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Wear Properties of the Surface Alloyed AISI 1020 Steel with $Fe_{(15-x)}Mo_xB_5$ by TIG Welding Technique

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Surface alloying caused the improvement in the mechanical/chemical properties of near surface regions of the steels. In the present study, surface alloying treatment with boron, molybdenum, and iron on the AISI 1020 steel was realized by the technique of TIG welding. Ferrous boron, ferrous molybdenum, and Armco iron were used for surface alloying treatment. Before the treatment, ferrous alloys were ground and sieved to be smaller than 45 μm. The powders were mixed to be composed of $Fe_{(15-x)}Mo_xB_5$, where $x = 1$, 3, and 5 (by at.%). Prepared powders were pressed on the steel substrate and melted by TIG welding for surface alloying. Wear tests of the surface alloyed AISI 1020 steels were realized against WC–Co ball using by ball-on-disk method under the loads of 2.5, 5, and 10 N at the sliding speeds of 0.1 m/s for 250 m sliding distance. Friction coefficient and wear rates of the surface alloyed steel with $Fe_{(15-x)}Mo_xB_5$ alloy powder are changing between 0.30 and 0.80 and 5.86×10^{-5} mm^3/m to 2.52×10^{-3} mm^3/m depending on applied load and alloy composition, respectively.

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1. Introduction

Modern industrial applications require parts with special surface properties such as high corrosion and wear resistance and hardness. Alloys possessing these properties are usually very expensive and their utilization drastically increases the cost of the parts. The most effective and economical approach to improve surface ability of machine parts and components to withstand harsh environments and high surface stresses is by creating surface layers that would possess a high level of corrosion and wear resistance. In this way unique service characteristics can be obtained such as a combination of high surface hardness with high impact strength of the bulk. This approach can be also effectively applied to refurbishing worn machine parts [1].

The hard facing alloys obtained using high-energy density sources such as electron beam welding, plasma arc and laser have been widely applied to enhance the wear and corrosion resistance of material surface [2–5]. The gas tungsten arc welding (GTAW) process (also called TIG welding) is used when a good weld appearance and a high quality of the weld are required. In this process, an electric arc is formed between a tungsten electrode and the base metal. The arc region is protected by a kind of inert gas or a mixture of inert gases. The tungsten electrode is heated to temperatures high enough for the emission of the necessary electrons for the operation of the arc [6]. Molybdenum and iron are a strong boride-forming element, which forms stabile borides like FeB, Fe_2B, Mo_2B, MoB, Mo_2B_5, $Fe_{13}Mo_2B_5$, $Fe_{14}MoB_5$, $FeMo_2B_2$, $FeMo_8B_{11}$, etc. [7–10]. These compounds have high melting temperature, hardness and wear resistance like Zr, Ti, and Cr borides [9, 10]. There is not enough study about the Fe–Mo–B alloys used for surface alloying treatments.

In this investigation, TIG process is used as a high energy density beam to form a high molybdenum Fe–Mo–B hard surface above the AISI 1020 steel with a powder mixtures consisting of ferrous molybdenum, ferrous boron, and iron. Main objective of the study is wear properties of the surface alloyed steels with $Fe_{(15-x)}Mo_xB_5$, where $x = 1$, 3, and 5 (by at.%) alloy against WC–Co.

2. Experimental procedure

The substrate material for the welding surface was prepared from AISI 1020 steel plates. Before welding, these specimens were ground and cleaned with acetone to remove any oxide and grease and then dried with compressed air. The nominal composition of ferrous molybdenum alloys used in the study (wt%) was as follows: 62% Mo, 0.5% Cu, 0.09% C, 0.98% Si, 0.03% P, and balance Fe. Ferrous boron and molybdenum were grounded by ring grinder and sieved to be 45 μm particle sizes.

