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Original Article

Wear behaviour of Cr_3C_2–Ni cermet reinforced hardfacings

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ABSTRACT

Submerged arc welding (SAW), plasma transferred arc welding (PTAW), and tungsten inert gas welding (TIG) technologies were used to produce austenitic stainless steel (SS) and nickel alloy (Ni) matrix based hardfacings without reinforcement and reinforced by Cr_3C_2–Ni cermet. As a substrate material normalized structural steel S355 has been chosen. Mechanical properties of produced hardfacings were assessed in terms of hardness (HV/30) and wear resistance tests. The latter property was analysed under different wear conditions: two-body (ASTM G132) and three-body (ASTM G65) abrasive wear tests. Microstructure and phase evolution were analysed by scanning electron microscopy (SEM) and X-ray diffraction analysis (XRD), respectively. Cermet particles in all the conducted tests proved its' selection – hardness and wear resistance of the reinforced hardfacings substantially increased. The addition of Cr_3C_2–Ni cermet increased the hardness twice on average in all utilized technologies leading to the higher wear resistance in further tests. Tendency of wear rate reduction is less expressed in SAW hardfacings, but in PTAW and TIG cases the strengthening effect is obvious: 8.6 and 8.1 times higher wear resistance of SS and Ni based PTAW hardfacings, respectively, and 7.5 and 4.8 times higher for TIG hardfacings. XRD analysis supported wear tests results proving the formation of the complex compounds.

1. Introduction

The failure of any engineering component is understood as loss of its performance or functions, and mainly could be of four general types: wear, deformation, fracture, and corrosion. Data from real engineering cases states that wear comprises approximately 55% of the total failures; in this amount abrasion wear makes up to 20% [1]. These numbers indicate the importance of searching of new abrasive wear solutions. Owing to the great importance of surfaces of engineering components, surface engineering and metallurgy has the great practical value, especially by the fact that these technologies allow to manufacture engineering components which exhibit high wear, corrosion or oxidation resistance, as well as self-lubrication properties without changing the substrate material [2]. Such properties enable the application of components under the different severe conditions. Hardfacings are produced (deposited, welded or sprayed) as the

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protective layer on the substrate, component or tool that are intended to be subjected to critical wear and temperature conditions. Nickel or iron based alloys have found their application in the industries where high thermal and corrosion resistance along with high wear resistance are required. This advantage is caused by their chemical composition – by the presence of wide range of alloying elements, particularly by the existence of the austenitic matrix phase with carbides and further precipitation hardening effect [3–5]. The components' performance at harsh temperatures and corrosion environment such as chemical and aerospace industry, electricity generation plants or other industries undergoes abrasion, corrosion, and oxidation at high temperature could be increased using nickel based superalloys.

Abrasive wear is probably the most significant factor for the implementation in agriculture sector which causes almost all mechanical failures. Farmers complain about the frequent recurrent work, machine downtime and substitute cost of worn-out implements. The quality of agricultural tools depends on their acting edge characteristics such as surface roughness and hardness. Therefore, implements should be made of material which is able to withstand high impact loads and aggressive wear conditions [6].

There are two basic approaches to reinforce the operating surfaces of any component: ex situ and in situ matrix reinforcement. In the ex situ addition, chemical incompatibility of matrix and reinforcement may lead to poor interfacial bonding because difference in the thermal properties could increase the risk of cracking at the poorly bonded interface. Contrary, in situ process can remove the interface problem as relatively harder phases are made to grow in the matrix under a suitable thermodynamic conditions [7].

Considerable number of surface modification techniques such as surface deposits, coatings and hardfacing have been developed over the years in order to reduce the problem of abrasive wear of components working under severe wear [8–10]. Welding is considered to be an easy and economical method to produce a hardfacing. The welding wire electrode is used to form a high wear resistant coating in different welding processes: gas metal arc welding (GMAW) [6], submerged arc welding (SAW) [11,12], tungsten inert gas welding (TIG), flux cored arc welding (FCAW). SAW has several advantages, the first one is that process might ensure high deposition rates and good penetration, the second one is the possibility to use multiple electrodes and easy reinforcement powder introduction, and the last is a comparatively low welder skills requirement, because process can be easily automated. The SAW hardfacing process involves the fusion of highly alloyed powder, which contains a chromium carbide, graphite, tungsten carbide, manganese, cobalt or other chemical elements by the electric arc under the layer of the flux [6,8,13].

TIG filler free welding process operating under the inert gas shielding is found to be quite effective for the modification of surface properties of metal alloy samples by controlled melting up to a required depth for standard tribological applications at the relatively low cost [7,14,15]. The main advantages of TIG process are deep case depths produced at low processing time with less environmental damage executed under a low supplementary and manufacturing cost.

Table 1 – Chemical composition and S355 used as the substrate (max wt.%).

Element	C	Mn	P	S	Si	Fe
Amount	0.22	1.60	0.05	0.05	0.05	balance

Plasma transfer arc welding (PTAW) is among the most easily automated and adaptable processes to produce the thick hardfacings with low manufacturing cost and high productivity compared with thermal spraying, laser cladding or other similar technologies [16]. The main advantage of such a hardfacing is the density and high thickness which are necessary for application in mining, oil–sand industries, production of mixer blades, furnace chutes, etc. [17,18]. It was reported that PTAW hardfacings, reinforced with WC–Co particles, provide significantly higher resistance than of generally used wear resistant steels [19]. Powder feeding system is generally used to transfer reinforcement into the arc area. There are a few different powder materials systems that are typical to PTAW: chromium carbide, WC–Ni and WC–Co, etc. [20]. These systems are suitable for SAW and TIG as well.

Numerous reinforcements are used to produce hardfacings for various wear applications where high hardness, high melting point and wear or corrosion resistance along with high thermal stability and conductivity are required. It was reported that the most frequently used reinforcements are WC or WC-based hardmetals [12], Co-based alloys (stellites) [19], Ni-based alloys [4,5], chromium carbide [3]. Authors suggested application of ferrocarbon and ferrochromium to produce martensitic structure of hardfacing [13]. WC-based cermets (ceramic metal composites) as a reinforcement are used because they combine the hardness of ceramics and the fracture toughness of metals, however, they sensitive to degradation at temperatures above 500 °C [21]. Chromium carbide is known to have excellent oxidation resistance, that is why CrC-based composites are widely used in high-temperature applications where high resistance to wear and corrosion–oxidation is required. Usually chromium carbide is combined with nickel in thermal spray applications. Owing to above mentioned properties such a hardfacing could serve as the barrier coating for high-temperature wear applications.

