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# INVESTIGATION OF SURFACE TOPOGRAPHY EVOLUTION OF SHEET ALUMINUM UNDER PRESSURE AND TENSION

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**Abstract.** Besides tool parameters and work piece properties, the accuracy of the finite element analysis depends much on contact conditions between the sheet and the tool. To a large extent, the contact conditions are determined by the material properties of the parts in contact as well as the relative motion and the contact pressure between them. A further factor influencing friction is the sheet surface topography which is changing due to tension, contact and sheet deformation.

In this paper, the surface topography evolution under pressure and under tension is presented and discussed. Therefore, basic experiments were done. In the experiments, the influence of different parameters like tension and contact pressure is determined.

To analyze the surface topography evolution, pre-defined spots on the samples were traced during the experiments. The changes in the surface topography before and after forming were analyzed by means of roughness measurement.

The intention is to get a correlation between flattening or roughness evolution and the parameters of the deformation. This correlation can be used to improve existing friction models used in the FE analysis.

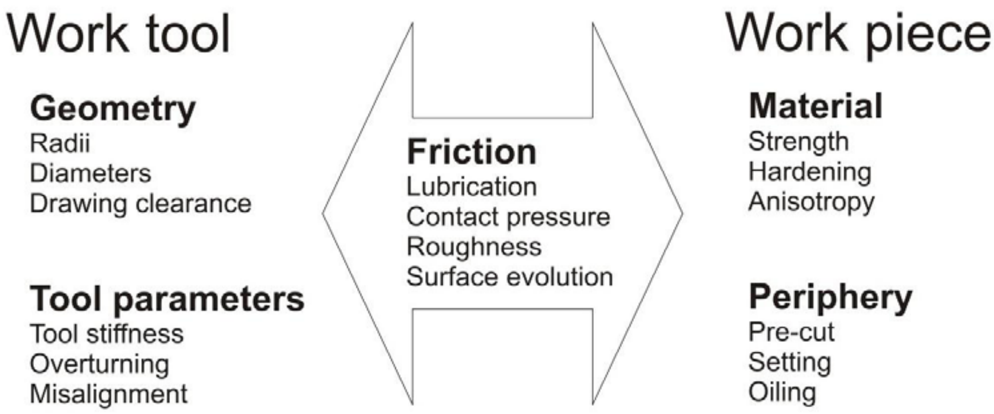


**Figure 1**: Main influences of deep drawing processes on the formed part

## 1 INTRODUCTION

Globalization, individualization, digitalization, and increasing competition are challenges the today's industry has to face. Incessantly, development and production time and costs have to be reduced. For the sheet metal forming community, decreasing the number of forming steps is a possibility to defy the competition. This requires more plastic deformation and higher precision of a single step. The demand on high process precision implies the demand of high accuracy of the computation by means of the finite element method (FEM), which is an essential tool in designing sheet metal processes.

The main influences of deep drawing processes on the quality of the formed part are displayed in Figure 1. To improve the accuracy of existing FE-analyses of deep drawing processes, these factors must be taken into account more detailed. A main factor influencing the contact conditions between the sheet and the tool is friction. In this paper, the evolution of the sheet surface topography due to pressure and tension is analyzed.

In near future, such considerations should lead to a new approach of friction modeling, taking into account the anisotropic roughness evolution, which is presented in this paper.

## 2 STATE OF THE ART

Friction is defined as the interaction between the surfaces of contacting bodies [1]. The surface topography of contacting bodies under normal pressure changes: normal loading and stretching cause flattening and roughening effects of the surface topography [2].

Considering aluminum, flattening of surface asperities only appears in combination of contact pressure and relative motion [3]. The appearance of only normal pressure shows no significant influence on the flattening effect. A shear stress on micro contact zones is needed for flattening [3]. While compressing aluminum cylinders, a linear dependency of roughness on tension (below 0.1) was shown [4, 5].

