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Influence of Glass Fiber Ratio on Drillability Characteristics of PA66 Polymer for Aerospace Applications

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ABSTRACT

This study examined the machinability of polyamide 66 (PA66) reinforced with glass fiber (GF) at 10%, 20%, and 30%. Cutting speeds of 40, 80 and 120 m/min and feed rates of 0.06, 0.09, and 0.12 mm/rev were used to examine thrust force (Fz) and surface roughness (Ra). Drilling operations were done using uncoated HSS and TiAlN coated HSS cutting tools. The goal of this research is to investigate the effect of cutting parameters (spindle speed and feed rate) and reinforcement ratios on thrust force (Fz) and surface roughness during cutting operations (Ra). Statistical analysis was used to determine the contribution of the cutting parameters to the results that were under investigation. For the purpose of examining the hole quality and damage mechanisms, scanning electron microscopy (SEM) was performed. The surface roughness values obtained in the 30% glass fiber added PA66 material drilled with an uncoated cutting tool were quite high. A high fiber rupture rate on the hole surfaces, matrix fragmentation, and other difficulties resulted in increased thrust force.

Cam Elyaf Oranının Havacılık ve Uzay Uygulamaları için PA66 Polimerinin Delinebilirlik Özelliklerine Etkisi

MAKALE BİLGİSİ

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Anahtar Kelimeler:
Poliamid 66 (PA66)
Cam elyaf (GF)
Delme
İtme kuvveti
Yüzey pürüzlülüğü

ÖZET

Bu çalışmada %10, %20 ve %30 cam elyaf (GF) ile güçlendirilmiş poliamid 66'nın (PA66) işlenebilirliği incelenmiştir. İtme kuvvetini (Fz) ve yüzey pürüzlülüğünü (Ra) incelemek için 40, 80 ve 120 m/dak kesme hızları ve 0,06, 0,09 ve 0,12 mm/dev ilerleme hızları kullanılmıştır. Kaplamasız HSS ve TiAlN kaplı HSS kesici takımlar kullanılarak delme işlemleri yapılmıştır. Bu araştırmanın amacı, delme işlemleri sırasında kesme parametrelerinin (işmili hızı ve ilerleme hızı) ve takviye oranlarının itme kuvveti (Fz) ve yüzey pürüzlülüğü (Ra) üzerindeki etkisini araştırmaktır. İncelenen sonuçlara kesme parametrelerinin katkısını belirlemek için istatistiksel analiz kullanılmıştır. Delik kalitesi ve hasar mekanizmalarını incelemek amacıyla taramalı elektron mikroskobu (SEM) ile incelemeler yapılmıştır. Kaplamasız kesici takımla delinmiş %30 cam elyaf katkılı PA66 malzemesinde elde edilen yüzey pürüzlülük değerleri oldukça yüksektir. Delik yüzeylerinde yüksek lif kopma oranı, matris parçalanması ve diğer zorluklar, artan itme kuvvetiyle sonuçlanmıştır.

1. INTRODUCTION (GİRİŞ)

As a matrix in polymer composite materials, polyamides, epoxy resins, polyesters, phenolic resins, and vinyl ester resins are commonly utilized due to their high strength and low density as well as their outstanding chemical stability and exceptional corrosion resistance [1]. These materials, on the other hand, are reinforced with various types of fibers [2], including glass, carbon, basalt, and aramid, because they have a poor hardness and a proclivity to creep at high temperatures, and hence require reinforcement [3,4]. Because of their superior mechanical and thermal qualities are well suited for use in aviation and maritime applications [5,6]. Furthermore, they offer a high filling capacity, a low and well-distributed internal tension in products, and are simple to process when it comes to filling materials. There is no stress accumulation at the interface

