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TEXTURES IN ALUMINUM FORGINGS

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ABSTRACT

Texture and microstructure variations in a forged 7050 Al alloy are analyzed. The results are compared to known texture effects in extrusion, shearing and plane strain deformation. Special attention is paid to locations where high local strains have been detected metallographically some of which show structural changes related to recrystallization and superplasticity effects. The capabilities of textures to characterize these local structures, to assess local mechanical properties and effects of unacceptable material flow are demonstrated.

I. INTRODUCTION

The characterization of material flow during forging is an important factor in controlling material properties,[1] but so far little is known about local microstructure and texture evolution. Commonly, methods of surface macro etching are used to visualize grain flow varying with local deformation. By this technique, unacceptable structures and irregular grain flow patterns caused by unfavorable forging conditions can be detected. Theoretical predictions of material flow by CAE methods have recently been used successfully to analyze deformation processes and directions for improvement of the forging process have been derived. However, the understanding of the evolving local microstructure and resulting materials properties is still rather incomplete. Some of the observed local structure variations are still unclear but suspected to affect the mechanical properties of the material and contribute to part rejection by the customer.

The optical methods consider mainly the shape changes of grains. But also textures are a characteristic feature of the microstructure of forged materials as strong orientation changes must also be expected, especially in critical deformation zones where strong variations in deformation geometry may occur. Besides affecting anisotropic properties,[5,6] texture data may also give useful information about the mode and geometry of local deformation and other microstructural effects (like recrystallization).[4] Thus, it could help to analyze these structures in addition to conventional metallographic methods and CAE computer modeling.

Due to the often complex strain history, textures have seldom been carefully investigated in forged samples. In rolling deformation, texture studies are quite common and used for material characterization[4] and applied anisotropy control.[5] The analytical methods involved to study deformation and recrystallization mechanisms may now be applied to the more complex deformation modes like forging with the goal of detecting and analyzing local variations in structures and material properties.

II. EXPERIMENTAL

The material used for this exploratory texture study was a critical part of a 7050 section airframe forged at ~400°C. The material flow occurring in this forging operation (starting from a rod pre-forged into a ~5 cm thick plate) is illustrated in Figure 1 which shows results of a numerical simulation of this forging process done with the ALPID code.[2] A special evaluation technique is used to monitor the motions of material points in the deforming cross-section. Initial patterns of material points, forming horizontal lines and a rectangular grid of circles, are mapped on the deforming cross-section. The final configuration of these patterns can be used to interpret and understand the metal flow in the forging and the local straining in the cross-section.

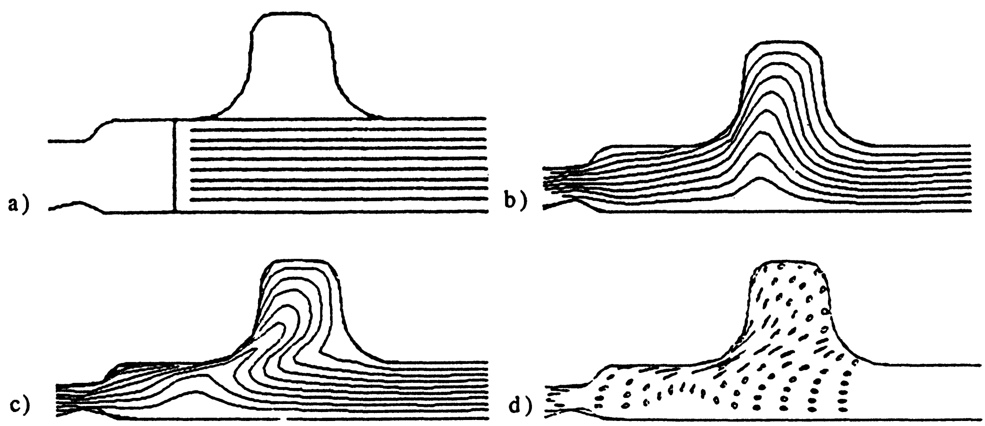


Figure 1 Material flow during forging of an airframe part (CAE simulation[2])
a) initial stage, b) intermediate stage, c and d) final stage

The area selected was a rib gradually filled with material during the process and with major material flow underneath. From this area, samples were cut in twelve different subsections, as illustrated in Figure 2:

- Two texture samples at the left (V_I) and right (V_A) part of the cross-section.
- Six horizontal texture samples (H_0 - H_5) taken along the midsection.
- Four texture samples (S_1 - S_4) taken in the region of highly irregular flow patterns at different angles of sectioning (2 x 25°, 35° and 65°, respectively) in order to match the observed direction of major grain flow.

