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Investigation of the Machinability and Properties of CW509L Brass Alloy

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Abstract: In this article, the machinability properties of CW509L lead-free brass alloy in machining were examined. The effects of 3 different feed rates and 3 different cutting speeds on chip morphology, dimensional accuracy of the workpiece and built-up edge parameters were investigated. The machinability of CW509L material was examined by considering the drilling process. The full factorial experimental design method was used in the experimental methodology. The impacts of the variants in the experimental work on the results obtained were numerically demonstrated by using ANOVA method. Thus, the effect of cutting parameters selected in a wide range on each output obtained has been systematically revealed. There is no systematic and comprehensive study in the previous research on the drilling process of CW509L brass alloy. With this study, solutions were found to the issues that may be coincided during machining with optimized machining parameters. Additionally, without the need to use additional elements in high weight ratios, The machinability of CW509L lead-free brass was examined using 3 different parameters.

Keywords: CW509L Lead Free Brass Material, Chip Morphology, Dimensional Accuracy, Built Up Edge, ANOVA.

CW509L Pirinç Alaşiminin İşlenebilirliğinin ve Özelliklerinin İncelenmesi

Özet: Bu makalede CW509L kurşunsuz pirinç alaşımının talaşlı imalatta işlenebilirlik özellikleri incelenmiştir. 3 farklı ilerleme ve 3 farklı kesme hızının talaş morfolojisi, iş parçasının boyutsal doğruluğu ve kesici kenar yığma ağız oluşumu parametreleri üzerindeki etkileri incelenmiştir. CW509L malzemesinin işlenebilirliği delme işlemi dikkate alınarak incelenmiştir. Deneysel metodolojide tam faktöriyel deneysel tasarım yöntemi kullanılmıştır. Deneysel çalışmadaki değişkenlerin elde edilen sonuçlara etkisi ANOVA yöntemi kullanılarak sayısal olarak ortaya konulmuştur. Böylece geniş bir aralıkta seçilen kesme parametrelerinin elde edilen her bir çıktı üzerindeki etkisi sistematik olarak ortaya konulmuştur. CW509L pirinç alaşımının delme işlemine ilişkin daha önce yapılan araştırmalarda sistematik ve kapsamlı bir çalışma bulunmamaktadır. Bu çalışma ile optimize edilmiş işleme parametreleri ile işleme sırasında karşılaşılabilecek sorunlara çözüm bulunmuş olacaktır. Ayrıca yüksek oranlarda ilave element kullanımına gerek duyulmadan CW509L kurşunsuz pirincin işlenebilirliği 3 farklı parametre kullanılarak incelenmiştir.

Anahtar Kelimeler: CW509L Kurşunsuz Pirinç Malzeme, Talaş Morfolojisi, Boyutsal Doğruluk, Kesici Kenar Ağız Birikintisi, ANOVA.

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1. INTRODUCTION

Brass materials are alloys consisting of high proportions of copper and zinc elements. Brass materials are widely used for many mechanical and industrial applications because of extraordinary properties like, ductility, high strength, wear and corrosion resistance, hardness, high thermal and electrical conductivity, recyclability, anti-bacterial, hygienic, acceptable processability and formability. Brass alloys are used in many areas of industry like healthcare, automotive, irrigation, pumping and plumbing, especially electrical and electronics [1]. CuZn40Pb2, one of the brass alloy types, is a copper-zinc alloy implicating approximately 60%