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between the reinforcements and the matrix as a result of the smooth spherical surfaces of these microparticles. As reinforcements, they are particularly well suited, particularly when coupled qualities such as isotropy or low melt viscosity are required [7]. A more promising alternative is to employ composite materials that are reinforced with fibers, which are becoming increasingly popular [8], particularly in the aerospace and aviation industries as well as the automobile, sporting goods, and marine industries [9,10]. Composite materials are named as heterogeneous materials that are formed by combining the properties of at least two different materials in a single and new material, rather than using single materials with limited properties [11]. Composite materials have properties such as stiffness level, fatigue and shrinkage level, resistance to pressure and tendency, sensitivity to high temperature and high corrosion resistance due to the different properties of at least two different materials [12]. Apart from these, it exhibits good tribological properties such as low density, high hardness, and high resistance to breakage. For this reason, it is widely used in many fields such as construction, space technologies, automotive industry, maritime, nuclear industry, robotic technology, health sector and chemicals, especially in the defense industry and aviation industry [1]. Composite materials are highly resistant to temperature, as well as being light, robust and resistant to impacts, allowing work to be carried out in many areas. It determines the basic properties of matrix, fiber, ball, interface and microstructure composite materials [13]. The fiber material is the component that can determine the strength and load-bearing properties of composites [14]. Glass fiber reinforced composites (GFRP) are obtained by using methods such as molding under pressure and vacuum, hand laying. The dimensions of the place to be used in the production phase and the geometric shape are also taken into consideration. Machining methods such as turning, drilling and milling are used to finalize composites produced in various conditions [15]. However, GFRP composites are not the isotropic structure found in metals and alloys. Therefore, various problems occur in the machining of GFRP composite. During the processing of fiber reinforced composites, it is important to increase the level of surface quality and increase the life of the tool. Machining costs have a significant impact on the cutting force and the quality level of the machined surfaces. The surface quality has a great influence on the mechanical properties of the composite material [16]. Therefore, the quality of the surface is one of the most important issues to be considered during the turning phase. Machining variables and also fiber length and proportions must be at appropriate values and ratios for the surface quality to be at the best level [17]. Drilling generally constitutes finishing, and the higher the reject rate of parts due to these holes, the higher the part defects and scrap material. Therefore, high quality drilling is always desired [18].

Taguchi technique and multiple regression analysis were employed by Latha et al. to model delamination during the drilling of GFRP composites with carbide drills, according to their findings. The researchers' findings revealed that the feed rate and drill bit diameter were the most significant input elements that could have an impact on delamination [19]. Krishnaraj et al. conducted a survey on the optimization of machining parameters for drilling thin Carbon fiber reinforced polymer (CFRP) laminates, which they published in the journal Composites Engineering. They stressed that the circularity of the hole is the most important aspect, and that feed rate was the most influencing factor on the thrust force, delamination, and hole diameter (all of which were measured) [20]. Gaitonde et al. investigated the effects of drilling parameters on thrust forces, hole sizes, and circularity in PA66 matrix-glass fiber reinforced composites with a 30 percent glass fiber content [21]. They discovered that the tip angle of the drill can have an effect on the thrust force and the roundness of the hole while drilling a hole. In order to decrease the thrust force, they advised a point angle of 115° when the drill had an 85° point angle to ensure the least amount of roundness error was produced. When drilling a 30 percent GFR polypithylamide matrix composite, Fçc and Ayparças discovered that the material of the cutting tool can have an impact on the surface roughness of the composite. In their research, they discovered that carbide drills created holes with lower surface roughness than holes produced with high-speed steel (HSS) drills [22].

However, while most of the literature is concerned with mechanical characteristics or machinability, most of the testing has been done with constant parameters. Although the drillability of PA66 reinforced with GF was evaluated at 10 percent, 20 percent, and 30 percent reinforcement ratios, cutting speeds, and feed rates using uncoated and TiAlN coated HSS drills for Fz and Ra, the results showed that the drillability was poor.

2. MATERIAL AND METHOD (MATERYAL VE YÖNTEM)

The polyamide 66 material utilized in this investigation was manufactured by adding 10%, 20%, and 30% glass fiber. Drilling of GFRP Composite with various fiber ratios at the cutting speeds of 40-80-120 m/min and feed rates of 0.06-0.09-0.12 mm/rev was used to examine the effects of fiber ratio, cutting speed, and feed rate on Fz and Ra (Figure 1). The experiments were carried out at three distinct levels of feed rate and cutting speed, which were established by taking into account the cutting tool recommendation as well as relevant research [23,24].

