

EFFECT OF HEAT TREATMENT ON THE CORROSION BEHAVIOUR OF LM6 IN SULPHURIC ACID AND SODIUM HYDROXIDE

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Abstract - Sulphuric acid (H_2SO_4) and sodium hydroxide ($NaOH$) are the main solutions used in water treatment stations to adjust the potential of hydrogen (PH). Pumps used in such stations must bear acidic and alkaline mediums. Pump parts such as impellers and casings could be made by aluminium silicon alloy (LM6) due to their cast-ability and corrosion resistance. In this paper, the corrosion behaviour of LM6 in acidic and alkaline solutions was investigated. The corrosion test samples of LM6 were prepared using a carbon dioxide sand casting mould. Test samples subjected to solution heat treatment. A corrosion test was conducted using the weight-loss method by immersing the samples in H_2SO_4 and $NaOH$. Resulted showed that the LM6 was more corroded in the alkali than in acid. Cumulative weight loss of non-heat-treated LM6 in H_2SO_4 was 11.23 mg/cm^2 while in $NaOH$ was 177 mg/cm^2 . Cumulative weight loss of heat-treated LM6 in H_2SO_4 was 8.44 mg/cm^2 while in $NaOH$ was 192 mg/cm^2 . The corrosion rate of non-heat-treated LM6 in H_2SO_4 was 78 MPY while heat-treated LM6 was 56 MPY. Concluded that LM6 is more corroded in $NaOH$ than in H_2SO_4 and the heat-treated LM6 was more corrosion resistance than the non-heat-treated one.

Key Words: LM6, Sodium hydroxide, Sulphuric acid, Sand casting, Corrosion rate

1. INTRODUCTION

The aluminium eutectic silicon alloy is an Al-Si alloy having 11-13% silicon which according to British Standard designated - LM6 [1-3]. Due to its distinguishes by good castability, low melting point, and good corrosion resistance, LM6 used to fabricate intricately shaped castings such as parts of pumps (impellers, housing, and manifolds) [4-6], as shown in Figure 1. The LM6 alloy possesses exceptional fluidity so that it is capable of producing intricate castings of thin sections [7]. The sand casting method one of the adopted processes used to produce aluminium and its alloys. It is considered relatively low-cost, besides being simple, and flexible, as compared with other techniques. It also allows for the large size and intricate components to be fabricated and is also used in mass-production [8]. Most of the large cast products are made using sand casting mould instead of other mould castings [9].

In the stations of the water treatment, in which adding some chemical needed appropriate pumps to stand up the working conditions. Adjusting water pH is accomplished by the addition of acids or alkalis. By adding alkalis raise the water pH while reducing the pH of water by adding acids. Raising the pH remains one of the most effective methods for reducing lead corrosion and minimizing lead levels in drinking water. Alkalinity could be changed independently of the hardness by the addition of sulphuric acid, sodium carbonate, or potassium carbonate [10]. Generally, the pH of water is adjusted using H_2SO_4 and $NaOH$. An alkaline is used in the treatment of drinking water to raise the pH of the water to a level that minimizes corrosion for this purpose sodium hydroxide is used [11].

