Investigation of the In Situ Ceramic Particles (TiCN, TiC) Composite Cladding on the Abrasive Wear Resistance of the Steel Substrate

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Received: 25 August 2019 - Accepted: 01 November 2019

Abstract

In this research, metal cored wire including the ferroalloy materials was used and cladded by FCAW process with different shielding gases as nitrogen and argon on steel substrate. The chemical analysis examination showed that the absorbed nitrogen in all of the samples was fabricated with nitrogen gas shielding. Consequence of XRD pattern indicated that the carbonitride phase (TiCN) precipitations appeared in weld metal that fabricated with shielding of nitrogen gas and titanium carbides (TiC) precipitate in the sample that fabricated with argon shielding gas. Optical and SEM examination results, revealed that the fine particles of titanium carbonitrides and titanium carbides precipitations sited in grain of ferrite structure and the mapping of elements explained the homogeneously precipitates of elements and phases in microstructure. Also, the hardness of sample that fabricated with argon shielding gas was lower than the sample that fabricated with nitrogen shielding gas. The wear test (ASTM G65) result indicated that sample was being consist of TiCN had higher abrasive wear resistance than other sample.

Keywords: Abrasive Wear Resistance, Low Carbon Steel, Titanium Carbonitrides, Titanium Carbides, Composite Cladding.

1. Introduction

The mechanical equipment are operating in aggressive working environment as wear and corrosion for long time. For increasing the service life, weld hardfacing techniques are employed to produce composite layers that are resistant to elevated-temperature, corrosion and abrasion on the surfaces of equipment [1]. Wear is a damage to a solid surface as a result of relative motion between its and another surface or substance [1,2]. The damage usually results in the progressive loss of material. The scientific measure used for wearing is volume loss. However, in engineering the concern of wear is usually associated with dimensional or appearance changes that eventually affect performance and not with volume loss. For any materials, wear can occur by a variety of mechanisms, depending on the properties of the material and the situation in which it is being used. Wear resistance is, therefore, not an intrinsic material property like hardness or elastic modulus [2]. There are four general ways by which that a material can wear in the aforementioned situations: adhesive, abrasive, fatigue, and oxidative processes. In Adhesive Wear, wear occurs as a result of bonding that takes place between two surfaces in contact. With these subsequent separation of the two surfaces, material from either surface may be pulled out, due by wear. In Abrasive wear, fracture, cutting, and plastic deformation processes can occur when the harder surface engages a softer surface. These mechanisms tend to produce machining-chip-like debris. In Fatigue or fatigue-like wear processes are those associated with crack initiation and propagation or progressive deformation as a result of repeated contact. In Corrosive wear processes are those associated with the loss of wear of in situ formed reaction product (e.g., oxide layers). Some fundamental criteria can be applied in the selection of a materials for wear applications. The primary criterion is that the material remain chemically, mechanically, and thermally stable under the operating conditions. Secondary criterion is the nominal contact stresses within the elastic range of the materials [1,2]. The iron-base alloys represent by far the largest usage of the hard surfacing alloys and will be discussed in more details. Iron-base hard surfacing alloys can be subdivided according to their metallurgical phase or microstructure, as :

a. Austenitic alloys
b. Martensitic alloys
c. Carbides alloys

Carbides are much harder than the surrounding matrix and provide excellent abrasion resistance. At the lower end of the carbon range (less than 3%), the quantity of carbides is small in comparison to the matrix in which they're dispersed and these alloys exhibit good abrasive. wear resistance while retaining good toughness. These carbides surfacing alloys are used to resist that combination of abrasion and impact conditions [1-3]. Hardfacing is a commonly employed method to improve surface properties of agricultural tools, components for

