18th IFHTSE CONGRESS
International Federation for Heat Treatment and Surface Engineering
IFHTSE

ANAIS
PROCEEDINGS
ISSN 1516-392X

COMPARISON OF CORROSION RESISTANCE OF A Fe-Mn-Al ALLOY BORONIZED BY PACK OR SALT BATH PROCESS[1]

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Abstract

Fe-Mn-Al alloys have been developed to replace traditional stainless steel in some applications, in less severe corrosive environments. In this work, an alloy of this class was subjected to two different boronizing treatments, aiming to verify the influence of these treatments on the hardness and sea water corrosion resistance of this alloy. The boronizing treatment was carried out using liquid and powder medium. The layer formed in liquid medium was harder but thinner. The sample boronized by salt bath process presented the biggest corrosion potential and the smallest corrosion current, followed by the pack boronized and the un-treated alloy.

Key words: Fe-Mn-Al; Salt bath; Pack; Boronizing; Corrosion.

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[1] *Technical contribution to the 18th IFHTSE Congress - International Federation for Heat Treatment and Surface Engineering, 2010 July 26-30th, Rio de Janeiro, RJ, Brazil.*

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1 INTRODUCTION

Iron base alloys with appreciable amounts of aluminum form protective alumina films on the surface but at the same time they may contain Fe_3Al and FeAl phases, which degrade severely their ductility at temperatures below to the ordering temperature. To avoid the formation of these phases, austenite stabilizer alloying elements such as Mn, Si and C may be added.[1,2]

Economic and strategic considerations shows the importance of developing austenitic alloys of the Fe-Mn-Al system that may replace, in some applications, traditional stainless steels which contain the chromium as the main corrosion resistance alloying element.

Although the steels of the Fe-Mn-Al system show some interesting mechanical properties, their low corrosion resistance in severe environments make them unacceptable as substitutes for conventional stainless steels.[3-7]

Surface treatment processes are currently used to improve the wear and corrosion resistance of engineering materials. These processes can be defined as treatments in which the surface and substrate are designed together to produce properties that are not attainable by either alone.[8,9] In this context, the possibility of producing wear and/or corrosion resistant layers in Fe-Mn-Al alloys may be an effective way to improve their performance and broadening their usage.

Boronizing is a surface treatment process that involves the diffusion of boron into a substrate at high temperatures. This is a surface hardening process that can be performed in metals by gaseous substances such as diborano or boron halides or by using liquid medium, such as melted borax, or alternatively by using solid agents.[10,11]

Boronizing in a gaseous environment is generally not used in industry due to the danger of the products which are used in this type of treatment. On the other hand, boronizing in a solid environment has a lot of industrial applications because of its cleanliness and simplicity. In liquid environment the reduction of Boron compounds can take place either through a electrochemical reaction or a chemical reaction, When using a chemical reaction a reducing agent is added to the boronizing bath.[12]

In this work, a Fe-Mn-Al alloy was boronized by salt bath immersion and by pack methods to verify the influence of these treatments in the corrosion resistance of the alloy.

2 MATERIALS AND METHODS

The alloy used in this work was produced using an Inductoterm induction furnace in normal atmosphere and a crucible coated with basic refractory. Table 1 shows the nominal and the obtained alloy chemical composition.

Table 1. Nominal and obtained alloy chemical composition

	Elements (% wt.)				
	Fe	**Mn**	**Al**	**Si**	**C**
Nominal	Bal.	32.00	8.00	1.50	1.00
Obtained	Bal.	31.22	7.54	1.34	0.93

Test specimens were cut and ground to 600 mesh sand-paper. For liquid boronizing, borax ($Na_2B_4O_7.10H_2O$) was melted in a stainless steel crucible using an electric furnace at 1000°C and then 10% aluminum was added. The bath was homogenized and the samples immersed in it for 5 hours at that temperature.

For pack boronizing a powder mixture of B_4C, borax and activator was prepared. The samples were covered by the powder inside a crucible and then sealed. For the comparison, the same temperature and time were used. After the treatments period the samples were air cooled.

Boronized samples were subjected to optical microscopy, microhardness and corrosion analysis. The micrographic analysis were performed on cross-sections of the obtained layers, after the samples were embedded in bakelite, ground with 1200 mesh sand-paper, polished and etched with 10% Nital.

The microhardness profile was obtained using a digital Vickers indenter with a 50g load.

Electrochemical polarization curves were obtained using natural sea water as electrolyte. The tests were conducted in the treated and untreated samples to compare their performance.

