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TEXTURAL EVOLUTION DURING DRAW-CUP TESTS OF THICK ALUMINUM 3004 ALLOY SHEET

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ABSTRACT

Cup tests were performed on hot rolled AA3004 alloy and the profile of the ears were measured. ODF's were determined from slices cut parallel to the cup wall at 0^o, 45^o and 90^o to the initial rolling directions. These determinations were compared to the Taylor-Bishop-Hill deformation model using full and relaxed constraints. The measured ear profile was compared to a continuum cup height calculation and the agreement was very good.

INTRODUCTION

Quantitative texture analyses theoretically should permit direct reliable predictions of mechanical and forming properties, thus making possible computer simulative processing for optimization of metal processing and fabrication. To examine if this ultimate goal can be attained to a degree useful for industrial purposes, the development of ears during cup testing was studied. Although the earing prediction methods have been discussed [1,2], recent studies [3,4] are statistical correlations rather than explicit comparisons between the measured ear profile with the actual evolved texture and the predicted profile from the modelled texture evolution.

In this report the profile of a drawn cup was measured together with the resultant texture in the cup wall.The texture prediction was performed using the method described herein. An exact derivation of the height of the cup is difficult since a constitutive relation has to be assumed [4]. However, during deep drawing the drawing limit is primarily affected by the through thickness anisotropy with little effect from the hardening coefficient [6]. Hence for this study a continuum flow analysis was derived. Despite these obvious simplifications the predictions compare quite favourably with the measured results such that for hot-rolled 3004 alloy, this analysis is within the realm of usefulness for in-plant applications.

EXPERIMENTAL METHOD

The recrystallized hot-rolled sheet of 2.3mm thickness was drawn using a cupping tester with blank radius, r_b = 27.5 mm, punch radius r_p = 16.5 mm and punch profile radius, r_{pp} = 5 mm. The earing profiles were measured using a profilometer and one cup was sectioned with slices parallel to the cup wall with RD 0^o, 45^o and 90^o to the vertical. The chemical composition in weight percent was 1.18 Mg, 1.01 Mn, 0.19 Si, 0.40 Fe, 0.15 Cu with the balance being Al.

Pole figures on these slices were averaged over a strain range since the beam covered an area about 6mm diameter during the total scan. Since the ODF generation is based on an incomplete pole figure determination with χ angles up to 80^o, 4 pole figures (111), (200), (220) and (113) were used to better extrapolate to the corresponding regions in the ODF where χ is greater than 80^o. The data acquisition was performed on concentric circles of χ in 5^o intervals up to 80^o and each circle consisted of 90 data points about the rotation axis normal to the specimen. The counts are continuously accumulated for 0.8 s during the 1 s which it takes to traverse 4^o. In the present set-up using 50 kV and 150 mA on a Cu rotating anode it takes approximately 1.9 hours to determine 4 pole figures.

RESULTS AND DISCUSSION

The stress state in the flange of the cup is illustrated in Fig. 1 following the description of Van Houtte et al [2]. In this analysis the possible textural change due to the bending upon cup wall formation is neglected. The flange deformation is considered to be one of compression in the direction of $S_{1'1'}$ where $\phi = \psi - \pi/2$, $S_{3'3'} = 0$ (sheet normal stress) $S_{1'2'}=S_{1'3'}=S_{2'3'}=0$ (the shear stresses) and $S_{2'2'}=0$ (the radial stress). The last condition holds only at the outside edge of the blank. At smaller radii, $S_{2'2'}$ increases. This necessarily positive stress is correlated to the ear profile by adjusting the $s = S_{2'2'}/S_{1'1'}$ ratio in the program. A value of $s=-0.2$ was found optimum for the 3004 alloy [2].

Since the compressive strain rate $\dot{\epsilon}_{1'1'} = -(\dot{\epsilon}_{2'2'}+$

$\dot{\epsilon}_{3'3'}$), for ideal deep drawing where $\dot{\epsilon}_{3'3'}$ is zero and insensitive to ϕ, no ears are observed. However, variation in $\dot{\epsilon}_{3'3'} = f(\phi)$ results in ears. To assess this condition a contraction ratio $q(\psi) = -\dot{\epsilon}_{2'2'}/\dot{\epsilon}_{1'1'} = -\dot{\epsilon}_{rr}/\dot{\epsilon}_{\phi\phi}$ is defined and calculated from the ODF [2] where $\dot{\epsilon}_{tt} = \dot{\epsilon}_{3'3'} = -(1-q)\dot{\epsilon}_{\phi\phi}$ and $\dot{\epsilon}_{rr} = -q\dot{\epsilon}_{\phi\phi}$ and t is the sheet thickness.

