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RESEARCH

Mechanical and Tribological Characteristics of TIG Hardfaced Dispersive Layer by Reinforced with Particles Extruded Aluminium

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ABSTRACT

The article presents the results of the implemented technology for generation of hardfaced dispersive layers obtained by additive material containing reinforcing phase of non-metal particles. The wear resistant coatings are deposited on pure aluminium metal matrix by shielded gas metal-arc welding applying tungsten inert gas (TIG) with extruded aluminium wire reinforced by particles as additive material. Wire filler is produced by extrusion of a pack containing metalized and plated by flux micro/nano SiC particles. The metalized particles implanting in the metal matrix and its dispersive hardfacing are realized by solid-state welding under conditions of hot plastic deformation.

Tribological characteristics are studied of the hardfaced layers of dispersive reinforced material on pure aluminium metal matrix with and without flux. Hardness profiles of the hardfaced layers are determined by nanoindentation. The surface layers are studied by means of Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) analysis. Increase by 15-31 % of the wear resistance of the hardfaced layers and 30-40 % of their hardness was found, which is due to the implanted in the layer reinforcing phase of metalized micro/nano SiC particles.

1. INTRODUCTION

The reinforced aluminium metal matrix composites (Al-MMCs) that are strenghtened by another phase, usually in the form of ceramic particles, fibres, whiskers are new constructional materials, because of its beneficial combination of metal plasticity and specific strength with higher wear resistance and hardness [1]. Their applications are determined by the improved properties of the metal matrix combined with preservation of their lightweight over unreinforced alloys. These composites are of interest of the researchers in different fields of the industry due to their excellent properties: elastic modulus, tensile strength at room and elevated temperatures, thermal resistance, increased hardness and wear resistance [1,2]. Deposited surface layers of those materials combine aluminium and aluminium alloys plasticity with the hardness and wear resistance of the reinforcing nonmetallic ceramic phase [3,4]. The present paper aims a study by nanoindentation of the mechanical characteristics of the hardfaced dispersive reinforced layers on aluminium matrix and determination of their tribological characteristics under dry abrasive friction conditions.

2. MATERIALS

The electroless nickel/copper coated micro/nano SiC particles and the prepared for hardfacing pure aluminium substrates are used as started materials [5]. A coating flux is elaborated on the basis of cryolite and three salts – sodium chloride, potassium chloride and magnesium chloride. The aim of the additional plating of the particles is to obtain flux coating on the metalized SiCp by treating of their surface through successive application of different flux components [6]. It is carried out plating of silicon carbide particles metalized in advance in order to obtain a coating of flux on their surface using the different solubility of those individual components within a water solution – the insoluble one (Na_3AlF_6) and the other water-soluble salts ($MgCl_2$, NaCl, KCl) [6].

Wire filler is used produced by direct extrusion of a pack containing metalized and coated by flux micro/nano SiC particles. During the hardfacing main flux components ($MgCl_2$, NaCl, KCl and Na_3AlF_6) on the SiCp surfaces formed a low melting eutectic which facilitates particles wettability and their interfacial bonding with the molten metal into the weld puddle. The flux covers and extra protects the aluminium alloy welding pool against additional oxidation during the hot impression-die forging and subsequent hardfacing under shielded gas metal-arc welding (TIG/MIG) [7].

3. MANUFACTURING OF REINFORCED WIRE FOR TIG HARDFACING

Implanting of micro/nano particles into the plastic aluminium matrix is provided by the workpiece (a pack) composed by several metal plates covered with the reinforcing phase containing film. The particles implanting in the metal matrix and its dispersive hardfacing are realized by solid-state welding under conditions of hot plastic deformation.

The deformed pack consists of billets of pure aluminium of the size: 10 mm width and 50 mm length with 1/3 mm thickness. Preparation of the billets is done under cold working by axial upsetting in completely closed die cavity in limited as width (10 mm) deformation space. The stamped embossed surface is a square mesh with cells 0.70 mm x 0.70 mm, 0.25 mm depth and 0.30 mm width. This kind of plate surface treatment provides easy deposition and adhesion of the micro/nano SiC particles between them.

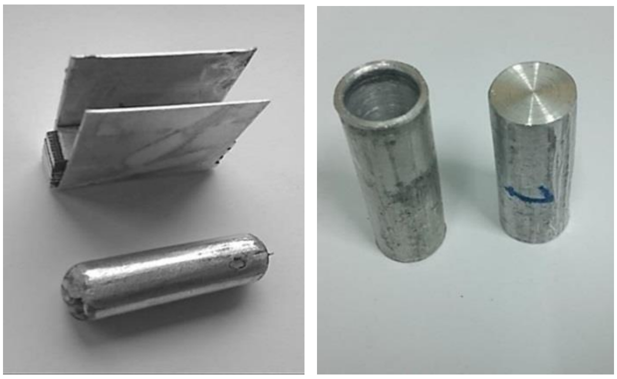
The up package sample consists of several embossed plates with a film containing the metalized SiC particles. The particle films remain intermediate (internal) and surrounded by the metal matrix during assembling the up package by preliminary compaction within completely closed die cavity. Using hot plastic deformation of the up package aims a metal bond between the embossed aluminium plates by solid-state welding and producing a monolithic article (wire) of dispersive reinforced material. Generation of monolithic article is only possible after a sufficiently high degree of deformation of the up package by upsetting (flat die forging) at temperatures higher than the recrystallization temperature or direct extrusion characterized by compressive stresses, as well as for sufficiently high strain [8].