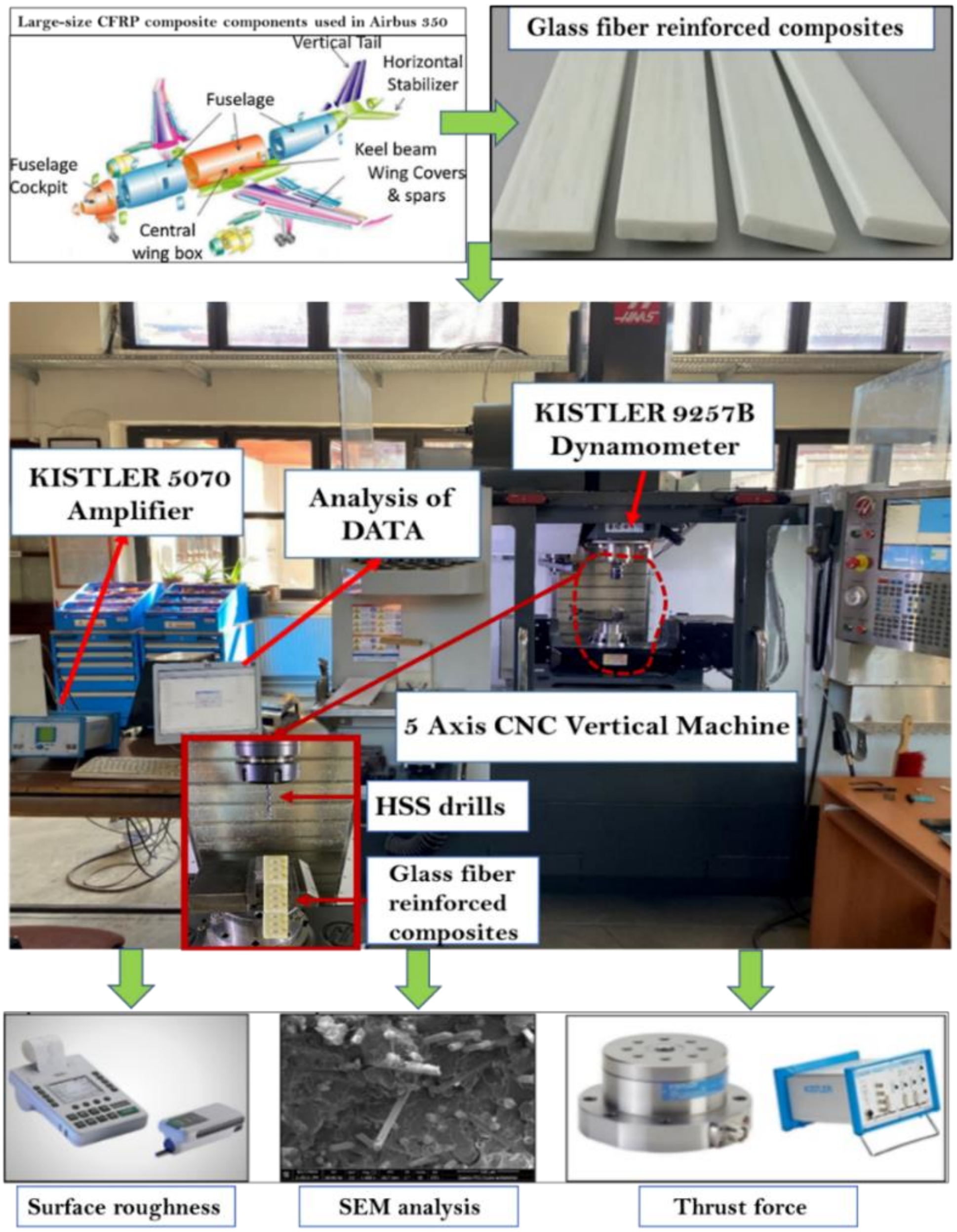


Figure 1. Experimental Setup (Deneysel düzenek)

