

# Characterization of Fe–Nb–B Base Hardfacing of Steel

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Recently hardfacing by welding has become a commonly used technique for improvement of material performance in extreme (high temperature, impact/abrasion, erosion, etc.) conditions. In the present study, three different alloy compositions of the Fe–Nb–B were used for hardfacing of the AISI 1020 steel by tungsten inert gas welding process and analyzed. The coatings were produced from a mixture of ferrous niobium, ferrous boron and iron powders in the range of  $-45\ \mu\text{m}$  particle size with different ratio. The coatings' thickness was set to 2–3 mm on the substrate. Microstructure, phase analysis and hardness of the manufactured hardfacing alloys were characterized. Deposition results indicate good quality thick coating and porosity free of the hardfacings. X-ray diffraction analyses showed that the alloyed layers include iron borides, FeNbB and iron phases. It was shown that surface alloyed layer has composite structure including steel matrix and well distributed boride phases.

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## 1. Introduction

Recently hardfacing by welding has become a commonly used technique for improvement of material performance in extreme (high temperature, impact/abrasion, erosion, etc.) conditions [1–3]. 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 [4–7]. Welding is a key technology to fulfill these requirements and to apply hardfacing alloys.

The most common processes are tungsten inert gas (TIG) [8], gas tungsten arc (GTA) [9], plasma transferred arc (PTA) [10], oxyacetylene welding (OAW), gas metal arc welding (GMAW), shielded metal arc welding (SMAW), and submerged arc welding (SAW) [11].

The TIG process has been used in a number of ways to modify the properties of steel surfaces, in which one can produce surfaces with desirable properties on relatively low-cost substrate materials. Several researches associated with the TIG method have been conducted [9, 12]. In the TIG process, which uses a nonconsumable tungsten electrode and an inert gas for the arc shielding, an electric arc is established between a tungsten electrode and the part to be welded [13]. To start the arc, high voltage breaks down the insulating gas between the electrode and the workpiece. Current is then transferred through the electrode to create an electrode arc. The metal to be welded is melted by the arc's intense heat and fuses together.

GTA surface modification by means of alloying is a process in which an alloy powder of a desirable composition and a thin surface layer of the substrate material are melted and then rapidly solidified to form a dense coating metallurgically bonded to the base material. A coated

surface obtained by the GTA technique has a potential to produce a fine microstructure with high hardness and wear resistance for synthesis onto various substrate materials.

Advances in surface modification of materials can be also achieved with GTA synthesis [8, 14, 15]. 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 [16]. 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 [17, 18].

PTA as a unique heat source for surface modification exhibits an enormous potential because of its low cost, easy operation and no need in a special surface treatment. Single or multilayer depositions provide strong metallurgical bonding between the deposit and the base metal, as well as porosity-free coating and relatively low dilution with substrate. In the PTA process, the heat of the plasma (arc of ionised gas) is used to melt the surface of the substrate and the welding powder, where the molten weld pool is protected from the atmosphere by the shielding gas [19]. While there is a great deal of study about surface hardening processes of boron containing

steel and alloys [7, 8, 11], there is not any study about the Fe-Nb-B alloys used for surface alloying treatments.

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

## 2. Experimental procedure

The steel with an area of 20 mm × 60 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 0.18% C, 1.37% Mn, 0.20% Si, and Fe in balance. 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 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. Powder mixtures composition used in the surface alloying treatment are Fe<sub>3</sub>B<sub>2</sub>, Fe<sub>11</sub>NbB<sub>8</sub>, and Fe<sub>5</sub>NbB<sub>4</sub> and then the mixtures mechanically alloyed 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 5:1. Mechanical alloying 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. GTA welding was applied to melt the substrate and alloy filler gas (99.9% argon) tungsten arc processing was used to perform the experiments with a DC current (110 A). The electrode was type W-2 pct ThO and the electrode diameter was 2.4 mm. The welding process speed was 60 mm/min, the gas flow rate was 12 l/min, and the distance between the torch nozzle and deposited powder was 3–5 mm.