The up package sample is forged using hot impression-die forging until a billet for direct extrusion is obtained. The die cavity of the inserts for impression-die forging of the up package of embossed plates and reinforcing phase, of diameter Ø15 and 60 mm length, corresponds to the extrusion container. The hot impression-die forging follows a pre- deformation heating (450 - 500 ^{0}C for the pure aluminium) and preliminary heating of the tool. A set of dies is directly mounted on a heating element with insulating housing and heated up to 250 – 300 ^{0}C.

A hot impression-die forging is realized by a 40 tonne hydraulic press at 20 mm/min speed; the load of the hot impression-die forging being over 320 kN which corresponds to forming a flash with 0.5 mm end height. Flat die forging is realized by different location (rotation) of the billet. Pre-deformation heating and forging at 90O billet rotation is carried out for each subsequent stroke (Fig. 1.). The flash is trimmed after closing the gap of the impression-die cavity and no more loose spots around the parting line of the forged workpiece (following the visual observation).

Fig. 1. Forged samples obtained at subsequent positioning - number of strokes after 90O rotation by impression-die forging.

The applied up to now technologies for direct extrusion of wire with particles [9,10] use thin-walled receptacle, where pieces of wire filler of deformable aluminium alloy and implanted particles are compacted. The present paper considers obtaining additive disperse reinforced wire filler by means of direct extrusion of impression-die forged package of covered embossed plates with metalized particles between them (Fig. 2).



a) b)

c)

Fig. 2. Up-package sample, forged body (a), thin-wall container (prepared for extrusion, b) and cross-section of the container (c).

Next figure gives morphology and structure of the impression-die forged package plates and reinforcing phase (metalized particles). The separate plates of pure aluminium and the closed in negative forms electroless nickel plated SiC particles can be seen in the cross-section of the prepared for direct extrusion container (Fig. 3).

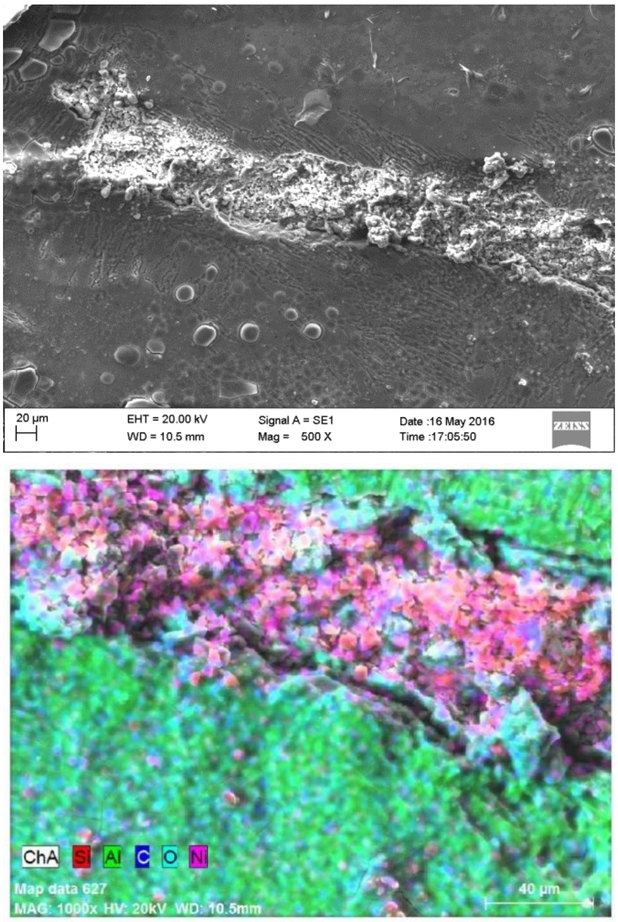


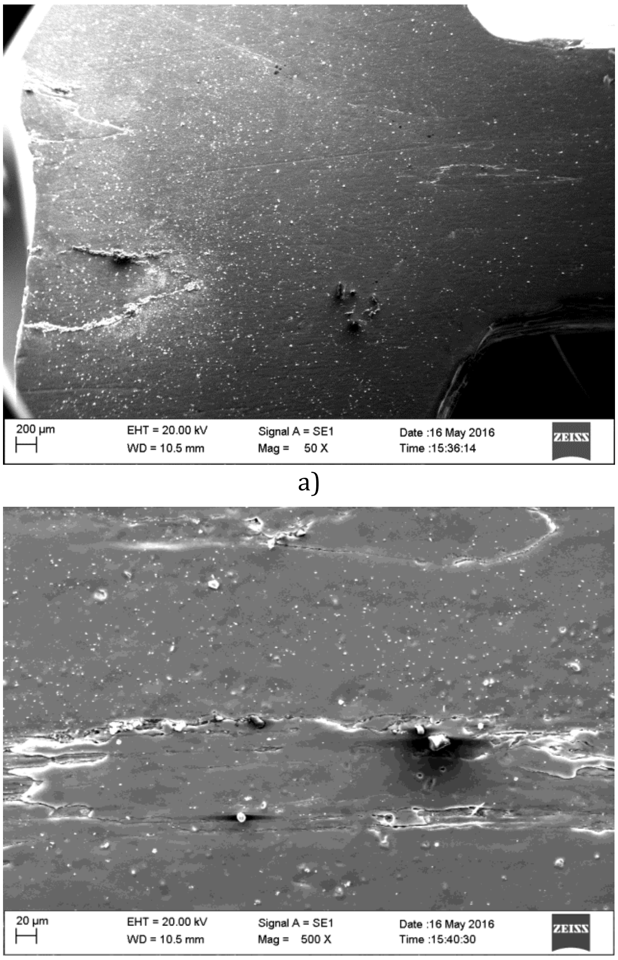
Fig. 3. SEM and EDX of the cross-section of the prepared for direct extrusion container with plates with closed electroless nickel plated micro SiC particles.

