

The Effect of Surface Finish on Aluminum Sheet Friction Behavior

2011-01-0534

Published
04/12/2011

Susan E. Hartfield-Wunsch
General Motors Company

Donald Cohen
Michigan Metrology

L. Rafael sanchez PhD
University of Colorado Denver

Lars-Erik Brattstrom
Saab Automobile

Copyright © 2011 SAE International

doi: [10.4271/2011-01-0534](https://doi.org/10.4271/2011-01-0534)

ABSTRACT

Aluminum sheet is commercially available in three surface finishes, mill finish (MF), electric discharge texture (EDT), and dull finish (DF). This surface finish impacts the friction behavior during sheet metal forming. A study was done to compare ten commercially available sheet samples from several suppliers. The friction behavior was characterized in the longitudinal and transverse directions using a Draw Bead Simulator (DBS) test, resulting in a coefficient of friction (COF) value for each material. Characterization of the friction behavior in each direction provides useful data for formability analysis. To quantitatively characterize the surface finish, three dimensional MicroTexture measurements were done with a WYKO NT8000 instrument. In general, the MF samples have the smoothest surface, with Sa values of 0.20-0.30 μm and the lowest COF values. The EDT samples have the roughest surface, with Sa values of 0.60-1.00 μm , and the highest COF values. The DF sample falls between the MF and EDT with Sa = 0.60 μm . Also, the EDT and DF samples have a more isotropic surface, as indicated by Stylus X Ra/Stylus Y Ra = 0.97-1.01, and the COF values are approximately the same in the transverse and longitudinal directions for these samples. The MF samples are less isotropic, with Stylus X Ra/Stylus Y Ra = 1.79-4.87, and the COF values are lower in the transverse direction than in the longitudinal direction for the MF samples.

INTRODUCTION

Friction is an important factor in sheet metal forming, and the surface texture of the sheet metal influences the friction. Surface texture is applied to the sheet by transferring the roll surface texture during the last cold rolling pass [1]. Common surface textures for aluminum sheet include mill finish (MF) which comes from ground rolls, electric discharge texture (EDT) which comes from EDT rolls, and dull finish (DF) which comes from shot blast rolls. The EDT finish is used extensively by European automotive manufacturers, and it is reported that it provides improved paint appearance over the MF [1,2,3]. The EDT finish has an isotropic, regular pattern which leads to a more homogeneous paint distribution [2,3]. Also, when adjacent aluminum and steel panels are painted, a similar surface finish will make them appear the same. The EDT aluminum surface texture is closer to the surface texture on steel sheet so by using the EDT on aluminum sheet, the paint appearance will be closer to that of the adjacent steel sheet [1,2].

It has also been shown that the EDT finish improves formability by providing lubrication pockets to maintain an even distribution of lubricant [1,2]. It also improves formability by providing an isotropic surface so that the friction and formability are the same in all directions [1,2].

The mill finish is not an isotropic surface and the friction and formability are not the same in all directions.

EXPERIMENTAL PROCEDURE

MATERIALS

[Table 1](#) shows the materials used in this study. All ten materials are commercially available aluminum sheet materials, from suppliers in North America, Europe, and Asia. Three surface finishes were studied, including mill finish (MF), electric discharge texture (EDT), and dull finish (DF). Surface texture measurements are described in the next section. Each material has been assigned a letter code to prevent identification of the supplier.

Table 1. List of materials used in this study.

Material	Surface Finish	Sa (μm)	Stylus X Ra Transverse Rolling Direction	Stylus Y Ra Longitudinal Rolling Direction
A	EDT	0.95	0.78	0.81
B	EDT	0.88	0.77	0.79
C	EDT	0.63	0.57	0.58
D	EDT	0.9	0.77	0.78
E	EDT	0.98	0.86	0.85
F	DF	0.6	0.52	0.51
G	MF	0.25	0.22	0.12
H	MF	0.3	0.27	0.08
I	MF	0.24	0.21	0.05
J	MF	0.29	0.27	0.06

SURFACE ANALYSIS

The 3D surface texture measurements were made with a WYKO NT8000 vertical scanning interferometer [4]. The WYKO system was configured with a 5X magnification providing a single field of view of about $1\text{mm} \times 0.9\text{mm}$, with a lateral resolution of about $1\mu\text{m}$ and a height resolution of less than 6nm . Configured in the “stitching mode” [5], multiple contiguous measurements were combined to provide a final measurement field of view of $10.0\text{mm} \times 0.9\text{mm}$ ([Figure 1](#)). The final measurement array size for a given location was about $5400\text{pixels} \times 480\text{pixels}$. [Figure 1](#) shows a typical measurement of an EDT surface finish. For each sample, the Y direction was aligned with the rolling direction.

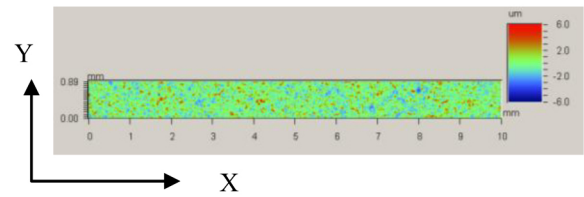


Figure 1. Typical measurement of an EDT finish.

The 3D roughness (aka areal roughness) many be quantified with many different parameters [6]. For this work the 3D average roughness, Sa was used. Additionally, the Normalized 3D Surface Volume (NVOL) can be a useful predictor of COF. The NVOL parameter was developed for the printing industry and represents the amount of fluid per unit area that would fill a surface from the lowest valley to the highest peak. NVOL is typically expressed in units of BCM which is an abbreviation for “Billions of Cubic Microns Per Inch Squared”. A 3D Gaussian areal filter with a shortwave cutoff of $33\mu\text{m}$, (providing a 300:1 spatial bandwidth for the given 10mm field of view [7]), was used to process the measurement data prior to the evaluation of the various 3D texture parameters (e.g. Sa).

