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

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Abstract :

In the present study, the microstructural and phase analysis of the surface alloyed AISI 1020 steels with $Fe_{13}B_7$ and $Fe_{10}Nb_3B_7$ 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 Fe_2B 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

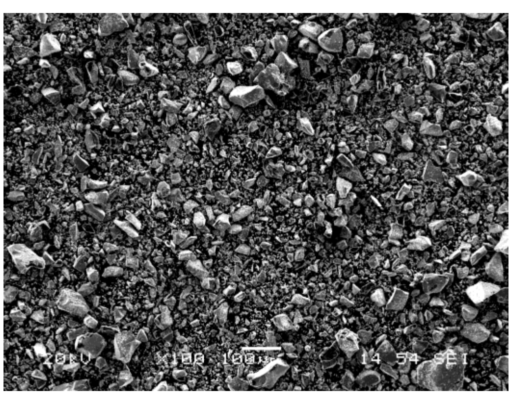
The deposition of surfacing layers by welding techniques, such as tungsten inert gas welding(TIG) [1],shield manual arc welding (SMAW), submerged arc welding (SAW) [2],plasma arc welding (PAW) [3], oxyacetylene welding etc. have been widely applied commercially in a wide range of industries in order 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].

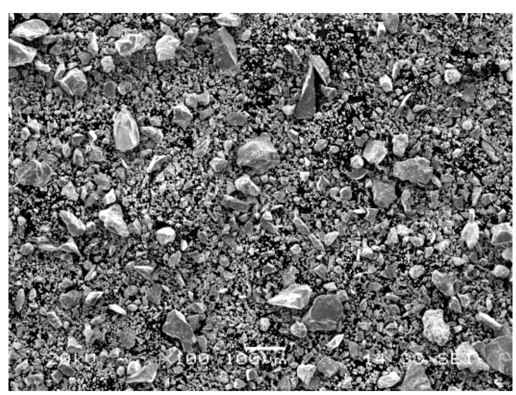
Boride coatings are generally very hard and can be used mainly in tribological applications where good abrasive wear resistance is needed. The coefficient of fraction in contacts with boride coatings is generally fairly high. Tribologically interesting boride coatings are titanium diboride and iron boride. Iron boride coatings may be useful as molds for plastic industry, glass technology, forming of plates, etc. because of in 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 Nb_3B_2, NbB, Nb_5B_6,Nb_3B_4, NbB_2 and Nb_2B_3 have been reported. The diboride NbB_2 (AlB_2 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 surfacealloyed 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 TIGprocessing 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 wereground and cleaned with acetone to remove any oxide andgrease 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 offerrous niobium alloys used in the study (wt%) was asfollows: 66% Nb, 0.17 %C, 2.67 %Al, 1.65 %Si, and balance Fe. Ferrous boron and niobium were grounded byring 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.





(a) (b)

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 $Fe_{10}Nb_3B_7$then the powders mechanically mixedhomogeneously in a planetaryball mill using steel balls. The milling was performedat 600 rpm under the ambient atmosphere and the ball-to-powder mass ratio was 3:1. Mechanical mixing wascarried out with a period of 2 h.
TIG welding was realized by an electric power supplyin which the welding torch was moved back and forthat 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

Deposition parameters	Value
Electrode	Type W-2 pct ThO_2
Electrode diameter	2,4 mm
Angle	70 degrees
Voltage (V)	20 V
Current (A)	110A
Heat input	2,2 MJ/m
Shielding gas	Argon (%99,9Ar)
Gas flow rate	12 l/min
Welding speed	60 mm/min

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

An X-ray diffractometer (Rigaku XRD/D/MAX/2200/PC) with Cu K_α radiation was used to analyze theconstituent phases in the microstructure. Microstructuralexamination was performed by optical microscopy (OM) and scanning electron microscope (SEM) tothe samples which were replaced in resin, ground on silicon carbide papers to 1200 grit, and then progressivelypolished with 0.3 μm Al_2O_3 paste.

The etchant was selected as a 3% Nital. Themicrostructures 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 layersand transition zone and matrix were measured by usingFuture-Tech FM 700 microhardness tester.

3. Resultsand 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 structuralchanges 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_2B 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.

