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EVALUATION OF THE APPLICATION OF BORON-BASED COATINGS ON AISI 1020 STEEL BY SMAW

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Abstract. *The application of hard coatings by engineering has significantly improved the life cycle of parts and equipment in the metal-mechanical industry. Its main advantage is increased wear resistance. Several welding processes are capable of producing these types of coatings. One of these is the SMAW process, characterized by being portable, low-cost, and highly versatile. Based on this, this study sought to combine surface engineering with welding engineering in an attempt to obtain a boron-rich coating through SMAW welding deposition. This research consisted of first carrying out a dilution test to obtain an initial parameterization. In sequence, four AISI 1020 steel sheets were cut, cleaned and four 1 mm deep channels were produced on them. To these was added a powdered agent containing boron. The addition of this agent was intended to increase the surface hardness of the samples and make them resistant to abrasive wear. Subsequently, welding was carried out with currents of 60 and 80 A. To characterize the coatings, visual characterizations were carried out through the liquid penetrant test and microstructural characteristics through optical microscopy. The results pointed to an inability to produce boron-based coatings using SMAW, due to the high presence of porosities and cracks, resulting from segregation problems during solidification.*

Keywords: *Coatings; Boron; SMAW.*

1. INTRODUCTION

Surface engineering has a wide spectrum of techniques that aim to improve the mechanical properties of metallic alloys, with the most diverse objectives, such as improvement of resistance to wear: abrasive, erosive, and corrosion.

Heck (2010), explains that surface alteration treatments can be defined as processes in which the material surface is modified to present properties that the material did not previously have. Both the substrate and the surface coating are developed to work together, achieving better properties, as each of them can't be achieved separately.

The functional modification of surfaces is in many cases the best way to control the tribological damage of a component (Straffelini, 2015). As a way of trying to reduce the wear and tear of these materials, several authors embrace the idea of using coatings, with their application in the most diverse sectors of industry. For the production of coatings, a large number of deposition techniques are available, some with a deposition capacity of a few micrometers to techniques capable of depositing several millimeters of coating (Budinski, 2014).

From these concepts, it can be said that in many cases it is possible to choose a less noble material or one with a lower cost and apply modifications or surface treatment so that it resists the requests in service that it naturally would not resist. Surface coatings play a key role in extending the cycle life of materials, parts, and components that will wear out during the equipment operation process. These coatings are customized for different modes of application, playing roles where the base materials are inefficient or simply do not have the appropriate properties for certain wear situations (Freire Júnior, 2012).

Eroglu (2009), points out that coatings applied to welding technology refer to the deposition of a filler metal on a base metal (substrate) to impart some desired property to the surface that is not intrinsic to the underlying base metal.

Coatings by welding have some advantages, such as improvement of surface properties at the desired location, quick application of the coating process, economical use of alloying elements with high costs, protection of parts, reduction of maintenance, replacement, and recovery of worn parts and use of low-cost materials and increased efficiency of components (Gomes, 2010).

The hard coating is pointed out by Srikarun et al. (2019) as an attractive option due to its simplicity and economy. He comments that with an adequate selection of coating materials, the production cost can be significantly reduced, considering the possibility of using low-alloy steels as the base metal.

Several welding techniques can be used to produce hard coatings, such as oxy-acetylene welding (OAW), gas metal arc welding (GMAW), shielded metal arc welding (SMAW), plasma transferred arc welding (PTAW), laser beam welding (LBW) and submerged arc welding (SAW)(Carvalho et al., 2016; Oo and Muangjunburee, 2018).

SMAW is the most economical, portable, and robust welding process that uses the power source, electrode holder, and electrode to weld metals. It is successfully used in the welding of ferrous metals (Baghel, 2022). Although the SMAW technique is considered to have low productivity, its use is recurrent in industries such as nuclear, aerospace, automotive, naval, transport, and offshore (Rathi, 2015; Khurshid et. Al, 2012; Liu, 2013).

The great versatility of the coated electrode makes it still a great competitor among the various types of welding. Since its use is still recurrent within important industrial branches, with it, it is possible, through the components of its flux, to add alloying elements in the weld bead (Kumar et. al, 2023). Buchanan (2009), for example, successfully used SMAW and Arc spray techniques to produce Fe-Cr coatings on gray cast iron discs.

The coatings produced by SMAW even showed lower values of porosity or inclusions compared to the arc spray technique. The dilution rate in welding is a percentage analysis measure represented by the ratio between the molten mass of the base metal over the total mass of the weld bead, which can be measured by the relationship between the corresponding areas (Holanda and Rebouças Filho, 2019).