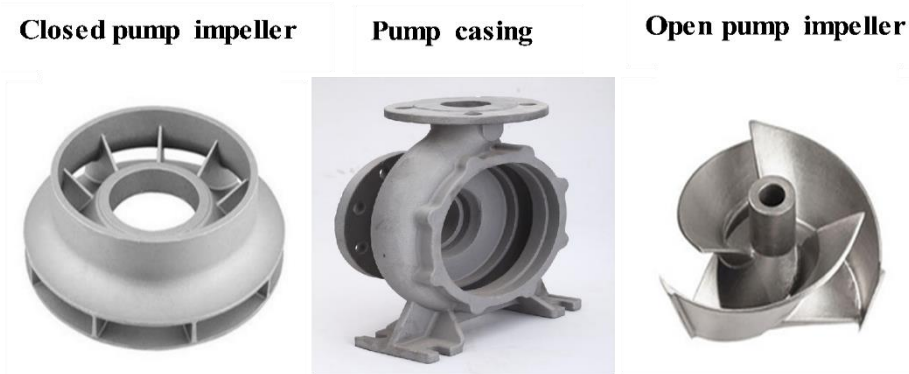


Fig - 1: Intricate shape components of Al-Si alloy

Kapil and Bhattacharyya (2017) [12] simulated 1 m³ of distilled water acidified with sulphuric acid to get plant water with pH 3.2, for that posse was required 20 grams of sodium hydroxide and 38.2 grams of sodium carbonate. Zueva et al. (2020) [13] studied a neutralization process using sodium chloride, potassium chloride, sodium hydroxide, and hydrated lime as precipitating agents in the treatment of wastewater from the fertilizer industry containing phosphate and fluoride ions which has a wide range of pH, from 1.5 up to 12. An acid is used in the treatment of wastewater treatment to adjusting the pH for wastewater to a level that minimizes the corrosion such as a sulphuric acid. The sulphuric acid uses to remove heavy metals by acidification in different concentrations and temperatures since this acid is more effective in comparison with nitric, hydrochloric and phosphoric acid [14].

The above studies have revealed the importance of LM6 in fabricating the intricately shaped casting parts such as parts of pumps and adopt the sand casting mould as the compatible method to fabricate such those parts. Such these pumps may use in the water stations either drinking water or wastewater treatment in which used sodium hydroxide and sulphuric acid to adjust the pH of water or to remove some minerals. This work has investigated the possibility of use pumps having LM6 parts in the water treatment stations which are used sulphuric acid and sodium hydroxide. Thus, the research work was aimed at the experimental investigation of solution heat-treated LM6 on corrosion properties using the weight-loss method. Corrosion test was conducted by immersion the heat-treated and non-heat-treated LM6 samples in 0.5M H₂SO₄ as the acidic solution and 0.5M NaOH as the alkaline solution.

2. METHODOLOGY AND EXPERIMENTS

The methodology adopted to implement this experimental work includes the following steps: materials preparation, casting of test specimens, heat treatment application, corrosion test procedure, and microstructure analysis.

2.1 Materials used

In this experimental work, Al-Si eutectic alloy used to produce test samples which its chemical composition is listed in Table 1. Acidic solution used was 0.5M sulfuric acid (H₂SO₄) to study the behavior of LM6 in acidic medium. Alkaline solution used was 0.5M sodium hydroxide (NaOH) to study the behavior of LM6 in alkaline medium.

Table - 1: Chemical composition of LM6 alloy by weight %, [15]

Element	Al	Si	Cu	Mg	Fe	Mn	Ni	Zn	Sn	Ti	Pb	other
Wt.%	85.95	12.0	0.1	0.1	0.6	0.5	0.1	0.1	0.05	0.2	0.1	0.2

2.2 Samples Preparation

In the induction furnace, LM6 was melted at about 700 ± 5 °C. The molten metal was poured into the prepared sand moulds. The molten metal was then left to solidify and cool. Next, the sand moulds were broken to eject the castings. The castings were then cleaned using a grinding machine. The specimens were then classified into two categories; Category A was non-heated samples, and category B was heat-treated samples. Corrosion test specimens having dimensions (15 x10 x8mm) were polished with different paper grades 600, 800, 1000, and 1200 grains of silicon carbide.

2.3 Heat Treatment of sample

To study the effect of heat treatment on the corrosion behaviour of LM6, one-half of specimens have subjected to the solution heat treatment followed by ageing hardening. The aim of conduct heat treatment was to uniform distribution of the silicon particles in Al. The silicon owns low solubility in aluminium, the maximum solubility of silicon in aluminium solid solution is 1.65% at the eutectic temperature (566 °C). The solution heat treatment has carried out in a muffle furnace at 490 ± 2 °C for 6 hours followed by quenching in warm water (60 ± 2 °C), then aged at 155 ± 2 °C for 5 hours, and lastly air-cooled.