It was decided to make GFRP and GBRP composites with varying reinforcement ratios and test the mechanical properties of these composites. A high-strength engineering thermoplastic known as Polyamide 66 (PA66) is used as the matrix material. It has good corrosion and abrasion resistance, self-lubricating characteristics, low impact resistance, and exceptionally high strength. The images of the glass fiber (glass fiber GF) reinforcement elements that were supplied and used in the composite are shown below. The coated aminosilane is reinforced with average chopped length 11 mm of diameter 4.5 mm PA2 types of short glass fibers (glass fiber industry, Turkey) as well as short glass fibers (glass fiber industry, Turkey) coated again surface aminosl.

The thrust force was measured with a piezoelectric dynamometer (Kistler 9257), which is connected to the 5070-A multichannel charge amplifier and Dynoware 2825A-02-01 software. The surface roughness of the holes was measured in order to determine the impact of the type of cutting tool used and the cutting parameters used in the cutting process. The hole surface roughness was measured using a Mahr brand MarSurf M 300 type profilometer.

3. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

During drilling, the cutting tool removes chip from the resin rich region on the outside of the GFRP composite. The thrust force causes rapid elastic loading of the workpiece material. The GFRP's anisotropy causes a decrease of stiffness, which causes force fluctuation. The perpendicular-to-fiber cutting zone causes a force signal variance when the cutting tool touches the fibers and advances. Moving from 0.06 mm/rev to 0.09 mm/rev boosted Fz values by almost 22%, and from 0.09 mm/rev to 0.12 mm/rev increased them by nearly 44%. These changes show that feed rate is more important than cutting speed. 30 percent GFRP had a higher Fz than 10% reinforcement at the same cutting speed and feed rate. The other feed rates and cutting speeds showed a similar tendency, with Fz values increasing with the glass fiber ratio. The glass fiber ratio increases with strength and hardness. The test results with coated drills (Figure 2d-e-f) show lower Fz values than uncoated cutting instruments (Figure 2a-b-c). Coated drills have a lower friction coefficient than uncoated cutting instruments. This coating has a high hardness value and hence allows for high-speed work [10]. The low coefficient of friction enables for easy chip evacuation. This is good for chip development. It also works effectively at high temperatures due to its low thermal conductivity. So it has good tool life and wear resistance at high temperatures [9].

All increases in cutting speed were reduced by approximately 8% compared to the uncoated cutting tool. The feed rate decreases by 11% compared to the uncoated cutting tool. Using a coated tool improves Fz value. The thrust force increases with increasing glass fiber ratio. Increasing the glass fiber ratio increases the material's elastic modulus and thus the thrust force. This impact is accompanied by a reduction in the contact area between the cutting tool and the workpiece, as well as a reduction in the specific cutting energy [11]. When feed rates increased at all the other parameters constant, the forces increased as well. Following the findings of previous studies [12,13], our results were found to be associated with increased uncut chip thickness and shear area. Ra values decrease with cutting speed (Figure 2g-2l). Like the thrust force, the observed discrepancy can be explained by increased tool-to-workpiece friction with increasing cutting speed. It also aids in chip removal. By increasing feed rate from 0.06 to 0.09 mm/rev at 40 m/min cutting speed, the Ra values improve by roughly 10% and 25%. The same feed rate increment increases the Ra levels by 50% and 30% at 80 m/min and 120 m/min, respectively.

