Vol. 40, No. 1 (2018) 73-80, DOI: 10.24874/ti.2018.40.01.06

Tribology in Industry

www.tribology.rs

RESEARCH

Introduction of Nickel Coated Silicon Carbide Particles in Aluminum Metal Matrix Hardfaced by MIG/TIG Processes on Precoated Flux Layer

V. Kamburov[a], R. Dimitrova[a], M. Kandeva[a]

Technical University of Sofia, 8 Kl. Ohridski Blvd, 1786 Sofia, Bulgaria.

Keywords:

Wear resistance
Tribology
Aluminium metal matrix composites
MIG and TIG processes
SiC particles
Hardfacing
Aluminium flux

Corresponding author:

V. Kamburov
Technical University of Sofia
8 Kl. Ohridski Blvd
1786 Sofia, Bulgaria
E-mail: vvk@tu-sofia.bg

A B S T R A C T

The aim of the study was to investigate an aluminium metal matrix surface layer hardfaced by shielded gas metal arc welding processes applying either metal inert gas (MIG) or tungsten inert gas (TIG), with standard wire filler onto the precoated flux layer – a baked resistant film containing electroless nickel coated micro/nano SiC particles. During baking, the components of the flux ($MgCl_2$, NaCl, KCl and Na_3AlF_6) form a low melting eutectic, which: protects the hardfaced surface from oxidation, provides electrical conductance and keeps the particles on the surface during welding, as well as facilitates particles wettability and their interfacial bonding with the molten metal into the weld puddle.
The hardfaced layers were studied by NDT, SEM and EDX, as well as nanoindentation and wear resistance tests. The results from the non-destructive radiographic test show lack of imperfections, porosity and slag inclusions only after TIG hardfaced using nano SiC particles. The wear resistance increased from 25 % (TIG) up to 71 % (MIG), which was due to the presence of the incorporated in the hardfaced layer reinforced phase of electroless nickel coated micro/nano SiC particles. The obtained wear resistance test results correspond to the obtained hardness test values.

1. INTRODUCTION

Ceramic reinforced metal matrix composites are new structural light materials because of the changed properties of the metal matrix: high specific strength and stiffness, increased hardness, wear resistance and good dimensional stability, suitable for creating high performance hybrid materials utilizing, matrices of light aluminium, magnesium and titanium alloys [1,2].

Ceramic-reinforced aluminium matrix composites are known as materials with high strength-to-weight ratio, superior tribological properties and corrosion resistance behaviour, for which they are replacing their monolithic alloys in the field of automobile, marine and aviation engineering [3]. The silicon carbide and alumina are mostly utilized compared to other synthetic reinforcing particulates but some industrial waste as fly ash (Al_2O_3, SiO_2, and

Fe_2O_3) have been suggested to be suitable as reinforcement in both single and hybrid composites [4]. Electroless nickel coated SiC particles could be used in applications of metal matrix composites because metalized ceramic particles have a better wettability in and incorporation from molten metal [5] and also have better wear resistance [6].

The present paper aims a study of hardfaced surface layers of dispersive reinforced material (electroless nickel coated ceramic particles) in pure aluminium metal matrix. The reinforced layers are deposited by shielded gas metal-arc welding (MIG/TIG) using standard wire filler onto the precoated flux layer of a baked resistant film containing metalized micro/nano SiC particles additionally coated by cryolite.

2. PRETREATMENT OF THE MATERIALS

The following materials for hardfacing were used: substrate of pure aluminium and electroless nickel coated silicon carbide microparticles, fraction 7-10 µm. To improve wettability of the reinforcement, a surface electroless nickel plating (Ni-P) on SiC particles in alkaline bath using two nickel salts ($NiSO_4$ and $NiCl_2$) is conducted [7].

The basic problem in wear resistant layers hardfacing using dispersive reinforced material (powder) on aluminium matrix is the incorporation of the reinforcing phase by the matrix and formation of a good adhesion between them. Particles cladding for the process of hardfacing by shielded gas metal-arc welding aims assisting the wettability of the non-metallic particles, which makes easier their incorporation in the metal matrix [8]. Deposition of stable surface layer by flux coated particles during shielded gas metal-arc welding provides:- protection of the hardfaced surface from oxidation as a resulting reaction with the oxide film, which gets detached as slag during the weld puddle crystallization; - sufficient electrical conductance during its melting; - fixing and retaining of the particles on basic metal surface during shielded gas arc hardfacing process; - easier wettability of the particles and their penetration in the molten metal in order to be obtained a dispersive reinforced coating.

