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Advanced Metallic Coating for the Improvement of Corrosion and Erosion Resistance of Iron Base Materials Used in Buildings and Special Works

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Various metallic materials are coated on Fe base materials via thermal spraying or welding process to improve both corrosion resistance as well as erosion resistance of the Fe base materials used in buildings and special works. The mechanical properties and corrosion resistance of the coat are estimated by means of hardness measurement and anodic polarization test. In additions, the effect of alloying elements and microstructure of the coatings on the mechanical and chemical properties of the coat is investigated using X- ray diffraction, Optical microscope, Transmission electron microscopy and Auger analysis. The coating deposited by tungsten inert gas (TIG) welding exhibit a good combination of hardness and corrosion properties.

Keywords *: advanced coatings, corrosion resistance, erosion resistance, iron alloy*

1. Introduction

Coating technology is widely used to produce various type of protective coatings which require wear resistance, thermal isolation, corrosion resistance, or aesthetic purpose. Among these coating processes, thermal spraying process and welding technique are the most commonly used for the deposition of metallic coating since they can coat wide surface area in a short time and at a relatively low cost. Up to date Al and Zn coating alloys are widely spray on Fe base structural parts to form a corrosion resistant protective layer. However, these materials are very soft and consequently those applications are restricted to the components or structure exposed to a mild corrosive environment.

Many parts of building or structures such as power plant and offshore platform are experienced very severe erosive attack as well as corrosive attack. For this reason, a study is conducted to evaluate the corrosion and erosion resistance of an advanced metallic coating.

2. Experimental procedure

2.1 Material and Sample preparation

Two commercially available materials, Fe-21.4Cr-14.2B-3Si-1.9Mn-5.3C (in atomic %) (Wire-A) and, Fe-24.7Cr-15.8B-2.7Si-1.3Mn-0.58C (Wire-B), were coated onto a Fe base substrate via thermal spraying and TIG welding. For thermal spraying, a twin wire electric arc spray TAFA880 was used. Since the feed stocks are composed of elements of different atomic size, an amorphous phase is expected to form in the arc spray coating which is suitable for good corrosion and erosion resistance of the coating material. The process parameters used for Arc spraying are shown in Table 1

Table 1. Processing parameters for Arc spray technique.

Voltage	40 volt
Current	250 amp
Stand off distance	30 cm
Wire Feed rate	125 mm/sec
Scanning speed	520 mm/sec
Atomizing gas Pressure (N_2)	60 psi

The process parameters are selected in such a way to increase the amorphous phase formation in the coating. One of the important ways to get the glass is to assure a proper melting of the alloy constituents to the liquid state followed by a rapid quenching.[1] Thus high voltage (40 volt) was selected such that the high energy arc was established and a proper melting of feedstock could be achieved. Even though the process has a high cooling rate, still the cooling rate of individual droplet can be enhanced by spraying using a high gas to metal flow ratio. (i.e. high gas flow to low wire feed rate). To reduce the oxidation

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of droplet, N_2 gas was used as atomizing gas. Also, the shorter, the spraying distance the higher the substrate heating which will increase the possibility of devitrification of the previously coated amorphous phase, and on the other side, larger the spray distance the poorer the coating density, so a nominal spray distance 30 cm was chosen.Multi pass TIG welding experiments were conducted at engineering work condition.

2.2 Hardness test

Vickers hardness test was performed to get an indication about the erosion resistance of the coatings. Since the arc sprayed coating thickness is about 250 μm a low load of about 25 gf was applied for about 10 sec. The hardness was also checked randomly at ten places throughout the arc sprayed coating and the hardness was averaged on about 10 measurements. In the case of TIG deposition the hardness was checked along a straight line profile from the substrate to the coating (cross - section) with a load of 500 gf.

