Mechanical Properties of Boronized Fe-0.94%Mn Binary Alloy

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Fe-0.94%Mn alloys were boronized at 1210 K during 4 h by the powder pack method. Three distinct regions of cross-sections were found in such alloys. The boride layers were characterized by means of microscopy in terms of coating morphology and thickness. The hardness and thickness of the boride layers were measured, and it was observed that they depend strongly on the thermal processes performed before boronizing the alloys.

Key words: Binary Alloys; Thermal Process; Boronizing; Boride Layer; Microhardness.

1. Introduction

Fe-Mn-based alloys are of great importance for stainless steel, non-magnetic steel, shape memory alloys, and a rather inexpensive damping material [1 – 4]. In considering the engineering materials, the main problem with Fe-Mn alloys is that they have a poor wear-resistance and microhardness [1, 5, 6]. Coating with certain compounds is one way of improving the hardness, wear resistance, fracture and yield strength of such material [7, 8]. One of the coating techniques is boronizing, a thermo-chemical surface treatment in which boron atoms diffuse into the surface of the work piece to form hard borides with the base material. It is a prominent choice for a wide range of tribological applications where the control of friction and wear is of primary concern [9 – 13].

Boronizing can be carried out in numerous ways, and alloying elements such as silicon, nickel, chromium, and manganese can influence the morphology, thickness, and nature of the boride layers consisting of either Fe_2B or FeB in Fe-based alloys [14, 15]. Corresponding to this, it has been found that nickel, chromium and manganese atoms preferentially enter the iron boride structure to substitute iron in Fe_2B in the coating [15 – 17]. Meanwhile, during the boronizing experiments different borided phases can be formed, depending on the amount of diffused boron from the surface to the matrix and the formation of boride layers depends on the nature of the substrate to be treated, the boriding agent, treatment temperature and time [10, 18, 19].

The use of surface coatings opens the possibility for material designs in which the specific properties are located where they are most needed. Boronizing has long been used to improve the surface properties of materials, as boride layers have a high hardness, oxidation resistance, wear resistance and fracture strength. Therefore, boronizing has been generally applied to improve the surface properties of valves, burner nozzles, etc. in the industry [8, 20, 21]. The object of the present study is to investigate the effect of thermal processes, before boronizing, on the grain sturcture and hardness of Fe-0.94%Mn binary alloys.

2. Experimental

The substrate material used in this study was an Fe-Mn binary alloy containing 0.94 wt% Mn. The samples with the dimensions $2.5 \cdot 3.0 \cdot 40$ mm^3 were cut from plates. The boriding of the Fe-0.94%Mn alloys was achieved in a solid medium using the powder pack method. In this method, a commercial Ekabor-II boron source and activator (ferro-silicon) were thoroughly mixed. The packed test samples were heated in an electrical furnace for 4 h at 1210 K under atmospheric pressure. After this process, the borided samples were removed from the furnace and cooled in air. Borided samples were sectioned from one side and prepared metallographically up to 1200-grid emery paper