Equipment for direct extrusion of wire is used for the deformation of the up package sample, which can provide 40 times reduction of the extrusion ratio and is suitable for solid-state welding of the embossed plates under hot plastic deformation. Extrusion was realized by Dipl. Eng. PhD B. Krastev, in the Institute of Metal Sciences, Equipment and Technologies „Acad. A. Balevski" with Hydroaerodynamics Centre, Sofia.

The extruded material represents a monolithic product (wire) of particle reinforced material (Fig. 4.). The coated strips (giving the plates boundaries) are not visible on the surface. The metalized SiC particles are closed and implanted in the aluminium matrix due to the obtained solid-state welding of the embossed plates of the up package sample under hot plastic deformation. The developed technology allows obtaining of additive material (wire filler) for tungsten inert gas welding of the length of about 1.5 m and small cross-section (5 - 7 mm^2).

Fig. 4. Pictures of the obtained through extrusion additive material (wire filler).

Next figure gives morphology and structure of the obtained through extrusion additive material (wire filler) with SiC particles. The boundaries of the pure aluminium plates are almost not visible in the longitudinal section of the unextruded billet, and of the extruded wire (Fig. 5a). The separate plates and the metalized SiC particles between them are deformed and solid-state-welded forming nearly homogeneous mass. A suitable magnification of the longitudinal section of the unextruded billet can provide determination of the boundaries between the plates in some places (Fig. 5b).



a)

b)

Fig. 5. SEM of the longitudinal section of the unextruded billet after extrusion with implanted electroless nickel plated micro SiCp.

Study of the longitudinal section of the unextruded billet after extrusion is carried out through (EDX) (energy dispersive X-ray spectroscopy). Figure 6 gives mapping image of the longitudinal section of the extruded wire with implanted nickelled micro SiCp with flux and the registered spectrum. The microanalysis shows the presence of the elements Al and Si.

About 0.5 g metalized particles are used as reinforcing phase for an impression-die forged package; it is about 1.5 – 2.0 % weight percents of the total weight (35 – 40 g). The maximum content of the implanted in the matrix reinforcing phase is determined by the possibility to realize welding under hot plastic deformation, i.e. by the respective effective strain at the selected process, as well as by the quantity of reinforcing phase closed between the plates.

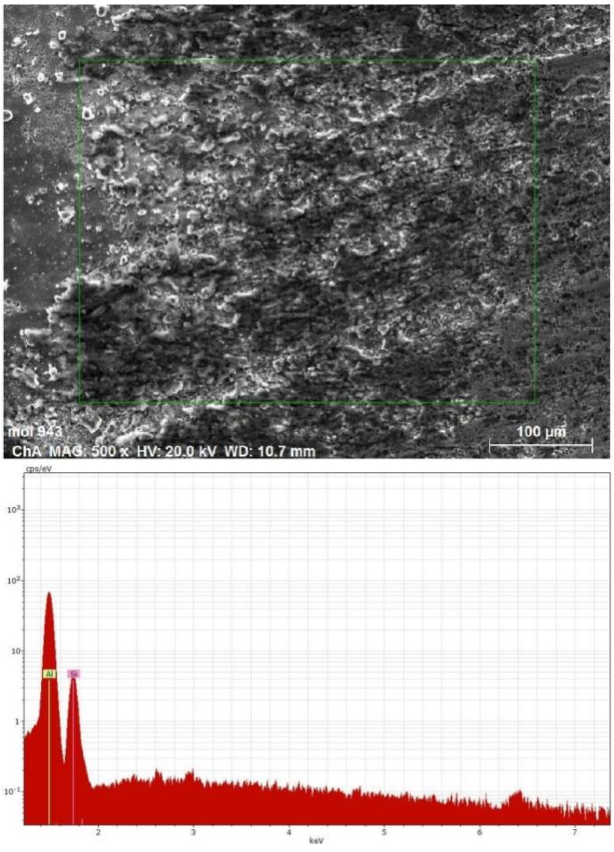
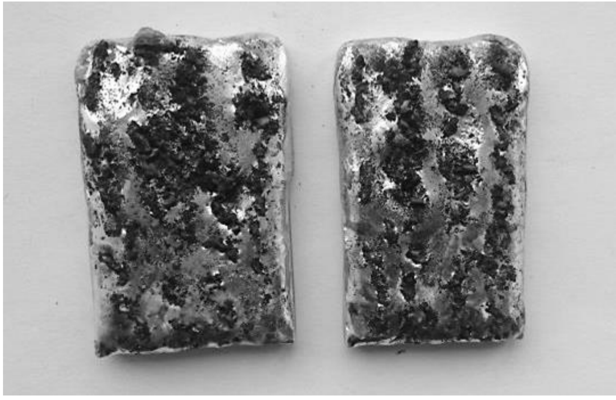


Fig. 6. EDXmicro-analysisofthe longitudinal section of extruded wire with implanted electroless nickel plated micro SiCp.