For the present research Cr_3C_2–Ni cermet based reinforcement was used to produce hardfacings; three different hardfacing technologies SAW, TIG, and PTAW were utilized. The influence of technological parameters as well as microstructure on behaviour of hardfacings in two- and three-body abrasive wear tests were analysed.

2. Materials and methods

The normalized structural steel S355 (EN 10025) has been chosen as the substrate material with nominal chemical composition presented in Table 1 to produce the composite hardfacings provided as bars with 10 mm × 10 mm cross-section and plates of 10 mm thickness.

Two compositions of matrix were used in this study: Castolin 16316 (standard austenitic stainless steel EN 1.4436 (EN-X3CrNiMo17-13-3), wt.%: C 0.03, Cr 17.5, Ni 13, Mo 2.7, bal. Fe) and Castolin 16221 (Ni-based self-fluxing alloy, wt.%: C 0.2, Cr 4, B 1, Si 2.5, max. Fe 2, Al 1, bal. Ni) with particle size with

Table 2 – Initial chemical composition of hardfacings.

Sample code	Hardfacing method	Matrix, wt.%	Reinforcement [R]
S-SS	Submerged arc welding (SAW)	99.9 castolin 16316 + 0.1 wire electrode	–
S-Ni		99.9 Castolin 16221 + 0.1 wire electrode	–
S-SS-R		99.9 Castolin 16316 + 0.1 wire electrode	Cr_3C_2–Ni
S-Ni-R		99.9 Castolin 16221 + 0.1 wire electrode	Cr_3C_2–Ni
P-SS	Plasma transfer arc welding (PTAW)	Castolin 16316	–
P-Ni		Castolin 16221	–
P-SS-R		Castolin 16316	Cr_3C_2–Ni
P-Ni-R		Castolin 16221	Cr_3C_2–Ni
T-SS	Tungsten inert gas welding (TIG)	Castolin 16316	–
T-Ni		Castolin 16221	–
T-SS-R		Castolin 16316	Cr_3C_2–Ni
T-Ni-R		Castolin 16221	Cr_3C_2–Ni

mesh – 10–45 μm (Table 2). The matrix of hardfacings produced by SAW was supplemented by 0.1 wt.% of low carbon welding wire. To obtain the reinforcement powder Cr_3C_2–Ni (80 wt.% Cr_3C_2, 20 wt.% Ni), 99.5 wt.% purity Cr with particle size of 6.65 μm and 99.7 wt.% purity Ni with an average particle size of 2.4 μm, and 99.7 wt.% purity carbon black with particle size 6.45 μm were ball-milled, afterwards plasticized and sintered in vacuum at the temperature of 1100 °C [22,23]. The sintered compact was manually crushed, and the powder fraction with the particle size 90–150 μm was separated by sieving. The original reinforcement content was supposed to be 40 vol.%, but due to dissolution of Cr_3C_2–Ni particles (especially in the case of SAW) after the process it decreased.

In order to evaluate suitability of technology utilized to produce hardfacings three different methods have been chosen SAW, PTAW, and TIG. Parameters of process were adopted accurately for the specific matrix and reinforcement combination. Surfaces of substrate samples were ground to eliminate oxides (or rust), dirt, grease, or oil in the coating area. Dimensions of samples have been chosen according to the requirements of wear test machines.

The single pass SAW process was accomplished on Integra 350 Professional (Miller) (MIG/MAG) using the standard flux AMS1 (LST EN 10204:2004; wt.%: SiO_2 38–44, MnO 38–44, CaF_2 6–9, CaO <6.5, MgO <2.5, Al_2O_3 <5, Fe_2O_3 <2, S 0.15, P 0.1), and low carbon welding wire with diameter of 1.2 mm fed at the velocity of 25.2 m/h to the welding zone under process parameters: welding current 180–200 A, voltage 22–24 V, travel speed –4 mm/s [8].

The single pass PTAW deposits were produced with the following process parameters: welding current 95 A, voltage 22–24 V, oscillation frequency 0.6 Hz, traverse speed 1 mm/s, the flow rates: plasma gas (Ar) 1.5 l/s, shielding gas (Ar) 6.5 l/s, carrier gas (Varigon®) 3.75 l/s (reinforcement), 2.75 l/s (matrix) on GAP 3001 DC (Castolin Eutectic®).

AirLiquide SAF-FRO Combiwig 4000 AC/DC (Italy) TIG inverter type of power source was used to produce hardfacings. Extra-large gas lens Jumbo cup (manufacturer TBI, Germany) ensured achievement of optimum results. Non-consumable electrode WL20 (manufacturer TBI, Germany) of 1.6 mm in diameter which maintains stable arc and prevents the pool from contamination was chosen. Process parameters: welding current 60 A, voltage 18 V, travel speed 1.4 mm/s. The tungsten electrode used was tapered with the angle of 15° and the tip geometry was conical with the flat tip end of 0.1 mm in diameter. The distance from the tip end to the substrate maintained during the process of forming hardfacing layer on substrate was from 1 to 2 mm.

Owing to necessity to evaluate and compare the influence of Cr_3C_2–Ni reinforcement, hardfacings in each technology were produced with and without reinforcement.

The microstructural images of the hardfacings were studied using (SEM) EVO MA-15 (Carl Zeiss, Germany) scanning electron microscope, equipped with the energy dispersive spectroscopy (EDS) device. Optical microanalysis was performed on MLA 10 and Carl ZeisAxio Scope A1. The microstructure was characterized after etching the surface with Gliceregia (15 ml HCl, 10 ml glycerol and 5 ml HNO_3) during 30 s. The X-ray diffraction (XRD) device AXS D5005 (Bruker, Germany), equipped with a Cu Kα radiation source, was used to study the phase composition of produced hardfacings (measuring step – 0.04° (SAW and PTAW hardfacings) and 0.02° (TIG hardfacings).

Mechanical properties of obtained hardfacings were assessed while executing Vickers surface hardness (HV/30) test; hardness tester Indentec 5030KV (Zwick/Roell, Germany) at the load of 294.3 N (30 kgf) with dwell time 10 s. Ten measurements were done on each hardfacing, and the average hardness values are presented.