2.3 Corrosion test

In this study anodic polarization experiments were conducted for the coated specimens following standard procedures.[2)] The coating surface was polished using a wet grinding papers with 240 grit SiC and then a 600 grit SiC paper. A corrosive environment of 1.0 N H_2SO_4 at 30 ℃ was chosen to study the corrosive behavior of the coatings by conducting linear polarization and Anodic dynamic polarization technique using a Silver- silver chloride standard electrode (SSCE) and graphite as secondary electrode. At first the open circuit specimen potential, that is the corrosion potential (E_{corr}), is obtained after 1 hr immersion. For linear polarization 10 mv, more noble or more active potential than the E_{corr} was applied at a potential sweeping rate of 0.6 V/h and the change in potential and current was recorded in a PC computer.

In the case of potentiodynamic experiments, the potential scan started from the potential of 50 mv increment from E_{corr} and proceeds through +1.5 V versus standard SSCE at a potential sweeping rate of 0.6 V/h.

2.4 Surface analysis

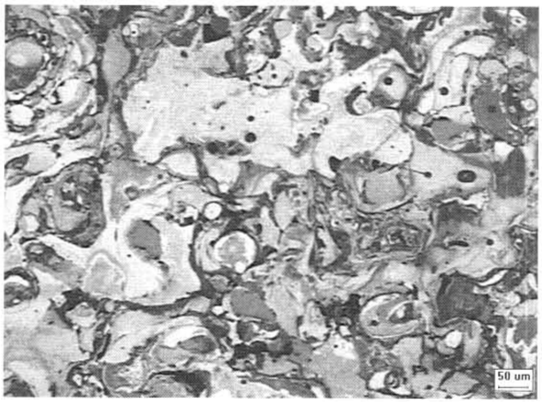
X-ray diffraction (XRD; Rigaku CN2301, monochromatic Cu K_α radiation) experiments were performed to examine the crystalline phase formed in the coatings and completed by Auger Electron spectroscopy (AES) for composition analysis.

2.5 Micro structural characterization

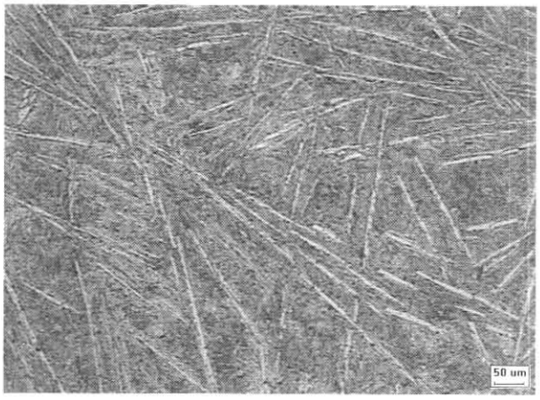
The coated samples were sectioned, hot mounted and polished following a standard procedure. The samples were observed by optical microstructure and SEM after etching with a solution of 4 parts of HCl and 1part of HNO_3. The arc sprayed coating was observed under TEM to confirm the amorphous phase formed.

3. Results and discussion

The representative microstructure of arc spray coating and TIG deposition are shown in Fig. 1 (a, b). The arc sprayed microstructure Fig. 1(a) show the typical characteristics such as splats, inclusion and porosities, whereas the TIG deposits shows dense intermetallic structures. The difference in microstructures can be attributed due to the different solidification mechanisms involved in these processes. The molten liquid droplet formed in the arc spray, impact and crush onto the substrate, leading to rapid quenching (up to 10^4 K/s) and resulting in metastable phases such as amorphous phase in the coating. Since the coatings are built up particle by particle they have a



(a)



(b)

Fig. 1. Optical microstructure of arc spray (a) and TIG welding (b) when coated using Wire-A.

