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Hard Facing Spelt Forever Remains

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ABSTRACT

Alternative routes in hard facing alloys for mining, marine and agricultural sectors are studies about possibilities other than traditional hard facing routes. These are composite preparation with other types of carbides and different behaviors of microstructures with variation in welding techniques. Methods of non-ferrous–based and Ni- and Co-based composite preparations are mostly laser cladding and plasma-transferred arc welding. In alternative tests, compression tests appear to describe effects of strain aging by service exposure with wear. In alternative processing, friction surfacing is studied on tool steels.

Keywords: *abrasive, agricultural sectors, bucket, carbide, cast iron hard facing, composite, compression tests, hard facing, rubber wheel, steel substrate, wear, welding*

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INTRODUCTION

Steel–white cast iron facing for mineral sand dredging and wear parts for heavy earthmoving equipment produce brittle and wear-resistant materials by moderate impact. Improvement of bonding mechanisms between white cast iron and steel during manufacture is developed by vacuum casting process for complex-shaped composites [1]. Abrasive wear innovations in agriculture have appeared to find relation between internal microstructure of substrate and external conditions of particles and forces involved for wear. These have included friction of particles and rpm of wheel in tests by modified rubber wheel [2]. Varying compositions of tungsten, chrome boride and molybdenum solid solution strengthened matrix in iron-based hard facing alloys have been tested under compression. Specimens have been electro-discharge machined (EDM) cylinders and compressed by 50 kN capacity mechanical testing system with hardened stainless steel plates [3]. Wear-resistant composite depositions steel by laser cladding for mining and mineral industry have accounted strategic matrices of Ni-, Co- or Fe-based alloys and hard-phase carbides at different ratios. Ni-based alloy with Spherotene powders have been optimized for laser processing in place of commercially available WC powders. Spherotene powders have spherically fused monocrystalline WC particles, and commercially available powders have contained spherical microparticles consisting of crushed WC agglomerates. High-power lasers for hard facing or laser cladding has referred to be more appropriate than traditional standard methods [4]. High-quality metallurgically fused deposits on relatively low-cost surfaces have been applied by plasma-transferred arc (PTA) hard facing. Soft alloys, medium and high hardness materials, and carbide composites could be deposited on a variety of substrates to achieve diverse properties such as mechanical strength, wear and corrosion resistance, and creep. Advantages of PTA are as follows: easy automation, high reproducibility, precise metering of metallic powder feedstocks resulting in lesser material quantity used, powder feed rates, gas flow rates, amperage, voltage, and heat input ensuring consistency, controlled heat input to ensure weld dilutions control, tougher and more corrosion resistant, low levels of inclusions oxides and discontinuities, smooth deposits without post-weld machining, and provide a variety of deposits in thicknesses depending upon torch powder and application [5, 6]. PTA welding has produced deposits of composite surface layer consisting of nickel base alloy with titanium carbide in powder form on to surface of low-alloy steel. Maximum hardness and minimum dilution at suitable arc current have been reported. Features of microstructures have described distribution of reinforcement particles, grain shape, particles size, boundary line between substrate and over layer, and microporosities in matrix [7].PTA composite layer of nickel base with tungsten carbide in powder form on to surface of low-alloy steel at a suitable arc current has produced high hardness and minimum dilution. Increasing current has increased dilution sand consequent decrease in hardness. Features inspected in microstructure of composite have been uniform distribution of reinforcement particles, regular grain shape, and half-dissolution of carbides in the matrix [8]. In corrosion-resistant hard facing, exceptional reliability and maintainability for metal-to-metal sealing in high-pressure gate valves used for offshore production wells have attributed from hard facing materials for aggressive environments PTA welds. Stellite, a cobalt-based material to nickel-based alloy substrates, has been experienced from tests of chemical composition, microstructure, galling and corrosion resistance [9]. Microstructure and high temperature stability have been studied by microscopy, microanalysis, dilatometry and thermodynamic modeling of iron-based hard facing deposited by manual metal arc (MMA) welding. As-deposited undiluted alloy contained mixture of M_7C_3 carbide and metastable austenite. Decomposition of austenite by annealing has formed ferrite and carbides in two steps [10]. In cobalt-based hard facing, alloys deposited by MMA welding, tungsten inert gas (TIG) welding and laser cladding relation between microstructure and abrasive wear properties have been investigated. Differences in microstructure at different freezing rates associated with three processes have given rise to the highest degree of dilution for MMA process and lower levels for TIG and laser depositions. These are in accordance formed increasing grain fineness, hardness and wear resistance [11]. In nickel-based hard facing, alloys deposited by arc welding have experienced simulation between conventional cast with and without large volume fractions of ordered precipitates. Relation among related variables has been justified [12]. Effects of ferroboron and ferrochromium with massive wire-based hard facing alloys have welded on steel substrate by open arc welding. Experiments have been interpreted by hardness test, scanning electron microscopy (SEM), X-ray diffraction (XRD) analysis and microhardness [13]. Chromium and cobalt have been major constituents in many welds hard facing alloys of mines; those could be substituted by ternary systems (Fe–Mo–Ni) of intermetallic-hardened abrasion-resistant weld materials stable at room temperature. Powder metallurgical techniques and arc-melting and submerged-arc welding process are prescribed. Pin-on-drum abrasive wear test, heat treatment and melting point analysis tests have been suggested. Microstructures of Fe–Mo–Ni alloys synthesized by arc-melting have produced (Fe,Ni), Mo_6 intermetallic plus austenite eutectic in an austenitic matrix. Silicon has improved poor abrasion resistances of these alloys after promoting formation of Laves phase, i.e. FeMoSi intermetallic. Heat treatment of explored alloy has produced second-phase precipitation in the matrix to raise hardness and reduce wear rate. Abrasive wear resistance has increased with continual increase in molybdenum and silicon content [14]. Corrosion- and wear-resistant coatings have been deposited by friction surfacing on tool steel substrate. Friction surfacing has low environmental impact and an energy-efficient process. Advantages have been capability of producing coatings with zero dilution and good metallurgical bonding. Effect of process parameters on the width of deposit produced by friction surfacing process has been investigated. Process parameters have been friction pressure, rotational speed and welding speed [15]. Simulated cast test piece to that of welding in high temperature-resistant nickel-based hard facing was experienced by incorporating intermetallic-ordered precipitation in solid solution hardened conditions. Computer modeled capability of estimating microstructure and strength as a function of many variables have been suggested [16].

