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Original Article

Designing a special cutting tool for high performance machining of CuZn40Pb2 brass alloy

Süleyman ÇİÇEK[1,2*], Adem ALTUN[1], Nima ZOGHIPOUR[1,2], Yusuf KAYNAK[2]

[1]*Design Center, Torun Bakır Alaşımları Metal Sanayi ve Ticaret A.Ş., GOSB, Kocaeli, Turkey*
[2]*Department of Mechanical Engineering, Marmara University, İstanbul, Turkey*

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ABSTRACT

In order to be competitive in manufacturing industries, it is essential to create high performance machining processes in manufacturing plant. One of the effective ways to improve the performance of machining processes is cutting tools. Although there are various standard cutting tools, it is also possible to design a special tool to have high performance cutting by eliminating the number of steps. This study focuses on designing a new cutting tools to have high performance machining process of one of the commonly known brass alloys, CuZN40Pb2 in mass production. In this study, two teeth form brazed carbide boring tools with different geometries in terms of radial rake angle and cutting-edge radius have been utilized in order to evaluate the machining performance during boring operation of CuZn40Pb2. Edge radius of brazed carbide cutting tools varied to enhance performance of cutting tool and resulting cutting forces and surface quality of machined parts are examined carefully. It illustrated that this designed tool provides high performance cutting by controlling some design parameters including edge radius and rake angle.

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INTRODUCTION

Copper and its alloys have dominant properties including high strength, hardness, ductility, etc. among which brass (Cu–Zn alloy) and its different types are widely used in electronics, automotive and sterile industry due to their higher plasticity, strength, hardness, and corrosion and tarnish resistance and antibacterial properties [1, 2]. Dealing with the manufacture of fittings and valves, these components are usually shaped as a semi-finished product by means of rolling or extruding a compact or hollow bar, followed by stamping, cold/hot forging or machining operations [1]. Pb is one of the fundamental alloying elements which added to metal compositions for the purpose of enhancing material machinability. This element does not dissolve in brass and its small particles disperse through the microstructure [2]. Consequently, formation of small brittle chips and improvement in the surface quality as well as decrease in the cutting forces and power consumption is accomplished thanks to the addition of Pb to the material composition [3]. Moreover, addition of S, Te [4], Ti [5] or graphite [6] can lead to augmentation of the machinability of brass alloys.

*Corresponding author.
*E-mail address: suleyman.cicek@torunmetal.com

Different geometric parameters such as radial rake, helix, primary and secondary clearance angles, etc. affect the machining performance. The values and distribution of cutting force components and the vibration acceleration amplitude is influences by the helix angle. Large helix angles of the cutting edge, appropriate tool-mounting systems are required to provide sufficient clamping force to prevent the tool from slipping out due to the high axial component of the cutting force. It should be also remembered not to exceed the permissible axial force in the spindle of the machine tool [7]. Rake angles come in two assortments, positive and negative. In the event that the main edge of the cutting tools is in front of the opposite, the angle is, by definition, negative. In actuality, if the main edge of the cutting tools is behind the opposite, the angle is, by definition, positive. At the point when a negative rake angle instrument is utilized, the material is cut by applying lower pressure which makes a pressure wave in front of the cutting tools. It requires a great deal of strain to keep the cutting tools in touch with the surface being cut. At the point when a positive rake angle is utilized, then again, the material is cut by isolating one atom of material from the work piece and making a chip that twists from the edge of the cutting tools. This cuts so promptly that we should put forth an attempt to hold the cutting tools back from delving into the workpiece. Contrasted with the negative rake angle, this is an extremely productive method of cutting [8]. Furthermore, the removed material and chip breakage is affected by clearance angle.

