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CONSIDERATIONS REGARDING CORROSION BEHAVIOR OF ALUMINUM ALLOYS PROCESSED BY FRICTION STIR PROCESSING (FSP) OR SUBMERGED FRICTION STIR PROCESSING (SFSP)

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ABSTRACT: Microstructural stability and submerged properties of aluminium alloys are critical to their integrity and service life in corrosive environments. Submerged friction stir processing (SFSP) and friction stir processing (FSP) have become effective methods for improving the surface characteristics of these alloys, potentially mitigating corrosion-related degradation. This study provides a analysis of the corrosion behaviour of aluminium alloys post-FSP/SFSP processing. The study reveals that FSP/SFSP can significantly refine grain structure, modify the distribution of intermetallic phases, and influence the nature of the oxide film, thereby affecting the corrosion resistance. The findings suggest that optimal FSP/SFSP parameters can be engineered to develop a corrosion-resistant microstructure while preserving the mechanical attributes of the aluminium alloys. This paper contributes to the improvement of knowledge regarding the corrosion processes in FSP/SFSP-treated aluminium alloys in order to use them in various working environments. The alternation in corrosion dynamics as a function of the modified surface conditions could be identified by using electromechanical assays, surface analytical techniques, and microstructural examinations.
KEYWORDS: Corrosion, Alloy Aluminium, FSP, Surface Friction Stir Processing

1. INTRODUCTION

Aluminium alloys, renowned for their lightweight properties and mechanical strength, find extensive utilization across diverse engineering applications. However, their susceptibility to localized corrosion phenomena remains a critical concern, particularly in aggressive environments. The solid-state material processing techniques, such as FSP/SFSP, have revolutionized the enhancement of aluminium alloy surfaces. These methods, derived from the fundamentals of Friction Stir Welding (FSW), involve controlled mechanical stirring of the material's surface, leading to significant microstructural modifications.

This study, is focused on the corrosion behaviour considerations for aluminium alloys subjected to FSP/SFSP. The investigation aims to show that there is a correlation between processing parameters, microstructural evolution, and electrochemical properties. Key aspects of the research include:

- Microstructural transformations:

FSP/SFSP induce dynamic changes in the alloy's microstructure. The intense plastic deformation, elevated temperatures and rapid cooling during processing lead to grain refinement, dissolution of precipitates, and dislocation rearrangement. We explore the impact of these transformations on corrosion susceptibility.

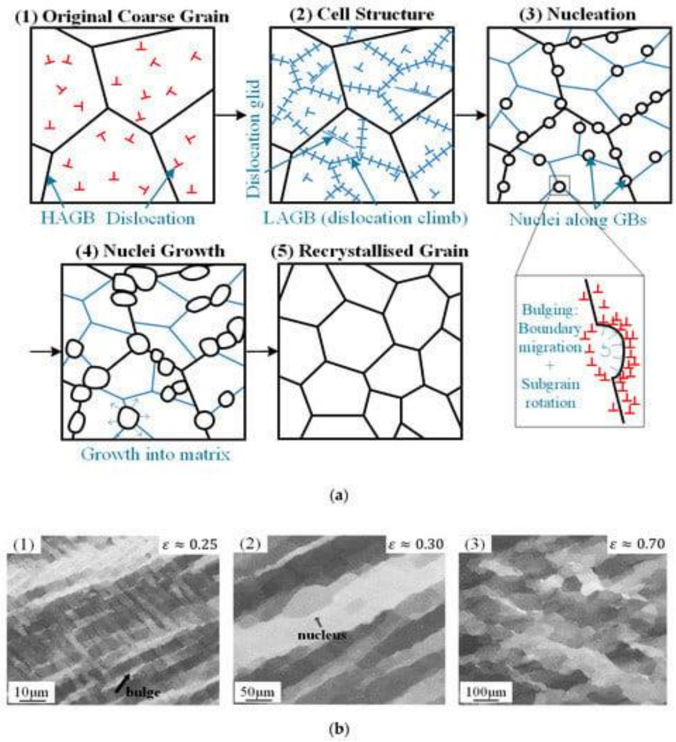

Figure 1. Development of new grains during DDRX: (a) schematic illustration, (b) experimental observation of as-annealed pure Al (99.999%) compressed at 350 °C and 1.11 × 10-2 s-1 [18]

- Corrosion Mechanisms:

By employing advanced characterisation methods (like X-ray diffraction and electron microscopy) Cold be identified corrosion mechanisms specific to FSP/SFSP-treated aluminium alloys. Localized corrosion modes, including pitting, crevice corrosion, and intergranular attack.

- Surface Integrity and Protective Layers:

The surface layer resulting from FSP/SFSP plays an important role in terms of corrosion resistance. From point of view of the formation of protective oxide layers, grain boundary segregation, and the role of residual stresses.

