

Influence of Boronizing Treatment and Parameters of Erosion Test on Sand Slurry Erosion of X52 Steel

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Abstract: Slurry erosion is one of the main problems associated with pipeline transportation of gas and oil. The impact of slurry concentration and velocity on slurry erosion resistance before and after boronizing API X52 steel was investigated in this study. Two slurry velocities of 4 and 6 m/s, and slurry concentrations of 400, 600, and 800 g/l were employed. Boronizing was performed at 900 °C for 4 h in a powder mixture containing 5% B₄C as the boron source, 5% NaBF₄ as the activator, and 90% SiC as the diluent. It was found that when the slurry concentration and velocity rise, so does the erosion rate, or weight loss. In comparison with the unboronized X52 steel, the results demonstrated that the formation of boride layers significantly improved the surface hardness and slurry erosion resistance.

Keywords: X52 steel; Boriding; slurry erosion.

1. Introduction

Pipelines are the least expensive and most adaptable way to transport large volumes of products continuously and efficiently, such as crude oil, natural gas, and refined petroleum, from production sites to refineries and consumers. X52 pipeline steel is a high-strength, low-alloy steel specifically designed for pipeline applications. Its availability, affordability, and good mechanical qualities make it widely used. Nevertheless, these steels experience severe deterioration in corrosive and wear environments, such as slurry erosion, which may result in equipment failure [1]. Pipelines operational efficiency and economic viability are severely hampered by slurry erosion, which is caused by repeated impacts of particles on the steel surface [2, 3]. Numerous variables, including the target material's microstructure, abrasive concentration, and slurry velocity, can influence how slurry erosion affects pipeline steel [4, 5].

Previous research has demonstrated that slurry erosion resistance tends to increase as slurry concentration and velocity increase [6, 7]. Preventing slurry erosion is crucial for maintaining the long-term viability of gas and oil pipeline networks [8]. To optimize the resistance of pipeline steel against slurry erosion, researchers and engineers have investigated a variety of approaches. Increasing the steel's surface hardness through processes such as heat treatment or coating application is one way.

Boronizing is a thermochemical process that produces carbon steels with strong, wear-resistant surface layers [9, 10]. This involves diffusing boron atoms into the surface of a metal component, forming a hard interstitial boron compound at the surface [11]. When plain carbon steels are boronized, two boride phases (Fe₂B and FeB) are formed. Because sawtooth-like Fe₂B is less brittle than FeB, it is preferred for industrial applications and permits the substrate steel

to be heat-treated again without changing its characteristics [12]. Several investigations have explored the relationship between boronizing and slurry erosion, highlighting the positive impact of boronizing heat treatment on steel performance [13, 14]. Boronizing is a comparatively easy method for enhancing structural steels' resistance to slurry by the modifying the layer's structure, phase composition, and hardness [15].

The ability of boronizing to improve API X52 steel's erosion resistance was also investigated under various test conditions, including slurry velocity and concentration. These promising results demonstrate that boronizing is a valuable technique for the oil and gas industry because, it can significantly improve the erosion resistance of pipeline steel.

2. Mode experimental

The material used in this study is X52 low carbon steel, which is supplied by Alpha pipe steel Company, Ghardaia, Algeria, which manufactures pipelines for "SONATRACH". Table 1 displays the X52 steel's chemical composition. Before boronizing, each sample was progressively ground to 600 grains on finer silicon carbide papers. Following this, they were cautiously washed with distilled water and acetone.

Table 1. Chemical composition of the X52 steel

Elements	Fe	C	Mn	Si	S	P	Nb	V	Ti	Al
X 52	Balance	0.12	1.22	0.23	0.001	0.011	0.03	0.03	0.002	0.034

90% SiC was used as the diluent, 5% NaBF₄ as the activator, and 5% B₄C as the boron source in the powder mixture used for boronizing. At 900°C, boronizing was performed for 4 h. An integrated digital instrument and a scanning electron microscope were used to measure the thickness of the boride. The existence of sharp and angular sand abrasive particles, which are principally responsible for erosion degradation, is demonstrated by the morphology of the sand particles in Figure 1. Granulometric analysis was used to measure the sand's particle size distribution. It is determined that the average particle size is about 160 µm.