Tool life characteristics of brazed carbide cutting tool machined against mild steel and optimization of machining parameters based on Taguchi design of experiments upon three factors including spindle speed, feed rate and depth of cut were examined by Dasgupta et al. [9]. Vaxevanidis et al. [10] investigated the machinability characteristics of a CuZn39Pb3 Brass alloy by evaluation of the cutting force, arithmetic surface roughness Ra and maximum height of profile Rt during longitudinally turning process considering the effects of rotational speed; feed rate and depth of cut. Klocke et al. [11] investigated the influence of tool coating and material on the machinability of low-leaded brass alloys (Pb<0.2%) to solve tool wear during external turning of CuZn21Si3P due to the hard silicon-rich κ-phase. Carbide tools with various coatings as well as polycrystalline diamond (PCD) tools were applied. According to their results, PCD showed higher performance than uncoated and coated carbide tools due to its high abrasive wear resistance and low adhesion tendency. Zoghipour et al. [12] used artificial neural networks modelling, and genetic algorithm-based optimization methods in order to predict and optimize the drilling process of low-lead brass alloys with different copper contents for minimization of the cutting forces, surface roughness and dimensional accuracy error using form drills. In another work [13], they studied the effects of cutting tool geometries and cutting parameters on surface integrity characteristics including surface roughness, dimensional accuracy, microhardness and microstructure of machined parts. Wyen et al. [14] conducted orthogonal turning tests on Ti–6Al–4V with different cutting-edge radii and changing cutting speeds and feeds and studied the machining forces. Vipindas et al. [15] studied the effect of cutting-edge radius on micro end milling in terms of force analysis, surface roughness, and chip formation for micro end milling of the Ti-6Al-4V titanium. Abainia et al. [16] optimized proposed cutting tool geometry by experimentally studying the effects of the tool back rake angle, and the cutting edge and inclination angles on the cutting forces, tool vibrations, and machined surface roughness for turning operations.

Drag finishing also called stream or racetrack finishing is an operation which includes dragging parts through a bed of free abrasive media mixed with an abrasive or polishing compound. In this operation, each workpiece/tool is individually clamped into the machine and subsequently dragged through grinding or polishing media. The abrasive compound adds really cutting capacity to eliminate substantial blaze or surface stock, adjusts edges and eliminates burrs. This operation is an economical surface finishing technology. Thus, it has a broad application area in industry in the last six decades.

Most of the researchers have dealt with the machinability of brass alloys using standard cutting tools within the scope of academic works. However, due to the high machinability property of brass alloys compared to the other metal types, form carbide and brazed cutting tools play the excelling role in terms of rapid, accurate and high-performance production for industrial manufacturers. In this study, two teeth form brazed carbide boring tools with different geometries including radial rake angle and cutting-edge radius have been utilized in order to evaluate the machining performance during boring operation of CuZn40Pb2. Current work includes detailed examination of cutting forces and machined surface characterizations in order to achieve a comprehensive understanding on influences of the cutting tool geometry such as radial rake angle and cutting-edge radius on machining process responses.

MATERIAL AND METHODS

In this experimental study, 110×90×30 mm of CuZn-40Pb2 (CW617N) bulks were set as the workpiece material. The chemical composition of the work material is presented in Table 1. Figure 1 depicts the microstructure of CuZN-40Pb2 work material. It includes both α and β-phase crystals. Furthermore, Lead element particles are dispersed in longitudinal and transverse directions.

Figure 2 demonstrates the geometrical specifications of the utilized cutting tools. In order to achieve a rapid, accurate and high-performance machining process, two teeth

Table 1. Chemical composition of the studied brass alloy [17]

Composition	Cu	Zn	Pb	Sn	Fe	Ni	Al	Others
CuZn40Pb2 (CW617N)	59.0	Rem.	2.5	0.3	0.3	0.3	0.05	0.2
Technical specifications	Structure		Elasticity modulus (GPa)		Density (g/cm³)		Machinability	
	α, β		96		8.43		%95	

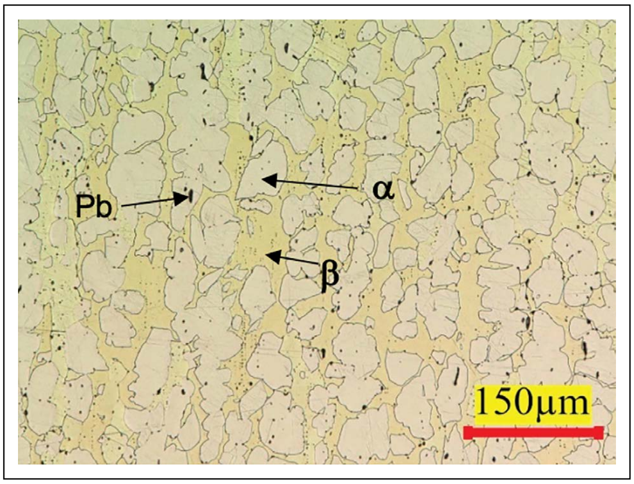

Figure 1. Microstructure of the work material.