The aim of cladding was to receive a coating of flux over metalized ceramic particles. A coating flux was elaborated on the basis of cryolite and three salts – sodium chloride, potassium chloride and magnesium chloride, using the different solubility of those individual components within a water solution - insoluble (Na_3AlF_6) and the rest of soluble in water salts ($MgCl_2$, NaCl, KCl) [9]. The cryolite was open in water with base pH, without the presence of an acid that can dissolve or compromise the metallized layer. The cryolite has a maximal solubility at pH 8.5 (100-200 g/L) without precipitation as it has to be seen from its aqueous solution solubility diagram [10]. Ammonia solution (25 % $NH_3(OH)$) which was heated up to 70-80 ^{0}C under the magnetic stirring condition was used. After reaching the required temperature electroless nickel coated SiCp was added to this solution and stirring was continued maintaining this conditions. After drying and milling the coated by cryolite metalized particles are mixed with rest salts in certain proportions (40.4% $MgCl_2$, 31.8 % NaCl and 25.4 % KCl and water until a slurry is obtained [11]. The aim was to obtain a low triple eutectic above the layer of cryolite) with a melting point of 450-500 ^{0}C [12].

The results of prepared for SEM/EDX analysis specimens containing layers with plated by cryolite metalized SiCp are shown on Fig. 1.

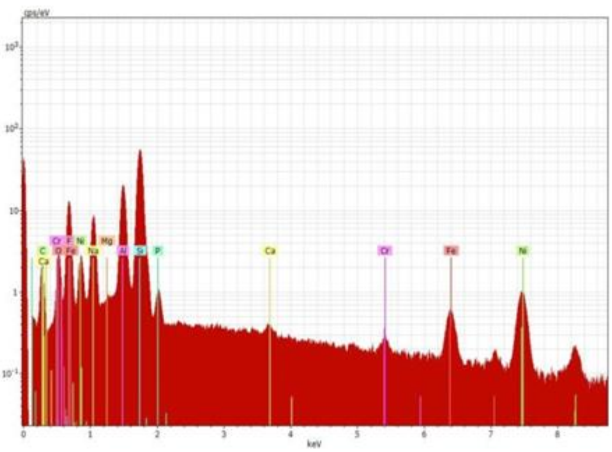

Fig. 1. Energy Dispersive X-ray microanalysis of electroless nickel and cryolite coated SiCp.

Specimens of pure aluminium with electroless nickel coated and flux coated micro/nano SiC particles (SiCp) layer were prepared, as well as a reference specimen. The aim of the cladding was to obtain flux coating on the metalized SiCp by treating of their surface through successive application of flux basic components and its subsequent application on the aluminium alloy lamellae (Fig. 2a), which should be hardfaced.

Drying and baking of the deposited on the substrates surface layer occurred under more than 550^{0}C; then the flux components ($MgCl_2$, NaCl, KCl and Na_3AlF_6) formed a low melting eutectic (Fig. 2b), and the surplus salts came out.

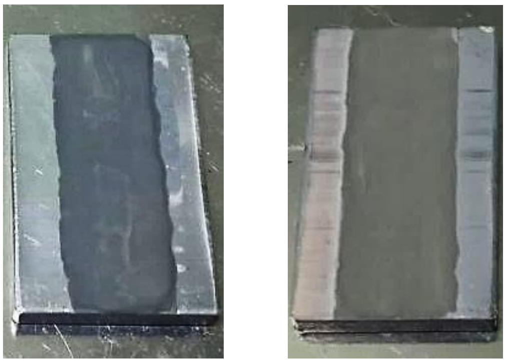

Fig. 2. Specimens with precoated film containing electroless nickel plated and flux coated micro/nano SiCp particles: (left) before drying; (right) after formation of eutectic.

A part of this eutectic containing also cryolite, remained on the surface of the particles, which slinked into it and arrived to the metal surface. The deposited SiCp layer with flux protects also the aluminium alloy surface against additional oxidation during the baking in an oxidizing environment and the subsequent hardfacing under shielded gas metal-arc welding.

3. TIG/MIG HARDFACING UPON PARTICLES CONTAINING FILM

The used starting materials were electroless nickel plated and flux coated micro/nano SiC particles and pure aluminium substrates of 60 mm x 35 mm dimensions, 6 mm thickness.

