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The Effects of Using Brass and Copper Wires on the Cutting Quality of Sleipner Cold Work Steel Cut by WEDM

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ABSTRACT: Wire electric discharge machining (WEDM) is widely used in dies, punches, aerospace and automotive sectors, since materials with high hardness, and temperature resistant, which are not possible to be cut with conventional machining methods, can be cut with high precision using the WEDM method. In this study, cutting speed (mm/min), material removal rate (mm^3/min), wire consume (g), machining time (sec), finish measure (mm) and surface roughness (µm) changes as a result of cutting high hardness cold work tool steel using copper and brass wire in WEDM method were investigated. In addition, worn wire and workpiece residues on the machined surfaces were detected by SEM (Scanning Electron Microscope) and EDX (Energy Dispersive X-Ray) analyzes as well as topography and composition were examined. In the case of using copper wire instead of the brass wire, wire consumption and processing time decreased by 23.30 % and 66.29 %, respectively, while MRR increased by 50 % because the copper wire electrode has higher electrical and thermal conductivity than brass wire electrode. In addition, the average dimensional deviation of the parts cut with copper wire decreased from 27 µm to 8 µm compared to the use of brass electrodes, and more precise measurements were obtained.

Keywords: WEDM, Stell, Wear, Surface Roughness, Material Removal Rate.

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WEDM ile Kesilen Sleipner Soğuk İş Çeliğinin Kesim Kalitesine Pirinç ve Bakır Tel Kullanımının Etkileri

ÖZET: Geleneksel işleme yöntemleriyle kesilmesi mümkün olmayan yüksek sertlik ve sıcaklığa dayanıklı malzemeler tel elektrik deşarjlı işleme (WEDM) yönteminde yüksek hassasiyetle kesilebildiğinden; bu yöntem kalıp, zımba, havacılık ve otomotiv sektörlerinde yaygın olarak kullanılmaktadır. Bu çalışmada, yüksek sertliğe sahip soğuk iş takım çeliğinin WEDM yönteminde bakır ve pirinç teller ile kesilmesi neticesinde elde edilen kesme hızı (mm/dak), talaş kaldırma oranı (mm^3/dak), tel tüketimi (g), işleme zamanı (sn), bitiş ölçüsü (mm), yüzey pürüzlüğü (µm) değişimi incelenmiştir. Ayrıca SEM (Taramalı Elektron Mikroskobu) ve EDX (Energy Dispersive X-Ray) analizleri ile işlenen yüzeylerde aşınmış tel ve iş parçası kalıntıları tespit edilerek topografya ve kompozisyon incelenmiştir. Pirinç tel yerine bakır tel kullanılması durumunda tel tüketimi ve işlem süresi sırasıyla % 23.30 ve % 66.29 azalırken, bakır tel elektrot pirinç tel elektrota göre daha yüksek elektriksel ve ısıl iletkenliğe sahip olduğundan talaş kaldırma oranı % 50 artmıştır. Ayrıca bakır tel ile kesilen parçaların ortalama ölçüsel sapması pirinç elektrot kullanımına göre 27 µm'den 8 µm'ye düşmüş ve daha yüksek ölçüsel hassasiyet elde edilmiştir.

Anahtar Kelimeler: WEDM, Çelik, Aşınma, Yüzey Pürüzlüğü, Talaş Kaldırma Oranı.

1. INTRODUCTION

Wire Electric Discharge Machining (WEDM) method is a non-conventional processing method in which conductive materials with high hardness are cut by thermoelectric method without mechanical contact, regardless of their hardness and shape (Magabe et al., 2019; Gaitonde et al., 2019). In this method, material erosion occurs as a result of sparking between the workpiece and the electrode material used, and then this debris is usually removed from the environment by spraying deionized water (Mukhopadhyay et al., 2019; Kumar et al., 2011). This method is widely used in dies, punches, aerospace and automotive sectors, since materials with high hardness and temperature resistant, which are not possible to be cut with conventional machining methods, can be cut with high precision using the WEDM method (Chaudhary et al., 2018; Ramaswamy et al., 2020; Lodhi and Agarwal., 2014; Alias et al., 2012). Uddeholm Sleipner material, which is a steel with high hardness, is used in the parts needed in automotive, civil and military aircraft, satellites and spacecraft areas as well as in the cutting, drilling and drawing molds used in these sectors. This steel is a chromium-molybdenum-vanadium alloy, general purpose cold work tool steel with high hardness and wear resistance (Pantazopoulos et al., 2006; Kirkhorn et al., 2012). It is very costly and difficult to cut such hard steels and alloys, which are increasingly used in industrial applications, with high dimensional accuracy and surface quality. For this reason, it has become imperative to determine the most accurate cutting methods and parameters and to obtain successful results by using these parameters. Ceritbinmez examined finish measure, surface roughness and hardness of the cut surfaces by cutting the cold work steel X153CrMoV12 material with different cutting passes and copper electrode in the WEDM method. The author emphasized that as the precision of the wire used in the WEDM method increases, the cutting quality increases, and a smoother surface can be obtained as the amount of rough stock allow left for finishing cutting decreases (Ceritbinmez, 2021). Biswas et al. analyzed the cutting of Al 7075 material with brass wire in the WEDM method. They used multi-objective genetic algorithm to optimize the WEDM process parameters such as pulse-on time, pulse-off time and wire tension for this alloy. As a result of experiments and analyzes, they recommended the use of pulse-on time (Ton = 0.2 μs), pulse-off time (Toff = 50 μs) and wire tension (Wt = 1.1 kg) parameters, respectively, for the best surface quality and machinability (Biswas et al., 2020). Patnaik et al. cut Ti-6Al-4V material using uncoated brass and zinc coated brass electrode wire with main/rough and finish/trim cutting strategy in WEDM method to analyse kerf width, material removal rate (MRR), phenomena of wire wear, and finally, surface integrity of the end product. They reported that the use of coated electrodes resulted in narrower kerf and higher MRR, respectively, compared to the use of uncoated electrodes. Also, Cu and Zn elements originating from weared wires were found on the machined surfaces. According to the results of the XRD analysis, Oxides of titanium, vanadium, and aluminum were detected on the WEDMed surface. They reported that oxides can form on the machined surfaces and that these oxides can increase the surface hardness (Patnaik et al.,2019). Sudhakara and Prasanthi used the Taguchi Method for the analysis of the surface roughness obtained as a result of cutting the VANADIS 4e (Powder metallurgical cold worked Tool steel) material with the WEDM method using coated brass wire of 0.25 diameter as electrode. As a result of their analysis, they suggested peak current (11-13 Amperes), wire tension (2-8 grams), spark gap set voltage (18-68 volts), water pressure (8-14 kg/cm^2), pulse on time (108-128 μsec), pulse off time (47-63 μsec) intervals for ideal surface roughness (Sudhakara and Prasanthi, 2014). Ramaswamy et al. analyzed the optimization of the process parameters necessary for the successful cutting of D3 die steel in the WEDM method using response surface methodology (RSM). They suggested 180 A current, pulse on time (Ton) 124 μs, pulse off time (Toff) 40 μs, 8 kg/cm^2 wire tension, 6 m/min wire feed and brass wire as optimal parameters to obtain minimum surface roughness (SR), wire consumption rate (WCR) and maximum material removal rate (MRR). They reported that the increase in current increased the MRR but negatively affected the SR. They determined that the wire consumption increased with the increase of wire feed and pulse interval, and that the increase of wire feed could cause wire breaks during machining (Ramaswamy et al., 2020). Ozkul et al. kept the pulse off time, voltage, pressure of fluid circulation, velocity of wire, wire tension and wire diameter parameters at constant values on the other hand used the pulse on time, feed rate, and the current value parameters as variables to drill the Uddeholm Sleipner cold-work tool steel material with WEDM. They reported that increasing the feed rate increases both roughness and deviations, while increasing current increases roughness but decreases deviations. In addition, they reached an average of 2,578 μm surface roughness values, with a minimum of 2,400 μm and a maximum of 3,021 μm in the cuts they made. Aldas et al. conducted a study to estimate the surface roughness with adaptive neuro-fuzzy inference system (ANFIS)-based approach as a result of the processing of Sleipner cold work tool steel in WEDM using feed rate, current, and pulse on time parameters as independent variables. Considering the average error rate, they reported that the Gaussian membership type at 5.53 % was better than the Bell-Shaped membership function at 13.23%.