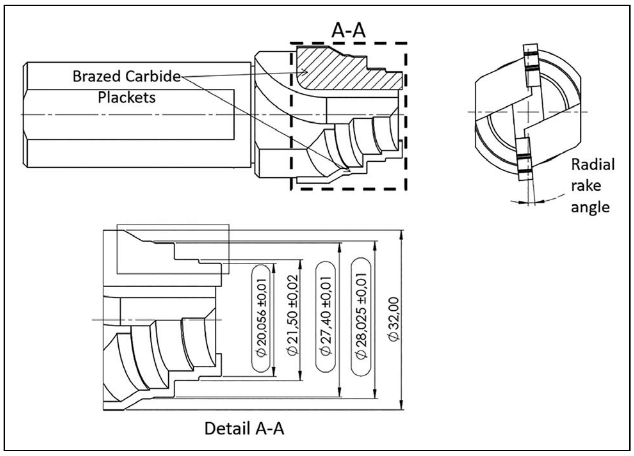

Figure 2. Technical specification of the designed and fabricated cutting tool.

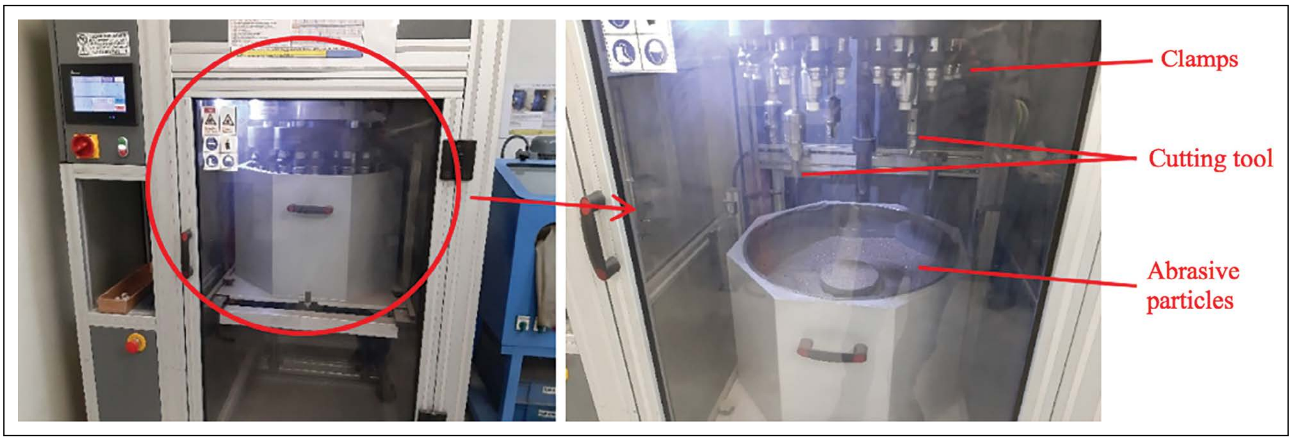

Figure 3. Drag finishing machine used in this study.

form brazed carbide boring tools with 0°, 5°, 10° and 15° primary and secondary clearance angles as of radial rake, 0° of helix and 9° and 21° of primary and secondary angles as the geometrical properties of the cutting tools were designed and manufactured. The utilized TINKAP 2016 drag finishing machine is given in Figure 3. Then, the tools were subjected to 4, 8, 20 and 40 minutes of drag finishing operation including right and left rotational movements with a table and head speed of 25 and 120 rpm. Figure 4 shows the edge radius obtained from various duration of the drag finish operation. The cutting-edge radius of the tools and surface topography were measured after every drag finishing operation using Keyence digital optical microscope. The machining tests were performed on Fanuc Robodrill α-D21LiB5 CNC machine under flood coolant at constant feed and cutting speed of 0.1 mm/rev and 100 m/min, respectively. The machining tests were carried out on pre-drilled holes of Ø17 mm, 17 mm in diameter and depth, respectively. The cutting forces measured using Kistler dynamometer type 9129AA at a sampling rate of 100 Hz for 10 seconds and the average of the thrust cutting forces (*Fz*) during measurement have been reported in this study. Surface roughness values was measured using Contracer CV-2100M4 measuring machine and the average of 5 measurements is reported. As surface roughness, Arithmetic mean surface roughness (*Ra*) and the average maximum peak to valley of five consecutive sampling lengths within the measuring length (*Rz*) are used and presented in this paper. Figure 5 shows the experimental test setup.

