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The use of NiAl coating deposited by ESD against the wear of sliding wire in GMAW contact tips

Gazaltı kaynak kontak uçlarında kayar tel aşınmasına karşı ESD ile yığılan NiAl kaplamaların kullanımı

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The use of NiAl Coating Deposited by ESD Against the Wear of Sliding Wire in GMAW Contact Tips

Highlights

- *NiAl coating has improved the service life of GMAW weld contact tips by 50% compared to uncoated tips.*
- *ESD coating of contact tips with NiAl generated phases that are different to NiAl electrode material.*
- *An industrially viable coating parameter for contact tips were sucessfully tested.*
- *NiAl coating generated surface hardness higher than that of Copper substrate by alloying.*
- *Spatter on the surface of contact tips were reduced dramatically, providing a better working conditions.*

Graphical Abstract

Electro Spark Deposition (ESD) coating of GMAW contact tips were carried out to improve the performance against sliding wire wear during welding operation.

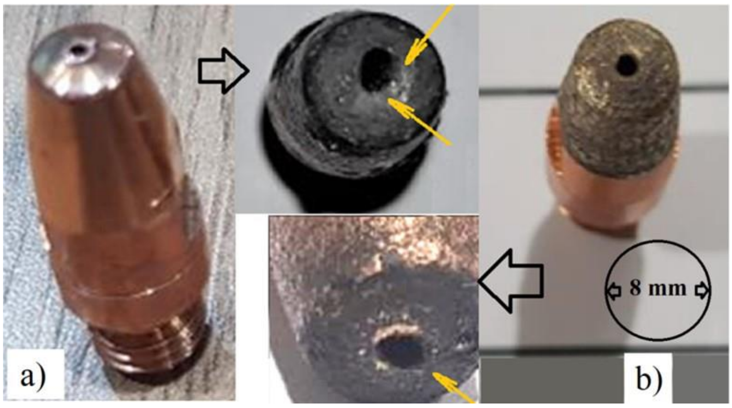

Figure. GMAW weld contact tips befor and after NiAl coated by ESD process.

Aim

GMAW weld contact tips were coated with NiAl using Electro-spark deposition technique in order to improve the service life of GMAW contact tips.

Design & Methodology

The GMAW contact tips were coated with NiAl using ESD coating technique and the specimens were tested in in-situ GMAW robotic welding conditions.

Originality

The coating of contact tips was carried out against sliding wire wear problem and the use of NiAl coating using ESD process for this purpose is an original approach in this field.

Findings

ESD coating of NiAl was successfully applied onto GMAW contact tips which were tested in situ using robotic weld statins in actual service conditions and it was observed that surface of cntact tips were alsmot spatter free and wear resistance improved by 50 %. A coating parameter for contact tips were sucessfully developed and tested.

Conclusion

The use of NiAl coating were found to improve the resistance against sliding wire wear that shortens the service life of contact tips. NiAl coating limits the sticking of spatter during welding operation and produce spatter-free surface.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

The use of NiAl Coating Deposited by ESD Against the Wear of Sliding Wire in GMAW Contact Tips

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Araştırma Makalesi / Research Article

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ABSTRACT

The wear during the sliding of wire in Gas Metal Arc Welding (GMAW) causes the contact tips to be replaced after a certain number of hours of service. In order to reduce the wear, GMAW weld contact tips were coated by NiAl using ESD (Electro Spark Deposition) with 60V and 500 Hz under Argon. The testing of contact tips were done on robotic GMAW stations and standard metallographic techniques and SEM microscopy were used to reveal the microstructure. The results indicate that the service life of contact tips can be extended as much as 50 % compared to uncoated contact tips in concern via the use of NiAl coating, affecting the wire friction wear performance during high temperature welding process.

Keywords: Wear, ESD coating, NiAl, contact tips.