Wear behaviour of hardfacings was examined in two different wear conditions two-body and three-body wear test seeking to find the most suitable abrasive wear application area. Detailed information on wear test parameters' is presented in Table 3 [20].

The samples for two-body and three-body wear tests were cut in 6 mm × 6 mm × 20 mm and 10 mm × 25 mm × 50 mm test pieces respectively.

3. Results and discussion

Microstructural analysis revealed typical Fe based (SS) or Ni-based (Ni) alloys microstructure of unreinforced hardfacings, they were not considered for further examination. Addition of Cr_3C_2–Ni particles had the specific influence for each series of hardfacings (Figs. 1–3).

Reinforcement particles were entirely dissolved in the SAW hardfacings (Fig. 1a and b) owing to higher welding current which leads to higher heat input during the process, and naturally higher dissolution rate.

Table 3 – Wear test parameters.

Test	Standard	Load, N	Rotational speed, 1/s	Linear speed, m/s	Duration, s	Type of abrasive	Abrasive size, mm
Two-body[a]	ASTM G132	5	1.05	0.4	3600	Al_2O_3[b]	0.08–0.1
Three-body[c]	ASTM G65, procedure A	130	3.6	2.4	1800	SiO_2	0.2–0.3

[a] Emery paper was changed after each 300 s.
[b] Electrocorundum/white aluminium oxide 15A8HM with 8 H mesh size.
[c] Abrasive feed rate (5.0–6.7) × 10^{-2} kg/s.

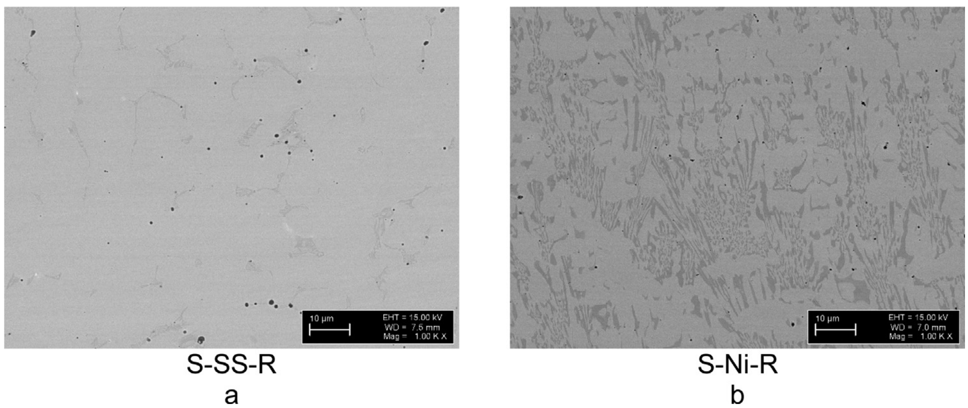

Figure 1 – SEM images of reinforced SAW hardfacings.

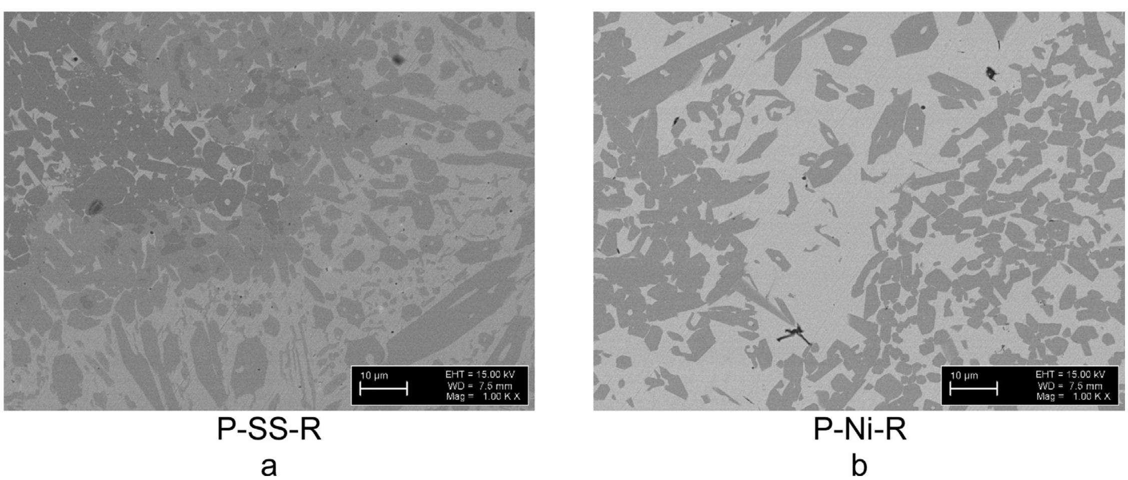

Figure 2 – SEM images of PTAW reinforced hardfacings.

In PTAW and TIG hardfacings Cr_3C_2–Ni particles remained integral and could be easily identified in Figs. 2 and 3. However, it is clearly seen that the amount of the Cr_3C_2–Ni particles is considerably lower in SS hardfacing, which is typical to Fe-based hardfacings.

Vickers hardness test results have showed the expected tendency: addition of Cr_3C_2–Ni cermet particles increased the hardness by 1.2–1.6 times for SAW, 1.7–2.7 for PTAW, and 1.6–2.8 TIG hardfacings. The similar tendency can be observed for all hardfacing technologies (Fig. 4).