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mining operation, soil preparation equipment and others [1,2]. An alloy is homogeneously deposited onto the surface of a soft material (usually low or medium carbon steels) by welding, with the purpose of increasing hardness and wear resistance without significant loss in ductility and toughness of the substrate. A wide variety of hardfacing alloys is commercially available for protection against. Deposits with a microstructure composed by disperse carbides in austenite matrix are extensively used for abrasion applications [3] and are typically classified according to the expected hardness. Nevertheless, the abrasion resistance of a hardfacing alloy depends on many other factors such as type, shape and distribution of hard phases, as well as the toughness and strain hardening behavior of the matrix [4]. Among the processes employed for hardfacing such as EBW, SMAW, LBW, SAW and FCAW, flux cored arc welding process has been used for many applications because it resulting in simplicity of operation. Hardfacing by flux-cored arc welding is efficient and suitable also for out-of-position welding, i.e., in the horizontal-vertical and overhead positions, which is particularly important in maintenance. Research in flux cored arc welding has been showed that a large concentration of dissolved nitrogen in a steel weld metal does not always lead to formation of pores. In this case, porosity formation was avoided because the nitrogen reacts with dissolved titanium in the steel[5]. Therefore, it was hypothesized that one can extend the same principle to the alloying process and achieve finer distribution of carbides or carbonitrides by using a reactive gas shielding methodology [6,7]. Purpose of this research is the fabrication of composite wear resistance layers that contain ceramic particles such as titanium carbides and titanium carbonitrides that in situ produced on the low carbon steel by flux cored arc welding by using nitrogen and argon shielding gases.

2. Materials and Methods

The 400mm×200mm×12mm low carbon steel specimens (ST52) were used for substrates base metals. The nominal chemical composition of ST52 steel given in (Table. 1.).

Table. 1. Chemical composition(wt.%) of ST52.

Element	Concentration
Fe	Bal
Al	0.020
C	0.220
Mn	1.600
Si	0.550
S	0.040
P	0.040

Ferrotitanium with crystalline graphite powder mixed and used as mixture powders in this investigation. By using of Ball Mill, powders are homogeneous and this grain size reaches to 60μm. Then by cored wire equipment generation, cored wire fabricated in 1.6 diameters. Before Surface welding, base metals cleaned by water and acetone. MIG welding equipment by different shielding gas was used for welding. Pure argon and nitrogen were used for shielding gas and welding was done in bead on plate conditions in 5 layers as shows in (Fig. 1.).

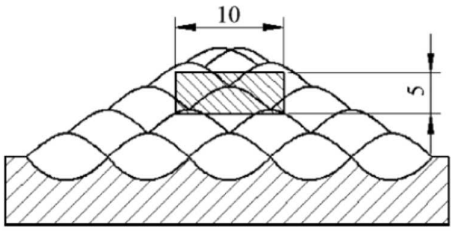

Fig. 1. Schematic of welded layers for each sample.

The welding process parameters for each welding conditions are given in Table. 2. After welding, deposits cooled in air. For examination three groups samples were cut between the passes 3 and4 with different dimensions. First samples were prepared in 10mm×10mm×3mm dimensions and then examined by PHILIPS Model of XRD set that equipped with X"pert software. Second group for chemical analysis and hardness test, optical and electron microscopy examination was prepared in 40mm×20mm×10mm dimensions. Chemical analysis of weld metals was determined by Optical Emission Spectroscopy (OES) by master model. By using of nitrogen/oxygen determinate equipment (Leco-EF-400) the nitrogen absorption content in the weld metal were determined.

Cross sections of the weld were polished and etched with Nital 3%. Optical (Prior England) and scanning electron (VEGA/TESCAN) microscopes (SEM) were used to study microstructure of the specimens. For study of wear mechanism Secondary electron allowed morphologic description of the worn surfaces. Backscattered Electron Imaging, EDS and mapping elements were used to qualitatively describe chemical variations in the microstructure. The bulk surface hardness of the hardfacing deposits was measured by the Rockwell hardness (HRC) method with master model. And third group samples sectioned for wearing test in 12.7mm×25.4mm× 76.2mm dimensions. Abrasive wear tests were carried out in a dry sand– rubber wheel testing machine (Fig. 2.) according to ASTM G65 standard. In this standard Rounded quartz particles with AFS 50/70 grain size was used by constant flow. Normal load 130 N and sliding distance of the tests are 4309m for each hardfacing specimens.

Abrasive wear resistance was determined from the mass loss results, which were measured with 0.01g resolution.