4. TIG WELDING BY PARTICLE REINFORCED WIRE FILLER

Shielded gas metal-arc welding applying tungsten inert gas (TIG method) is realized by IWEng. St. Alexiev, using ESAB welding equipment HELIARC 353i. Several welded seams are subsequently laid on the pre-treated surface of the basic metal of pure aluminium. The obtained hardfaced layers are coated with slag of various morphology and structure (Fig. 7).



a) Specimens welded without flux

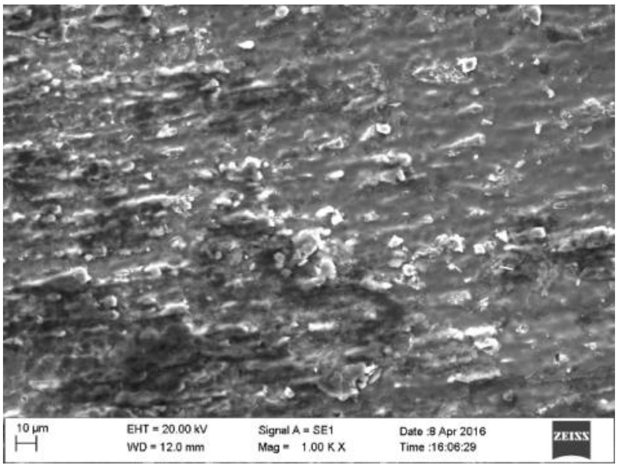
b) Specimens welded with flux coated particles

Fig. 7. Picturesof surfaces of hardfaced pure aluminium substrates with wire of dispersive reinforced extruded aluminium.

In the case of samples with plated particles, the slag is grey and is uniformly distributed on the surface (Fig. 7b). It can be easily washed away from the surface by distilled water, and can be totally removed without damaging the hardfaced layers, if suitable (acid) solution is used. In thecase of specimens without flux, the slag is distributed in stripes of the emerged from the melt and then agglomerated particles, which are strongly fixed between the welded layers (Fig. 7a). Slag cannot be removed mechanically without damaging the hardfacedlayers.

5. MORPHOLOGY AND STRUCTURE OF THE OBTAINED HARDFACED DISPERCIVE LAYERS CONTAINING SILICON CARBIDE MICROPARTICLES

Microparticles (about 5 to 10 µm size) wetted by the aluminium alloy matrix are observed in the cross-section of TIG welded seams without flux. They are of sharp shapes sticking up the metal matrix surface and forming the specific insular relief shown in Fig. 8.



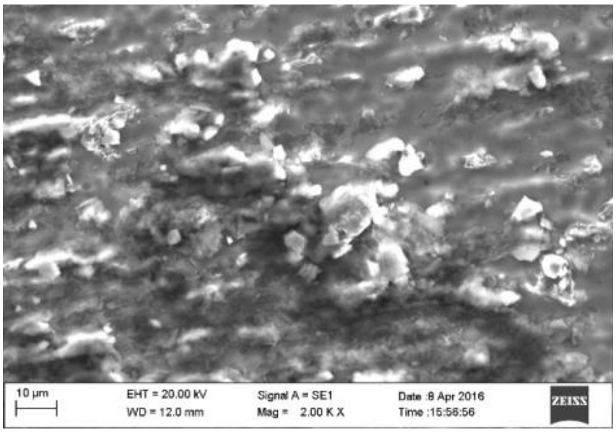


Fig. 8. SEM of the cross-section of TIG hardfaced specimen with wire of extruded aluminium, dispersive reinforced by electroless nickel plated SiCp without flux.

The visual results of the SEM are confirmed by the EDX-microanalysis /energy dispersive X-ray spectroscopy. Figure 9 gives the mapping image of the ground cross-section of TIG welded specimen with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles without flux, as well as the registered spectrum of the shaded sector. The microanalysis shows the presence of the elements Al, Si, O and C (Fig. 9).

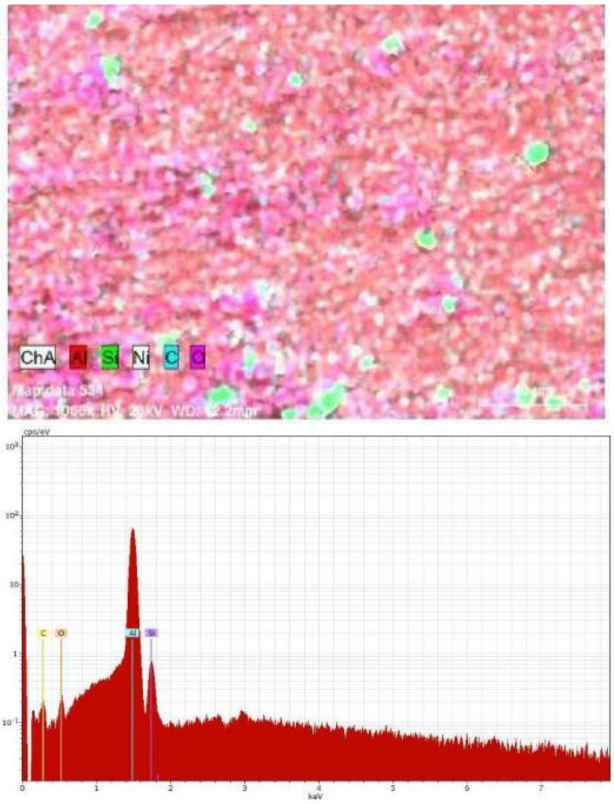


Fig. 9. EDX microanalysis of the cross-section of TIG hardfaced specimen with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles.