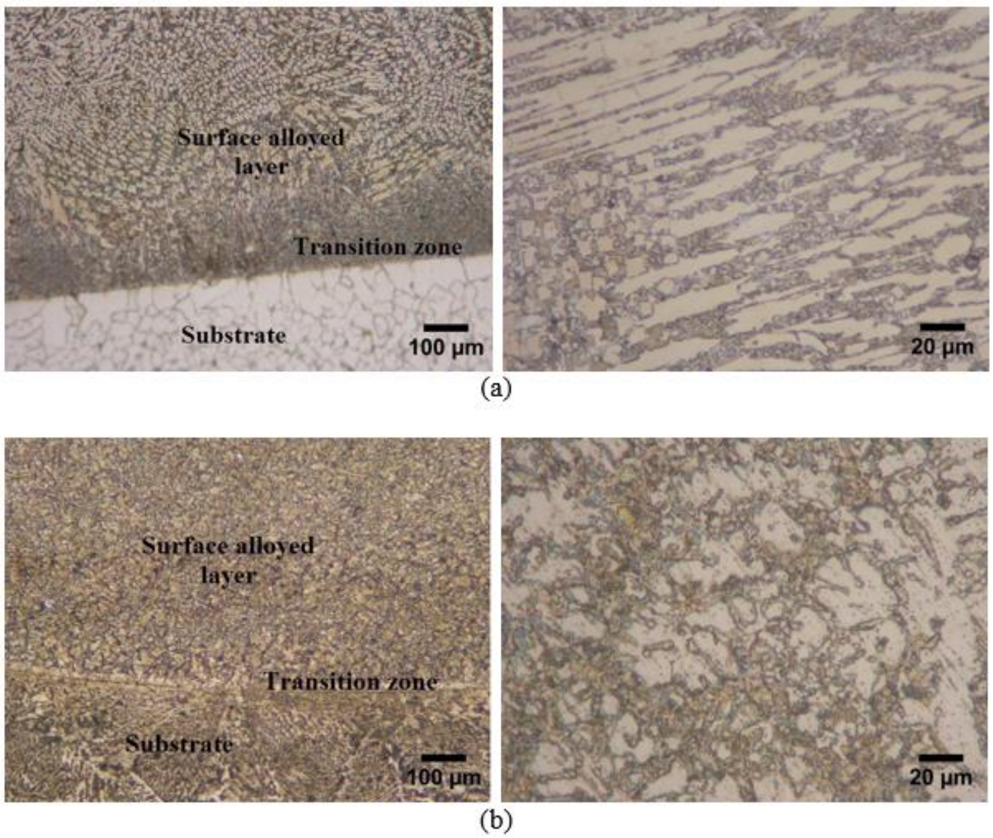
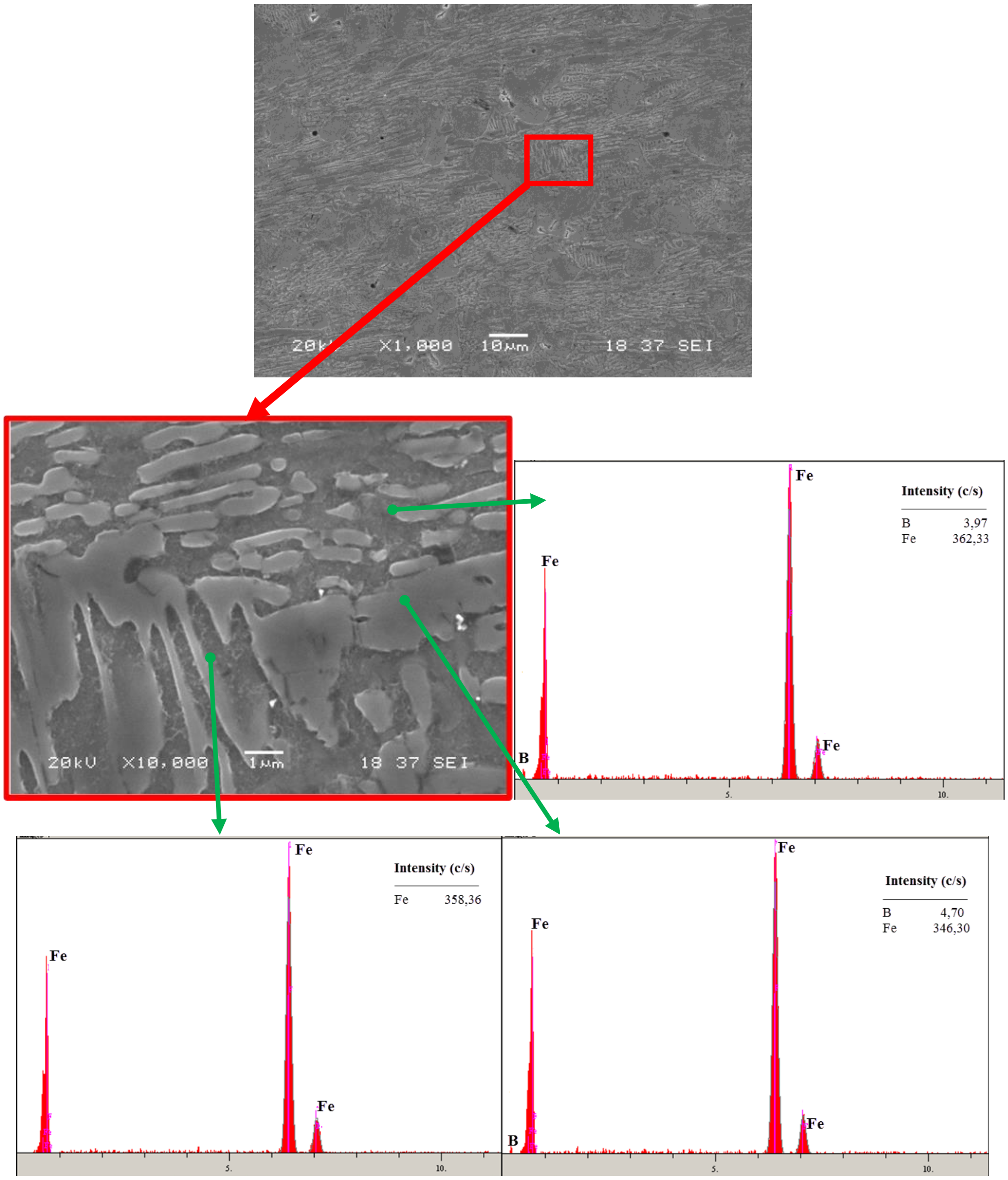