Table. 2. Welding Parameters.

Process	Manual FCAW
Welding Equipment	GAAM ELECTRIC Model : PARS MIG602
Wire Radius	1.6Mm
Arc Length	5Mm
Voltage	28 V
Current	290 A
Number of Pass	5
Gas Protection	Pure Nitrogen Pure Argon
Purity of Gas	99.99%
Gas Flow	Argon Gas :12 L/Min Nitrogen Gas : 15 L/Min
InterPass Temperature	℃ 200
Polarity	DCEP
Feeding Rate	Mm/Min^{7000}
Welding Rate	240 Mm/Min
Heat Input (For Each Pass)	$Kj/Mm^{1.7458}$

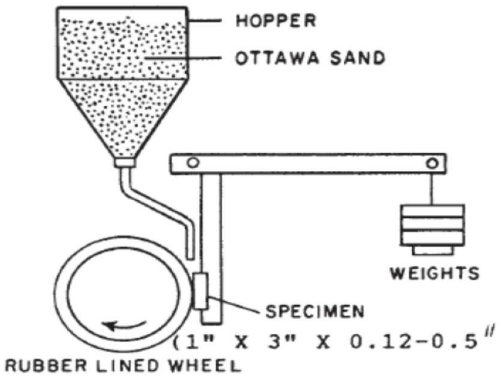

Fig. 2. Schematic of sand-dry rubber wheel wear test [7].

3. Results and Discussion

Table. 3. given the chemical composition of hardface layers samples that fabricated by argon and nitrogen shielding gas. Table. 3. represents all of the elements particularly titanium in the sample that fabricated by nitrogen shielding gas (sample S2) are lower than sample S1.The result of this, related to using nitrogen for shielding gas, Because nitrogen gas promote the arc temperature and cause burning of elements in comparing by argon gas [8]. Fig. 3. presents the X-ray diffraction pattern for sample S1. X-ray diffraction analysis of the sample S1 that fabricated with Ar shielding gas, confirmed the presence of TiC (FCC crystal) and ferrite (α-Fe-BCC crystal) in the deposit.

Table. 3. Chemical composition(wt.%) of hardface layers.

Element	S1(Ar)	S2(N_2)
Fe	88.365	89.145
Ti	8.510	8.200
Al	0.300	0.250
C	1.000	0.800
V	0.400	0.280
Mo	0.450	0.410
Mn	0.420	0.370
Cr	0.140	0.150
Si	0.120	0.100
Ni	0.070	0.070
Zn	0.080	0.080
W	0.070	0.070
Cu	0.040	0.040
Pb	0.020	0.020
S	0.008	0.008
P	0.007	0.007

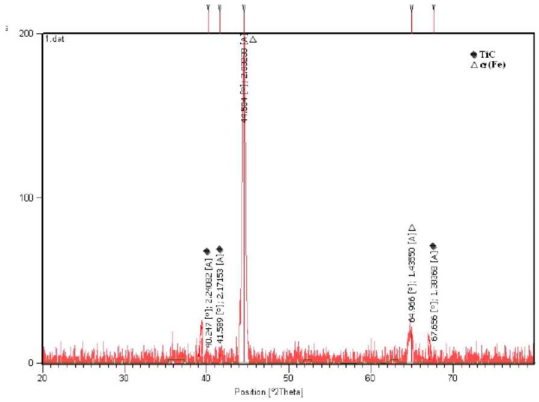

Fig. 3. X-ray diffraction pattern of sample S1.

The cause of formation of TiC is related to more tendency of titanium to formation of carbides. Fig. 4. shows the gibbs free energy formation of carbides.

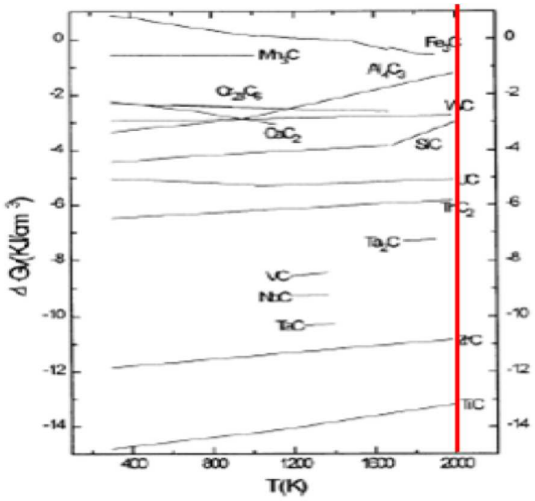

Fig. 4. Gibbs free energy formation of different carbides[8].

