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Araştırma Makalesi / Research Article

Spot Welding of AISI 1010 Steel Sheets Coated with WC by ESD Technique

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ABSTRACT: Surface coatings made with different methods change the surface properties of metallic and non-metallic materials and improve properties such as wear resistance. As a result of a hard surface coating, the surface is protected against wear, but problems may arise in arc and high-energy welded joints. Besides how the general properties of the coating layer change after the welding process, the mechanical properties of the welded joint are also important. In this study, tungsten carbide (WC) coating was carried out on AISI 1010 steel by ESD method at constant current using different frequencies and voltages and later two identical specimens were joined by spot welding at constant current and pressure. In order to reveal the welding zone, the samples were sliced into two, and then moulded and classical metallographic processes were applied. After metallographic processes, images were taken with an optical microscope and Electron microscopy to examine the microstructures formed in the weld zone. The results show that WC coated steel sheets cause localized alloying in the weld zone and therefore drastic changes in microstructures.

Keywords: AISI 1010 steel, Low carbon steel, Spot resistance welding, Electro-Spark Deposition (ESD), Tungsten Carbide (WC) Coating.

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ESD Tekniği ile WC Kaplanmış AISI 1010 Çelik Sacların Nokta Kaynağı

ÖZET: Değişik yöntemlerle yapılan yüzey kaplamaları, metalik ve metalik olmayan malzemelerin yüzey özelliklerini değiştirmekte ve aşınma direnci gibi özellikleri iyileştirmektedir. Sert bir fazla yüzey kaplama sonucunda, yüzey aşınmaya karşı korunmakta ancak ark ve yüksek enerjili kaynaklı birleştirmede sorun çıkabilmektedir. Kaplama tabakasının genel özelliklerinin, kaynak işlemi sonrasında nasıl değiştiğinin yanında, kaynaklı birleştirmenin mekanik özellikleri de önemlidir. Bu çalışmada, sabit akım, farklı frekans ve voltajlarda AISI 1010 çeliği üzerine ESD yöntemi ile tungsten karbür (WC) kaplama işlemi yapılmış ve daha sonra iki aynı özellikteki numune, sabit akım ve baskı kuvvetinde nokta kaynağı ile birleştirilmiştir. Kaynak bölgesini ortaya çıkarmak için numuneler ikiye bölünmüştür, daha sonra kalıba alınarak ve klasik metalografik işlemler uygulanmıştır. Metalografik işlemler sonrasında kaynak bölgesinde oluşan içyapıları incelemek için optik mikroskop ve Elektron Mikroskopisi ile görüntüler alınmıştır. Sonuçlar, WC kaplı çelik sacların kaynak bölgesinde bölgesel alaşımlamaya sebep olduğunu ve bu nedenle mikro yapılarda ciddi değişiklikler olduğunu göstermiştir.

Anahtar Kelimeler: AISI 1010, Düşük Karbonlu Çelik, Nokta direnç kaynağı, Elektro-Kıvılcım Biriktirme (ESD), Tungsten Karbür (WC) kaplama.

1. INTRODUCTION

In addition to mainly overcome the corrosion of metallic and non-metallic materials, surface coatings are widely used in almost every field of the industry to obtain various properties. ESD (Electro Spark Deposition) coatings have been applied to the steel in order to improve its existing mechanical properties or to gain some other properties, and have been subjected to some tests for general use (Kayalı and Talaş, 2019; Talaş et al., 2016). For this purpose, very hard alloys such as WC, CrC, medium hard alloys containing Co or different electrode materials containing soft metals such as Ag were selected for coating on steels and other alloys (Tang, 2009; Wang et al., 2009). Coatings made on stainless steel samples with these electrodes were subjected to severe wear and torsion tests, and significant improvements were made on the wear and torsion strength values of stainless-steel samples via ESD coating process (Jiao, 2018). TiC–TiB_2 composite coating was deposited by electrical discharge hardening onto the surface of 40Cr steel with a TiC–TiB_2 composite rod as electrode (Tang, 2016). TiB_2 / Ni coatings on the copper alloy electrode surface prepared by electrospark deposition were studied (Cheng et al., 2011). A titanium carbonitride (TiCN) coating was produced and compared to a tungsten carbide (WC) ESD coating (Miller et al., 2014). To improve the lifetime of electrodes used for the resistance spot welding of Zn-coated steel sheets, a TiB_2–TiC composite coating was fused onto the surface of spot-welding electrodes using an electro-spark deposition (ESD) process (Luo et al., 2014). In order to increase the life of conventional copper electrodes in resistance spot welding of Zn-coated sheet steel, a multi-layer Ni/(TiCP/Ni)/Ni composite coating was deposited onto the copper electrode top surface by electro-spark deposition (Zou, 2009). To obtain toughened Fe_2B coating and overcome various limitations of boriding, electro-spark deposition (ESD) was used to prepare nanocrystalline Fe_2B coating (Wei et al., 2017). The tribological properties of the coatings obtained by electro-spark alloying of C45 steel surfaces were studied (Padgurskas et al., 2017).