CAST IRON HARDFACING IN MINING INDUSTRY

Huggett et al. [1] described interfacial studies of steel–white cast iron applicable for mineral sand dredging and wear parts for heavy earthmoving equipment. Interfacial examinations have included quantitative x-ray mapping (QXRM) and electron beam backscattered diffraction (EBSD) mapping. The authors suggested that the use of this composite has been new and produced permission of brittle and wear-resistant materials encountered by moderate impact conditions. This exploration has provided an enhanced understanding for improvement of bonding mechanisms between white cast iron and steel during manufacture. The authors have developed new vacuum casting process to prepare composite white iron/steel wear parts applicable for use in medium impact, high wear mining applications. Excellent bonding in new process has provided method of manufacturing complex-shaped composites. Compared to original steel wear parts, new composite processes have showed improvements in field trials of wear life.

Applications of alloy composites have been traditional in mining industry. These products are hard faced wear plate, vacuum-brazed plates and wear bars, various carbide tools inserted into drill bits, and powder metallurgy products. Limitations of these processes are (1) methods of manufacture, (2) expensive capital equipment, and (3) high raw material costs. Explanation of limitations are described by (a) limited deposition thickness depending on the type of welding arc process used hard-faced plate have been produced from multi-head welding, (b) requirement of expensive heat treatment vacuum furnaces and high-tolerance machining of surfaces to be bonded by brazing, etc. The authors have summarized various alloy joining processes in Table 1.

Additional limitations for manufacturing composites have been (1) composites often have limited design scope, that is, require flat faces, plates and simple geometric shapes; and (2) require complicated fixing methods to enable wear protection to be effective: white iron hard faced plate and white iron vacuum-brazed bars and plates. Wear performance has been provided by microstructure of hard complex chromium carbides supported within a ferrous alloy matrix or possible variations in compositions of hard facing raw materials in vacuum brazing. High carbide volume fractions have provided better field performance. Restrictions of manufacturing methods for alloy composites have been developed by (1) orientation of product, (2) unlimited thickness, (3) elimination of machining; (4) production of larger composite components, (5) lower differences in thermal expansion of wear material and substrate, (6) complexity of shapes, and (7) eliminate cracking. Using a previously developed vacuum brazing process, the authors have described the following methods: (1) high-tolerance mating steel and white iron surfaces with thin copper shim of 0.lmm thick between mating surfaces, (2) heating in high vacuum furnace to melt and flow copper across mating surfaces under capillary action, and (3) during vacuum brazing by white iron, liquid copper at the surface of steel allows copper to dissolve iron present in these alloys, forming a binary alloy that grows across the interface. Thus, in the absence of a brazing alloy, above melting point of white cast iron, it has wetted surface of steel substrate [1]. An optical micrograph is shown in Figure 1.

Table 1. *Summary of alloy joining processes [1].*

Process	Bond	Cost	Shapes	Section thickness	Wetting	Comments
Welding	Metallurgical	Low	Joints + pads	<6 mm	Excellent	High distortion
Brazing	Mechanical	Low	Joints	<0.5 mm	Good	Low strength
Sintering	Metallurgical	Med/High	Complex	10–75 mm	Good	High pressure
Casting	Mechanical	Low	Complex	10–250 mm	Poor	Chilling/ poor bonding
Sol-gel	Metallurgical	Med	Complex	<5011 m	Good	Limited thickness
Cast bond (CSIRO)	Metallurgical	Med	Plate + Tube	20–75 mm	Good	Molding limited
Explosion	Metallurgical + Mechanical	High	Plate	<100 mm	Good	Shape limited

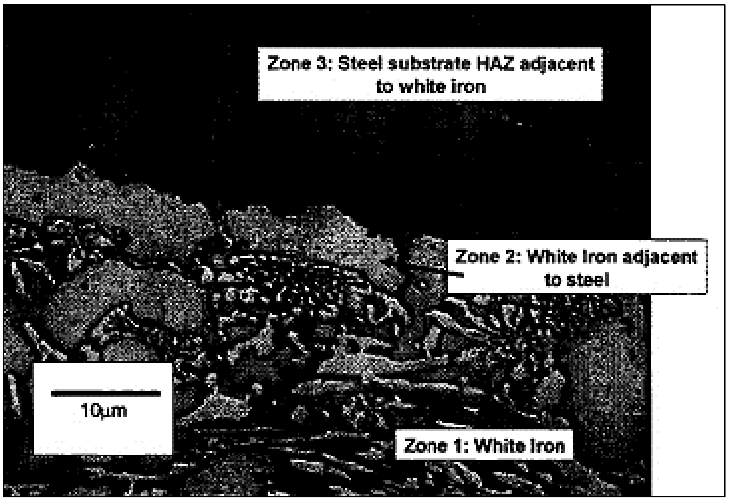

Fig. 1. *Optical micrograph of interface [1].*

Fig. 2. *Original ESCO V6lEL T bucket teeth [1].*

In field trials of vacuum cast composite alloy in mining conditions have applied to use wear parts that was stopped after approximately 100 hours' operation due to cracking of the white iron component of the composite wear teeth (Figure 2).