In this figure titanium carbides in 2000˚k has the lowest free energy in comparison of other carbides, moreover titanium concentration is more than other elements in weld pool, therefore titanium carbides were formed in solidification of weld deposit. So, the result of ferrite phase formation related as: a-Carbon concentration reduction that occurred by absorption of titanium and formation of titanium carbides, so carbon concentration in residue of melt, was poor, b-By using of interpass temperature up to 200˚c in solidification process low carbon austenite was formed and by cooling, it was transformed to ferrite phase[8,9]. Fig. 5. presented the X-ray diffraction pattern of sample S2. This figure shows that nitrogen gas shielding confirmed the presence TiCN and ferrite (α -Fe-BCC crystal) in the weld deposit. The Cause of ferrite formation in matrix is same as it is appeared in sample S1 that was welded by argon gas shielding. Fig. 6. shows the gibbs free energy formation of different nitrides.

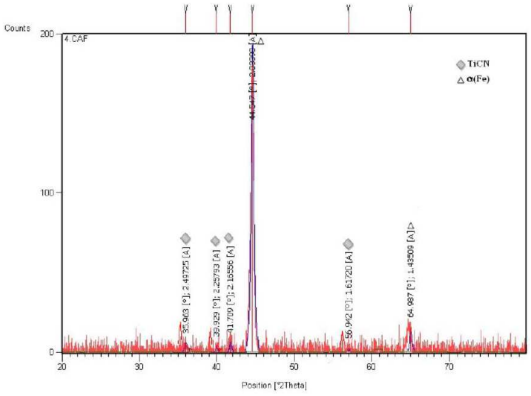

Fig. 5. X-ray diffraction pattern of sample S2.

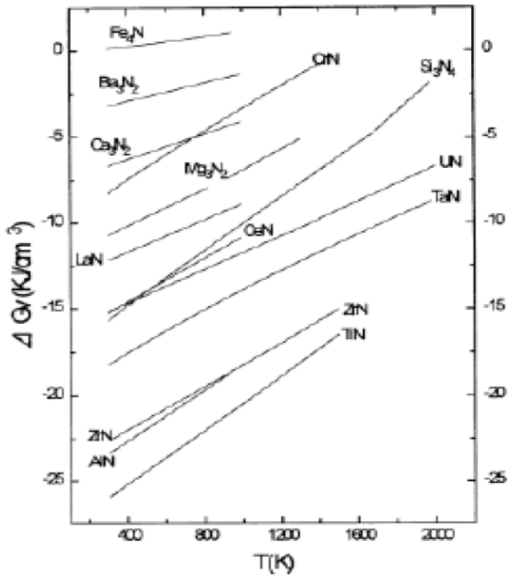

Fig. 6. Gibbs free energy formation of different nitrides[8].

The typical microstructure of the sample S1 is shown in Fig. 7. It can be seen ferrite matrix with fine titanium carbides that disperse homogeneously in the matrix. These precipitations have cubic shapes and synthesis in the melting and solidification as secondary particles that emended in the matrix.

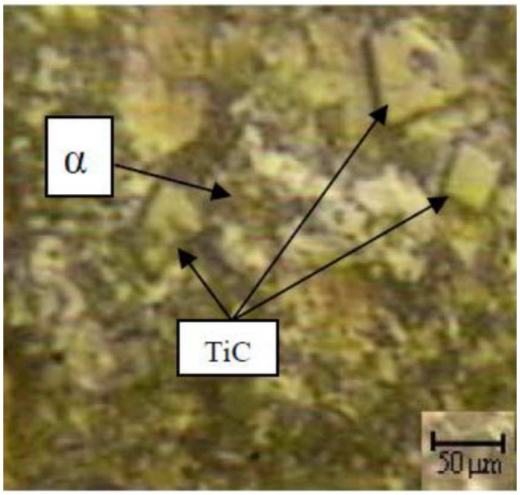

Fig. 7. The OM photomicrograph of sample S1.