Ultra-hard surfaces were obtained by coating TiB_2 with ESD on AISI 1020 and 1018 low carbon steel samples (Agarwal and Dahotre, 1998). The tip surfaces of the Cu–Cr–Zr electrodes were coated with Cr–Ni filler metal by using electro-spark deposition (ESD) coating method under 40, 80, and

120 V. Consequently, the effects of the coating on electrode characteristics and properties of the TRIP800 resistance spot weldment were investigated (Emre and Bozkurt, 2020). In coatings deposited on HSS tool steels, the life of tool steels is increased by 2000% (Reynolds et al., 2003). A coating with a hardness of 1542 HV was obtained on AISI 304 stainless steel by using ESD and a ceramic layer such as Cr_7C_3 or Fe based amorphous alloy (Fe, Cr, Mo, Cd, C, B) electrode (Frangini et al., 2002; Wang et al. 1997). WC-based (Co, Mo, Ta etc.) hard alloys were coated with ESD technique on low carbon steel and pure titanium substrates to form an abrasion resistant coating which improved service life for 4.3 and 1.4 times on steel and pure titanium, respectively (Chen and Zhou, 2006).

In the ESD coating process, a crack-free, uniform and metallurgically bonded deposited layer was obtained by with and without additional layer such as pure Ni electrode, in order to add new features to, which is widely used in the industry besides steel (Liu et al., 2000). In recent years, studies have been carried out on the equipment and process used to increase the efficiency during the process, apart from the method of using different electrode pairs to maximize the new properties obtained in coatings made by the ESD process (Liu et al., 2005). The spot welding of coated surfaces are complicated process in which the reaction between Zn or coating materials and spot weld electrodes are the main concern. This, in turn, affects the weld performance and metallurgical characteristics (Emre and Kaçar, 2016; Müftüoğlu and Keskinel, 2007). For steel, there is vast amount of study involving the performance of resistance spot weld electrode tips and metallurgical reactions between the coated electrodes and welded sample (Emre and Kaçar, 2016; Müftüoğlu and Keskinel, 2007; Tumuluru, 2007; Gedeon and Eagar, 1986), however, there is very limited data available for the spot welding of WC coated steel sheets.

In this study, AISI 1010 steel was ESD coated and spot welded following the coating with WC. The spot weld zone was sliced and metallographically characterized using optical microscopy.

2. MATERIALS AND METHODS

AISI 1010 steel is ESD coated at different frequencies and voltages, and then welded with resistance spot welding. The metallographic processes have been applied by slicing the specimens into two from the weld zone. The composition of the iron-based material, AISI 1010, which is coated using electro-sparking deposition with WC electrode, is shown in Table 1. The voltage and frequencies used during the coating are 383 Hz (f3), 950 Hz (f6) and 1374 Hz (f9) and voltages are 48V (v3) and 78V (v6). WC electrode is of the 99% purity and commercially available. Table 2 shows frequencies and voltages sued in this study.

Table 1. Nominal composition of AISI 1010 steel and WC electrode material used in ESD coating (wt%)

Material	C	Mn	Si	Fe	Co	W
Steel	0.08-0.11	0.78	0.032	Bal.	-	-
WC	8.7	-	-	-	2.4	88.7

Table 2. The voltage and frequencies used during the coating

Experiment Parameters	F3V3	F3V6	F6V3	F6V6	F9V3	F9V6
Frequencies	383 Hz	383 Hz	950 Hz	950 Hz	1374 Hz	1374 Hz
Voltages	48V	78V	48V	78V	48V	78V

For coating, the SZ-3000 branded ESD coating machine is used, which has a power of 3KW, can produce a voltage in the range of 20-140V and whose coating frequency can be adjusted in the range of 100-1800 Hz. During the coating process, argon was used as the protective gas and the coating time was selected as 90s. The image of the test setup and coating machine prepared to ensure the rotation of the base material for the coating process and the passage of the current are shown in Figure 1.