HARDFACING IN AGRICULTURAL SECTORS

Chotěborský and Linda [2] have described abrasive wear innovates new materials in agriculture. Method has been finding relation between internal microstructure of substrate and external conditions of particles and forces involved for wear. Abrasive wear evaluation in agriculture henceforth has included friction of particles and rpm of wheel in tests by modified rubber wheel instrument based on the ASTM G65. The authors have evaluated (1) friction force has been proportional to the volume loss for single-phase materials like steel; (2) friction force, frequency and amplitude have represented cohesive strength between hard phase and matrices for multiphase materials like cast iron or metal matrix composite; and (3) frequency has been the limitation of using rubber wheel method, which was 200 Hz and suggested to require computation [2]. Friction mechanism between abrasive particles and abraded material has been a random process between a rubber wheel and sand particles, which could cause equivalent linear motion of particles if their interaction has maintained rotation at a certain frequency. Applying a rotational movement to be an equivalent linear one, then interaction between particle and material could cause sliding of material to cause friction justified by friction coefficient. Distant frictional force has referred to cause energy loss as heat, e.g. distant friction between a chisel and soil to increase fuel consumption. Thus friction coefficient has been dependent on boundary conditions of particles and sliding material. Boundary conditions were influenced by the size of particle and adhesion phase, e.g. microstructure of a metal with two very different phases, such as solid solution and intermetallic, has different friction coefficient than a microstructure with a solid solution. The total friction energy consumption was indicated by frictional force. Therefore, the density of friction energy was represented by "amount of friction energy in relation to friction stressed amount of mass". Friction process has been characterized by indicators that determine the critical energy level in terms of (a) density of friction energy, (b) intensity of wear, and (c) mean shear stress. Obviously, abrasive wear of multiphase material has not been explained. This explanation has described the relationship between microstructure, volume loss of materials, and test condition [2]. Experimental results are presented in Table 2. Volume loss represented how many cubic millimeters have been given out per one meter of test distance. Friction force and its standard deviation were calculated from all measurements. Standard deviation values have showed a change in friction force at varying measurements. Hardness of tested materials was determined by standard Rockwell tester at 150 kg load.

COMPRESSION TESTS IN HARDFACING

Tungsten-strengthened matrix with varying compositions of 10–15, 20, and 30 wt% tungsten/chrome boride content in iron-based hard facing alloys and molybdenum solid solution strengthened matrix with 10–15 wt% W/Cr boride content have been fabricated by Tyler Wiggins [3]. Compressive strength determination of ferrous-based hard facing alloys has showed to be exceeding 2340 MPa and nonferrous-based hard facing to that of 4346 MPa (Mo-strengthened matrix with 10–15 wt% W/Cr boride) and 4107 MPa (W-strengthened matrix with the same 10–15 wt% W/Cr boride). Increasing W/Cr boride content to 20% have showed decrease in compressive strength to 3378 MPa, and further for 30% to be 2713 MPa. Specimen dimensions fabricated have been EDM cylinders with 3 mm diameters and 2.41 mm heights. Compression testing setup using a 50 kN capacity mechanical testing system have been used with hardened 440C stainless steel plates to compress samples [3].

Table 2. *Measured values of tested materials [2].*

Sample no.	Volume loss, $mm^3/m \times 10^{-3}$	Friction force, N	Hardness, HRC
1	2.8 ± 0.3	14.72 ± 1.22	56 ± 1.5
2	292 ± 38	13.56 ± 0.32	N/A
3	166 ± 15	14.61 ± 0.42	N/A
4	43.6 ± 3.5	15.75 ± 0.52	N/A
5	14.7 ± 0.9	16.72 ± 0.44	40 ± 2.2
6	4.1 ± 0.6	15.98 ± 0.32	58 ± 1.4
7	16.2 ± 1.1	17.09 ± 0.35	38 ± 2.5
8	5.2 ± 0.4	16.3 ± 0.36	47 ± 1.7
9	3.7 ± 0.25	15.72 ± 0.22	56 ± 1.3
10	2.6 ± 0.07	16.09 ± 0.51	59 ± 1.3

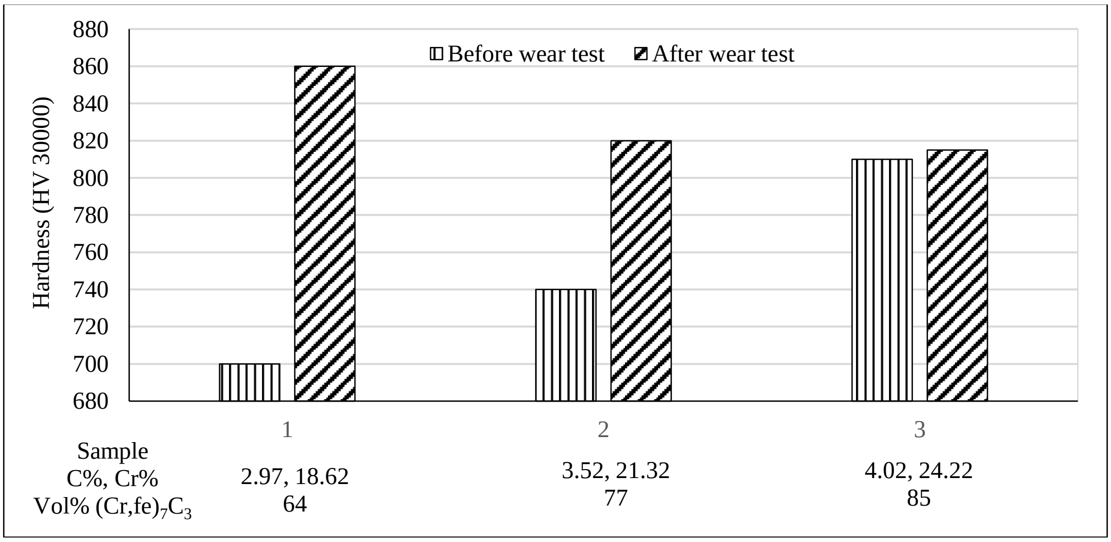

Fig. 3. *Hardness values for hypoeutectic, eutectic, and hypereutectic samples of Fe–Cr–C. The lower carbon content alloys showed significantly higher hardness values after the wear testing [3].*

