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# Experimental and numerical investigations of yield surface, texture, and deformation mechanisms in AA5754 over low to high temperatures and strain rates

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ABSTRACT

The effects of strain rate and temperature on the yield and flow stress of AA5754 sheets are presented under uniaxial (tension and compression), dynamic (tension), and simple shear loading conditions. The present study investigates the anisotropic behavior of AA5754 sheets through experiments performed in the rolling (RD), 45° to rolling (DD), and transverse to rolling (TD) directions at room and elevated temperatures. The experimental results show that the strain rate sensitivity varied from negative at room temperature to positive at elevated temperatures (>150 °C), and the anisotropy was inversely proportional to the strain rate. Texture analysis was conducted on the specimens after uniaxial tension and simple shear deformation, using the neutron diffraction and electron back-scattered diffraction (EBSD) techniques. Rotation rate maps and orientation stability parameters, determined by the rate-sensitive model, were used to explain the kinematic stability of the initial texture components in AA5754 sheets during uniaxial tension and simple shear deformation. A visco-plastic self-consistent (VPSC) polycrystal model was used to simulate the evolution of the initial texture components in AA5754 sheets during uniaxial tension and simple shear deformation.



## 1. Introduction

The increasing use of aluminum in the automotive industry is mainly governed by the need for lower fuel consumption, which requires reducing the weight of the vehicle, thus providing the most energy efficient solution (Cole and Sherman, 1995). The replacement of steel with aluminum decreases the weight by as much as 40% as a result of its high strength-to-weight ratio. In addition, other qualities of sheet aluminum alloys — (1) high formability in stamping while retaining strength, (2) uniform, smooth surface after forming, and (3) high quality finish — make them desirable materials for use in the automotive industry (Burger et al., 1995). Therefore, investigations of 5xxx series aluminum alloys have focused on

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the Portevin-Le Chatelier (PLC) effect, strain rate sensitivity, strain hardening and texture evolution, since these factors affect the structural response during forming operations and in crash failure.

Uniaxial tension experiments have been carried out on 5xxx series alloys by several researches (Naka and Yoshida, 1999; Wagenhofer et al., 1999; Sarkar et al., 2001; Li and Ghosh, 2003; Clausen et al., 2004; Picu et al., 2005; Kang et al., 2006; Abedrabbo et al., 2007; Hadianfard et al., 2008; Khan and Baig, 2011). These studies concluded that the stress–strain curves show serrated flow behavior at lower temperatures. However, there was an absence of serrated flow and a decrease in flow stress at elevated temperatures. The former was due to DSA, while the latter can be attributed to the increase in the mobility of the solute atoms, which eliminates the serrated flow behavior. In addition, AA5754-0 and AA5182 sheets softened at 121 and 93 °C, respectively, and there was a steady decrease in strain hardening and an increase in SRS with increased temperature (Abedrabbo et al., 2007). Picu et al. (2005) reported negative SRS for temperatures ranging from −100 to 80 °C, i.e., the DSA mechanism dominated the behavior in this temperature range. The work of Park and Niewczas (2008a) on AA5754 alloy revealed two kinds of flow instability, the PLC effect at room temperature and adiabatic deformation at −270 °C. Almost all uniaxial tension experiments are performed using hydraulic or screw-driven tensile testing systems, and the resultant strain measurements were obtained using an extensometer or machine displacement. However, Kang et al. (2006) used digital image correlation (DIC) to measure full field strain and the SEM topography image correlation technique was used to perform strain mapping to the grain level. Biaxial experiments were also performed by Iadicola et al. (2008) on AA5754-O sheet alloy, and stresses were measured using the X-ray diffraction method.