The welding unit ERIDAN 210 was applied for the MIG cladding process in argon protective environment. Wire filler of diameter Ø1.2 mm and chemical composition of AlMg4.5 (not containing Si) was used as additive material. Electric current 140 A and voltage 20 V are the technological parameters of the MIG process.

The welding unit HELIARC 353i (ESAB) was applied for the TIG cladding process in argon protective environment. The additive material used was wire filler of Ø3.2 mm and chemical composition of AlMg4.5Mn. TIG hardfacing process technological parameters were 90-93 A and 14-15 V.

Fig. 3. Test sample photographs during TIG hardfacing on the substrate with precoated film containing electroless nickel plated and flux coated micro/nano SiCp particles.

The selected filler wires were not Si alloyed in order to avoid the influence on SiCp particles registering by the next conduct of EDX microanalysis. Four weld seams were consecutively applied on the treated surface of a pure aluminium substrate with a preliminary deposited baked film containing electroless nickel plated and flux coated SiCp (Fig. 3). If the substrate surface treatment and/or the film baking regime are incorrect, the film could be destroyed during the shielded gas welding.

4. NDT, SEM, EDX, HARDNESS AND WEAR RESISTANCE TEST PROCEDURES

The metallographic specimens were prepared according to ASTME 407-99 and ASM Handbook “Metallography &Microstructures”. “Struers Prolectrol" electrochemical polishing and etching control system unit was used.

The hardfaced layers morphology and structure were studied by SEM “EVO MA10 Carl Zeiss” with integrated Energy Dispersive X-ray detector System “Bruker” (EDX). Specimens’ hardness was tested by Fischerscope® Nanoindenter, applying SEM “EVO MA10 Carl Zeiss” for determination of prints distribution.

The hardfaced layers wear resistance was studied according to the procedure developed in the Laboratory of Tribology, TU–Sofia [13].

The relative change of wear resistance represents a dimensionless quantity indicating in percentage how much the coating wear resistance is higher or lower than the wear resistance of the reference specimen (TIG standard wire hardfacing without SiCp) [14].

The present study used a reference specimen of TIG hardfaced layer with standard wire filler on substrate of pure aluminium without the SiCp film on its surface. Aiming an even surface for wear resistance study without removing material with the reinforced phase, the hardfaced surfaces were sized (calibrated) and heat treated (annealed) at 280–320 ^{0}C.

4.1 Morphology and structure of the obtained hardfaced layers

Groups of microparticles (of 5-10 μm size), wetted by the aluminium alloy matrix) are visible in the cross-section of the MIG seams. The particles are of sharp irregular shapes, part of them raised above matrix surface, forming the specific "insular" relief shown in Fig. 4.

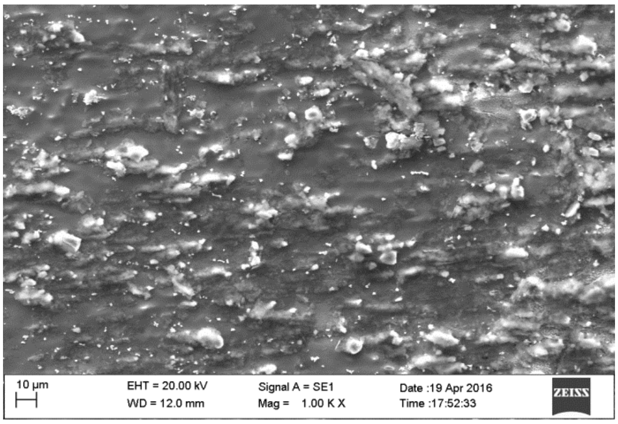

Fig. 4. SEM of the specimen hardfaced by MIG dispersive reinforced layer containing micro SiCp.

The visual results of the scanning electron microscopy were confirmed by the energy dispersive X-ray microanalysis of elements.

Figure 5 shows mapped image of the metallographic specimen of the sample with dispersive reinforced layer containing micro SiC particles, hardfaced by MIG process and the registered spectrum. The microanalysis shows the presence of the elements Al, Si, O and C. The distribution of micro SiCp groups established by SEM completely corresponds (Fig. 5) to the zones of increased concentration of the elements Si, F and Mg located in the metal alloy matrix and raised above it (the zones of lack of Al).

