THE TEXTURE AND MECHANICAL PROPERTIES OF AL-Li ALLOY SEMIPRODUCTS

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ABSTRACT - The texture of matrix phase and orientation of δ' - precipitates in sheets, rods, plates, gorgings and extruded shapes from 1420 and 1441 alloys of Al-Li-Mg and Al-Li-Mg-Cu systems were investigated by direct pole figure method using reflections of these phases. Inhomogeneity of rolled sheets, plates and rods textures resulted from the inhomogeneity of applied stress field during fabrication and recrystallization nonuniformity through the cross section. The effects of crystallographic texture, fibre and layered structures on anisotropy of yield stress and fatigue crack propagation kinetics in these materials have been discussed.

Keywords: Al-Li-alloys, δ'-phase, texture, anisotropy, microcrack, fracture.

INTRODUCTION

The fatigue crack propagating behavior strongly depends on the texture characteristics and inhomogeneity of texture through the cross section of the sheet and plate of Al-Li alloys [1-3]. The developing of delamination process, highly non-linear and tortuous fatigue crack propagation during the testing on stress-strain and fatigue behavior has been found to occur in these materials. These effects could be explained by structural inhomogeneity, texture distribution characteristics and as sequence by crack tip shielding features. The crystallographic texture, fibre and layered structures could be responsible for anisotropy of mechanical properties and inhomogeneity of these characteristics along cross section. As reported for 1420, 1441 alloys semiproducts[4-7] the contribution of crystallographic textures in rolling sheets and extruding rods to yield stress anisotropy enhances the effect of fibre structure. The texture, typical to 1420 alloy sheets, leads to abnormal yield stress plane anisotropy with higher value of this parameter in long-transverse direction [4,5].

The textured 8090 and 1441 plates show a fatigue crack deviation and branching and through-thickness delamination during fatigue crack propagation and fracture toughness testing [8,9]. The fatigue crack behavior of these materials which is crystallographic in character is determined by effect of the localized slip following from the matrix texture and shearable nature of δ' particles. As result the fracture mode with pronounced crystallographic-shear facets on the surface is initiated. Inhomogeneous localized deformation mode is favored by the presence of δ' particles [2, 8].

The problem of fatigue crack propagation behavior and tortuous crack path morphology formation in AL-Li alloys is not properly understood yet and intensively discussed. As it follows from above the deformation texture investigation of 1441, 1420 alloys semiproducts and distinctive features of δ'-precipitates could play an important role in these processes.

MATERIALS AND METHODS

The studied materials are 1420 and 1441 alloys in form of hot-rolled 25 mm thick plates, cold- and hot-rolled 1÷7 mm thickness sheets, extruded shapes 1÷10 mm wall thick, 100-120 mm diameter rods and forging in quenched and aged conditions.

The direct pole figures and integral function $P_{\beta=0\text{-}360^\circ}(hkl) = f(\alpha)$ for angle-interval from 0° to 75° was constructed by means of automatic texture goniometer DART-UM1 using CuK_α X-ray radiation. The matrix texture was analyzed by (220) and (400) pole figures, δ'-phase texture - by (100) and (110) pole figures.

The center-notched fatigue (CNF) specimens 160 mm in width cut from 7 mm thick sheets and 5 mm thick, 200 mm in width specimens cut from central part of 25 mm thick plate are used to perform the test on fatigue crack propagation and R-curve. All tests were curriedd out under constant cycle load at a frequency 5 Hz in lab air.. The specimens for eccentric tension test were cut from 25 mm plate. Tensile test determined by standart specimens. Microstructure and fracture surface relief were examined by optic microscope-goniometer and electron scanning microscope .