Ball-on-disk arrangement was used for friction and wear test. The WC–Co ball, 10 mm in diameter, was used in the wear test. The WC–Co ball has mirror like surface finish. Most of the materials are encountered with ambient temperature and humidity in the industrial applications. Therefore, the friction and wear tests were carried out at room temperature (21 ± 3 °C), relative humidity being 64 ± 5 conditions. Wear tests were carried out under the loads of 2.5, 5, and 10 at 0.1 m/s sliding speed for 250 m distance. Mean Hertzian contact pressures [11] calculated for WC–Co ball under the loads of

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2.5, 5, and 10 N are 530, 660, 840 N/mm^2, respectively. Knowing that, the compressive yield strength of WC–Co ball is 4510 MPa.

3. Results and discussion

Surface alloying modification by ferrous boron and ferrous molybdenum filler alloys was realized by means of TIG welding. In the process, a thin surface layer of the base metal were simultaneously melted together with ferrous alloys and then rapidly solidified to form a dense coating bonded to the base metal. Surface alloyed layer consists of iron, boron, and molybdenum. Figure 1 shows cross-sectional micrographs of the alloyed layers of the $\mathrm{Fe}_{(15-x)}\mathrm{Mo}_x\mathrm{B}_5$, where $X = 1$, 3, and 5 (by at.%) alloys. The thickness of the hard-faced layer ranged from 2 to 3 mm. The melted surfaces of the surface alloyed steel have smooth and rippled surface topography.

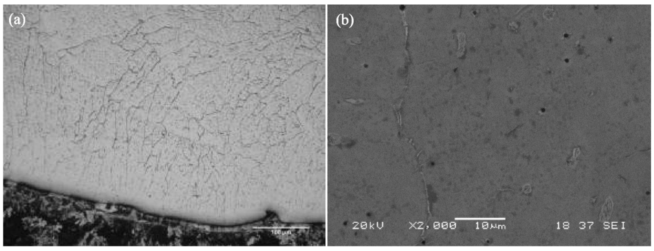

Fig. 1. Optical (a) and SEM (b) images of surface alloyed AISI 1020 steel with $\mathrm{Fe}_{(15-x)}\mathrm{Mo}_x\mathrm{B}_5$, where $x = 3$ (by at.%) alloy.

Microstructural examinations of the alloyed surface layer showed that three distinct regions took place on the cross-section of the surface alloyed steels which were: alloyed layer consisting of boride phases near the grain boundaries of steel matrix and distributed in the grain structures as shown from Fig. 1a. As shown from Fig. 1b, boride phases are well-distributed in the steel matrix as *in situ* composite structure. Some parts of the alloyed layer have much more dense boride phase in the alloyed layer as seen in Fig. 1. It is possible that the boride phases of the alloyed layer consist of $\mathrm{Fe_2B}$, $\mathrm{Fe_{13}Mo_2B_5}$, $\mathrm{Mo_2FeB_4}$, and iron phases which were detected by X-ray diffraction (XRD) analysis. The results are supported by phase diagram of B–Fe–Mo [7]. Eroglu [12] and Bourithis et al. [13] studied on boron addition to the steel surface for surface alloying and they explained that the borides formed in the alloyed layer realized close up the grain boundaries. As known, the hardness of transition metals ranged from 2000 HV to 4000 HV [14].

Figure 2a shows the variation of friction coefficients as a function of applied load with different alloyed layers ($x = 1$, 3, 5) against WC–Co ball at the sliding speed of 0.1 m/s for 250 m sliding distance. It is clear from this figure that the friction coefficient is changing between 0.48 and 0.81 according to alloy composition and applied load. While the higher the applied load caused to, the higher the friction coefficient for the alloy compositions of $x = 1$ and $x = 3$; friction coefficients of the alloy composition of $x = 5$ are nearly equal to each other for all applied loads.

