Characterization of Fe-Nb-V-B Base Hard Surface Alloyed Steel

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Abstract

In this study, surface alloying treatment with iron, niobium, vanadium and boron on the AISI 1020 steel was performed by the technique of Tungsten inert gas (TIG) welding. The surface alloying was produced from a mixture of ferrous boron, ferrous niobium, ferrous vanadium and iron powders in the range of 75 μm particle size with different ratio. The alloy composition was prepared to be composed of Fe10Nb2VB7. The prepared powder mixture was mechanically pressed on the steel substrate and melted by TIG welding for hard facing. The coating thickness was set to be 2-3 mm on the substrate. Coated layer formed on the steel substrate was investigated using by optical and scanning electron microscopy, Energy dispersive spectroscopy attached to SEM, X-ray diffraction analysis and Vickers micro-hardness tester. The surface alloying results showed that good quality thick coating layer and porosity free hardface. X-ray diffraction analyses showed that the alloyed layer includes borides of iron, vanadium, niobium and iron phases. It was shown that the surface alloyed layer has a composite structure containing homogeneously dispersed boride phases in the steel matrix.

1. Introduction

With advancing technology, surface engineering is getting more and more important. For this reason, studies on increasing the performance of the metallic materials by changing their surface properties are increasing with new methods and techniques [1]. Among these methods, hard surface alloying has a wide range of applications. Hard surface alloying process is easily applied to steel surface by techniques such as tungsten inert gas (TIG) [2], plasma arc welding (PAW) [3], submerged arc welding (SAW) shield manual arc welding (SMAW), oxyacetylene welding [4]. Among these techniques, the TIG welding method has a wide range of applications in the industry, with advantages such as moderate deposition rate, low cost and compatibility with a wide variety of materials [5-8].

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 an extended solid solution of alloying elements [9, 10]. 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 [11].

Complex Fe-based alloys with titanium, niobium, molybdenum and vanadium in combination with carbon and boron gained importance by achieving wear resistance due to the precipitation of different abrasion resistant hard phases and by optimized matrix properties [4]. The conventional thermo-chemical process for boriding is very slow. Therefore, different welding techniques have been used for surface alloying using pure boron powders or powders containing boron [12]. In recent years, many investigations have been conducted on the boron included alloys for hard facing cladding to improve the hardness and wear resistance of industrial parts [13-17]. While there is a great deal of study about surface hardening processes of boron containing steel and alloys, but there is not any study about the Fe-Nb-V-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, ferrous vanadium, ferrous boron and iron by TIG welding technique.

2. Experimental Procedure

In this study, steel with chemical composition % is 0.18% C, 1.37% Mn, 0.20% Si and Fe (balance) (by wt.) was used as a substrate material. Before the coating, these plates were sectioned to be dimensions of 30x70x5 mm and their surfaces were cleaned mechanically and ultrasonically. Ferrous niobium, ferrous boron, ferrous vanadium and pure iron powders are used as hard surface alloy materials. For this reason, ferrous alloys taken in rock form have been subjected to crushing, grinding and sieving processes to be less than 75 μm. Pure iron powder is only subjected to sieving. The surface alloying powder mixture was prepared by using a ball mill for 2 hours at 200 rpm from the ground ferrous boron niobium and vanadium powders and iron (75 μm) to be 50%Fe- 10%Nb- 5%V- 35%B (by at.).

The prepared powders were pressed on the steel substrate under the pressure of 100 MPa. Then the surface alloy powders and the substrate were melted together by the TIG welding method and the hard surface alloying process was
completed. After hard surface alloying treatment, the samples were subjected to sandblasting to remove the remains and dross from the surface. The coating parameters applied to the surface coating process with TIG methods are shown in Table 1.

