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EXPERIMENTAL AND STATISTICAL EVALUATION OF THE MACHINABILITY OF PURE ZINC BY TURNING METHOD

ABSTRACT

In this study, the machinability of pure zinc during dry turning is examined experimentally. Low melting point and high ductility of zinc enable easy machining, while low strength and hardness result in a limiting factor for the usage of high-loading applications. Zinc samples (99.58% purity) are turned using a TiAlNi-coated carbide cutting tool at feed rates of 0.1-0.2mm/rev, depths of cut of 0.2-0.4mm, and cutting speeds of 20-40m/min. Surface roughness was evaluated as the main indicator of machinability, and the effects of parameters were statistically examined using S/N and ANOVA analyses. Optimum surface quality was observed at a low feed rate (0.1mm/rev), low cutting speed (20m/min), and 0.2mm depth of cut. Maximum surface roughness was achieved at high cutting speed and feed rate settings. The ANOVA results revealed that the depth of cut was the most influential parameter on surface roughness, followed by the feed rate and cutting speed, respectively. The R^2 value of 91.32% indicates a strong correlation between the model and the experimental results.

Keywords: Pure Zn, ANOVA, Turning, Surface Roughness, Machining

1 INTRODUCTION

Pure zinc is a transition element with an atomic number of 30 and 99.58% pure in commercial form, which has no additives or elements inside, leading to disadvantages for high loading applications such as breaking when subjected to high stress. Without additives, the homogenous crystal structure of zinc results in low yield strength owing to low resistance to slip on shear planes, making plastic deformation easier at a small amount of stress, limiting the high-strength applications such as columns, pressure vessels, aircraft parts, gears, engine components, and automotive chassis components. Moreover, high temperature applications lower the strength and hardness of zinc, which already has a low melting point and corrodes when reacted with acids and bases. For this reason, zinc is usually preferred as an alloy, and with an annual production of about 13 million tons, it is one of the most used elements among other metals. While pure zinc has a limited elongation and tensile strength in casting form, it has become an important casting alloying element when combined with aluminum by

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providing high wear and corrosion resistance, high strength and hardness, and good fluidity. Using copper and titanium, materials can be manufactured both physically and mechanically for use as fasteners at an optimum level in the automotive and electronic industries.