2.4 Corrosion Test

After the specimens were produced, half of them were subjected to solution heat treatment (T6) to study the effect of solutions. This study has investigated the corrosion behaviour of heat-treated and non-heat-treated LM6 under acidic and alkaline mediums. Two different solutions have used namely are sulphuric acid (H_2SO_4) as an acidic medium and sodium hydroxide (NaOH) as an alkaline medium using the weight-loss method. The experiment has started with cutting the samples using a saw machine with dimensions (15x10x8mm). Grinding and polishing of each sample to a degree of softness was performed with SiC emery papers (400, 600, 800, and 1200 grit). The specimens were washed with distilled water and ethanol, then the specimens have dried in hot air. Each sample has weighed using a four-digit balance. Some specimens were immersed in acidic solution, while other specimens were immersed in an alkaline solution at ambient temperature. The specimens were immersed in a separate glass vessel contenting 300 ml of solution. In the acidic solution, the exposure time was 8 days and the weight has measured after every 24 hours. While in the alkaline medium, the exposure time was 48 hours and the weight has measured after every 6 hours. The corrosion test steps immersion in acidic solution shown in Figure 2, while Figure 3 shows the corrosion test steps immersion in alkaline solution.



Fig- 2: Corrosion test steps immersion in acidic solution (H_2SO_4)

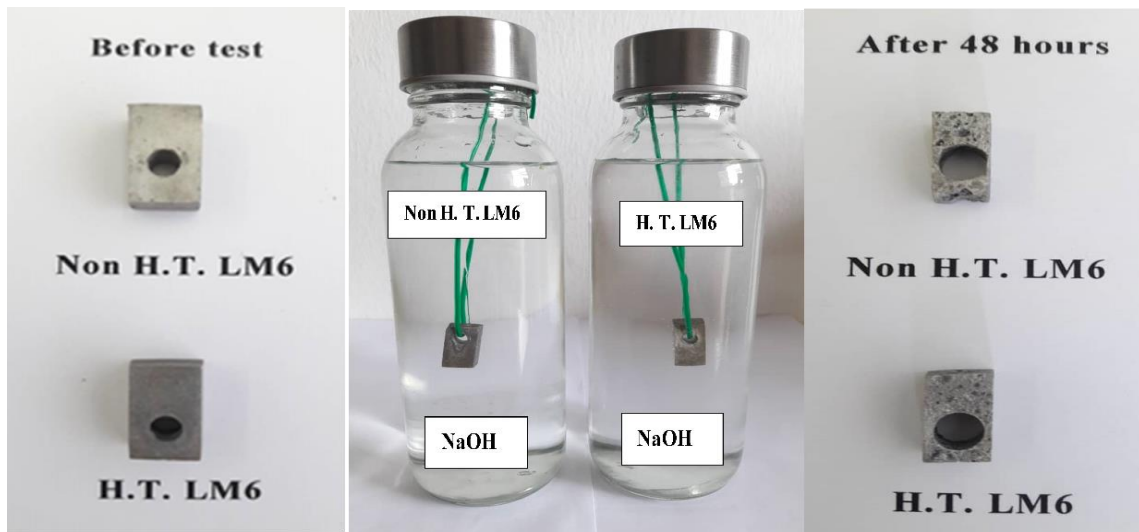


Fig - 3: Corrosion test steps immersion in alkaline solution (NaOH)

The samples have removed from the corrosion mediums and cleaned the oxidation layers caused by the corrosion using a soft brush. Then, the samples have immersed in (HNO₃) for 5 minutes at room temperature, then washed via ethanol followed by distilled water and dried in hot air. Finally, the samples have reweighed using a four-digit balance. These steps were repeated at the end of every period to calculate the difference of the weights before returning the sample to the solution once again.

2.5 Microstructure

Mechanical properties of different copper content composites were investigated in both heat-treated and non-heat treated conditions. The specimens were subjected to mechanical tests include; tensile test and hardness test. These tests were conducted on all samples of Al-Si composites reinforced with different copper contents, and on the base alloy LM6 heat treated and non-heat treated. The samples surfaces were prepared by cutting, grinding, and polishing with different paper grades 600, 800, 1000, and 1200 grains of silicon carbide. Microstructure characterization of the samples was conducted before and after corrosion test using optical microscope. Figure 4 shows the sample microstructure before corrosion test, Figure 5 shows the sample microstructure after immersing in H₂SO₄ for 8 days, and Figure 6 shows the sample microstructure after immersing for 48 hours in NaOH.

