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Analysis of Corrosion Rate in Low-Carbon Steel ASTM A36 and AISI 1020 in Sulfuric Acid Solution Using Heat Treatment Temperature and Immersion Time Variations

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Abstract

This study investigates the corrosion rate of low-carbon steel ASTM A36 and AISI 1020 in sulfuric acid solution under varying heat treatment temperatures and immersion times. Samples were subjected to heat treatment at 600, 820, and 1100 ℃, followed by immersion for 24, 48, and 72 hours. The results reveal significant effects of heat treatment temperature and immersion duration on corrosion performance. At 600 ℃ with a 72-hour immersion, ASTM A36 exhibited a corrosion rate of 140.68 mm/year, while AISI 1020 showed 149.07 mm/year. At 820 ℃, the corrosion rates for ASTM A36 and AISI 1020 were 102.34 mm/year and 96.48 mm/year, respectively. At 1100 ℃, ASTM A36 demonstrated a corrosion rate of 87.97 mm/year, compared to 121.08 mm/year for AISI 1020. The findings highlight that increasing heat treatment temperature generally reduces the corrosion rate, though the effect varies by material.

Keywords: corrosion rate; heat treatment; low-carbon steel; sulfuric acid; immersion time.

1. Introduction

Corrosion poses a significant challenge in industrial applications, especially in environments where metals are exposed to aggressive agents like acids. This electrochemical reaction between metals and their surroundings leads to material degradation, including rusting and the loss of mechanical properties [1], [2]. The effects of corrosion extend beyond reducing the lifespan of metallic components, also increasing maintenance costs and the risk of failure in critical applications.

Low-carbon steels, such as ASTM A36 and AISI 1020, are extensively used in structural and industrial fields due to their cost-effectiveness, weldability, and favorable mechanical properties [3]-[5]. ASTM A36 is commonly used in ship hulls and construction frameworks, while AISI 1020 is often preferred for applications requiring ease of machining and shaping [6], [7]. Despite their wide application, both steels are prone to corrosion, particularly in acidic environments like sulfuric acid, which is frequently encountered in various industrial processes [8], [9]. The relevance of sulfuric acid in these applications includes its use in chemical processing, battery production, and metal pickling processes, making the study of corrosion in such environments critically important [10].

The corrosion resistance of these steels largely depends on their composition and treatment. Alloying elements like nickel (Ni), chromium (Cr), and manganese (Mn) can enhance corrosion resistance by forming protective oxides or altering the steel's microstructure [11]. However, the relatively low alloy content of ASTM A36 and AISI 1020 makes them susceptible to degradation in corrosive conditions. Heat treatment, involving controlled heating and cooling, is known to improve the mechanical and chemical stability of steels by modifying their microstructure, such as by promoting phase transformations, refining grain size, and enhancing the distribution of carbides [12].

Several studies have explored the effects of heat treatment on corrosion resistance in various materials. Lateritic nickel steel exhibits improved resistance when treated at specific temperatures and the microstructure of stainless steels, including austenitic and martensitic types, significantly influences their corrosion performance [13], [14]. However, limited research exists on the combined effects of heat treatment temperature and immersion time on the corrosion rate of low-carbon steels in highly corrosive environments.

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This study aims to fill this gap by systematically investigating how varying heat treatment temperatures (600, 820, and 1100 °C) and immersion times (24, 48, and 72 hours) affect the corrosion rate of ASTM A36 and AISI 1020 steels in sulfuric acid. The selection of these parameters is based on their practical relevance in industrial heat treatment processes and their potential to influence phase transformations and surface chemistry [15]. The novelty of this research lies in its comprehensive approach, combining thermal processing and exposure duration to optimize the corrosion resistance of these commonly used low-carbon steels, providing both theoretical insights and practical guidelines for industrial applications [15], [16].

2. Experimental Methods

This study was conducted to evaluate the corrosion rates of low-carbon steels ASTM A36 and AISI 1020 in sulfuric acid solution under varying heat treatment temperatures and immersion times. The experimental procedure involved several stages, including sample preparation, heat treatment, immersion testing, and data analysis.