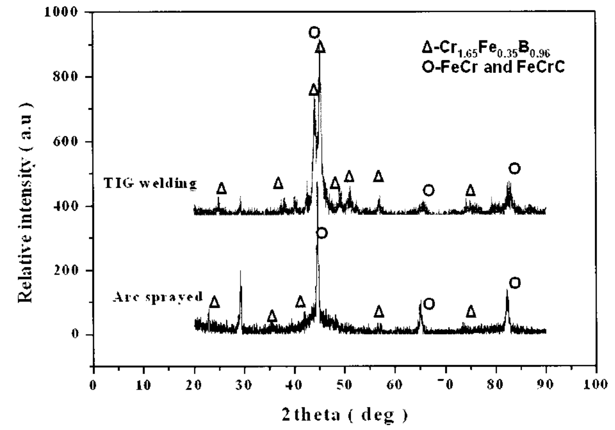


Fig. 2. XRD analysis of arc sprayed and TIG weld coatings

lamellar structure and usually exhibit a high level of porosity.[3)]

In the case of multipass TIG welding a relatively slow cooling of the liquid takes place, resulting in solid solutions and high concentrated elements can precipitate as intermetallic phase.

X-ray diffraction experiments performed, for identification of the crystalline phases formed in the coatings are shown in Fig. 2 The main constituents of both the coatings were FeCr solid solution matrix and chromium rich boride phase like $Cr_{1.65}Fe_{0.35}B_{0.96}$. The peak broadening found at 45 ℃ of Bragg angle gives an indication about the presence of amorphous phase.

In order to confirm the presence of the amorphous film, arc spray coatings were observed in TEM. Thin foils for TEM observation were made by electrolytic polishing method to investigate the microstructure of the surface layer. The TEM bright field images shown in Fig. 3 (a, b, c, d) of the arc spray coating demonstrate the existence of an amorphous phase, microcrystalline and dendrite structure respectively.

In the same manner, to identify the different phases present in the TIG welding the coatings were analyzed by AES. The phases identified in the microstructure are shown in Fig. 4. From AES, B (rich) -Fe- Cr phase,