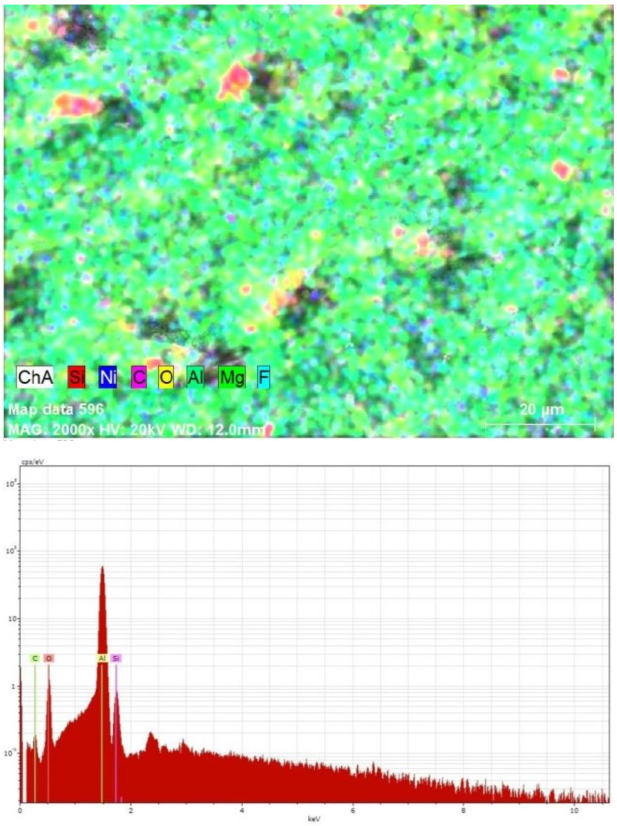

Fig. 5. EDX microanalysis of the metallographic specimen hardfaced by MIG process dispersive reinforced layer containing micro SiCp.

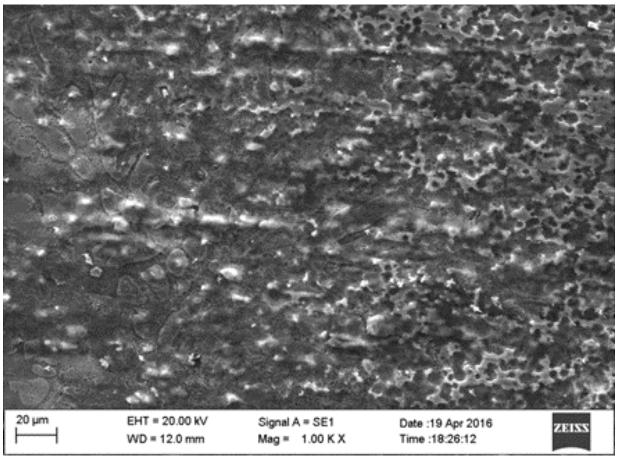

Fig. 6. SEM of the specimen hardfaced by TIG dispersive reinforced layer containing micro SiCp.

Groups of micro particles (of about 10 μm size), wetted by the aluminium alloy matrix are visible in the cross-section of the TIG seams. The particles are of shapes raised above metal the matrix surface, and forming the specific "insular" relief (Fig. 6). The visual results of the SEM were confirmed by the EDX microanalysis.

Figure 7 shows a mapped image of the metallographic specimen of the sample with dispersive reinforced layer containing micro SiCp particles, hardfaced by TIG process and the registered spectrum. The EDX shows the presence of the elements Al, Si, C and Mg (Fig. 7).

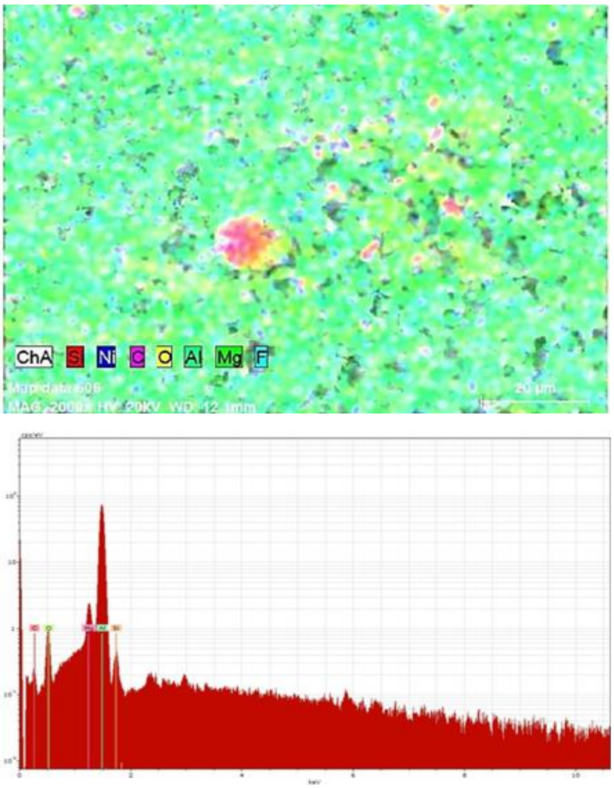

Fig. 7. Energy Dispersive X-ray microanalysis of the metallographic specimen hardfaced by TIG process dispersive reinforced layer containing micro SiCp.

