Corrosion Behaviour of Silicon Steel Prepared with Recycled Steel Scrap After 24-Hour Immersion in 3.5 wt.% NaCl Solution

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1. Introduction

Electrical steels, or silicon steels, are essential soft magnetic materials used in the construction of stators and rotors due to their favourable magnetic properties and cost-effectiveness. The magnetic characteristics of these steels are influenced by factors such as sheet thickness, chemical composition, microstructure, and notably, grain size. Research indicates that larger grain sizes generally enhance the soft magnetic properties. It was reported that, samples with finer grains exhibited approximately 15% higher core loss with minimal impact on magnetic flux density, making low core loss and high magnetic flux density desirable for electrical machinery [1-4].

Stators and rotors are composed of numerous thin electrical steel sheets utilized in electromagnetic devices. Despite being designed to prevent liquid ingress, these devices often operate in harsh environments, including high pressure, elevated temperatures, and exposure to aggressive gases like CO_2 and H_2S, which compromise mechanical integrity. Over time, steam condenses into droplets, and CO_2 corrosion becomes a significant challenge in the oil and gas sector. Dissolved CO_2 forms carbonic acid, leading to aggressive conditions that can severely degrade performance.

Grain size plays a crucial role in electrical steel design, affecting both magnetic and mechanical properties. Studies indicate that coarser grains may offer better corrosion resistance in certain environments, while finer grains can enhance reactivity and susceptibility to corrosion. However, the relationship between grain size and corrosion resistance in ferrous alloys is complex and influenced by environmental factors. Variability in findings emphasizes the need for case-by-case studies to isolate the effects of grain size from other microstructural changes during refinement, ensuring a comprehensive understanding of corrosion behaviour in different conditions [4-9].

The objective of this study is to investigate the corrosion behaviour of silicon steel sheets prepared in induction furnace using commercial FeSiAl75 and recycled steel scrap. The research employed weight loss and electrochemical measurements (Figure. 1) to assess corrosion. Additionally, scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDS) was utilized to characterize the corrosion product layer, supporting the gravimetric and electrochemical findings.

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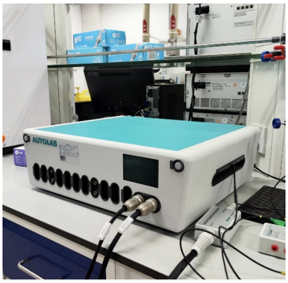

Figure 1. Electrochemical workstation employed for EIS and Tafel plots measurements

2. Result and discussion

The corrosion behaviour of prepared electrical steel with ≈ 6.5% Si (wt.) was examined using metallographic microscopy, gravimetric, electrochemical, and surface analysis techniques. The gravimetric and electrochemical results indicated that material is corrosion resistant. Scanning electron microscopy and energy dispersive X-ray spectroscopy analyses revealed a more homogeneous and compact corrosion product layer on the surface which further acts as a corrosion barrier.

The findings suggest that the reduced corrosion resistance observed with increasing time is linked to the formation of corrosion product which further prevent localised corrosion. Additionally, higher density of active sites at the grain boundaries promotes metal dissolution and decreases the stability of some corrosion product layer formed on the metal surface. Overall, the study highlights the significant impact of corrosion product on the corrosion behaviour of electrical steels.

The electrochemical workstation is utilized for potentiodynamic polarization tests, conducted at a scan rate of 1 mV/s, covering a potential range from −0.4 V to 0.4 V. To assess the corrosion rate, hydrogen evolution was measured through immersion tests. The sides of the samples were sealed with silicone rubber to prevent corrosion. All samples were evaluated in 3.5% NaCl solution at a temperature of 25±1°C. The test results after 24 hour of immersion in 3.5% NaCl are demonstrated in Figure 2.

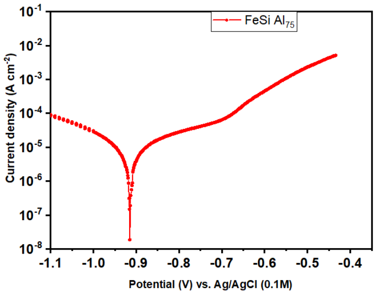

Figure 2. Potentiodynamic polarization curve of Si steel

The behaviour of the Si steel during anodic polarization is complex due to simultaneous Fe, Al and Si dissolution and hydrogen evolution, rendering the anodic Tafel slope less informative. Nonetheless, the Tafel extrapolation method can effectively differentiate between samples by examining variations in corrosion current density (I_{corr}) and corrosion potential (E_{corr}). Additionally, the polarization resistance (R_p) can be determined using the Stern-Geary equation 1, which shows an inverse relationship with I_{corr} (Table 1):

$$R_p = \frac{\beta_a \cdot \beta_c}{2.303 I_{corr}(\beta_a + \beta_c)} \tag{1}$$

where β_a and β_c represent the anodic and cathodic Tafel slopes, respectively.

Table 1. Potentiodynamic polarization data of Si steel

Sample	E_{corr} **(VSCE)**	I_{corr} **(μA·cm⁻²)**	$-\beta_a$ **(V·dec⁻¹)**	β_c **(V·dec⁻¹)**	R_P **(Ω·cm²)**
$FeSiAl_{75}$	–0.92	10.21	0.23	–0.19	2450

3. Conclusion

The EIS measurements indicated that the Si-steel sample exhibited a larger capacitive loop. This observation is associated with the development of a thicker and more stable protective corrosion product layer. Additionally, the potentiodynamic measurements revealed that the corrosion current density for the $FeSiAl_{75}$ was significantly lower compared to that of the other Al content samples. Both the anodic and cathodic current densities were also found to be reduced in the 6.5% silicon steel.

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