

Effects on Surface Roughness and Friction on Aluminum Sheet under Plain Strain Cyclic Bending and Tension

2011-01-0535

Published
04/12/2011

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doi:[10.4271/2011-01-0535](https://doi.org/10.4271/2011-01-0535)

ABSTRACT

During sheet metal forming, the friction and surface roughness change as the sheet slides, bends and stretches against the tools. This study assessed evolution of friction and surface roughness changes on aluminum sheet with two surface finish conditions, mill finish (MF) and electron discharge texture (EDT), in both the longitudinal and the transverse rolling directions of the sheet. The sheets were tested using a three pin Draw Bead Simulator (DBS). Surface roughness of the sheet evolved as a result of bending at the first shoulder, reverse bending at the middle pin, bending at the second shoulder and unbending at the exit. Stretching conditions and sheet-pin contact were also varied to see the impact on surface roughness. In general, the largest surface roughness change for the transverse direction was observed at the convex side of the exit shoulder pin and on the convex side of the first shoulder for the longitudinal direction. Roughness changes along the flow direction were significantly smaller for the EDT surface, with a maximum change around 30%. Surface roughness changes of up to 400% were observed for the mill finish material. Friction differences for the two sheet surfaces are also discussed.

INTRODUCTION

The continuous improvement of the forming process using aluminum alloy sheets requires an in-depth analysis of the surface topography of the sheet. The characterization of the surface texture of aluminum alloys is one of the basic parameters influencing formability, friction, and paint appearance in the forming of automotive parts [1]. This is

more significant as more surface texture technologies become available. Electro Discharge textures (EDT) are credited with improved painting and formability and now are used more extensively in Europe [1, 2], while traditional mill finish [MF] textures are still popular in North America.

The introduction of 3D non-contact, interferometer optical profilers has permitted the description of the surface topography to extents not permitted by traditional 2D profilers. This is particularly important for the study of contact and friction phenomena, where 3D instruments can distinguish the geometrical changes on surface texture resulting from the complex interactions between the sheet, tool, and lubricant. An extensive presentation of surface characterization techniques and its applications can be found in [4]. In their studies of sheet metal surfaces, M. Pfestorf et al [3] showed the significant advantages offered by 3D instruments. M. Pfestorf applied 3D methods to study topographic changes on sheets loaded using strip friction and a compression and torsion test. Parameters provided by 3D analysis, such as the maximum ratio of closed void area, were found useful to assess the performance of textured surfaces. In this study, 3D non-contact interferometer is used to measure changes in texture for aluminum alloy sheet under cyclic stretching and compressing during its passage through cylindrical draw beads.

EXPERIMENTAL PROCEDURE

Aluminum sheet was cyclically bent and stretched using a Draw Bead Simulator (DBS). In this test, patterned after H. Nine [5], the sheet metal is pulled between three cylindrical

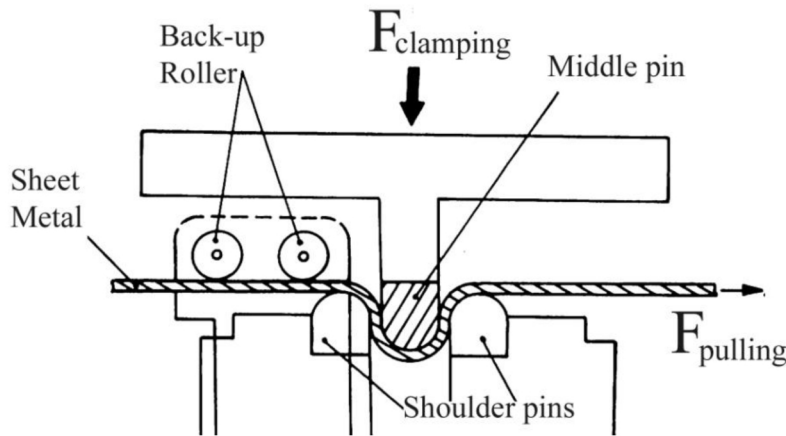


Figure 1. Schematic of the Draw Bead Simulator with fixed pins

pins, as shown in Figure 1. All tests were run at full penetration, with the center of the pins aligning along a straight line.