The distribution of micro SiCp groups established by SEM (Fig. 6) completely corresponds to the zones of increased concentration of the element Si (Fig. 7) located in the metal alloy matrix, raised above the matrix (the zones of lack of Al).

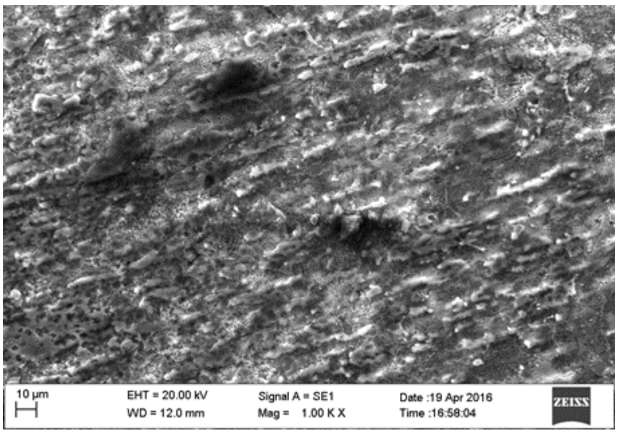

Fig. 8. SEM of the specimen hardfaced by TIG dispersive reinforced layer containing nano SiCp.

Groups of agglomerated nanoparticles, wetted by the aluminium alloy matrix are visible in the cross-section of the TIG welded seams shown in Fig. 8.

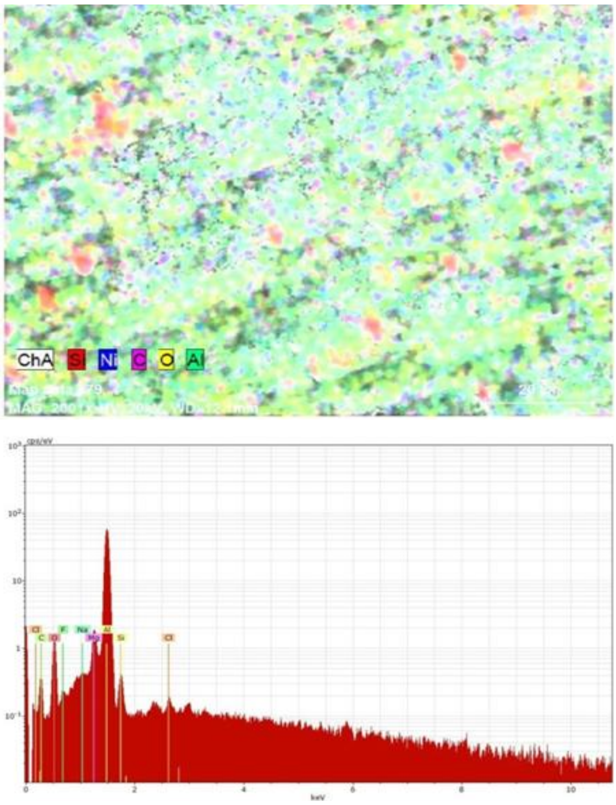

Fig. 9. EDX microanalysis of the metallographic specimen hardfaced by TIG process dispersive reinforced layer containing nano SiCp.

Figure 9 shows mapped image of the metallographic specimen of the sample with dispersive reinforced layer containing nano SiC particles, hardfaced by TIG process and the registered spectrum. The visual results of the scanning electron microscopy were confirmed by the EDX, which shows the presence of the elements Al, Si, Ni and C (Fig. 9).

4.2 Results of the hardfaced layers mechanical properties

Uneven surface corresponding to the subsequently welded seams was obtained in case of hardfaced by MIG process pure aluminium specimens with precoated film containing electroless nickel and flux coated micro SiCp particles (Fig. 10). The come out on top slag is located between them in the form of separate flakes containing particles and flux elements. Incomplete fusion and lack of penetration between the surface layer and the basic metal was visually found.

