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The Use of Cu-W Sinters in MIG-MAG Welding Contact Tips for Improved Continuous Wire Abrasion Performance

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ABSTRACT: Gas metal arc welding is one of the most widely used welding methods in the industry. Especially when large volume welded manufacturing is required, this method is very successful and practical. The wear of the contact guides, which guide the wire at the tip of the welding torches, but most importantly, provide electrical current transmission, may cause the production time to be extended and the calibration period to be minimized. In this study, the most worn part of the contact guides used in the Gas Welding robots were assembled by making pins from doped and undoped copper powders using the powder metallurgy method. The wear performance was compared by making the obtained pin driven contact guides under mass production conditions. In the study, pressing and sintering processes were carried out with Cu and Cu+W powders. The hardness of the contact guides was characterized by their microstructure and XRD results. It was observed that CuW5 and CuW10 powder mixtures were more successful.

Keywords: Powder Metallurgy, Abrasion Resistance, MIG-MAG Welding Method, Contact Nozzle

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1. INTRODUCTION

Arc welding processes such as gas metal arc welding (also known as MIG/MAG) and gas tungsten arc welding (also widely referred to TIG), are commonly used in both manual and automatic welding operations of various structural materials, i.e. steels and stainless steels in industry (Durgutlu and Gulenç, 1999; Ezer and Cam, 2022; Serindag and Cam, 2022; Serindag et al, 2022). In the MIG/MAG welding method, the welding torch has been developed to carry out the tasks of transmitting the current from the power cable to the electrode, and also transferring the shielding gas to protect the weld pool and arc plasma. It is also a tool to create an electric arc between the workpiece and the tip of electrode required for sustaining the welding operation. MIG/MAG torches are in general made of copper alloy with a high current conductivity and reliable high temperature operation. However, the high welding current values used in robotic systems increase the average temperature in welding torches. This causes the temperature of torches and especially the contact runner or wire guide, which is in direct contact with the arc plasma, rise to significantly high temperatures and thus accelerates their wear rates tremendously (Kou, 2002; Adam et al., 2001; Shimizu et al., 2006). By coating the wire guide surface using the electro-spark method with the intermetallic materials, the amount of wear was highly reduced and the adhesion of metal droplets to the wire guide surface by splashing was also prevented to a large extent (Yazar et al., 2022). As in many mechanical systems with moving parts, such as machine, wear is the prime cause that leads to the operational failure. One of the solutions to this problem is to use wear resistant hard phases in materials with soft matrix. In hard phase containing composites, however, effects of applied load onto the surface, pin shear rate and volume fraction of second phase in the matrix have been studied to observe the shift in the wear behaviour between mild and severe modes, for example, in SiC reinforced copper matrix composites, increasing SiC ratio or decreasing the test shear rate under dry sliding wear, it delays the formation of severe wear up to the point where mild and severe transition is observed (Zhang et al., 2008; Singla et al., 2009). SiC particles in the metal matrix composite usually act as the load bearing artefact and reduce the extent of frictional deformation in the subsurface region. The separation of the metal matrix and damaged subsurface region due to microcrack propagation during repeated loads is the primary wear mechanism. The heat generated during the sliding operation, i.e. thermally activated subsurface deformation plays an important role in tearing and separating the surface layer from the substrate material, which is the case for severe wear condition (Zhang et al., 2008; Gautam et al., 2008). As in SiC reinforced metal matrix composites, ceramic particle reinforcements can also improve high-temperature mechanical properties as well as their wear properties without severely deteriorating the electrical and thermal conductivity of the matrix. Therefore, second phase particle-reinforced copper matrix composites are of interest in many industrial applications such as switch or relay contact materials, load bearing wear-resistant and heat-resistant materials, brush materials, and torch nozzle materials (Jamwal et al., 2020; Donghua and Dongdong, 2014; Dube et al., 2009). In industrial applications, high wear resistance is a well-defined property for copper matrix composites. Some earlier studies showed that, the property of base material is also the dominant controlling factor in addition to external operational factors as mentioned above i.e. the ambient temperature, test load and shear rate to affect the friction and wear performance of composites (Selvakumar and Vettivel, 2013; Deshpande and Lin, 2006; Tjong and Lau, 2000; Dhokey and Paretkar, 2007). As tungsten does not dissolve in copper i.e. they are immiscible, Cu+W is traditionally considered a composite material. However, the WCu composite prepared by standard powder metallurgy is low in density and its microstructure is generally irregular, resulting in a reduction in high temperature wear resistance and arc ablation resistance. In addition, severe wear occurs due to sliding contact at high loads and high speeds. In both aluminum alloys and Al_2O_3/Al alloy composites, the occurrence of severe wear is also affected by normal load, sliding speed, and sliding distance, and is characterized by significant increase in wear rate, large surface wear, and even large-scale material transfer to the counter surface (Deuis et al., 1997; Zou et al., 2020; Childs, 1980).

In order to increase the wear resistance of the wire contact runners or guides used in MIG/MAG torches and consequently to improve the production costs by increasing the service life, the production of pins obtained by sintering of pure Cu and W powders and the in situ wire wear performance were investigated.