Gazaltı Kaynak Kontak Uçlarında Kayar Tel Aşınmasına Karşı ESD ile Yığılan NiAl Kaplamaların Kullanımı

ÖZ

MİG kaynaklarında telin kayması sırasındaki aşınma, belirli bir hizmetten süresinden sonra kontak uçlarının değiştirilmesine neden olur. Aşınmayı azaltmak için MİG kaynak kontak uçları, Argon altında 60V ve 500 Hz ile ESD (Elektro Kıvılcım Biriktirme) kullanılarak NiAl ile kaplanmıştır. Kontak uçlarının testi robotik MIG istasyonlarında yapılmış olup, mikroyapıyı ortaya çıkarmak için standart metalografik teknikler ve SEM mikroskobu kullanılmıştır. Sonuçlar, yüksek sıcaklıkta kaynak işlemi sırasında tel sürtünmesinin aşınma direncini etkileyen NiAl kaplamanın kullanılmasıyla ilgili kaplamasız kontak uçlarına kıyasla temas uçlarının hizmet ömrünü % 50'ye kadar uzatılabileceğini göstermektedir.

Anahtar Kelimeler: Aşınma, ESD kaplama, NiAl, kontak uçları.

1.INTRODUCTION

Arc welding requires electric current by which a metal wire is melted during this high temperature joining process. All the parts that are in touch with wire and close to the arc plasma volume experiences high temperatures and high thermal efficiency or conductivity is required to ward off the heat from this part of welding zone. One of the parts that are subjected to heat the most is weld contact tip which directs the wire to the high temperature arc region and also conduct the electric current [1, 2]. A continuous friction between the welding wire and weld contact tips causes a wear around the front outlet of the contact tip where the wire moves along. Outer surfaces are usually coated with a residue from the high temperature products such as inorganic compounds and spatter accumulation originating from the arc region, and hence blocking the contact tip end resulting in a short circuit by clogged tip cavity, burnback and wear [3-5]. Wear is a process where the opposing surfaces experience high level of friction and lead to the formation of surface defects and or loose particles from any surfaces. Sliding wear does not usually involve the formation of debris in high amounts, which elevates the surface wear; in addition to the presence of spatters, the effect of contact load is also another parameter which, at low values and sliding speeds, causes mild surface wear and produce low friction by tribolayers such as oxide wear debris generated during sliding process [2, 6-9]. ESD coating is electro spark coating that uses micro arc to generate liquid drops and alloy the surface giving it a different composition and hence different properties [10]. ESD is applied for some purposes, such as increasing the corrosion, erosion and wear resistance of materials, reducing or preventing oxidation, reducing thermal load at high temperatures, and reducing maintenance costs. ESD (Electro-Spark Deposition) coatings have been applied to the steel and copper parts in order to improve

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its existing mechanical properties or to gain some other properties, and have been subjected to some tests for general use [11, 12].

An intermetallic is a type of metallic alloy that forms an ordered solid-state compound between two or more metallic elements. Intermetallics are generally hard and brittle, with good high-temperature mechanical properties and Nickel aluminides are one of the most feasible type of intermetallics in use [13]. NiAl and Ni_3Al intermetallics, types of nickel based intermetallics, have low density and excellent high temperature resistance against oxidation wear behaviour. Ni_3Al, which is more ductile compared to NiAl type intermetallic alloys were also subject of research on wear [14-18] but NiAl type of intermetallics are merely investigated based on their wear properties [19, 20]. Since the oxidation of NiAl is characterized by adherent and protective Al_2O_3 scale, which also helps with the lowering of friction forces. NiAl intermetallics are also studied for tribological properties such as abrasion resistance properties with and without TiB_2 additions. This research showed that the tribological performance of NiAl alloys are comparable to Ni_3Al alloys and show good tribological behavior[21].

In this study, GMAW weld tips were coated by ESD machine (60V and 500Hz) using NiAl electrodes which were produced by vacuum arc melting and SEM (Scanning Electron Microscopy) was carried out on the surface of tips following the coating and the use in service for 4 weeks.