There are many studies in the literature on the cutting of materials with different properties by WEDM method, but the absence of a similar study on the cutting of Sleipner steel with a hardness of 60-62 HRC using copper and brass electrodes makes this study unique and pioneering. In general, when the literature studies are examined, the processing of different materials with WEDM parameters and the effects of these parameters on the workpiece are reported. But the subjects needed in the industry; processing time, cost, dimensional accuracy and performance of cut quality.

In this study, Sleipner steel, which is increasingly used in the mold industry, is discussed also the material properties and WEDM cutting quality are studied in a way that has never been done before. In the light of this information, cutting speed (mm/min), material removal rate (mm^3/min), wire consume (g), machining time (sec), finish measure (mm), surface roughness (µm) changes as a result of cutting high hardness cold work tool steel using copper and brass wire in WEDM method were investigated. In addition, worn wire and workpiece residues on the machined surfaces were detected by SEM (Scanning Electron Microscope) and EDX (Energy Dispersive X-Ray) analyzes as well as topography and composition were examined. As a result, process performance and workpiece surface quality were analyzed when copper wire is used instead of brass wire. Although the use of copper wire provides advantages in metal removal rate and machining speed, it has been determined that the machined surfaces are rougher than the use of brass electrodes due to the high electrical and thermal conductivity of copper wire.

2. MATERIALS AND METHODS

2.1 Materials

In this study, cold work tool steel Uddeholm Sleipner, which is increasingly used in industry, was used as workpiece. Thanks to its chrome - molybdenum - vanadium alloy components, this steel has features such as high wear resistance and strength, high hardness and compatibility with heat treatment, and suitability for WEDM (Wire Electric Discharge Machining) and EDM (Electric Discharge Machining) machining. The technical specifications of this steel, which is supplied from Alseko Metal company as hardened billet with dimensions of 250 x 300 x 90 mm, are given in tables 1 and 2, respectively. The test sample sizes used in the experiments were 14.5 x 10 x 90 mm, and these samples were sliced using a WEDM bench from hardened billet material of 250 x 300 x 90 mm.

Table 1. Mechanical and physical properties of Sleipner

Hardness (HRC)	Heat conductivity (W/m•°C)	Specific heat capacity (J/kg•°C)	Modulus of elasticity (kN/mm²)	Thermal expansion coefficient	Density (g/cm³)
60-62	400-500	460	205	$12.7x10^{-6}$	7.73

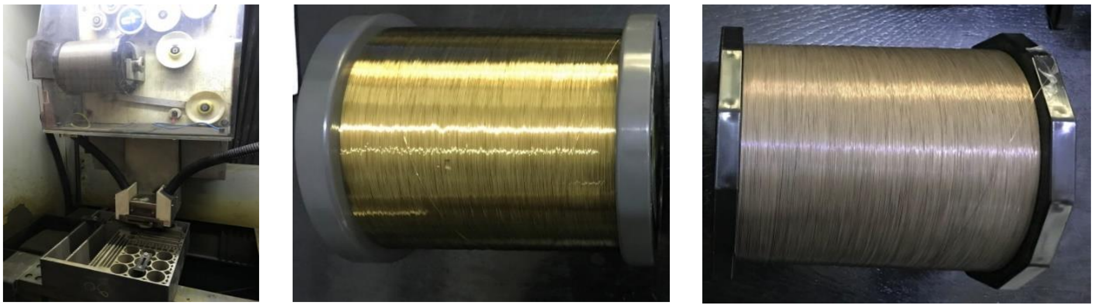
Table 2. Chemical Composition (% wt.) of Sleipner Stell