Fig. 8. shows the microstructure of sample S2 surface. It can be seen that, matrix obtained ferrite phase accompany with fine and homogeneously disperse of titanium carbonitride. By comparing of Fig. 7. And Fig. 8., distribution of titanium carbonitride particles in the matrix of sample S2 are finer and higher than titanium carbide particles in sample S1.

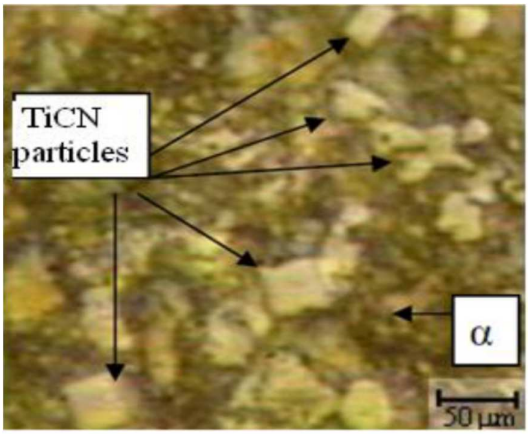

Fig. 8. The OM photomicrograph of sample S2.

Fig. 9. indicates the photomicrograph of scanning electron microscopy for sample S1. This figure demonstrates that the matrix is embedded by fine and dispersive of titanium carbide. Fig. 10. shows localized spectra are taken to identify the ferrite matrix(rich in iron)(Fig. 10.a) and TiC precipitate (rich in titanium and carbon) particles(Fig. 10.b).

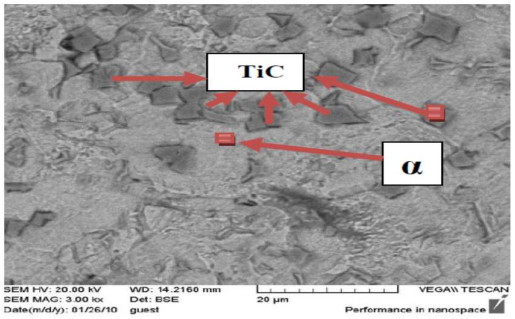

Fig. 9. SEM photomicrograph of the sample S1.

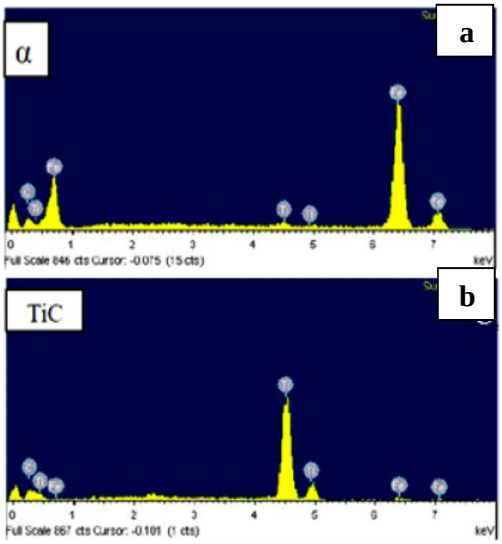

Fig. 10. EDS from (a) matrix and (b) precipitations of the sample S1.

Indeed the presence of iron element in point analysis of titanium carbides is related to high concentration of this element in alloy. However the mapping of elements (Fig. 11.) represents the iron element is concentrated in matrix and titanium element in precipitations, but carbon is dispersed in both of the matrix and precipitations. Scanning electron microscopy photomicrograph with point analysis (EDS) of sample S2 are presented in Fig. 12. This figure indicates that the matrix is embedded by fine and dispersive of more TiCN. The EDS illustrates analysis characterization of the matrix the rich in iron element and precipitations rich in titanium, carbon and nitrogen. Fig. 13. shows the fine titanium carbonitride particles in high magnification by SEM and EDX analysis.