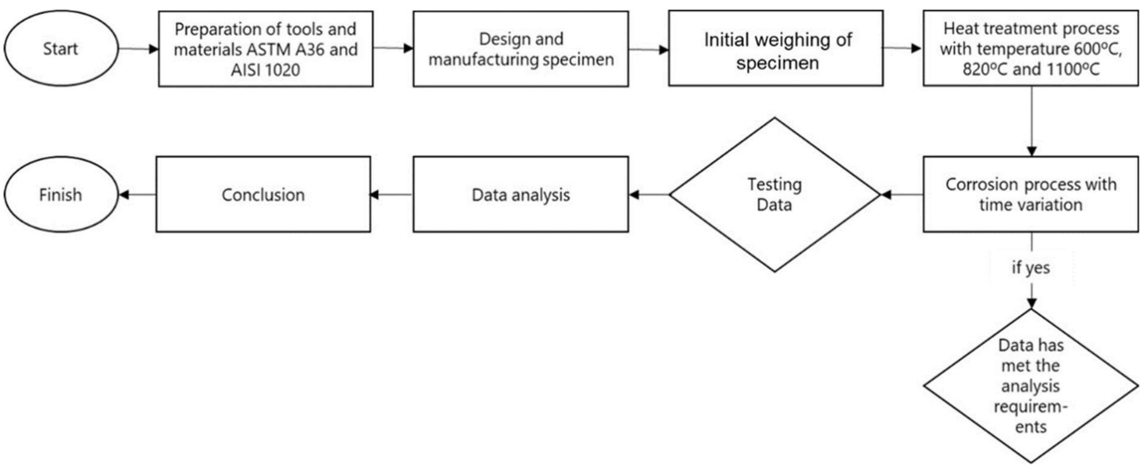

Figure 1. Research flow chart

2.1 Materials

ASTM A36 and AISI 1020 steels were selected for this study due to their widespread industrial applications. The chemical compositions of the materials are shown in Table 1.

Table 1. Chemical Composition of ASTM A36 and AISI 1020 Steels

Material	Carbon (%)	Manganese (%)	Silicon (%)	Sulfur (%)	Phosphorus (%)	Iron (%)
ASTM A36	0.25 - 0.29	1.03	0.28	0.05	0.04	98.0
AISI 1020	0.17 - 0.23	0.30 - 0.60	-	0.05	0.04	99.08-99.53

2.2 Sample Preparation

Experimental design is a description of the experimental process to be studied such as design drawings or sample photos. Experimental design adjusts the formulation of the problem being studied which describes the research or testing process to be carried out. If the formulation of the problem is more than one experimental design, it then will be adjusted to the number of problem formulations sought and each is given a description of the working method or process.

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The materials used in this study were low carbon steel ASTM A36 and AISI 1020. The specimen making began with cutting the plate to be heat treated and used as a test specimen. The aluminum plate sheet was cut using a cutting machine into a size of 50 mm × 50 mm with a thickness of 3 mm.

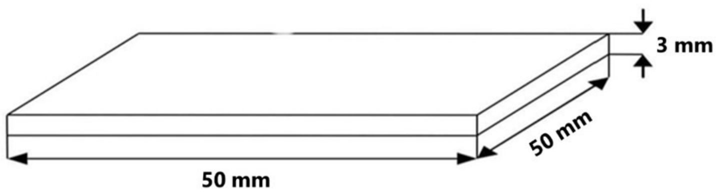

Figure 2. Specimen design

The heat treatment process is carried out at a temperature of 600, 820, and 1100 °C with cooling process using air. The heat treatment and normalizing process of ASTM A36 and AISI 1020 steel can be seen in the following Figures 3 and 4.

Figure 3. Heat treatment process

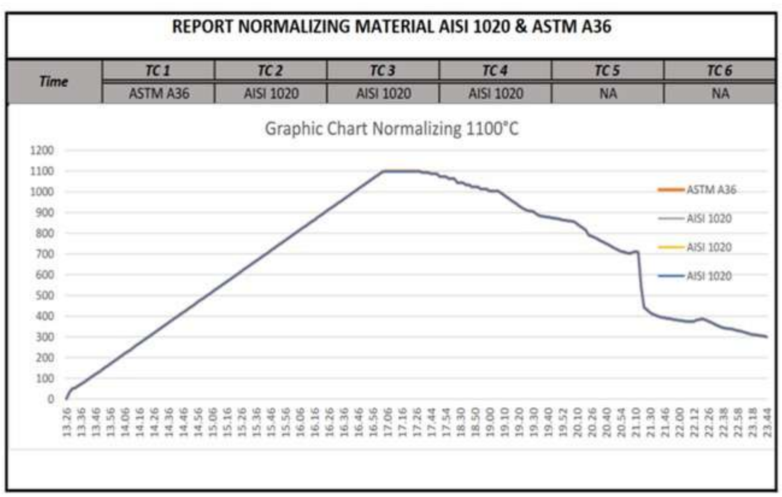

Figure 4. Report normalizing materials specimen

The corrosion testing followed the immersion method using a 1 M sulfuric acid (H_2SO_4) solution. Specimens were immersed for durations of 24, 48, and 72 hours at room temperature. After immersion, specimens were removed, rinsed with distilled water, cleaned with alcohol to remove corrosion products, and dried. The image is shown in Figure 5.