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1.5-2.5% lead, 35% and above zinc, and less than 1% tin, iron, nickel and aluminum in total [2]. Lead in the alloy is of critical importance due to its positive contributions to the production of the material, such as excellent chip breaking, high cutting parameters and low tool wear. Because the solubility of lead in brass alloy is quite low. Therefore, lead decomposes into spherical precipitates within the entire microstructure. Thus, the shear strength is significantly reduced, this leads to very good chip breaking and therefore machinability of the brass. Also, the low melting point of lead is 327.5 ^{0}C, which reduces friction by allowing lead to form a thin semifluid film during cutting, thus reducing cutting forces and tool wear [3]. However, since lead is in the heavy metal group that poses a danger to humans and nature, the lead rate in plumbing materials produced from brass alloys, particularly in drinking water, mustn't be more than 0.2% [4]. For this reason, new materials are constantly produced lead-free. One of these new materials is CW509L. But many problems are encountered regarding the processability of lead-free brass. One of the biggest problems in processing lead-free brass is that the chips do not break, especially during the drilling process. This situation also reveals new problems. Fundamental research has been delivered about the machinability of lead-free brass in recent years. The effects of microstructure and silicon on cutting forces, chip formation, tool wear and tool temperatures were analyzed. Based on this, various approaches have been investigated to improve machinability to ensure high performance cutting operations [3]. As an alternative to lead-free brass, a new lead-free brass that had high strength and machinable properties, was developed for powder metallurgy by adding titanium to bismuth-containing brass and its properties were examined [4]. The machinability of lead-free brass in high-speed micro turning was investigated. In the study, surface topography, burr formation, chip formation and tool wear were examined. Additionally, a statistical model was improved to appreciate the contributions of process parameters regarding surface roughness, crown height, and average burr height [5]. Using the α–β duplex phase brass (CuZn40), (CuZn40CrFeSnBi) brass that has 0.6% tin, 0.3% chromium, 0.2% iron and 1%-3% bismuth content by mass was constituted in casting process, beside mechanical properties, microstructure and processability were examined [6]. The machinability properties of CuZn39Pb3 leaded brass and CuZn21Si3P lead-free brass were compared in machining. It has been viewed that the tool wear of CuZn21Si3P is expressively upper than of CuZn39Pb3 brass during machining, under similar conditions [7]. Heat treatments were implemented in lead-free brass alloys CuZn38As (CW511L), CuZn42 (CW510L) and CuZn36 (C27450) for the purpose of changing the microstructure and raising the phase essence for preferable chip crackability and developed machinability [8]. There is no systematic and comprehensive study in the previous research on the drilling process of CW509L brass alloy. In this article, the machinability properties of CW509L lead-free brass alloy in machining were examined. The effects of 3 different feed rates and 3 different cutting speeds parameters on chip morphology, dimensional accuracy of the workpiece and built-up edge parameters were studied. The machinability of CW509L material was examined by considering the drilling process in this article. The full factorial experimental design method was used in the experimental methodology. The impacts of the variants in the experimental work on the results obtained were numerically demonstrated by using the ANOVA method. With this study, solutions were found to the issues that may coincide during in machining with optimized machining parameters. Additionally, without the need to use additional elements in high weight ratios, the machinability of CW509L lead-free brass was examined using 3 different parameters. Brass drilling was carried out for the first time using CW509L lead-free brass alloy. It is aimed to expand the use of materials that are harmless to the environment and human health. Thus, the gap in the literature was eliminated and promising new studies will be directed.

2. MATERIALS and METHODOLOGY

2.1. Materials

In experimental studies, Ø47x110 dimensions, CW509L lead-free brass stick material was used. It was supplied by SARBAK company in Tekirdağ, TÜRKİYE. K10 quality tungsten carbide was used for cutting tool. For the surface hardness and microstructure image of the CW509L material, bakelite was taken using the Struers CitoPress-5 device. Keyense Optical Microscope was used for the microstructure image of CW509L material. Machinability properties were made on the FANUC Robodrill α-D21LIB machine. Tool wear was measured with a Keyense Optical Microscope. Dimensional accuracy measurements were made with DEA 3D CMM measuring device. The full factorial experimental design method was used in the experimental methodology. With this study the impacts of the variants in the experimental work on the results obtained were numerically demonstrated by using the ANOVA method. Chemical composition of CW509L brass alloy is given in Table 1 [9]. Technical properties of CW509L are given in Table 2 [9]. The hardness measurement results of CW509L are given in Table 3.

