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Final Report

Surface Roughening in Formed Al Sheets for Automotive Applications

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Abstract

New experimental and analytical tools for characterizing various types of forming-induced surface roughening have been developed and used to study the evolution of surface roughening in 6000 series aluminum sheets in the T4 condition. Particular attention was focused on the evolution of the "diamond defect," which often requires a subsequent mechanical surface treatment to achieve an acceptable surface finish. Testing was primarily done in plane strain tension and samples evaluated at various strain levels up to and including the forming limit. Characterization techniques included optical and scanning electron microscopy, white light phase shift interferometry, and orientation imaging microscopy. Roughening patterns were observed to communicate through the sheet thickness, e.g., peaks on one side correspond to peaks on the other; valleys to valleys. At the grain or grain cluster scale, roughening was found to be governed by the Schmid rather than the Taylor factor.

Principal Products of this Fundamental Research

The results of this fundamental study of surface roughening in formed 6022 T4 aluminum sheets are largely contained in the three Ph.D. theses and three archival publications listed in Table 1 and 2 below:

Table 1

Ph.D. Theses

1. Glenn W. Jarvis, "The Effect of Mechanical Surface Texture on Sheet Metal Formability," Carnegie Mellon University, May 1998, 364 pages.
2. Paul S. Lee, "Relation of Surface Roughness to Texture and Microstructure in 6xxx Aluminum Sheets," Carnegie Mellon University, April 1999, 238 pages.
3. Yoon S. Choi, "Surface Roughening of 6022-T4 Al Sheets Deformed in Plane Strain," April 2001, 271 pages.

Table 2

Referenced Technical Papers Published and Accepted for Publication

4. Y.S. Choi, H.R. Piehler, L.G. Hector, and A.D. Rollett, "Quantification of Deformation-Induced Surface Roughening Using Modified Roughness Parameters and Fourier Filtering," in Innovations in Processing and Manufacturing of Sheet Materials, TMS, 2001, pp.209-218.
5. P.S. Lee, H.R. Piehler, A.D. Rollett, and B.L. Adams, "Texture Clustering and Long-Range Disorientation Representation Methods: Application to 6022 Aluminum Sheet," Metallurgical and Materials Transactions A, Vol. 33 A, 2002, pp.3709-17.
6. Y.S. Choi, H.R. Piehler, and A.D. Rollett, "Formation of Meso-Scale Roughening in 6022-T4 Al Sheets Deformed in Plane Strain Tension," accepted for publication in Metallurgical and Materials Transactions A. 31 pages.

Copies of publications 4-6 are appended. Theses 1-3 are available from University Microfilms.

The major findings contained in these six publications are identified next, followed by a description of current follow-up studies motivated by this fundamental research program.

Major Theoretical and Experimental Findings:

1. Two new mesostructural parameters (5) are identified and used to characterize correlation over large distances:
 - a. the variance of the orientation distribution function, which reveals orientation clustering
 - b. the disorientation correlation function, which characterizes orientation ordering or orientation autocorrelation

Both these methods have been used to begin interpreting surface roughening in 6022 T4 sheet deformed in plane strain tension.

2. Two new surface roughness parameters (4) based upon the distributions of the roughness peaks and valleys, the peak-to valley mean height roughness (R_{mh}) and the 10% mean height roughness (R_{pv}) were introduced and used to improve the quantification of 3-D roughness patterns.
3. Major insights into the evolution of the "diamond defect" were obtained (4) by dividing the roughness pattern into three wavelength regimes and tracking their evolution with strain.
4. Slip-banded and non slip-banded grains tend to form hills and valleys, respectively, wherever these two types of grains are next to each other (6).
5. Criteria based on the Schmid factor provide a better prediction of slip-banding and non slip-banding behavior than those based upon the Taylor factor (6).
6. Roughening patterns were observed to communicate through the sheet thickness, e.g., peaks on one side corresponded to peaks on the other and valleys corresponded to valleys, yielding a pattern of ribbing rather than corrugation (3)

Future Directions

This study made significant use of the prior insights provided by Jarvis (1) on mechanically surface textured 6111 T4 sheet. Jarvis found that mechanical surface texturing led to a new form of surface instability termed distributed lineal localizations. These localizations are characterized in Figure 1 (provided by Choi). Among Jarvis' other findings is that mechanical surface texturing seems to influence bulk mechanical properties. The potential for mechanical surface texturing to increase bulk mechanical properties and decrease surface roughening is currently being investigated.

Figure 1

Characterization of Surface Roughness

White light phase-shift roughness map (right)

Areal power spectral density (below)

Areal auto-correlation coefficient (bottom right)

Texture 11: hexagonal, small rim, small crater spacing

In-plane shear: effective strain = 0.174

The rolling direction is horizontal.