Carbon (C)	Silisium (Si)	Manganese (Mn)	Chrome (Cr)	Molybdenum (Mo)	Vanadium (V)	Iron (Fe)
0.9	0.9	0.5	7.8	2.5	0.5	Remnant

The Sleipner used in this study is a high alloy tool steel with a very specific profile. It is also a very good steel for any surface treatment. This combination means that Uddeholm Sleipner is a versatile and classic tool steel for medium duty cold work tools. It is widely used in thin die cutting, die cutting and forming, cold working applications, powder compaction processes due to these properties. It has a special place among modern tool steels, especially with its legendary toughness, very high hardness and very good barrel strength. Sleipner has a very high wear resistance thanks to the mixture of carbon and molybdenum it contains. Originally produced for the mold industry, Sleipner is in the semi-stainless class. Although it is mentioned as stainless steel in some sources due to its high corrosion resistance, it is definitely not stainless. However, thanks to its 7.8 % chromium content and high production technology, it is well above the average in terms of corrosion resistance. In addition, 0.9 % C (Carbon) expressed in table 1 has an effect on wear resistance and hardness, 7.8 % Cr (Chrome) is important for tensile strength and cutting edge durability, 2.5 % Mo (Molybdenum) increases the machinability and strength of steel, 0.5 % Mn (Manganese) determines hardness and brittleness, 0.9 % Si (Silisium) increases the strength of the material, while 0,5 % V (Vanadium) is very important for wear resistance, it is a major factor in hardening (heat treatment) of steel.

2.2 Machining Methods

In this study, "Charmilles Robofil 290P" brand WEDM machine was used to cut Sleipner cold work tool steel. Since this bench has a cutting precision of 0.003 mm, it is widely used in many industrial areas. It is known in the literature and industry that materials such as Brass, Zinc coated brass, Diffused brass, Molybdenum etc are used as electrodes in the WEDM method (Deshmukh et al., 2019). In this study, "Sodick e35" brand Brass (copper-zinc alloy) and "Bedra topas plus X" brand Copper (zinc rich brass double layer coating) wires with a thickness of 0.25 mm were used as electrodes. As shown in figure 1, the color of the copper wire is brown and the color of the brass wire is shiny gold color. Also, deionized water was used to remove the debris from the workpiece during cutting.



a) b) c)

Figure 1. Work Materials; a) Machining centers, b) Brass Wire (E35), c) Copper Wire (SWX-25)

In this study, the regions to be analyzed according to the cutting direction of the test samples cut with the dimensions of 14.5 x 10 x 90 mm are shown in figure 2. Three different regions of this cut piece were examined as headpiece, middle and underside. Surface roughness and dimensional measurements were made separately from these regions of the test samples cut with copper and brass electrodes. The surface structure and especially the dimensional sensitivity of these areas are very important in terms of their compatibility with the installation site and their service life.

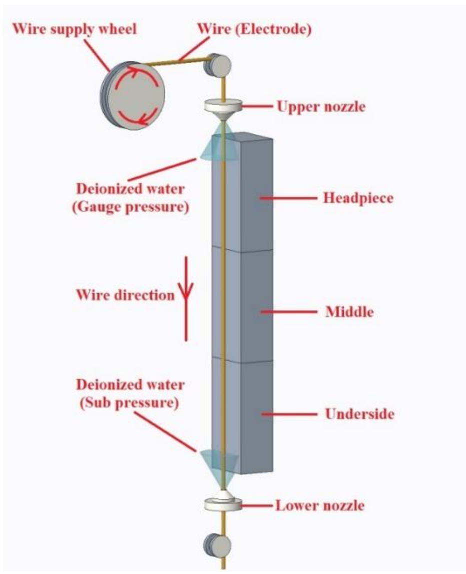


Figure 2. The cut workpiece and the examined areas

2.3 Analysis Methods of Cut Parts

Mitutoyo digital micrometer with 0-25 mm measurement range and 0.001 mm measurement accuracy was used for dimensional checks. In addition, for the surface roughness test, measurements were made from the cut surface of each sample by Mitutoyo SJ-210 and average values were reported as shown figure 3. Measuring force and stylus tip of the roughness measuring device used were 0.75 mN and 2 µmR 60°, respectively. The average values of 3 different measurements for each surface were reported. Average surface roughness value (Ra), which is the most used surface roughness measurement parameter in the literature, were taken into account in surface roughness measurements. This value is the absolute arithmetic average of the profile fluctuations that occur upwards from the center of the material (Nalbant et al., 2007).

Figure 3. Surface roughness measurement device (Mitutoyo SJ-210)

The topography and composition of the sample surface in the machined regions were analyzed using the "Thermo Fisher Scientific Apreo S" Scanning Electron Microscopy (SEM). Çetin et al. used this instrument to also analyze the microstructural, wear and corrosion properties of boronised AISI 904L super austenitic stainless steel (Çetin et al., 2021). Energy Dispersive X-Ray Analysis (EDX) was used for chemical element detection of worn electrode and workpiece residues on machined surfaces. The EDX is an analytical technique used for the elemental analysis or chemical characterization of a sample (Mandaloi et al., 2016). A scanning electron microscope is a type of electron microscope that obtains images by scanning the sample surface with a focused beam of electrons. Electrons interact with atoms in the sample, producing different signals that contain information about the topography and composition on the sample surface. Energy dispersive x-ray spectroscopy, also called EDX, EDS or EDAX, provides a better understanding of the surface material during the SEM analysis process. EDX analysis is used to obtain the elemental composition of a sample and provides a more quantitative result than can be achieved with SEM analysis alone.