EXPERIMENTAL

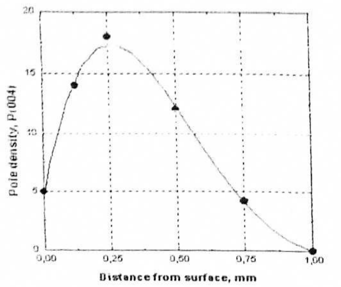
The inhomogeneity of a texture is characteristic feature of the all investigated sheets and plates from 1 to 25 mm in thickness independent of a rolling operating. The brass-type texture {110}<112> together with the incomplete axial components {110}÷{531}<112> or {110}÷{311}<112> (angle rotating around rolling direction from 19° to 32°) was developed at central layers of rolling semiproducts. At surface layers the components of shear texture {111}<110> and {001}<110> arise. The second component was accompanied by orientations {113}<332> and {112}<111> which related with {001}<110> by rotation around long-transverse direction <110> on angles 25° and 35°. The formation of last two components was related with further shear deformation of material possessing {001}<110> texture. The highest values of pole density of {001}<110> and {111}<110> shear textures corresponds to layers spaced from 0.1 to 0.25 of thickness (t) apart surface. For example in 2 mm 1441 alloy sheet the pole density of shear-texture {001}<110> maximum is 20 units for layers situated at 0.1t, and it approaches zero at 0.25t.

The brass-type texture with scattering ±20° dominated at central layers of these sheets. During heat treatment the recrystallization processes are developed more intensively in near-surface layers with shear-type texture. The contribution of cubic orientation to recrystallization texture is relatively small, several percent from volume. Abnormal plane anisotropy of yield stress (~10%) is the sequence of the plane deformation texture with high Taylor factor $\bar{M}$ in long-transverse direction <111>.

The macrostructure examination of complex-shaped 1441 alloy forging indicates that the turbulent metal flow during fabrication occurs. As result the shear-texture {123}<541> throughout the cross section develops. This type of texture is related to the plane deformation texture {110}<112> by means rotating around long-transverse direction <111> on 19°.

The homogeneous texture {110}÷{311}<112> was observed in 1420 alloy extruded shapes with shelves and edges thickness from 1 to 10 mm. The exception is the thin surface layers 0.02÷0.5t. In the contrary to the rolling-sheet symmetric shear-texture in these layers asymmetric shear-texture (001)[110]÷(113)$[3\ 3\ \bar{2}]$ arises, Fig.1,2. The lack of layer-by-layer texture inhomogeneity in these semiproducts follows apparently from the homogeneous character of stress distribution in material during deformation. The recrystallization of extruded shapes with homogeneous texture is uniform and the recrystallization cubic texture fraction is 20% in all layers. As calculated the fraction of (001)[100] texture lowers the averaged Taylor factor $\bar{M}$ up to 8%. Crystallographic anisotropy of yield stress in these extruded shapes was not revealed by mechanical testing due to opposite effect of fibre texture.

The texture of 1420 alloy rods dia. 100÷120 mm is highly inhomogeneous through the cross section and is composed of two axial components <100>+<111>. The ratio between these components could be varied from 1:2 to 1:3. The development of recrystallization in <100> oriented materials results in higher scattering angle of this component. The recrystallization proceeded more intensively in external than in central layers and was accompanied by the development of mixed grain structure. The grains of different shape arises: equiaxial and fibre. The crystallographic anisotropy determined by <111> texture in central zone of rod is increased by the fibre structure effect and resulted in anisotropy of yield stress value ≅ 20%.



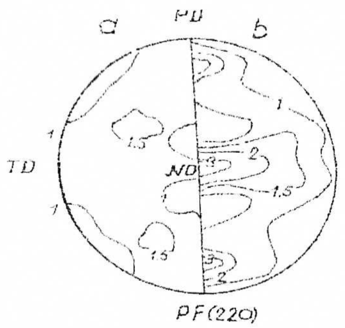


Fig. 1 The distribution pole density P(004) through 2 mm thick sheet of 1441 alloy.

Fig. 2. The texture of 1420 alloy 2 mm thick wall extruded shape across transverse section: a- for surface layer, b- for 0.07 t apart surface.

In dependence on position of layer in semiproducts and thermomechanical treatment it was observed two type of orientation relationship between δ‘ and matrix phases. As could be seen from Fig.3 in central zone of 1420 alloy rods the texture of δ‘ precipitates is similar to the matrix texture (Fig. 3a). The difference is in the values of axial component <111> pole density. At the same time at surface layers the texture of δ‘ phase is different from axial matrix texture (Fig. 3b).