Generally, in applications involving overlay welding, it is necessary to minimize the dilution rate, which can be done by modifying the welding parameters such as the advance speed, the current used, and the electrode applied, among others (Nadezhdin and Davison, 2004). To exemplify the importance of the dilution rate, Coronado et. al. (2009) explains that for the application of a single deposited coating layer, high levels of dilution reduce wear resistance.

Kanjilal et al. (2006), concluded that the width of the weld and the height of the reinforcement play important roles for the qualities and properties of the weld. They found that varying voltage and welding speed did not have much effect on depth of penetration and height and current of reinforcement had the greatest effect on depth of penetration.

Therefore, this study aims to evaluate the production of boron-based hard coatings using the SMAW technique. The characterization of the coatings was based on the analysis of visual aspects, non-destructive tests and microstructure analysis.

2. EXPERIMENTAL PROCEDURES

For the experimental procedure, an AISI 1020 steel plate was used. A low-carbon steel was chosen due to its good weldability and mechanical properties that could highlight any performance gains of this steel when coated.

Firstly, nine flat bars with rectangular shapes measuring approximately 150 mm × 60 mm to eliminate solid, liquid, and pasty impurities from the substrate, such as grease, scale, and oxides, in addition to promoting better electrical contact between the sample and the equipment. For this, the surface of the plates was prepared by sanding with an 80-grit flap disc and subsequently cleaning with alcohol.

Subsequently, surface weld beads were produced in position 1G on plates without joint preparation, using a Merkle Balmer welding source, model Super 260 Generation 4, with an AWS E6013 coated electrode of Ø 2.5 mm. Three different currents were used, 60 A, 80 A, and 100 A, and 3 samples were produced for each current. As the SMAW process was carried out manually, the average welding speed for making the beads was 4.5 mm/s.

After producing the weld beads, the macrostructure characterizations were carried out. For this, the samples underwent metallographic preparation following (ASTM E3 − 11, 2011). This included the steps of cutting, grinding, polishing, and etching the samples with a 3% Nital solution for 3 seconds.

Sanding was carried out on a four-way manual sander with 80, 240, 400, 600, and 1200 mesh sandpaper. For the polishing stage, a metallographic polisher from the Teclago, model PVV, with alumina suspension with a particle size of 1 μm was used.

Macrographic analyses were carried out to observe aspects of the macrostructure and mainly to measure the percentage of dilution. For this analysis, a trinocular stereoscope with 0.8 x magnification and the Image J software was used to measure the penetration and filler metal areas.

To calculate the dilution, the methodology adopted by Srikarun et al. (2019), according to the scheme shown in Figure 1. This methodology consists of measuring the bead filling area and the penetration area in the fused zone and applying Eq. (1).

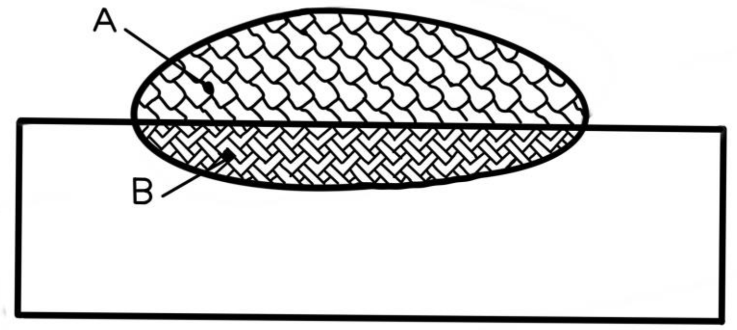

Figure 1: Schematic dilution measurement.

$$Dilution\ (\%) = \frac{Area\ B}{Area\ A\ +\ Area\ B} * 100, \qquad (1)$$

where Area B are the penetration area, and Area A were the bead filling area.

After the pre-tests, 6 AISI 1020 steel sheets were cut, approximately 150 mm long, 22 mm wide, and 12 mm thick. Four grooves were produced on the sheets with a depth of approximately 1 mm. A powder agent containing 5%wt B4C, 5%wt KBF4, and 90%wt SiC was added to these grooves and subsequently, weld beads were produced with 60 and 80 A, with an AWS E6013 electrode with a diameter of 2.5 mm. The choice of these two currents was based on the criterion of having the lowest dilution values, a situation described by other authors as the most favorable for the production of hard coatings.

After producing the coatings, visual inspections and surface quality control were carried out using the penetrating liquid technique to identify surface discontinuities, such as porosities, cracks, and undercuts.

