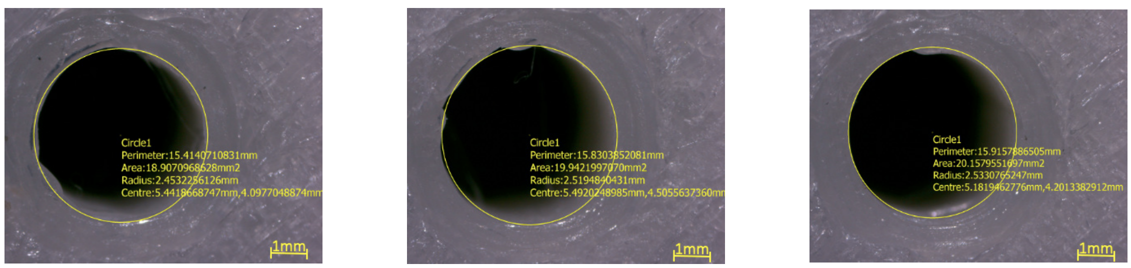
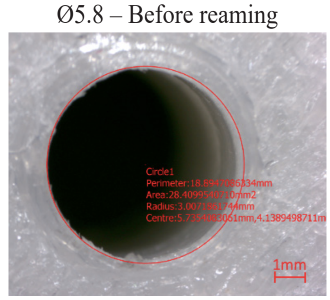


Figure 6. Effect of production technique on surface roughness

As it is known from the literature, one of the most important 3D printer production parameters is size tolerance. For this reason, in the scope of this study, dimensions of the holes, produced by three-dimensional printers, measured before and after reaming process. Considering the surface quality data, the dimensions of the holes with diameters of 5.8 and 5.9 mm were taken, and their size tolerances were examined. Three different diameter values obtained during the design of the hole, which is determined as Ø5.8 in the computer during the design with three-dimensional printer, are given in Figure 7.

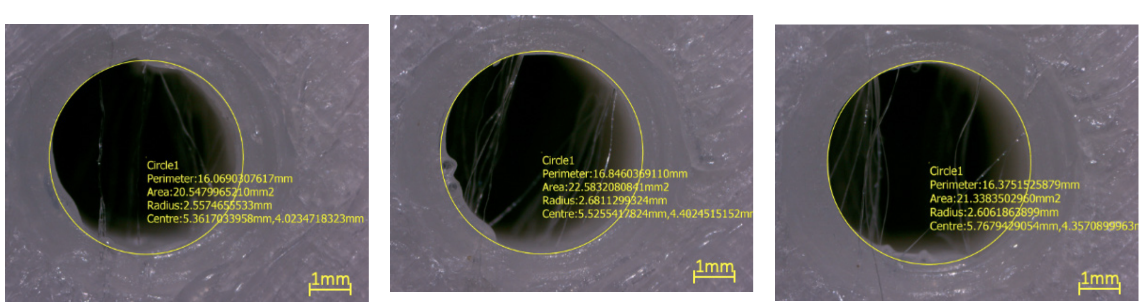


Ø5.8 – Before reaming

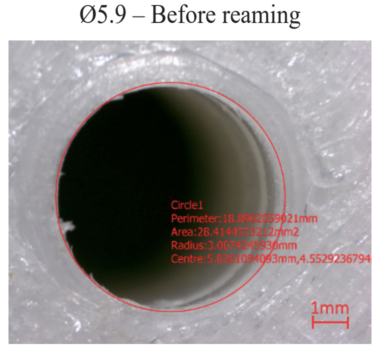


Ø5.8 – After reaming

Figure 7. Sizes of 5.8 diameter holes produced by 3D printers before and after reaming



Ø5.9 – Before reaming



Ø5.9-After reaming

Figure 8. Sizes of 5.9 mm diameter holes produced by 3D printers before and after reaming

Datas of circles such as perimeter, area, radius and centre are given in Figure 7 and Figure 8. These data were obtained by means of software integrated to the microscope and these graphs were created. When the data is carefully examined, it will be understood that the exact dimensions of the circles given in the figure are examined. Figure 7 illustrates three different diameter values, produced as 4.9 mm, 5.02 mm and 5.06 mm, respectively. The diameter value, which is designed as 5.8 mm in computer, can be obtained with an average diameter of 4.99 mm. However, as can be seen in Figure 7, 6 mm diameter was obtained after reaming.

Similar data were repeated in Figure 8 for 5.9 mm diameter. The holes designed as 5.9 mm in the computer are manufactured in a three-dimensional printer. The post-production diameter values are 5.1, 5.36 and 5.2 mm and the average is 5.22 mm. After reaming, the diameter is 6.00.

IV. CONCLUSION

Designing and manufacturing of new polymer technologies are advanced day by day. Especially the using of polyamide materials is known to be quite large. Dimensional accuracy and surface quality, which are important subjects of design and manufacturing, continue to be investigated for various materials. Using of new production techniques, such as additive manufacturing, together with modern numerical controlled machines has led to a relatively new way of manufacturing. In this context, this study will help designers, for polyamide material, about production technique planning and size-surface quality of holes.

In this study, two different production techniques were used to drill holes depending on various parameters. It has been demonstrated whether the holes produced by additive manufacturing can achieve the quality of the drilled / reamed holes produced by conventional methods after a process such as reaming by means of PA produced by additive manufacturing and PA6G, a casting product of conventional production techniques.

The results show that the reaming process at high feed rates the holes manufactured by the three-dimensional printer, significantly increases the surface quality. Even better results have been obtained from the polyamide material produced by casting. The surface quality of casting polyamide is improved with an optimum proportion of machining allowance for reaming. The quality of the holes produced by the three-dimensional printer is quite low and reaming is definitely needed. It is possible to obtain better hole surfaces by using different three-dimensional printing parameters.

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