2. MATERIALS AND METHODS

The chemical composition and mechanical properties of 1.8 mm thick Cu coated commercially produced FEE 340 steel used in the experiments are shown in Table 1. SG2 quality 1 mm welding wire was used as the welding wire and its chemical composition and mechanical properties are also shown Table 1. In situ welding tests were carried out with manifold HB 205 mixed gas i.e. shielding gas. The properties of the shielding gas are given Table 2.

Table 1. Chemical properties (% by weight) and mechanical properties of 1.8 mm FEE 340 steel and SG2 quality 1 mm welding wire.

C	Mn	Al	P	S	σy, MPa	σmax,MPa	% Elongation
0.12	1.5	0.015	0.03	0.03	340	410	23
0.06	1.1	<0.005	0.012	0.011	430	540	28
Ductile-brittle transition temperature (°C): -29, Impact (J): 70							

Table 2. HB 205 Standard shielding gas mixture (% by volume).

	Argon	**Carbondioxide**	**Oxygen**
HB 205	93	5	2

In this study, Fronius Transpuls Synergic 4000 brand gas arc welding machine was integrated to ABB brand robot and used. The chemical composition and mechanical properties of the pin-mounted contact tip are given Table 3.

Table 3. Chemical composition (wt%) and mechanical properties of the contact tip.

Cu	**Cr**	**Zr**	**σy, MPa**	**σmax, MPa**	**% Elongation**	**Hardness-Brinell) (HB30)**
Kalan	0,3-1,2	0,03-0,3	10	400	13	130

The performances of a commercially purchased contact tip (Figure 1) with a hole diameter of 1.18 mm and a sintered pin mounted contact tip were compared with the test process ABB brand gas metal arc welding robot (Figure 1).

Figure 1. Image of ABB gas metal arc welding robot. ABB arc welding robot contact guide image (hole diameter 1.18 mm).

During the arc welding process, as the wire passes through the hole at the contact tip, the wear resistance decreases with the high heat generated during welding, the diameter of the hole grows and in some cases this hole is closed or becomes completely unusable with spatters. In order to eliminate the above-mentioned reasons, the pin mounting hole with a depth of 5 mm and a diameter of 4 mm was discharged from the end part of the wire contact guide (Figure 1), where the wear was intense, and the pin was produced and then assembled into this hollow tip. On the inside of the contact runner, there is a channel of 1 mm from one end to the other for the passage of the welding wire with a diameter of 1 mm.

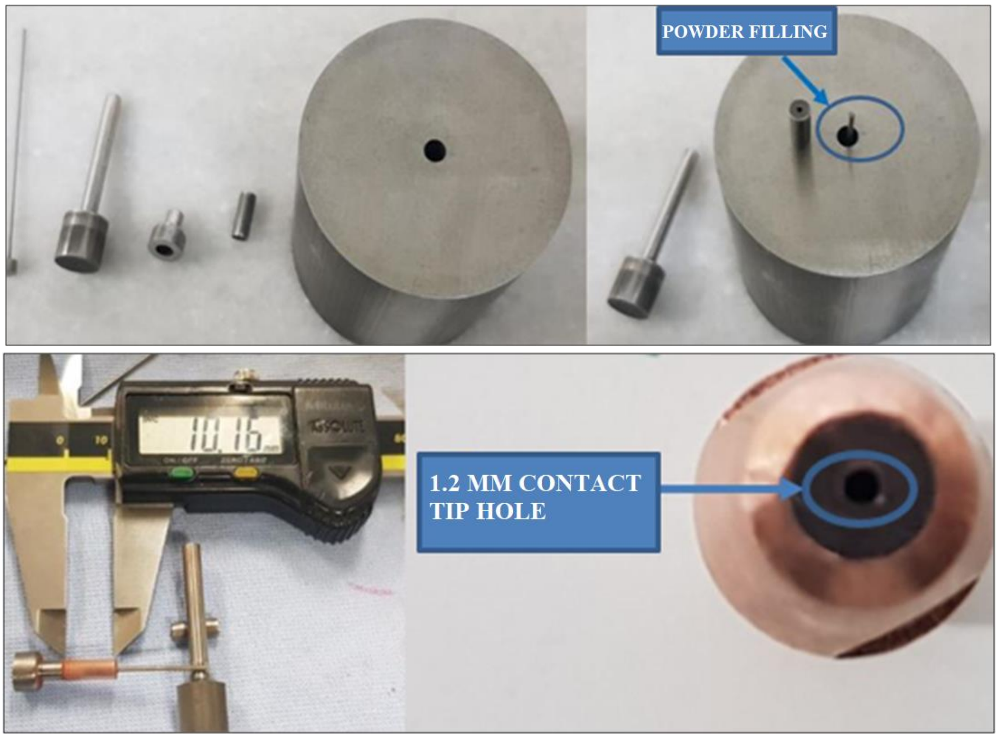


Figure 2. Contact guide pin in compression die (Above); image of compressed pin (Left-Below) in contact guide pin (Right-Below). In terms of the way the die is made, a pin passes through its middle and forms the inner hole of the contact tip.

Cu (325 mesh) and W (12 micron) powders were used in the production of the pins used in this study. Ambient conditions were kept the same for all mixtures during powder weighing and compaction processes.