After non-destructive testing, microstructural analysis was performed using the metallography technique following (ASTM E3 − 11, 2011). The Insize ISM-M1000 optical microscope and the ScopePhoto3.0 software, both from UFGD, were used.

3. RESULTS AND DISCUSSION

The pre-tests that consisted of dilution analysis can be seen in Figure 2, and in Table 1 we can see the average values and standard deviation of the dilution rates. As pointed out in the literature, the dilution rates behaved proportionally to the current increases, with a small difference between the 60 and 80 A currents, with values of 41.24 ± 1.35 % and 41.76 ± 2.21 %, respectively and in a more significant way for the samples welded with 100 A, whose value was 44.46 ± 1.75 %.

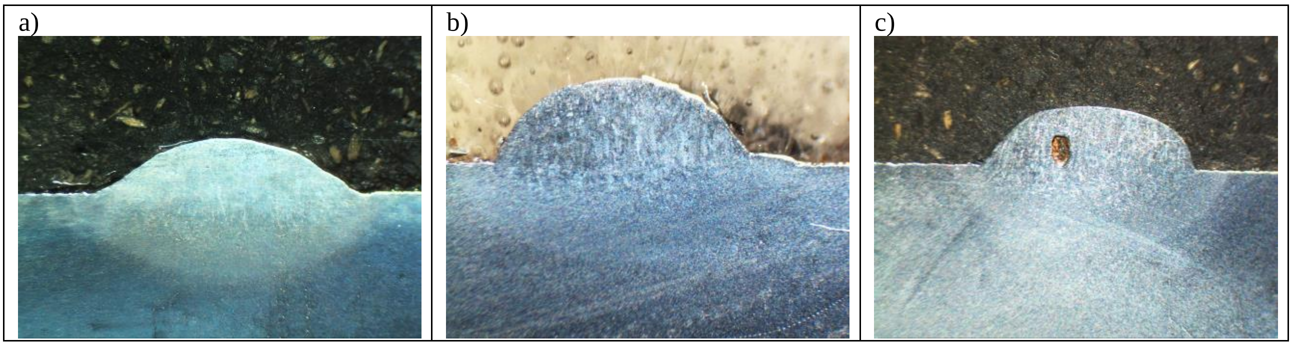

Figure 2: Macrographs (0,8X), a) 60 A; b) 80 A and c) 100 A

Table 1: Dilution rates (%)

Sample	Average dilution rate
60 A	41,24 ± 1,35
80 A	41,76 ± 2.21
100 A	44,46 ± 1.75

After the dilution results, currents of 60 and 80 A were chosen for the production of the coatings, as there was no significant difference in the dilution rate between them.

Once the coatings had been produced, their surface quality was checked as shown in Figure 3. In one of the samples welded with 60 A (3a), the following defects were identified: entrapment of gas bubbles, in addition to the presence of porosities in the weld bead in the lower part of the sample.

In Figure 3 (b), in a sample also welded with 60 A, the defects identified were similar, namely: porosity, craters, slag inclusion, spatter on the base metal, and gas bubbles.

In Figures 3 (c) and (d), similar defects appeared throughout the coating. The samples welded at 80 A demonstrated a higher amount of spatter, showing that with a slightly higher current value, there is greater reactivity of the boron-containing powder, leading to a more explosive type of metal transfer. The adhered slag occurred due to the presence of metallic or non-metallic particles, being from the electrode or the flux retained in the molten zone with a high melting point. When solidification occurs, the inclusions are retained inside the molten zone. Slag inclusions, as well as porosities, can act as stress concentrators, favoring the initiation of cracks.