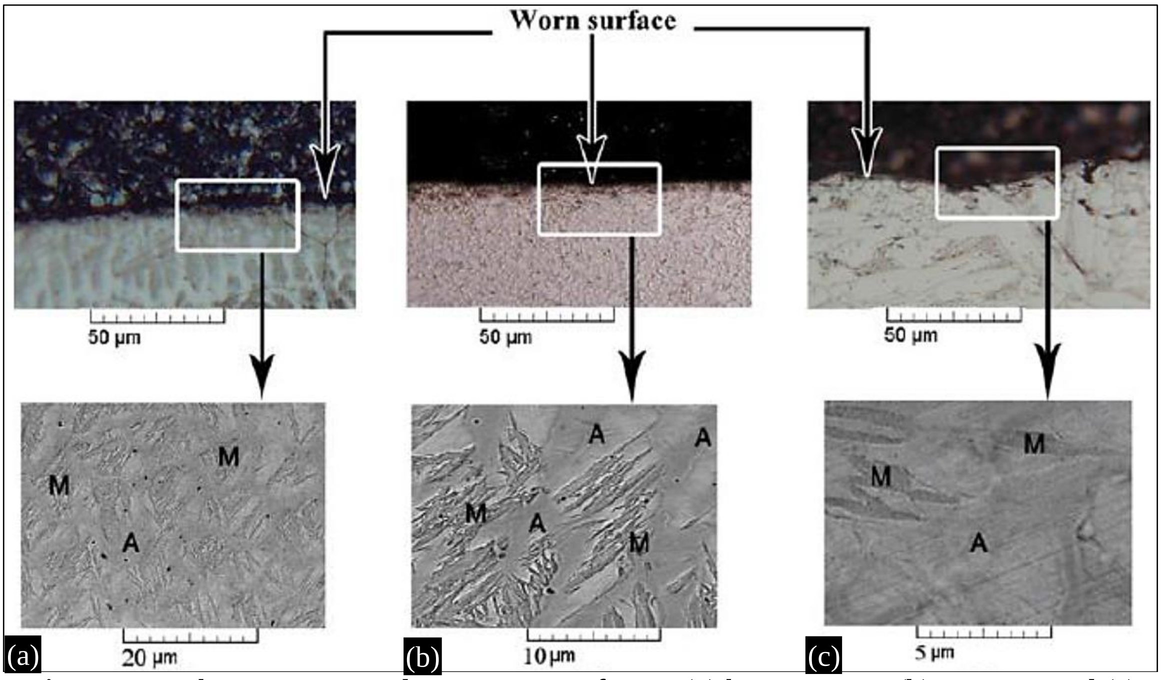

Fig. 4. *Optical microscope and SEM images of worn (a) hypoeutectic, (b) eutectic, and (c) hypereutectic samples. The M refers to martensite structures and A refers to austenite regions.*

Figure 3 has shown an increase in hardness for each sample after wear test was conducted. Increased hardness values occurred due to work hardening that was done to the samples during wear test which has caused austenite to transform into martensite by a stress-induced mechanism. Martensite structures are shown in optical microscope and respective SEM images of cross-sections of each sample are shown in Figure 4.

LASER CLADDING IN HARDFACING ALLOYS

Tobar et al. [4] explored wear-resistant composite depositions on C25 by laser cladding for mining and mineral industry. Compositions of deposition have been based on strategic matrices of Ni-, Co- or Fe-based alloys and hard-phase carbides at different ratios, e.g. tungsten carbides (WC), which has provided coating hardness well above 1000 HV (Vickers). These commercially available WC powders have contained spherical microparticles consisting of crushed WC agglomerates. Modifications by authors have introduced application of patented Spherotene® powders consisting of spherically fused, monocrystalline WC particles, being extremely hard, between 1800 and 3000 HV, and mixtures of Ni-based alloy with Spherotene powders optimized for laser processing were presented (Technolase®). The authors have suggested the use of high-power lasers for hardfacing or laser cladding to be more appropriate than traditional standard methods like arc welding, oxy-fuel gas welding and thermal spraying [4].

PLASMA-TRANSFERRED ARC (PTA) WELDING IN HARDFACING

PTA hard facing has been a method of depositing high-quality, metallurgically fused deposits on relatively low-cost surfaces. Soft alloys, medium and high hardness materials, and carbide composites could be deposited on a variety of substrates to achieve diverse properties such as mechanical strength, wear and corrosion resistance, and creep. Advantages of PTA over traditional welding processes such as oxy-fuel (OFW) and gas tungsten arc welding (GTAW) have been as follows: easily automated, high reproducibility, precise metering of metallic powder feedstocks, resulting in lesser material quantity used, i.e. powder feed rates, gas flow rates, amperage, voltage, and heat input; ensuring consistency from lot to lot; controlled heat input to ensure weld dilutions control to be 5%–7%; tougher and more corrosion resistant; low levels of inclusions, oxides, and discontinuities; smooth deposits without post-weld machining; and provide a variety of deposits in thicknesses from 1.2 to 2.5 mm (0.05–0.10 in.) or higher at a deposition rate of single pass of 1 kg/h up to 13 kg/h depending upon torch, powder and application [5]. Thus this achieves more reliable pump sealing, improve equipment performance, and reduce consumption of natural resources [6].

PTA welding has been used by Tajoure and Tajouri [7] to deposit composite surface layer of nickel base (PMNICr50P alloy) with titanium carbide (TiC) in powder form on to surface of low-alloy steel 18G2A type according to polish standard. The authors have reported maximum hardness of 754 HV and minimum dilution of 4.6% by using an arc current of 80 A. Dilution has increased and hardness has decreased with an increase in current to 120 A. Reported features of microstructure of nickel base with titanium carbide have been as follows: (1) uniform distribution of reinforcement particles, (2) irregular grain shape, (3) relatively small particles size, (4) regular boundary line between the substrate and over layer with the presence of black area along the boundary line; and (5) few microporosities in matrix [7].