First two sets of columns show surface hardness values of hardfacings without reinforcements. It is clearly seen that different hardfacings' formation technologies do not affect values of Vickers hardness dramatically in case when austenitic stainless steel was used as the matrix (Fig. 4, first set of columns). A slight effect of used technologies was observed on Ni-based matrix (Fig. 4, second set). The two last sets of results have revealed higher influence of process used to produce hardfacings. The higher hardness values were reached in case of PTAW and TIG technologies. It can be explained by higher content of hard cermet particles in the hardfacing, as microstructure analysis of SAW hardfacings showed total fusion of reinforcement. According to the presented results of mechanical tests the leading technology is PTAW. Austenitic stainless steel (SS) matrix reinforced with Cr_3C_2–Ni (SS-R) showed higher growth of hardness (from 201.4 to 551.8 HV/30

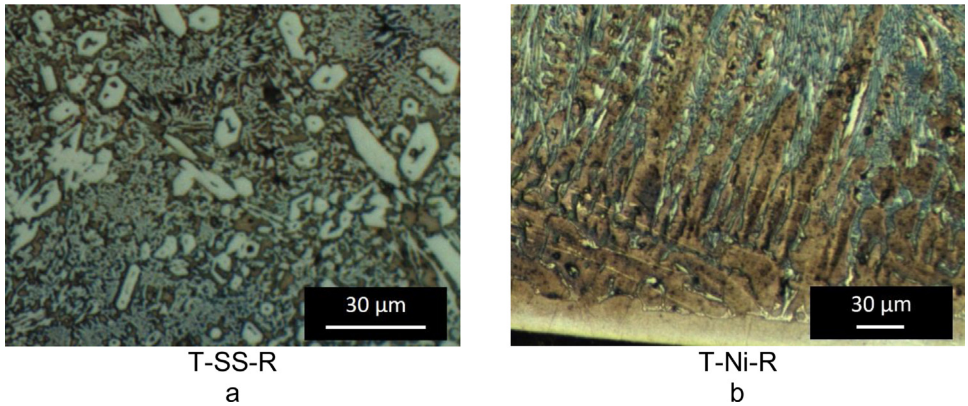

Figure 3 – Optical microscope images of TIG reinforced hardfacings.

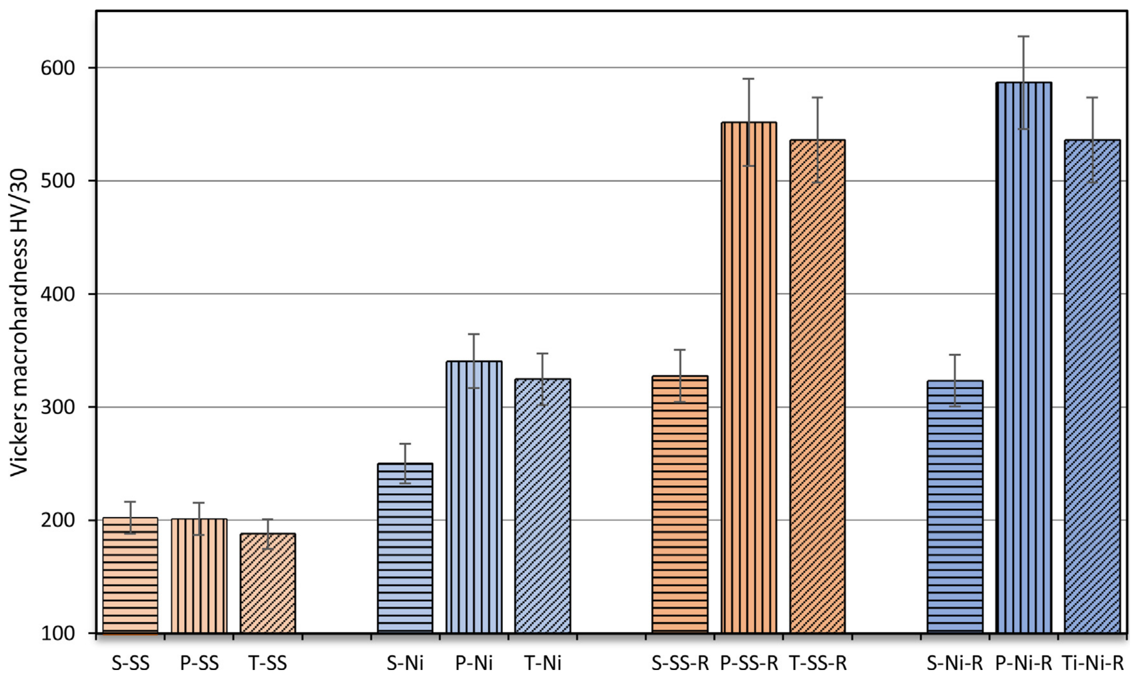

Figure 4 – Vickers hardness of SAW, PTAW and TIG hardfacings.

in PTAW, and from 187.9 to 536.2 HV/30 in TIG) comparing with reinforced Ni-based matrix (Ni-R) (from 340.6 to 586.9 HV/30 in PTAW, and 324.7 to 536.4 HV/30 in TIG) because initial hardness of unreinforced SS matrix was small (187.9–202.5 HV/30).

The results of the two-body wear tests were straight proportional to those of hardness test results (Fig. 5). The toughness of the hardfacings should have a rather minor impact, as according to [24], the lower is the impact angle of the abrading particles, the more important is the hardness and the less important is the fracture toughness of the worn material; as in the case of presented study the impact angle could be considered zero, i.e. abrasive particles do not hit the surface, the hardness is assumed be the dominant factor. As two sets of columns in Fig. 4 showed lower hardness values, consequently unreinforced SS and Ni hardfacings possessed higher wear ratio (Fig. 5). Wear resistance of reinforced hardfacings confirmed influence of applied technology on wear behaviour: under the two-body abrasive wear conditions, the reinforced SAW hardfacings S-SS-R and S-Ni-R exhibited from 8 to 10 times higher wear than PTAW hardfacings, and from 2 to 6 times – than TIG hardfacings, respectively.

Parallel to the above mentioned results of two-body wear test, three-body abrasion wear test proved positive effect of Cr_3C_2–Ni particles [25] addition to the Fe or Ni-based matrix which lead to from 1.4 to 1.8 times for SAW, 8.1–8.4 times for PTAW, and 4.1–9.0 times lower wear of TIG hardfacings (Fig. 6). The results of this test as well as for two-body abrasive wear test are straight proportional to hardness study. Reinforced austenitic stainless steel and Ni-based alloy TIG and PTAW hardfacings demonstrated nearly the same wear level. It allows to state that both technologies are suitable to produce hardfacings working under the three-body wear test conditions. The growth of wear resistance was more expressed in iron based hardfacings (SS) particularly for PTAW