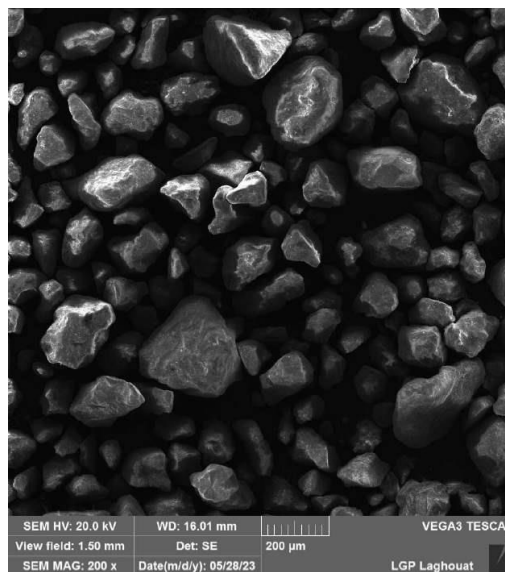


Figure 1. SEM micrograph of the sand particles used in the testing of slurry erosion.

As illustrated in Figure 2, the principal components of the slurry erosion tester are a cylindrical aluminium chamber, shaft, motor, and steel rod on which two specimens are fixed. A variable speed motor can rotate the shaft at various speeds. Both the slurry concentration and

rotational velocity can be adjusted using this test method. Tests for slurry erosion were performed on cylindrical samples with a diameter of 8 mm and a height of 30 mm.

Three different sand contents (400, 600, and 800 g/l) and two distinct flow rates (4 and 6 m/s) were employed. The tests were performed at room temperature, with a fixed testing period of 24 h (6 h for each interval). This equates to travel distances of 345 km and 518 km, respectively, for speeds of 4 and 6 m/s. The weight difference between the specimen's starting and final weights following slurry erosion testing was averaged to determine the average weight loss. The weight of specimens before and after testing was measured using an OHAUS microbalance with an accuracy of ± 0.01 mg. Using a Mitutoyo MVK-H1 microhardness tester, Vickers microhardness measurements were performed on unboronized and boronized samples. The samples were exposed to a load of 100 gf (0.1 kg) for 10 s, as per ASTM E92-17. The composition of the boride layers formed under the research boronizing conditions was studied using an X-ray source Cu K α ($\lambda = 1.54 \text{ \AA}$). The microstructural observations of both boronized and unboronized X52 steel, were examined using a Tescan Vega III scanning electron microscope.