Also, the presence of iron element in point analysis of TiCN is related to high concentration of iron in alloy. The mapping elements (Fig. 14.) represent that, iron element is concentrated in matrix and titanium is concentrated in precipitations, but carbon and nitrogen elements are dispersed in both of the matrix and precipitations homogeneously.

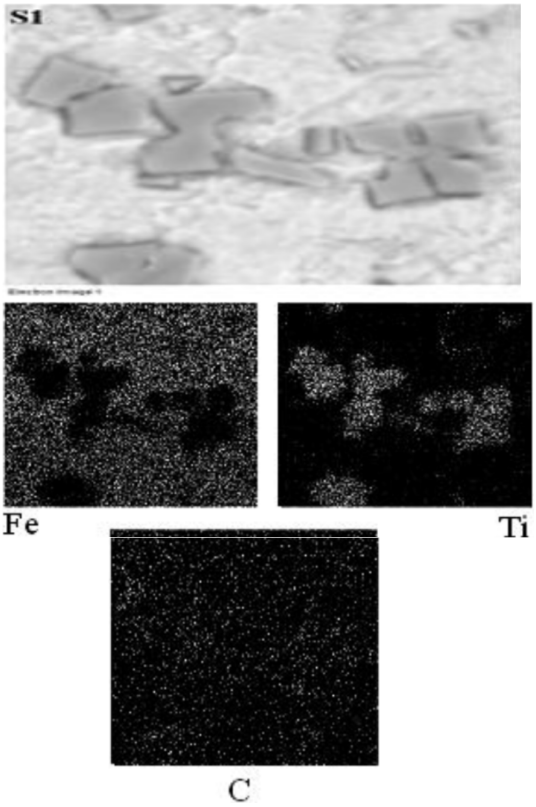

Fig. 11. Mapping elements pattern of the S1 sample.

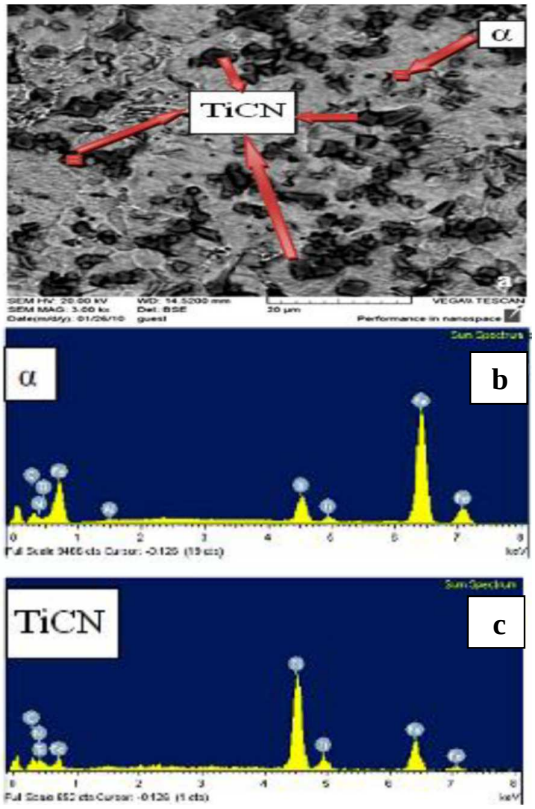

Fig. 12. a. SEM photomicrograph, b. EDS from matrix and c. EDS from precipitations of the sample S2.

The result of measuring nitrogen content in sample S2, shows that the nitrogen content absorption is 0.130 percent that is representative of nitrogen solving in weld metal and gained composite particles.