High strain rate tension experiments by Smerd et al. (2005) on AA5182 and AA5754 sheets, using a tension split Hopkinson bar (TSHB), showed that both alloys exhibited significant increases in ductility under a dynamic regime. A comprehensive study was recently performed by Khan et al. (2009,2010a,b) on high- and low-hardening Al alloys, and they reported that the small scale yield surfaces showed completely different behaviors with different proportions of isotropic and kinematic hardening. Uniaxial and biaxial compression experiments on sheet alloys were initially performed by Tozawa (1978) using a rectangular specimen by stacking and gluing the sheet material. However, recent studies by Boger et al. (2005) and Lou et al. (2007) developed a new technique for in-plane compression experiments for sheet materials. In this technique, two flat steel plates and a hydraulic cylinder system are used to stabilize the sheet sample, and the stress–strain curves are obtained after making corrections for the friction between sample surfaces and supporting plates. Bouvier et al. (2006b) performed proportional and non-proportional simple shear experiments on AA5182-O to study the monotonic responses and Bauschinger effect. They concluded that the strain hardening increased with monotonic deformation, and no work-hardening stagnation was observed during strain path reversal with a small Bauschinger effect. Recently various experiments and modeling on various alloys and in particular Al alloys were reported by Ghavam and Naghdabadi (2011), Khan and Liu (2012), Brahme et al. (2011), Hamelin et al. (2011), Luo et al. (2012) and Sung et al. (2010) and explained the deformation mechanism at various strain rates, loading history and temperatures. However, a comprehensive study on AA5754 sheets has not been conducted, and the temperature dependence of SRS under various loading conditions, such as uniaxial (tension and compression) and simple shear loading, has not been determined.

Texture measurements on AA5754 alloy have been reported by Park and Niewczas (2008b) using Cu K$\alpha$ radiation. (1 1 1) and (2 0 0) pole figures showed that the commercial strip cast (SC) material (both as-received and annealed) exhibited a typical rolling texture with the β-fiber extending from copper to the Brass texture components. In the case of a deformed specimen under tension in the rolling direction (RD) at 4.2 and a 300 K temperature range with an initial strain rate of $10^{-4}\ s^{-1}$, the <1 1 1> and <1 0 0> are stable and meta-stable end orientations. Kang et al. (2006) used the electron backscattering diffraction (EBSD) technique to determine the evolution of texture during tensile deformation, and revealed that there was no significant change in the volume fraction of eight primary texture components with increasing strain under tensile deformation. The results of the texture evolution of an AA5754 sheet were presented by Banovic et al. (2008) at different levels of strain under various strain paths (uniaxial tension, plane strain, and equibiaxial tension). It was found that similar deformation textures developed in the RD- and TD-oriented samples under each mode of deformation. However, the evolution of specific orientations depended upon the amount of deformation and the initial intensity of the texture components in the as-received material. While the basic observation of texture evolution in the AA5754 sheet was conducted for uniaxial, plane strain, and equibiaxial tension in the previous studies, absent from these works was the theoretical analysis explaining why the initial texture components depended upon the macroscopic deformation state. However, as far as we could ascertain, no study has yet documented the texture evolution and kinematic stability of initial texture components in the AA5xxx during simple shear deformation.

The main objective of the present study was to provide comprehensive experimental results for AA5754 sheets over a wide range of strain rates and temperatures using the same batch of material. This includes strain hardening, flow behavior and anisotropy under quasi-static, dynamic and simple shear loading conditions. The comprehensive experimental results provided the temperature dependence of SRS under various loading conditions such as uniaxial (tension and compression) and simple shear loading conditions. Texture measurements were performed to explain the evolution of the initial texture components in the RD- and TD-oriented samples during uniaxial tension and simple shear loading conditions. Moreover, a rate-sensitive polycrystal model (Choi et al., 2000a,b) was used to calculate the effect of the loading direction on the kinematic stability of initial texture components in the AA5754 sheet during uniaxial tension and simple shear deformation. A visco-plastic self-consistent (VPSC) polycrystal model (Molinari et al., 1987; Choi et al., 2000, 2007) was also used to simulate the evolution of the initial texture components in the AA5754 sheet during uniaxial tension and simple shear loading.