Table 1. Experimental Parameters of TIG Surface alloying.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode Type</td>
<td>W-2 pct ThO₂</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</td>
<td>20 V</td>
</tr>
<tr>
<td>Current</td>
<td>110 A</td>
</tr>
<tr>
<td>Heat input</td>
<td>12.3 kJ/cm</td>
</tr>
<tr>
<td>Protective gas Type</td>
<td>Ar (%99.9 Ar)</td>
</tr>
<tr>
<td>Flow</td>
<td>12 L/min</td>
</tr>
<tr>
<td>Welding speed</td>
<td>Travel speed 1.16 cm/s</td>
</tr>
</tbody>
</table>

Heat input Q = \eta U I / (V x 1000) (kJ/cm); U: voltage (V), I: current (A), V: travel speed (cm/s), \eta = efficiency coefficient (\eta = 0.65 for the TIG method) \[18\]

After metallographic preparation of hard surface alloyed specimens, microstructural studies were carried out with Nikon Epiphot 200 optical microscope (OM) and JEOL JSM – 6060 scanning electron microscope (SEM). An X-ray diffractometer (Rigaku XRD/D/MAX/2200/PC) with Cu Kα radiation was used to analyze the constituent phases realized in the microstructure. The hardness of the phases formed in the alloyed layer, transition zone and matrix were measured under 0.1 N load by using Future Tech FM 700 micro-hardness tester.

3. Results and Discussion

As a result of the microstructural studies of the surface alloyed layer formed on the steel to be Fe₁₀Nb₂VB₇ composition, it is seen that the thickness of the hard coated layer is about 2 to 3 mm (see, Fig. 1). It has been determined that sharp separation line was formed between alloyed layer and steel matrix (Fig. 1(a)). These are (i) \(\alpha\)-Fe and two different phases of borides layers namely FeNbB and \(M₂B\) (\(M:Fe,V\)) in the surface alloyed layer, (ii) separation line, and (iii) steel matrix. EDS analysis marked as 1 and 2 on the SEM micrograph showed that white colored phases includes Nb and Fe beside B, see Fig.3 (a and b). These EDS analyses support the FeNbB phase determined by XRD analysis. Light gray matrix phases include Fe element beside small V and Nb pics which indicate that the matrix Fe-Nb-V solute solutions. Dark gray phase took place in the eutectic morphology includes Fe and V and small B peaks which indicate that \(M₂B\) (\(M:Fe,V\)) phases as determined in the XRD analysis. Coga et.al study showed that FeNbB phase and \(Fe₂B\) phase realized in the Fe-Nb-Cr-B included surface alloyed AISI 430 steel realized by flame spray which is an other surface alloying treatment method \[19\]. The study supports the present study results. Earlier study of Kilinc et.al showed that FeNbB and \(Fe₂B\) boride phases formed in the surface alloyed layer realized by the alloy composition which includes Fe-Nb-B, similarly \[20\]. In addition these, In the study of Fernandes et al., surface alloying with Fe-Nb-Si-B based metallic glass on AISI 1020 steel was performed and FeNbB and \(Fe₂B\) phases were similarly detected in the resulting surface alloy layer \[21\]. As shown from the studies that Fe-Nb-B includes alloys presents the FeNbB and \(M₂B\) phases in the alloyed layer.
The hardness values of the boride phases of FeNbB and M2B in the eutectic colonies, separation line and substrate material in the Fe-Nb-V-B based hard surface alloyed region formed on the steel surfaces with TIG welding were 2804±150 HV0.01, 995±47 HV0.01, 407±49 HV0.01 and 181±7 HV0.01, respectively. As a result, the hardness of the boride phases and the eutectic structure was found to be higher than that of the hardness of the base metal. As known, the hardness of metal (Fe, Nb, V) borides are changing between 1800-3700HV [22,23].

4. Conclusion

The surface alloying treatment was successfully realized by tungsten inert gas processing on the steel with Fe10Nb2VB7 alloy composition powders. The results as follows:

1. Surface alloying process was realized on AISI 1020 steel substrates by TIG welding, successfully.

2. The alloyed layer was porosity free and moderately smooth rippled surface topography.

3. The alloyed steel includes three different regions which are surface alloyed layer which includes Fe, B, Nb and V, separating line and steel matrix.

4. The surface alloyed layer includes primary α-Fe, FeNbB and M2B borides in an eutectic structure together with primer α-Fe phase.

5. The hardness of the FeNbB and M2B boride phases took place in the eutectic colonies, separation line (transition zone) and steel matrix are 2804±150 HV0.01, 995±47 HV0.01, 407±49 HV0.01, and 181±7 HV0.01, respectively.

References