Impact of Aluminium Ageing in an Industrial Stamping Process

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Abstract. The automotive industry's efforts to reduce vehicle weight are driving the increasing adoption of aluminium alloys in vehicle chassis components. However, using aluminium alloys introduces challenges in forming processes, influenced by diverse factors such as material storage conditions and natural ageing, which can affect the formability. The present study investigates the effect of natural ageing on the formability of the AW 5754-H111 alloy by examining two storage conditions: as received (no ageing) and aged for two months. Formability tests were performed to characterise the mechanical behaviour and determine the material's formability limits. During these tests, the Portevin-Le Châtelier (PLC) effect, a plastic deformation instability, was observed. Its temperature dependence was further examined through controlled-temperature tests. Additionally, the study incorporated experimental and numerical analyses of an industrial stamping process for a component made from this alloy. Key findings include the characterisation of formability limits under different ageing conditions in the principal strain space, an analysis of the PLC effect across diverse temperature ranges and fracture modes, and validation of numerical models against experimental results for the diverse stamping stages. This work provides valuable insights into the mechanical performance of aged aluminium alloys in industrial applications.

Keywords: Sheet metal forming; Aluminium alloy; Formability; Portevin-Le.Châtelier (PLC) effect

1 Introduction

The automotive industry faces pressure to cut emissions, increasing the demand for lightweight materials. Aluminium alloys, especially 5000-series like AW 5754, offer a solution due to their low density and strong mechanical properties. With magnesium as the main alloying element, AW 5754 provides corrosion resistance, stiffness, and high yield strength while keeping weight minimal, helping manufacturers meet strict reduction targets [1].

Despite these advantages, 5000-series aluminium alloys are primarily used for interior applications due to their susceptibility to surface irregularities, particularly the Portevin-Le Châtelier (PLC) effect. This form of plastic instability is prevalent in Al-Mg alloys and is significantly influenced by two key factors: temperature and strain rate [2].

Understanding sheet metal forming processes, particularly the stamping process, is crucial for maintaining high-quality manufacturing standards, as process success depends on material properties and deformation conditions. While research on sheet metal forming is extensive, studies on the impact of storage time or natural ageing on material formability remain limited. This paper examines how natural ageing affects the mechanical properties of AW 5754-H111 aluminium alloy, investigates the Portevin-Le Châtelier (PLC) effect and its temperature dependence, and validates a numerical stamping analysis through experimental data to ensure reliability in real-world applications.

2 Experimental work

This section outlines the experimental procedures used to mechanically characterize the AW 5754-H111 sheet with 2.1 mm thickness and determine its formability limits under two different storage conditions. Condition A, which represented the as received state with no natural ageing, and Condition B, where the material was aged for two months in the warehouse. Mechanical characterization was performed using tensile tests following the ASTM Standard E8/E8M-22 [3], and formability limits were evaluated through a variety of tests, including tensile, Bulge, Nakajima, and notched formability tests under quasi-static conditions.

The filed variables, such as strains and displacements, were measured by means of a Dantec Dynamics Q-400 DIC system, using two cameras to capture high-resolution images. The temperature-controlled tests were performed using an INSTRON 5966 with an integrated INSTRON 3119-606 furnace.

3 Results and Discussion

Fig. 1 presents the formability limits for both conditions A and B. The forming limit curves (FLC) were

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determined using two distinct methods applied in the Nakajima tests: the planar valleys method [4] and the ISO Standard 12004-2 [5]. While there is some variation between the two conditions, it is not significant enough to alter the formability limit curve. Therefore, the graph in Fig. 1 represents the forming limit curve (FLC_A) from condition A, along with the necking points from condition B. Additionally, the fracture points show minimal variation. The fracture forming limit (FFL) and the shear fracture forming limit (SFFL) for aged condition B are similar to the limits of condition A.

