The effects of niobium addition on the iron boride base hardfaced steel

Saduman Sen1,2, Bulent Kilinc1, and Ugur Sen1
1Faculty of Engineering, Department of Metallurgical and Materials Engineering, Sakarya University, Turkey
2Arifiye Vocational School, Sakarya University, Turkey

Abstract:
In the present study, the microstructural and phase analysis of the surface alloyed AISI 1020 steels with Fe13B7 and Fe10Nb3B7 alloys. Hard facing treatment was realized by TIG welding technique. Ferrous boron, ferrous niobium and Armco iron were used for the surface alloying treatment. The coatings' thickness was set to be 2-3 mm on the substrate. Coated layers formed on the steel substrate were characterized by x-ray diffraction analysis (XRD), optical and scanning electron microscopy (SEM) and micro-hardness test. The results showed that the alloyed layers have composite structure including steel matrix and well distributed boride phases. X-ray diffraction analyses showed that the alloyed layer includes iron borides and α-iron and, SEM and EDS analysis of the Nb-free alloy has eutectic structure of α-iron, FeB and Fe2B phases and blocky iron boride phase. Nb addition in the iron boride base hardfacing alloy caused to formation of niobium borides besides iron boride phase in the eutectic microstructure.

Key words: Hardfacing, niobium, borides, TIG welding

1. Introduction

The deposition of surfacing layers by welding techniques, such as tungsten inert gas welding (TIG) [1], shield manual arc welding (SMAW), submerged arc welding (SAW) [2], plasma arc welding (PAW) [3], oxyacetylene welding etc. have been widely applied commercially in a wide range of industries in order to improve the wear and corrosion resistance of the parts [4]. Among the welding deposition techniques, TIG welding is one of the processes widely used for hardfacing applications. However, controlling dilution of the deposit by a substrate material is rather difficult in this process and hence it is possible that dilution in the deposits produced by this process could be quite high [5]. 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. This method of surface modification can be used to reinforce local surfaces in machine guide ways and in various wear resistance applications. TIG surface alloying associated with rapid heating and cooling rate provided a unique opportunity for the non-equilibrium synthesis of materials and produced rapidly solidified fine microstructures with extended solid solution of alloying elements [6].
Boride coatings are generally very hard and can be used mainly in tribological applications where good abrasive wear resistance is needed. The coefficient of friction in contacts with boride coatings is generally fairly high. Tribologically interesting boride coatings are titanium diboride and iron boride. Iron boride coatings may be useful as molds for plastic industry, glass technology, forming of plates, etc. because of their peculiar tribological property of giving very low wear and high corrosion resistance at the same time [7].

The conventional thermochemical process for boriding is very slow. Therefore, different welding techniques have been used for surface alloying using pure boron powders or powders containing boron [8]. In recent years, many investigations have been conducted on boron included alloys for hard facing cladding to improve the hardness and wear resistance of industrial parts [9-13]. Borides of niobium are recognized as potential candidates for high-temperature structural applications [14-16], due primarily to their excellent properties such as high melting temperature, high strength, high thermal and electrical conductivity, and good chemical stability [17,18]. Six types of binary niobium borides Nb₃B₂, NbB, Nb₅B₆, Nb₃B₄, NbB₂ and Nb₂B₃ have been reported. The diboride NbB₂ (AlB₂ type, Hexagonal) have high melting point, high hardness, high electric conductivity and superconductivity [19].

The main goal of the study was to investigate the phase analysis, microstructural and mechanical properties of the surface alloyed AISI 1020 steel with ferrous boron, ferrous niobium and iron by TIG welding technique.

2. Materials and Method

The steel with an area of 20 mm x60 mm and a thickness of 5 mm is used as substrate material in the TIG processing experiments in the present study. Its chemical composition in wt% is 0.21% C, 0.18% Si, 0.52% Mn and Fe in balance. Before the surface alloying treatment, 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 boron alloys used in the study (wt%) was as follows: 19.63% B, 0.44 %C, 0.05 %Al, 0.98 %Si, and balance Fe. The nominal composition of ferrous niobium alloys used in the study (wt%) was as follows: 66% Nb, 0.17 %C, 2.67 %Al, 1.65 %Si, and balance Fe. Ferrous boron and niobium were grounded by ring grinder and sieved to be under 45 µm grain size. Fig. 1 shows the scanning electron microscopy (SEM) images of the ferrous boron and ferrous niobium powders used in the surface alloying treatment.
Figure 1. SEM images of (a) ferrous boron and (b) ferrous niobium powders.

Powder mixtures composition used in the surface alloying treatment are Fe$_{13}$B$_7$ and Fe$_{10}$Nb$_3$B$_7$, then the powders mechanically mixed homogeneously in a planetary ball mill using steel balls. The milling was performed at 600 rpm under the ambient atmosphere and the ball-to-powder mass ratio was 3:1. Mechanical mixing was carried out with a period of 2 h. TIG welding was realized by an electric power supply in which the welding torch was moved back and forth at a constant speed. TIG welding was applied to melt the substrate and alloy filler. The welding parameters are listed in Table 1.