One of the common coating methods for the corrosion protection of some metals is the galvanization technique, consisting of two methods as hot-dip galvanization and electrogalvanization. In the hot-dip galvanization method, zinc protects the material from corrosion due to its high resistance in the long term, enabling a more economical process compared to long-term painting and PVD coating methods. Similar to the hot-dip method, the main purpose of electrogalvanization is to protect metal for corrosion with a zinc coating. In addition, in this method, the surface is immersed to an electrolyte solution and as a result of the process, a brighter, thinner, and homogeneous zinc layer is formed. The good throwing power of zinc provides a good coating on complex surfaces such as gears, screws, and nuts, which generates ease of operation by increasing the material diversity. While pure zinc is inherently difficult to machine and the studies based on machinability are limited, numerous studies are available on alloyed zinc. Bayraktar and Hekimoğlu examined the effect of zinc content and the coating of cutting tool in the machining of Al-(5-35)Zn alloys. While increased zinc addition is found to have a positive effect on the machinability of Al-Zn alloys, TiAlN-coated tools had negative effects. As a result, it can be concluded that increased zinc content can enhance the surface quality due to low cutting force along with high chip removal performance [1]. Stevenson and Stephenson studied the mechanical behavior of zinc during machining. As a result, they concluded that the voltage measured during cutting was consistent with the voltage measured during compression, and that the thrust force could be considered negligible. Thus, the fact that zinc can be processed predictably makes it a frequently preferred material [2]. Liu demonstrated a new approach to designing and synthesizing microalloyed Zn biodegradable alloys with improved mechanical properties. An increase in Mg addition resulted in an improvement on strength, and Zn-Mg alloys with refined grains showed much higher resistance to fracture than pure zinc. Under the synergistic effects of additional grain refinement and rapid cooling rate, the yield stress, elongation percentage, and hardness increase of microalloyed Zn-Mg alloy were higher than pure zinc when compared to pure zinc [3]. Jarzebska et al. examined the feasibility of the production of mini tubes from hydrostatically extruded rods of biodegradable pure zinc by the EDM process. Experiments have shown that high pulse currents result in poor surface quality and thicker casting layers on pure zinc treated with HSE. Minitubes were found to be less susceptible to microstructural changes after EDM, demonstrating mechanical properties similar to those of pure zinc processed with HSE in rod form. This study demonstrates that EDM can be a functional method for producing biodegradable zinc-based microstructures if optimal processing parameters are applied [4]. Vojtech et al. investigated the mechanical and corrosion properties of newly developed, biodegradable Zn-based alloys aimed for bone fixation applications, which is a possible alternative to Mg-based alloys. The results showed that the Zn-Mg alloys, in their as-cast condition, exhibited good mechanical strength attributed to their inherent structure. In addition, due to the better corrosion resistance of zinc alloys compared to magnesium alloys, it is predicted that they may prevent adverse reactions in the tissue during the healing process. Zn-based alloys dissolve more slowly in the body, resulting in a healing period in harmony with the biological environment [5]. Kubasek and Vojtech investigated Zn-based alloys as alternative biodegradable materials in their experiments. The examined Zn-Mg alloys were found to have high corrosion resistance and mechanical properties in the cast state, suggesting that Zn-Mg alloys may be suitable materials for biodegradable implants [6]. Prakash and Pruthviraj conducted microstructural studies on as-cast zinc-aluminum-SiC-graphite hybrid composites. Their study showed that hybrid composites with increased SiC content, a hard ceramic, exhibited higher hardness and lower wear loss. In the study, hybrid Zn-Al-SiC-graphite composites were produced using liquid metallurgy. These composites were observed to have higher wear resistance compared to single-phase composites. Thus, hybrid structures play an important role in materials engineering by strategically utilizing different phase compositions to optimize the material's mechanical and physical properties [7]. Hekimoğlu and Turan investigated the effect of zinc content on the structural and mechanical properties of Al-(5-50)Zn alloys and found that the density and hardness increased with increasing zinc content in Al-(5-50)Zn alloys. Furthermore, tensile and compressive strength values increased up to a 30% zinc content, decreasing thereafter. Consequently, the zinc content appears to create an optimum value for mechanical strength. While increasing zinc content increases hardness, it does not consistently increase strength, so this ratio must be carefully adjusted when designing [8]. Previous studies show the usage of alloying elements instead of pure zinc. In this study, lathe machining was performed. In the turning process, the workpiece rotates around its own axis, and the cutting tips advance parallel or perpendicular to the workpiece, removing chips from the workpiece, thus creating cylindrical or superficial geometries [9, 10, and 11]. The results of the turning process and its performance during the work depend on the parameters used [12, 13, 14, 15, and 16]. These parameters consist of cutting speed, feed rate, and depth of cut. The process consists of two phases as rough turning and finish turning. The purpose of rough turning is to complete the material removal process in a practical way with high feed rate and depth of cut, while in finish turning, unlike the roughing method, low feed rates and depths of cut are used. At the end of the process, a surface finish method is applied to provide high surface quality. There exist various lathe machines for different purposes such as universal, CNC lathe and revolver. The high accuracy and mass production capabilities of the CNC lathe make it one of the most preferred ones. This study aims to determine the machinability of pure zinc, a material commonly used in alloys and therefore lacking sufficient studies on its machining properties in its pure form, and to fill a significant gap in the literature. Pure zinc's low melting point, low hardness, and ductility allow for easy machining, while also allowing for a simple determination of the effects of machinability parameters. Pure zinc has limited but direct applications in anode, battery, and battery production, and as a coating material. Furthermore, machining data can provide a reference base for future zinc alloy development. The input and output parameters of pure zinc are shown in Figure 1.

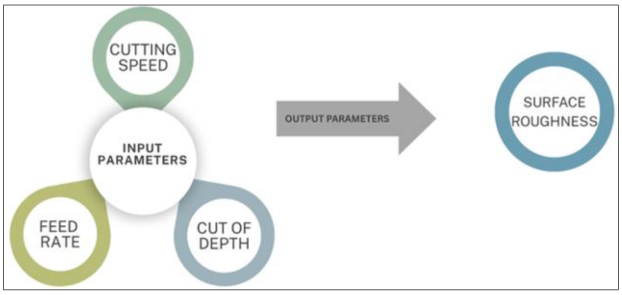

Figure 1. Input and output parameters of the experimental study

2. RESEARCH SIGNIFICANCE

The main objective of this study is to experimentally determine the effects of turning parameters (feed rate, depth of cut, cutting speed) on the surface roughness of pure zinc, a material commonly used in alloys but lacking sufficient data in its pure form. The research confirms the easy machinability of pure zinc due to its low melting point, low hardness, and ductility, thereby simply revealing the effects of machinability parameters and filling a significant gap in the literature. Furthermore, it establishes a reference base for future development studies on zinc alloys. The derived machinability data will contribute to the optimization and efficiency of production processes for zinc-based materials, especially in direct applications of pure zinc, such as anode, battery production, and coating materials, and for fasteners in sectors like automotive and electronics.