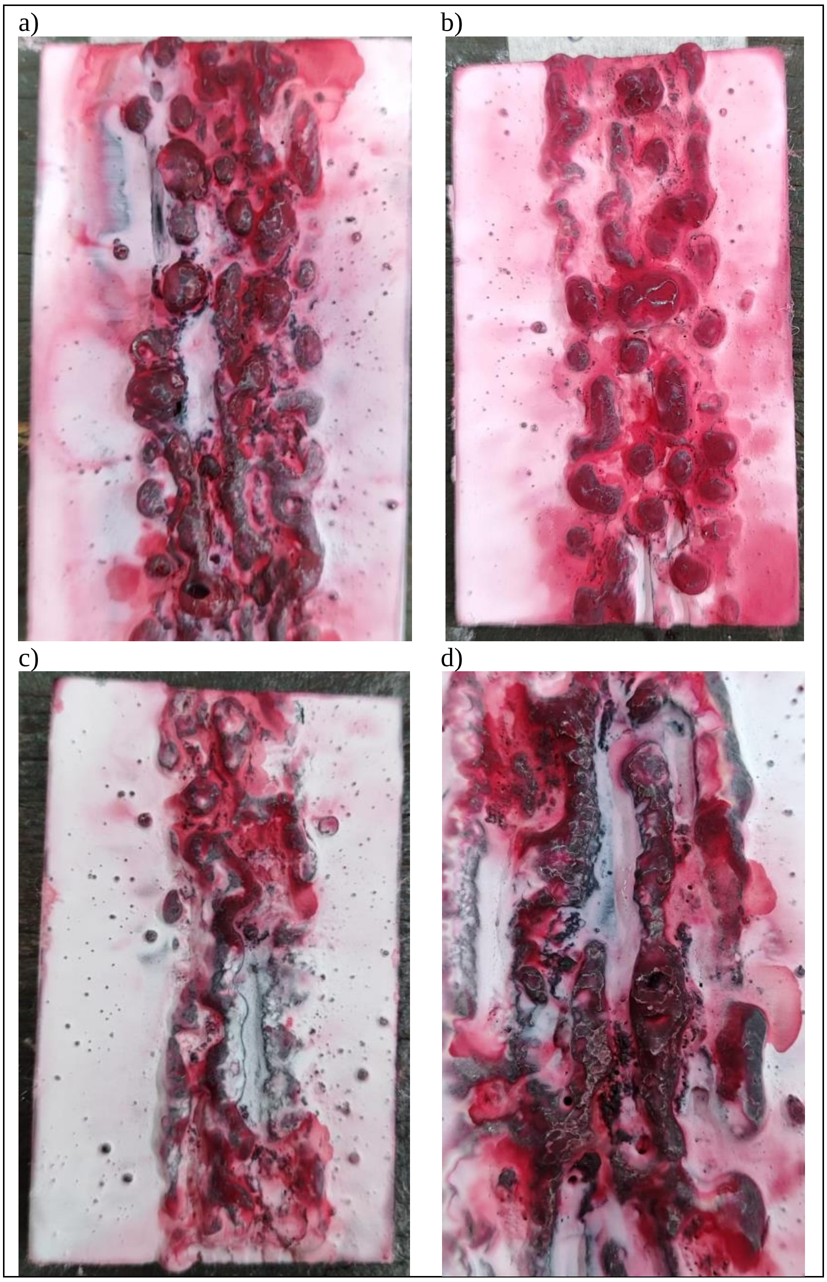

Figure 3: NDT's testing, a) and b) 60 A; c) and d) 80 A samples.

Modenesi et. al (2012), points out that depending on the degree of deoxidation of the molten metal at the tip of the coated electrode or the presence of external components, gas bubbles can form at the tip of the electrode, causing explosive metallic transfer of small drops of molten metal.

After the non-destructive analysis, microstructural analysis was carried out to verify whether the discontinuities presented continued into the weld bead.

Figure 4, shows the fusion zone of one of the samples welded at 60 A. Several microcracks can be seen more clearly from the region close to the heat-affected zone to close to the surface. This type of crack, associated with coatings with the presence of boron, has already been discussed by Pollnow (2016), after welding AISI 1020 steel with the presence of a borid layer, the author identified similar cracks, indicating the discontinuity as solidification cracks, caused by boron segregation in the fusion zone.

Furthermore, a typical microstructure of a fusion zone for AISI 1020 steel after welding is observed, with the presence of ferrites, mainly acicular and grain contour, aligned to the direction of heat extraction.

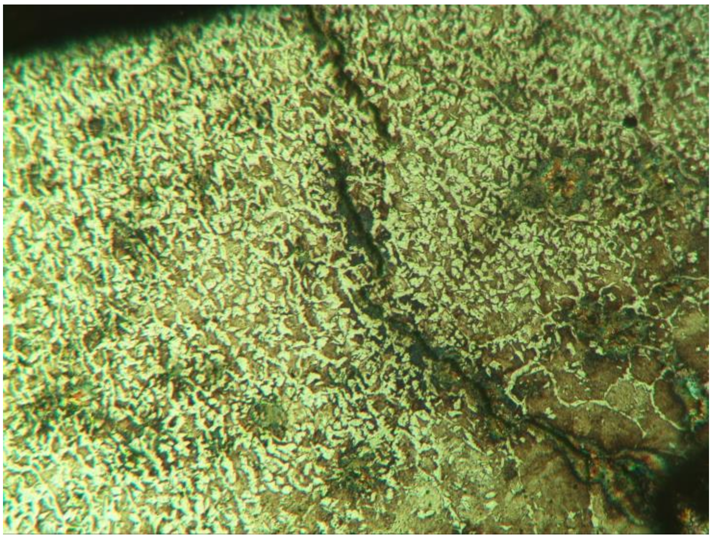

Figure 4: Fused zone of sample 60 A (100X magnification)

In Figure 5, the presence of micro and macroporosities can be seen, generated due to the intense reactivity of the boron-containing powder during welding. This reactivity impairs the protection effect and stability of the electric arc generated by the electrode coating. This inability to protect leads to the formation of microporosities and gas bubbles that, when they do not collapse, end up giving rise to macropores.