2. MATERIALS AND METHODS

2.1 Selection of aluminium alloys

The following aluminium alloys represent a cross-section of materials commonly subjected to FSP/SFSP to investigate their corrosion behaviour:

- Al-Mg Alloys (5xxx Series):

Characterized by its superior ability to withstand corrosion and weldability, these alloys are often chosen for studies focusing on the interplay between magnesium content and the FSP/SFSP-induced microstructural changes.

- Al-Zn-Mg-Cu Alloys (7xxx Series):

These strong alloys can easily experience stress-corrosion cracking and are frequently selected to assess the efficacy of FSP/SFSP in mitigating such vulnerabilities.

- Al-Cu Alloys (2xxx Series):

The 2xxx series alloys, with copper as the primary alloying element, are prone to localized corrosion and thus serve as a suitable subject for exploring the impact of FSP/SFSP on corrosion resistance.

- Al-Si Cast Alloys (3xx.x Series):

Given their widespread use in the automotive industry, these cast alloys are of particular interest for determining how FSP/SFSP can refine silicon precipitates and improve corrosion performance.

- Al-Li Alloys:

Lightweight and high-strength, Al-Li alloys are studied for their potential in aerospace applications, with FSP/SFSP offering avenues to enhance their ability to resist corrosion while maintaining mechanical properties.

Each of these alloy series presents unique challenges and opportunities for corrosion behaviour modification through FSP/SFSP. The selection is based on the desired balance between the ability to withstand force and resist corrosion, as well as the specific environmental conditions the alloys will encounter in service.

It is essential to note that the processing parameters of FSP/SFSP, such as the speed at which the tool rotates, moves across the material, and the tool's geometry, significantly affect the microstructural characteristics and, consequently, the corrosion behaviour of these alloys. Therefore, the chosen alloys should be processed under a range of conditions to comprehensively understand the correlation between FSP/SFSP parameters and the resulting corrosion performance.

2.2 FSP/SFSP processing parameters

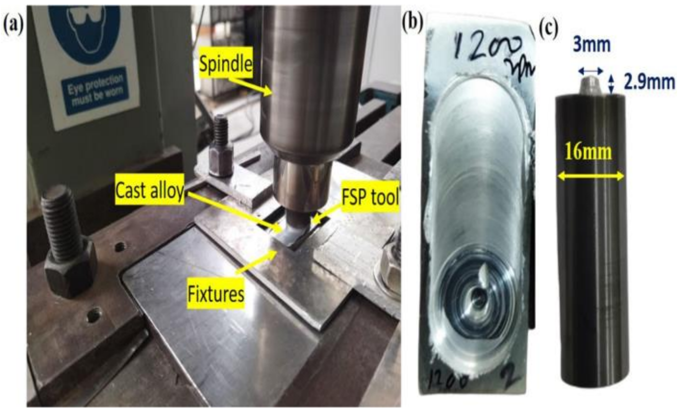

Figure 2. a) FSP setup, b) FSPed specimen, and c) FSP tool [19]

The following processing parameters are critical:

- Tool rotational speed:

The rotational speed of the FSP/SFSP tool is a pivotal parameter that influences heat generation and material flow. It is typically measured in revolutions per minute (rpm). Optimal tool rotation speed can enhance material mixing and homogenize the microstructure, which is beneficial for corrosion resistance.

- Tool traverse speed:

This parameter dictates the rate at which the tool moves across the workpiece. Measured in millimetres per minute (mm/min), the tool traverse speed affects the thermal exposure and cooling rate of the processed zone, thereby impacting the corrosion properties.

- Axial force:

The downward force applied by the tool affects the depth of material affected by the process. A balanced axial force ensures adequate material deformation without causing defects that could compromise corrosion resistance.

- Tool tilt angle:

The angle at which the tool is tilted relative to the workpiece surface can alter the pressure and shear forces during processing, affecting the microstructure and, consequently, the corrosion behaviour.

- Shoulder diameter:

The diameter of the tool's shoulder influences the extent of the heat-affected zone and the pressure applied during processing. A larger shoulder diameter can increase heat input and material flow, affecting the corrosion characteristics.

- Pin profile:

The geometry of the tool's pin (cylindrical, threaded, tapered, etc.) plays a role in material stirring and flow patterns, which can modify the arrangement of alloy components and precipitates, impacting corrosion resistance.

- Tool material:

The composition and properties of the tool material can affect the wear of the tool and the potential transfer of tool material to the workpiece, which may influence the corrosion behaviour of the processed alloy.

For instance, a study has shown that a combination of a rotational speed of 600 rpm and a traverse speed of 70 mm/min resulted in the lowest corrosion rate for a pure commercial aluminium. These parameters are essential for tailoring enhancing the microstructure in order to boost resistance against corrosion while maintaining the mechanical properties of the aluminium alloys.

It is important to note that the optimal processing parameters may vary depending on the specific aluminium alloy being treated and the desired corrosion resistance characteristics. Therefore, systematic experimentation and analysis are required to determine the most effective FSP/SFSP conditions for each application.