Highlights:

- The most effective machining parameters influencing surface roughness are the depth of cut (with a contribution of 21.79%) and feed rate (with a contribution of 16.27%), respectively; the cutting speed has a lesser impact.
- The lowest (best) surface roughness value (1.025) was achieved with a low feed rate (0.1mm/rev), low depth of cut (0.2mm), and low cutting speed (20m/min).
- At a constant depth of cut, both increasing the feed rate and increasing the cutting speed significantly increase the surface roughness (e.g., increasing the cutting speed from 20m/min to 40m/min resulted in a 110.94% increase in surface roughness).

3. MATERIAL AND METHOD

The effective machining length of pure zinc used in the experiments was preferred as 150mm and a diameter of 20mm. A TiAlNi-coated carbide tool was used due to its high temperature and wear resistance. A total of eight experiments were conducted using two different values for feed rate, depth of cut, and cutting speed. The roughness values of the resulting surfaces were also taken into account. In this study, a TiAlNi-coated carbide tool from the Korloy brand was selected, offering easy machining of difficult-to-machine materials and a geometry and high-quality performance compatible with various material classes and processing parameters. The TiAlNi coating aimed to prevent chip adhesion. Low cutting forces prevented the formation of a rough surface during the machining of pure zinc, which is soft and low strength. Korloy's tool inserts, thanks to their high machining performance and interaction with cooling-controlled tool systems, prevented the low-melting-point zinc surface from melting, creating an efficient working environment. The machining parameters of the pure zinc material are shown in Table 1. The experimental setup is given in Figure 2.

Table 1. Machining Parameters

Parameters	Levels
Feed Rate (mm/rev)	0.1 - 0.2
Depth of Cut (mm)	0.2 - 0.4
Cutting Speed (m/min)	20 - 40

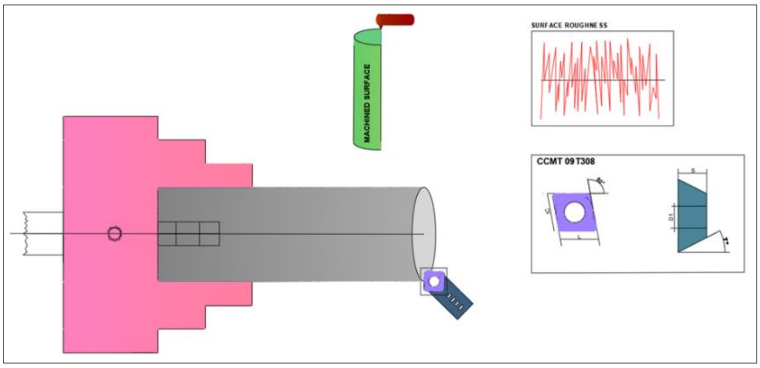

Figure 2. Experimental setup

4. STATISTICAL ANALYSES

Statistical analysis is the scientific evaluation, processing and conclusion of the interaction between the parameters of cutting speed, feed rate, cutting depth, and surface roughness obtained in experiments. [17, 18, and 19]. In this study, it is to reach the results of the interactions between these parameters and to what extent the machinability of pure zinc is affected by the ANOVA analysis method. [20, 22, and 23]. As a result of the analysis, it was aimed to determine the characteristics of pure zinc under different conditions, the optimum processing parameters and to find the optimum conditions to reduce production costs and time.

5. RESULTS

Surface roughness is one of the most important parameters used as an output parameter in machinability experiments, which is achieved by matching the input parameters of the material, tool, and machinability. Surface roughness is an indicator of physical conditions such as friction and tool wear that occur during processing, directly reflecting the overall quality of the part. Because the surface quality affects the cost and time of production, finding the optimum surface quality is crucial for production efficiency. The experimental result of surface roughness is shown in Figure 1. The optimum value was reached in the fifth experiment with the parameters of feed rate 0.1mm/rev, cutting depth 0.2mm, cutting speed 20 m/min, and an average surface roughness value of 1.025.

The average S/N plot for surface roughness is shown in Figure 4, the ANOVA results are shown in Table 2, and the S/N response results are shown in Table 3. When the results are examined, it is seen that the optimal level is achieved at low feed rate and cutting speed, and high depth of cut. The most effective parameters for achieving the optimum value are the depth of cut, which has the steepest slope, followed by feed rate and cutting speed. The second level of depth of cut is preferred for achieving the optimum result, while the first level of feed and cutting speed is preferred. Based on the ANOVA analysis, the most influential parameters were depth of cut, feed rate, and cutting speed, with contribution values of 21.79, 16.27, and 4.04, respectively, and these results were found to agree with the S/N graph analysis. In ANOVA analysis, a value of 0.05 is expressed as the significance level. A p value less than 0.05 indicates that the machinability input parameters are consistent with each other, but this does not mean that all small values are significant. A value that is too small (such as 0.01) increases the risk of overlooking a potential effect. The p values in our study show that feed and depth were less than 0.05, while cutting speed was greater than 0.05. Because the ANOVA analysis was not one-sided, this does not mean that cutting speed is insignificant; it indicates a slight trend but lacks sufficient statistical power. The R2 value of 91.32% represents good agreement between the input and output parameters. This ratio demonstrates that the experimental factors were successful in explaining the S/N ratio.