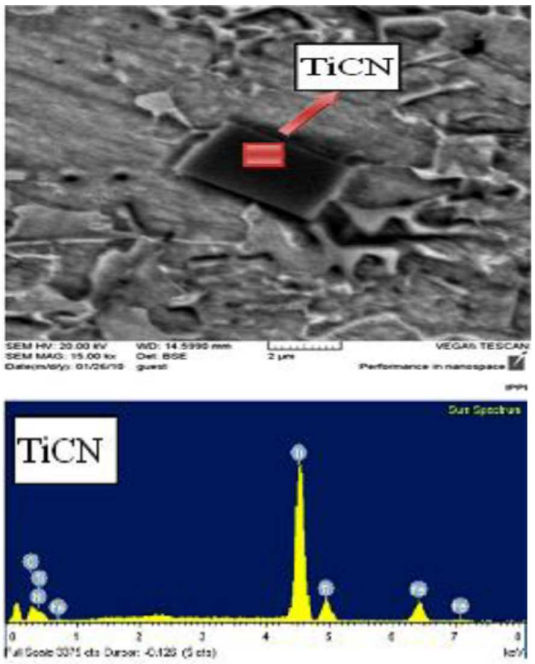

Fig. 13. SEM photomicrographe and EDS of TiCN in sample S2.

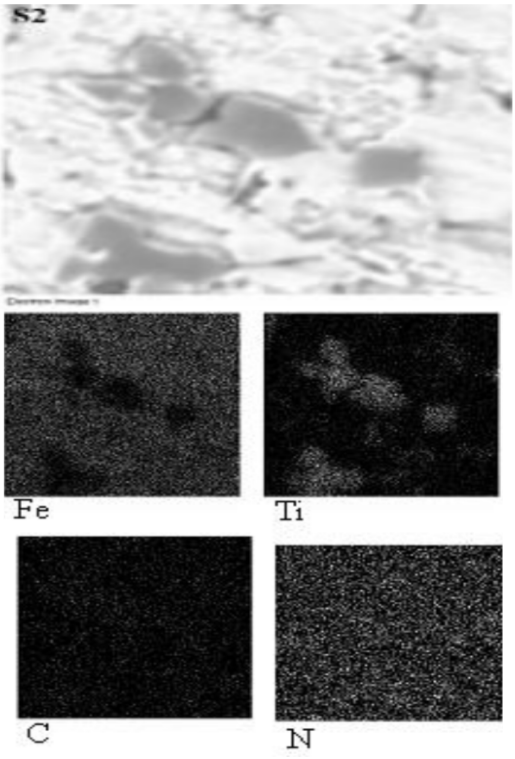

Fig. 14. Mapping elements pattern of the sample S2.

Fig. 15. shows the average hardness of samples it can be seen that with presence of TiC or TiCN hard particles. Hardness in these deposits may be related to various microstructural features including the ferrite matrix, size and distribution of composite particles or secondary phases as TiC or TiCN.The results explain that sample S2 has higher hardness than sample S1, because sample S2 component is contained of TiCN particles [10]. These particles are caused to increasing of the hardness of weld deposit more than TiC component that was appeared in sample S1.

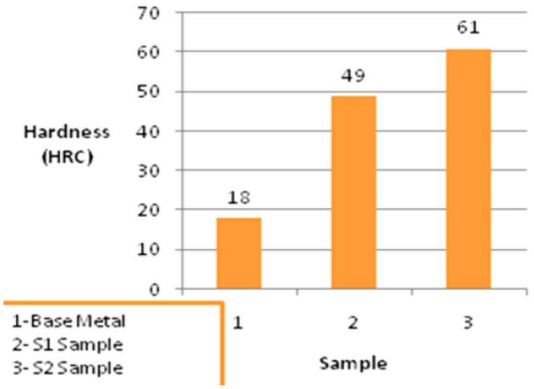

Fig. 15. Surface hardness of the dhffernt samples.

Fig. 16. shows the mass loss results from the dry sand–rubber wheel tests in 4309m sliding distance. The best abrasion resistance was obtained of specimen that welded by nitrogen shielding gas and consist of TiCN in microstructure, in which the elevated volume fraction of coarse TiCN particles provided a barrier against indentation, grooving and cutting. This beneficial effect is probably reinforced by TiCN particles, which prevent the detachment of TiCN particles due to their most finely distribution in the matrix and their higher hardness than TiC particles. Micro-ploughing and micro-cutting were the main abrasive micro-mechanisms observed in Ti concentrated hardfacing alloys. In hardfacing alloys (sample S1) intensive micro-ploughing was observed, due to lower hardness of TiC particles (Fig. 17.).