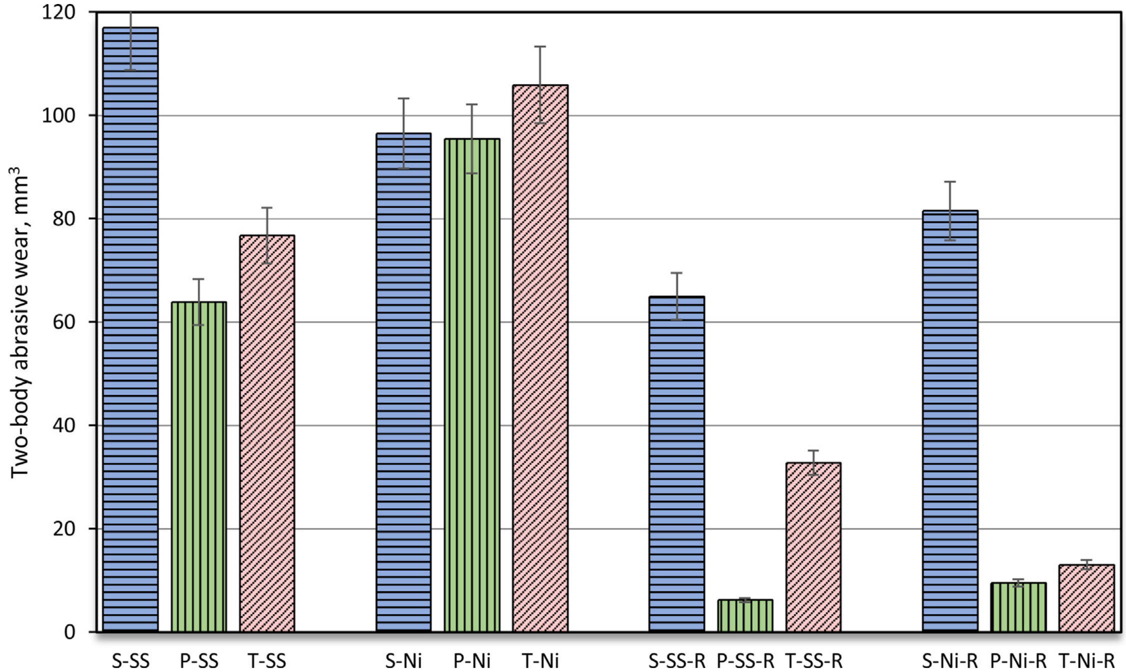

Figure 5 – Comparison of two-body abrasive wear tests of SAW, PTAW, and TIG hardfacings.

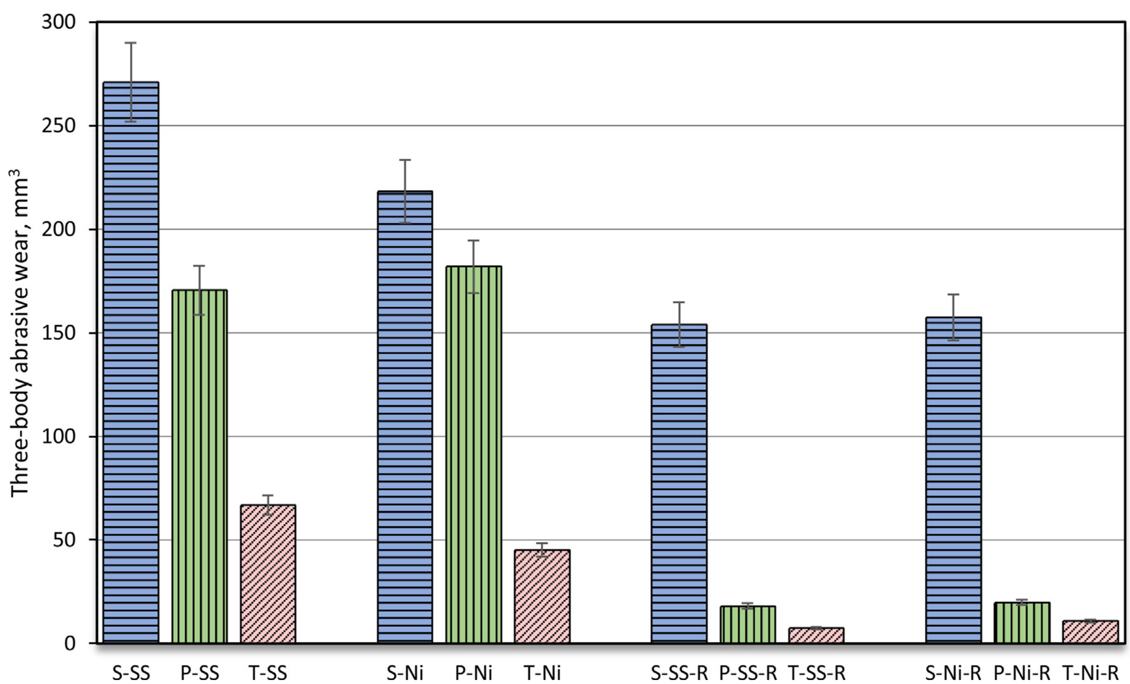

Figure 6 – Comparison of three-body abrasive wear tests of SAW, PTAW, and TIG hardfacings.

technology. The higher wear resistance of the latter can be explained by the presence of Cr_3C_2–Ni particles in the hardfacing. As the most reliable cause of comparatively low wear of the SS-R type hardfacings secondary martensitic transformation of the retained austenite [2,8] can be assumed. As it is clearly depicted in Fig. 3 TIG hardfacings overcame two above mentioned technologies, even unreinforced SS and Ni-based composites showed comparatively low wear 66.77 mm^3 (T-SS) and 45.12 mm^3 (T-Ni). Growth of wear resistance of Ni-based alloy after reinforcement with Cr_3C_2–Ni was not so high as for SS hardfacings.

The lowest overall wear rate in both two-body and three-body abrasive wear tests was observed testing austenitic stainless steel based (SS) Cr_3C_2–Ni reinforced hardfacings produced by means of PTAW and TIG technologies. As austenitic stainless steel matrix demonstrated more promising results,

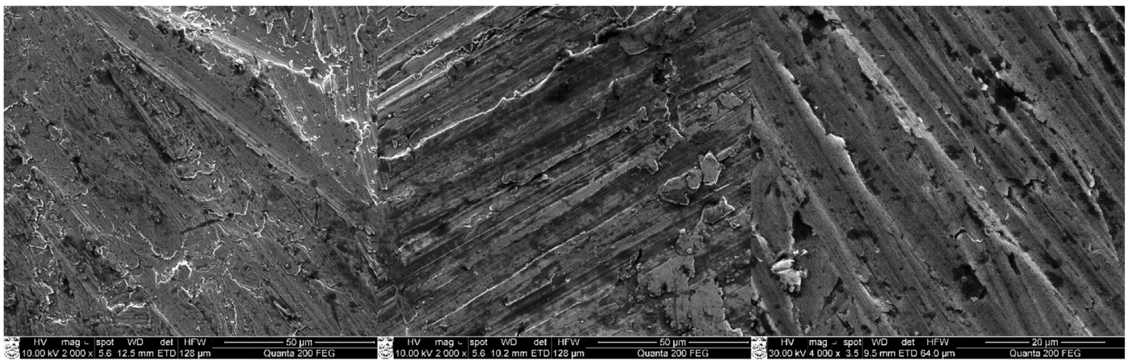

Figure 7 – Worn unreinforced hardfacings in two-body abrasive wear test.