Fig. 10. Photograph and radiogram (NDT) of hardfaced by MIG process pure aluminium specimens with precoated film containing electroless nickel plated and flux coated micro SiCp.

The nanohardness variation for MIG hardfacing on precoated film of electroless nickel and flux coated micro SiCp particles by in depth towards the basic metal is determined. The measured average value of the hardness in the zone of hardfaced layers was HU = 791 MPa, and into the hardfaced specimen basic metal was HU = 321 MPa. The hardness in the zone of the MIG welded seams was about 2.4 to 2.6 times higher than that of the basic metal of pure aluminium. This is due both to the alloying elements in the wire filler and to the implanted in the layer reinforcing phase of electroless nickel coated SiC particles contained in the preliminary coated on the aluminium substrate film.

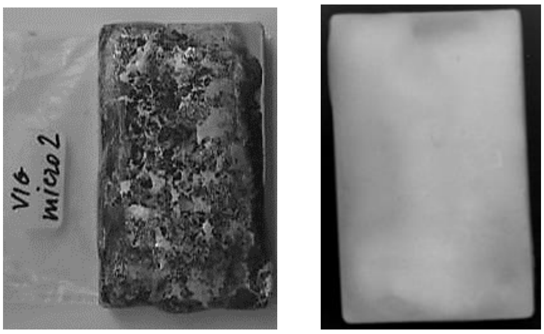

Fig. 11. Photograph and radiogram (NDT) of hardfaced by TIG process pure aluminium specimens with precoated film containing electroless nickel plated and flux coated micro SiCp particles.

Steady surface with distinction of the subsequently welded seams was obtained in case of hardfaced by TIG process pure aluminium specimens with precoated film containing electroless nickel plated and flux coated micro SiCp particles. The come out on top slag was in the form of small flakes (Fig. 11). The results of the non-destructive radiographic test show porosity in one of the specimens.

The nanohardness variation for TIG hardfacing on precoated film of electroless nickel plated and flux coated micro SiCp particles in depth towards the basic metal is determined. The measured average value of the hardness in the zone of hardfaced layers was HU = 693 MPa, and into the hardfaced specimen basic metal was HU = 319 MPa. The nanohardness in the zone of the TIG welded seams on the precoated film of electroless nickel plated and flux coated micro SiCp particles was about 1.9 to 2.5 times higher than the basic metal. The increase coincided with the values obtained in the MIG process.

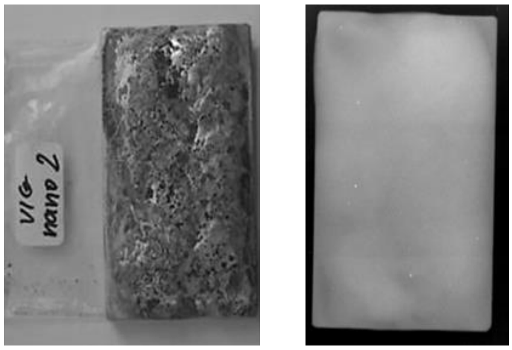

Fig. 12. Photograph and radiogram (NDT) of hardfaced by TIG process pure aluminium specimens with precoated film containing electroless nickel plated and flux coated nano SiCp.

Steady surface was obtained in case of hardfaced by TIG process pure aluminium specimens with precoated film containing electroless nickel and flux coated micro and nano SiCp particles; the subsequently welded seams were almost indistinguishable. The come out on top slag formed homogeneous layer on the surface with almost no presence in the zone of the welded seams (Fig. 12).

The results from the non-destructive radiographic test show lack of imperfections and of porosity and slag inclusions.

The nanohardness variation in depth towards the basic metal of the TIG welded seams with nanoparticles reinforcement is determined by nanoindentation and SEM. The measured average value of the hardness in the zone of hardfaced layers was HU = 709 MPa, and into the basic metal was HU = 340 MPa.

Hardness established in zone of the TIG welded seams on the precoated film of electroless nickel and flux coated nano SiCp particles was 1.9 to

2.5 times higher than basic pure aluminium hardness. The increase of hardness in case of weld cladding without reinforcing phase was about 1.6 to 1.8 times and was due to the alloying elements of the filler material. The comparative study with the specimen without reinforcing phase showed that about 40 % of hardness increase in the hardfaced layers resulted from the imbedded reinforcing phase of metalized SiCp, and not from the filler material.

4.3 Results of the hardfaced layers tribological properties

Experimental results for the characteristics of wear were obtained by means of the described in the tests procedures device and method under the given test conditions.