3 RESULTS AND DISCUSSION

Figure 1 shows the optical micrographs of the boronized samples. For both treatments the layer/substrate interface is smooth, but in the salt bath treatment (Figure 1A), the layer showed no thickness uniformity. Regarding to the thickness, the pack boronizing formed a thicker layer, about 326 µm, against 30 µm of the liquid treatment; this behavior can be explained by the difference in the boron potential of each media. According to Lyakhovich et al.,[13] liquid environment boronizing in molten salts is obtained from the formation of a galvanic cell. In the latter, the substrate plays the role of the cathode whereas the reducing agent's fine particles (which stay in suspension in the bath) play the role of micro-anodes. Therefore, the driving force of boronizing in molten salts is the potential difference between the treated-piece surface and the reducing agent. In pack process the boron potential is a dependence between the concentration of the boron donor component and activator component in the powder mixture.[14]

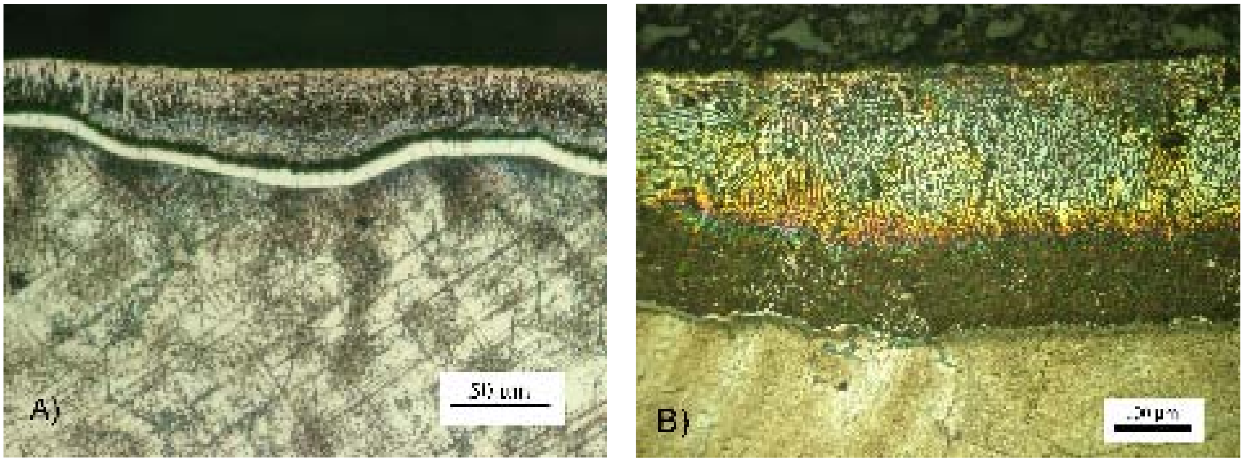

Figure 1. Optical micrographs of the borided samples; A) Salt bath boronizing; B) Pack boronizing.

Figure 2 shows the microhardness profiles of the boronized samples. As can be seen, a great difference occurred between the two treatments. Although a thicker layer was formed in the pack boronizing, the obtained surface hardness was smaller than in the liquid treatment, 780HV and 1378HV respectively. Besides that, the hardness in the pack boronized sample decreased gradually until 300HV at 150 depth and then increase until reaches its maximum (955HV) at a depth of 263. This maximum hardness value corresponds to the layer darker zone in the micrograph (Figure 1B).

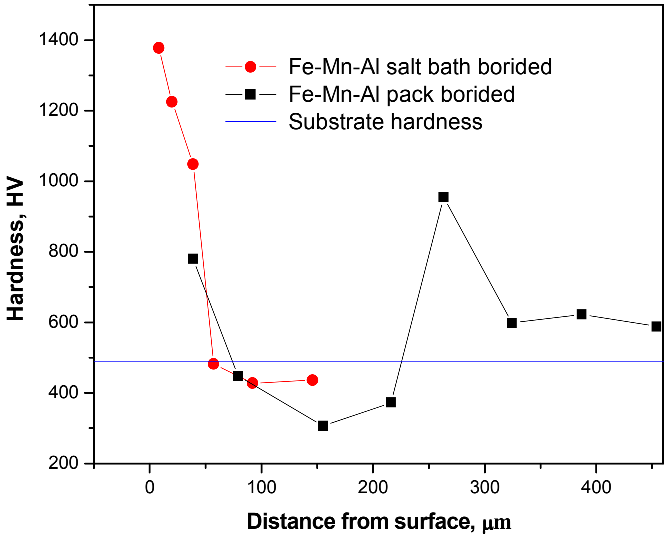

Figure 2. Microhardness profiles of the borided samples.

Figure 3 shows the boronized and un-treated samples electrochemical polarization curves. A stainless steel AISI 316 polarization curve was added as pattern. The un-treated Fe-Mn-Al alloy showed the lowest corrosion potential (745 mV), but a small passivation band was formed due probably to the formation of Aluminum oxides films.