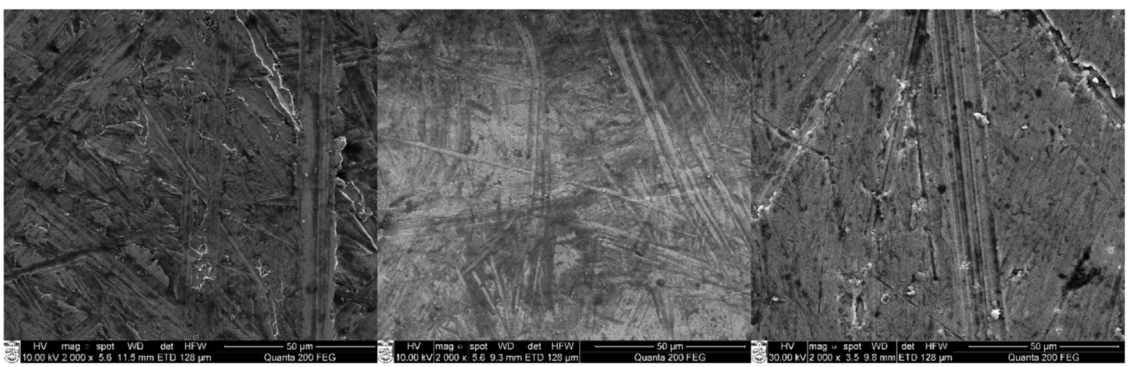

Figure 8 – Worn reinforced hardfacings in two-body abrasive wear test.

it was decided to analyse wear mechanism of SS based hardfacings. It was reported that [26] mode of wear mechanism depends on the microstructure and particularly on the formation of secondary phases, therefore optical microscopic analysis before wear tests and SEM analysis of worn surfaces was accomplished.

All Cr_3C_2–Ni unreinforced hardfacings showed the presence of micro-ploughing wear mechanism after two-body abrasive wear test. It is clearly seen in Fig. 7 that surface layer was shifted to the opposite sides of the wear track.

Combination of micro-cutting and micro-ploughing wear mechanisms was observed in reinforced SAW hardfacings tested under the two-body abrasive wear (Fig. 8a). Dominant wear pattern of PTAW hardfaced surfaces was micro-cutting (Fig. 8b), TIG samples wear pattern united two mechanisms: micro-cutting and micro-ploughing with predominant cutting (Fig. 8c). Among the studied hardfacings, the abrasive grooves were the shallowest in the case of PTAW ones, what corresponds well with their highest resistance to abrasion, seen at Fig. 5. This fact, owing to the particular attribute of the technology, can be explained by higher amount of primary carbides in the structure [26]. No brittle cracking was observed which allows to affirm suitability of these technologies to produce hardfacings.

Three-body abrasive wear test SEM images revealed the same principle wear mechanism for all samples: micro-cutting. Obviously deeper and larger scars have been found in SAW hardfacings with lower hardness and higher wear rate (Fig. 9a). Smoother worn surfaces of PTAW and TIG hardfacings were caused by tackling of abrasives movement and its penetration inside the matrix by the cermet reinforcement (Fig. 9b and c). It should be noted that despite a modest part of hard carbide particles crumbled from cermet reinforcement during the test, the rest remained well integrated in the matrix.

The preserved reinforcement in PTAW and TIG hardfacings better tackled abrasive particles from removing hardfacing material. In Fig. 9a and b it is clearly seen that the grooves, left by abrasive particles in the SAW hardfacing, are quite long, i.e. nothing prevented them from removing the material; at the same time, in the PTAW hardfacing, the material around reinforcement was worn out, while the reinforcement remained relatively unworn, i.e. the reinforcement particles interrupted the movement of abrasive and the removal of the hardfacing matrix.

As unreinforced hardfacings did not show any specific properties, Cr_3C_2–Ni cermet strengthened surfaces have been subjected for XRD analysis to reveal formation of the particular phases in the microstructure. To achieve accurate results,

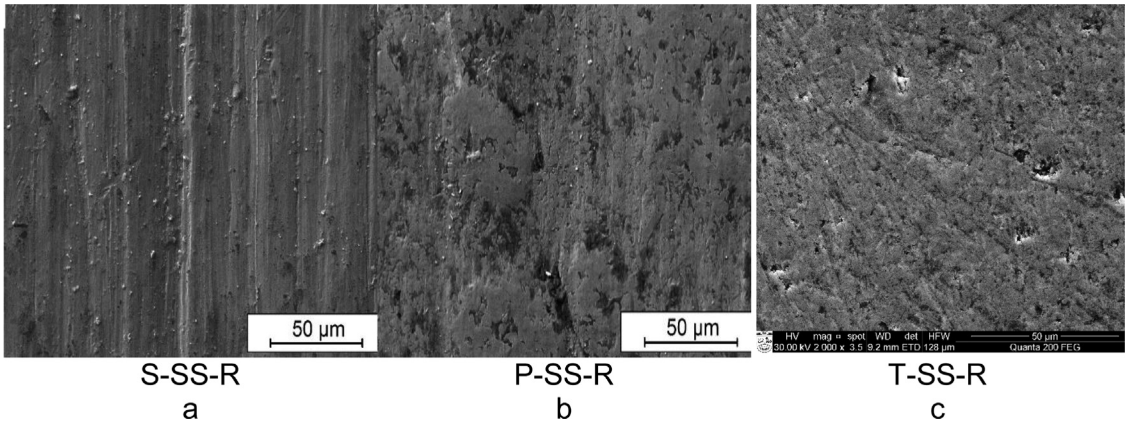

Figure 9 – Worn reinforced hardfacings in three-body abrasive wear test.