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Figure 5. Sulfuric acid soaking process

The weight of each specimen was measured before and after immersion using a digital balance with 0.01 g precision. The weight loss was calculated as the difference between the initial and final weights. The following is shown in Figures 6 and 7. The corrosion rate was determined using formula 1 [17].

$$CR = \frac{8.76 \cdot W}{D \cdot A \cdot T} \quad (1)$$

Where CR is a corrosion rate (mm/year), W is a weight loss (g), D is the material density (g/cm³), A is the exposed surface area (cm²) and T is the immersion time (hours).

Figure 6. Specimen weighing process before immersion

Figure 7. Specimen weighing process after immersion

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The corrosion rate was compared at different heat treatment temperatures and immersion times for ASTM A36 and AISI 1020. Statistical analysis was conducted to identify significant differences and trends in corrosion performance.

3. Results and Discussion

The results of this study examine the corrosion behavior of ASTM A36 and AISI 1020 steels in sulfuric acid solution, focusing on the effects of heat treatment temperatures and immersion durations. The findings are presented and analyzed to address the research objectives.

3.1. Corrosion Behavior Without Heat Treatment

Table 2 shows the weight loss and corrosion rate of ASTM A36 and AISI 1020 steels without heat treatment.

Table 2. Weight loss and corrosion rate without heat treatment

Material	Immersion time (hours)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/year)
ASTM A36	12	57.152	56.820	0.33	217.19
ASTM A36	24	57.152	56.126	1.03	335.60
ASTM A36	72	57.152	55.591	1.56	170.20
AISI 1020	12	56.872	56.440	0.432	275.61
AISI 1020	24	56.872	55.960	0.912	402.35
AISI 1020	72	56.872	55.392	1.480	272.85

The data reveal that AISI 1020 exhibits higher corrosion rates than ASTM A36 at all immersion times. This difference is attributed to the higher manganese content in ASTM A36, which enhances its resistance to corrosion. Both materials show a peak in corrosion rate at 24 hours, followed by a decrease, possibly due to the formation of a passive oxide layer.

3.2. Effect of Heat Treatment on Corrosion Rate

The corrosion rates of ASTM A36 and AISI 1020 at different heat treatment temperatures and a 72-hour immersion are summarized in Table 3.

Table 3. Corrosion rates at different heat treatment temperatures

Heat treatment temperature (°C)	ASTM A36 corrosion rate (mm/year)	AISI 1020 corrosion rate (mm/year)
600	140.68	149.07
820	102.34	96.48
1100	87.97	121.08

The results indicate that increasing heat treatment temperature generally reduces the corrosion rate for both materials. For ASTM A36, the corrosion rate decreased from 140.68 mm/year at 600 °C to 87.97 mm/year at 1100 °C. This improvement is attributed to grain refinement and reduced internal stress achieved through heat treatment.

In contrast, AISI 1020 exhibited an increase in corrosion rate at 1100 °C, reaching 121.08 mm/year. This anomaly may result from structural changes, such as grain coarsening or phase instability, reducing its corrosion resistance at higher temperatures.

3.3. Effect of Immersion Time on Corrosion Behavior

The relationship between immersion time and corrosion rate at temperatures of 600, 820, and 1100 °C is illustrated in Figures 8, 9, and 10.