Table 4. Mixing ratios of powders used in this study (wt. %)

Specimen Code	W	Cu
CuW5	5	95
CuW10	10	90
CuW15	15	85
Cu	0	100

The powder mixtures were contained in glass tubes at the amounts given in Table 4 and were mixed in the mixing drum for 24 hours in order to mix them homogeneously. In order to prevent the powder mixtures from being affected by the ambient humidity, they were stored in a low humidity environment and in tightly closed containers. The metal+ceramic powder mixture and pure metal powders, which were mixed in the rotating drum for 12 hours, were pressed in a powder compression die (Figure 2 a, b) under 20 tons of load at a feed rate of 2 mm/min. Subsequently, as shown in Figure 2c, a dimensional check was made before the centre pin bar was removed. The pin, which was to be mounted in the contact guide, reached the raw strength and was ready for sintering. Pre sintering compaction ratio of the contact runners/pins at this stage was calculated to be approximately 91% by measuring dimensions, weight and calculating through densities of each component. Electric resistance heat treatment furnace, which can reach a temperature of 1100C, was used for sintering of compressed pins. The contact guide was made ready for the assembly operation by sintering at 720C for 75 minutes under Argon gas (12 lt/min) in the well type sintering furnace. After sintering, the compaction rate increased to 95%. During sintering, free sintering was preferred and samples were placed on the ceramic boat in the heat treatment furnace. A 1.2 mm drill bit was used to guide the pin-mounted contact guides to the gap where the gas metal arc welding wire would pass. After the welding process, the pieces that were tested in the wire erosion device were sliced for microscopic examination (Figure 3a). The final version assembled on the robot welding machine is given in Figure 3b. In situ parameters for testing the produced contact pins: 135 Amps and welding torch travel speed of 2 m/min.

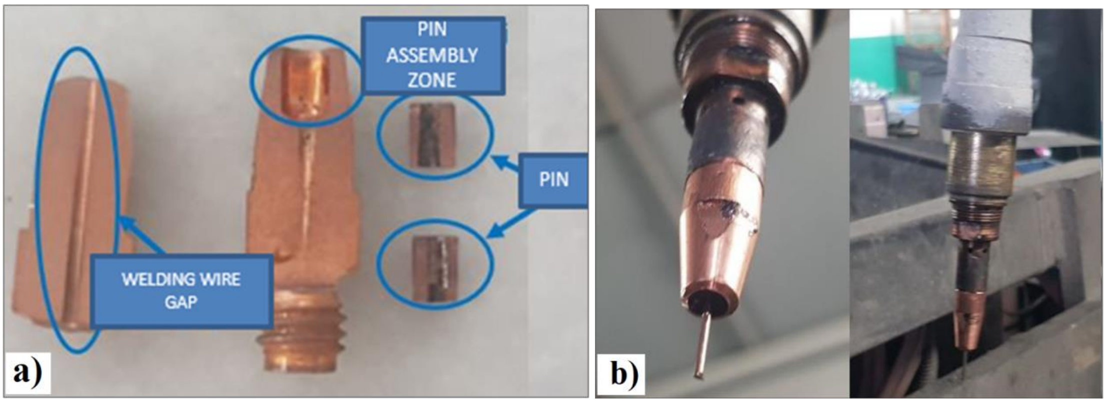


Figure 3. a) Close-up image of the general view of the contact guide cut with the wire erosion machine, b) Image of the part with the assembly of the contact guide pin.

3. RESULTS AND DISCUSSION

The nozzles and contact guides of welding torches, which provide gas flow to the welding area, are more exposed to the thermal effect from the arc and heat up to a temperature of 180-320 °C and above when operated continuously for several minutes without insufficient cooling (Adam et al., 2001). The resistivity values that increase with increasing temperatures increase the electrical resistance of the wire/surface contact and cause more heating. More importantly, with increasing temperature, the tribo performance of the material is seriously affected, and the wear of the guides that are not cooled enough accelerates. In addition to reducing the guide replacement time, the worn guide makes it difficult to draw the weld seam properly, and it prevents the welding seams from appearing smoothly by making right-left movements of the wire (Adam et al., 2001; Shimizu et al., 2006). In this case, it becomes difficult to visually accept the weld seam.

3.1 In-situ Test Results of Pin-mounted Contact Guides

In situ tests of Cu and CuW pins produced by powder metallurgy were made under real production conditions. The performance of the contact guides produced by the commercial forming method and the performance of the parts produced by powder metallurgy were tested at this stage. In Table 5, in situ production numbers of pinless contact guides and contact tips produced by powder metallurgy are shown. The results show that the pin-containing contact tips produced by powder metallurgy outperformed the commercial contact tips. It is a surpisingly good result to achieve with a pin produced with pure Cu powder that does not contain Cr and Zr, with a production difference of only 8%. Since it does not outperform the commercial contact tips production numbers, no further work has been done on it. Although the heat transfer is quite high with the use of pure Cu, it is thought that the very small amount of porosity between the powders reduces the wire/surface contact area and therefore delays the abrasion. In addition, they are subject to very easy deformation and deformation, as long as the wire surface roughness is very good, they do not adversely affect the tribological properties.