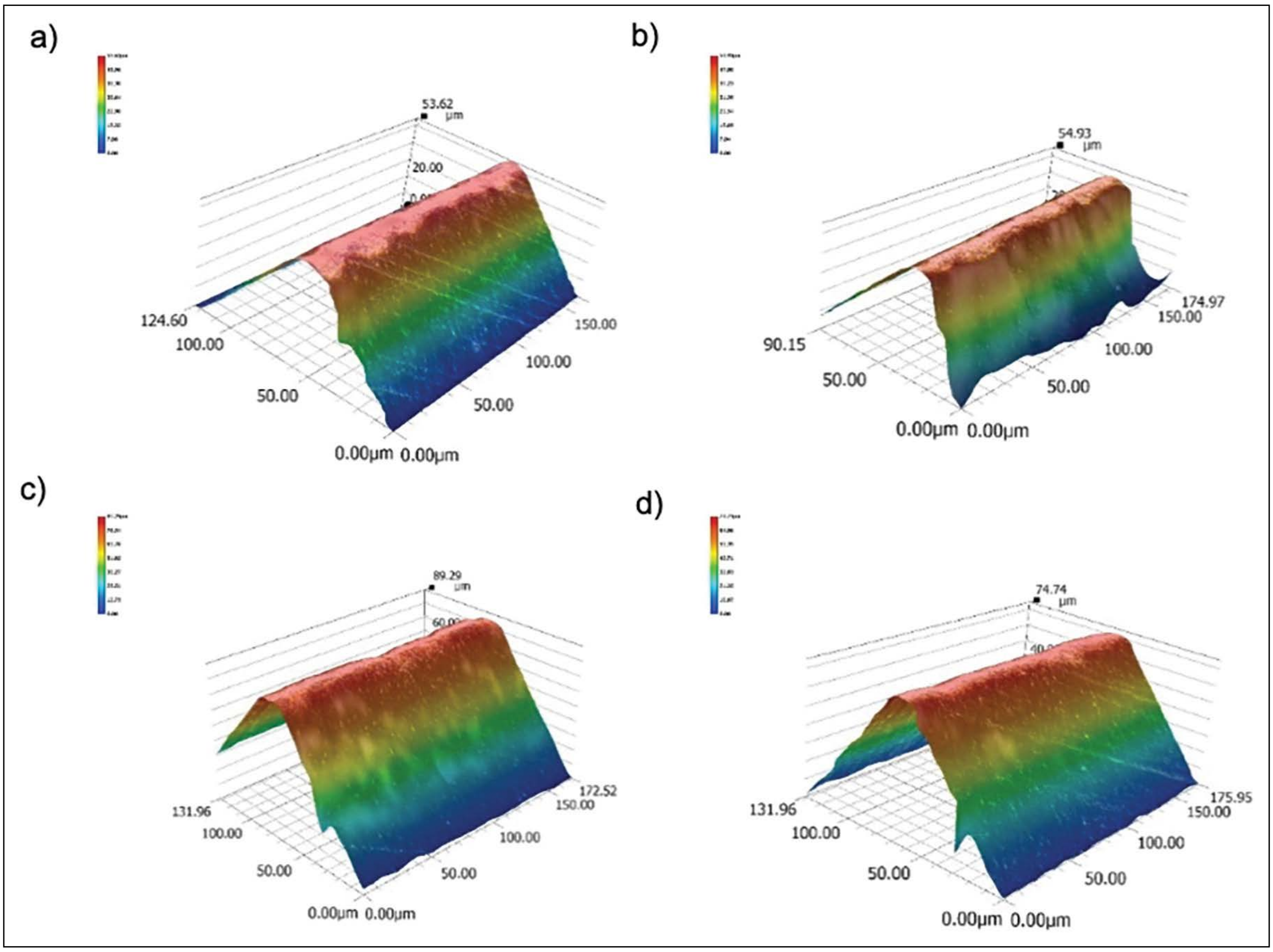

Figure 4. Images of the cutting-edge radius of the tool having 5° of radial rake cutting tool after drag finishing operation; **(a)** 4 min. **(b)** 8 min. **(c)** 20 min. **(d)** 40 min.