Figure 13 gives the graphs of relative wear intensity for the hardfaced layers on precoated film with metalized micro/nano SiCp particles under shielded gas metal-arc welding MIG/TIG conditions. The dash line shows the results for the reference sample with TIG layer deposited on the treated basic metal without particles.

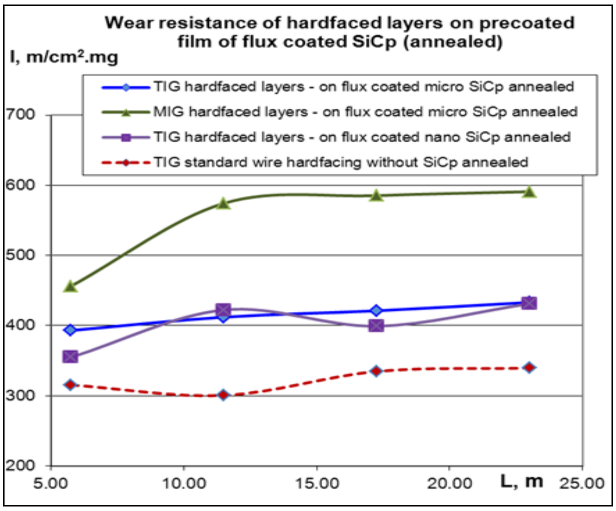

Fig. 13. Variation of wear resistance with the covered friction way for specimens with hardfaced layers on precoated film of electroless nickel and flux coated SiC particles.

Lowest wear rate and highest wear resistance showed the specimens with hardfaced dispersive layer obtained by MIG process on precoated film of flux coated micro SiC particles. Improved relative wear resistance exhibited also the specimens with hardfaced dispersive layer obtained by TIG process on precoated film of nickel and flux coated micro/nano SiC particles.

Figure 14 shows the test results for the relative change of the wear resistance for hardfaced layers obtained under shielded gas metal-arc welding MIG/TIG.

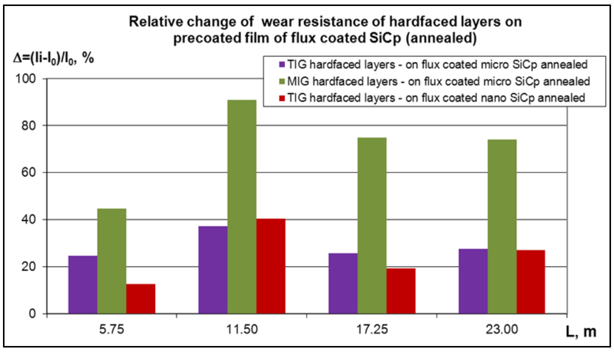

Fig. 14. Relative change of wear resistance after various friction ways for specimens with hardfaced layers on precoated film of electroless nickel and flux coated SiC particles.

The average relative change of the wear resistance for hardfaced layers obtained by TIG process on precoated film with metalized micro and nano SiC particles was in the interval from 25 % to 29 %. The average relative change of the wear resistance for hardfaced layers obtained by MIG process on precoated film with metalized micro SiC particles was higher: 71 % to 72 %. The annealing of sizing specimen surfaces reduces the relative wear resistance with 9-10 % for MIG and with 6-7 % for TIG hardfaced layers.

The obtained wear resistance test results correspond to the obtained hardness test values. The higher MIG process wear resistance is related to the higher hardness of the layers.

5. CONCLUSIONS

1. Wear resistant hardface dispersive reinforced layers are obtained by introduction of electroless nickel coated silicon carbide particles in molten aluminum hardfaced by shielded gas metal-arc welding MIG/TIG processes on precoated film using flux.
2. The presence in the hardfaced dispersive reinforced layers of wetted by the aluminium alloy matrix SiC particles groups is proved by non-destructive radiographic test (NDT), scanning electron microscopy (SEM) and energy dispersive X-ray microanalysis (EDX).
3. It is established the increase in the hardness and the wear resistance of the surface layers of

dispersive reinforced material obtained by shielded gas metal-arc welding MIG/TIG processes with filler material on precoated eutectic containing flux coated micro/nano SiC particles. The results from the non-destructive radiographic test show lack of imperfections, porosity and slag inclusions only after TIG hardfaced using nano SiC particles.