To determine a Coefficient of Friction (COF), the mechanical effects of the sheet must be factored out. This requires two types of test specimens. The first type of specimen is pulled between the roller beads, which consist of pins supported by ball bearings (Figure 2). Friction on the bearings is considered small and it is neglected. The pulling and clamping forces (measured with load cells) measure the bending and unbending resistance of the sheet under “frictionless” conditions.

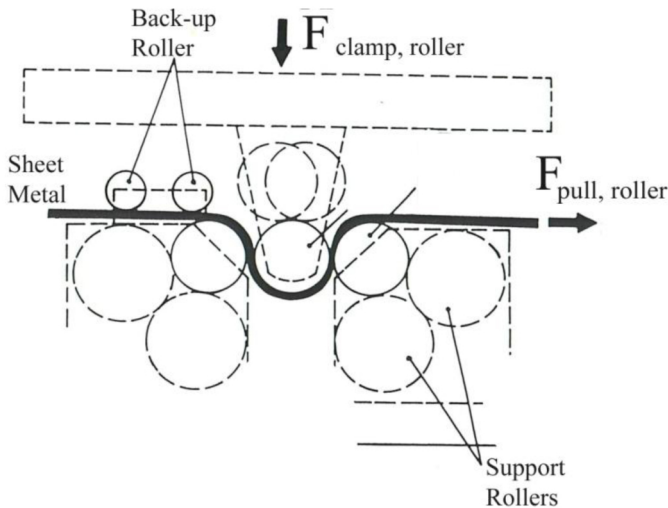


Figure 2. Schematic of the Roller DBS with pins supported by rollers

The second type of specimen is pulled between fixed beads of equal radii shown in Figure 1. The pulling and clamping forces measure the loads required to slide the sheet over the fix pins and to bend and unbend the material. The COF is

then calculated by subtracting the roller from the fixed load according to Equation 1 [5].

$$\mu = \frac{1}{\pi} \frac{F_{Pull,Fix} - F_{Pull,Roller}}{F_{Clamp,Fix}} \quad (1)$$

The DBS data, used in equation 1 are the average data at mid stroke $\pm 25\%$ of the steady state curve. Static friction, inertial, and other transient effects occurring at the beginning and at the end of the pulling phase are not used in the calculation of the DBS COF. For each material in this study, ten tests were performed with the roller bead, followed by ten tests in each direction with the fixed bead, for a total of 30 test samples per material. All testing was performed with chromium plated NAAMS D6510 cast iron draw beads, hardened to HRC 56-58, with 0.6-1.0 g/m² of commercially available pre-lube oil.

The materials used in this study fit into the AA6022 grade (supplier 1) and the GMW15192M-AL-S-6000-IH-90-E grade (supplier 2), where IH stands for “Improved Hemming” [6]. Surface texture studies included mill finish (MF) from suppliers 1 and 2, and electro discharge texture (EDT) from supplier 2. DBS tests included the directions longitudinal to the grain (L) or rolling direction, and the transverse (T) direction. Sample sizes were around 0.97- 0.99 mm thick, 50.8 mm wide, and were DBS tested along 150 mm test length. Table 1 shows the DBS results.

During its flow through the fix beads, one side of the sheet makes contact with the shoulder pins (side A), and the other side slides along the middle bead (side B). Figure 3 defines the sections of interest for this study. The resultant sample was cut into the five sections shown, to a size amenable for surface analysis. This method is approximate since the sample is collected at test end (zero speed), as opposed to the

Table 1. DBS test results along L and T for AA6022 and GMW15192M-AL-S-6000-IH-90-E aluminum alloys

Material	Surface Finish	Rolling Direction	Roller Force N	DBS Friction Coefficient
AA6022	Mill Finish	Longitudinal	3273	0.078
	Mill Finish	Transverse	3120	0.048
GMW15192	Mill Finish	Longitudinal	3212	0.088
	Mill Finish	Transverse	3078	0.031
GMW15192	EDT	Longitudinal	3114	0.122
	EDT	Transverse	2944	0.115