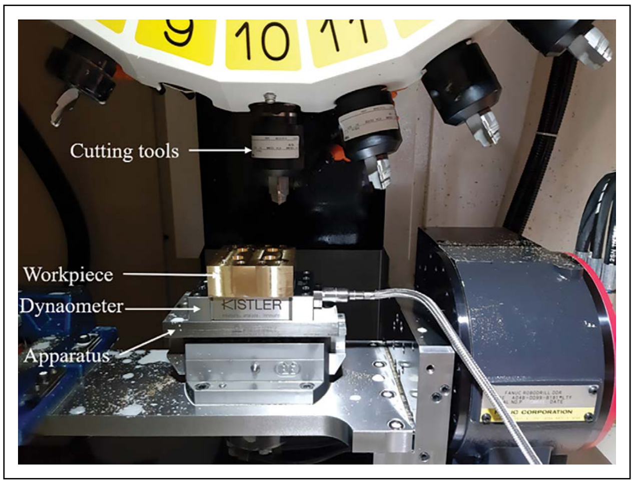

Figure 5. Experimental test setup.

RESULTS AND DISCUSSION

Evaluation of the Edge Radius of the Cutting Tools

The cutting-edge radius of the tools has been measured after drag finishing. Figure 6 shows the selected zone for cutting-edge evaluation. The comparison of the measured values has been demonstrated in Figure 7 for the specified zone. Maximum cutting-edge radius was measured as approximately 21 µm on the tool having 10° of radial rake angle subjected to 40 minutes of drag finishing. However, the lowest one was measured as approximately 5 µm at 5° tool with 4 minutes of drag finishing. The edge-radius of the grinded tool before drag finishing was measured as equal to 3.8 µm. As it is seen, the cutting-edge radius has been intensified with the increase in the drag finishing operation duration. This is due to the used abrasive property of the utilized mixture in the process resulting in deburring and edge-breaking of the sharp edges. With the increase in the radial rake angle, the cutting-edge has variated which might be due to the angle between the contact of the rake face of the cutting tool and abrasive particles.

Cutting Forces

As two main parameters are considered for designing cutting tools that are rake angle and edge radius, the effect of these two parameters on force component is discussed in this section. Figure 8a presents the force variation of designed cutting tools with various duration of drag finish