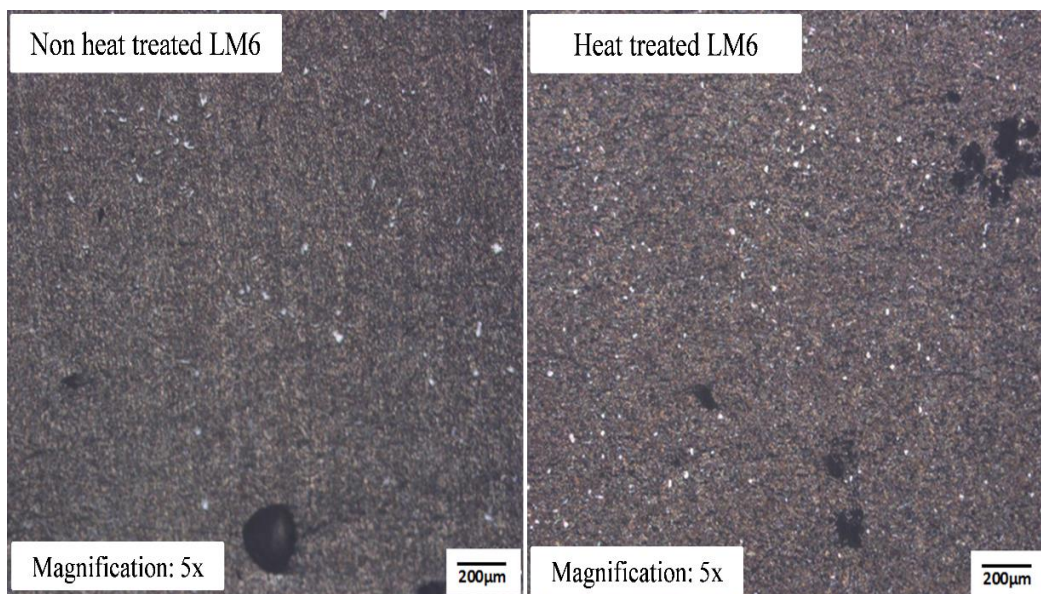


Fig - 4: Microstructure of LM6 sample before the immersion test

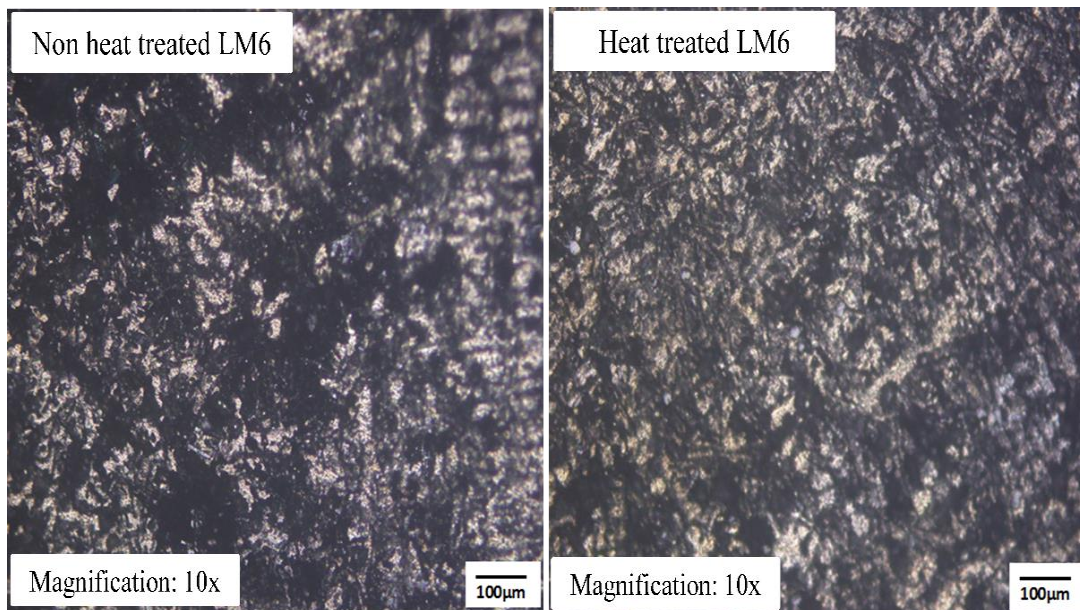


Fig - 5: Microstructure of LM6 sample after immersion in H₂SO₄

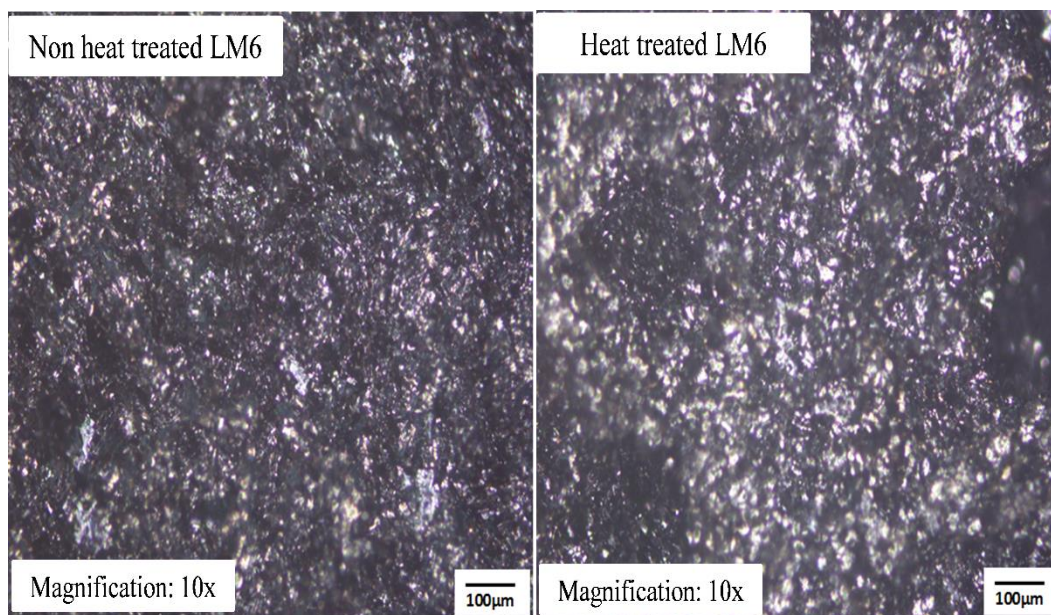


Fig - 6: Microstructure of LM6 sample after immersion in NaOH

3. RESULTS AND DISCUSSION

3.1 Weight Loss

The weight loss of samples has calculated by subtracted the final weight from the initial weight at the end of every stage. The cumulative weight has listed in the tables and plotted in the figures to compare the differences. Table 2 represents the cumulative weight loss (mg/cm²) in H₂SO₄ every 24 hours for 8 days, while Table 3 represents the cumulative weight loss (mg/cm²) in NaOH every 6 hours for 48 hours. Figure 7 shows the cumulative weight loss (mg/cm²) in H₂SO₄ every 24 hours for 8 days, while Figure 8 shows the cumulative weight loss (mg/cm²) in NaOH every 6 hours for 48 hours.

Table - 2: Cumulative weight loss (mg/cm²) in H₂SO₄

Immersion period (h)	24	48	72	96	120	144	168	192
Before HT	1.28	2.56	3.84	5.12	6.82	8.10	9.66	11.23

After HT	1.04	1.87	2.67	3.56	4.71	5.63	6.96	8.44
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Table - 3: Cumulative weight loss (mg/cm²) in NaOH

Immersion period (h)	6	12	18	24	30	36	42	48
Before HT	29	46	66	89	111	136	156	177
After HT	27	42	61	85	111	141	165	192