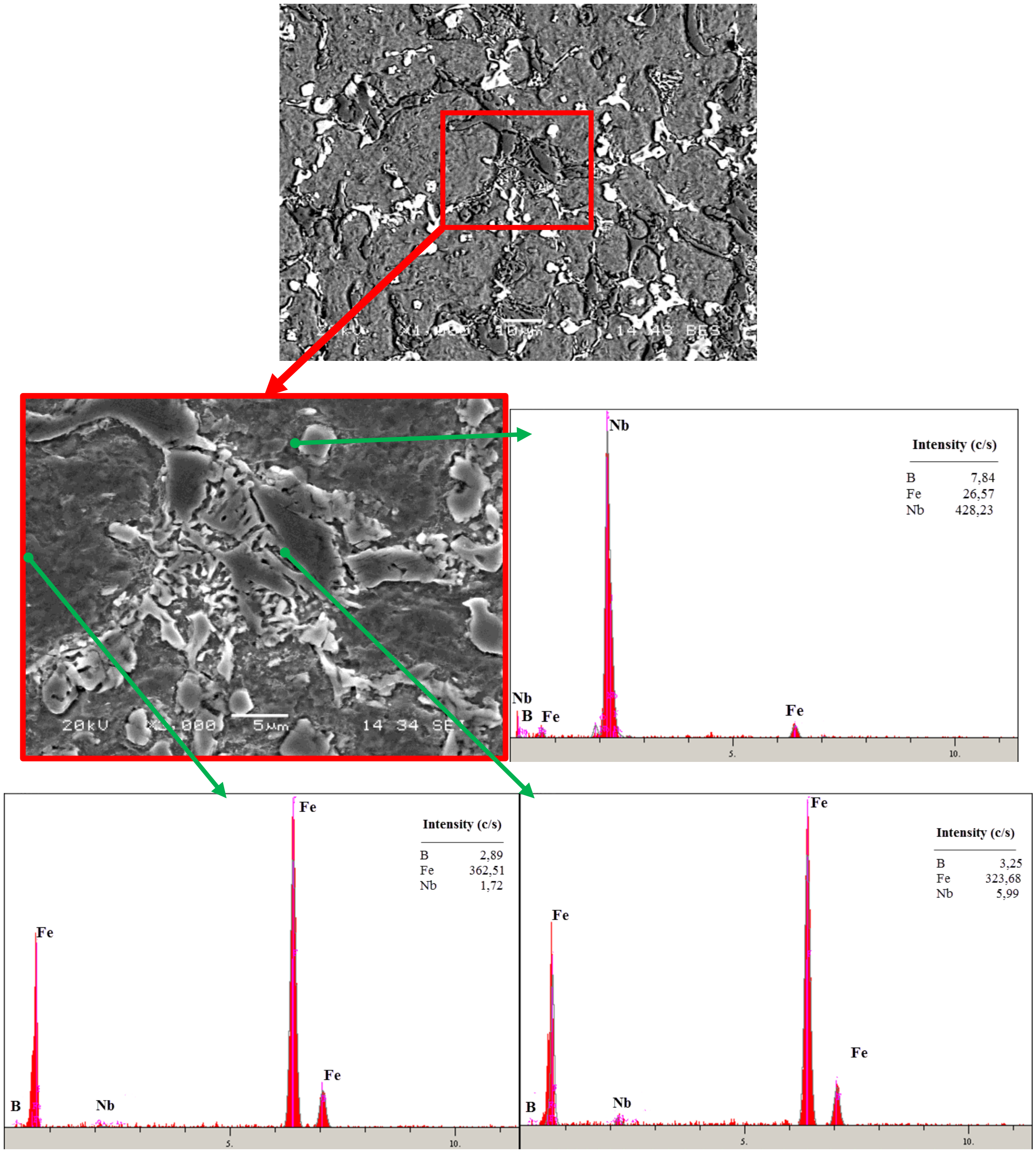