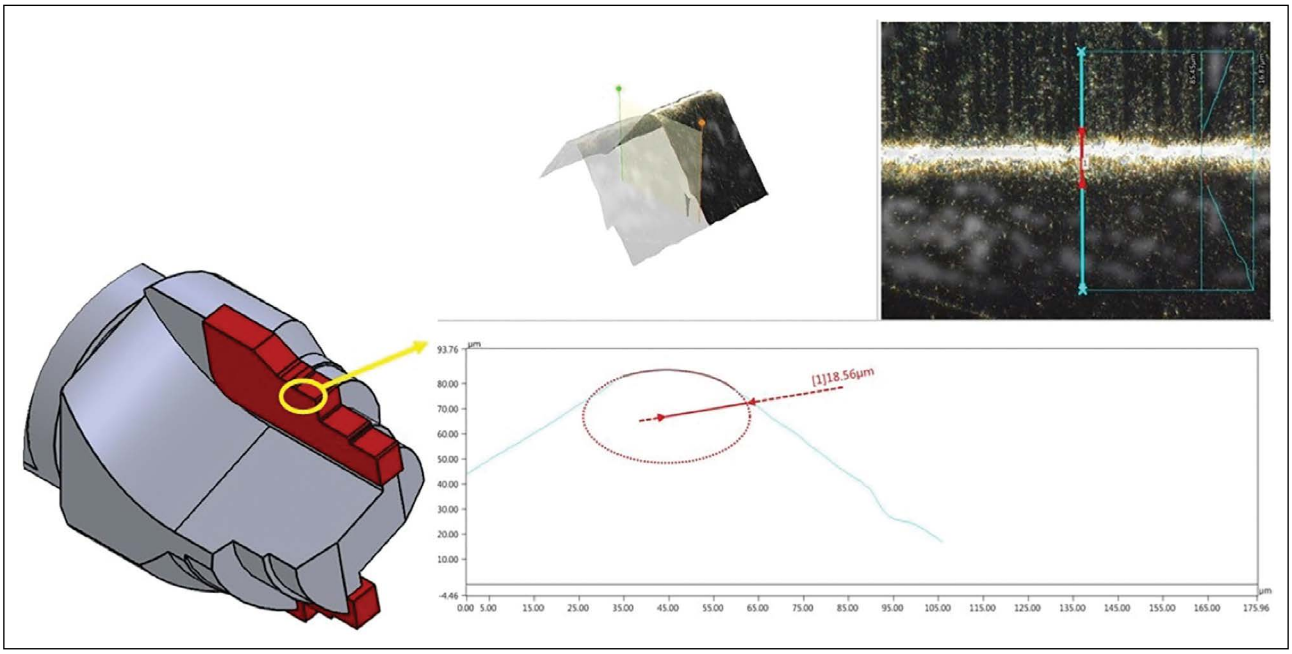

Figure 6. Measured edge radius of cutting tools with 15° radial rake angle after 20 min. of drag finishing.

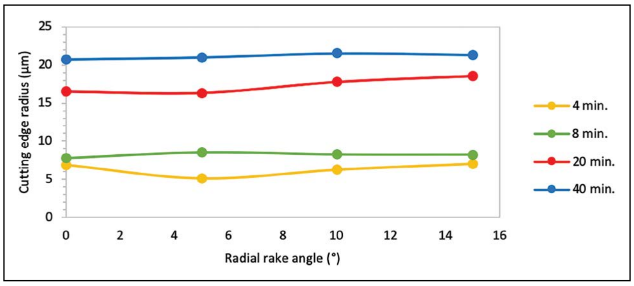

Figure 7. Measured edge radius of cutting tools with 15° radial rake angle after 20 min. of drag finishing.

and constant rake angle as a function of cutting time. It is obvious that increased drag finish time and hence increased edge radius results in increased force during machining process. The larger the edge radius, the higher the forces are generated during cutting process. This result is consistent with the available literature on machining various engineering materials due to the increase in the contact area between cutting tool and workpiece. Figure 8b depicts the role of rake angle along with edge radius on the force variation during machining process. Overall trend illustrates that increased rake angle leads to reduce cutting forces. This results also show good agreement with the literature. Indeed, this study confirms that both parameters play major role on controlling force in machining process. Considering the material removal rate that is much higher with this special cutting tools, it is important to reduce cutting force to have controllable machining process in machining brass alloys in mass production. Thus, by preferring smaller edge radius and larger rake angle, it is possible to substantially reduce the power requirement for machining this material.

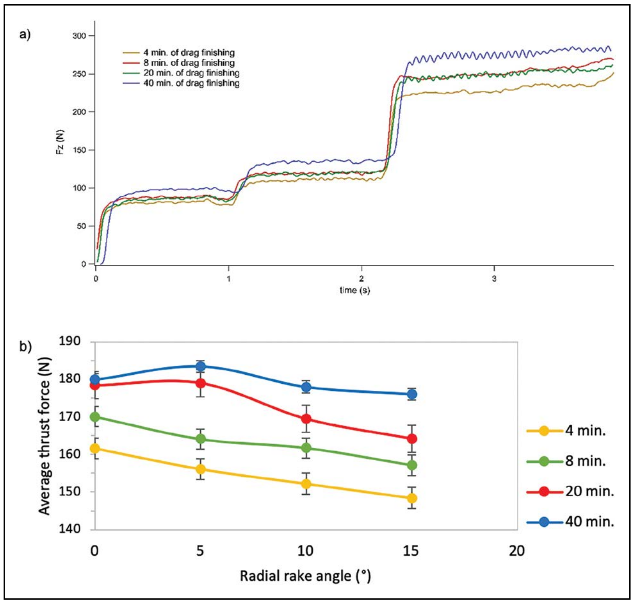

Figure 8. Measured cutting forces; **(a)** cutting forces of 5° of radial rake angle, **(b)** average cutting forces for all the used tools.