Table 1: Chemical composition of CW509L brass alloy

Brass alloy		Cu	Zn	Pb	Fe	Si	Al	Ni	Sn	Other Total
CW509L	Min%	59	Rem.	-	-	-	-	-	-	-
Max%		59	Rem.	0.2	0.2	-	0.05	0.3	0.2	0.2

Table 2: Technical properties of CW509L

Material	**CW509L**
Structure	α+β
Machinability	50%
Density	8.4 g/cm³
Electrical Conductivity	25 % IACS
Thermal Conductivity	122 W/(m·K)
Elasticity Module	105 GPa
Coefficient of Thermal Expansion	20.8 10-6 /K
Melting Point	880-910 °C
Hot Forming	650-750 °C
Soft Annealing	450-550 °C
Soft Annealing Time	1-3 hours
Stress Relieving	200-250 °C
Stress Relieving Time	1-3 hours

Table 3: Hardness measurement results of CW509L

Measurements	**Hardness (HB)**
1. measurement	106.4
2. measurement	103.8
3. measurement	106.9

2.2. Experimental Methodology

Whit this study, the effects of 3 different cutting speed and 3 different feed rate parameters on the chip morphology, built up edge and dimensional accuracy parameters were examined on the FANUC Robodrill α-D21LIB machine. Hole drilling work on CW509L material was carried out on 9 different samples with 9 different cutting tools. In the experimental work, 3 different feed rates and 3 different cutting speeds values were made by drilling holes on the sample pieces for 20 repetitions. As results of the experimental work, the results of these 3 cutting speeds and feeds on dimensional accuracy, chip morphology and built-up edge deposits on the workpiece were evaluated. The full factorial experimental design method was used in the experimental methodology [10]. The impacts of the variants in the experimental work on the results obtained were numerically demonstrated by using the ANOVA method. ANOVA (analysis of variance) is the utilization of a statistical method to assign the impact of singular factors. ANOVA can explain openly the effect of each factor on the operating events [11].

3. RESULTS and DISCUSSION

3.1. Dimensional Accuracy

In industry, obtaining products of the desired size and quality relies on lots of parameters like feed rate, cutting speed, bench and cutting tool. Soft brass materials may bend more easily during processing than hard brass, which may reduce the dimensional accuracy result. While soft alloys are easier to machine, hard and high-strength alloys may require grinding or heat treatment during processing to ensure optimal production conditions [12]. To minimize negative effects, obtain the best result, 3 different cutting speeds and 3 different feed rates values of CW509L lead-free brass material were determined and hole drilling operations were performed on the samples. 9 different experiments were carried out on 9 different tools and a total of 20 holes were drilled in each tool. Hole diameter dimensional accuracy measurement was made on a 3D CMM measuring device. Different feed rates and cutting speeds values are given in Table 4. The drill diameter and hole diameter values of the drilled sample are given in Table 5.

Table 4. Different feed rates and cutting speeds parameters.

Sample	Spindle Speed (rpm)	Feed (mm/rev)	Cutting Speed (m/rev)	Dimensional Accuracy
1	5000	200	80	5.157
2	5000	400	80	5.151
3	5000	600	80	5.170
4	7500	200	120	5.178
5	7500	400	120	5.153
6	7500	600	120	5.149
7	10000	200	160	5.168
8	10000	400	160	5.170
9	10000	600	160	5.172

Tablo 5: Drill diameter and hole diameter values.