Tajouri and Raddad [8] have studied PTA composite layer of nickel base (Deloro alloy 22) with tungsten carbide in powder form on to surface of low-alloy steel 18G2A type according to polish standard. At an arc current of 60 A, maximum hardness of 1489 HV and minimum dilution of 8.4% were achieved. Increasing current 120 A to dilutions have increased and consequent hardness has decreased. Features inspected in microstructure of composite have been uniform distribution of reinforcement particles, regular grain shape and half-dissolution of carbides in the matrix [8].

NON-FERROUS VALVE HARDFACING BY PTA

Exceptional reliability and maintainability for metal-to-metal sealing in high-pressure gate valves used for offshore production wells have been attributes of corrosion-resistant hard facing materials. Developments of new hard facing materials for aggressive environments have been PTA weld of hard facing Stellite cobalt base materials to nickel base alloy substrates [9]. Superior corrosion resistance by PTA has been referred than spray and fuse as well as high-velocity combustion spray ("D"-gun) methods. The author has experienced from tests of chemical composition, microstructure, galling and corrosion resistance of different hard facing prepared by different methods of facing [9].

IRON-BASED HARDFACING ALLOYS

Microscopy, microanalysis, dilatometry and thermodynamic modeling of Fe–30Cr–3.8C wt% deposited by MMA welding have been investigated by Atamert and Bhadeshia [10] to study microstructure and high temperature stability. Mixture of M_7C_3 carbide and metastable austenite containing a high chromium concentration was found in as-deposited undiluted alloy. Properties of alloy were investigated by annealing where decomposition of austenite into a mixture of ferrite and carbides resulted at temperature 750°C with rapid formation of $M_{23}C_6$ carbides precipitation, followed by equilibrium-phase mixture of Cr-depleted ferrite and M_7C_3.

COBALT-BASED HARDFACING ALLOYS

Relationship between microstructure and abrasive wear properties of cobalt-based hard facing alloys deposited by MMA welding, TIG welding and laser cladding was investigated by Atamert and Bhadeshia [11]. Differences in freezing rates associated with three processes by typical deposition conditions have given rise to differences in microstructure. Degree of dilution has been the largest by MMA process whereas TIG and laser deposits have exhibited lower levels of mixing with base plate. Scale of microstructure decreases in the same order, i.e. MMA, TIG and laser cladding, with associated increase in hardness. In abrasion test with alumina as an abrasive, wear rate is higher with MMA deposits, so that weight loss has been linear with time. Lower wear rates were observed in laser and TIG deposits having refined microstructures and higher carbon concentration.

NICKEL-BASED HARDFACING ALLOYS

The simulation experiments done by Atamert and Bhadeshia [12] over conventional nickel-based hard facing alloys deposited by arc welding have described effects of large volume fractions of ordered precipitates in addition to solid solution strengthening in improved alloy. Computer model has been capable of estimating microstructure and strength as a function of welding conditions and other variables.

MASSIVE HARDFACING AND USE OF Fe–Cr AND Fe–B POWDERS

Karip et al.[13] have investigated the effect of ferroboron and ferrochromium with massive wire-based hard facing alloys. Addition of Fe–Cr and Fe–B powders to massive wire during welding processes has been hard faced layers by three different powder mixtures and three different proportions. Matrix has been AISI 1020 steel substrate and the process has been open arc welding. Interpretations of experiment have been done by hardness test, SEM and XRD analysis. Microhardness was referred to be improved by increasing ferroboron content and increasing powder mixture amount [13]. Fe–Cr and Fe–B powders in hard faces have produced Cr_7C_3, Cr_2B_3 and Cr–B. Samples (B3, C3, D3) in Table 3 produced by 60%FeCr–40%FeB powder addition exhibited maximum microhardness.

Hard facing samples were produced by open arc welding using massive wire 1.2 mm in diameter, and Fe–Cr and Fe–B metallic powders on AISI 1020 steel. Powder mixture ratios used in tests are shown in Table 3 and welding parameters in Table 4. Chemical compositions of massive wire and Fe–B and Fe–Cr metallic powders are given in Table 5. Samples have been polished and etched with Kelling's reagent (33 ml HCl, 33 ml H_2O, 33 ml methyl alcohol and 1.5 g $CuCl_2$) for quantitative analysis of carbide boride/matrix phases. Hardness test, SEM and XRD analysis were done to the samples.

Table 3. *Compositions of powder mixtures [13].*

A	pure massive wire
B	75% m. wire – 25% powder
B1	m. wire + 100% FeCr
B2	m. wire + 90% FeCr– 0% FeB
B3	m. wire + 60% FeCr–40% FeB
C	50% m. wire – 50% powder
C1	m. wire + 100% FeCr
C2	m. wire + 90% FeCr–10% FeB
C3	m. wire + 60% FeCr–40% FeB
D	25% m. wire + 75% powder
D1	m. wire + 100% FeCr
D2	m. wire + 90% FeCr–10% FeB
D3	m. wire + 60% FeCr–40% FeB

Table 4. *Welding parameters [13].*

Voltage, V	25	Travelling speed, mm/min	150
Powder feeding rate, g/min	60	Oscillation width, mm	40
Wire feeding rate, g/min	60	Current, A	200

Table 5. *Chemical compositions of samples [13].*

Chemical compositions of massive wire			
% C	% Si	% Mn	% Fe
0.1	0.6	1.1	Balance
Chemical compositions of FeCr			
% C	% Cr	% Si	% Fe
8	64	1	Balance
Chemical compositions of FeB			
% B		% Fe	
10		Balance	

Increasing boron content has promoted the growth of primary Cr_7C_3 and increased volume fraction of hard phases to subsequent increase in hardness. Increasing powder addition consequently has increased B, C and Cr contents to affected microstructure by supporting both primary carbides and secondary carbides. High hardness and wear resistance gained by precipitation of different abrasion-resistant hard phases have selected iron-based alloys with molybdenum (Mo), titanium (Ti), niobium (Nb), in combination with boron (B) and carbon (C).Mining, cement plant, thermal power plants, and iron and steel industries have widely used high chromium irons due to their higher hardness and excellent abrasive resistance attributed from chromium carbides. In addition, combination of hardness and toughness of hard-faced alloys was referred from addition of alloying elements and rapidly solidified fine crystalline microstructure containing finely distributed hard phases. High abrasion resistances and high hardness were achieved from coarse hard phases. Logically, hardness of hard phases and/or hardness of matrix should be higher than the hardness of abrasive. Surface hardness, wear, oxidation and corrosion resistance of engineering components have appeared from borides. This has promoted the development of primary hard phases such as boride. “Boride-rich cored wires are used widely in cladding or hard surfacing of industrial applications by spraying or welding methods”. Effects of massive wire with additional powder in proportion of ferrochromium and ferroboron have been investigated.