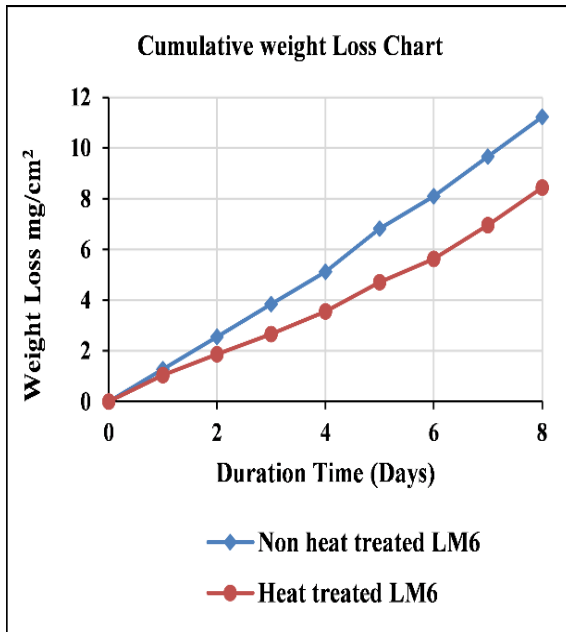


Fig - 7: Weight loss of LM6 in H₂SO₄

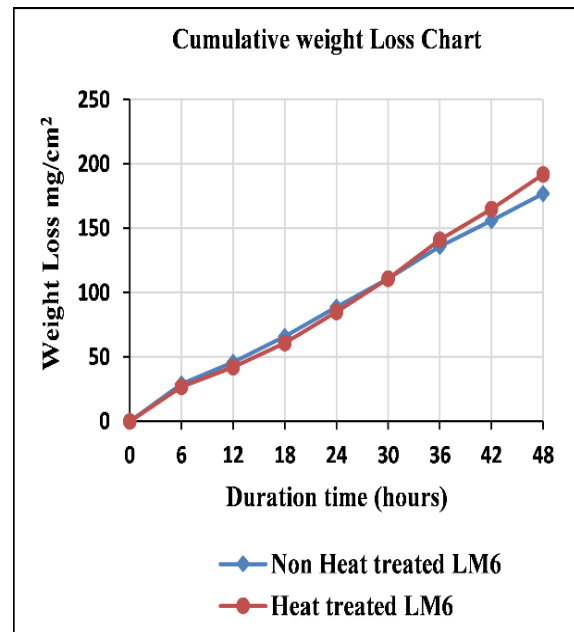


Fig - 8: Weight loss of LM6 in NaOH

3.2 Corrosion Rate

Corrosion Penetration Rate (CPR) calculated by equation $(CPR = \frac{K \cdot \Delta W}{\rho \cdot A \cdot T})$

Where

K is constant depends on the unit used, in case unit of **CPR** is miles per year (MPY) **K**=534

ΔW: weight loss (mg), **ρ**: density (g/cm³),

A: surface area (in²), **T**: immersing time (hour).

The Corrosion Penetration Rate has listed in the tables and plotted in the figures to compare the differences. The density of the sample was 2.5 g/cm³ and the surface area was 7.00 cm² (1.085 in²). Table 4 represents the CPR (mpy) in H₂SO₄ every 24 hours for 8 days, while Table 5 represents CPR (mpy) in NaOH every 6 hours for 48 hours. Figure 9 shows the CPR (mpy) in H₂SO₄ every 24 hours for 8 days, while Figure 10 shows CPR (mpy) in NaOH every 6 hours for 48 hours.

Table - 4: Corrosion Penetration Rate (mpy) in H₂SO₄

Immersion period (h)	24	48	72	96	120	144	168	192
Before HT	71	71	71	71	77	75	77	78
After HT	55	55	47	47	54	50	53	56

Table - 5: Corrosion Penetration Rate (mpy) in NaOH

Immersion period (h)	6	12	18	24	30	36	42	48
Before HT	6458	5056	4883	4930	4901	5003	4928	4875