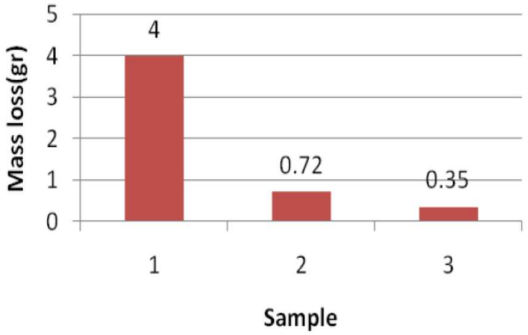

Fig. 16. Mass loss of wear testing of the different samples.

In specimen that was welded by nitrogen gas shielding, increasing of the abrasion resistance by Micro-ploughing and micro-cutting were considerable and virtually no continuous grooves were observed that it is related to high hardness of TiCN particles (Fig. 18.). Because The "stopper" action of TiCN particles is an abrasive particles were blocked cutting the matrix [11,12].

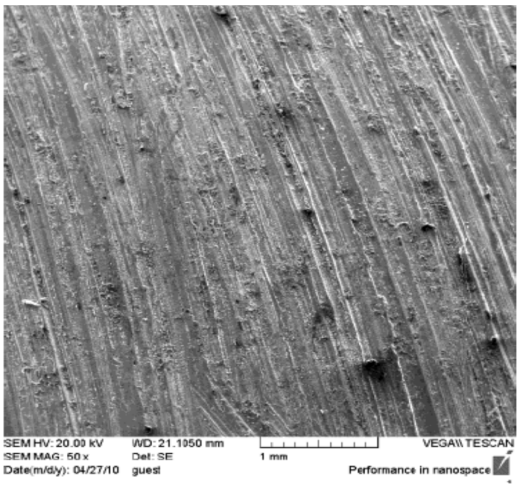

Fig. 17. SEM photomicrograph of worn surface of the sample S1.

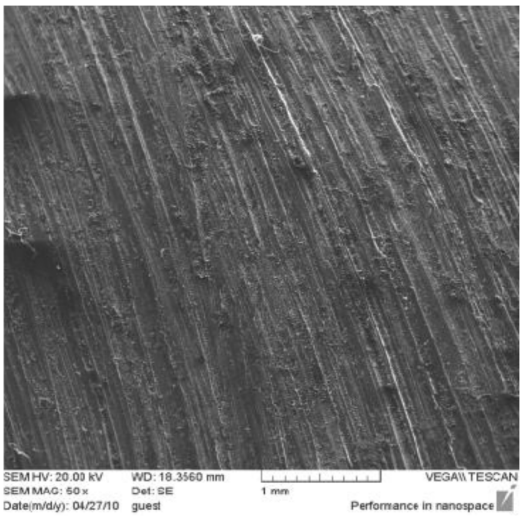

Fig. 18. SEM photomicrograph of worn surface of the sample S2.

4. Conclusions

1. Flux cored arc welding is a process that have ability to dissolve a large concentration of nitrogen in a steel weld metal deposit by using nitrogen gas.
2. Microstructure of Ar shielding gas, confirmed the presence of TiC in ferrite matrix but in nitrogen gas shielding TiCN in ferrite matrix in the weld deposits are indicated.
3. In comparison of samples that were welded, distribution of TiCN particles in the matrix of sample S2is finer and higher than carbide particles in sample S1.
4. Average hardness of sample S2 is higher than sample S1, because sample S2 component is contained of TiCN particles.This particles increasing the hardness of sample S2 more than sample S1 that contains TiC carbides.
5. Micro-ploughing and micro-cutting were the main abrasive micro-mechanisms observed in Ti concentrated hardfacing alloys. In titanium carbides hardfacing alloys (sample S1), intensive micro-ploughing was observed, due to lower hardness of TiC particles. In specimen that was welded by nitrogen shielding gas, the increasing of the abrasion resistance with micro-ploughing and micro-cutting were considerable and virtually no continuous grooves were observed that it is related to high hardness of TiCN particles.

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