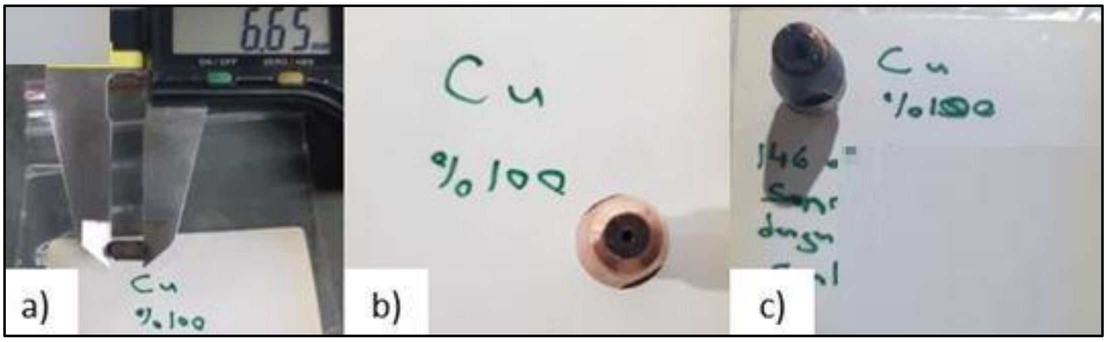


Figure 4. a) Cu (100%) sintered pin visual, b) Cu (100%) contact guide visual to be tested in mass production, c) Cu (100%) contact guide visuals with mass production trial.

Table 5. Cu contact guide production numbers and difference percentage.

Ratio	Commercial tips	Contact tip with pin	Diff. (%)
Cu (%100)	71732	66284	-8

Tests of the Cu-W series were performed twice to test the repeatability of the observed performance. Among the tests performed, CuW5 and CuW10 samples gave the best results, and these samples were tested for mass production. The mass production test was terminated due to the chassis (short circuit). Except for a general color change, ie blackening, there is no macroscopic damage to the contact runners. Blockage due to build-up damage from spatter is very limited, but wear-related damage is more pronounced.

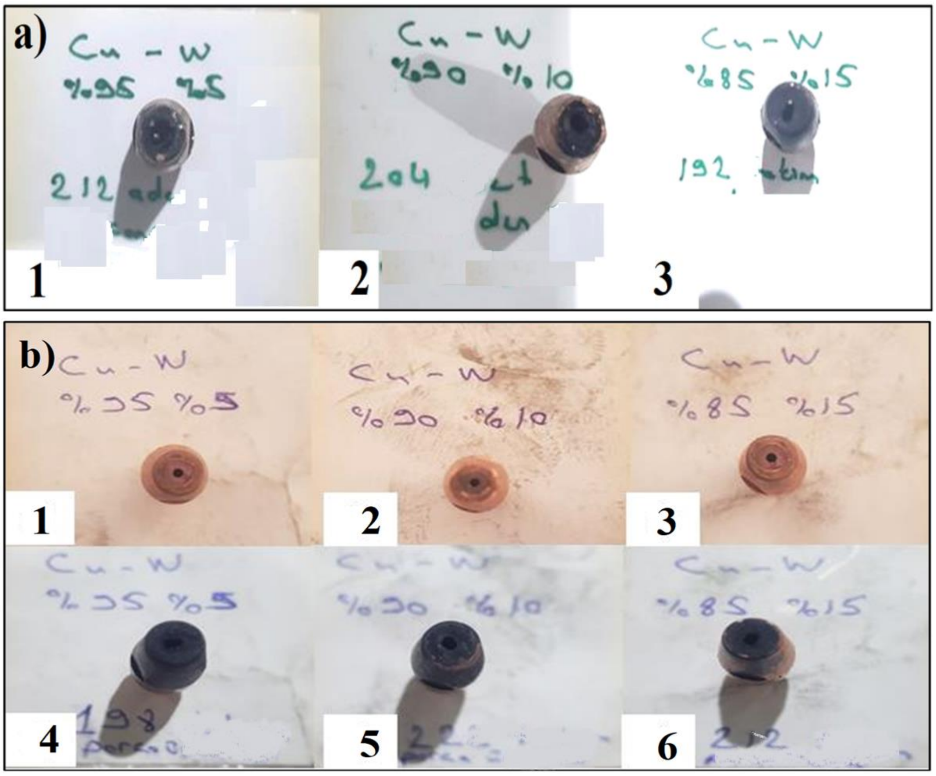


Figure 5. A) 1) CuW5, 2) CuW10 and 3) CuW15 contact guide images with mass production trial. B) 1) CuW5, 2) CuW10, 3) CuW15 before mass production trial, 4) CuW5, 5) CuW10 and 6) CuW15 contact guides visuals with mass production trial.

Table 6. Cu-W contact guide production numbers (Test 1 and Test 2) and difference in percentage.