Surface Quality

The surface quality of the machined holes is evaluated in terms of surface roughness values of *Ra* and *Rz* as shown in Figure 9. The minimum measured surface roughness values are achieved as *Ra*=0.32 µm and *Rz*=2.92 µm with the cutting tool having 15° of radial rake angle after being subjected to 40 minutes of drag finishing. However, the maximum obtained values are *Ra*=1.80 µm and *Rz*=8.42 µm using the cutting tool having 15° of radial rake angle after being subjected to 4 minutes of drag finishing. The surface

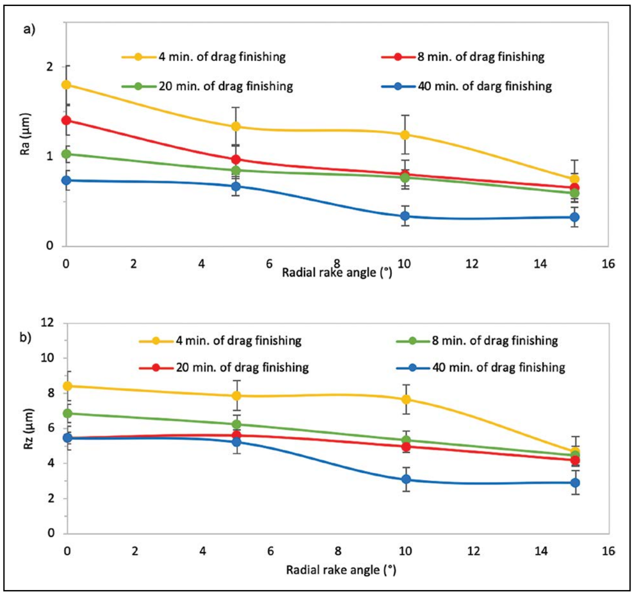

Figure 9. Measured surface roughness values of the specimens; **(a)** *Ra*, **(b)** *Rz*.

roughness of the machined parts decreases with the increase in the radial rake angle and drag finish duration. The chip thickness is at its maximum value which is a function of the involve angle of the cutting tool with the workpiece in drilling operations, when deploying tools with larger tool edge-radius. This specification of the tool helps the cutting process to ploughing rather than shearing [18] which results in smoother surface roughness. Figure 10 shows the topography of the machined surfaces with carbide brazed cutting tools. Feed marks are obvious on all the surfaces. However, some small swells are seen on the surface of the specimen machined by the tool which has been subject to lower drag finishing duration. This can be attributed to the sharpness of the cutting edge of the tool.

CONCLUSION

This paper presents the results of an experimental study on the influences of the radial rake angle and cutting edge-radius on the cutting forces, and surface quality