Table 1. Experimental Parameters of TIG Welding Surfacing

<table>
<thead>
<tr>
<th>Deposition parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode</td>
<td>Type W-2 pct ThO$_2$</td>
</tr>
<tr>
<td>Electrode diameter</td>
<td>2.4 mm</td>
</tr>
<tr>
<td>Angle</td>
<td>70 degrees</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>20 V</td>
</tr>
<tr>
<td>Current (A)</td>
<td>110 A</td>
</tr>
<tr>
<td>Heat input</td>
<td>2.2 MJ/m</td>
</tr>
<tr>
<td>Shielding gas</td>
<td>Argon (%99.9Ar)</td>
</tr>
<tr>
<td>Gas flow rate</td>
<td>12 l/min</td>
</tr>
<tr>
<td>Welding speed</td>
<td>60 mm/min</td>
</tr>
</tbody>
</table>

Heat input $Q = 60 \times I \times V / S$, $I$: current, $V$: voltage, and $S$: travel speed [20].

An X-ray diffractometer (Rigaku XRD/D/MAX/2200/PC) with Cu K$_\alpha$ radiation was used to analyze the constituent phases in the microstructure. Microstructural examination was performed by optical microscopy (OM) and scanning electron microscope (SEM) to the samples which were replaced in resin, ground on silicon carbide papers to 1200 grit, and then progressively polished with 0.3 \( \mu \)m Al$_2$O$_3$ paste.

The etchant was selected as a 3% Nital. The microstructures of the cross-section of the alloyed layers were observed by using OM (NICKON EPIPHOT) and SEM (JEOL JSM – 6060 LV) analysis, the hardness of the phases formed in the alloyed layers and transition zone and matrix were measured by using Future-Tech FM 700 microhardness tester.

3. Results and Discussion

Surface alloying modification by ferrous boron and ferrous niobium 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. Mixing powders and the substrate surface were melted, showing a clear interface between the melted and steel matrix. The thickness of the hardfacing layer ranged from 2 to
3mm. The melted surface gave a good quality thick coating, porosity free and moderately smooth rippled surface topography. It can be seen that significant structural changes occur by adding the ferro-niobium to powder mixture. As shown from the figures that the surface alloyed layer including boron and iron (Nb free) has the blocky Fe$_2$B phases well distributed. Whereas, surface alloyed layer including Fe, Nb and B has the boride phases which are distributed grain boundaries as blocky phases and eutectics of the borides and iron phases. Niobium boride has small blocky structure in the alloyed layer and well distributed as seen in Figures 2 and 3.

![Figure 2. Optical micrographs of the (a) Fe$_{13}$B$_7$ and (b) Fe$_{10}$Nb$_3$B$_7$ alloy composition](image)

As shown from the figure 3a, iron borides which were detected by EDS analysis formed in the in situ composite structure found in the alloyed layer include primary borides and eutectic colonies as constituent structure. Deniz [21] and Iakovou et al. [22] 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. SEM-EDS observations as seen in figure 3b showed that there are three different forms on the microstructure which were grey forms, dark forms and white blocky and needle forms. EDS analysis showed that the dark and white forms consist of Fe and B elements and Nb, B and Fe (small amount) elements, respectively. Gray color form taken place between white and dark forms might be iron matrix which includes dominantly Fe element.
In order to understand microstructural changes and to correlate with the other results, XRD analysis was performed. Figure 4 shows the XRD spectra of the surface alloyed layers of the steel with Fe$_{13}$B$_7$ and Fe$_{10}$Nb$_3$B$_7$ alloys. The possible phases in the surface alloyed layer consist of $\alpha$-Fe, FeB, Fe$_2$B, FeB$_2$, Nb, NbFeB, and NbB$_2$ phases beside the iron boride phases respectively. The hardness of the boride phases, eutectic colonies took place in the alloyed layer and base metal are 1863±85 HV$_{0.01}$, 867±76 HV$_{0.01}$, and 181±7 HV$_{0.01}$, respectively. As known, the hardness of iron boride phases are changing between 1600 and 2000HV [23]. Conclusively, the hardness of the
boride phases and eutectic structure is very high according to the base steel. The hardness of the boride phases, eutectic colonies took place in the alloyed layer and base metal are 1667±95 HV$_{0.01}$, 665±96 HV$_{0.01}$ and 181±7 HV$_{0.1}$, respectively.

![Figure 4](image-url)  
**Figure 4.** X-ray diffraction analysis of (a) Fe$_{13}$B$_7$ and (b) Fe$_{10}$Nb$_3$B$_7$ alloys.

**Conclusions**

The main conclusions of the study should be summarized as follows:

- The alloyed layers of Fe-B and Fe-Nb-B gave a good quality thick coating, porosity free and moderately smooth rippled surface topography.
- The surface alloyed layer including boron and iron (Nb free) has the blocky Fe$_2$B phases well distributed in the constituent eutectic structure. Whereas, surface alloyed layer including Fe, Nb and B has the boride phases which are distributed grain boundaries as blocky phases and eutectics of the borides and iron phases. Niobium borides have small blocky structure in the alloyed layer and well distributed.
The possible phases in the surface alloyed layer consist of $\alpha$-Fe, FeB and Fe$_2$B, and NbFeB, NbB$_2$ phases beside the iron boride phases.

The hardness of the boride phases, eutectic colonies took place in the alloyed layer and base metal are 1863±85 HV$_{0.01}$ and 1667±95 HV$_{0.01}$, 867±76 HV$_{0.01}$, and 181±7 HV$_{0.1}$, respectively.

REFERENCES