{111} pole figures were measured in reflection mode on these relatively small samples (1 x 0.5 cm). The data were corrected for background and defocusing errors. The results are presented in Figure 3. The pole figures V_I and V_A are rotated[2] 90° around Y.

It can be seen that a large variety of textures is present within the investigated cross-section. Samples V_I and V_A (Figures 3a and 3b) show very similar textures, with mainly <110> in the Z-direction and ~<112> in the X direction which corresponds to a ~(011) [211] "B" orientation. The {110} direction is known as a stable compression type texture and these components probably represent stable components with some (distorted) elements of a plane strain texture type.

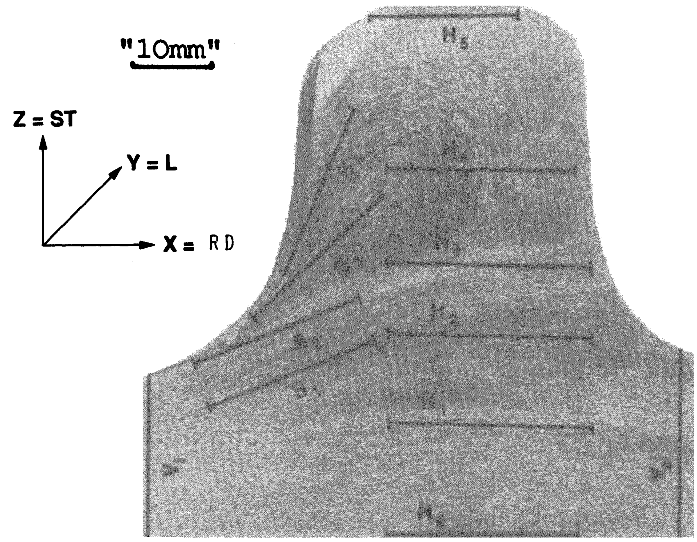


Figure 2 Microstructure of the forged part investigated (cross-section) (locations and names of texture sampling indicated)