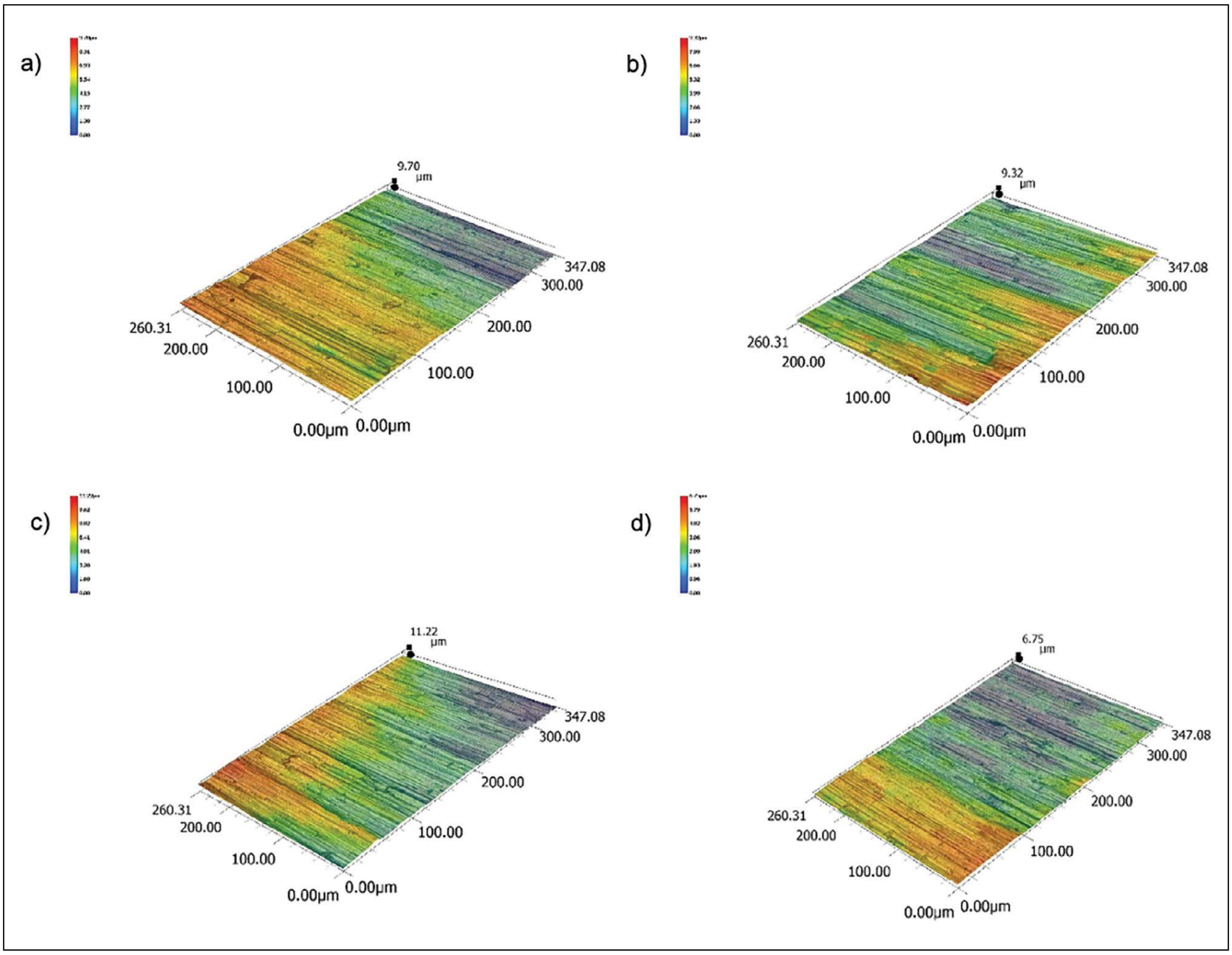

Figure 10. Topography of the machined surfaces with 5° of radial rake cutting tool after drag finishing operation; **(a)** 4 min. **(b)** 8 min. **(c)** 20 min. **(d)** 40 min.

in CuZn40Pb2 brass with special form carbide brazed tool and the following conclusions are obtained.

The advantage of using of special cutting tools to the standard ones can be summarized as reduction in the number of operations and thus reducing cycle time in production process. Subsequently, the machining duration in order to obtain the desired geometry has been decreased due to the elimination of the frequent cutting processes with numerous tools and unwanted tool change movements which is unavoidable when machining with standard cutting tools.

The cutting edge-radius of the cutting tools intensifies with the increase in the drag finishing operation duration.

The radial rake angle of the cutting tool has a small effect on the cutting-edge radius.

Increasing the cutting edge-radius results in better surface quality on the machined surface.

The cutting forces increase with the increase in the cutting-edge radius due to the contact area between tool and workpiece.

Overall, this study provides very strong evidence that with chosen cutting tool geometry and drag finishing operation conditions, it is possible to reduce surface quality of the machined part. For further studies, it is planned to investigate the drag finishing operation conditions including rotational speed and abrasive particles composition.

Data Availability Statement

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

Author's Contributions

Süleyman Çiçek: Corresponding author, cutting tool design, reviewing the paper.

Adem Altun: Cutting tool design, reviewing the paper.

Nima Zoghipour: Design and performing of the experiments, data collection and preparation of the paper.

Yusuf Kaynak: Guiding the experimental work and review and editing the paper.

Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics

There are no ethical issues with the publication of this manuscript.

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