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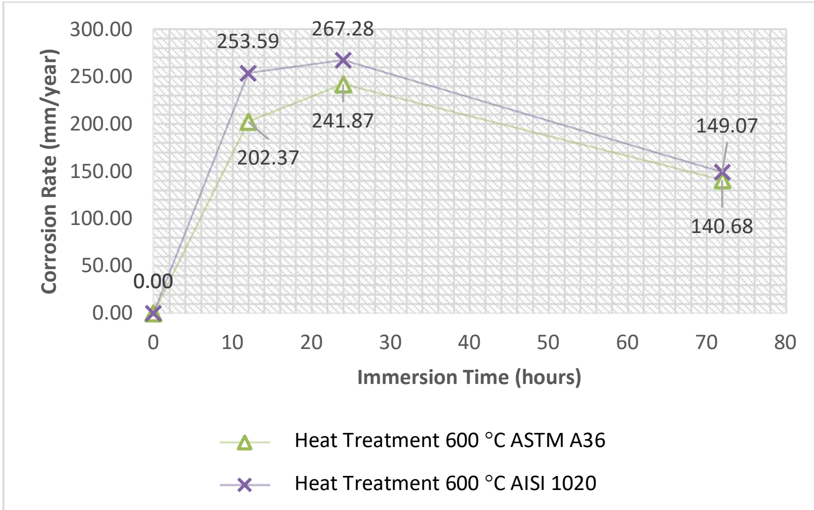

Figure 8. Corrosion rate of ASTM A36 and AISI 1020 over immersion time in temperature 600 °C

Figure 8 shows that the corrosion rate on AISI 1020 heat treatment 600 °C with sulfuric acid solution for 12 hours is known with a corrosion rate of 253.59 (mm/year) and for immersion for 24 hours the corrosion rate is known to be 267.28 (mm/year), and 72 hours the corrosion rate is known to be 149.07 (mm/year). The following is a list of differences in the corrosion rates of ASTM A36 and AISI 1020 steel with heat treatment 600 °C which have been tested with sulfuric acid liquid.

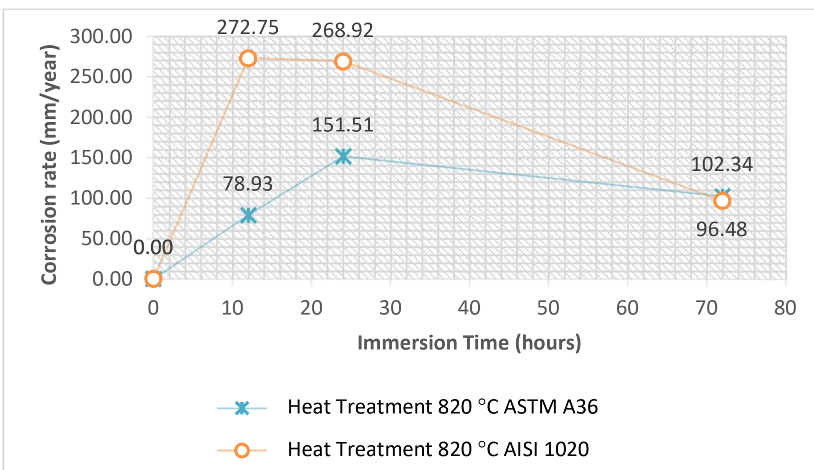

Figure 9. Corrosion rate of ASTM A36 and AISI 1020 over immersion time in temperature 820 °C

Figure 9 shows that the decreasing corrosion rate of AISI 1020 steel after heat treatment at 820 °C in sulfuric acid over time is due to the progressive formation and stabilization of a protective corrosion product layer on the steel surface. Initially, at 12 hours, the corrosion rate is high (272.75 mm/year) because the fresh steel surface is directly exposed to the acid, which aggressively dissolves the metal. By 24 hours, the corrosion rate slightly decreases to 268.92 mm/year as a thin protective layer begins to form, reducing the acid's direct attack on the surface. After 72 hours, the corrosion rate drops significantly to 96.48 mm/year due to the thickening and stabilization of this layer, which acts as a barrier to further corrosion. This phenomenon, known as passivation, is influenced by the material's composition, the microstructural changes induced by heat treatment at 820 °C, and the longer immersion time, which allows the protective layer to develop and reduce corrosion effectively.