3. RESULTS AND DISCUSSION

3.1 Test Parameters and Key Findings

In this work, as a result of industrial applications and machine safe working parameters, the most suitable processing parameters for cutting with copper and brass wire are selected and given in table 3. In addition, these values are the parameters of the WEDM machine that prevent wire breakage and provide the highest performance. After the copper and brass wire selection in the "Robofil 290 P WEDM" machine, the wire tension values were automatically 1.1 and 1.2 kg for copper and brass, respectively. This is related to the strength and electrical conductivity of copper and brass materials. In the literature, there are cutting qualities such as roughing, semi-finishing, finishing in cutting with

WEDM and E2, E3, E7 parameters that can be adjusted according to these cuts (Günen et al., 2022). However, only one cut was made in this study. In addition, 40A current, 80V voltage, 1 µs pulse on time and 21 µs pulse off time machine parameters were used.

Table 3. Experimental set-up and cutting parameters

Wire Type	Wire Tension (kg)	Wire Speed (m/min)	Feed Rate (mm/min)	Gauge Pressure (bar)	Sub pressure (bar)
Copper	1.1	13	70	7.4	7.3
Brass	1.2	13	70	7.4	7.2

After the selected cutting parameters, the cutting speed, MRR values shown in table 4 were read and recorded on the machine control panel. In the wire consumption calculation, the wires consumed in each section were removed from the scrap boiler and weighed on a "Etasis Electronic Scale" (0.001 precision). The processing time was also determined using a stopwatch.

Table 4. Experimental results

Wire Type	Speed (mm/min)	MRR (mm³/min)	Wire Consume (g)	Processing Time (sec)	Finish Measure (mm)			Surface Roughness (µm)		
					Head	Middle	Under	Head	Middle	Under
Copper	1.20	32.40	1333.00	3170.00	10.012	10.003	10.008	2.707	2.937	2.809
Brass	0.80	21.60	1748.00	4782.00	10.050	10.014	10.017	2.653	2.710	2.573

Since the surface roughness is one of the most important parameters in manufacturing, studies have been carried out on the parameters affecting the surface roughness by cutting materials such as AISI 1040, 2379, 2738 steel materials in the WEDM method (Gökler and Ozanözgü, 2000). Lodhi et al. reported that the current (A) and pulse on time (µm) parameters are the most effective parameters affecting the surface roughness in the WEDM method (Lodhi et al., 2019). In this study, the effects of the wires used in WEDM cutting on the SR of the machined surfaces were examined and it was determined that the average surface roughness was lower in the use of brass wire than in the use of copper wire, due to the lower cutting speed as shown in fig.4 and 5. In addition, the high arc formed in the use of copper wire increased the amount of melted and evaporated material, thus making the surface rougher.

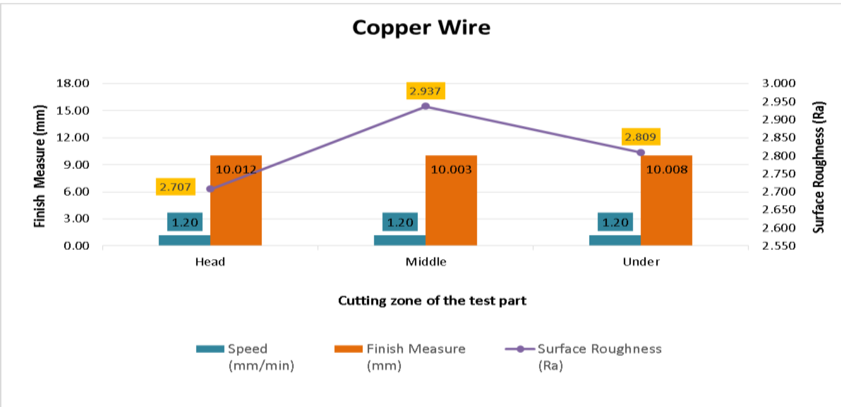


Figure 4. Effects of copper wire usage on cutting Quality

The fact that the cutting speed is lower in the use of brass wire compared to the use of copper wire is due to the fact that the conductivity of the copper wire is higher than that of the brass wire.

Due to the high electrical conductivity of the copper wire, the arc between the workpiece and the electrode has increased, allowing more material to be cut in a shorter time. For these reasons, more MRR and lower machining time were obtained in the use of copper wire compared to the use of brass wire as shown in fig 6. The WEDM method is a thermal material removal method based on the intense sparking, heat and evaporation principle between the workpiece and the electrode. These situations cause sudden heating in the workpiece and cause sudden cooling when the dielectric liquid in the environment comes into contact with the workpiece. This affects the surface morphology of the workpiece, and both the workpiece and the electrode material are worn.

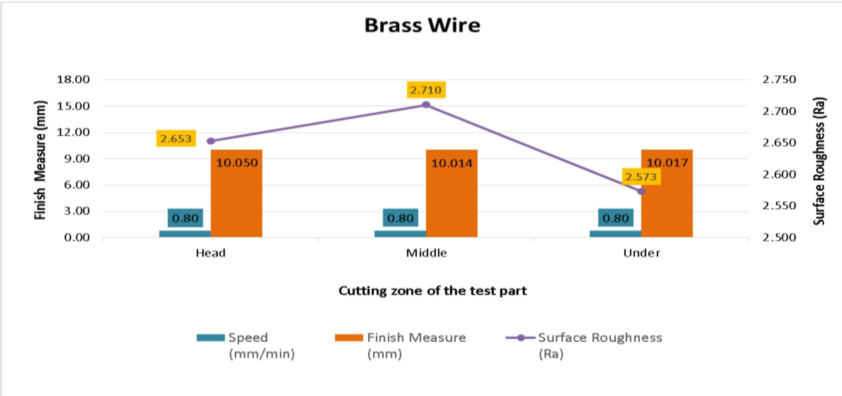


Figure 5. Effects of brass wire usage on cutting quality

The brass wire consumption was higher than copper wire consumption because of same rotation speed of the wire spool in the use of both copper and brass electrodes as well as the copper wire cutting more material in a shorter time as shown figure 6.