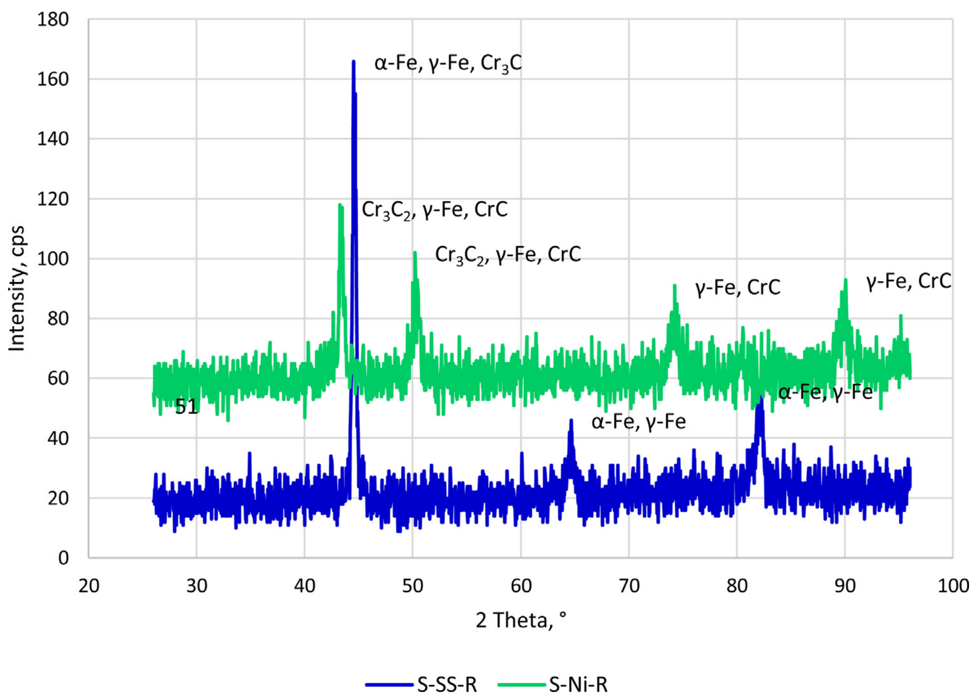

Figure 10 – S-SS-R, S-Ni-R XRD spectrum.

the surface of each hardfacing was smoothly polished. The dominant phases in the S-SS-R were observed to be solid solution of chromium in α-Fe supported by small amount of secondary carbide Cr_3C (Fig. 10). Different type of chromium carbide Cr_3C_7 was indicated in P-SS-R along with composed γ-Fe accompanied by solid solution of Cr in Fe [27] (Fig. 11). The dissolution of carbon in the retained austenite caused presence of comparatively low content of secondary carbides. Two main compounds were identified in T-SS-R hardfacing namely solid solution $Cr_{0.19}Fe_{0.7}Ni_{0.11}$ and Cr_7C_3 (Fig. 12). It is worth mentioning that a minor deflection from the Cr_7C_3 standard diffraction peaks and experimental maximums of hardfacings is observed (76–85°) due to fact that Cr carbide in the hardfacing is not of a pure Cr_7C_3 stoichiometric composition, i.e. part of the Cr atoms in the carbide lattice may be replaced by Fe. It distorts the lattice of carbide, whereas the diffractogram reveals a shift of the diffraction peaks towards larger (when lattice contracts) or smaller (when lattice grows) angles.

The S-Ni-R hardfacing's diffractogram notably showed formation of CrC, Cr_3C_2 with a minor scale of γ-Fe (Fig. 10). Cr_3C_2 carbide and nickel-based secondary carbide $NiC_{0.22}$ along with minor amounts of Cr_3Si and Cr_2B (not denoted in the XRD spectrum) were observed in P-Ni-R hardfacings (Fig. 11). Three typical compounds: solid solution $Ni_{2.9}Cr_{0.7}Fe_{0.36}$, Cr_3C_2, and graphite existed in T-Ni-R hardfacing (Fig. 12). The dominating solid solutions in the both hardfacings formed using TIG significantly differ one from another in their elemental composition (Cr in T-SS-R and Ni in T-Ni-R). The carbides formed are also differ: T-SS-R hardfacing contains Cr_7C_3 carbides while in T-Ni-R Cr_3C_2 is identified. In addition, free graphite was found in the latter.

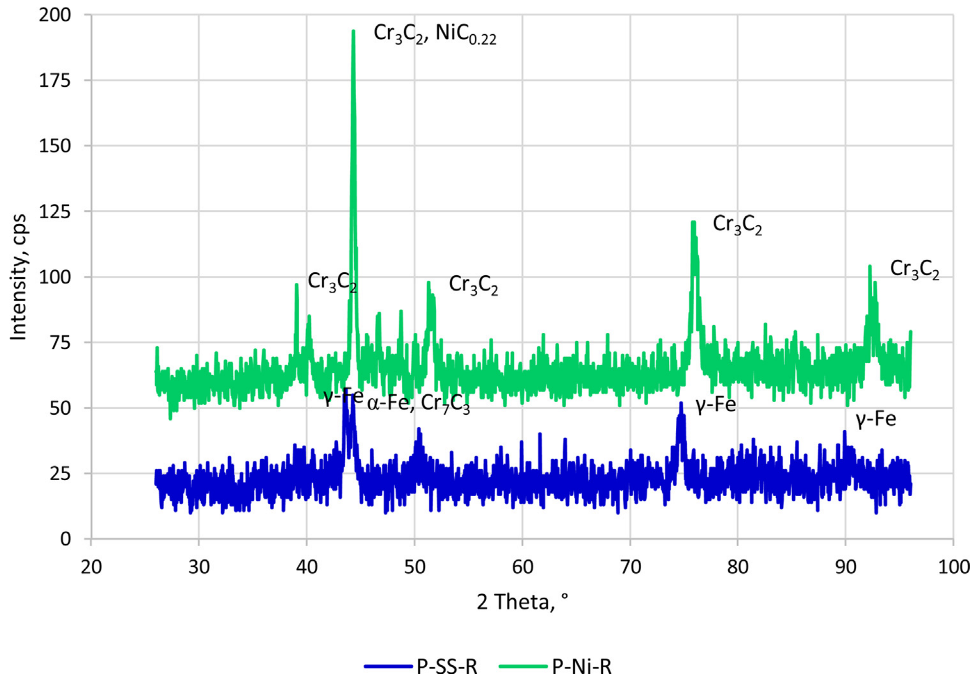

Figure 11 – P-SS-R, P-Ni-R XRD spectrum.