$M_{23}C_6$ carbides have nucleated and grown throughout a peritectic reaction between liquid and M_7C_3 carbides, producing carbide with a core-shell structure (M_7C_3–$M_{23}C_6$) at higher chromium levels (>30 wt%Cr). Samples B1 and D1 contained 36.88% and 51.32% Cr to form duplex carbides (Figure5(a, b)). In XRD result of B1 and D1 samples, only M_7C_3-type

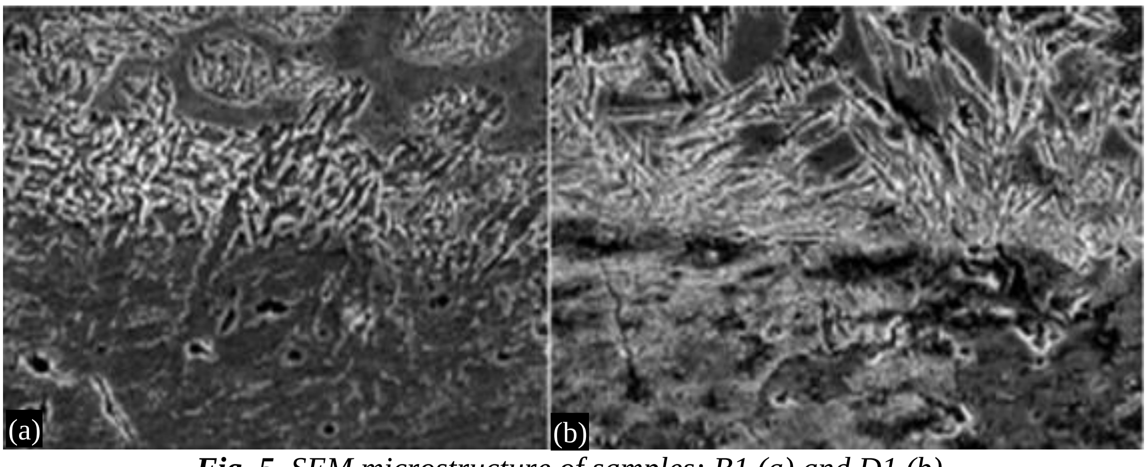

Fig. 5. *SEM microstructure of samples: B1 (a) and D1 (b).*

carbide was detected. Difference of chromium content in duplex carbides was determined by energy-dispersive X-ray spectroscopy(EDX) analysis (B1: Cr: 36.88,Fe: 54.52 and C: 8.6; and D1: Cr: 51.32, Fe: 34.31 and: 14.37). Inner carbide phase (darker) has included more chromium and carbon than that of outer carbide phase (lighter). The author has described that evidence has showed(i) "high chromium white iron(45 wt% chromium) including 4% C has duplex structure consisting of dark core and lighter shell". Core is M_7C_3 and lighter shellis $M_{23}C_6$;(ii) wavelength dispersive spectrum analysis to Fe–Cr–C alloys has found that content of $M_{23}C_6$ phase was lower than M_7C_3 phase.Thus$M_{23}C_6$ carbides have existed in addition toM_7C_3 carbide B1, D1, B2 and D2 samples.

ALTERNATIVE ALLOYING ELEMENTS IN HARDFACING TO TRADITIONAL METHODS

Scholl [14] described chromium and cobalt have been major constituents in many weld handmaking alloys of mines those could be substituted by intermetallic-hardened abrasion-resistant weld materials. These new alloys based on ternary systems (Fe–Mo–Ni system) contained a hard intermetallic compound in an FCC matrix and stable at room temperature. Techniques used have been powder metallurgical techniques and arc melting and submerged-arc welding process with alloyed metal powder additions. Pin-on-drum abrasive wear test, heat treatment and melting point analysis tests for each alloy have been suggested successively. Microstructures of Fe–Mo–Ni alloys synthesized by arc-melting and similar alloys made by welding possessed similar microstructures, i.e. (1) a (Fe,Ni),Mo_6 intermetallic plus austenite eutectic and (2) in an austenitic matrix. Poor abrasion resistances of these alloys have been improved by silicon additions to the alloy, which has promoted formation of Laves phase FeMoSi intermetallic. Heat treatment of explored alloy (Fe–20Mo–15Ni–5Si) at 550°–650°C has caused second-phase precipitation in matrix that raised hardness about 14 points HRC to 50 HRC. Wear rate of this alloy has been 6.3–6.5 mg/m after measurement by pin-on-drum abrasive wear test. The author has said that this has been twice the wear resistance of commercial high-carbon high-chromium alloys. Better abrasive wear resistance has been achieved though larger volume fractions of hard-phases and ternary intermetallic compound (Fe_2MoSi_2) formed in Fe–20Mo–10Ni-–5Si composition with continual increase in molybdenum and silicon content [14].