Sample	Drill diameter (mm)	hole diameter of drilled sample (mm)	Deviation (mm)
1	5.142	5.157	0.015
2	5.142	5.151	0.009
3	5.152	5.17	0.018
4	5.148	5.178	0.03
5	5.146	5.153	0.007
6	5.146	5.149	0.003
7	5.156	5.168	0.012
8	5.146	5.17	0.024
9	5.15	5.172	0.022

When the dimensional accuracy results obtained as a result of the experiment were evaluated, according to the results given in table 5, all holes were larger than the drill diameter by a minimum of 9 microns and a maximum of 30 microns. In general, as a result of drilling operations in production, it is an acceptable result that holes up to 10 microns are larger than the drill diameter. But it was observed that some results deviated beyond the acceptable value. In experiments conducted at 160 m/min cutting speeds, it was observed that the deviation in hole diameters increased as the feed rate increased. As a result, the cutting speeds used in the experiment were 80-120-160m/min and the feed values affected the dimensional accuracy results in the range of 9 to 30 microns.

Variance analysis results for dimensional accuracy are given in Table 6. The graph showing the optimum values of the effect of feed and cutting speed parameters on dimensional accuracy is given in Figure 1.

Table 6: Analysis of Variance (ANOVA) for the dimensional accuracy

Sources	Degrees of Freedom	Sum of Squares (SS)	Variance	F-Value	P-Value
Feed	2	6.343	3.172	0.46	0.659
Cutting Speed	2	13.794	6.897	1.01	0.442
Error	4	27.319	6.83		
Total	8	47.456			

S = 7.2861   R-Sq = 32.22%   R-Sq(adj) = 0.00%

According to the variance analysis results given in Table 6, the R-Sq value of the analysis results is below 80% and is 32.22%, indicating that the analysis data cannot give a reliable result. The fact that the P value is higher than 0.05 means that both cutting and feed parameters are not very effective on dimensional accuracy.

In the optimization chart given in Figure 1, it was determined that the dimensional accuracy value was at the optimum level when the cutting speed was 88.4956 (m/min) and the feed rate was 200 (mm/min).

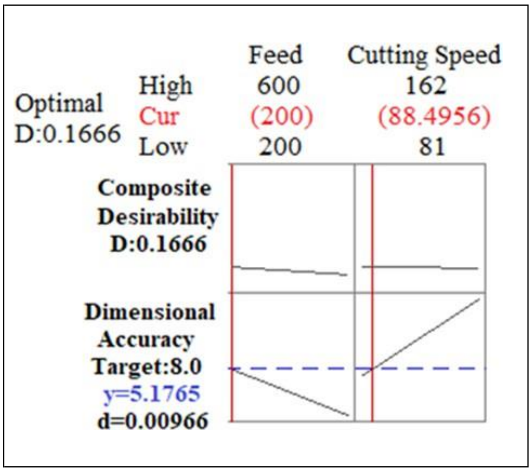

Figure 1: Optimization graphic.

3.2. Chip Morphology

Chip formation is one of the most momentous criteria in defining machinability properties. When machining brass material at low cutting speeds, chip accumulation is often observed at the edge of the cutting tool. With changing geometry, tool wear, poor surface quality and material damage may occur [13]. The most suitable chip type to process in chip morphology is short and small particle chips. Since long chips are difficult to control in machining, these chips are undesirable types of chips. Especially in mass production, long chips are wrapped around the tool holder like a vine branch, and it damages the ATC arm, mechanism during machine tool changes. One of the biggest difficulties in processing CW509L and similar lead-free materials is that these materials produce long chips. For this reason, chip morphology is considered important in this study. Cutting speed and feed rate parameters are very important to break the chips. CW509L material was processed on the FANUC Robodrill α-D21LİB machine. According to the feed and cutting speed test parameters results given in Table 4, the chips obtained as a result of 9 different experimental studies were collected and given in Figure 2.

According to the chip images given in Figure 2, it was viewed that samples number 2,3,4 and 6 produced long chips. It was revealed that when the feed rate was increased to 0.1 mm and above, the length of the chips became longer. Chip thicknesses of 0.1 mm and above are more durable and therefore more difficult to break. As a result, it has been revealed that the chips produced when the feed rate is lower than 0.08 mm are suitable for production, and these are the chips in images numbered 1,5,7,8,9.