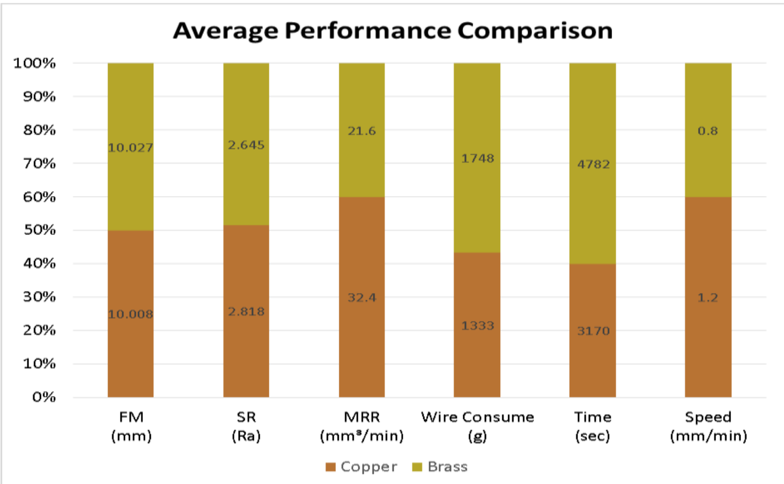
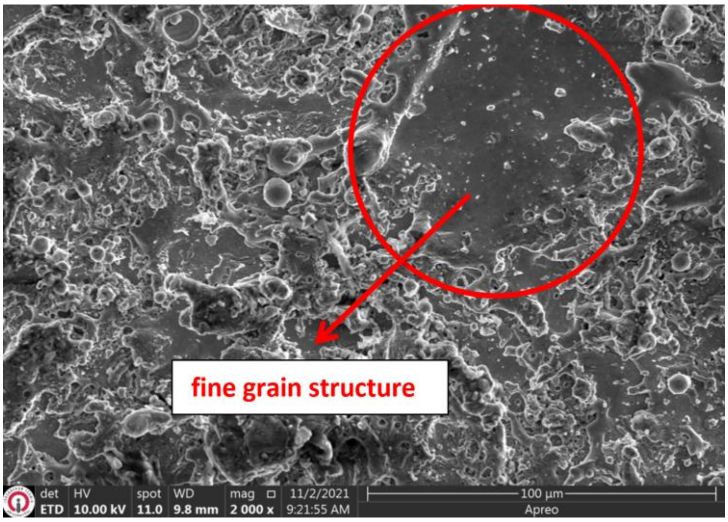
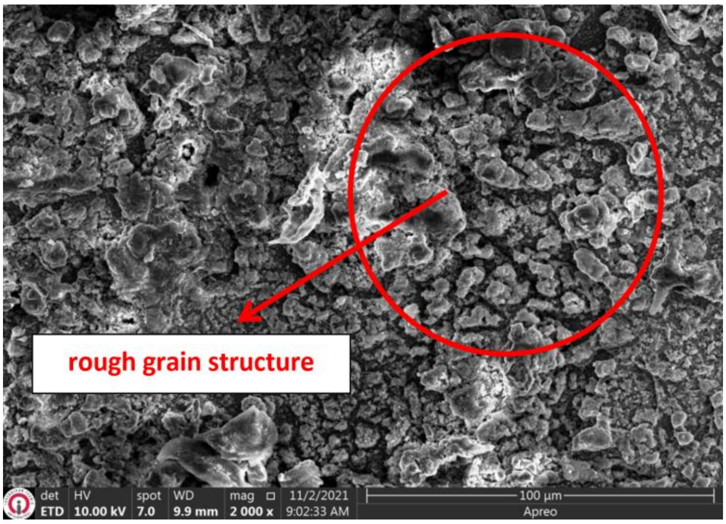


Figure 6. Average performance comparison of using Copper and Brass wire



a)



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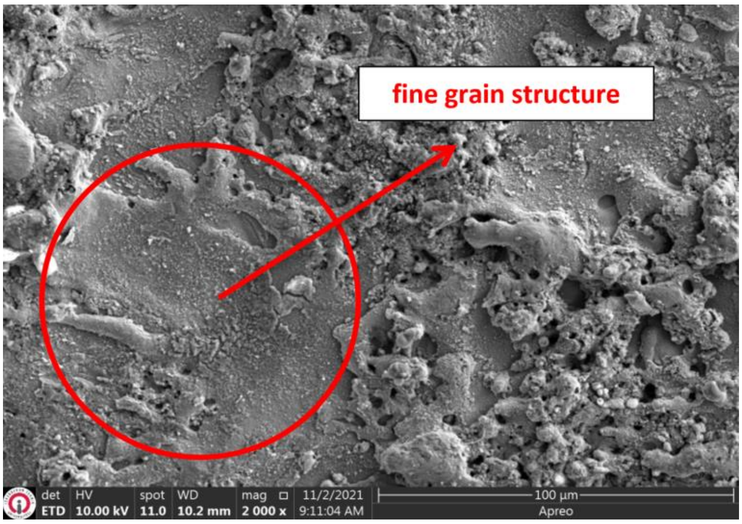


c)

Figure 7. SEM analysis of surfaces cut with Copper Wire; a) Headpiece, b) Middle, c) Underside

Reolon et al. emphasized that in cutting Inconel alloy IN718 material with WEDM, the zinc-coated copper wire has a higher performance in wire feed rate and wire consumption than uncoated brass wire (Reolon et al., 2018). In this study, the use of zinc rich brass-coated copper wire reduced the processing time and wire consumption by 66.29 % and 23.30 %, respectively, compared to the use of brass wire. Wang et al. analyzed that better machining performance can be achieved by reducing the vibration of the wire electrode used in the WEDM method (Wang et al., 2021).