Mixture	Commercial	Contact tip with pin (Test 1/2)	Diff. (%)
Cu-W (%95-5)	71732	96248/89892 (-%7)	34/25
Cu-W (%90-10)	71732	92616/100788 (+8%)	29/41
Cu-W (%85-15)	71732	87168/96248 (+%9)	22/34

3.2 Microscopic Study

Optical pictures of the contact tips in the Cu-W series, which are polished and taken after cutting vertically, are given in Figure 6-8. As seen in Figure 6, 7 and 8 that copper contact tips has blank, featureless microstructure compared to W containing contact pins. Contact pins are also featureless but this is because the both W containing pin and holding contact pins are not etched. Contact pin containing W shows W particles in black spots, mostly homogeneously distributed within the matrix and the number density appears to be increasing as the W powder additives are increasing in percentage. The interparticle distance in general may be an effective measuring comparison for the evaluation of results, that is, with CuW15 the interparticle distance is obviously lower and higher with CuW5. CuW10 may have optimum distance as comparison to CuW15 and CuW5 specimens. During the test process or during the cutting phase, it is observed that the W powders are displaced and gaps appearing as porosity are formed. So, it is seen that the number of black gaps in the contact runners given in Figures 7 and 8 has decreased. The low wear resistance of some CuW pins exposed to high temperatures is explained by the lower high temperature wear resistance and arc ablation resistance of CuW composites produced with standard powder metallurgy, resulting in different wear resistances (Zou et al., 2020). As seen in Figure 6a, it has been determined that the contact tips were welded to the main terminal body, and it is thought that the pin tips, which reach very high temperatures during the test phase, will be joined in this way both due to the high current effect and also due to the high ambient temperature. Hole widths show the amount of wear. It is seen that the cross-sectional ratios (AR) of the hole sizes are 1.33, 1.28 and 1.44 mm, respectively, taking into account the CuW15, CuW10 and CuW5 samples. In this case, it is seen that the CuW5 sample is exposed to the most wear. However, the least change or the least proportional deviation was seen in the 90/10 sample.

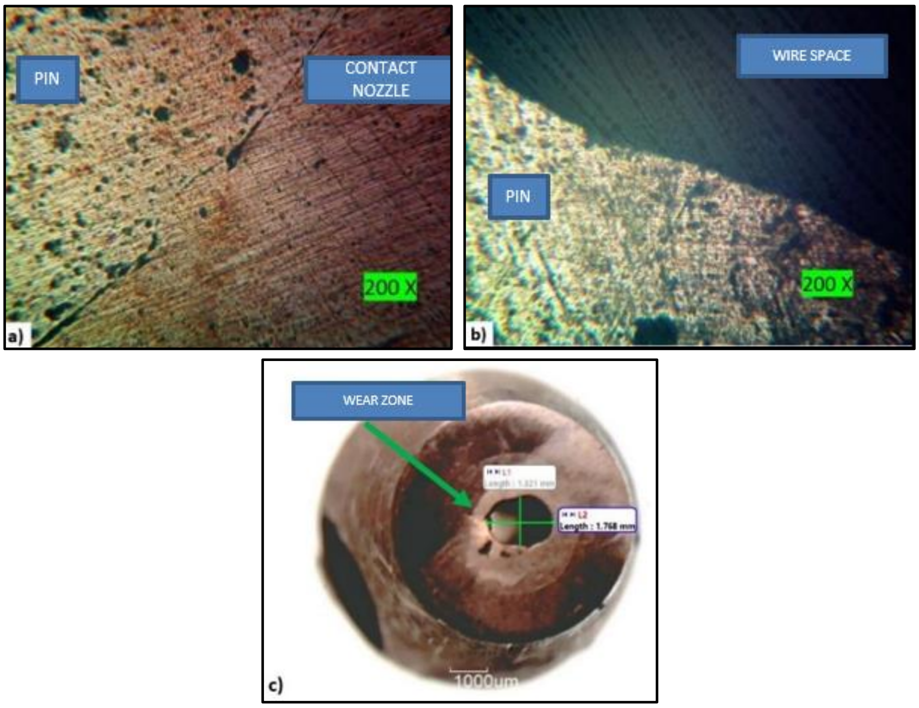


Figure 6. a) CuW15 microstructure image, b) pin and wire drive cavity 200x magnification, c) CuW15 close-up image (hole dimensions 1.768mm x 1.321mm AR:1.33).

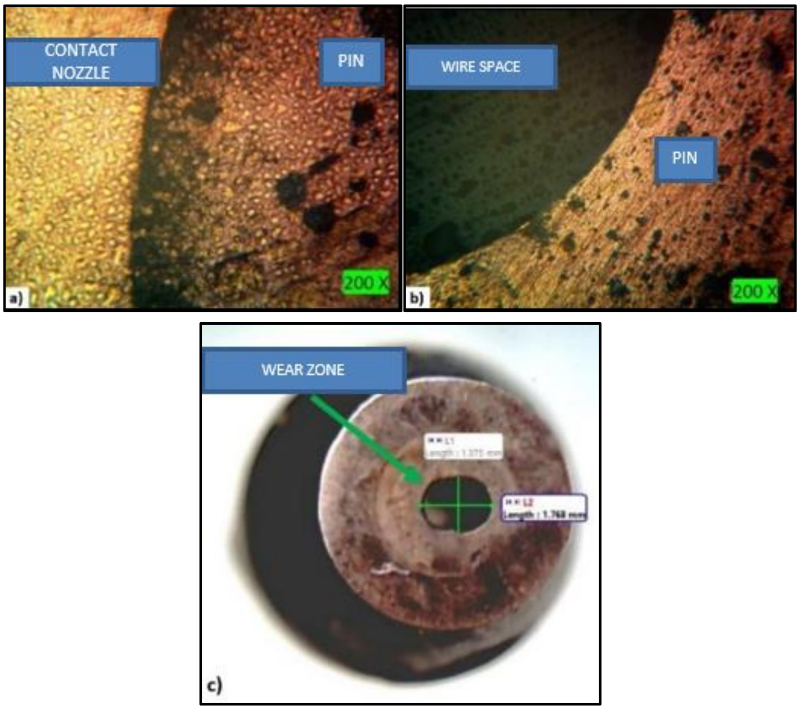


Figure 7. a) CuW10 microstructure image, b) Contact guide (pin) and wire feed hole 200x magnification, tested in mass production, c) CuW10 close-up image (Hole dimensions 1.768mm x 1.375mm, AR:1.28)