2.MATERIAL AND METHOD

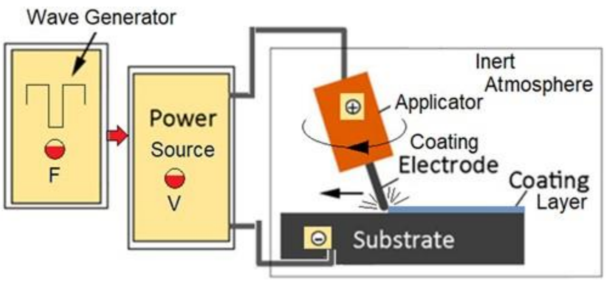


Figure 2. Schematic of the ESD coating system

In this study, GMAW weld tips were coated by ESD technique (60V and 532Hz) using NiAl electrodes; a schematic of ESD is given in Figure 1. The NiAl electrodes were produced by vacuum arc melting using high purity powders of Ni and Al (>99%, Alfa Aesars), which were compacted under the pressure of 150MPa and then remelted under 10-4 mbar vacuum assisted by Argon flushing. A rod of 3 mm diameter was obtained after remelting as an electrode for ESD coating. Metallographic study was performed using optical microscope (Olympus) and SEM (Scanning Electron Microscope - Zeiss-LEO 1430 VP) on the surface of contact tips following the ESD coating process and after 4 weeks in service. Coating thickness was measured on the optical microscope with an in built scale on specimen that was etched with v/v 1 % HF+Ethanol (Bal.) mixture and then with Nital. The ESD coating was performed for a period of 2 minutes on the contact tip which was fixed on a rotating holder. The applicator also rotates during the operation. Hardness measurements were made on coated and uncoated copper contact tips using Shimadzu HMV brand microhardness tester with 50gr load. The coated contact tips with a nominal composition of max. 1.2 wt. % Cr, max. 0.3 wt. % Zr and Cu (Bal.) were tested on an industrial welding robot (Figure 2) using a 1 mm welding wire (Magmaweld MG3) at a current of approximately 300A. GMA welding of 1 mm thick base metal and M10 nut was used to test the weld contact tip.

Figure 2. a) Robot arm used for the study and b) automotive part welded using coated contact tips

The number of complete welds were counted to compare the results against unused copper tips. The inspections of welds were made visually after the welding was completed. Spattering is one of the problems that affect the quality of weld as well as causing more labour intensive work to clean up [22, 23]. This results in more clean up time and labour cost and hence, the study was aimed to reduce these expenses and time consumption on maintining the weld tips and removing spatters on the surface of workpieces. To reduce the amount of spatter on the surface copper tips and the wear, the outer surface of copper tips were also coated. The surface perpendicular to wire outlet bore were particularly multi-coated to provide a support against sliding wear as the observations suggest that wear of copper tips results in keyhole formation, by driving the wire on one side. A homogeneous wear would be an advantage in this situation.

3.RESULTS AND DISCUSSION

3.1.The coating formation and the wear characteristics

GMAW contact tips (Figure 3) were coated with NiAl using ESD and uncoated weld tip was also tested for the control purposes. Orifice or wire guiding bore diameter, which is just over 1 mm to ease the passage of the welding wire in unused weld tips, was measured before and after the service. Bore diameter measurements and observations showed that there is always a wear around the orifice, especially within a 2mm in length from the tip surface towards inside. The wear on contact tips was evaluated by the ratio of orifice diameters of coated and uncoated weld tips and was always less than 1. The diameter of used contact tip is usually 50% larger than that of unused contact tip, although it would mostly depend on the service duration, too. This shows that wear in this part of contact tips needs to be improved drastically.