The height of the cup was approximated considering flow of material at some point on the flange where the radius becomes r_p and deformation ceases except for bending to form the cup wall. In the above definition plane strain is not enforced. Thus, $1/q \quad dv_r/dr + dv_\phi/d\phi = 0$ where v's signify velocities and $dv_\phi/d\phi$ can be approximated by v_r/r if v_r is insensitive to ϕ. By integration with limits of r_b and r_p the time for the flow of the initial flange through the point at r_p with $v_r(r_p)$ can be related to the height of the cup by eqn (1): $h(\psi) = (r_b^{q+1} - r_p^{q+1})/(q+1)r_p^{q}$. For plane strain where $q = 1$, Lin et al [4] calculated the height of the cup due to the average elongation of the flange to be eqn (1) + t + 0.43 r_{pp}. In the subsequent calculations the measured height was correlated to this sum with the $q(\psi)$ derived from the texture.

The measured cup profile shown in Fig. 2 is compared with predictions using the initial texture with s ratios of -.2, -.3 and -.5. Careful scrutiny shows that -.2 is a slight overestimate of the peak-trough difference whereas -.3 is almost exact. The fit of the profile is emphasized in this discussion rather than the magnitude correspondence of the heights. Fig. 3 compares the measured profile with the data points determined with s = -.2 from the slices near maximum strain and from those using the full constraint (FC) and relaxed constraint (RC) of pancake model according to Dezillie et al [5]. The ODF of initial sheet (Fig. 5) has been transformed into a set of 1600 weighted crystallite orientations. In the RC case the orientation of the pancake was rotated such that the direction of minimum strain was that normal to the sheet. To better illustrate the texture predictions using the Leuven software [7], q values calculated from the slices at 0^o, 45^o and 90^o to RD and those from the simulated ODFs after 13 increments of 5% strain are shown in Fig. 4. It is noted that the value for q used in Fig. 3 were taken with ϕ' angles with respect to the specific drawing direction. Thus at $\phi' = 90^o$ which corresponds to the experimental condition the better fit depends on the draw direction. However, other parameters such as the strain rate sensitivity could affect this result. Fig. 5 shows the ODF for the initial, 0^o slice and the corresponding FC and RC simulations. It is noteworthy that the RC models results in sharper peaks than the FC one.

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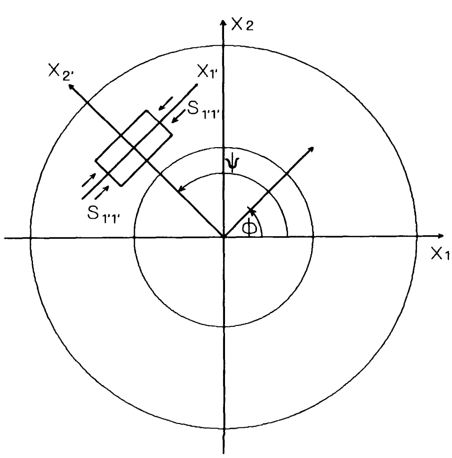


Fig. 1. Schematic of a circular blank in a cup test.

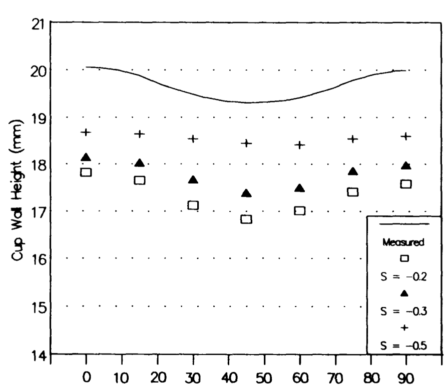


Fig. 2. Earing profiles of measured and predictions using stress ratio s =-0.2, -0.3 and -0.5.

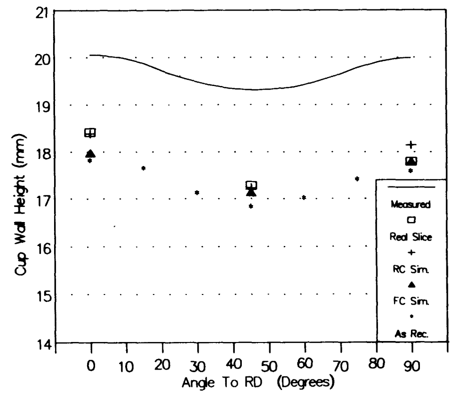


Fig. 3. Earing profiles measured by profilometer (full line) and those determined from ODF of as-received sheet and of the three wall slices and those from simulated textures with s = -0.2