An X-ray diffractometer (Rigaku XRD/D/MAX/2200/PC) with Cu K<sub>α</sub> radiation was used to analyze the constituent phases in the microstructure. Metallographic analysis was performed by optical microscope to the samples which were replaced in resin, ground on silicon carbide papers to 1200 grit, and then progressively polished with 0.3 μm Al<sub>2</sub>O<sub>3</sub> paste. The microstructure of the samples was revealed by a solution of 10 g FeCl<sub>3</sub>·6H<sub>2</sub>O 30 ml HCl, and 120 ml distilled water. The microstructures of the cross-section of the alloyed layers were observed by using optical microscope (NICKON EPIPHOT), the hardness of the phases formed in the alloyed layer and transition zone and matrix were measured by using Future Tech FM 700 microhardness tester.

## 3. Results and discussion

Figure 1a–c shows optical micrographs of the different composition Fe-Nb-B base surface-alloyed specimens fabricated by TIG welding. Ferrous boron and niobium and iron powders with different ratio and a thin layer of the substrate surface were melted 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 the unmelted regions. The thickness of the hardfacing layer ranged from 2 to 3 mm. The melted surface gave a good quality thick coating, porosity free, and smooth rippled surface topography. Microstructures of the Fe-Nb-B base 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 in the eutectic matrix well distributed, and different structures like cuboids, globular borides, and late morphology. As seen in Fig. 1, borides formed in the *in situ* composite structure found in the alloyed layer include primary borides and eutectic colonies between borides. Deniz et al. [8] and Iakovou et al. [7] 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.

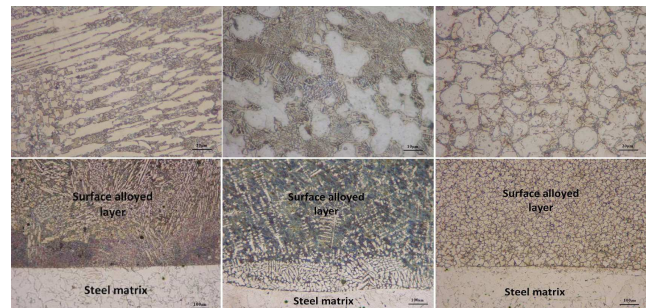


Fig. 1. Cross-sectional micrographs of hardfacing layer.

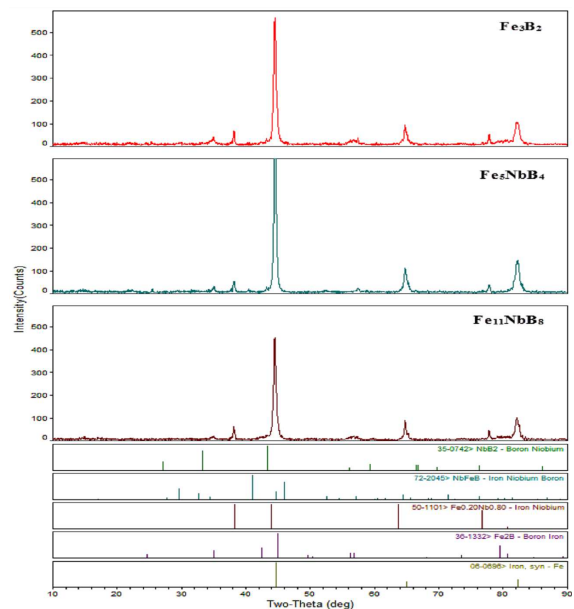


Fig. 2. X-ray patterns of the hard faced surface layers on steel.

Figure 2 shows the XRD patterns of the Fe–Nb–B base alloyed (hard faced) surface layers of the steel. The phases in the surface alloyed layer consist of Fe solid solution, Fe<sub>2</sub>B, NbB<sub>2</sub>, NbFeB and Fe<sub>0.2</sub>Nb<sub>0.8</sub> phases. The hardness of the boride phases, eutectic colonies took place in the alloyed layer; transition zone and base metal are  $1689 \pm 85$  HV<sub>0.01</sub>,  $867 \pm 76$  HV<sub>0.01</sub>,  $387 \pm 42$  HV<sub>0.1</sub>, and  $181 \pm 7$  HV<sub>0.1</sub>, respectively. As known, the hardness of iron boride phases is changing between 1600 and 2000 HV [13]. Conclusively, the hardness of the boride phases and eutectic structure is very high according to the base steel.

