A Review of Anisotropy in Al-Li (2195) Alloy for Aerospace Applications

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Introduction

Studies of the various high strength aluminum alloys highlight the significant interests of aerospace industry to Al-Li alloys. It has been concluded that the various particles that form during natural and artificial aging provide barriers to dislocation motion during the micromechanical process of slip, which is the microstructural mode of deformation for most metallic materials. This impedance provides these materials with improved strength properties over conventional aluminum alloys while their various chemical compositions lead to lower densities than their conventional counterparts. Al-Li alloys are typically anisotropic and they exhibit strong textures. The texture or crystallographic orientation of a material is a measurement of the orientation of crystallographic planes in specific directions, namely the rolling, transverse, and normal directions of a sample.

Anisotropy of mechanical properties in different directions of measurement is a concern in the forming of metals into shapes and parts. It is tied into considerations of the yield locus. Various factors cause anisotropy in metals, including elongated grains [4], and the presence of second-phase precipitates. Researchers agree that crystallographic textures or preferred orientations resulting from thermomechanical treatment such as hot or cold rolling or stretching are most directly responsible for anisotropy in metal alloys. For Al-Li alloys, crystallographic texture may also have an indirect effect on anisotropy resulting from the heterogeneous distribution of the primary strengthening precipitates on specific habit planes. For these reasons, texture analysis is important for characterization of Al-Li materials.

Several sources summarize the sources of texture and its effects on mechanical properties. In brief, texture arises from the rotation of material grains during the slip process when deformation occurs, which subsequent produces rotation of the crystallographic planes within the crystals comprising the grains. There is a limited number of slip systems available during slip, therefore the rotations occur towards a limited number of 'end-points' thus producing a deformation texture. Therefore the resulting texture depends on the nature of the imposed stress system and it reflects the symmetry of the forming operation.

Pole figures are graphical representations of texture. They are stereographic projections that show the distribution of particular crystallographic directions relative (usually) to material directions such as the rolling direction (RD) and transverse direction (TD) in sheet materials. A pole figure exhibiting a typical rolling texture reflects the symmetry of the rolling process in that certain crystallographic planes are aligned parallel to the rolling plane and particular directions in these planes are parallel to the rolling direction. While pole figures are useful in the analysis of texture, they are merely qualitative representations of texture. On the other hand, the orientation distribution function (ODF) gives quantitative information about the spread of orientations throughout the texture of a material. As a full mathematical description, it can be applied objectively in understanding texture development and in the prediction of anisotropic properties.

Experimental Procedure

Material

The Al-Cu-Li 2195 material used in this investigation was produced at Reynolds Metals Co. as 3.81 cm-thick plates in the T3 condition (heat treated and cold rolled); the weight percentages of the aluminum alloying elements are given in Table I.

Table 1: Chemical Composition of 2195 Al-Li Alloy

Al	Cu	Li	Fe	Mg	Mn	Si	Ti	Zn	Zr	Ag
Balance	3.9	0.9	0.04	0.33	≤ 0.01	0.2	0.02	0.01	0.14	0.32

The as-received plate was cut into sections then solutionized in air for one hour at 540±C following with a water quench. Subsequently, the sections were additionally cold rolled to various thickness reduction percentages (0, 10, 20, and 30% reductions) to induce various amounts of deformation.

Hardness Distribution through Thickness

In order to obtain a general profile of the hardness through the thickness of the plate, hardness measurements were made at seven positions through the thickness of the plate as shown in Fig. 1.

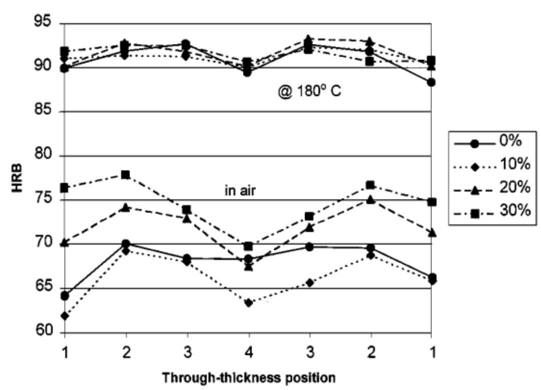

Figure 1 Through-thickness hardness variation of rolled and aged plates.

Rockwell B-scale measurements were carried out at a position near the plate surface, at the center of the plate, and at two positions between the center and the surface on both sides of the center. Assuming the characteristics of the plates to be symmetric about the center, the positions of the measurements were numbered from either plate surface starting at one, through four, at the plate center. Specifically, the distance from the surface to the measurements at position one was near 5% of the total thickness of the plate. The other measurements were spaced apart approximately 15% of the total plate thickness. A notation for through-thickness position may be assumed such that the position is described as a percentage of the total thickness, *t*, as measured from the plate surface. In this fashion, the following designation is given: position 1D0:05*t*, position 2D0:2*t*, position 3D0:35*t*, and the center position 4D0:5*t*. It is heretofore assumed that there is agreement within a reasonable variant of measured values from one side of the plate to the equivalent position on the other side. In hardness measurements, the variation from one side to the other was as low as approximately 0.05% and up to near 3.5% (approximately 1%, due to the accuracy of the hardness tester). Subsequent tensile tests also support symmetry of characteristics about the plate center.