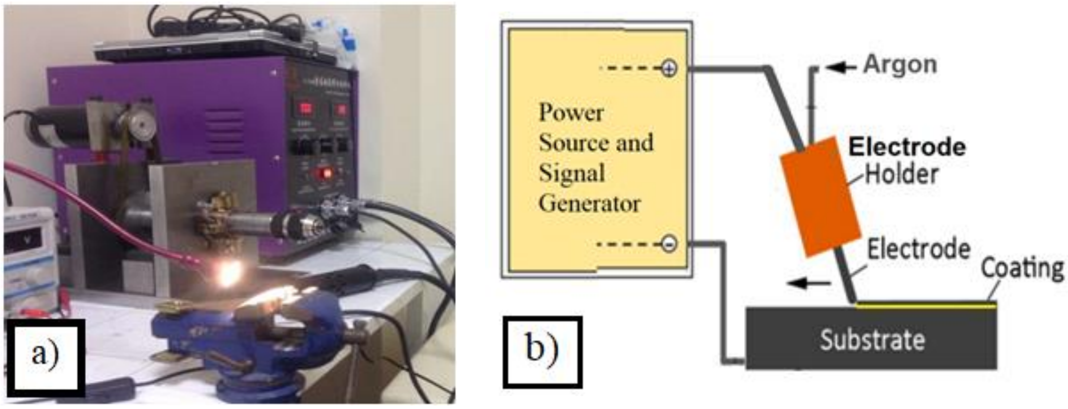

Figure 1. a) Electro-Spark Deposition (ESD) setup and b) principle of ESD coating

Specimens of 100 mm long, 2 cm wide and 0.75 mm thick, made of AISI 1010 quality steel, were spot welded using approximately 80A with an electrode compression force of 270 kN using an AC spot welding machine. For microstructure analysis, 1.5 mm thick samples were cut from the coated and spot-welded surfaces with precision cutting from the middle of the coating. Since the dimensions of the cutting result are small, it is taken into the cold moulding process in order to provide better holding in the sanding process. The cold moulding process is mostly created by mixing the hardener and the resin material together, and the mixture is hardened in the mould after a certain period of time. Grinding (up to 1200G) and polishing (Alumina solution - 1 micrometer) processes were carried out with the Metkon brand Gripon 2V model grinding equipment at an average speed of 250 rev/min. The microstructure images of the samples were taken and interpreted by electron microscopy. V3 corresponds to 48V and V6 corresponds to 78V. 5% HNO_3 acid with Ethanol mixture was used for etching. The resistance spot welding was done using copper electrodes and ATİKER OW-SPT-015K machine was used for the study.

3. RESULTS AND DISCUSSION

The images taken with the optical microscope of the samples where coating, welding respectively, are given in Figure 2. When the general properties of the samples with ESD coating are considered, pearlitic and ferritic structures were formed around the weld zone. Hard phase formation is not observed at the junction of the spot weld. There are structures similar to carbide formation in the weld zone, i.e. dark and angular shaped. In addition to fine bainitic structures, intermediate martensitic phase formation has also occurred in the weld zone, especially in HAZ.

The microstructure in as received condition is in the structure of ferrite + pearlite and it is known that the dark coloured area is pearlite and the light-coloured structures are ferritic. On the other hand, grain sizes are generally homogeneously distributed, and microstructural changes occurring due to hot rolling are observed in the microstructure.