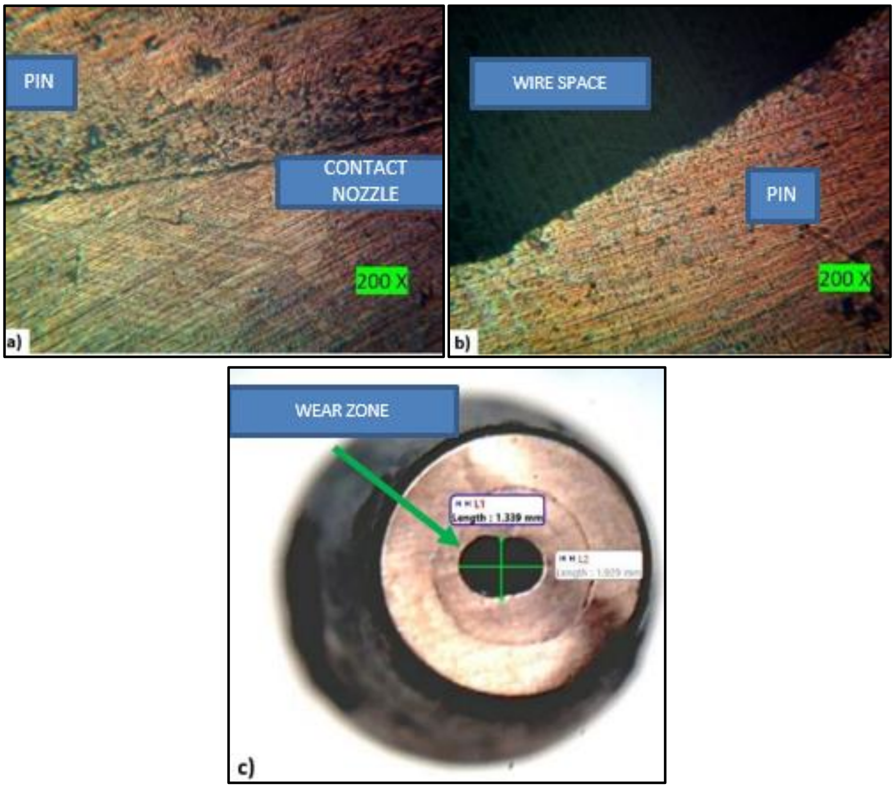


Figure 8. a) CuW5 microstructure image, b) Contact guide (pin) and wire feed hole 200x magnification, c) CuW5 close-up image (hole dimensions 1.929mm x 1.339mm, AR: 1.44).

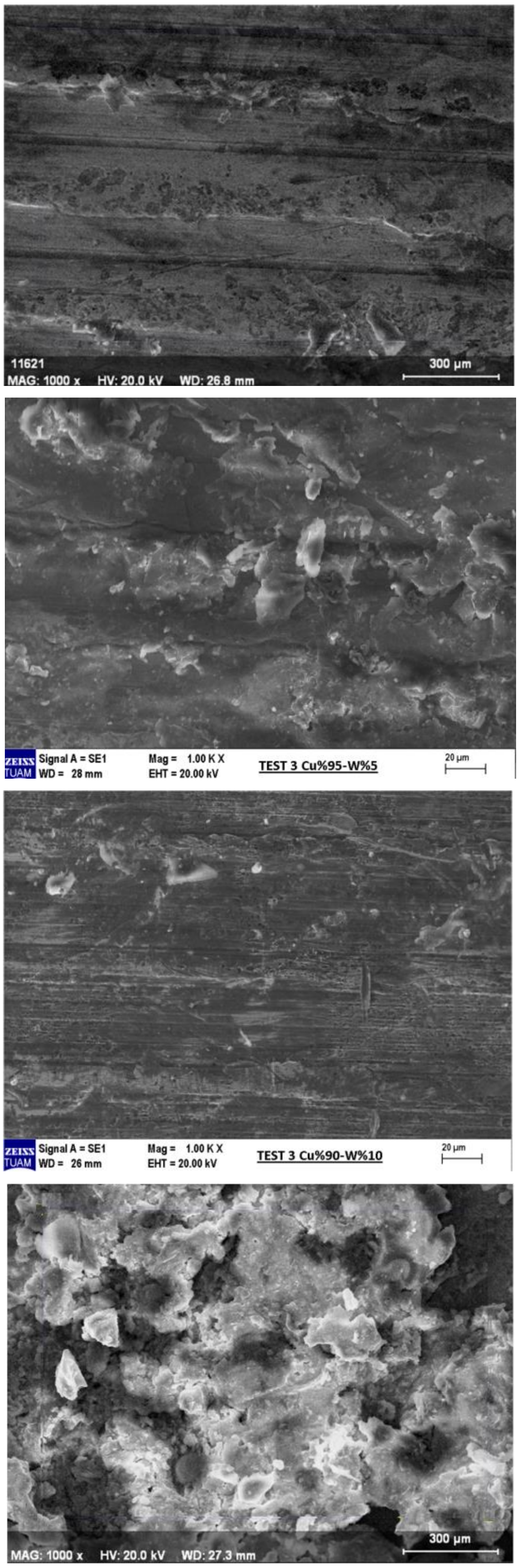
Wear analysis of the cross-sections of the contact guide pins is given in Figure 9. From the sections, it was observed that the inner part of the CuW sinters at CuW15 and CuW5 ratios were covered with oxide, but at CuW10 ratios, the sintered pin was not oxidized or oxidized very little. Another important criterion is the hole expansion rates. This ratio will give information about the amount of wear and therefore about the wear resistance. While CuW15 sample was exposed to 35.4% expansion, CuW10 sample showed 11.5% expansion. Since the CuW5 sample expanded by 31.5%, the best ranking in terms of abrasion resistance is CuW10, CuW5 and CuW15.