4. The average relative change of the wear resistance of specimens with MIG layers deposited on precoated film with metalized micro SiC particles is higher (71 % to 72 %), and the annealing of calibrating specimen surfaces reduces the relative wear resistance with 9-10 % for MIG hardfaced layers. The hardness in the zone of the MIG process layers has doubled.
5. The average relative change of the wear resistance of specimens with TIG layers deposited on precoated film with electroless nickel plated micro and nano SiC particles is in the interval 25 % to 29 %, and the annealing of calibrating specimen surfaces reduce the relative wear resistance with 6-7 % for TIG hardfaced layers. The hardness increase being about over one and a half times due to the embedded reinforcing phase of metalized SiCp.

Acknowledgements

This study is connected with the completion and the financial support of the Project DUNK-01/3 "University R&D Complex for innovation and transfer of knowledge in micro/nano-technologies and materials, energy efficiency and virtual engineering" funded by the Bulgarian Ministry of Education and Science.

REFERENCES

[1] G. Veeresh Kumar, C. Rao, N. Selvaraj, *Mechanical and Tribological Behavior of Particulate Reinforced Aluminum Metal Matrix Composites – a review*, Journal of Minerals and Materials Characterization and Engineering, vol. 10, no. 1, pp. 59-91, 2011, doi: 10.4236/jmmce.2011.101005

[2] A. Vencl, A. Rac, I. Bobić, Z. Mišković, *Tribological properties of Al-Si alloy A356 reinforced with Al_2O_3 particles,* Tribology in Industry, vol. 28, no. 1-2, pp. 27-31, 2006.

[3] D.K. Das., P.C. Mishra, S. SIngh, R.K. Thakur, *Properties of ceramic-reinforced aluminium matrix composites - a review*, International Journal of Mechanical and Materials Engineering, vol. 9, no. 12, pp. 1-16, 2014, doi: 10.1186/s40712-014-0012-9

[4] B. Stojanovic, M. Babic, S. Mitrovic, A. Vencl, M. Pantic, *Tribological characteristics of aluminium hybrid composites with silicon carbide and graphite - a review*, Journal of the Balkan Tribological Association, vol. 19, no. 1, pp. 83-96, 2013.

[5] J. Hashim, L. Looney, M. Hashmi, *The wettability of SiC particles by molten aluminum alloy*, Journal of Materials Processing Technology, vol. 119, no. 1-3, pp. 324-328, 2001.

[6] M. Kandeva, A. Vencl, E. Assenova, D. Karastoyanov, T. Grozdanova, *Abrasive wear of chemical nickel coatings with boron nitride nano-particles,* in 11th International Conference "THE A" Coatings in Manufacturing Engineering, 1-3 October, 2014, Thessaloniki, Greece, pp. 319-325.

[7] R. Dimitrova, *Electroless nickel coatings on silicon carbide particles using two nickel salts in alkaline solution*, in 8th International Working Conference "TQM – Advanced and Intelligent Approaches", 2–5 June, 2015, Belgrade, Serbia.

[8] R. Dimitrova, *Investigation of creation possibilities of dispersive reinforced aluminium metal matrix for hardfacing*, PhD Thesis, Technical University of Sofia, 2016, Sofia, Bulgaria.

[9] R. Dimitrova, V. Kamburov, R. Rangelov, *Development of flux for SiC particles inclusion in aluminium melt*, in XXIII International Scientific Technical Conference "Foundry 2016", April 13-15, 2016, Pleven, Bulgaria (in Bulgarian).

[10] *Risk Assessment Report of Trisodium hexafluoroaluminat*e, CAS-No. 13775-53-6.

[11] D. Williams, *Assessment of Candidate Molten Salt Coolants for the NGNP/NHI*, Heat – Transfer Loop, ORNL/TM-2006/69, Technical Report, Oak Ridge National Laboratory, USA, 2006, doi: 10.2172/1360677

[12] T. Utigard, *The properties and uses of fluxes in molten aluminum processing*, The Journal of The Minerals, Metals & Materials Society, vol 50, iss. 11, pp. 38-43, 1998, doi: 10.1007/s11837-998-0285-7

[13] M. Kandeva, A. Vencl, D. Karastoyanov, *Advanced Tribological Coatings for Heavy-duty Applications: Case Studies*, Marin Drinov Academic Publishing House, Sofia, Bulgaria, 2016.

[14] R. Dimitrova, M. Kandeva, V. Kamburov, *Mechanical and Tribological Characteristics of TIG Hardfaced Dispersive Layer by Reinforced with Particles Extruded Aluminium*, Tribology in Industry, vol. 39, no. 1, pp. 9-19, 2017, doi: 10.24874/ti.2017.39.01.02