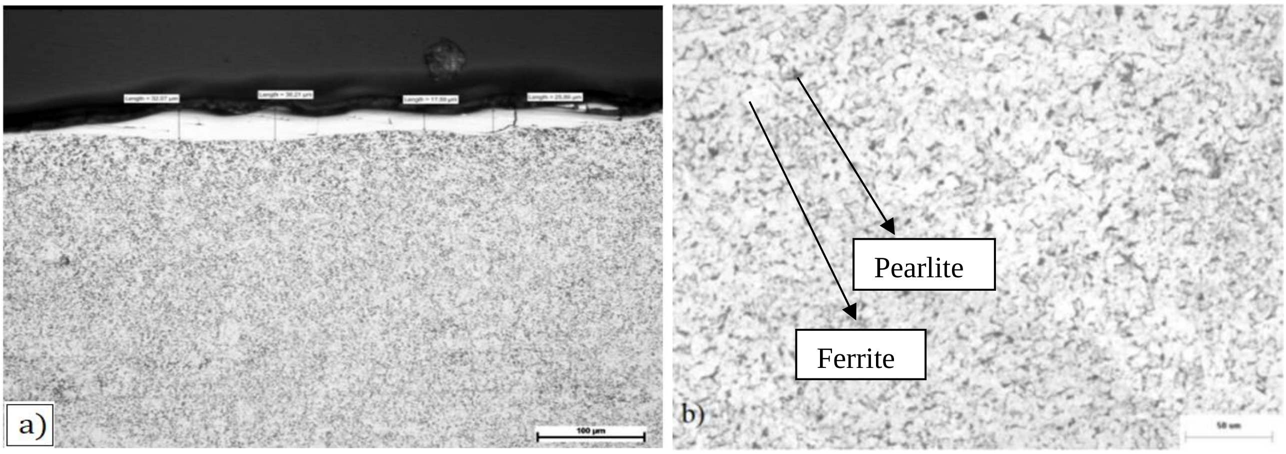

Figure 2. a) Thickness measurements of WC coating layer on the surface coated with ESD (Scale bar is 100 micron) and, b) microstructure of the 1010 steel in as received condition (Scale bar is 50 micron)

Table 3 shows the nugget diameters of spot welds and the length of HAZs along one side of the spot welds. As a result of the thickness measurements taken from the weld area and other parts of the spot welds of WC coated sheet metal, it can be said that the greatest spot weld size was observed with uncoated spot welds. The width of HAZ does not show a regular change with respect to change in frequency and voltage but weld zone width varies with respect to increasing frequency of the ESD source. Table 4 shows that hardness variations also follow the changes as in Table 3, too. The hardness variation with respect to change in voltage is not regular and irrespective of frequency. However, the hardness of HAZ drops as the frequency increases and it is interesting that as the voltage increases the hardness decreases slightly; it may be the effect from the high heat input with high voltage input, resulting in slower cooling rate and hence softer microstructures form or tempering effect reveals itself.

Table 3. The nugget diameters in mm with respect to frequency and coating voltage

WC	Uncoated	F3V3	F3V6	F6V3	F6V6	F9V3	F9V6
Weld Zone	3,44	3,27	3,07	3,12	3,04	3,06	2,99
HAZ	2,97	2,94	2,84	2,95	2,98	2,80	2,77

Table 4. The weld nugget and HAZ hardness values in HV with respect to frequency and coating voltage

WC	Uncoated	F3V3	F3V6	F6V3	F6V6	F9V3	F9V6
Weld Zone	233.3	407.3	437.2	412.8	504.8	426.7	399.6
HAZ	211.2	356.3	303.4	332.3	312.4	292.6	287.6

Figure 3 shows the microstructures from the specimens that were coated WC by ESD technique. In other zones, no clear findings in microstructure were observed. When the microstructures of spot weld zones are examined, in general, it can be seen that the most of the spot welds show a complete and sound joint. Except for the f9v6 sample, the weld zone in other specimens appears to remain the same.