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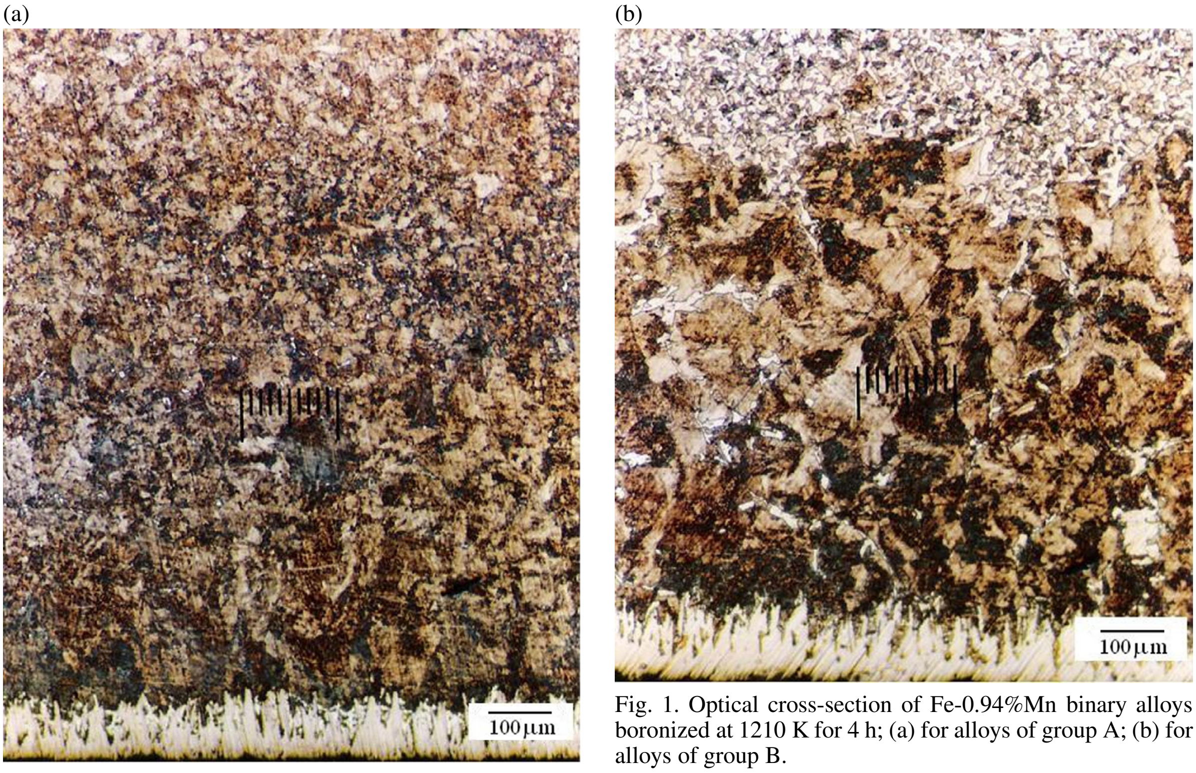

Fig. 1. Optical cross-section of Fe-0.94%Mn binary alloys boronized at 1210 K for 4 h; (a) for alloys of group A; (b) for alloys of group B.

and then polished, using 0.3-Am alumina pastes. The polished samples were etched by 4% Nital before the tests. A group of samples was borided just after cut from plates that we called A, and the others, called B, were borided after a thermal process (annealed) for 10 h at 1000 K to ensure a similar initial microstructure to avoid internal stresses. The presence of borides formed in the coating layer was confirmed by means of X-ray diffraction (XRD) and microscopy. Meanwhile, the thickness of the coating layer and surface analysis were studied by a microscopy. Tensile tests were carried out with a constant cross-head speed at a strain rate of $1.2 \cdot 10^{-6}$ s^{-1}. The microhardness of the borides was measured by using a Vickers microhardness tester and a load of 100 g. Many indentations were made on each coating film under each experimental condition to check the reproducibility of the hardness data. Further experimental details were described in [22].

3. Results and Discussion

It is well known that a boride layer on the upper surface of the specimen forms as a result of boron diffusion into the surface in the boronizing process [10, 12, 19, 23, 24]. Figures 1a and b show the optical microstructure of the boronized A and B group of Fe-0.94%Mn binary alloys. The boride formed on the surface of the substrate has a dentricular morphology for all samples. The thickness of the boride layer of borided samples called A is about 60 μm, whereas that of borided samples called B is about 90 μm. Previous studies have shown that the characteristics of this boride layer depend on the physical state of the boride source used, boronizing temperature, treatment time, stress and properties of the boronized material [10, 18, 19, 25, 26]. In the present study it was found that the thermal process affects the thickness of the boride layer. At higher magnifications, three distinct regions were observed on the cross-sections of the borided A and B group alloys surface: (i) a surface layer consisting of iron boride, (ii) a transition zone and (iii) a matrix that is not affected by boron (Fig. 1). The prominent phases (FeB and Fe_2B) formed in the boride layer were revealed by XRD analysis (Fig. 2). These phases, established at the surface, were also explained with the amount of the diffused boron from the surface to the matrix at the Fe-based alloys by other researchers [26 – 28]. It can be seen in Fig. 2 that the

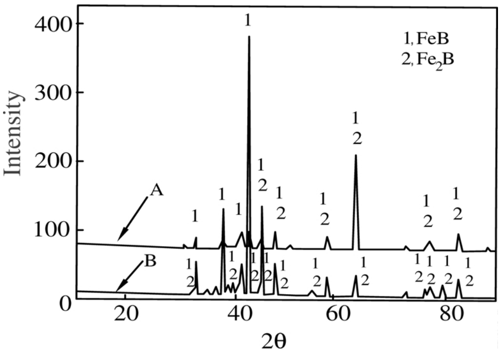

Fig. 2. X-Ray diffraction pattern of A and B group Fe-0.94%Mn binary alloys boronized at 1210 K for 4 h.