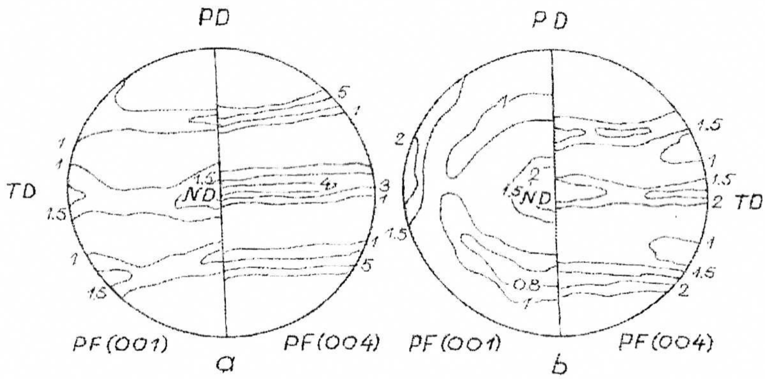
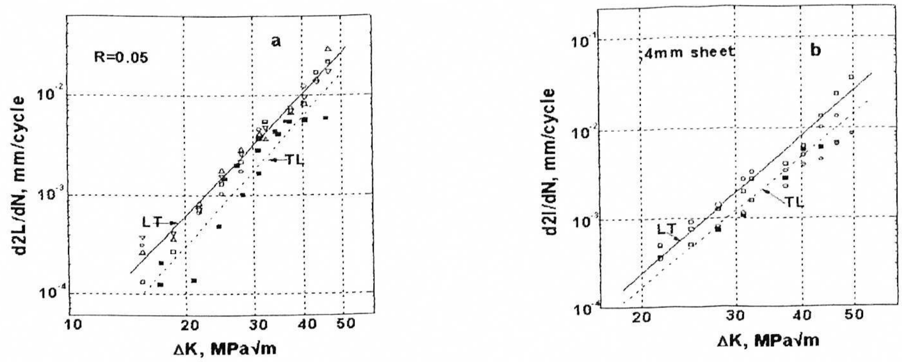


Fig. 3. The texture of 1420 alloy Dia. 120 mm extruded rod: a- inner part, b- outer part: left- δ‘- phase and right- matrix phase. PD- extruded direction.

The CNF specimens of 1441 alloy plate had the uniform plane-deformation matrix texture with domination of the brass-type {110}<112> component. The δ‘-phase precipitates beside this texture had (001)[110] + {310}<001> orientations. As have been mention above the matrix- and δ‘-texture of 1-7 mm sheets is nonuniform across the thickness and differ one another only in pole density.

Fracture surface relief depends on direction of applied stress and type of material. In 5 mm CNF specimens of 25 mm plate the fracture surface morphology is quite different for LT and TL directions. In LT specimens the crack propagation path is deviated from the plane of maximum normal tensile stress not more that 5°. The relief of fracture surface is rough in character and has a saw type profile. In TL specimens the crack propagation path takes the form of zigzag line with section of path which length is up to several cm, deflected with respect to notch direction through angles ±53°÷58°. The crack path can change their growth direction to mirror-plane symmetric relative plane parallel to the loading direction and normal to rolling plane. As result the wedge-like sections along crack line with angle 70° in apex is induced. Fracture surface has a fractal structure. One consist of intersecting facets forming diheders elongated in crack path direction with dihedral angles 70°.

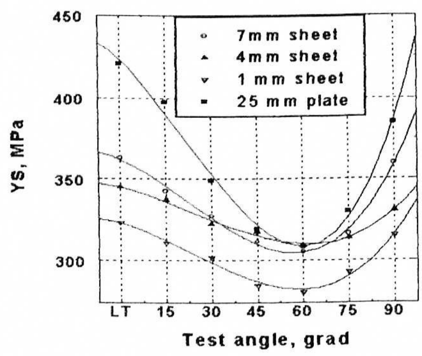
Fig. 4 demonstrates results of the test on crack propagation rate in TL and LT 5 mm CNF specimens from 25 mm plate and 1 mm thick sheet of 1441 alloy. Because of bending crack propagation character of plate in ΔK and $d2l/dN$ calculation as crack length used the value of crack projection on normal direction to the axis of applied stress. As could seen from Fig.4 the crack propagation rate in TL specimens of sheet and plate has the smaller value than one in LT specimen.



Fig/ 4 Tte fatigue crack propagation rates test in CNF specimens of plates (a) and sheets (b) in TL and LT direction.

In 7 mm sheet center-notched specimens with nonuniform texture across thickness above-mentioned fractal structure of fracture surface is observed in reduced scale. This structure is layered in character.