3.3 SEM Results

The wear surface pictures of Cu, CuW15, CuW10 and CuW5 series, which were tested in situ, are given in Figure 10. The wear characteristics of the pure Cu sample and CuW5, CuW10 and CuW15 samples given in Figure 10a differ. While the pure Cu wear in Figure 10a contains very deep wear marks, the CuW5 in Figure 10b and CuW10 in Figure 10c are sufficiently superficial. The other non-superficial wear trace was seen on the CuW15 sample. Although it is not expected that the wear marks are deep or have a fragmented appearance, it can be explained by the exposure of the matrix to arc heat, not sintering at high enough temperatures, insufficient sintering time or high additive ratio. It is thought that the increase in wear with the increase in the additive ratio, the increase in the amount of W powder in the electrical resistance and the increase in the temperature with the joule effect, and the subsequent softening of the wire contact surface, may cause both the W powders to break off and the formation of porosity and the deepening of the wear marks. It has been observed that similar excessive wear traces are very few or absent in CuW10 and CuW5 samples formed by sintering copper and W powder additive. As seen in Figure 10, the fact that the wear is linear and superficial is due to the welding wire going as close to the surface as possible and the matrix being soft. Particularly, it is observed that the wear and also the convection heat from the welding arc increases the temperature at the tip, where it is quite high, and in this case, the active gas, CO_2, reacts actively in this region, under high heat energy in the arc column created by the arc plasma, and a part of the O_2 in the gas mixture.

Figure 9. Close-up image of the cross-section of the contact guide (pin) a)CuW15, b)CuW10 and c)CuW5) tested in mass production.

(Lancaster, 1984) should be expected to form oxides. Intermittent initiation of the protective gas flow during each new weld seam initiation of the continuous gas flow may cause sudden oxidation and nitriding of the contact runners in contact with the ambient air. In addition, the presence of oxygen in the gas mixture used and the effect of high temperature show that oxide formation is possible in the same way. It should be noted that thermally induced material softening inhibits mechanical mixing of wear particles, although material transfer and retransfer processes occur in the severe wear regime. When the main wear mechanism is scraping material adhesion, contamination, and delamination, as the mechanism suggested in the above section, the parts exposed to cyclic loads between the sliding surfaces may become trapped in the matrix or matrix particle interface due to fatigue. The fact that W particles in Cu matrix are not exposed to deformation or are exposed to very little due to their hardness compared to Cu matrix, and the interfacial bond strength with Cu is low (Ma et al., 2018; Chen et al., 2016) causes W powders to break off from the matrix and cause abrasion or scraping.



a) b) c) d)

Figure 10. SEM wear trace images from Cu, CuW5, CuW10 and CuW15 specimens

As can be seen in Figure 11, as a result of the line analysis taken from the regions where wear occurs and where it does not occur, the amount of Cu in the uneroded region is higher. It is thought that the sinter surface is rich in Cu before the wear occurs, a homogeneous layer is formed by the combination of Cu powders on the surface during heat treatment, or it is enriched in Cu by plastering the softer Cu powders on the surface during pressing. The reduction of Cu in the worn parts (Figure 11a and b) causes oxidation and removal from the environment with the effect of corrosion, either by the abrasion of the surface of the welding wire or by the convection of Cu or by the effect of high temperature and the oxygen in the mixed gas.