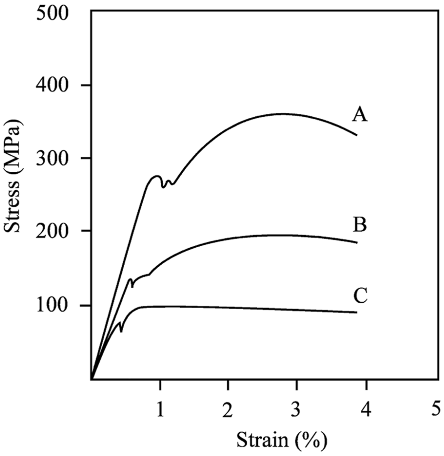

Fig. 3. Typical stress-strain curves of A and B group Fe-0.94%Mn binary alloys. C represents unboronized Fe-0.94%Mn binary alloys.

dominant phase for the A group samples is FeB, while the dominant phase of the B group samples is Fe_2B. These results can be confirmed with ultimate stress values obtained from the stress-strain curves of boronized samples. It is evident from Fig. 3 that the ultimate stress or the yield stress (stress at 0.2% offset strain) of A group samples is higher than that of B group samples due to the volume thermal treatments, and also to surface modification as expected in considering the plastic deformation of the materials.

In order to investigate the mechanical properties of boronized Fe-0.94%Mn binary alloys, the microhardness and grain structure were obtained from A and B group alloys. As shown in Fig. 1a and b, A group alloys have a fine grained structure, while B group alloys are coarse and fine grained for the transition and matrix region, respectively. On the other hand, hardness measurements were performed on the boride layer, on the layer just below the boride layer, and on the matrix by the Vickers (100 g) method. In Fig. 4, it is possible to observe how the hardness of borided Fe-0.94%Mn binary alloys (A and B) changes from the boride layer to the matrix. As it is seen from Fig. 4, the hardness of the boride layer is much higher than that of the matrix because of the hard FeB and Fe_2B in the boride layer as determined by XRD (Fig. 2). The same results have been obtained in [13, 26, 28, 29]. In addition, the hardness values of boride layer in the A group alloys are much higher than those in the B group alloys. This suggests that the FeB phase in the boride layer of the A group alloys is a dominant phase. Clearly, we think that the improvement in the mechanical properties of the A group alloys is more noticeable than that of the B group alloys because of thermal processes. From the experimental results of hardness, grain structure and ultimate stress, the decisive conclusion is obtained that the thickness of boride layers and the possibility of the formation of FeB and Fe_2B strongly depend on the thermal processes before boronizing Fe-0.94%Mn binary alloys as well as on the substrate composition, temperature and time treatment.

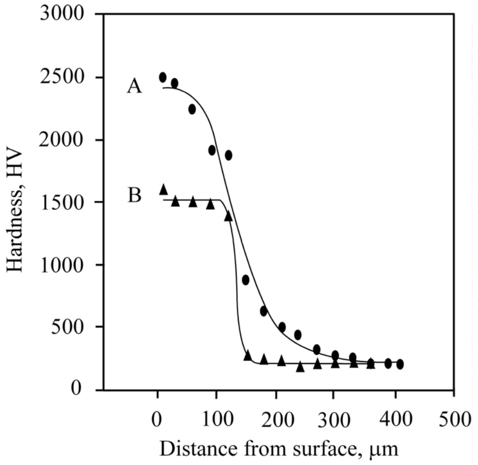

Fig. 4. Hardness variation of boronized Fe-0.94%Mn binary alloys as a function of distance.

4. Conclusions

The main conclusions obtained by our study are as follows:

1. Boride layers formed on Fe-0.94%Mn binary alloys have a dentricular morphology. The microstructure of the borided Fe-0.94%Mn binary alloy surfaces showed three distinct regions, the boride layer, the transition zone and the matrix. The possibility of for-

mation of phases on the surface depends on the amount of the diffused boron atoms from the surface to the matrix because of thermal processes.

2. The hardness values of the borided layer formed on the surface of Fe-0.94%Mn binary alloys are much higher than those of the matrix because of the sequence of hard FeB and Fe_2B phases in the boride layer.

3. The improvement of the mechanical properties of borided Fe-0.94%Mn binary alloys depends on the thermal treatment before boronizing the alloys.

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