Optimization of the controlled cooling condition in batch-type furnace for the recycled Al-Mg-Si based alloy sheets

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In this study, the shape, size and distribution of precipitates and/or clusters according to the alloy composition (Mg: 0.4 ~ 0.8 w.t. %, Si: 0.6 ~ 1.2 w.t. %) of Al-Mg-Si based alloy sheets were simulated by Monte Carlo method in the condition of batch-type heat treatment process. Based on the results, the precipitates and clusters in the suggested cooling with and without pre-aging conditions (Solid-solution condition: 400 ~ 500 ºC, cooling condition: ~150 ºC, pre-aging condition: 80 ~ 120 ºC) were predicted by Matcalc software (computer simulation of phase transformation and microstructure evolution in metallic systems). The optimized heat treatment conditions derived based on the analysis results were applied to the small-sized coils, and the microstructure and mechanical properties were evaluated respectively. Most cluster sizes were less than 5nm observed in HRTEM. The yield stress and elongation to failure were above 100 MPa and 25 %, respectively. In addition, the Al-Mg-Si based sheets containing the scraps of combinations of 3xxx, 5xxx and 6xxx series sheets were heat treated in the same condition, and microstructure and mechanical properties of the heat-treated recycled sheets were evaluated.

Keywords: *aluminum, batch-type furnace, Pre-aging, heat-treatment simulation, solid-solution*

1. Introduction

Aluminum alloy sheets have revolutionized the transportation industry by providing lightweight yet strong materials that contribute to increased fuel efficiency, reduced emissions, and improved overall performance in various modes of transportation. In this introduction, we will explore the importance and applications of aluminum alloy sheets in transportation. Al-Mg-Si alloys are a subset of aluminum alloys, renowned for their excellent combination of strength, corrosion resistance, and weldability. The primary alloying elements in these materials are aluminum (Al), magnesium (Mg), and silicon (Si). These alloys are typically heat-treated to achieve the desired mechanical properties, and natural aging plays a crucial role in this heat treatment process.

Natural aging is a crucial phenomenon in the metallurgy of Al-Mg-Si based alloys, which are commonly used in various industrial applications, including aerospace, automotive, and structural components. This process is integral to the development of desirable mechanical properties and the enhancement of material performance over time. In this introduction, we will delve into the concept of natural aging, its significance in Al-Mg-Si alloys, and its impact on microstructure and properties of the alloys. Natural aging, also known as ambient temperature aging or room temperature aging, is a time-dependent phase transformation that occurs after the initial heat treatment of Al-Mg-Si alloys. It involves the precipitation of fine, coherent, and semi-coherent strengthening phases within the alloy's microstructure. The primary strengthening phases that form during natural aging are typically θ' and θ'', which are metastable phases rich in aluminum and silicon.

The process of natural aging begins immediately after quenching the alloy from a high-temperature solution treatment and artificially aging it. During the initial stages of cooling, some solute atoms, such as magnesium and silicon, become supersaturated within the aluminum matrix. As the alloy gradually returns to room temperature, these solute atoms start to diffuse and cluster together to form the strengthening phases. This precipitation process is highly sensitive to time and temperature, and it continues to evolve over an extended period, even at ambient conditions.

The effects of natural aging on Al-Mg-Si based alloys are profound. As the precipitates grow and multiply, they hinder dislocation movement within the crystal lattice, leading to significant improvements in strength and hardness. Additionally, these precipitates can also enhance resistance to corrosion and stress corrosion cracking. The balance between strengthening and ductility is crucial, and it can be tailored by controlling the aging time and temperature.

Continuous heat treatment processes are essential in the production of Al-Mg-Si alloy sheets, as they enable precise control over the material's microstructure and mechanical properties. In this introduction, we will explore the concept of continuous heat treatment for Al-Mg-Si alloy sheets, its significance in achieving desired material characteristics, and its role in enhancing the performance of these sheets in various applications.