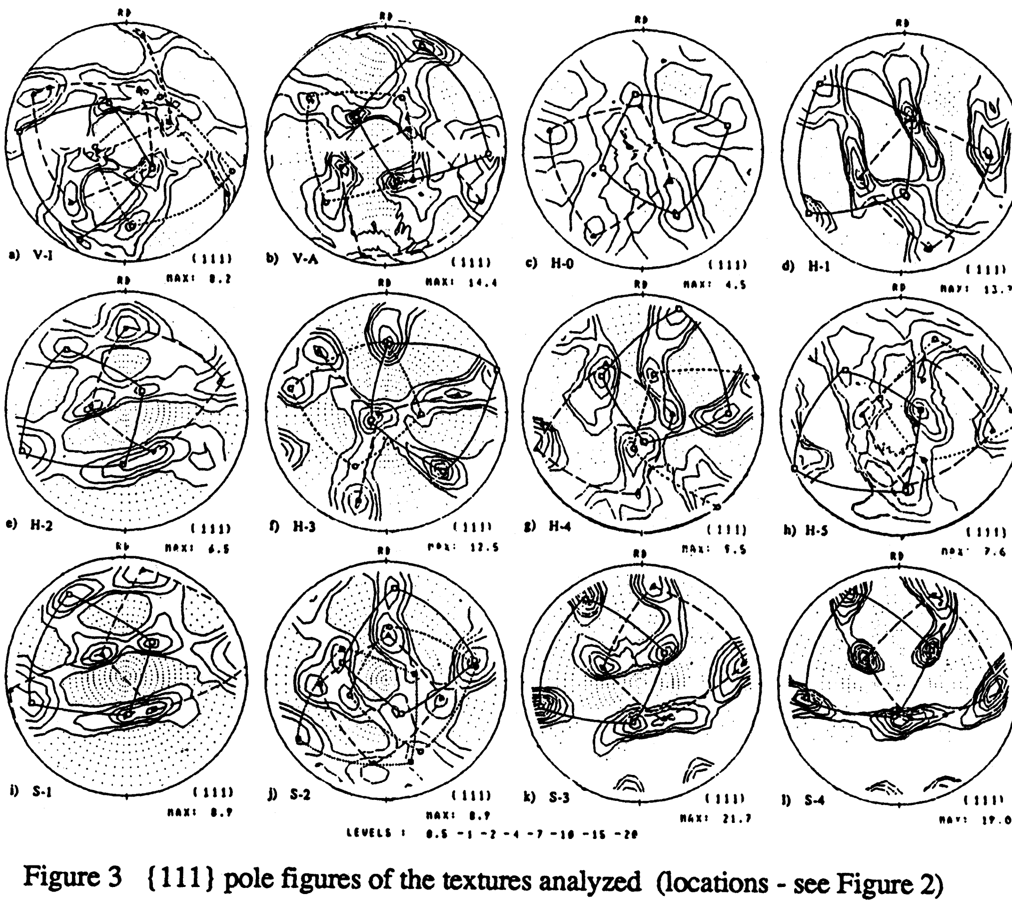


Figure 3 {111} pole figures of the textures analyzed (locations - see Figure 2)

For the H_0-H_5 samples taken from the area with less irregular turbulences in grain flow, the textures (Figures 3c-3h) show several drastic changes along the full height of the section. At the bottom (Sample H_0, Figure 3c), the relative weak texture is similar to a shear texture probably less deformed and somewhat distorted by surface shear. For samples H_1 and H_2 (Figures 3d-e) main components are also close to {110}. Samples H_4 and H_5 (Figures 3g and 3h) are also similar to the ~plane strain texture (H_1), only somewhat rotated around Y. The same is valid for sample H_3 which is ~30° rotated around Y with respect to H_1.

The sharpest textures are measured in the samples "S" taken from the areas of highest irregular grain flows (Figures 1 and 2). The Samples S_1, S_3 and S_4 (Figures 3i, k, l) show similar, relative simple textures. All three consist of only two (symmetrical) ~{011} <211> B orientation somewhat shifted with overlapping {111} poles of the two variants (especially for Sample S_4). The ~12° ND rotated textures are due to a certain obliquity of the cross-section.

Besides this shift, the sharpness of the texture components varies significantly from relative weak intensities in S_2 (2-4 x Random) to strong (7-8 x) in S_1 and S_3, and even very strong (11-13 x) in S_4 (due to the overlapping (111) poles). Sample S_2 (Figure 3i), shows a weaker and much more complex texture which indicates a more complex local deformation history. In this area, material flow is strongest and very fine striations are observed (Figure 2). In fatigue tests, in smooth axial fatigue specimens cracks preferentially initiate at these sites.

III. DISCUSSION

A large variety in texture types and strengths can be observed in forging reflecting history and local geometry of deformation. Some effects are related to the initial texture of the pre-forged plate, somewhat modified due to extensive material rotation occurring during forging operations. These texture variations occur in the more homogeneously deformed regions (V_I, V_A, H_1, H_3 - H_5) and can be interpreted as retained and rotated initial forging textures. A significantly different appearance in some textures (Samples S_1, H_2, S_3, S_4) is related to an area of strong local material flow. The S_1-H_2 textures form a band which extends over the whole cross-section (Figure 2) separating the bottom from the upper region where material flow mainly stops after the cross-section is completely filled. By further compression, excess material moves along the lower part (Figure 1) and severe local shearing creates this band of fine grained structure. Also, the S_3-S_4 represents an area of high local (shear) deformation as material passes by and fills up the rest of the cross-section, while underneath it, material flows in the opposite direction. This bends the grain elongation direction right underneath the S_3 section (Figure 1). The observed orientation can be observed near the surface of extruded bars (Figure 4) as a typical extrusion/shear type texture. It is related to the stable B-type shear and plane strain texture component (~{112}<110>) by a 30° TD (=<111>) rotation and so, represents a combined shear and plane strain type deformation.

The S_2 texture does not fit into that scheme. Optical local microstructure analysis revealed that, in this region of highest local deformation (Figure 1), a surprisingly fine equiaxed grain structure is present compared to the elongated structure of the adjacent area (e.g., S_1, Figure 6). Here, strong deformation at the elevated temperature has obviously induced some recrystallization effects. The

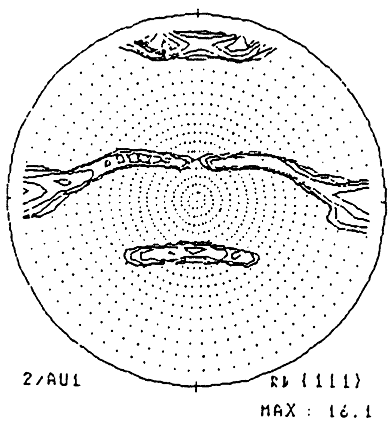


Figure 4 Example for shear texture near the surface of an extruded Al bar.