Texture Measurements

For texture measurement, slices approximately 3 mm thick and 25 mm£25 mm were cut from the bulk material. Polishing and etching of the surface was performed to remove the damage layer resulting from cutting.

Results and Conclusion

Figure 2 exhibits the ODFs characterizing the *0.2t* position of maximum strength (determined by hardness tests) through the thickness of the various rolled plates. The ODFs in Fig. 2 consist mainly of copper texture components with some S orientations, which diminish with increased deformation.

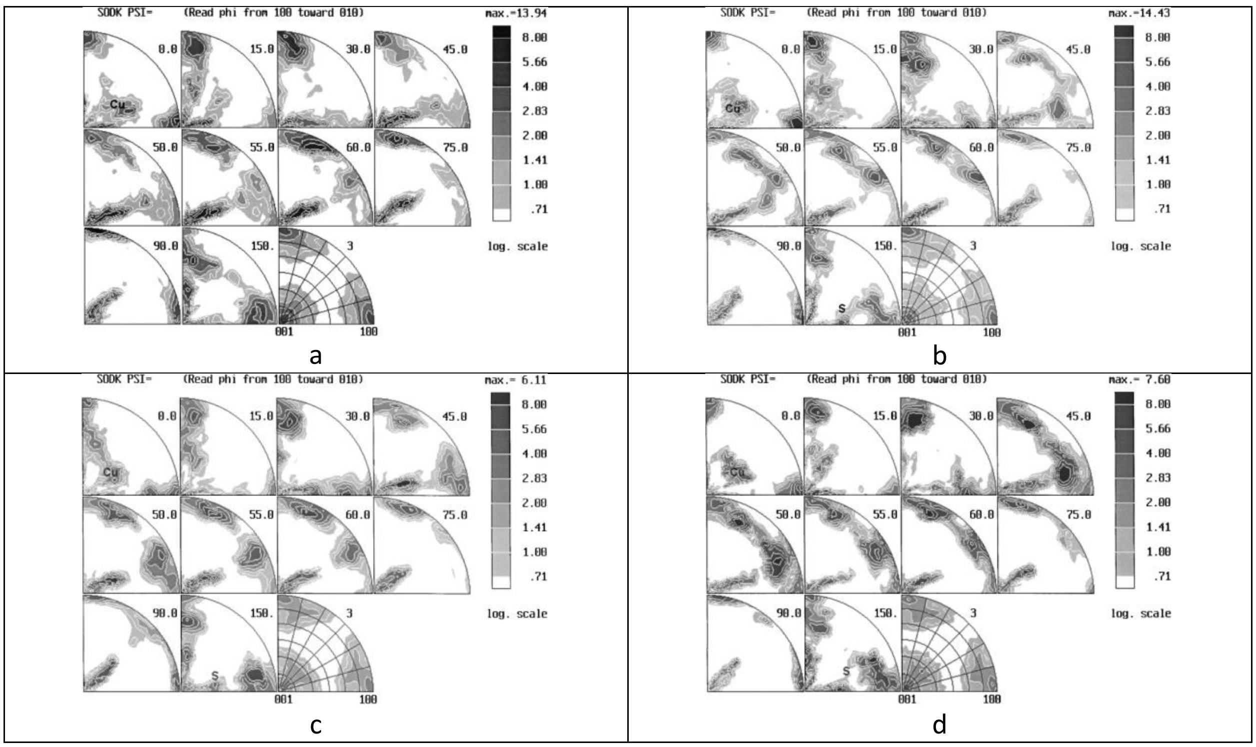

Figure 2: Examples of through thickness texture as (a) as received, (b) 0% cold work and natural aged, (c) 10% cold rolled and natural aged, (d) 10% rolled and artificial aged.

Alternatively, the textures in *0.5t* exhibit mainly a strong brass orientation. Flattening of grains during the rolling process leads to a shear misfit along the grain interfaces. Three shear misfit strains, ϵ_{xy}, ϵ_{xz}, and ϵ_{yz}, may be assumed to result from the shear forces producing the deformation.

The usual texture orientations expected for rolled aluminum alloys were generally observed in the Al-Cu-Li plate material. The copper and S orientations observed in the ODFs from the 0.2*t* through-thickness position are consistent with flat grains as may be predicted using the Taylor relaxed constraints model. The texture gradient is evidenced by comparing ODFs between the 0.2*t* and the 0.5*t* (center) position. At 0.5*t*, no copper component or significant S component is visible, whereas brass is the dominant orientation seen. The through-thickness texture variation in the plate is likely due to the differing amounts or modes of deformation experienced at different positions though the plate. Most of the rolling process is concentrated near the surface of the plate whereas the center of the plate experiences the least amount of the total deformation. Increasing the amount of deformation beyond the as received condition affects the intensity values along the ideal fibers in the Al-Cu-Li material studied. Increasing deformation does not always signal a corresponding intensity increase. In some cases, the intensity on the fiber decreases with increasing deformation. This may be due to changing modes of deformation with additional deformation.

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