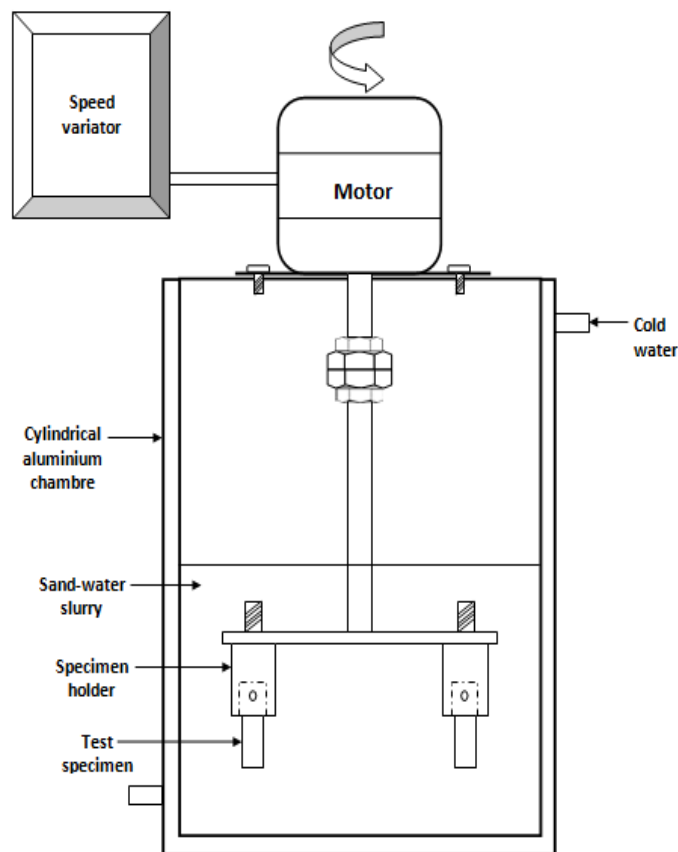


Figure 2. Design of the slurry erosion tester

3. Results

3.1 Microstructure

Figure 3 shows the scanning electron microscopy (SEM) microstructure of the initial state of our X52 steel, which consists of ferrite (F) (black regions) and pearlite (P) (white regions). Ferrite is a solid solution of carbon in iron with a centered cubic crystal structure. It is relatively soft and ductile, allowing easy formability and machinability. On the other hand, pearlite is a lamellar structure composed of alternating layers of ferrite and cementite, which

occurs by the eutectoid reaction of austenite during slow cooling. It's harder and stronger nature provides increased strength and wear resistance.

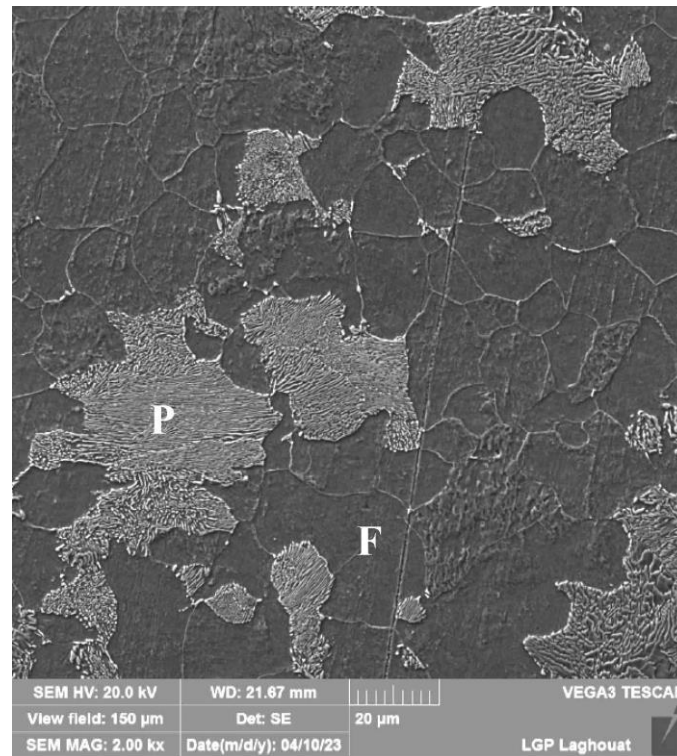


Figure 3. SEM structure (ferrite + pearlite) of X52 steel in the initial state

3.2 Impact of Boronizing on Thickness and Hardness of the Boride Layer

The SEM micrograph of the polished and etched surface of the as-received API X52 steel after boronizing at 900°C and 4 h is shown in Figure 4a. The boride layers of boronized sample exhibit a sawtooth-like morphology. The totality of the boride layer comprises the Fe_2B phase, which has a sawtooth shape and interlocks with the steel substrate, making it extremely difficult to remove [16]. Figure 4b shows the X-ray diffraction analysis of the boronized X52 steel after 4 h at 900°C. When the XRD analysis is examined, Fe_2B phase is formed due to the chemical composition of the X52 steel and powder mixture. According to the literature [17, 18], the powder used with 5% boron source and 5% activator only allows the formation of the boride Fe_2B . Additionally, it can be observed that the layer thickness is about 140 µm. However, it should be noted that this thickness is an average of many boride layer needle lengths. It has been observed in several studies [19, 20] that the thickness of the boride layer increases with increasing boronizing temperature or boronizing time. Hardness is simply the ability of steel to resist deformation, especially in the presence of external forces. It establishes steel's resistance to wear, indentation, and scratches. For steels that can withstand extreme conditions and provide exceptional force, boride layers are a real alternative. For a slurry velocity of 6 m/s, the Vickers microhardness of the X52 steel improved by approximately 830%, from 175 HV for the unboronized (as-received) sample to 1630 HV for the boronized specimens. The resulting Fe_2B boride layer is extremely hard and frequently harder than unboronized steel. The special atomic structure and chemical composition of the borides are responsible for their exceptional strength.