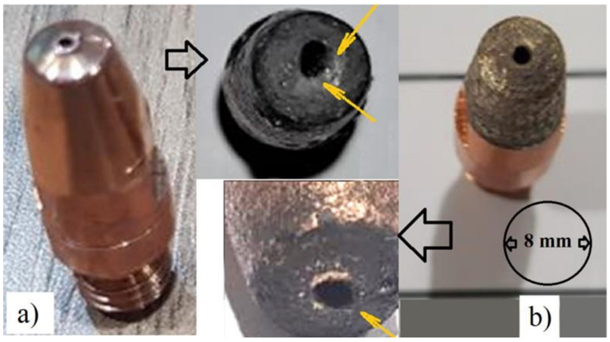
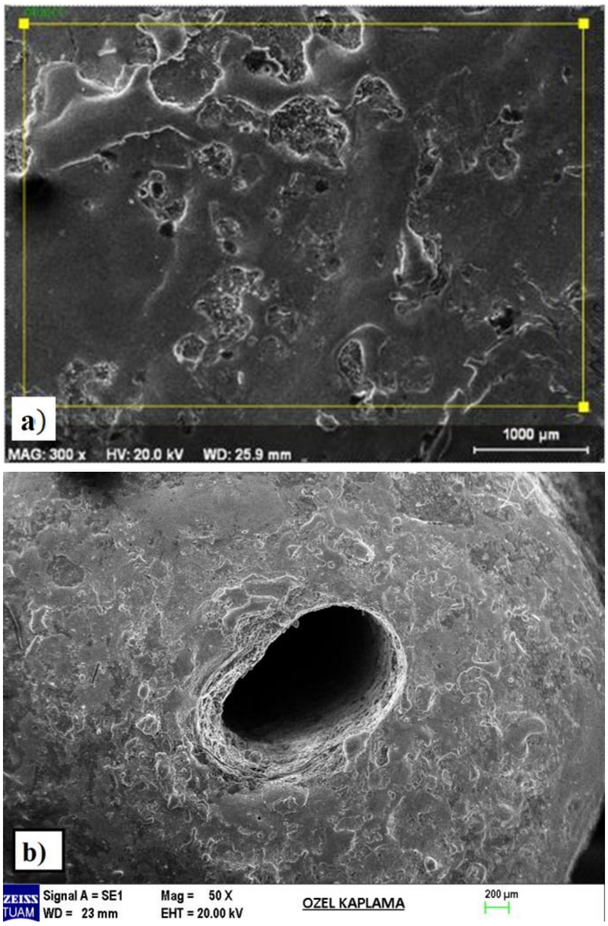


Figure 3. a) Unused and used copper contact tips and b) unused NiAl coated and used NiAl coated copper contact tips; arrows show worn regions.

As shown in Figure 3 that uncoated weld tips are prone to multiple side wear due to sliding wire but NiAl coated wire present single point wear as shown by arrows in Figure 3a and b. The surface of weld tip was successfuly coated as seen in Figure 3a NiAl coated surface of Cu weld tip shows smooth appearance of NiAl layer. Figure 3b shows worn outlet bore after service.

3.2.Coating characterization and hardness

General appearance of the coating is shown in Figure 4a, b and d. Figure 4c gives the EDX compositional analysis of ESD coating on the contact tip, which indicates that the coating is composed of Ni, Al and significant amount of Cu as possibly result of alloying with substrate materials, that is Cu. The ESD coating thickness on the contact tips are varied but an average coating thickness of 34.14 µm ±14 µm was measured along the ESD coating of contact tip. Coating is in general continuous and there are no cracks observed along the coating. Smooth surface is the result of molten drops spreading on the surface of copper contact tips. Such appearance is very common in ESD coated surfaces. Porosity is also observed throughout the surface due to trapped gases forming either in contact with previously deposited layer and hence air or Argon gas is released through these outlet holes or gas metal reactions ocucuring on the surface of molten metal dropping out of electrode.



Spectra: object

Element	Series	Net	unn. C [wt.-%]	norm. C [wt.-%]	Atom. C [at.-%]
Carbon	K series	5245	13.37	14.40	36.78
Oxygen	K series	2635	10.35	11.15	21.37
Aluminium	K series	7821	7.44	8.01	9.11
Iron	K series	385	0.33	0.35	0.19
Nickel	K series	9268	15.11	16.27	8.51
Copper	K series	21170	46.26	49.82	24.05

c) Total: 92.9 %

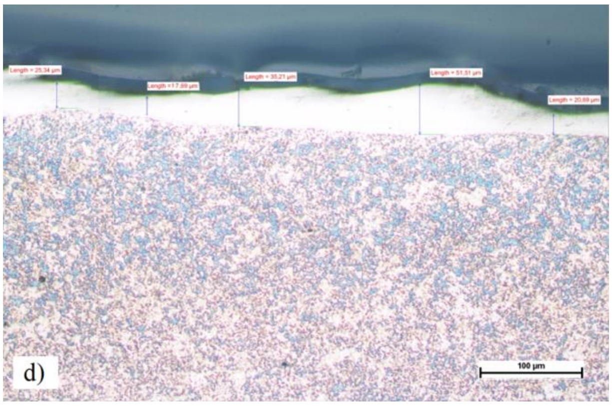


Figure 4. a) NiAl coated contact weld tip and b) SEM image of worn NiAl coated surface of contact tip, c) EDX result of coating in a and d) optical image of coating on substrate.