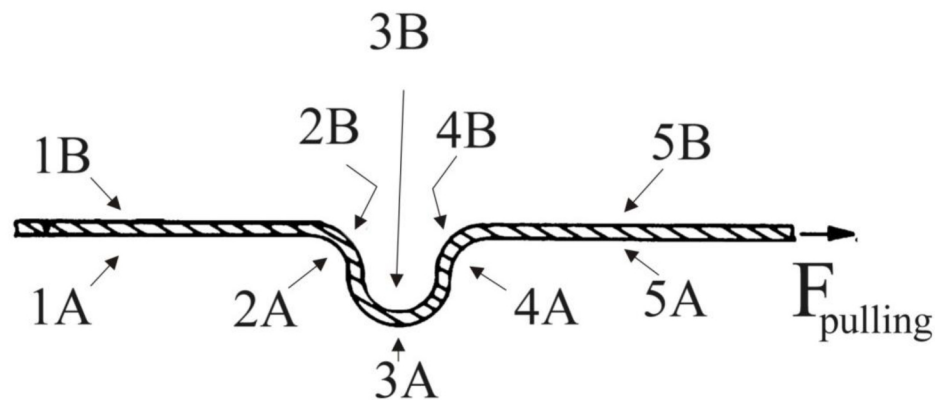


Figure 3. Selected sections for surface analysis

nominal speed (85 mm/s). Since the material was strain rate insensitive, and the pulling force is programmed to collapse in negligible time, the approximation is deemed justified.

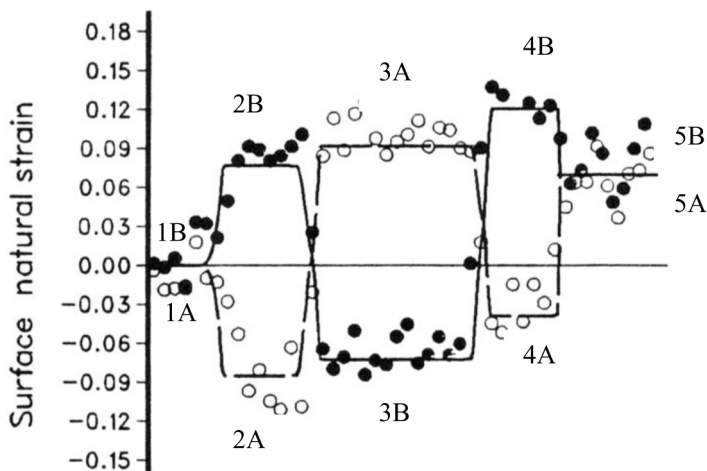


Figure 4. Typical DBS surface strain distribution

underwent (i) compressive strains at 2A upon bending to the first shoulder, (ii) tensile strains at 3A upon reverse bending over the middle pin, (iii) compressive strains at 4A upon bending over the second shoulder pin, and (iv) tensile strains at 5A upon unbending at the outlet. Since the test pulling force increases from zero at section 1 to a maximum at section 5, the compressive strains are largest at 2A, and decrease for sections 3 and 4. Surface strain variations for side B are opposite to side A. During testing, the sample width remains approximately unchanged. This defines a condition of plane strain along the width where all straining occurs along the direction of flow and through thickness.

The sections were cut using wire EDM in order to avoid potential distortions during the cutting operation. The sections were analyzed using a WYKO NT-2000 3D surface profiler. Settings consisted of 5.1X magnification with a field of view of 1.28 mm × 0.96 mm with a resolution of 736 × 480 pixel arrays. For this work, the 3D average surface roughness, S_a , was primarily used.

Figure 4 shows experimental DBS surface strains measured using grid analysis [7]. This figure represents typical strain distribution for DBS sections as shown in Figure 3, and it is included for illustration purposes. For side A the surface layer