The distribution of microparticle groups (SiCp) established by SEM fully corresponds to the zones of higher concentration of Si, which are located inside the metal-alloy matrix and stick up above it.

Microparticles (about 5-10 µm size) wetted by the aluminium alloy matrix are observed in the cross-section of TIG welded seams with flux. They have rounded uneven shapes sticking up the surface and forming the specific relief shown in Fig. 10.

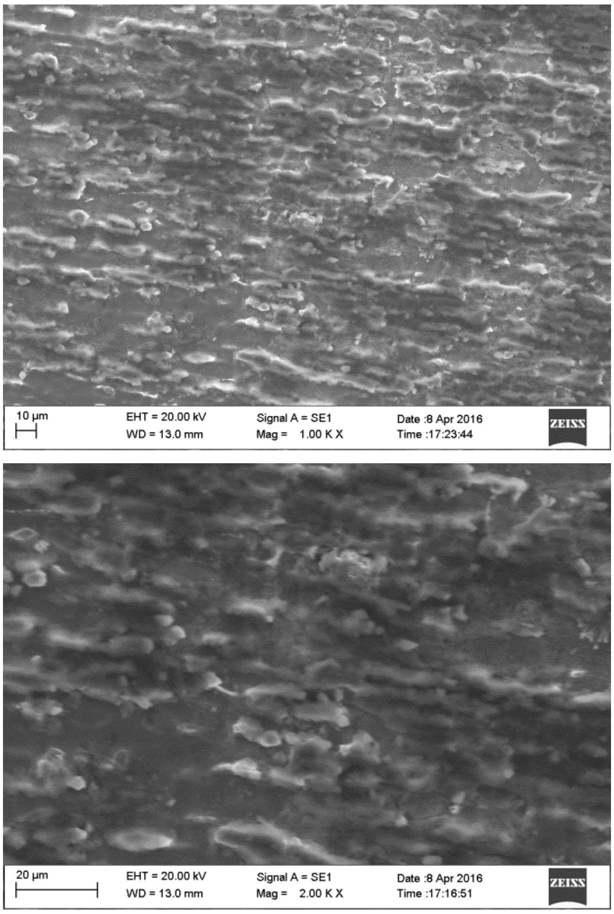


Fig. 10. SEM of the ground cross-section of TIG hardfaced specimen with wire of extruded aluminium, dispersive reinforced by electroless nickel plated micro SiCp coated with flux.

Figure 11 gives the mapping image of the ground cross-section of TIG welded specimen with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles coated with flux, as well as the registered spectrum of the shaded sector. The microanalysis shows the presence of the elements Al, Si, O, C and F.

The visual results of the SEM are confirmed by the elemental EDX-microanalysis (energy dispersive X-ray spectroscopy).

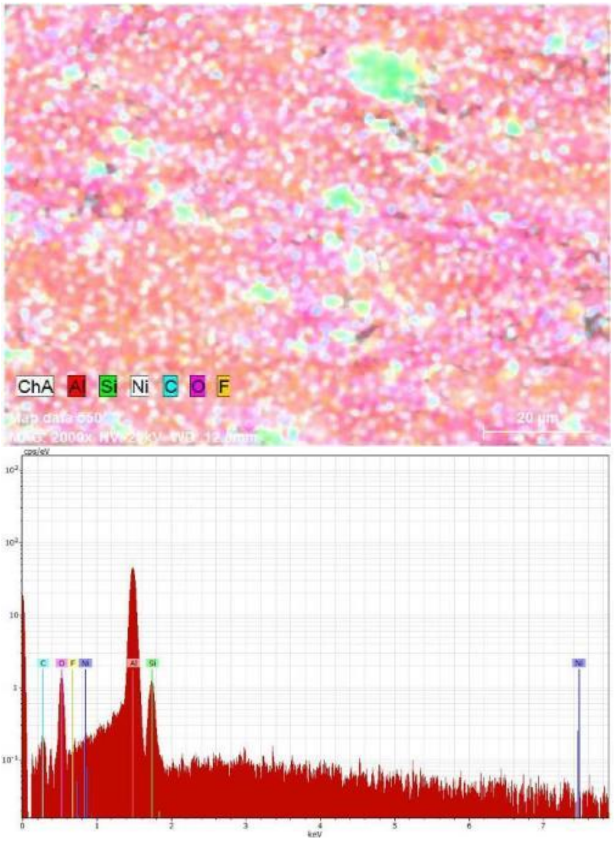


Fig. 11. EDX microanalysis of the ground cross-section of TIG hardfaced specimen with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles, coated with flux.

6. RESULTS OF THE HARDFACED LAYERS NANOINDENTATION TESTS

Scanning electron microscopy is carried out for each print after the nanoindentation tests of the hardfaced layers deposited by dispersive reinforced extruded aluminium wire. The exact location of the prints with regard to the hardfaced layer geometry, as well as the distances between the prints is established.

The graph in Fig. 12 shows the nanohardness variation in depth towards the basic metal found by nanoindentation and SEM in the case of hardfaced layers deposited by the extruded aluminium wire dispersive reinforced with electroless nickel plated SiC microparticles without flux.