TOOL STEEL M2 DEPOSITION OVER LOW-CARBON STEEL BY FRICTION SURFACING IN HARDFACING

Corrosion and wear-resistant coatings have been deposited by Raju et al. [15] through another traditional route of friction surfacing. Compared to other alternative technologies, friction surfacing has low environmental impact and an energy-efficient process. Repair and reclamation of worn and damaged components have established this process as a new area. Advantages have been capability of producing coatings with zero dilution and good metallurgical bonding. The authors have coated AISI M2 tool steel on low-carbon steel to explore effect of process parameters on the width of deposit produced by friction surfacing process to suit industrial applications. Strong influences of process parameters have referred about good-quality coating characteristics and integrity. The discussed process parameters have been friction pressure, rotational speed and welding speed. The width of deposit was found to vary with (1) friction pressure, (2) rotational speed, (3) combined effect of friction pressure and rotational speed, as well as (4) combined effect of friction pressure, rotational speed and welding speed. [15]. An important factor for obtaining successful coatings was selected from process parameters based on material properties. The width of deposit lied between 11.48 and 17.47 mm. The width of deposit was directly proportional to friction pressure and inversely proportionality to rotational speed and the combined effect of friction pressure and rotational speed. Information and guidance about the width of deposition and selection of process parameters were studied after depositing on different geometrical shapes and sizes such as on (i) flat, (ii) circular,(iii) circumferential surfaces, (iv) edge, (v) central recess, (vi) precise locations, (vii) pre-formed hole spot areas, and (viii) sharp corners.

The authors have experienced deposition of tool steel M2 as rotating consumable rod, termed as mechtrode of diameter 10.5 mm and length of 290 mm on low-carbon steel substrate of 330 mm × 220 mm × 11 mm dimensions. Both tool steel M2 and low-carbon steel were used in annealed condition. Mechanical (Table 6) and chemical composition (Table 7) tests have performed for mechtrode and substrate materials.

Technical specifications of friction surfacing machine have been(i) motor capacity: 30kW, (ii)permissible spindle speed: 2500 rpm (maximum), (iii) axial load: 50 KN max, and (iv) table size: 330 mm× 450 mm. The process parameters such as spindle speed, table feed and axial force were controlled by using CNC technology. Identified process parameters (a) friction pressure range: 5–10 KN;(b) welding speed range: 40–60 mm/min; and (c) rotational speed range: 100–300 rpm were selected. Table 8 shows treatment combinations with response (width) obtained indicating corresponding deposits.

Table 6. *Mechanical properties of low-carbon steel and tool steel M2.*

Sl. No.	Material	Yield strength, (N/mm^2)	Tensile strength, (N/mm^2)	% of elongation	Hardness, (HV)
1	Low-carbon steel	317	504	28.84	185
2	Tool steel M2	453	827	16.86	270

Table 7. *Chemical composition of low-carbon steel and tool steel M2 (% in wt.)*

Material	C	Mn	P	S	Cr	Mo	Ni	V	Si
Low-carbon steel	0.21	0.655	0.026	0.019	0.022	0.012	0.017	--	--
Tool steel M2	0.791	0.16	--	--	3.83	5.3	--	1.82	.034

Table 8. *Selected process parameters for tool steel M2 deposit on low-carbon steel and response (width).*

Sl. no.	Process parameters			Response (width, mm)
	Friction pressure (MPa)	*Speed of mechtrode (rpm)*	*Welding speed (width, mm)*	
1	5	100	40	11.48
2	10	100	40	17.47
3	5	300	40	11.91
4	10	300	40	13.59
5	5	100	60	12.20
6	10	100	60	15.77
7	5	300	60	11.89

Surface phase alteration to decrease depreciation over time has been sub-discipline of material science. Friction surfacing has derivative advantages of solid-state fusion welding like excellent metallurgical bond and forged microstructure. Fusion welding produces (i) coarse microstructure, (ii) high levels of dilution, (iii) porosity, (iv) oxidation, and (v) hot cracking. Friction surfacing process was considered an advanced technique to produce (a) clean, (b) dense, (c) fine microstructure, and (d) joining dissimilar metal combinations. Edge retention of industrial knifes was traditionally processed. Friction surfacing was accepted as (i) reliable, (ii) repeatable process, (iii) for many combinations of metals deposit on (iv) different varieties of substrates.

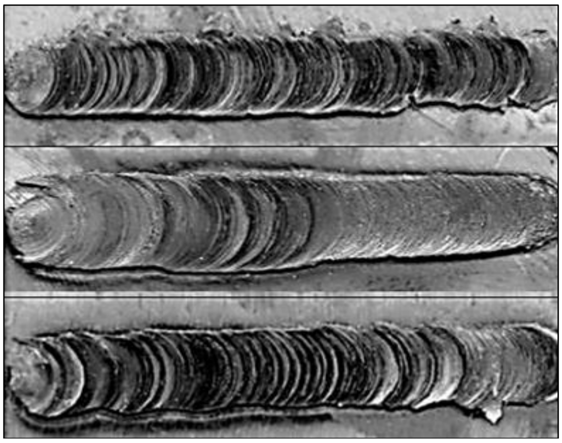

Fig. 6. *Deposit prepared on specimen numbers 5, 6 and 7 in Table 8.*

A rotating cylindrical consumable rod was fed against a substrate by applying axial force continuously on consumable rod. Heat generated has softened the rubbing end of rotating consumable rod to plasticize metal on substrate, which has traversed with respect to vertical consumable rod in horizontal position. Thus plasticized metal was deposited over substrate. Different metal coatings were made such as tool steel coatings on mild steel or stainless steel on mild steel. Advantages of friction surfacing have been clean, good quality and high-efficiency green manufacturing technology. Industrial applications of friction surfacing focused on manufacturing of long-life cutting tools with strong resistance to delamination, prominent uses in hard facing, damage repair or corrosion resistance, e.g. repairing oil pipes and marine under water devices. Cladding applications by multilayer friction surfacing has been another technique, e.g. depositing hard facing metals on knife cutting edges of different categories such as dies, tools, punches and blades required for chemical, medical, food processing and agricultural industries. This process suggested to be carried out in open air and in underwater without sealing and inert gas atmosphere. Friction surfacing of different metal substrates was applied with different coating combinations comprising hard coatings on soft substrates and soft coatings on hard substrates (Figure 6).