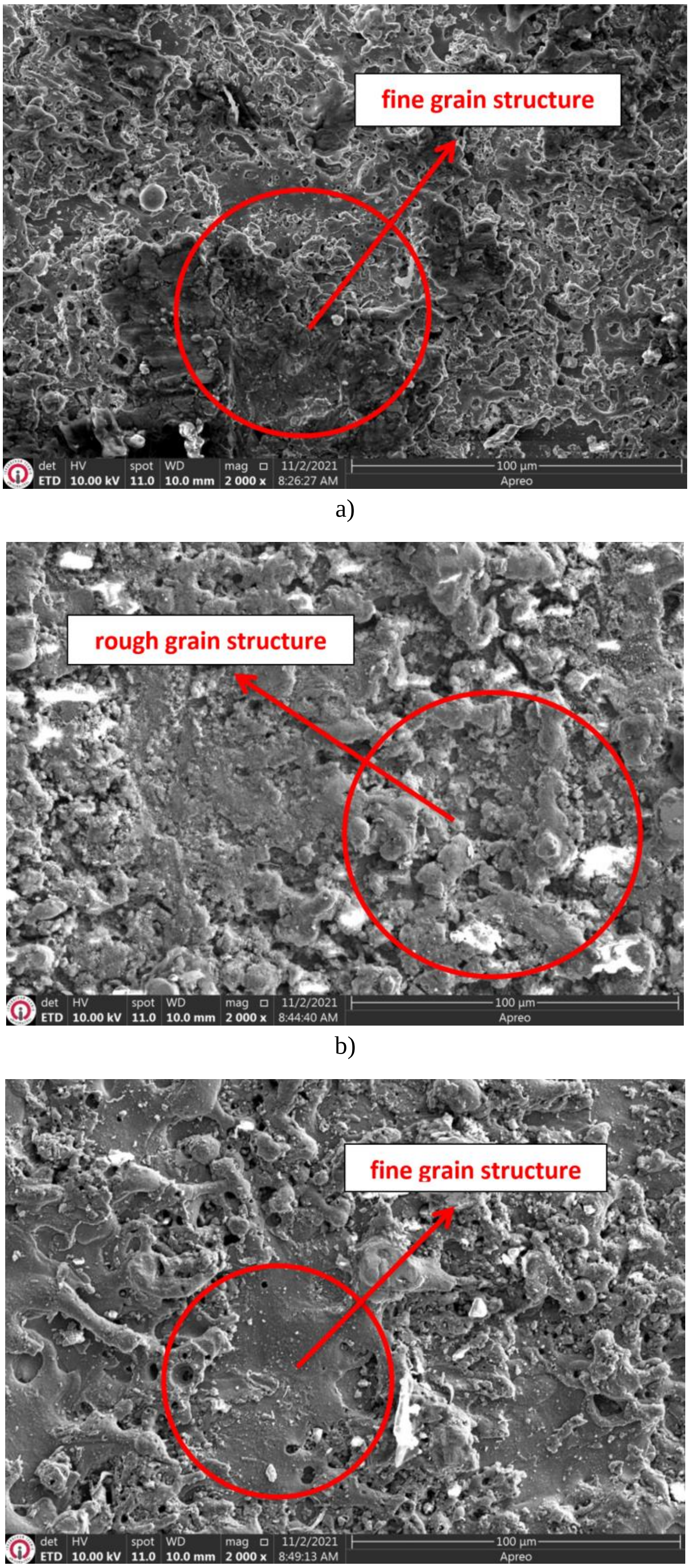


Figure 8. SEM analysis of surfaces cut with Brass Wire; a) Headpiece, b) Middle, c) Underside

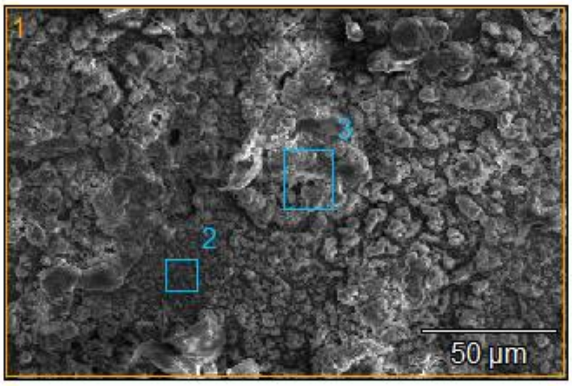
Zhang et al. reported that wire vibration affects not only the geometry profile of the components but also the recast layer thickness, material removal rate, surface morphology (Zhang et al., 2018). Rao et al. reported that wire tension has an effect on kerf width and surface roughness, in addition, less surface roughness and smooth surface profiles can be obtained as a result of low current and high wire tension (Rao et al., 2020). Regarding this issue, Straka et al. emphasized that the geometrical accuracy of the eroded surface has deteriorated significantly due to increasing flushing pressure (Straka et al., 2021). The "Charmill Robofil 290P" WEDM machine used in this study sprays water on the upper and lower parts of the cut area of the workpiece during cutting. The sprayed water ensures that the melted material and eroded wire residues are removed from the workpiece as a result of thermal effects. As a result of the measurements made, it has been determined that since the water sprayed on the upper and lower parts of the workpiece first contacted the upper and lower parts of the machined surfaces, it caused the surface roughness of these regions to be lower than the surface roughness of the middle parts. It is clearly seen in the middle regions of figures 7 and 8 that the effect of the washing liquid on the middle parts is low and the washing cannot be done properly, causing the melted materials to stick to the surface again and thus increasing the roughness. Similarly, due to the change of wire stability depending on water pressure, dimensional accuracy increased in the middle parts of the cut workpiece compared to the lower and upper parts. SEM images of regions headpiece, middle and underside cut with copper and brass wire are shown in figure 7 and 8 separately. The element percentages determined according to the EDX analysis results of the middle part of the workpiece cut with copper and brass wire are given in table 5.