The measured average value of the hardness in the zone of hardfaced layers is HU=456 MPa varying between the minimal value HU=420 MPa and the maximal value HU=496 MPa. The measured average hardness value of the hardfaced specimen basic metal is HU=311 MPa varying between the minimal value HU=294 MPa and the maximal value HU=325 MPa.

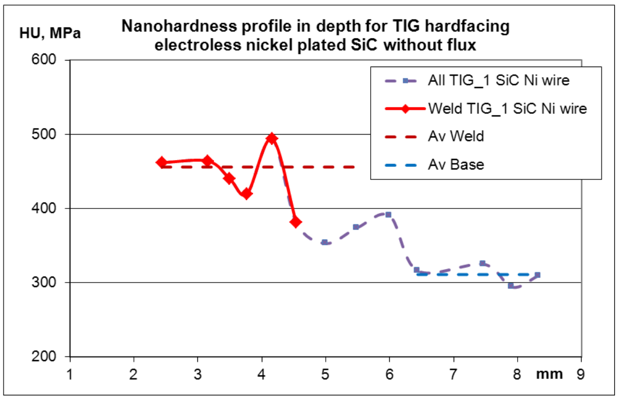


Fig. 12. Profile of nanohardness variation in depth for TIG hardfacing with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles, without flux.

Hardness increase in the zone of hardfaced layers with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles without flux is about 1.3 to 1.6 times higher than that of the basic metal of pure aluminium. Hardness increase in the hardfaced layer after the welding process is due to the implanted reinforcing phase of electroless nickel plated micro SiCp, because the metal matrix of the extruded wire filler is of pure aluminium. Hardness variation in depth in the cross-section of the hardfaced layers is quite irregular.

The nanohardness variation in depth hardfaced layers deposited by wire filler of extruded aluminium reinforced by electroless nickel plated SiC microparticles coated with flux is found by nanoindentation and SEM, it is shown in Fig. 13.

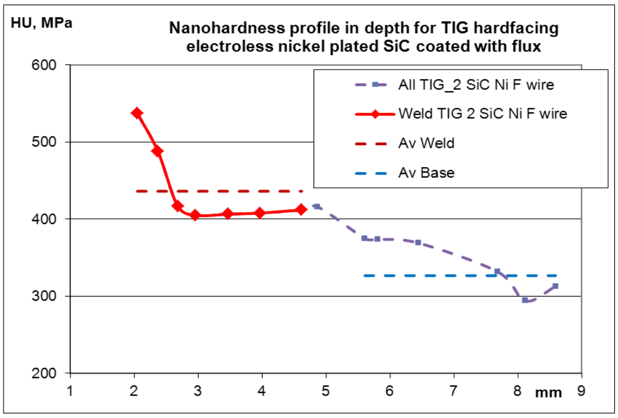


Fig. 13. Profile of nanohardness variation in depth for TIG hardfacing with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles, coated with flux.

The measured average value of the hardness in the zone of hardfaced layers is HU=436 MPa varying between the minimal value HU=405 MPa and the maximal value HU=537 MPa. The measured average hardness value of the hardfaced specimen basic metal is HU=327 MPa varying between the minimal value HU=294 MPa and the maximal value HU=369 MPa.

Hardness increase in the zone of hardfaced layers with wire of extruded aluminium reinforced by electroless nickel plated SiC microparticles coated with flux is about 1.2 to 1.6 times higher than that of the basic metal of pure aluminium. Hardness increase in the hardfaced layer after the welding process is only due to the presence of reinforcing phase of electroless nickel plated micro SiCp, because the metal matrix of the extruded wire filler is of pure aluminium. Hardness variation in depth in the cross-section of the hardfaced layers is rather regular.

7. WEAR RESISTANCE TESTS

Ground cross-sections are prepared according to ASTME 407-99 and ASM Handbook “Metallography and Microstructures.” Grinding is realized by sandpaper from 800 to 2400 (4000). Ground cross-sections are developed by means of electrochemical polishing and etching electrochemical equipment “Struers Prolectrol". Morphology and structure of the hardfaced layers are investigated by scanning electron microscope (SEM) “EVO MA10 Carl Zeiss” with built in Energy Dispersive X-ray detector System “Bruker” (EDX).

The wear resistance of the hardfaced layers is tested by the procedure developed in the Science-practical laboratory “Tribology” at the Department of „Material’s Science and Technology“, the Faculty of Industrial Technology of the Technical University – Sofia. Abrasive wear at dry sliding was studied in laboratory tests by means of pin-on-disk tribotester for the sliding friction between the specimens and fixed abrasive surface [11-16].

The wear resistance tests are carried out without removing of the material containing the implanted reinforcing phase; the hardfaced surfaces are heat-treated (annealed) at 280 – 320 ^{0}C during two hours after being preliminary sized (calibrated). Geometric macro and micro precision characteristics of the test and processing surfaces, as well as resulting effective mechanical contact, were taken into account in processing the results [17].

8. HARDFACED LAYERS RESULTS OF WEAR RESISTANCE TESTS

Experimental results shown in below diagrams are obtained by the procedure and device used for the wear characteristics of sized and heat-treated specimens under the corresponding tests conditions. Table 1 shows the parameters of the carried out experiment.

Table1. Wear resistance test parameters.