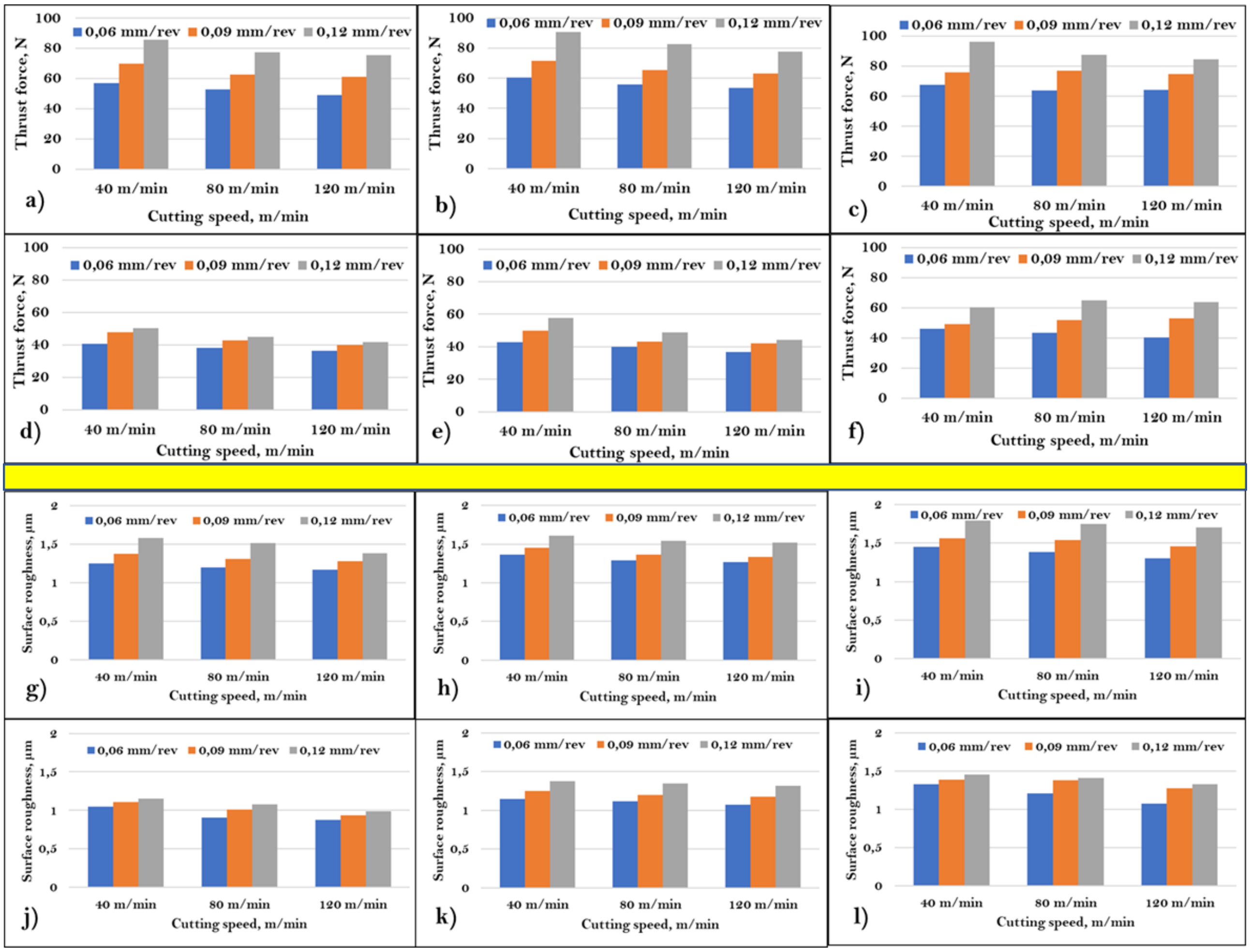