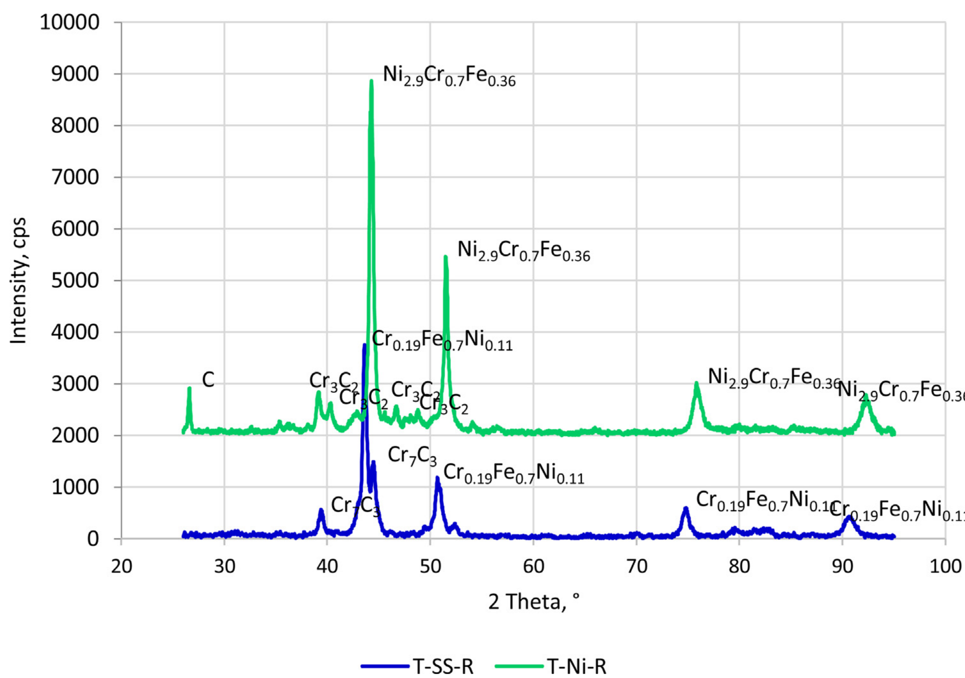

Figure 12 – T-SS-R, T-SS-R XRD spectrum.

4. Conclusions

In the present research influence of Cr_3C_2–Ni cermet addition to austenitic stainless steel and Ni-based alloy matrix for the aim to produce hardfacings were studied. The following statements could be drawn as conclusions:

1. Synthesized Cr_3C_2–Ni particles are suitable reinforcement for the production of submerged arc (SAW), plasma transferred arc (PTAW), and tungsten arc welded (TIG) hardfacings. However, in terms of wear resistance more prominent effect was achieved with two latter technologies.
2. Microstructure analysis revealed higher dissolution rate of Cr_3C_2–Ni in austenitic stainless steel than in Ni-based alloy matrix. The precipitation of secondary carbides in SAW hardfacings was comparatively low, what caused higher wear rate.

3. Hardness values of unreinforced austenitic stainless steel matrix hardfacings' are not sensitive to applied technologies; average hardness of SAW, PTAW, and TIG hardfacings was ~200 HV/30. Ni-based alloy matrix hardness showed the input of the technology: the highest hardness was achieved on PTAW hardfacing was 340 HV/30.
4. If compared with unreinforced hardfacings addition of Cr_3C_2–Ni reinforcement increased the hardness twice on average with all the utilized technologies; this effect was more pronounced for austenitic stainless steel matrix in PTAW and TIG technologies (2.7 and 2.8 respectively).
5. Wear resistance of hardfacings tested under two- and three-body wear conditions increased firmly adding cermet particles. Wear rate reduction tendency is less expressed in SAW hardfacings: in two-body test 1.8 times less for austenitic stainless steel (SS), and 1.1 times for Ni-based (Ni) matrix; in three-body test 1.7 times for SS, and 1.4 for Ni.
6. The highest growth of wear resistance was achieved in PTAW hardfacings where reduction of wear reached 8.6 times for SS, and 8.1 times for Ni-based matrix reinforced hardfacings. Exceptionally high wear resistance was noticed while testing TIG hardfacings under three-body abrasive wear test: it overpassed SAW Fe based hardfacings by 15, PTAW ones by 2.6 times, and SAW Ni-based hardfacings by 14, PTAW ones by 2 times.
7. The dominant phases in the S-SS-R were the solid solution of chromium in α-Fe and small amount of secondary carbide Cr_3C. Different type of chromium carbide Cr_3C_7 and γ-Fe was indicated in P-SS-R along with solid solution of Cr in Fe.
8. The S-Ni-R XRD analysis showed formation of CrC, Cr_3C_2 with a minor scale of γ-Fe. Cr_3C_2 carbide and nickel-based secondary carbide $NiC_{0.22}$ along with minor amounts of Cr_3Si and Cr_2B were observed in P-Ni-R hardfacings.
9. XRD spectrums determined that $Cr_{0.19}Fe_{0.7}Ni_{0.11}$ solid solution (cubic lattice, *Fm3m* spatial group) and Cr_7C_3 carbides (orthorhombic lattice, *Pmcm* spatial group) dominate in T-SS-R hardfacings. Different compounds were observed in T-Ni-R hardfacing: $Ni_{2.9}Cr_{0.7}Fe_{0.36}$ solid solution (cubic lattice, *Fm3m* spatial group), Cr_3C_2 carbides (orthorhombic lattice, *Pmcm* spatial group), and graphite (rhombohedral lattice, R3 space group).

Taking into an account all these considerations it can be stated that addition of Cr_3C_2–Ni cermet leads to the formation of high abrasive wear resistant, hard and strong hardfacings; further research will be concentrated on an erosion wear tests of the same compositions.

Conflicts of interest

The authors declare no conflicts of interest.

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