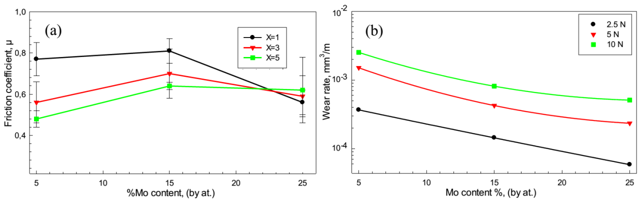

Fig. 2. (a) Friction coefficient and (b) wear rate of surface alloyed AISI 1020 steel with $\mathrm{Fe}_{(15-x)}\mathrm{Mo}_x\mathrm{B}_5$, alloys for $x = 1$, 3 and 5.

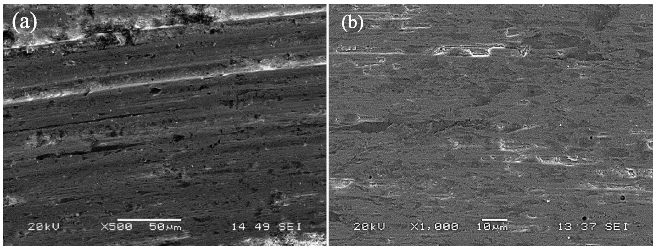

Fig. 3. SEM micrographs of the worn surfaces of the surface alloyed AISI 1020 steel with $\mathrm{Fe}_{(15-x)}\mathrm{Mo}_x\mathrm{B}_5$, alloys for (a) $x = 1$ and (b) $x = 3$ for 5 N load.

Figure 2b presents the wear rate of the surface alloyed AISI 1020 steel with $\mathrm{Fe}_{(15-x)}\mathrm{Mo}_x\mathrm{B}_5$, alloys for $x = 1$, 3 and 5 against WC–Co ball. As shown from the figure, the increase in applied load caused the increase of wear rate for all alloy compositions. Archard equating shows that increasing load reasoned the increase of wear rate [15]. As shown from the figure, the increase in molybdenum content in the alloy composition caused the decrease of wear rate according to applied load. SEM studies showed that increase in molybdenum concentration in the alloy composition caused to higher content of the boride phases in the surface alloyed layers (Fig. 3). Increase in the molybdenum content in the alloy composition 400% caused to decrease of the wear rate about 84%, 84% and 80% for 2.5, 5, and 10 N applied loads, respectively. However, load is effective parameters in the wear test which is caused to increase of wear rate between 465% and 771% according to molybdenum content of the alloys.

Abrasive scratches and its deep grooves were realized on the wear track of the surface alloyed AISI 1020 steel with $x = 1$ alloy composition. The wear mechanism of the surface alloyed layers with $x = 5$ composition showed that micro abrasive scratches and oxidative wear took place on the worn surface. Wear mechanism was changing with molybdenum content increment from the severe abrasive wear to mild abrasive wear. In general, WC–Co is used for the abrasive applications and machining process of the metals in industry. The wear mechanism was abrasive-oxidative.

4. Conclusions

1. It has been proven that surface alloying treatment of AISI 1020 steel using by $Fe_{(15-x)}Mo_xB_5$, alloys for $x = 1$, 3, and 5 wear realized by TIG welding.
2. Hard faced layers of the steel consist of Fe_2B, $Fe_{13}Mo_2B_5$, Mo_2FeB_4, and iron phases.
3. Increase of the molybdenum content in the alloy composition caused the increase of boride phases formed in the alloyed layers.
4. The friction coefficient is changing between 0.48 and 0.81 according to alloy composition and applied load. While the higher the applied load caused to, the higher the friction coefficient for the alloy compositions of $x = 1$ and $x = 3$, friction coefficients of the alloy composition of $x = 5$ are nearly equal to each other for all applied loads.
5. Increase in applied load caused the increase of wear rate for all alloy compositions. But increase of molybdenum content in the alloy composition caused the decrease of wear rate for all applied loads.
6. Wear mechanism of the surface alloyed AISI 1020 steel with $Fe_{(15-x)}Mo_xB_5$ alloys for $x = 1$, 3, and 5 alloys was changing with molybdenum content increment from the severe abrasive wear to mild abrasive wear.

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