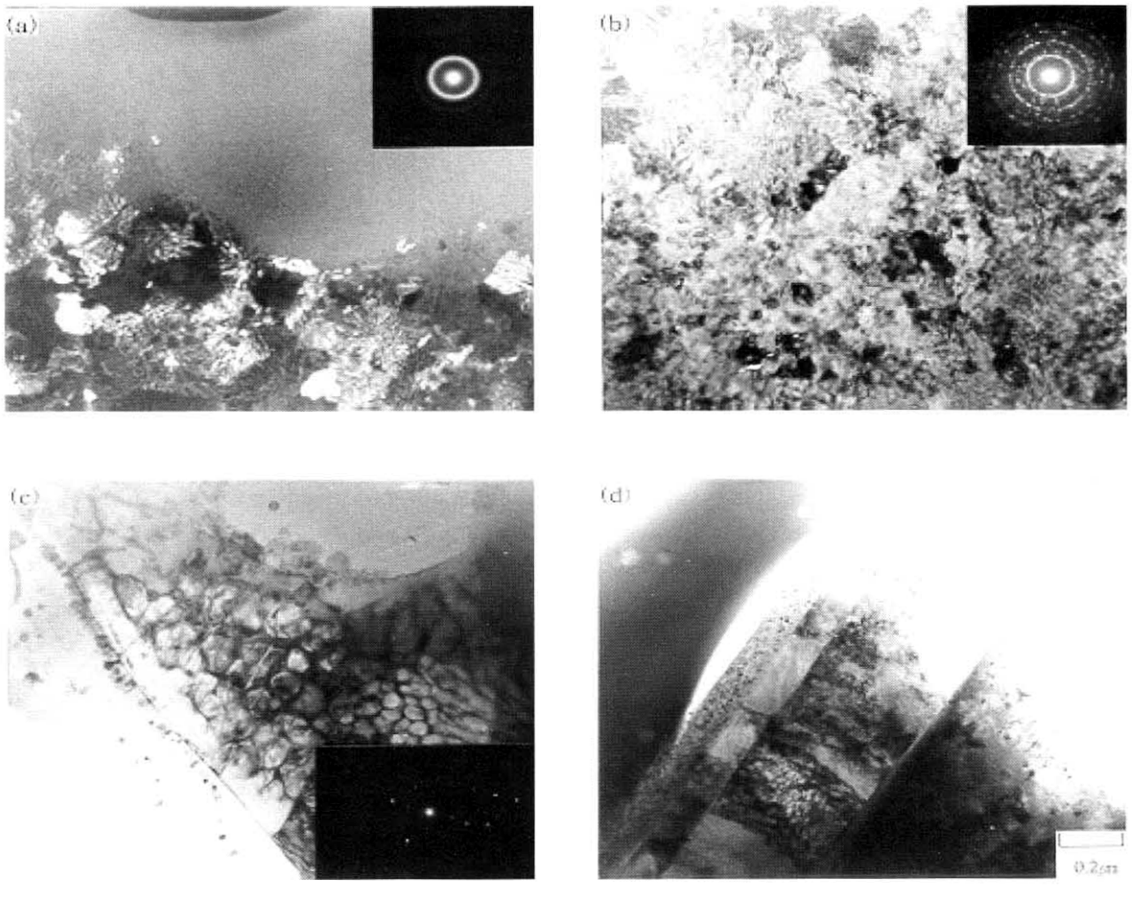


Fig. 3. TEM micrograph showing the microstructure of the Arc spray coated using wire-A alloy (a) amorphous, (b) Micro-crystalline, (c) and (d) are dendrite by thermal deviation.

Table 2. Vickers microhardness of the arc spray and TIG welding

Coating Materials	Process	Hardness(Hv)
Wire A	TIG welding	774
	Arc spray	460
Wire B	TIG welding	680
	Arc spray	430

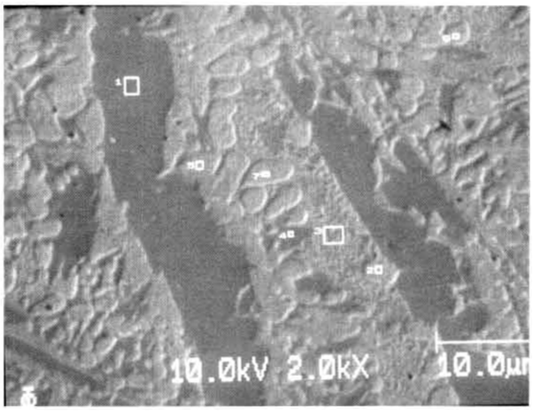


Fig. 4. SEM image showing the microstructure of TIG coating, using wire-A

Fe(rich)-C-Cr phase and Fe-Cr were identified and their atomic concentration (excluding the oxygen content) were determined as B48-Fe31-Cr16, Fe77-C7-Cr4 and Fe82-Cr7 was respectively.

As an indication of the erosion resistance, hardness measurements were carried out as explained in experimental section and their results are tabulated in Table 2.

A high hardness of about 772 HV was obtained from the coating prepared by TIG welding, using the wire- A as feedstock. In comparison the same composition for the hardness exhibit a low of about 430HV when prepared by arc spraying. This low value of the microhardness is attributed due to the very high porosity of the coating produced by arc spray. Among the two wires, wire -A shows higher hardness than the wire-B this could be attributed due to the higher concentration of carbon content in wire-A. Carbon atoms will prefer to occupy the interstitial sites with iron atom lattice and because they have a high bonding energy with iron, an increase in hardness is observed with higher concentration of carbon atom. Since the hardness is high for TIG welded technique made from, the wire -A, it is expected that these coatings will show a better erosion resistance in service.

The corrosion behavior of the prepared coatings was also studied as it is one of the major objectives of this study.