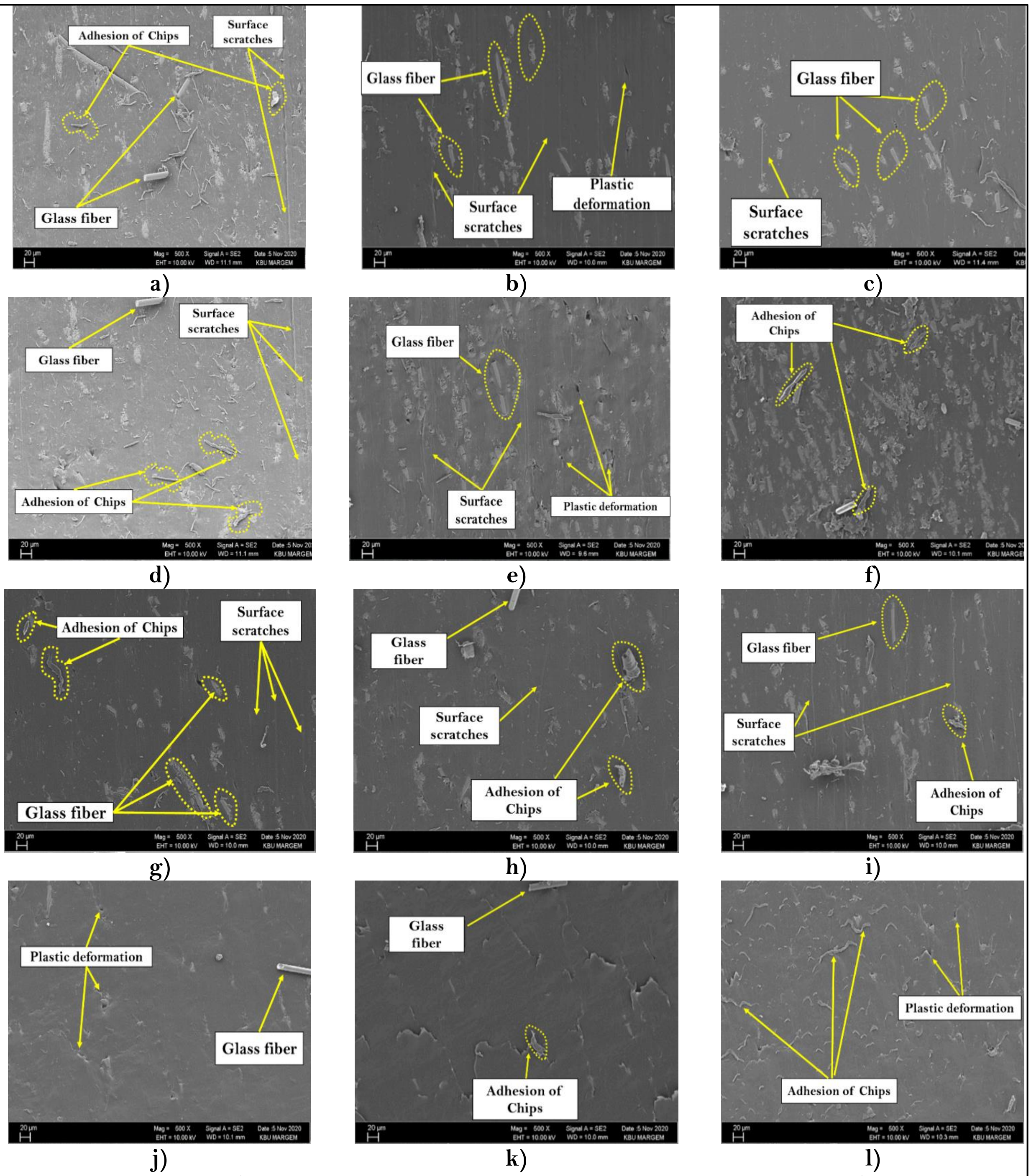