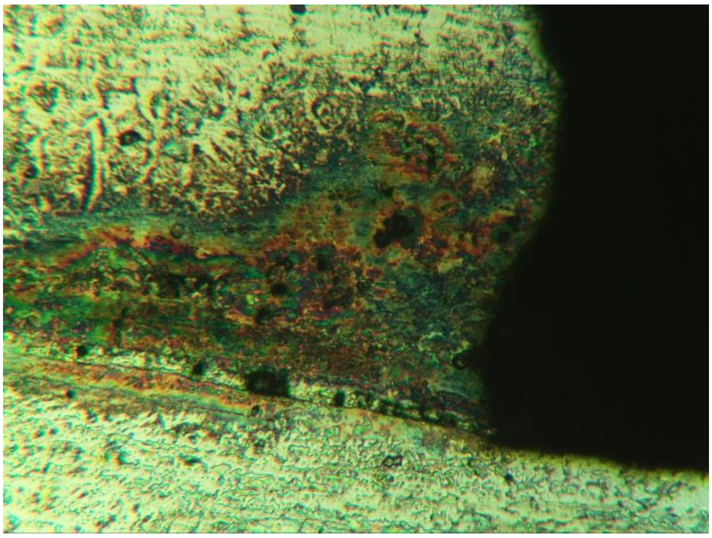

Figure 5: Micro and macroporosity, Fused Zone 60 A (200X magnification)

Figure 6, shows the melted area of the coating produced with a current of 80 A. The discontinuities found are similar to those observed with a current of 60 A. Porosity and some microcracks are observed, with a region that is evolving towards possible delamination.

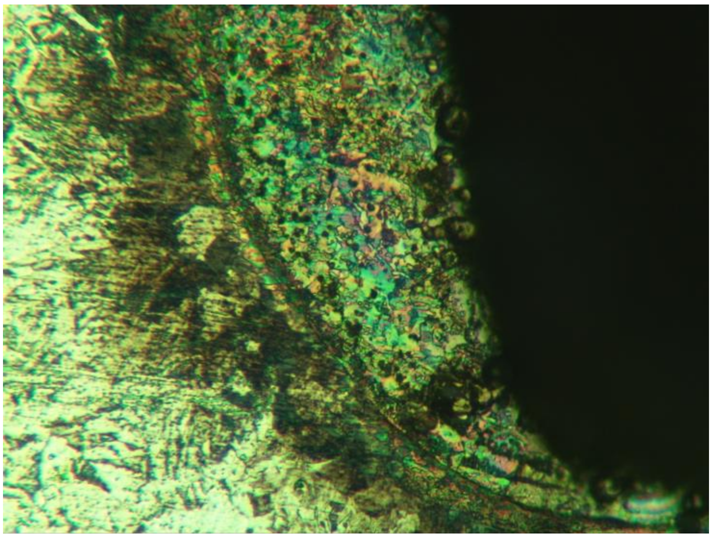

Figure 6: Porosities and microcracks, Fused zone 80 A (400X magnification).

4. CONCLUSIONS

After a detailed analysis of the visual quality and microstructure of the coatings, it was found that with the welding parameters and the way the material is fed, it is unfeasible to produce boron-rich coatings through the SMAW process. This inability is due to several points such as:

- Analysis of the coatings using the liquid penetrant technique showed a series of discontinuities for all current values used, demonstrating an inability of the metal to maintain metallurgical continuity and possibly losses in mechanical properties;
- The welding defects presented are associated with the addition of boron-containing powder, as these problems were not seen in the pre-test samples for dilution analysis;
- It is worth mentioning that both the samples welded with 60 A and 80 A showed similar defects, such as porosity and cracks, generated by segregation problems in the weld pool during the solidification stage.

It is suggested as a possible alternative for the production of quality coatings to attempt to insert boron into the structure of the coated electrode or in the form of a flux to be added to the plate, however, a detailed study must be made of the proportion of boron that must be used.

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