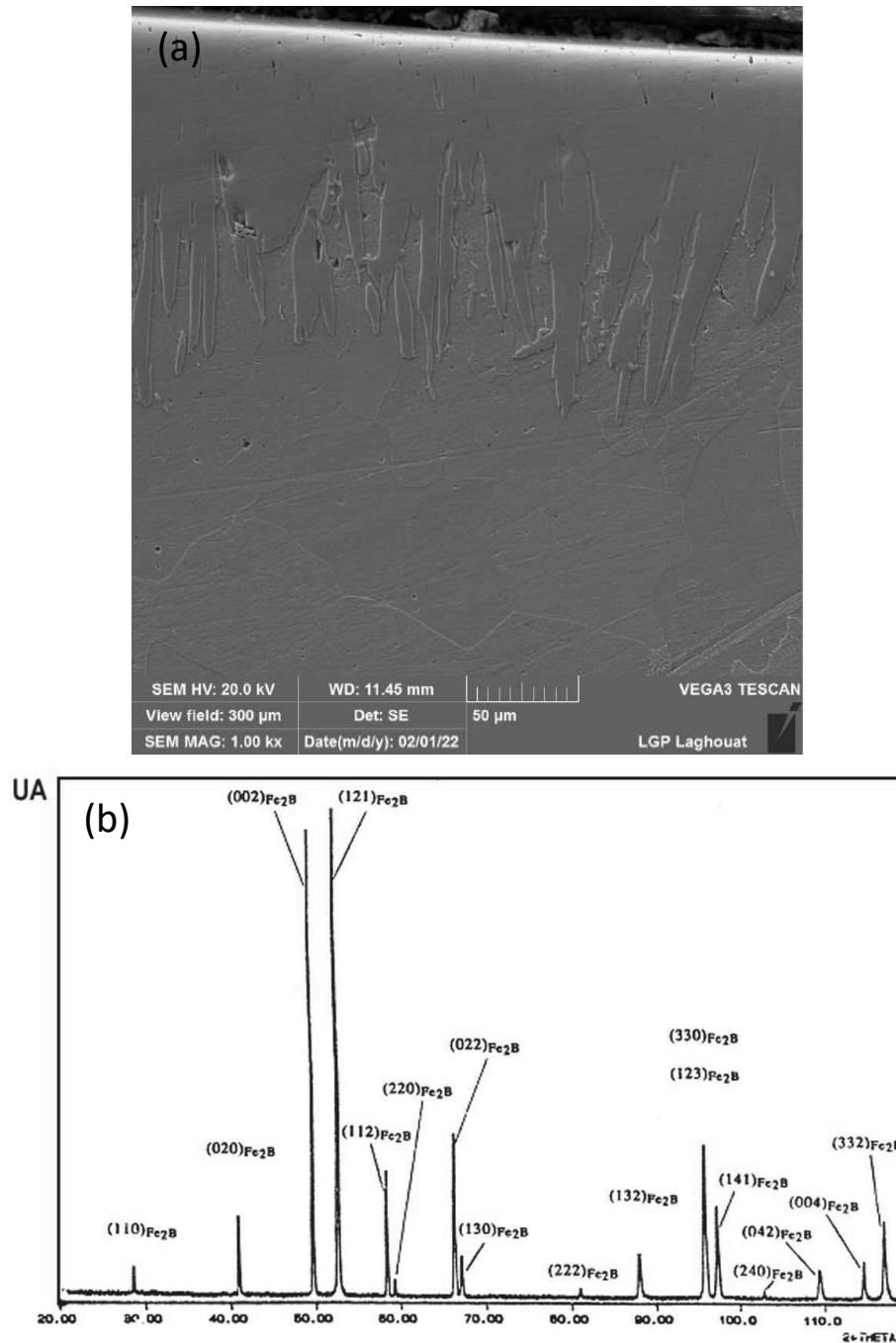


Figure 4. a) Micrograph of the boride layer on X52 steel. b) X-ray diffraction patterns of boronized X52 steel.