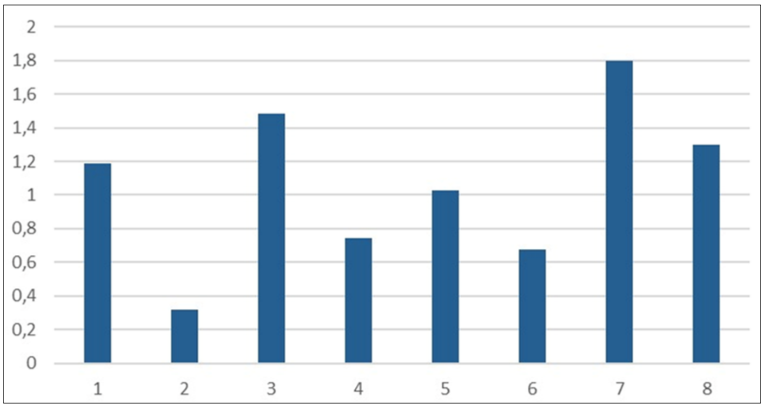

Figure 3. The variation of surface results

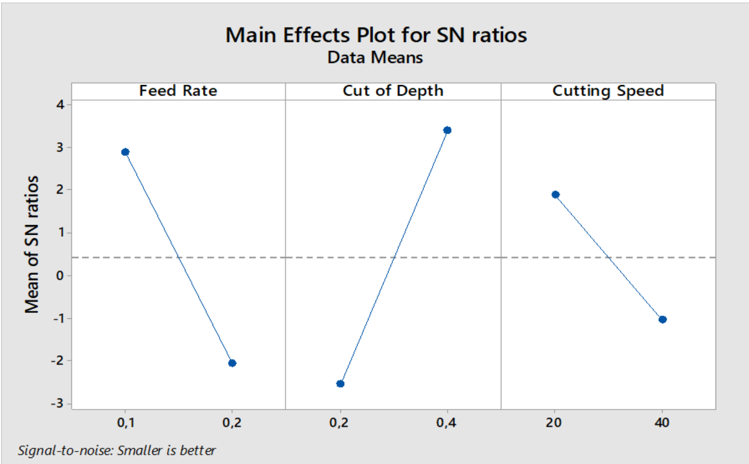

Figure 4. S/N graph for surface roughness

Table 2. ANOVA analysis for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	0.5618	0.5618	0.56180	16.27	0.016
Cut of Depth	1	0.7524	0.7524	0.75236	21.79	0.010
Cutting Speed	1	0.1396	0.1396	0.13957	4.04	0.115
Residual Error	4	0.1381	0.1381	0.03453		
Total	7	1.5918				
R^2:91.32%						

Table 3. S/N response for surface roughness

Level	Feed Rate	Cut of Depth	Cutting Speed
1	2.902	-2.557	1.881
2	-2.062	3.397	-1.040
Delta	4.964	5.954	2.921
Rank	2	1	3

In this study, the surface roughness achieved during the turning of pure zinc with a TiAlNi-coated carbide cutting tool was experimentally investigated. The results obtained and the conclusions drawn from these results are given below.

- The highest surface roughness value was obtained in the seventh experiment, which had a surface roughness of 1.8 at a 0.2mm/rev feed rate, 0.2mm depth of cut, and 40m/min cutting speed.
- Increasing the depth of cut under constant feed and cutting speed resulted in a decrease in surface roughness.
- Increasing the feed rate while the depth of cut and cutting speed were constant also increased the roughness value.
- By fixing the feed at 0.1mm/rev, the depth of cut at 0.4mm, and increasing the cutting speed from 20m/min to 40m/min, a 110.94% increase in surface roughness occurred.
- The optimum value appeared at the lowest value of the S/N ratio in the ANOVA outputs.

CONFLICT OF INTEREST

The author(s) declare that they have no potential conflict of interest.

FINANCIAL DISCLOSURE

This research received no financial support.

DECLARATION OF ETHICAL STANDARDS

The authors of the article declare that the materials and methods used did not require ethics committee approval and/or regulatory approval.

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