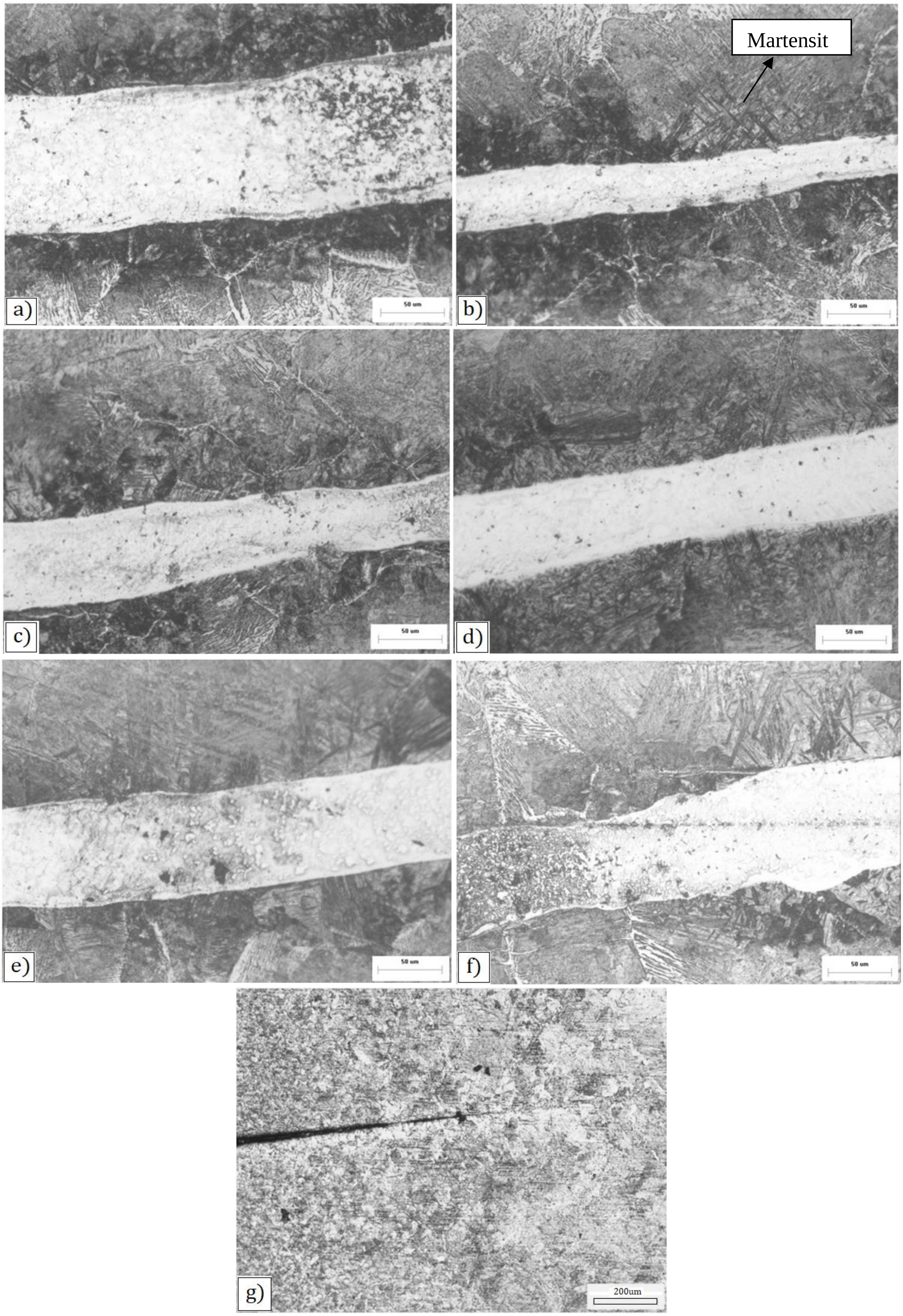

Figure 3. Microstructural images of spot welds made in uncoated condition and at different frequency and voltage values; a) f3v3, b) f3v6, c) f6v3, d) f6v6, e) f9v3, f) f9v6 and, g) Uncoated

It is important that uncoated spot welds are regular and the regions close to spot welds are darker in colour. It can be seen that ferritic and pearlitic structures are formed around the weld zones of the samples. The weld joint is rarely oxidized but the indication of finer structures in the welding area is clearly observed. Apart from the fine bainitic structures, the formation of martensitic phases is also seen in dark patches. Martensite formation, during which experiences a volumetric growth, creates very high local stresses and this causes the matrix structure of the steels to distort excessively and the deformation of the lattice structure leads to increased hardness following the fast-cooling process (Müftüoğlu and Keskinel, 2007). Si in steels is one of the important elements for general matrix hardness, and at the same time, when C is present, secondary phases for example by forming carbides of Fe and Cr, provide wear resistance but overhardened matrix may lead the formation of cracks due to over-alloying by W and WC dissociation (Tumuluru, 2007). This is highlighted by the formation of martensite near the weld zone and heat affected zone as seen in Figure 3.

4. CONCLUSION

In this study, the microstructures of AISI 1010 steel whose surfaces were coated with WC by using electro spark coating method, were investigated after metallographic examination.

- Measurements from the welding zone of steel which is coated with WC, showed that the thickness of the weld zone decreases at constant voltage with increasing frequency.
- It can be concluded that the increase in coating frequency improves the weldability of the WC coated AISI 1010 steel.
- As a general conclusion in the microstructure analysis taken from the weld zone, it can be seen that the pearlitic and bainitic structures are present in the weld zone. Due to the rapid cooling of the samples, their martensitic structures are observed occasionally.

5. 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.

6. AUTHOR CONTRIBUTION

Başar Ersegün ÇELİK and Esin Tuğba ŞİMŞEK have the full responsibility of the paper about determining the concept of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript and critical analysis of the intellectual content with the final approval.

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