3. CORROSION TESTING METHODOLOGY

The evaluation of corrosion resistance for aluminium alloys subjected to FSP/SFSP is conducted through a systematic approach that encompasses both electrochemical and physical examinations. The methodology is structured as follows:

3.1 Sample preparation

Post-FSP/SFSP aluminium alloy specimens are prepared to standardized dimensions. Surface finishing is performed to ensure consistency across test samples. The specimens are then cleaned and degreased prior to testing.

3.2 Surface chemistry

Surface chemistry refers to the study of chemical reactions and processes that occur at the interface between two phases, such as a solid surface and a gas or liquid. It focuses on understanding the behaviour of molecules, atoms, and ions at the surface of materials and how surface properties influence chemical reactions and interactions.

Key aspects of surface chemistry include:

- Adsorption: The adhesion of molecules or ions from a gas or liquid onto a solid surface. Adsorption can be physisorption (weak, reversible interactions) or chemisorption (strong, chemical bonding).
- Surface Reactions: Chemical reactions that take place on the material surface reactions can occur between adsorbed species and surface sites, resulting in the creation of new compounds or products.
- Surface Energy: Refers to the energy linked with a material's surface, impacting characteristics such as wettability, adhesion, and catalytic activity.
- Surface Structure: Pertains to the organization of atoms or molecules at the material's surface, which can differ from the bulk structure and impact surface properties.
- Catalysis: Surfaces can act as catalysts by providing active sites for chemical reactions to occur. Understanding surface chemistry is crucial for designing efficient catalysts.
- Corrosion and Passivation: Surface chemistry plays a key role in the corrosion resistance of materials. Passivation, where a protective oxide layer forms on the surface, can inhibit corrosion.
- Surface Modification: Techniques like surface functionalization, coating, and thin film deposition alter the surface chemistry of materials for specific applications.

By understanding and manipulating surface composition, structure, and reactivity, it can achieve targeted modifications for enhanced performance.

3.2 Electrochemical testing

- Potentiodynamic polarization:

A potentiostat is employed to measure the polarization behaviour of the specimens. The Tafel extrapolation method is utilized to determine corrosion potential (E_corr) and corrosion current density (i_corr).

- Electrochemical impedance spectroscopy (EIS):

EIS tests are conducted to evaluate the impedance characteristics of the oxide film and the charge transfer resistance at the metal/solution interface.

- Salt spray testing (ASTM B117):

Specimens are exposed to a salt spray environment to simulate accelerated corrosion conditions. The duration of exposure is determined based on the expected service environment of the alloy.

3.3 Physical examinations

- Visual inspection:

Following electrochemical testing, specimens are visually inspected for signs of pitting, crevice corrosion, or other forms of degradation.

- Microstructural analysis:
  - Optical Microscopy and Scanning Electron Microscopy (SEM) are used to study how the structure changes after corrosion testing.
  - Energy Dispersive X-ray Spectroscopy (EDS) is used to analyze the elements present at the corrosion sites.

The collected data from electrochemical tests and physical examinations are analysed to draw correlations between FSP/SFSP parameters and corrosion behaviour. Statistical tools are employed to validate the significance of the results.

3.5 Reporting

The findings are compiled into a comprehensive report detailing the corrosion resistance of the aluminium alloys post-FSP/SFSP treatment. Recommendations for optimizing FSP/SFSP parameters to enhance corrosion resistance are provided.

This methodology provides a robust framework for assessing Studying how aluminium alloys are affected by FSP/SFSP methods helps researchers understand how these techniques can make the material perform better in corrosive settings.

4. CONCLUSIONS

The thorough study of how aluminium alloys react to corrosion subjected to Friction Stir Processing (FSP) and Submerged Friction Stir Processing (SFSP) has yielded significant insights into the microstructural and electrochemical impacts of these advanced material processing techniques. The study has demonstrated that FSP/SFSP can effectively modify the surface and near-surface regions of aluminium alloys, leading to enhanced grain refinement, homogenization of precipitates, and alterations in the oxide film characteristics.

Electrochemical analyses have revealed that FSP/SFSP-treated aluminium alloys exhibit modified corrosion potentials and passivation behaviours, suggesting an improved resistance to localized corrosion phenomena such as pitting and crevice corrosion. The salt spray tests further corroborate these findings, indicating a prolonged resistance to corrosive attack in simulated marine environments.

The correlation between FSP/SFSP was found by the researchers that figured out how to adjust things like how fast a tool spins, how fast it moves along, and how much force is applied in order to make aluminium alloys more resistant to corrosion.

This gives us a way to tweak these settings to get the best results in preventing corrosion.

The study also shows that using FSP/SFSP can help customize the corrosion resistance of aluminium alloys for different uses, especially in industries where durability and strength are very important.

In conclusion, FSP and SFSP are effective methods to improve the ability of aluminium alloys to resist corrosion. This research contributes to the field of corrosion science and materials engineering by offering a pathway to extend the service life of aluminum alloy components, thereby supporting their sustainable use in various industrial sectors.

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