3.3 Erosion Behavior of the X52 Steel

The X52 steel surfaces may sustain serious damage because of the abrasive effects of the dispersed sand particles in the slurry. Designing pipelines that can withstand this harsh operating environment requires an understanding of the factors that affect slurry erosion resistance. Every sample was weighed both before and after exposure to the slurry for 6, 12, 18, and 24 h at varying slurry concentrations and velocities to calculate the erosion rate.

3.3.1 Impact of Sand Concentration on Slurry Erosion Resistance

The weight loss of the X52 steel specimens before and after boronizing at slurry concentrations of 400, 600, and 800 g/l, and at slurry velocities of 4 and 6 m/s, is depicted in Figure 5. As the test time increases, weight loss increases.

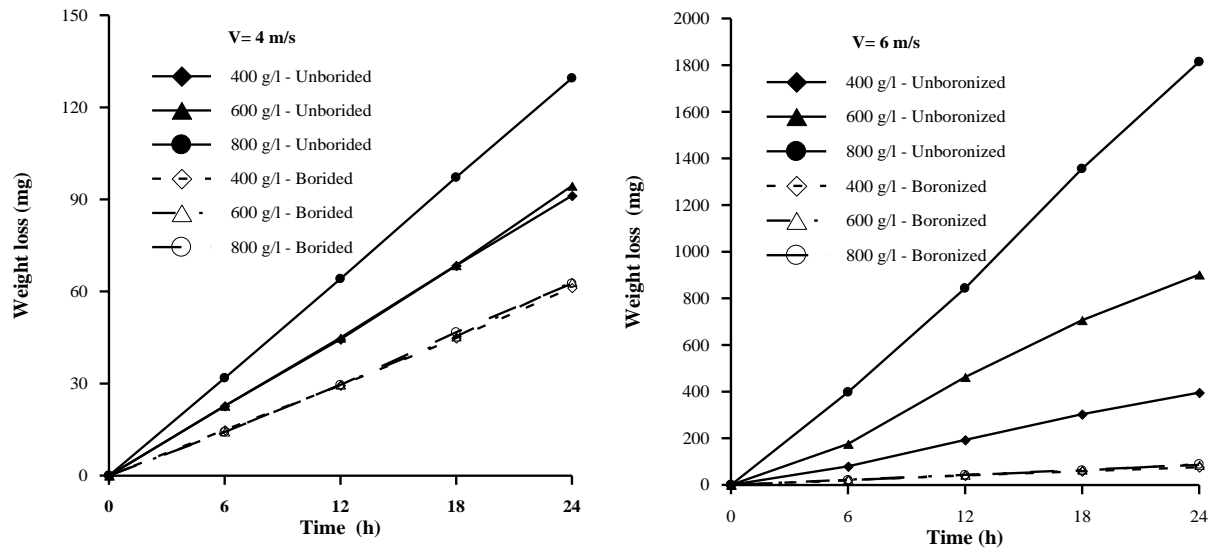


Figure 5. Evolution of weight loss as a function of exposure time for X52 steel at different slurry concentrations before and after boronizing a) $V=4$ m/s b) $V=6$ m/s

Regardless of exposure time, weight losses for concentrations of 400 g/l and 600 g/l are nearly equal at a speed of 4 m/s. However, the effect increases significantly at a concentration of 800 g/l. The weight loss varies significantly depending on the concentration of sand at a speed of 6 m/s. In addition, the weight loss of the X52 steel generally increases with the concentration of the slurry. Previous research has shown that as the slurry concentration increases, the erosion rate also tends to increase [21, 22]. This is explained by the fact that the sand particles and the X52 steel surface interact more. Higher particle concentrations cause more frequent collisions with the X52 steel's surface, which accelerates erosion. Elevated concentrations cause enhanced particle-surface interactions, which increase erosion rates. The weight loss of the boronized samples remains unaffected by the sand concentration. This indicates that the samples are well-protected against erosion by the boronizing treatment. Boronizing the X52 steel not only makes the surface harder, but also makes the steel more resistant to slurry erosion. Compared with X52 steel that had not been treated, boronized X52 steel demonstrated remarkable resistance to erosion from sand slurry. By acting as a barrier, the boride layer shields the underlying steel from the abrasive particles found in sand.