The hardness values are more pronounced when compared to coated and uncoated surface, i.e. approximately 119±11 $HV_{0.05}$ for uncoated contact tip and 248±23 $HV_{0.05}$ for NiAl coated surface. The effect of coating causing an increase in hardness values stems from the fact that alloying element from the NiAl electrode alloys base metal in the vicinity of surface and fast cooling experienced during ESD coating process. The alloying behaviour of elements, i.e. substitutional or interstitial, and solubility within each other will determine on the degree of matrix hardening.

The solubility of Ni in Cu shows a complete solid solubility while Al and Cu are partially soluble in both solid and liquid phases according to the equilibrium phase diagram [24, 25]. Both Al-Cu system and Ni-Al system produce many intermetallic phases [25]. Although, the ideal cooling conditions give a way to the formation of such phases, non equilibrium cooling conditions are more representative of this ESD alloying process. The XRD results in Figure 5 indicates that there are many compounds formed following the coating by ESD on Cu weld tip.

The XRD analysis of NiAl rod used as coating electrode showed that the coating rod was a single phase (β) NiAl with B2 ordered crystal structure and the XRD result from the coating is given in Figure 6 b. The β NiAl coating is deposited on Cu surface at short intervals (i.e. high frequency) and this in turn makes the freezing process faster than usual as the heat input is relativley low compared to normal arc welding. In an ideal situation, βNiAl single phase should have formed on the surface but the presence of two more intermetallics phases suggest that the freezing is dominated by fast cooling (will manifest itself as high C_{solid}/C_{liquid} compositional ratio being greater than k_a, the solute partitoning coefficient) [26] and hence the completion of NiAl phase on the surface is not equilibrated due to phase seperation at liquid stage. This requires an understanding of having a liquid of NiAl molten drops which completes the reaction of solidification on the surafce by forming near equilibrium and non equilibrium phases such as Ni_3Al and Ni_2Al_3 intermetallics phases that are also present in the ESD deposited coating. A rapid alloying of liquid electrode material drop with Cu is promoted by the high solubility of Cu in Ni and hence a layer of CuNi solid solution is expected between coating and Cu substrate.