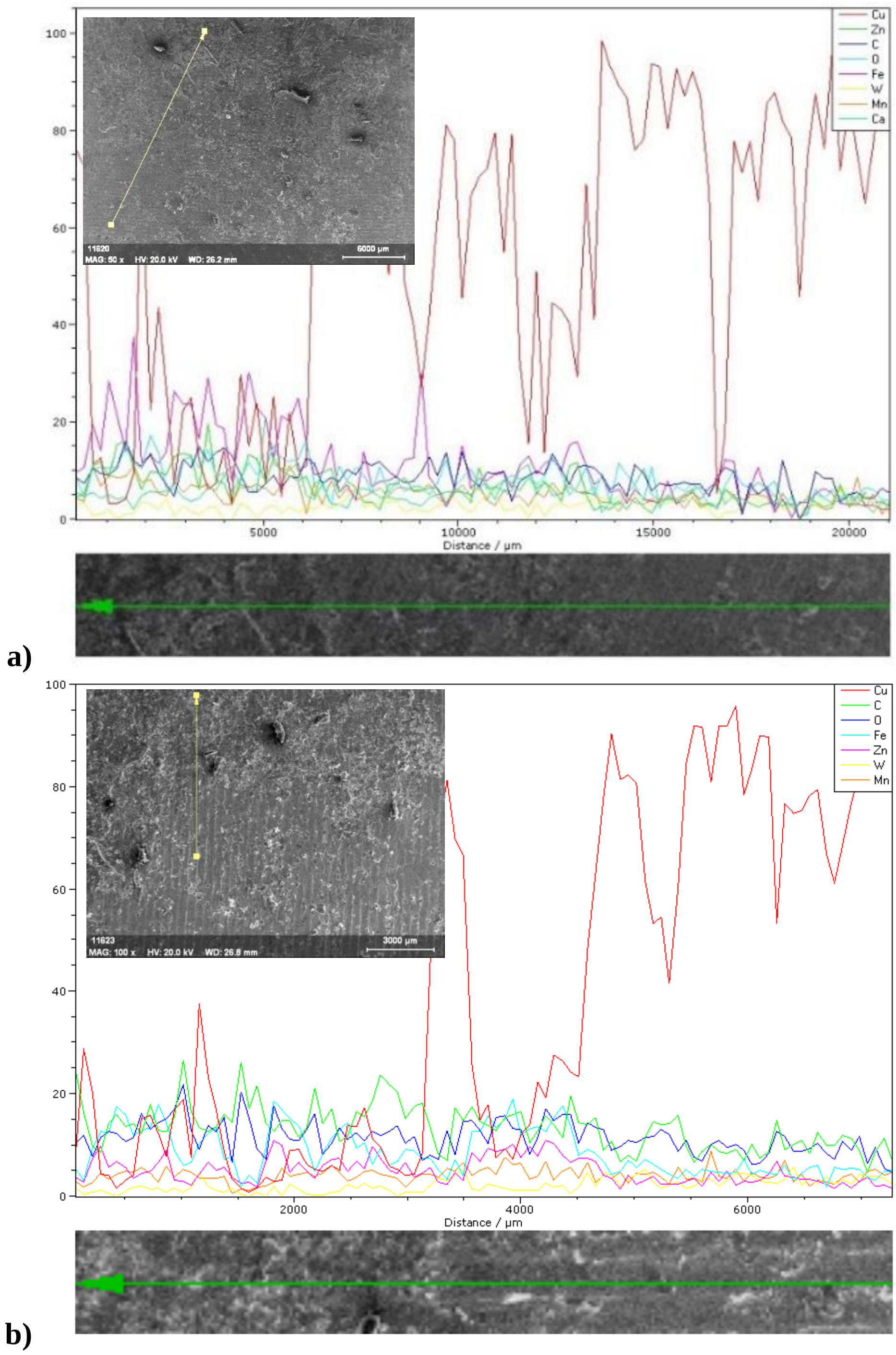


Figure 11. SEM and EDX analyzes of the wear surfaces of Cu10W and Cu5W samples

Regarding the softening of the surface and sub-surface areas close to the wire and matrix contact surface during the movement of the welding wire at the contact tips, arc instability may occur during sliding because the welding wire receives the electric current from different points under the continuous friction effect of the abrasive. When surface materials adhere to the opposing surface and show plastic deformation in the shear direction, microcracking may start at some weak bonding sites, particularly the particle-Cu interface. The softened material under shear and compressive stress is then pushed forward by the abrasive to form a thick shear layer. As subsurface deformation continues, cracks coalesce and grow, forming an interface between the abrasive material and the substrate at a given depth. As the tip of the subsurface crack approaches the contact surface, some layer of surface material is broken off and separated from the substrate, i.e. the matrix. Figures 10 and 11 show the condition of Cu-W sinter material after testing and the wear process of these composites.

4. CONCLUSIONS

The pins prepared with powder metallurgy containing Cu and 5%, 10% and 15% W were mounted on the MIG/MAG contact tips, and the following results were obtained as a result of the in situ production tests of the contact tips produced in this way:

1. According to test results, the wear trace appearances showed that the samples with the lowest (% 5) and the highest amount (%15) of additives experienced more wear than that of CuW10 sample due to the high amount of particle which reduces the interparticle distance.

2. The wire wear traces also show negative change at the contact tips according to the amount of additive, i.e. 5% and 15% W additions are poor in resistance in wire erosion.

3. Short-circuit damage was observed after 89892 mm long arc welding for CuW5 and 100788 mm for CuW10. This indicates that CuW10 sample is more resistant to wear damage due to better number of particles i.e. optimum interparticle distance.

4. For CuW15 sample, the test was terminated due to the wear on the tip after the 96248 mm long welding, and the targeted numbers were also reached. However, the length of weld is still high with CuW10 specimens.

5. When the wear traces are compared, Cu, CuW5 and CuW15 specimens appears to have suffered from deeper and wider form of wear whereas, the traces of CuW10 specimens spears to be shallow and less distorted due to the presence of optimum amount of W particles.

5. ACKNOWLEDGEMENTS

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6. CONFLICT OF INTEREST

Author(s) 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

Mustafa YAZAR has carried out experiments, collected experimental data and analyzed them. Şükrü TALAŞ has designed the research process and interpreted results.

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