Normal load	P = 4,53 N
Nominal contact area	A_a = 225.10^{-6} m^2
Nominal contact pressure	P_a= 2,01 N/cm^2
Average sliding speed	V = 13,1 cm/s
Abrasive surface	Corundum P 320

The experimental part of the procedure included following operations: - preparation of specimens 15.0 x 15.0 mm; - evaluating of specimen’s mass m_o by electronic balance WPS 180/C/2 within 0.1 mg accuracy; - fixing the specimen in the loading head of the tribotester; - setting of given normal load P and covering the corresponding friction way; - measurement of specimen’s mass m_i after the covering of the friction way.

Figures 14 and 15 show the results for the mass wear rate and the relative wear resistance (similar to the wear factor [18]) of the tested TIG hardfaced layers with wire of reinforced aluminium at different content of the reinforcing phase. The reference specimen of the basic metal is given with dash-line.

Lowest mass wear rate and highest relative wear resistance show the specimens with TIG hardfaced layers by filler of extruded aluminium reinforced with electroless nickel/copper plated micro SiC particles without flux. The specimens with TIG hardfaced layers by filler of extruded aluminium reinforced with electroless nickel plated micro SiC particles, as well as those with nano SiC particles with flux show improved relative wear resistance too.

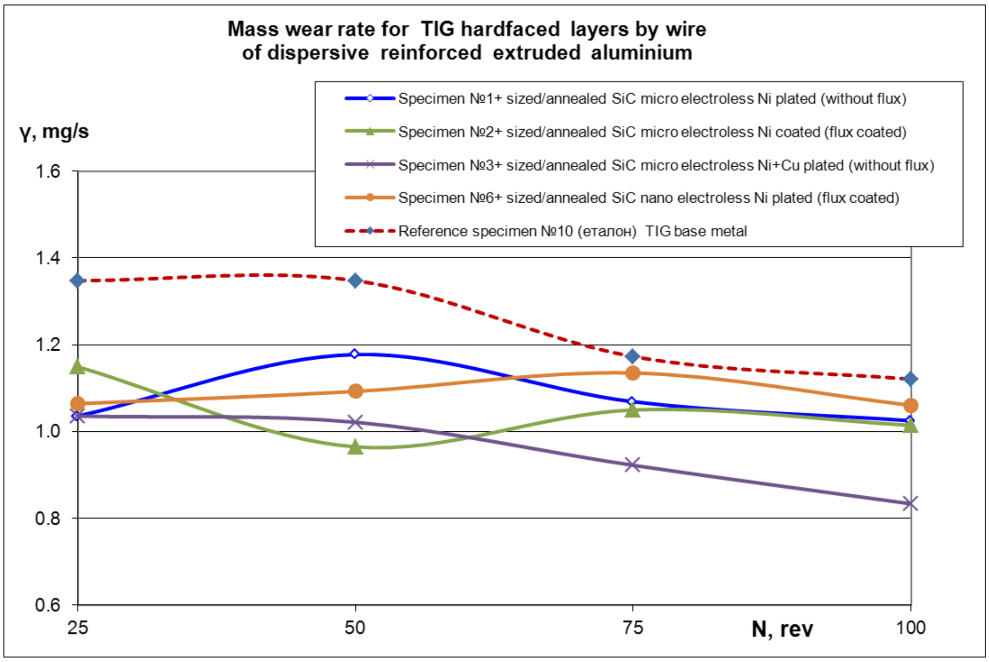


Fig. 14. Mass wear rate for TIG hardfaced layers by wire filler of dispersive reinforced extruded aluminium.

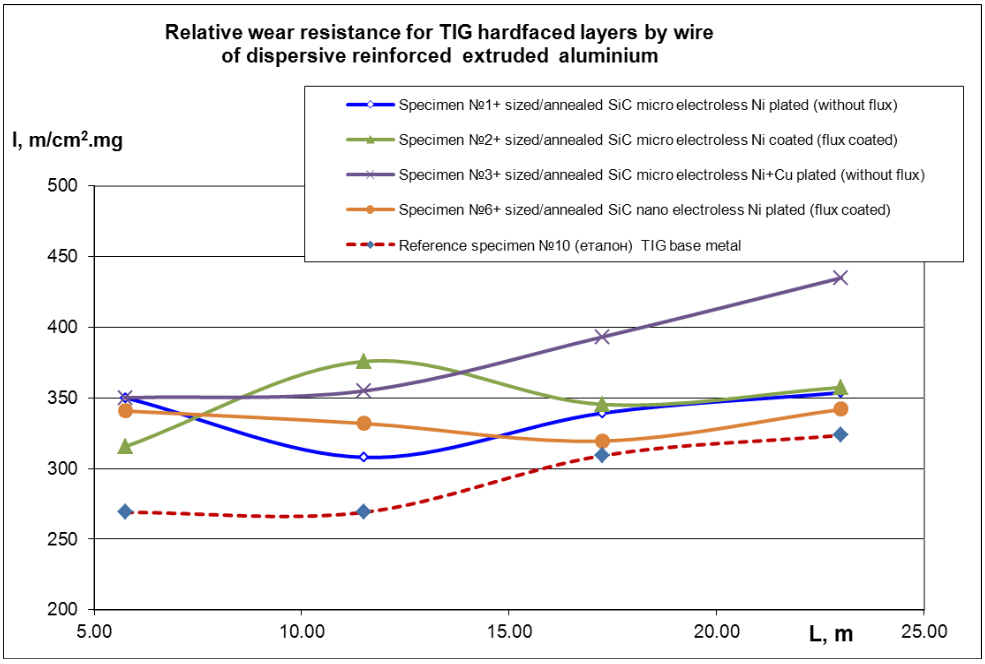


Fig. 15. Relative wear resistance for TIG hardfaced layers by wire filler of dispersive reinforced extruded aluminium.