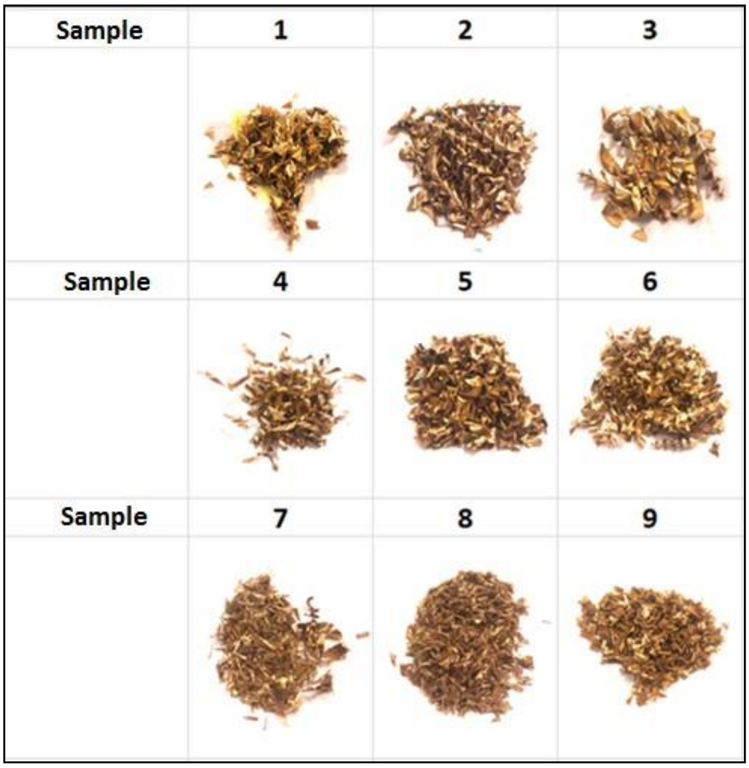

Figure 2. Chip formations of 9 samples

3.3. Built Up Edge

Built up edge formation appears as a conclusion of the fractional increase at the tool and chip interface, reaching a critical level, leading to full or partial adhesive contact. For this reason, the tool and workpiece are required to have sufficient chemical stability and surface properties that will prevent corrosion [14]. In general, brass materials tend to build up edge formation in cutting tools due to their high copper content. Keyense Optical Microscope was used for building edge formation. Cutting tool edge views of 8 tools are given in Figure 3. Owing to the breakage of sample number 7 during the studies, there is no image of this sample.

Chip adhesion was observed on all cutting tool edges. When the feed per revolution increases to 0.08 mm or more, the chips become long because they are thick. When the tip parts of the drills operating under these parameters were examined, maximum cutting tool edge formation was observed. In experiments with feed per revolution of 0.08 and below, the formation of cutting tool edges was observed less.