Table 5. Average weight % values of the elements contained in the middle regions cut with copper and brass wire

Wire Type	C	O	Si	V	Cr	Mn	Fe	Cu	Zn	Mo
Copper	8.50	22.02	1.22	0.18	2.81	0.38	43.42	3.85	16.45	1.14
Brass	5.36	19.17	0.71	0.21	2.56	0.41	34.43	14.70	21.54	0.88

The average values of EDX results from 3 different regions of machined surfaces as shown in figures 9(a) and 10(a) are listed in table 5. The chemical content of the Sleipner work piece used in this study consists of carbon (C), silisium (Si), manganese (Mn), chrome (Cr), molybdenum (Mo), vanadium (V) and iron (Fe), but elements such as copper (Cu) and zinc (Zn) were found on the machined surfaces as shown in figure 9 c), d), e) and 10 c), d), e). These elements, which are not found in the chemical structure of the workpiece, are eroded electrode residues. Since the outer coating of "Bedra topas plus X" copper wire is zinc rich brass double layer coating, residues of the coating material on the wire surface were found on the processed surfaces as shown in figure 9. It has been determined that the Zn ratio of the worn coating material on the processed surfaces in the use of copper wire is higher than the Cu ratio as shown in table 5. "Sodick e35" contains 63-67 % copper (Cu), 37-33 % zinc (Zn) in its brass wire structure and is called copper/zinc alloy. Cu and Zn elements were found intensively on the surfaces of the cuts made using brass wire as shown in figure 10. In general, according to the EDX analysis results, it was observed that the rate of corroded wire on the machined surfaces was higher in the use of brass wire than in the use of copper wire. In addition, worn elements contained in the structure of the work piece Sleipner material were found on the machined surfaces. In this study, the cutting surfaces of cold work tool steel cut in the WEDM method, which has not been seen before in the literature, were examined by dividing into 3 different areas such as headpiece, middle and underside. As can be seen from the analysis and measurement results, it has been proven that these three different surfaces show different properties from each other. In addition, two different electrode materials such as copper and brass were used to minimize the differences of these surfaces and to obtain better surface quality.

cu4(1)



a)

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Image Pixel Size: 0.41 µm
Acc. Voltage: 10.0 kV
Magnification: 2000

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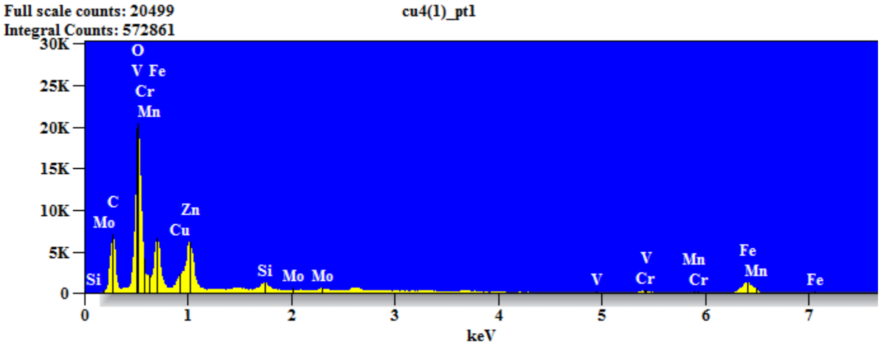

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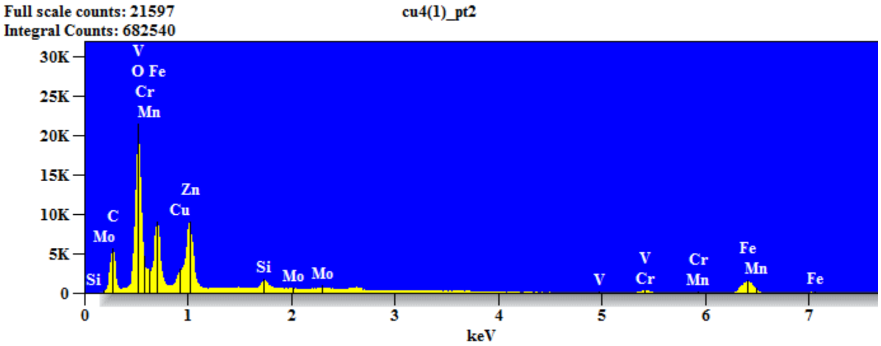
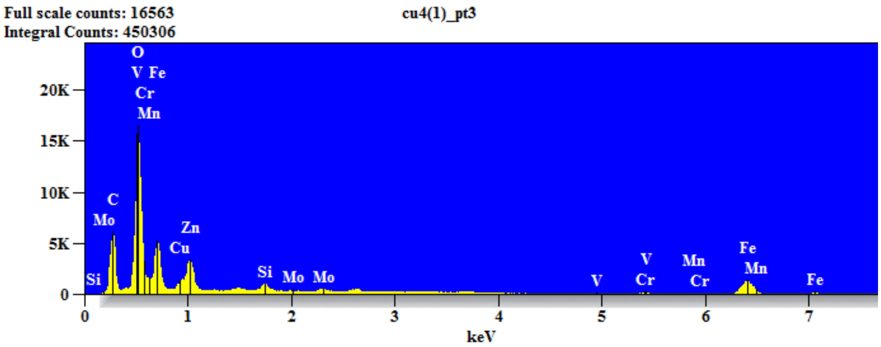


d)



e)