3.3.2 Impact of Slurry Velocity on Slurry Erosion Resistance

The velocity at which the slurry flows through the pipeline is an important factor that influences the slurry erosion resistance. It affects the rate of erosion by determining the impact energy of the slurry particles on the steel surface. The increasing weight loss of the X52 steel specimens before and after boronizing for varying slurry velocities (4 and 6 m/s) at 800 g/l slurry concentration is shown in Figure 6. It was observed that the slurry erosion of API X52 steel increases with increasing slurry velocity.

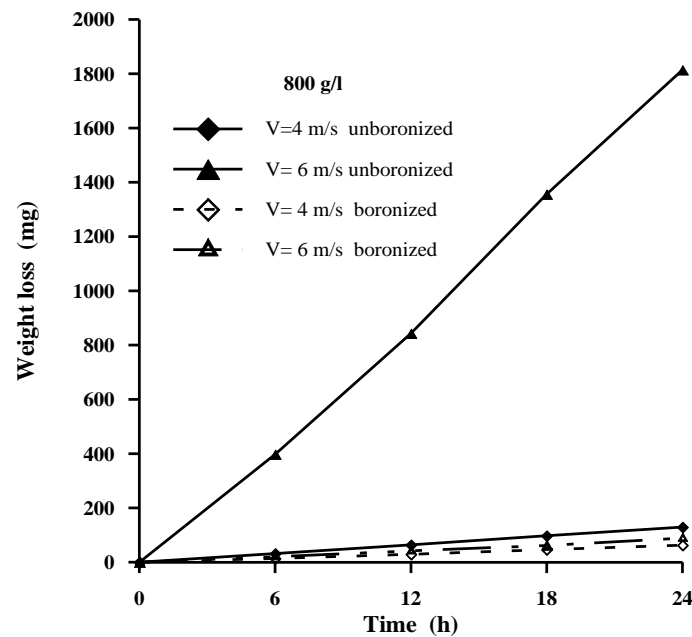


Figure 6. Evolution of weight loss as a function of exposure time for X52 steel at different slurry velocities at the same slurry concentration (800 g/l) before and after boronizing.

The weight losses for the slurry erosion test after a 24 h exposure period were 1.22 mg for 4 m/s and 19.85 mg for 6 m/s. According to several studies, at a higher particle velocity, the higher kinetic energy of the abrasive particles leads to a higher rate of material removal [23, 24]. For a slurry velocity of 6 m/s, the boronized samples showed a significant increase (up to 23 times) in slurry erosion resistance compared with unboronized samples. Research has indicated that an increase in the slurry velocity is generally accompanied by an increase in the erosion rate. This is because faster particles strike the steel surface with more energy, which results in greater material loss. Basha et al. [25] stated that because impact velocity affects the kinetic impact energy, it also affects the erosion rate and degradation mode. The erosion rate generally increases with impact velocity. It is significant to note that, at every velocity in our investigation, unboronized X52 steel loses more weight than boronized X52 steel.

4. Conclusions

1. With an increase in the slurry concentration, the rate of X52 steel slurry erosion increases. Particles collide with the steel surface more frequently when there is a high concentration of slurry. Therefore, as the concentration of the slurry increases, more steel removal occurs.
2. The formation of a layer of Fe₂B boride on the X52 steel improved the slurry erosion resistance. By acting as a barrier, the Fe₂B boride layer shields the underlying steel from the abrasive particles found in sand.
- 3 The X52 steel erodes more quickly as the slurry velocity increases. This is because more material is removed from the matrix when particles move faster because they have more kinetic energy.

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