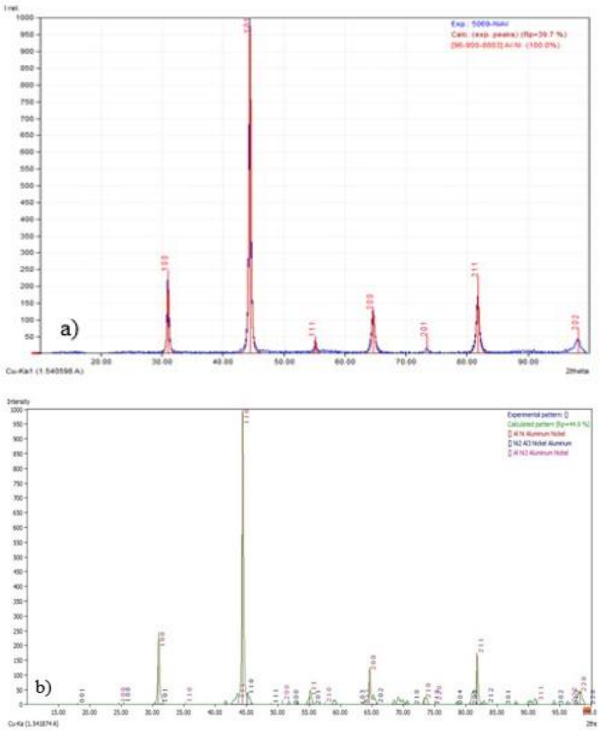


Figure 5. XRD results from a) NiAl rod and b) NiAl coating

3.3.The testing of weld tips

The results from the service performance sheets show that coated copper weld tips overdo the performance from the coated weld tips showing the effect NiAl coatings in response to uncoated tips. Uncoated weld tips performs 184 pieces per week but NiAl coated weld tips were used to produce 384 pieces per week, generating a wear free surfaces with more than 50% improvement. Coated tips performed better with an orifice clean of sparks and thick residues as oppose to uncoated tips. The longevity of copper contact tips is very much comparable to uncoated copper tips. Sticking of droples due to spattering was eliminated almost 100% because of a thermal barrier effect and also possibly due to oxidation of coating. Intermetallic based NiAl coating by ESD also limits the formation of surface alloying in case of spatter (in the form of molten droplets from the arc plasma) strike the surface of contact tip as the compound Al_2O_3 on NiAl coating surface [13] has a high melting point and chemically inert as a substrate [27]. NiAl coatings perform better than uncoated surfaces due possibly to their best resistance against corrosion at high temperatures by which weld tips become softer and more prone to wear. The abrasion tests of NiAl and $NiAl_3$ intermetallics showed that NiAl has a better wear resistance than $NiAl_3$ phase [19] in which the wear rate of $NiAl_3$ was double of NiAl intermetallics and addition of TiB_2 improved the wear resistance by 2 to 4 times [21]. NiAl dry sliding wear test also showed that, with increasing Al, the wear rate decreases [28] and in general wear rate of NiAl intermetallics are 3 times better than that of Cu in pure form [29]. The arc temperature may reach above 10,000°K [1] but nozzle temperature may only reach around 500°C [2], which is still lower than transformation point of NiAl [13] and may not be enough to make some intermetallics ductile but with toughness unlike of Cu. At this temperature, sliding wire may grind away Cu more than intermetallic phase coating but a harder coating will also prevent the Cu from being ground away and improve the service performance with a possible constriction.

4.CONCLUSION

Following conclusions can be drawn from this study:

- Weld tips were successfully coated by ESD method and tested in industrial conditions for a viable performance.
- Coating of NiAl have created a thermal barrier between arc source and weld tip, helping improve the resistance against spatter sticking to the surface.
- NiAl coating on the surface of copper contact weld tips provided wear resistance against sliding wire performing better than that of uncoated surface.
- Coating of Cu contact tip surface with NiAl electrode resulted in the formation of phases different than that of NiAl electrode material.
- The contamination on the contact tips which were exposed to high arc temperature and arc fumes was relatively less compared to uncoated contact tips.

5.ACKNOWLEDGEMENT

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mustafa YAZAR: Performed the experiments and analysed the results.

MİLAT KUL: Performed the experiments and analysed the results.

Ali KEMAL ALP: Help with experiments and wrote the manuscript.

Şükrü TALAŞ: Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

6.REFERENCES

[1] Lancaster J.F., "The physics of welding", ***Physics in Technology***, 15:73-79, (1984).

[2] Adam G., Sievert T.A., Quinn T., Vigliotti P., "Contact Tube Temperature during GMAW", ***Welding Journal***, December, 37-41, (2001).

[3] Yamada T. and Takana O., "Fluctuation of the Wire Feed Rate in Gas Metal Arc Welding", ***Welding Journal***, 66: 35-42, (1987).

[4] Villafuerte J., "Stronger copper for longer lasting contact tips and electrodes", ***Welding Journal***, 82: 50-52, (2003).

[5] de Meneses V.A., Gomes J.F.P. and Scotti A., "The effect of metal transfer stability (spattering) on fume generation, morphology and composition in short-circuit MAG welding", ***Journal of Materials Processing Technology***, 214: 1388-1397, (2014).

[6] Childs T.H.C, "The sliding wear mechanisms of metals, mainly steels", ***Tribology International***, 13(6): 285-293, (1980).

[7] Shimizu H., Yokota Y., Mizuno M. and Kurokawa T., "Wear mechanism in contact tube", ***Science and Technology of Welding and Joining***, 11: 94-105, (2006).

[8] Matsui H. and Hattori T., "Abrasion phenomena of the contact tip in consumable electrode arc welding", ***Welding International***, 32: 475-484, (2018).

[9] Rigney D.A., "Sliding wear of metals", ***Annual Review of Materials Science***, 18: 141-163, (1988).

[10] Wang J.S., Meng H.M., Yu H.Y., Fan Z.S. and Sun D., "Characterization and wear behavior of WC-0.8 Co coating on cast steel rolls by electro-spark deposition". ***International Journal of Minerals, Metallurgy and Materials***, 16(6): 707-713, (2009).