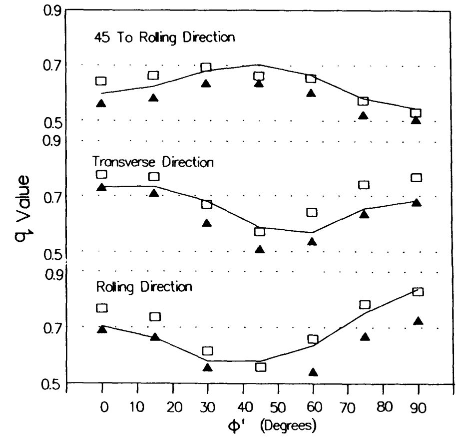
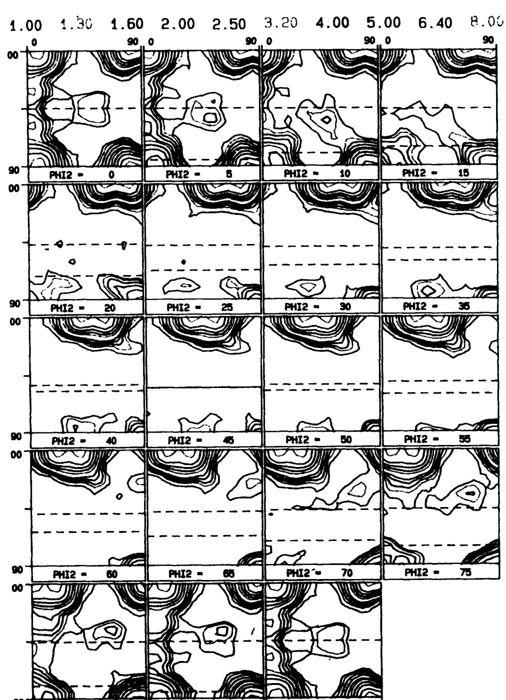
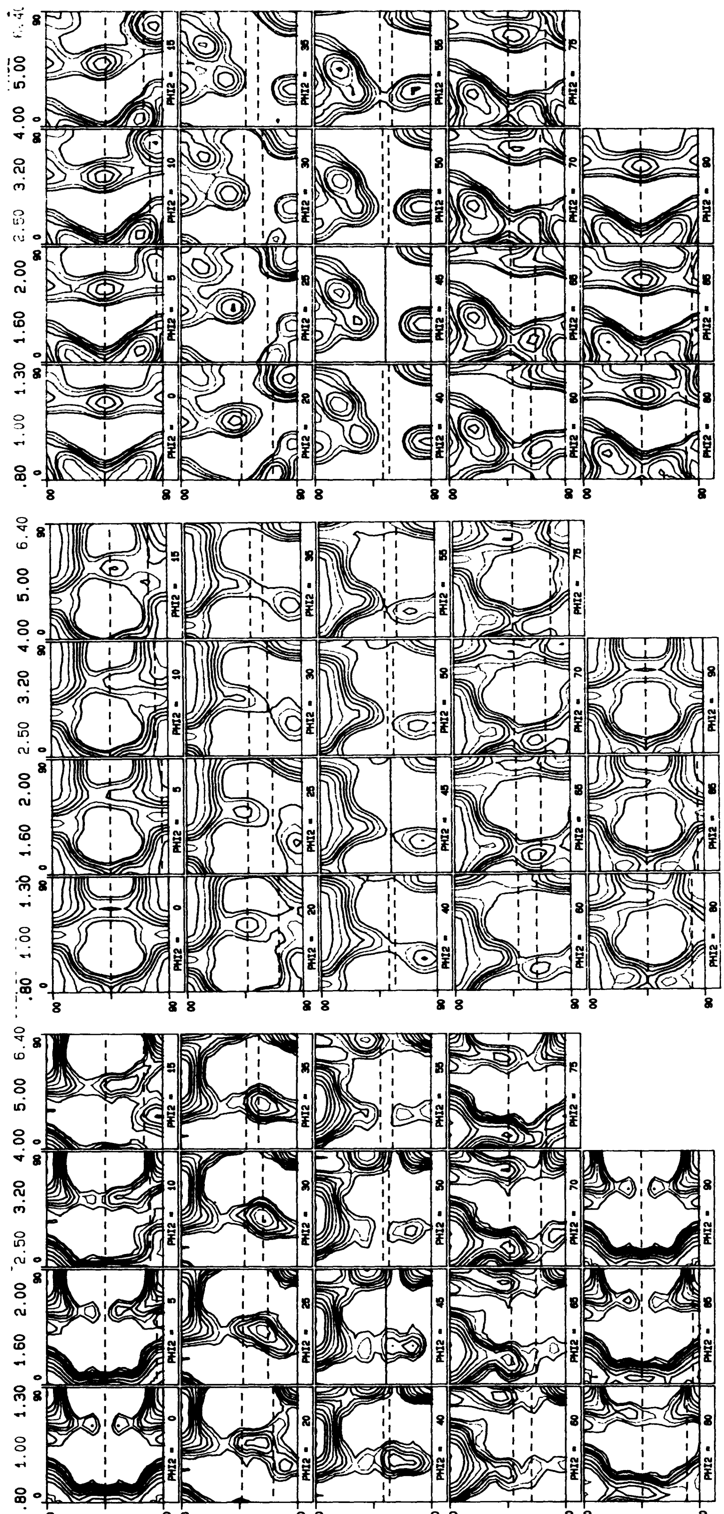


Fig. 4: Comparison of q with respect to specific drawing direction using slices of 0^{o}, 45^{o} and 90^{o} and the corresponding ones from FC and RC models.



(a) initial texture

Fig. 5: Complete O.D.F. of AA3004



(b) measured slice

(c) FC using 13 steps of 5% strain

(d) RC using 13 steps of 5% strain.

Fig. 5. Complete O.D.F. of AA3004 for 0^o orientation.