COMPUTER MODELING OF HARDFACING ALLOYS

Simulated cast test piece to that of welding in high temperature-resistant nickel-based hard facing was experienced by Atamert et al. [16] by incorporating intermetallic-ordered precipitation in solid-solution-hardened conditions. The authors have computer modeled capable of estimating microstructure and strength as a function of many variables [16].They have described the use of hard facing materials for applications where surfaces were subjected to wear, oxidation and corrosion. It has improved desired properties in economical way to surface of component without influencing its bulk properties. Iron-based, cobalt-based and nickel-based alloys were hard-faced after careful assessment of service conditions and knowledge of material properties specific for the application. Choice of correct deposition technique and its variables have controlled wear. A wide range of techniques have deposited, e.g. arc welding, plasma spraying and laser cladding.

CONCLUSIONS

Studies of interfacial studies of steel–white cast iron applicable for mineral sands dredging and wear parts for heavy earthmoving equipment have been concluded as follows: (i) the use of this composite is new and produced permission of brittle and wear-resistant materials encountered by moderate impact conditions; (ii) enhanced understanding for improvement of bonding mechanisms between white cast iron and steel; (iii) development of new vacuum casting process to prepare composite; (iv) manufacture of complex-shaped composites, and (v) improvements appeared in field trials of wear life.

Abrasive wear innovations in agriculture were concluded as follows: (i) finding relation between internal microstructure of substrate and external conditions of particles and forces involved for wear; (ii) friction of particles and rpm of wheel were tested by modified rubber wheel instrument; (iii) friction force to be proportional to volume loss for single-phase materials like steel; (iv) friction force, frequency and amplitude represented cohesive strength between hard phase and matrices for multiphase materials like cast iron or metal matrix composite; and (v) frequency was the limitation for using rubber wheel method.

Tungsten-strengthened matrix with increasing compositions of tungsten/chrome boride content in iron-based hard facing alloys and molybdenum solid-solution-strengthened matrix was fabricated. Compressive strength determination of ferrous-based hard facing alloys showed to decrease with greater additions.

Wear-resistant composite depositions on C25 by laser cladding for mining and mineral industry was based on strategic matrices of Ni-, Co- or Fe-based alloys and hard-phase carbides at different ratios. Tungsten carbide (WC) powder was modified by mixing patented Spherotene® powders consisting of spherically fused, monocrystalline WC particles and Ni-based alloy. It was suggested to use high-power lasers for hard facing or laser cladding.

PTA hard facing was used for depositing high-quality, metallurgically fused deposits on relatively low-cost surfaces. Soft alloys, medium and high hardness materials, and carbide composites could be deposited on a variety of substrates to achieve diverse properties such as mechanical strength, wear and corrosion resistance, and creep. Advantages are that they are easily automated, high reproducibility, precise metering of metallic powder feedstocks, resulting in lesser material quantity used, i.e. powder feed rates, gas flow rates, amperage, voltage, and heat input, consistency, controlled heat input to ensure weld dilutions, tougher and more corrosion resistant, low levels of inclusions, oxides, and discontinuities, smooth deposits without post weld machining, and provide a variety of deposits of different thicknesses. PTA welding was used to deposit composite surface layer of nickel base with titanium carbide (TiC) in powder form on to surface of low-alloy steel. Dilution behavior was discussed such that hardness has decreased with increase in current to 120 A. A similar dilution behavior was studied by PTA composite layer of nickel base with tungsten carbide in powder form on to surface of low-alloy steel.

Metal-to-metal sealing in high pressure gate valves used for offshore production wells necessitates corrosion-resistant hard facing materials. PTA-weld of hard facing Stellite cobalt-based materials to nickel-based alloy substrates was referred to be superior in corrosion resistance.

Microstructure and high temperature stability of mixture of carbides and metastable austenite containing a high chromium concentration was found in as-deposited undiluted alloy. Properties of alloy were investigated by annealing decomposition of austenite into a mixture of ferrite and formation of carbides precipitation of other allotropies.

In Co-based hard facing alloys, the relation between microstructure and abrasive wear properties were studied after deposition by MMA welding, TIG welding and laser cladding. Differences in freezing rates associated with three processes by typical deposition conditions produce differences in microstructure. Degree of dilution was the largest by MMA process. Scale of microstructure decreases in the same order with associated increase in hardness. In abrasion test with alumina as an abrasive, wear rate was higher with MMA deposits.

Effect of ferroboron and ferrochromium with massive wire-based hard facing alloys were processed by open arc welding. Microhardness was improved by increasing ferroboron content and increasing powder mixture amount.

Chromium and cobalt were the major constituents in many traditional weld hard facing alloys of mines. Those were substituted by intermetallic-hardened abrasion-resistant weld materials, e.g. ternary systems of (Fe–Mo–Ni) containing a hard intermetallic compound. Powder metallurgical techniques, arc-melting and submerged-arc welding process with alloyed metal powder additions were adopted. Microstructures of Fe–Mo–Ni alloys were synthesized by arc-melting to contain intermetallic plus austenite eutectic and an austenitic matrix. Abrasion resistances of these alloys were improved by silicon additions, which promote formation of Laves phase FeMoSi intermetallic. Heat treatment and continual increase in molybdenum and silicon content of explored alloy raised hardness and wear resistance.

Friction surfacing suggested low environmental impact and an energy-efficient process. Repair and reclamation of worn and damaged components were established in this process as a new area. Advantages are as follows: (i) capability of producing coatings with zero dilution, (ii) good metallurgical bonding, and (iii) effect of process parameters on width of deposit to suit industrial applications. Widths of deposit vary with (1) friction pressure, (2) rotational speed, (3) combined effect of friction pressure and rotational speed, as well as (4) combined effect of friction pressure, rotational speed and welding speed.

Simulated cast test piece to that of welding in high temperature-resistant nickel-based hard facing was prepared by incorporating intermetallic-ordered precipitation in solid-solution-hardened conditions. Computer model is capable of estimating microstructure and strength as a function of many variables, e.g. wear, oxidation, and corrosion. It san economical way without influencing bulk properties of iron-based, cobalt-based and nickel-based alloys after careful assessment of service conditions and method of deposition.

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