Figure 9. EDS analysis of Copper electrode residues found on machined surfaces

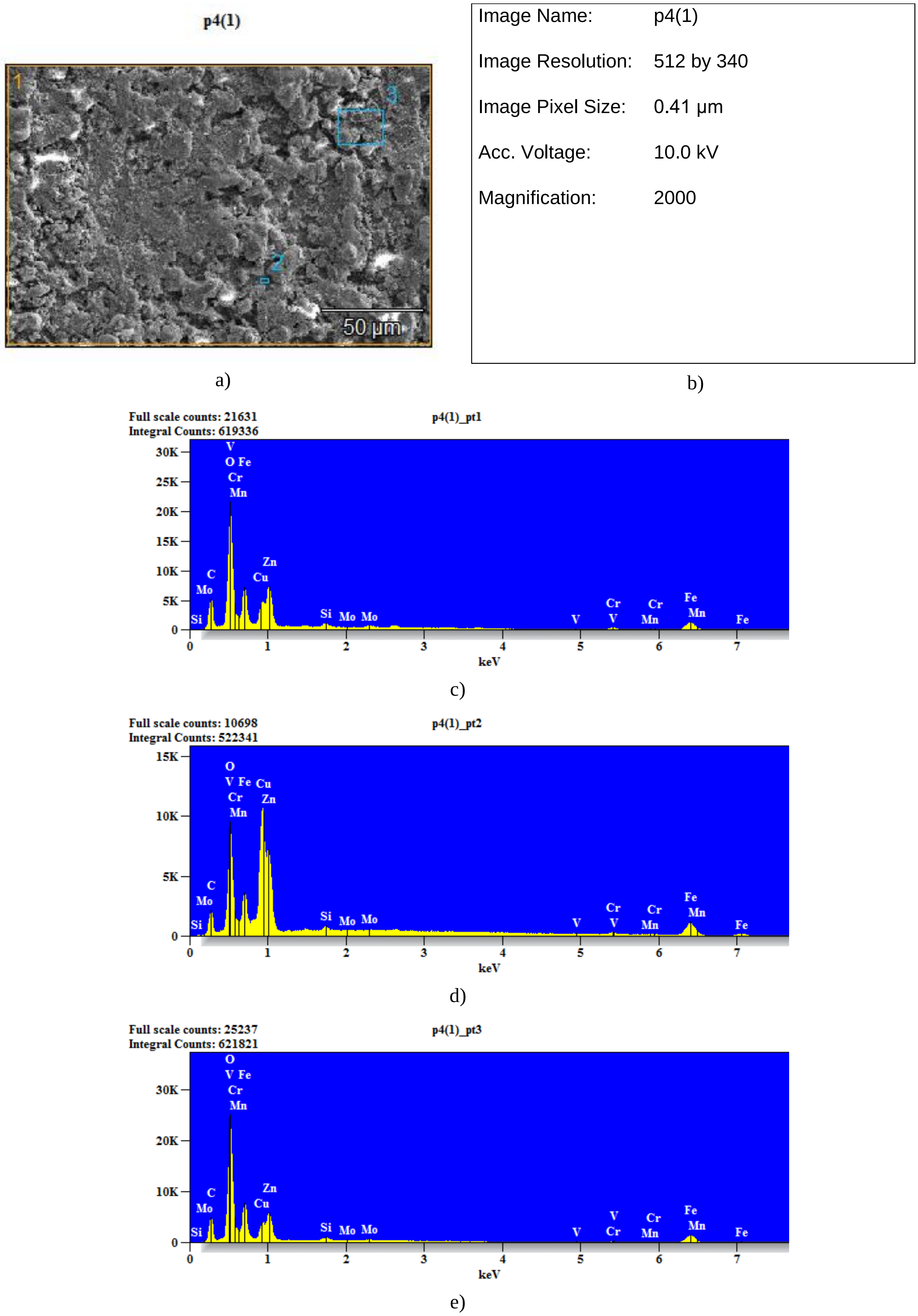


Figure 10. EDS analysis of Brass electrode residues found on machined surfaces

The dimensional accuracy obtained in this study is of great importance in adapting the cut workpiece to the mounting location. Having suitable values for surface roughness, which is another quality parameter, increases the fatigue strength and corrosion resistance of the material, as well as makes it look aesthetically pleasing (Sangwan et al., 2015). MRR, time and wire consume, which are indispensable for performance and cost evaluation in industrial applications, are the most followed parameters. The analysis of all these values as a result of cutting a high-hardness tool steel with copper and brass electrodes arouses curiosity for users. In addition, as can be seen from the SEM and EDX results obtained in this study, the presence of elements other than the chemical composition of the material on the processed surfaces proved the effect of the processing method on the material. Maybe this situation can be a remarkable issue in the use of mold materials such as Sleipner cold work tool steel in medical applications and food industry.

4. CONCLUSION

The main conclusions are as follows:

- In the case of using copper wire instead of brass wire, wire consumption and processing time decreased by 23.30 % and 66.29 %, respectively, while MRR increased by 50 %. In addition, the average dimensional deviation of the parts cut with copper wire decreased from 27 μm to 8 μm compared to the use of brass electrodes, and more precise measurements were obtained.
- The fact that the cutting speed is lower in the use of brass wire compared to the use of copper wire is due to the fact that the conductivity of the copper wire is higher than that of the brass wire. Due to the high electrical conductivity of the copper wire, the arc between the workpiece and the electrode has increased, allowing more material to be cut in a shorter time. For these reasons, more MRR and lower machining time were obtained in the use of copper wire compared to the use of brass wire.
- It has been determined that since the water sprayed on the upper and lower parts of the workpiece first contacted the upper and lower parts of the machined surfaces, it caused the surface roughness of these regions to be lower than the surface roughness of the middle parts. Similarly, due to the change of wire stability depending on water pressure, dimensional accuracy increased in the middle parts of the cut workpiece compared to the lower and upper parts.

In general, according to the SEM and EDX analysis results, it was observed that the rate of corroded wire on the machined surfaces was higher in the use of brass wire than in the use of copper wire. In addition, worn elements contained in the structure of the work piece Sleipner material were found on the machined surfaces.

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6. CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

7. AUTHOR CONTRIBUTION

Ferhat CERİTBİNMEZ and Erdoğan KANCA designed the structure. Ferhat CERİTBİNMEZ fabricated the device, carried out the experiments work, the theoretical calculations, in collaboration with Erdoğan KANCA, and wrote up the article. Ferhat CERİTBİNMEZ and Erdoğan KANCA contributed to the interpretation and English writing. Both of authors have read and approved the final version of the article.

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