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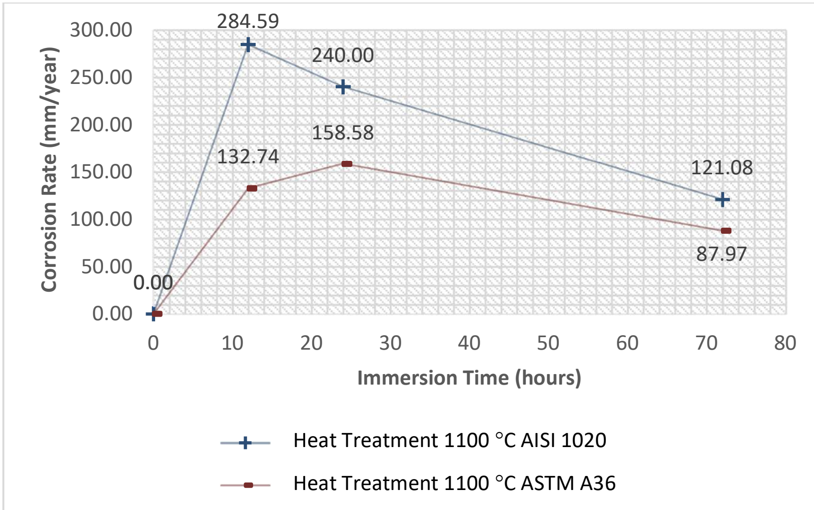

Figure 10. Corrosion rate of ASTM A36 and AISI 1020 over immersion time in temperature 1100 °C

Figure 10 shows that the decreasing corrosion rate of AISI 1020 steel after heat treatment at 1100 °C in sulfuric acid over time is caused by the progressive formation and stabilization of a protective corrosion product layer on the steel surface. Initially, at 12 hours, the corrosion rate is high (284.59 mm/year) due to the direct and aggressive reaction between the fresh steel surface and the acid. By 24 hours, the corrosion rate decreases to 240.00 mm/year as a thin protective layer begins to form, partially shielding the steel from further acid attack. After 72 hours, the corrosion rate significantly drops to 121.08 mm/year as the corrosion product layer becomes thicker and more stable, effectively reducing direct exposure of the steel to the acid. This phenomenon, known as passivation, is influenced by the material's composition, the effects of heat treatment at 1100 °C, and the aggressive nature of the sulfuric acid environment.

3.4. Comparison Between ASTM A36 and AISI 1020

From the test results that have been carried out on ASTM A36 and AISI 1020 steel specimens, the results obtained are in the form of data on weight loss and corrosion rates of the two specimens. In the ASTM A36 steel specimen that has undergone a 12-hour immersion test, there was a weight loss of 0.33 g, while at a 24-hour immersion time there was a weight loss of 1.03 g. Meanwhile, for the corrosion rate on ASTM A36 steel after a 72-hour immersion test, the data produced was 170.20 mm/year. ASTM A36 consistently demonstrated superior corrosion resistance across all conditions compared to AISI 1020. This difference is due to its lower carbon content and balanced alloying elements, which contribute to a more stable oxide layer during corrosion.

Based on several similar studies, ASTM A36 consistently demonstrates better corrosion resistance than AISI 1020 in acidic environments. Highlighted that ASTM A36, with its lower carbon content and balanced alloying elements forms a more stable oxide layer providing superior protection against corrosion. The corrosion aligns with results where ASTM A36 showed a corrosion rate of 170.20 mm/year after 72 hours of immersion. It was found that AISI 1020 experienced higher corrosion rates compared to ASTM A36 due to its more reactive microstructure, leading to a less stable oxide layer. Additionally, heat-treated carbon steels showed that while heat treatment at high temperatures (like 820 °C) improved corrosion resistance, AISI 1020 still exhibited higher corrosion rates due to its lower alloy content compared to ASTM A36. Overall, ASTM A36's lower carbon content, more stable oxide layer, and superior microstructure contribute to its better corrosion resistance, even after heat treatment, making it more resistant than AISI 1020 in sulfuric acid solutions.

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4. Conclusion

Sulfuric acid solution causes the same type of corrosion on low-carbon steels ASTM A36 and AISI 1020, namely uniform corrosion. Heat treatment also influences the corrosion rate of ASTM A36 and AISI 1020 steel plates. With 72 hours of immersion under 600 °C heat treatment, ASTM A36 exhibits a corrosion rate of 140.68 mm/year, while AISI 1020 shows a corrosion rate of 149.07 mm/year. At 820 °C heat treatment, ASTM A36 achieves a corrosion rate of 102.34 mm/year, compared to 96.48 mm/year for AISI 1020. Under 1100 °C heat treatment, ASTM A36 achieves the lowest corrosion rate of 87.97 mm/year, while AISI 1020 has a higher corrosion rate of 121.08 mm/year. In conclusion, ASTM A36 demonstrates better corrosion resistance due to its higher chromium and manganese content compared to AISI 1020. On the other hand, AISI 1020 is less resistant to sulfuric acid's corrosive nature, making it more prone to corrosion.

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