The continuous heat treatment process for Al-Mg-Si alloy sheets typically involves the following key steps:

Homogenization: The alloy sheets are heated to a specific temperature to ensure uniform distribution of alloying elements and remove any segregation or inhomogeneity that may have occurred during previous processing stages. This step is critical for achieving consistent material properties.

Solution Heat Treatment: After homogenization, the sheets are rapidly quenched to a specific temperature to dissolve any precipitates that may have formed. This step is essential for maintaining the alloy in a supersaturated solid solution state, which is necessary for subsequent aging.

Aging: Aging is the heart of the continuous heat treatment process. During this phase, the alloy sheets are held at a controlled temperature for a specified duration. This allows for the precipitation of fine and evenly distributed strengthening phases, such as θ' (theta prime) and θ'' (theta double prime), within the microstructure. The selection of aging temperature and time is crucial in tailoring the mechanical properties of the sheets, including strength, hardness, and ductility.

Cooling and Coiling: After the aging process, the sheets are typically cooled and coiled for further processing or storage. The cooling rate and coiling conditions can also influence the final material properties.

Continuous heat treatment processes are integral to the production of high-quality Al-Mg-Si alloy sheets. They provide the means to control the microstructure and mechanical properties of these sheets, resulting in materials that meet the stringent demands of various industries. This approach ensures consistent, efficient, and cost-effective manufacturing of alloy sheets for a wide range of applications. However, batch-type heat treatment process can perform various heat treatment conditions and has a lower process cost compared to continuous heat treatment. Therefore, the microstructure and mechanical properties of the Al-Mg-Si alloys through the batch-type heat treatment process for automotive is actively researched. In this study, in order to meet the mechanical properties and microstructure of the Al-Mg-Si alloy sheet through the continuous heat treatment process, the batch-type heat treatment conditions of the alloy were derived through simulation results, and the microstructure and mechanical properties of the annealed sheet treated by batch-type condition were analyzed.

2. Experimental

In this study, the shape, size and distribution of precipitates and/or clusters of the 6061 alloy were simulated by Monte Carlo method in the condition of batch-type heat treatment process. Based on the results, the precipitates and clusters in the suggested cooling with and without pre-aging conditions (Solid-solution condition: 400 ~ 500 ºC, cooling condition: ~150 ºC, pre-aging condition: 80 ~ 120 ºC) were predicted by Matcalc software (computer simulation of phase transformation and microstructure evolution in metallic systems). The optimized heat treatment conditions derived based on the analysis results were applied to the small-sized coils, and the microstructure and mechanical properties were evaluated respectively.

3. Results and Discussion

The microstructure analysis of the 6061 alloy sheets treated in the batch type furnace revealed significant changes in the material's grain structure. Prior to heat treatment, the alloy exhibited a coarse and non-uniform grain structure. However, after the heat treatment process, the microstructure showed a finer and more uniform distribution of grains. This is indicative of the recrystallization and grain refinement that occurred during the heat treatment. The mechanical properties of the 6061 alloy sheets were significantly improved after treatment in the batch type furnace. This improvement can be attributed to the precipitation hardening effect resulting from the heat treatment process.

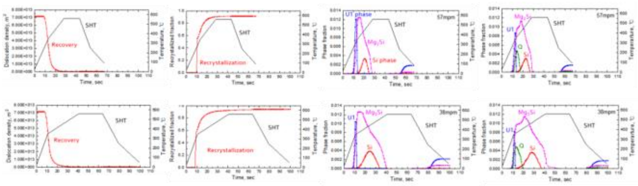

Figure 1. Simulation results of 6061 alloy sheet under continuous heat treatment condition

4. Conclusion

The observed finer and more uniform grain structure post-heat treatment is essential for improving the mechanical properties of the alloy. Smaller grain sizes contribute to increased strength and ductility. The increase in hardness and mechanical strength is primarily attributed to the formation of strengthening precipitates, such as Mg_2Si, within the alloy matrix. These precipitates hinder dislocation movement and enhance the strength. Discuss the specific heat treatment parameters used in the batch type furnace, including temperature and soaking time. These parameters play a crucial role in achieving the desired microstructure and mechanical properties.