[11] Kayalı Y. and Talaş Ş., "Investigation of Wear and Corrosion Behaviour of AISI 316 L Stainless Steel Coated By ESD Surface Modification", ***Protection of Metals and Physical Chemistry of Surfaces***, 55(6): 1148-1153, (2019).

[12] Talaş Ş., Mertgenç E. and Gökçe B., "ESD coating of copper with TiC and TiB2 based ceramic matrix composites", ***IOP Conference Series-Materials Science and Engineering***, 146: 012005, (2016).

[13] Talaş Ş., "Nickel Aluminides" in "***Intermetallic Matrix Composites: Properties and Applications***", Ed. by Rahul Mitra, Series in Composites Science and Engineering (2018).

[14] Miracle D.B., "The physical and mechanical properties of NiAl", ***Acta Materialia***, 41: 649–684, (2003).

[15] Sikka V.K., Deevi S.C., Viswanathan, S., Swindeman, R.W. and Santella, M.L., "Advances in processing of Ni3Al-based intermetallics and applications", ***Intermetallics***, 8: 1329–1337, (2000).

[16] Gong K., Luo H.L., Feng D. and Li C.H., "Wear of Ni3Al-based materials and its chromium-carbide reinforced composites", ***Wear***, 265: 1751–1755, (2005).

[17] Demirel M. & Mehtap Muratoglu, M., "Influence of load and temperature on the dry sliding wear behavior of aluminium-Ni3Al composites", ***Indian Journal of Engineering & Materials Sciences***, 18: 268-282, (2011).

[18] Jozwik P., Polkowski W. and Bojar., "Applications of Ni3Al based intermetallic alloys- current stage and potential perceptivities", ***Materials***, 8: 2537-2568, (2015).

[19] Xue, B., Zhu, H., Shi, X., "Tribological performance of NiAl alloy containing graphene nanoplatelets under different velocities", ***Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology***, 231(6): 799-809, (2016).

[20] Hawk J.A. and Alman D.E., "Abrasive wear of intermetallic-based alloys and composites", ***Materials Science and Engineering*** A, 239–240: 899-906, (1997).

[21] Hawk J.A. and Alman D.E., "Abrasive wear behavior of NiAl and NiAl–TiB2 composites", ***Wear***, 225–229: 544-556, (1999).

[22] Kah P., Suoranta R. & Martikainen J. Advanced gas metal arc welding processes. ***International Journal of Advanced Manufacturing Technology***, 67: 655–674 (2013).

[23] Kristóf D., Németh L. "Investigation of the Contact and Wear of the Welding Wire and MIG-Welding Contact Tips". In: Jármai K., Farkas J. (eds) ***Design, Fabrication and Economy of Metal Structures***, Springer, Berlin (2013).

[24] Porobova S., Markova T., Klopotov V., Klopotov A., Loskutov O. and Vlasov V., "Copper-based alloys, crystallographic and crystallochemical parameters of alloys in binary systems Cu-Me (Me=Co, Rh, Ir, Cu, Ag, Au, Ni, Pd, Pt)", ***AIP Conference Proceedings***, 1698: 030005, (2016).

[25] Raghavan V., "Al-Cu-Ni (Aluminum-Copper-Nickel)", ***Journal of Phase Equilibria and Diffusion***, 27: 389-391, (2006).

[26] Pinomaa T., Laukkanen A. and Provatas N."Solute trapping in rapid solidification", ***MRS Bulletin***, 45(11), 910-915, (2020).

[27] Brumm M.W, Grabke H.J, "The oxidation behaviour of NiAl-I. Phase transformations in the alumina scale during oxidation of NiAl and NiAl-Cr alloys", ***Corrosion Science***, 33: 1677-1690, (1992).

[28] Johnson B.J., Kennedy F.E. and Baker I., "Dry sliding wear of NiAl", ***Wear***, 192(1–2): 241-247, (1996).

[29] Zhang Y.S., Wang K., Han Z. and Liu G., "Dry sliding wear behavior of copper with nano-scaled twins", ***Wear***, 262(11–12): 1463-1470, (2007).