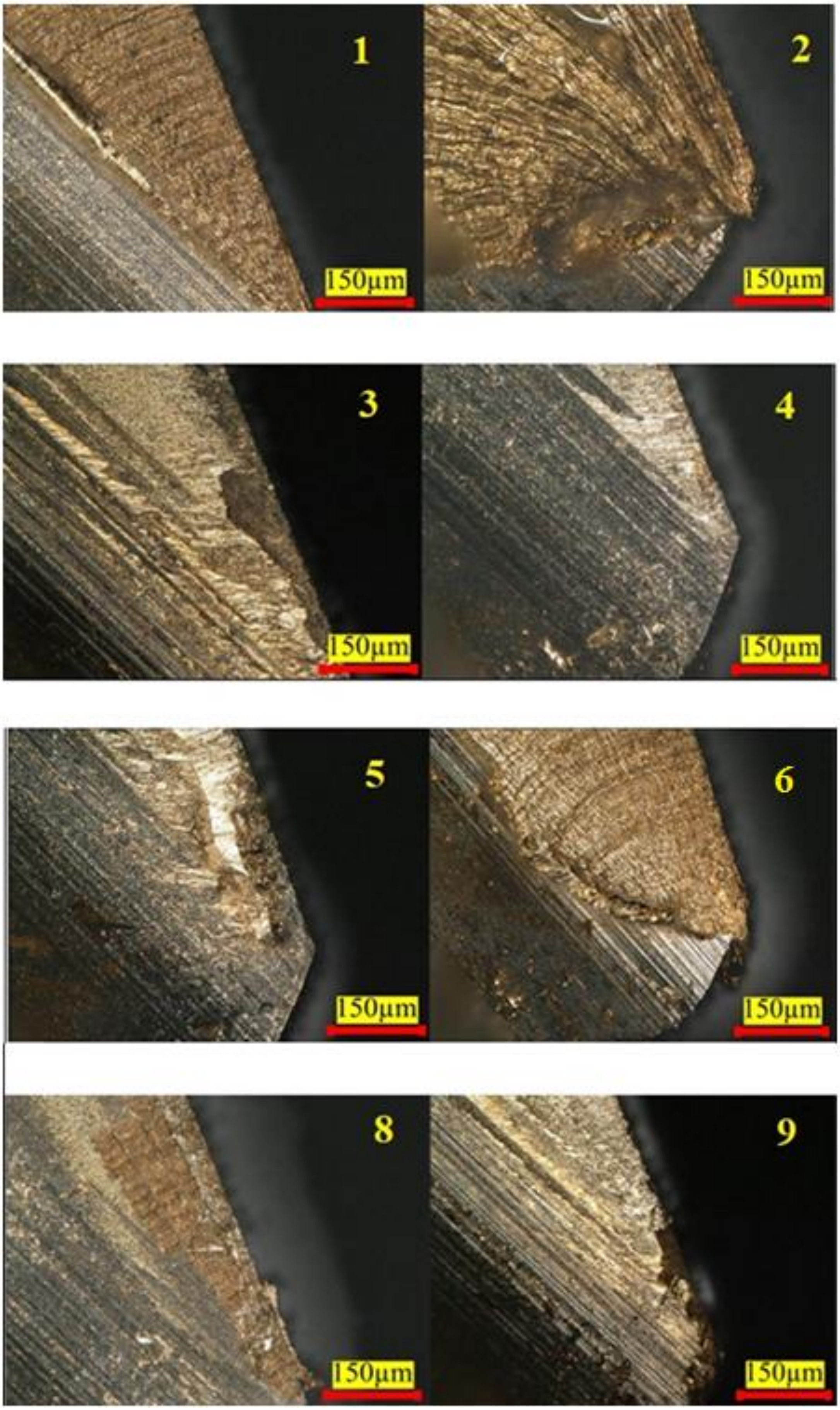

Figure 3. Surface images of 8 samples

4. CONCLUSIONS

In accord with the results of the experimental work, the most suitable parameters for dimensional accuracy were found to be **Cutting Speed of 88.4956 m/min** and **Feed Rate of 200 mm/min.** According to the chip images given in Figure 2, it was seen that the images of experiments 1,5,7,8 and 9 give the best results. It was observed that chips numbered 2, 3, 4 and 6 were undesirably long chips. Cutting tool edge views of 8 tools are shown in Figure 3**.** Chip adhesion was observed on all cutting tool edges. Especially in the images of experiments 2, 3 and 6 chip formation at the cutting tool edge was at the maximum level. With this study, CW509L lead-free brass was used first time solutions were found to the problems that may be coincided during machining with optimized machining parameters. Additionally, without the need to use additional elements in high weight ratios, The machinability of CW509L lead-free brass was examined using 3 different parameters. With this study, 3 different parameters were examined by using CW509L lead-free brass for the first time. A new method that was not available in literature was created with the ANOVA method. A new method has been created that can be very useful for the negative processes associated with the use of lead-free brass in industry.

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