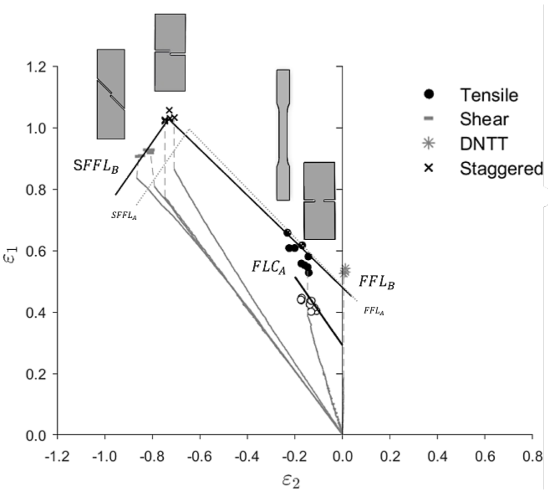

Fig. 1. Representation of the forming limits in the principal strain space for both conditions.

Fig. 2 presents the true stress vs. true strain curves from tensile tests for the range of temperatures analysed, from 50°C to 125°C. At room temperature (20°C), the serration observed is less intense than at temperatures between 50°C and 100°C. From 107°C onwards, the PLC effect is almost entirely suppressed, and the serration in the plastic zone of the curves becomes less noticeable, with the band amplitude decreasing by approximately 58.02% compared to the serration at 100°C.

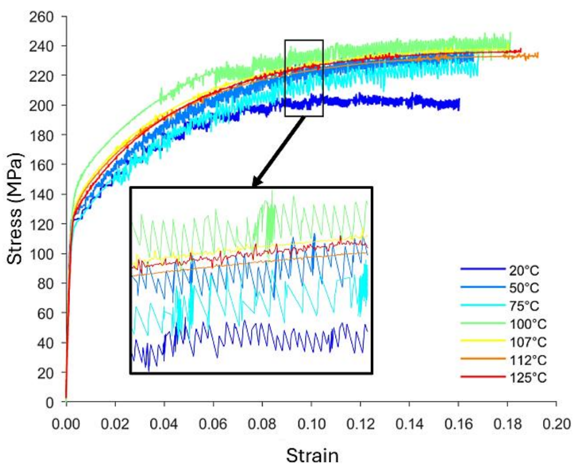

Fig. 2. True stress-strain curve for temperatures ranging from 20ºC to 125ºC.

In Fig. 3, the numerical strain values along the analyzed trajectory closely match the experimental results, positioning them within the pure shear region in the principal strain space. The third stamping operation exhibits the highest strain levels, making it the most representative choice for inclusion in the figure.

When analyzing the principal strain results from the stamping operation, it is essential to account for experimental findings from temperature-controlled tensile tests, as higher temperatures are linked to reduced formability. As temperature increases, both numerical and experimental principal strain values along predefined trajectories tend to move closer to the unsafe zone, increasing the risk of unexpected necking. This occurs because rising temperatures lower the formability limit curve. This correlation highlights the critical need to monitor temperature during the stamping process, as it directly affects the material's integrity and performance.

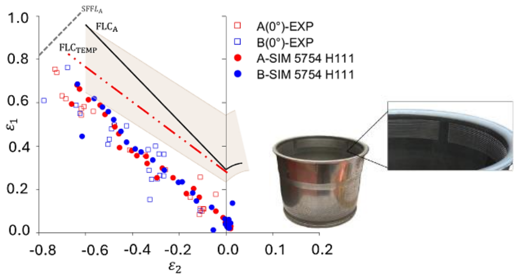

Fig. 3. Comparison of experimental and numerical results for the principal strain fields in the third stamping operation to manufacture the outer guide.

4 Conclusions

This study assessed the impact of storage time on the formability of AW 5754-H111 aluminium alloy, finding that a two-month ageing period had no significant effect on mechanical properties or formability limits. Fracture limit slopes varied by approximately 6.5%.

The research also examined Portevin-Le Châtelier (PLC) instabilities, showing that natural ageing does not affect PLC, but the temperature does. Instabilities were reduced by 58.02% at 107–125°C but intensified at 20–75°C. Formability decreased with temperature in Mode I but improved in Mode II, peaking at 175°C in shear tests.

Numerical analysis of the Outer Guide stamping process aligned well with experimental data, confirming model reliability. The second and third stamping operations were critical, as higher temperatures increased the likelihood of principal strain values reaching the unsafe zone.

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