#### 4. Conclusions

The hardfacing was successfully synthesized by tungsten inert gas TIG processing of steel with Fe<sub>3</sub>B<sub>2</sub>, Fe<sub>11</sub>NbB<sub>8</sub>, and Fe<sub>5</sub>NbB<sub>4</sub> alloy composition powders. The results of this investigation can be summarized as follows:

- A thickness of the hardfacing layer of 2–3 mm was coated on steel by the TIG process.
- The hard faced surface gave a good quality thick coating, porosity free, and smooth rippled surface topography. The microstructure of the alloyed surfaces consists of boride phases in the eutectic matrix well distributed and different structures like cuboids, globular borides, and late morphology.
- The phases formed in the alloyed layers are Fe<sub>2</sub>B, NbB<sub>2</sub>, NbFeB, Fe<sub>0.2</sub>Nb<sub>0.8</sub>, and Fe.
- The hardness of the boride phases, eutectic colonies took place in the alloyed layer; transition zone and base metal are  $1689 \pm 85$  HV<sub>0.01</sub>,  $867 \pm 76$  HV<sub>0.01</sub>,  $387 \pm 42$  HV<sub>0.1</sub>, and  $181 \pm 7$  HV<sub>0.1</sub>, respectively.

#### References

- [1] A. Zikin, M. Antono, I. Hussainova, L. Katona, A. Gavrilovic, *Tribol. Int.* **68**, 45 (2013).
- [2] C. Katsich, E. Badisch, *Surf. Coat. Technol.* **206**, 1062 (2011).
- [3] E. Badisch, M. Kirchgaßner, *Surf. Coat. Technol.* **202**, 6016 (2008).
- [4] H. Berns, A. Fischer, *Metallography* **20**, 401 (1987).
- [5] J.W. Yoo, S.H. Lee, C.S. Yoon, S.J. Kim, *J. Nucl. Mater.* **352**, 90 (2006).
- [6] J.H. Kim, H.S. Hong, S.J. Kim, *Mater. Lett.* **61**, 1235 (2007).
- [7] R. Iakovou, L. Bourithis, G. Papadimitriou, *Wear* **252**, 1007 (2002).
- [8] G. Deniz, S. Sen, U. Sen, in: *63rd Annual Assembly and Int. Conf. of the International Institute of Welding*, Ed.: M. Kocak, Gedik Education Foundation, Istanbul 2010, p. 207.
- [9] M.H. Korkut, O. Yilmaz, S. Buytoz, *Surf. Coat. Technol.* **157**, 5 (2002).
- [10] A. Zikin, I. Hussainova, C. Katsich, E. Badisch, C. Tomastik, *Surf. Coat. Technol.* **206**, 4270 (2012).
- [11] M. Kirchgabner, E. Badisch, F. Franek, *Wear* **265**, 772 (2008).
- [12] S. Buytoz, M. Ulutan, M.M. Yildirim, *Appl. Surf. Sci.* **252**, 1313 (2005).
- [13] S.C. Juang, Y.S. Tarng, *J. Mater. Process. Technol.* **122**, 33 (2002).
- [14] Yu.C. Lin, S.W. Wang, Y.C. Lin, *Surface* **200**, 2106 (2005).
- [15] Y.C. Lin, S.W. Wang, *Wear* **256**, 720 (2004).
- [16] S. Buytoz, *Surf. Coat. Technol.* **200**, 3734 (2006).
- [17] Y.P. Kathuria, *Surf. Coat. Technol.* **132**, 262 (2000).
- [18] J.S. Selvan, K. Subramanyán, A.K. Nath, *J. Mater. Process. Technol.* **91**, 29 (1999).
- [19] A. Zikin, S. Ilo, P. Kulu, I. Hussainova, C. Katsich, E. Badisch, *Mater. Sci.* **18**, 12 (2012).