Figure 2. Optical micrographs of the (a) $Fe_{13}B_7$ and (b) $Fe_{10}Nb_3B_7$ alloy composition

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.


20kV X1,000 10µm 18 37 SEI
20kV X10,000 1µm 18 37 SEI
Fe
Intensity (c/s)
B 3,97
Fe 362,33
Fe
B
Fe
5.
10.
Fe
Intensity (c/s)
Fe 358,36
Fe
Fe
5.
10.
Fe
Intensity (c/s)
B 4,70
Fe 346,30
Fe
B
Fe
5.
10.

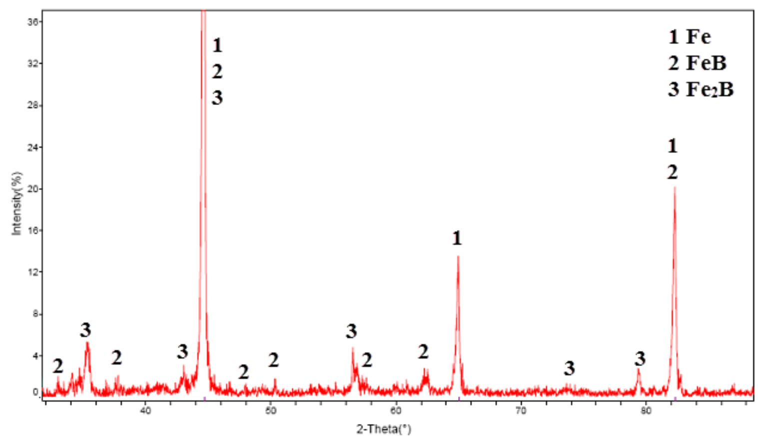
(a)



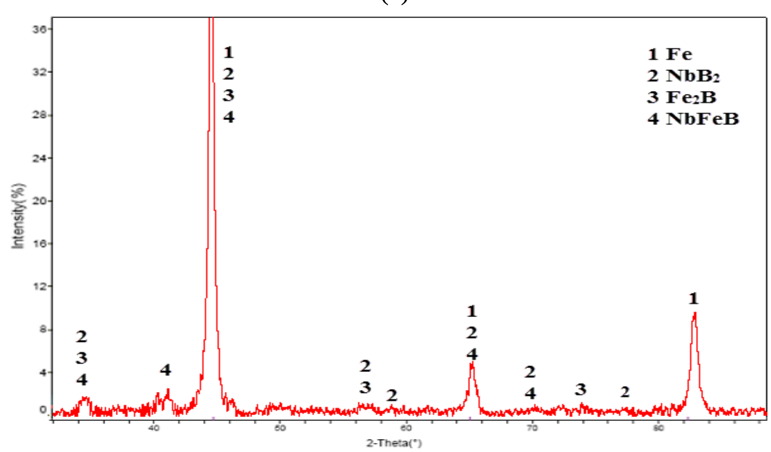
(b)

Figure 3. SEM micrographs and EDS analysis of the (a) $Fe_{13}B_7$ and (b) $Fe_{10}Nb_3B_7$ alloys.

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 $Fe_{10}Nb_3B_7$ alloys. The possible phases in the surface alloyed layer consist of α-Fe,FeB and Fe_2B, FeBand NbFeB, 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 $HV_{0.1}$, 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.



(a)



(b)

Figure 4. X-ray diffraction analysis of (a) $Fe_{13}B_7$ and (b) $Fe_{10}Nb_3B_7$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_2B 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 α-Fe, FeB and Fe_2B, and NbFeB, NbB_2phases 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.

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