Ingomogeneity texture distribution charachteristics is strong nfluence on mechanical properties of standart tensile test and fracture toughness test. For example, minimal value of yield tensile strength of specimens, cut in plane rolling from 1441 alloy sheets and plates take place in 60° LT direction (Fig. 5).



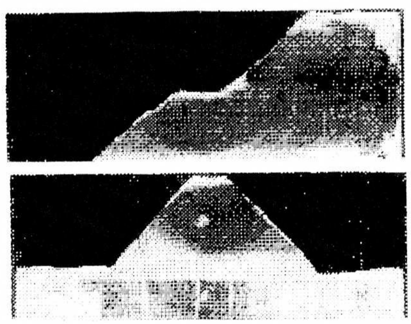


Fig. 5 The distribution Yield Tensile Strength of sheets and plates in plane rolling depend on test angle.

Fig. 6 The distortion crack pripagation in CNF specimens of 1441 alloy of 25 mm thick plate.

DISCUSSION

The investigations of specimens after mechanical test on crack propagation rates and fracture toughness by scanning microscope showed on transgranular faceted morphology of fracture surface of the plates and sheets of AL-Li alloys given an indication of crystallographic mode of crack extension. Stereographic analysis and measurements of angles between crack path and facets on the fracture surface gives an identification of crystallographic mode crack extension. The crack growth occurs by shear along to {111}<110> slip systems ahead of the crack tip. It is accepted that crack propagation behavior is related to type and extent of plastic relaxation zone around crack tip [10].

To consider the plastic relaxation mechanism around the crack tip in (110) $[\bar{1}\,1\,2]$ extruded sheets and plates, the resolved shear stress values on octahedral slip systems in the matrix and δ^1 phases for biaxial tensile stress condition was estimated. The active slip system with maximal resolved shear stress was definned. It was established that for stresses applied along $[\bar{1}\,1\,2]$ and [111] axis (LT ana TL specimens) the pairs of equal shear stressed systems (111) $[0\,1\,\bar{1}]$ $(1\,1\,\bar{1}]$ [011]the active. In result of the localized deformation by these systems, which are equal inclined to (110) plane, the diheders with angle 70° in apex o $\bar{1}$ n the fracture surface is formed.

From symmetry of the pole figures of plates and sheets it follows the availability of two mirror-plane symmetric components in {110}<112> deformation texture. During crack propagation from one to another of grains group with mirror-plane symmetric orientations the zigzag transferring of the crack path occurs. A localized deformation extent around the crack tip determines the fractal structure scale of fracture surface.

In LT specimens of plates the Shmid factors *m* for δ' and matrix phases are equal, while in TL specimens the *m* value for δ' phase have to be larger on 14%. It means the geometric softening of δ' phase in TL specimens which stimulates the planar slip localization. It is believed that the softening of the shearable δ' particles stimulates localized deformation mode, results in crack branching and thus enhances the crack propagation resistance. It demonstrates Fig. 4

In 1-7mm thick sheets the texture is inhomogeneous through the thickness. As pointed above in surface layers the {111}<110>+{001}<110> texture was developed while in central part the brass-type texture dominated. But the difference in dl/dN vs ΔK dependencies for LT and TL specimens is identical to that for 5 mm specimens cut from 25 mm plates, where the texture is homogeneous. Such behavior is determined by the fact that material of central layer plays a leading role in the fracture of the sheets.

The inhomogeneity of texture across thickness of 25 mm plates and 1-7 mm thick sheets causes a stress concentration at the boundary of layers with different texture during plastic deformation. It stimulates the delamination and hamper the developing of local planar deformation through the thickness. Minimal value of yield tensile strength sheets and plates of 1441 alloy on 60° rolling direction associated with low Teylor factor for axis tension specimens <511>+<311>. This effect is more expressed in specimen cut from central zones thick plates then in thin sheets where had mixed mode texture. Maximal value of yield tensile strength in long direction supplied by fibre structure, as in transverse direction at concern 60°L a raise YTS was provided texture hardening.

The similarity or distinction in matrix- and δ'- textures are defined perheps by the type of δ'-formation mechanism: through the spinodal decomposition of aluminum-lithium solid solution or by formation and grow of particles. It is obviously, that the δ'- and matrix-texture investigation in Al-Li alloys semiproducts give the possibility to understanding of orientation dependence of the fatigue fracture characteristics and yield stress anisotropy of these materials.

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