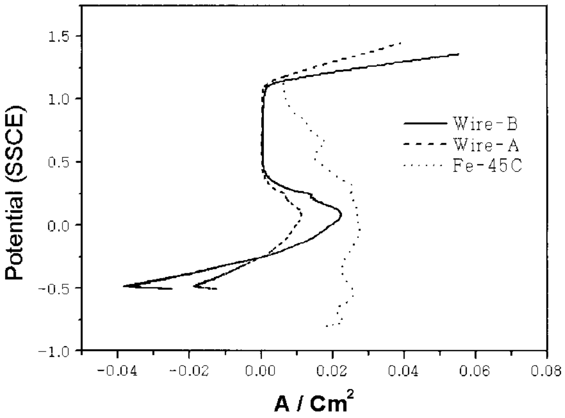


Fig. 5. Potentiodynamic anodic polarization plot

Fig. 5. shows the corrosion behavior of the TIG coating of wire -A, wire- B and C45 steel substrate. The anodic dissolution curve of C45 steel, because of its large critical anodic density and relatively noble primary passive potential, is difficult to passivate in acid solutions, which means high corrosion of c45 steel will takes place. To avoid this, alloying element like Cr, Ni are added to increase the passivation[4] by reducing the critical current density, Since the coating wires have a high concentration of B, Cr, Si, it is expected that the elements provide a efficient corrosion inhibition. As expected the coatings obtained from TIG welding of wire -A, and wire -B when subjected to corrosive environment get passivated as shown in Fig. 5. Among the wire A and B, wire A shows a better corrosion resistance this can be understand by analyzing the primary passivation potential, passivity region, pitting potential. In this case all the above said potentials are almost the same for the two wires. But the primary passivation potential can be achieved at a minimum current (passive current or critical current) in the case of coatings obtained from wire-A which indicates that this coatings obtained are less active and so higher corrosion resistance than the coatings obtained from wire B.

By performing linear polarization technique, corrosion current was obtained. The corrosion current is a direct indication of corrosion rate i.e. Corrosion rate (R) = K x $I_{Corrosion}$, where K is the material constant. The corrosion current of wire-A, TIG coating sample is less than the wire -B coating implies that wire-A TIG coating have better corrosion resistance and this result is also a good accordance with the result of potentiodynamic tests, whereas the corrosion current is very high for arc sprayed coatings than the weld coatings, showing that high susceptible to corrosion and the reason may be attributed to high porosity of arc spray coatings. But the reason for the improvement of corrosion resistance for wire-A with respect to corrosion resistance of wire- B TIG coating is not clear because the carbon concentration is the only significant compositional difference between the wire A and B and so further studies should be made to understand the improvement of corrosion resistance of wire-A.

4. Summary

In an aim, of improving both the corrosion and erosion resistance of iron based materials two advanced metallic coating techniques, thermal wire arc spray and TIG weld coating are used for the two commercially available iron based alloys. The corrosion and erosion properties obtained are compared with some reference materials are shown in the Table 3.

It is well known that, if lower the corrosion current, higher the corrosion resistance and if higher the hardness, high erosion resistance could be expected. A drastic improvement of erosion resistance was obtained in TIG weld coatings and increase in hardness is due to the presence of hard phase like BFeCr and FeCrC. At the same time better corrosion resistance than the steel is also shown by the coatings, but the corrosion and erosion resistance are poor for arc spray coatings it could be due to the high porosity. It should be noted that TIG weld coating is a slow process and also coating is applicapable for only smaller areas, whereas in the case of thermal spray coatings, the process is fast and it could be coated for relatively large area. Again the corrosion and erosion resistance of thermal sprayed coatings mainly depends on the porosity present in the coating, higher the porosity poorer the properties. So techniques like High Velocity-Oxy Fuel (HVOF) which can produce dense and even amorphous coating should be studied to further improve the corrosion and erosion resistance of iron based materials.

Table 3. Comparison of erosion-corrosion properties with coating process

Process/Properties	TIG welding	Arc spray	Reference material	
			Steel	Stainless steel
Vickers hardness	774	460	180	240
Corrosion current (mA/cm^2)	4.93	8.56	No passivation	2.85

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