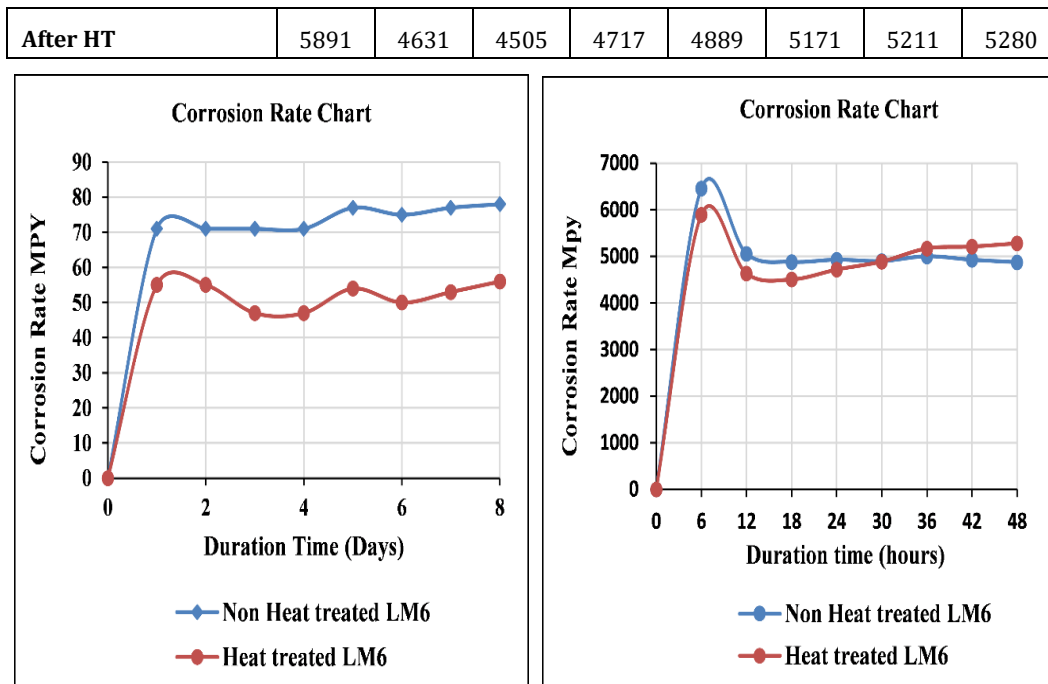


Fig - 9: Corrosion Rate of LM6 in H₂SO₄

Fig - 10: Corrosion Rate of LM6 in NaOH

The corrosion behaviour of the LM6 before and after heat treatment has clarified through the cumulative weight loss charts and corrosion penetration rate charts. The result displayed that the heat-treated LM6 had more corrosion resistance than non-heat treated ones, especially in acidic solution. From the cumulative weight loss chart, the cumulative weight of heat-treated LM6 in H₂SO₄ for 8 days was 8.44 mg/cm² while before heat treatment was 11.23 mg/cm² as shown in Figure 7. From corrosion penetration rate charts, the corrosion rate of heat-treated LM6 in H₂SO₄ for 8 days was 56 mpy while before heat treatment was 78 mpy as shown in Figure 9. In the case of immersing in alkaline solution, there was not observed much different in the effect of applying heat treatment. The cumulative weight loss of heat-treated LM6 in NaOH was 177 mg/cm² while before heat treatment was 192 mg/cm² as shown in Figure 8. The corrosion rate of heat-treated LM6 in NaOH was 5280 mpy while before heat treatment was 4875 mpy as shown in Figure 10.

The LM6 possessed better corrosion resistance in the acidic medium than in the alkaline medium. This confirmed the conclusion reported by [16] that the samples immersed in acidic solution had corrosion rates lower than the samples immersed in alkaline solution. Applying heat treatment improved the corrosion resistance of LM6. The result revealed that the heat treatment had noticeably improved the corrosion resistance of LM6 in H₂SO₄, while unstable corrosion behaviour in the case of NaOH solution.

4. CONCLUSION

From the results, can be concluded that LM6 had more corrosion resistance to the acidic solution than to the alkaline solution and the heat-treated LM6 had more corrosion resistance than the non-heat-treated alloy in case of immersion in acidic solutions. In alkaline solution, in initial periods heat-treated LM6 more corrosion resistance than that non-heat-treated while in the progressed periods the non-heat treated more corrosion resistance than heat-treated alloy, but in both cases, the corrosion rate was very high. Therefore, LM6 products can be used in the water stations that using the acidic solution and could not use in the water station that used alkaline solution.

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