The average roughness along the X and Y directions, Stylus X Ra and Stylus Y Ra, were derived from the 3D data sets by evaluating the average roughness of all individual profiles along the X and Y directions respectively. The Stylus X Ra and Stylus Y Ra parameters were found after the appropriate stylus filters with a 0.8mm long wave cutoff was applied to the data [8]. Along the X direction, about 480 individual profiles with 10 cutoffs per profile were used to evaluate Stylus X Ra. Along the Y direction, about 5300 parallel profiles consisting of 1 cutoff per profile were used to find Stylus Y Ra. [Table 1](#) includes the Sa, Stylus X Ra and Stylus Y Ra values for the materials in this study.

FRICITION TESTING - DRAW BEAD SIMULATOR

Friction testing was performed with a Draw Bead Simulator (DBS). In this test, the sheet metal is pulled to slide between three cylindrical pins. At full penetration the center of the pins align along a straight line. [Figure 2](#) shows a schematic of the DBS equipment.

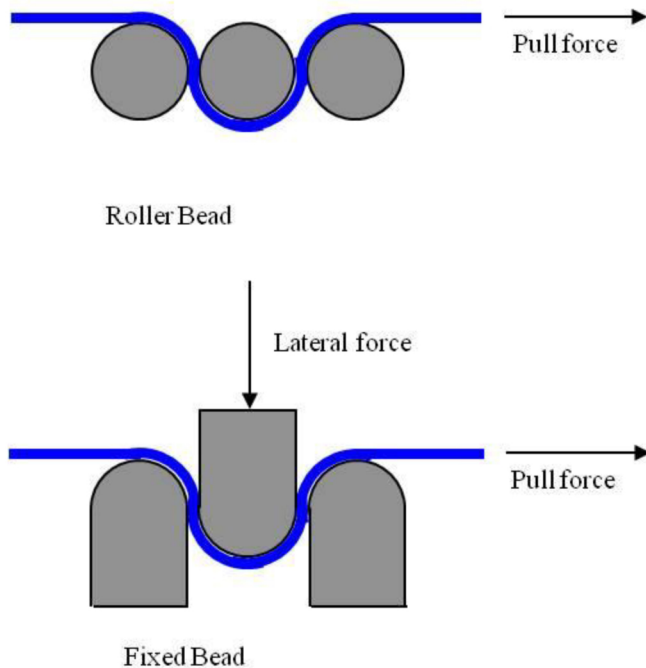


Figure 2. Schematic of Draw Bead Simulator for Friction Testing.

To determine a 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 bead, which consists of pins supported by ball bearings. 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. The second type of specimen is pulled between fixed beads of equal radii. The pulling and clamping forces measure the loads required to slide, and to bend and unbend the material. The COF is then calculated by subtracting the roller from the fixed load according to equation 1 [9].

$$\mu = \frac{1}{\pi} \times \frac{\text{Pull force (fixed bead)} - \text{Pull force (roller bead)}}{\text{Lateral force (fixed bead)}}$$

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 prelube oil.

RESULTS

Figure 3 shows the average surface roughness, S_a , in μm , for the ten sample groups. The data represents five measurements for each sample, with error bars representing 95% confidence intervals for the measured mean values. This means that there is only a 5% chance that the actual mean value is outside the bars, assuming the data is normally distributed. It is seen that the EDT and DF sample groups on the left side of the graph have higher roughness values than the MF samples on the right side of the graph.

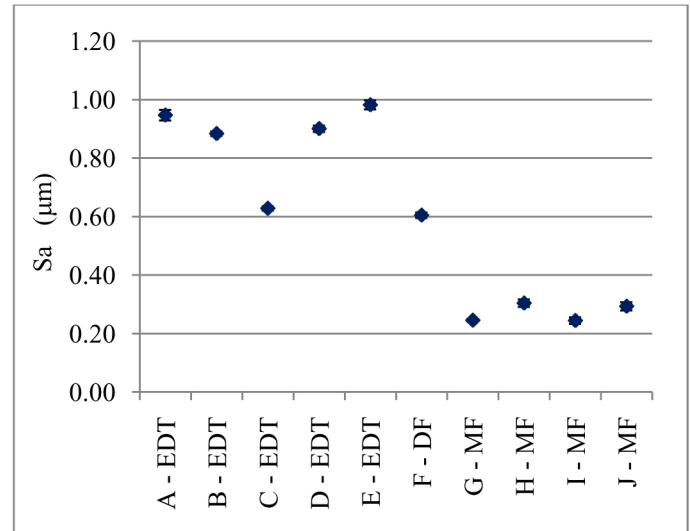


Figure 3. Average roughness (S_a) values for each material.

Figure 4 shows the Stylus X Ra divided by the Stylus Y Ra, which indicates the isotropy of the material. Error bars represent the 95% confidence interval. For a perfectly isotropic material, the Stylus X Ra = Stylus Y Ra, so the ratio becomes one. It is seen in Figure 4 that all of the EDT samples have Stylus X Ra/Stylus Y Ra ratios near one, indicating that these materials are isotropic. All four of the MF samples have values higher than one, indicating that the roughness is greater in the X direction (transverse rolling direction) than in the Y direction (longitudinal rolling direction).

The Normalized 3D Surface Volume (NVOL) in Billions of Cubic Microns Per Inch Squared (BCM) is seen in Figure 5 for each material, representing the amount of fluid per unit area that would fill a surface from the lowest valley to the highest peak. Error bars represent the 95% confidence interval. It is seen that the EDT samples on the left side of the