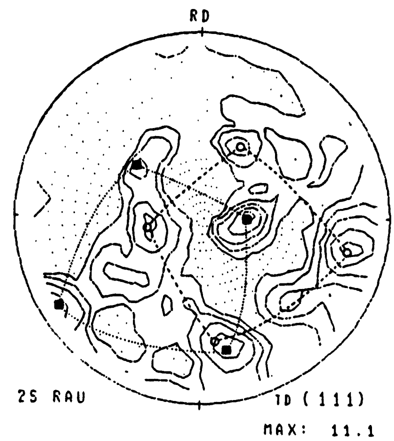
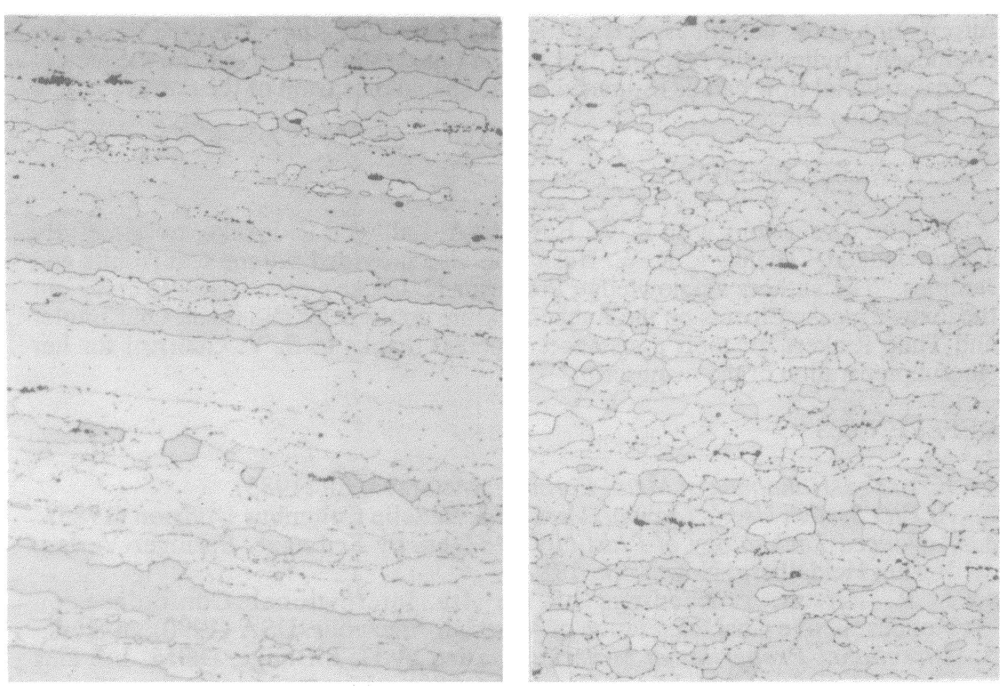


Figure 5 {111} pole figure of a fatigue test sample surface, cracked near area S_2 (Figure 3j)



a) Sample S_1 100 μ b) Sample S_2

Figure 6 Optical micrograph of local grain structures (transverse sections) structure resembles that observed in superplastic forming, where initially coarse elongated grains are gradually transformed into a fine equiaxed structure during slow high temperature deformation. This agrees with the weak, multicomponent texture is found at the crack surface (Figure 5, compared to Figure 3j). The implied softening effects enhances localization of deformation in this area, as can be observed in Figure 2 more than predicted (Figure 1). Tensile tests performed on samples taken from this area showed a significant decrease in maximum elongation to 5% (compared to >10% in other areas). These microstructural changes also affect fracture properties as crack initiation was preferentially located in this area. It can be interpreted as enhanced boundary cracking at random boundaries caused by grain boundary sliding effects as observed in sharp textured X7091 Al alloy.[6]

IV. SUMMARY AND CONCLUSIONS

A thorough investigation of textures was carried out in a 7050 airframe forging section containing major grain flow irregularities. The observed differences in both texture types and intensities show that this microstructure parameter is sensitive to local changes in deformation geometry. Some variations can be related to initial texture effects modified by local compression and shear strain. In the critical region of enhanced grain flow, a newly formed strong ~{110}<211> type texture occurs characteristic for strong local material flow (extrusion). Within this region, significant microstructure and texture transformations are observed which indicate a deformation and recrystallization effects, similar to superplastic forming mechanisms. This investigation shows that texture data can be used to obtain information about certain aspects of material flow in forging. The type of texture components indicate the type and direction of (local) strain involved and the area of critical material flow can be estimated by the spatial extension of the corresponding texture components.

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