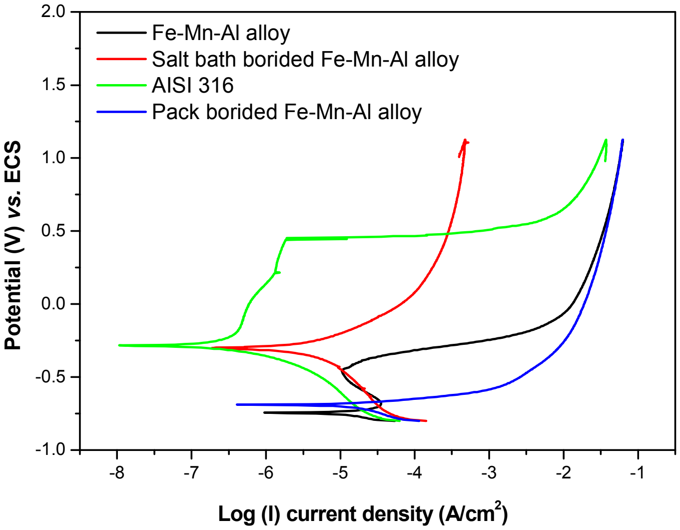

Figure 3. Electrochemical polarization curves of the treated and un-treated samples. AISI 316 as pattern.

In other hand, no passivation band occurred in boronized samples, and just a small increase occurred in the corrosion potential after pack boronizing. Therefore, we can consider that pack boronizing decreased the Fe-Mn-Al corrosion resistance. After liquid boronizing, the corrosion potential increased 437 mV in comparison with un-treated sample, and the current decreased, implying in improvement in the sample corrosion resistance, nearly to the AISI 316 behavior.

4 CONCLUSIONS

Different layers were formed in the Fe-Mn-Al alloy with the different boronizing treatment.

The layer formed with pack treatment was deeper and homogeneous, but with lower hardness than the one formed by liquid boronizing.

Corrosion resistance was improved after Fe-Mn-Al liquid boronizing, nearly to that of AISI 316.

For this alloy, salt bath boronizing led to better corrosion resistance and higher hardness in comparison with pack boronizing.

REFERENCES

1 CAIRNS, R.; HAM, J. U.S. Patent 3,111,405, November 1963.
2 HUARNG, S.H. M.S. Thesis, National Tsing Hua University, 1983.
3 ALTSTETTER, C.J.; BENTLEY, A.P.; FOURIE, J.W.; KIRKBRIDE, A.N. Processing and Properties of Fe-Mn-Al Alloys. *Mater. Sci. Eng*. V.82, p.13. 1986.
4 WEN, T.; JING, B.; JU, T. Electrochemical polarization and pitting behaviour of Fe-Al-Mn alloys in chloride solutions. *J. Mater. Sci*. V.22, p.3517, 1987.
5 TJONG, S.C. Aqueous corrosion properties of austenitic Fe-8.7A1-29.7Mn-1.04C alloy. *Surf. Coat. Technol*. V.28, p.181, 1986.
6 SHIN, S.T.; TAI, C.Y.; PERNG, T.P. Corrosion behavior of two-phase Fe-Mn-Al alloys in 3.5% NaCl solution. *Corrosion*. V.49, p.130, 1993.
7 RUSCAK, M.; PERNG, T.P. Deformation and cracking behavior of Iron-Manganese-aluminum alloys in Sodium Chloride solution. *Corrosion*. V.51, p.738, 1995.
8 SUBRAMANIAN, C.; STRAFFORD, K.N.; WILKS, T.P.; WARD, L.P. On the design of coating systems: Metallurgical and other considerations. *J. Mater. Proc. Technol.* V.56, p.385-397, 1996.
9 SIDKY, P.S.; HOCKING, M.G. Review of inorganic coatings and coating processes for reducing wear and corrosion. *British Corrosion Journal*. V.34, p.171-183, 1999.
10 STEWART, K. Boronizing protects metals against wear. *Advanced Materials and Processes*. V.3, p.23-25, 1997.
11 MARTINI, C.; PALOMBARINI, G.; CARBUCICCHIO, M. Mechanism of thermochemical growth of iron borides on iron. *Journal of Materials Science*. V.39, p.933-937, 2004.
12 ALLAOUI, O.; BOUAOUADJA, N.; SAINDERNAN, G. Characterization of boronized layers on a XC38 steel. *Surf. Coat. Technol.* V.201, p. 3475–3482, 2006.
13 LYAKHOVICH, L.S.; KOSACHEVSKII, L.N.; DOLMANOV, F.V.; KRUKOVICH, M.G. Liquid process of chemical heat treatment without electrolysis. *Met. Sci. Heat Treat*. V.14, p.156, 1972.
14 JAIN, V.; SUNDARARAJAN, G. Influence of the pack thickness of the boronizing mixture on the boriding of steel. *Surf. Coat. Technol.* V.149, p.21-26, 2002.