Figures 16 gives the results of the tests for the relative wear resistance change in the case of TIG hardfaced layers by filler of reinforced aluminium by different content of the reinforcing phase.

The average relative wear resistance change for the case of TIG hardfaced layers by filler of extruded aluminium reinforced without flux by electroless nickel plated micro SiC particles is 15 % to 16 %, and for those with electroless nickel/copper plated particles attains 30 % – 31 %.

The average relative wear resistance change in the case of TIG hardfaced layers wire filler of extruded aluminium reinforced with flux by electroless nickel plated micro SiC particles is 19 to 20 % and for those with plated nano SiC particles is 14 % to 15 %.

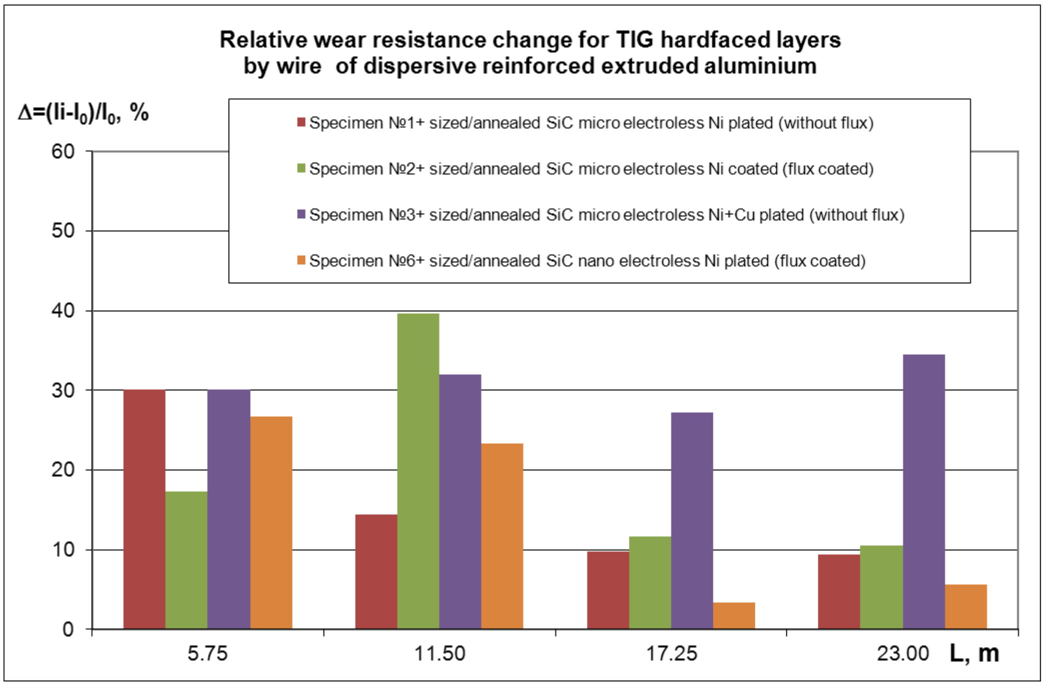


Fig. 16. Relative wear resistance change for specimens with TIG hardfaced layers by filler wire of dispersive reinforced extruded aluminium.

The higher nanohardness and wear resistance of TIG hardfaced layers wire filler of extruded aluminium reinforced by micro/nano particles compared to the basic metal is due to the formation of layers with wetted and alloyed reinforcing phase of the metalized particles.

The higher average relative wear resistance of TIG hardfaced layers with extruded aluminium wire filler reinforced with electroless nickel/copper coated micro SiC particles corresponds to the higher hardness of the hardfaced layers.

9. CONCLUSION

1. The effectiveness is proved of a new technology for producing wire filler for hardfacing from aluminium billet pack with deposited intermediate layers of micro/nano SiC particles designated for hot impression-die forging and subsequent direct extrusion.
2. Wear resistant surface layers are obtained by introducing a reinforcing phase during tungsten inert gas (TIG) hardfacing using extruded wire as additive material containing electroless nickel plated SiC particles. In the case of flux absence the slag is distributed in the form of strongly fixed strips, while in the case of flux presence in the wire the slag is regularly distributed on the surface and can be easily washed away.
3. Nanohardness increase in the zone of TIG hardfaced layers is 1.2 to 1.6 times higher than that of the basic metal. About 30 – 40 % of the increase is due to the implanted in the hardfaced layers reinforcing phase of electroless nickel plated micro SiC particles. In the case of flux plated particles the hardness variation in depth of the hardfaced layer is more regular distributed.
4. The average relative wear resistance of TIG hardfaced layers with wire filler of extruded aluminium reinforced by electroless nickel and copper plated SiC particles is twice higher than that of the layers reinforced by electroless nickel plated particles.
5. The additional coating of particles by flux increases the average relative wear resistance of TIG hardfaced layers reinforced by electroless nickel plated micro SiC. This is due to the better wetting and alloying of the reinforcing phase of the metalized particles by melted aluminium matrix into the weld puddle.
6. A correlation is established between the obtained wear resistance test results (after specimens sizing/annealing) and the obtained nanohardness test results.

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