Figure 2. Thrust force variation for a) 10%GFR-uncoated, b) 20%GFR-uncoated, c) 30%GFR-uncoated, d) 10%GFR-coated, e) 20%GFR-coated, f) 30%GFR-coated, and Surface roughness variation, g) 10%GFR-uncoated, h) 20%GFR-uncoated, i) 30%GFR-uncoated, j) 10%GFR-coated, k) 20%GFR-coated, l) 30%GFR-coated (İtme kuvveti değişimi, a) %10 GFR kaplamasız, b) %20 GFR kaplamasız, c) %30 GFR kaplamasız, d) %10 GFR kaplamalı, e) %20 GFR kaplamalı, f) %30 GFR kaplamalı ve Yüzey pürüzlülük değişimi, g) %10GFR kaplamasız, h) %20GFR kaplamasız, i) %30GFR kaplamasız, j) %10GFR kaplamalı, k) %20GFR kaplamalı, l) %30 GFR kaplamalı)

There is an average of 8% increase in Ra value when the feed rate increased from 0.06 to 0.09 mm/rev at 40 m/min cutting speed, and an average of 10% increase by 0.12 mm/rev increase. In the light of these results, it is seen that the feed rate is a more efficient factor on Ra than the cutting speed. SEM images obtained from the hole surfaces depending on the cutting speed are given in Figure 3. In addition, it was observed that 30% GFRP reached higher Ra values than 10% GFRP at the same cutting speed and feed rate. Similarly, for different feed rates and cutting speeds, Ra values increased with increasing glass fiber ratio. Ra values increased with increasing glass fiber ratio, indicating a similar tendency for various feed rates and cutting speeds. Figure 3d-3f shows the hole surface varies with the glass fiber ratio. Under the same cutting conditions, the uncoated drill has higher Ra values than the coated drill. This is explained by the coated drill's strong wear resistance, low friction coefficient, and the elimination of chips between the tool and the workpiece. Ra grew with the glass fiber ratio. Due to the glass fiber ratio and difficult cutting, this increase in surface roughness could be read as an increase in material strength [14]. Uncoated cutting tools also produce a higher Ra value. The matrix material binds to the hole surface and reduces surface damage at low feed rates (Figure 3g-i). Surface roughness is exacerbated by matrix fragmentation caused by high temperatures and high feed rates [15]. As seen in Figure 3j to 3l, the coated tool generates a superior surface by lowering friction and thus heating. Based on these findings, fast cutting speed and low feed rate improve surface quality at low glass fiber ratios. The best surface quality was 0.88 m in testing with coated cutting tools at 120 m/min and 0.06 mm/rev.



a) to c) 40 – 80 – 120 m/min cutting speed for uncoated tool at the feed rate 0.06 mm/rev,
d) to f) 10%, 20% and 30% GF at the feed rate of 0.06 mm/rev and cutting speed of 120 m/min,
g) to i), the cutting speed of 40 m/min and feed rate of 0.06, 0.09 and 0.12 mm/rev with Uncoated tool
j) to l) the cutting speed of 40 m/min and feed rate of 0.06, 0.09 and 0.12 mm/rev for with Coated tool

Figure 3. SEM images of hole surfaces (Delik yüzeylerinin SEM görüntüleri)

4. CONCLUSIONS (SONUÇLAR)

In this research, the machinability of single-reinforced and hybrid glass fiber-reinforced polymer composites (PA66) were investigated. To begin, polymer composites reinforced with varying ratios of carbon fibers were created. Later, machined samples were created to determine the influence of cutting parameters and reinforcement ratio on the thrust force and hole surface roughness of the fabricated samples. The materials utilized in the fabrication and the quality of the machined holes was both evaluated using scanning electron microscopy (SEM). Following are the conclusions that may be drawn from this research:

• Drilled with an uncoated cutting tool, the 30% glass fiber added polyamide 66 (PA66) material had very high surface roughness values. Adding 30% glass fiber to polyamide 66 (PA66) material causes fiber rupture on hole surfaces, matrix fragmentation, etc. The inaccuracies enhanced surface roughness.

• The SEM photos show that as the glass fiber ratio increases, the surface roughness increases due to the material's durability and forced drilling. The coated tool is tougher than the uncoated tool, allowing for easier drilling and improved surface quality.

• As a result of the drilling tests, it has been established that PA66 based fiber reinforced polymer composites are prevalent. In this paper, a generic approach for fabricating various types of composites is provided from the beginning of the fabrication process through the end of the drilling operation. This approach will be used frequently in the future for a wide range of technical components, and the characteristics identified during this study will be used to guide the process.

• The study's novelty and future advice is that an appropriate combination of glass fiber should be favored for optimal machinability and mechanical properties of GF/GB reinforced polymers rather than employing only glass fiber reinforcement.

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