In general, for numerical modeling of friction conditions, the Coulomb friction law with a constant coefficient is used. Thereby, the influence of the surface topography of the sheet is not taken into account. In the recent years, several methods were developed in order to describe surface topographies and flattening effects [2, 6-10] (for more information, see [11]). The general idea of these methods is a mathematically description of friction. The influence of the surface topography evolution of the sheet is not taken into account.

A first method that considers the irreversible changes that occur in the surface conditions during deep drawing of metallic sheets was developed for DC06 steel [10].

In this paper, the surface topography evolution of aluminum AlMg3 under pressure and tension is considered. An anisotropic behavior of roughness evolution is found out. Furthermore, an outlook on further experiments as well as on a new idea of numerical friction modelling is given.

## 3 EXPERIMENTS & RESULTS

To determine the surface topography evolution under pressure and under tension, basic experiments were done. Therefore, pre-defined spots on the samples were traced during the experiments. The changes in the surface topography before and after forming were analyzed by means of roughness measurement. The material used in this study is the aluminum alloy AlMg3 with an initial sheet thickness of $s_0$ = 1 mm.

First, the appearance of only pressure was studied. The next experiment used to analyze the surface topography evolution was a tensile test.

### 3.1 Roughness Measurement

The roughness was measured by the topography and roughness measurement tool HOMMEL ETAMIC T8000. The probe arm measures the roughness by probing the surface line per line. The sampling length amounts 1.5 mm with 1500 values per line. The measurements were done in and 90° to rolling direction. In each direction five lines were measured and for each approach four samples were considered.

The investigated parameter is the arithmetic mean surface roughness $R_a$. This is the arithmetical mean of the sums of all profile values, the average variation from the mean line. It is non-sensitive for extreme profile heights or depth and, therefore suitable for consideration of changes on surfaces [12].

### 3.2 Influence of only Pressure

The roughness of the untreated samples was measured before any experiments. Then, some of the samples were encountered pressures of 5 MPa and 15 MPa. Again, the roughness was measured. The results are pictured in Figure 2.

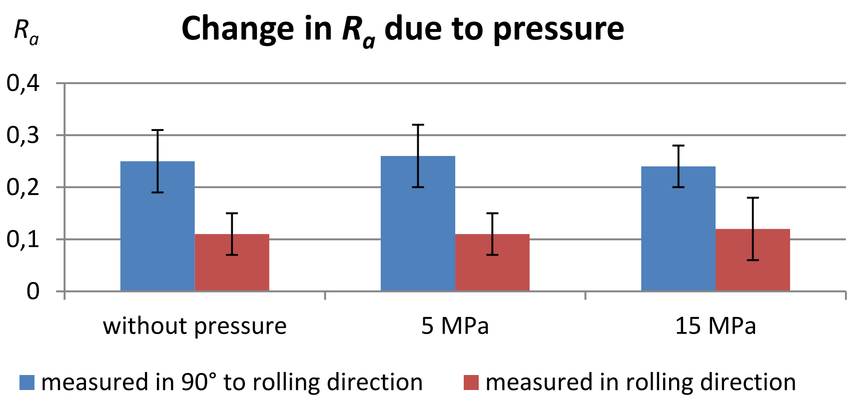


**Figure 2**: Change in $R_a$ due to contact pressure

The appearance of only normal pressure without any relative motion shows no significant influence on the roughness evolution of the sheet surface. This statement corresponds with Emmens [3].

### 3.3 Tensile Test

The Tensile Test was carried out on the dilatometer DIL 805A/D+T. A sketch of the geometry of a dilatometer sample is pictured in Figure 3. The samples were extended 6%, 8% and 10%. Samples were cut in three different angles to rolling direction (0°, 90° and 45°). Thereby the surface topography evolution in different directions of tension can be investigated.

Per extension, the surface topographies of four samples were analyzed by means of roughness measurement.

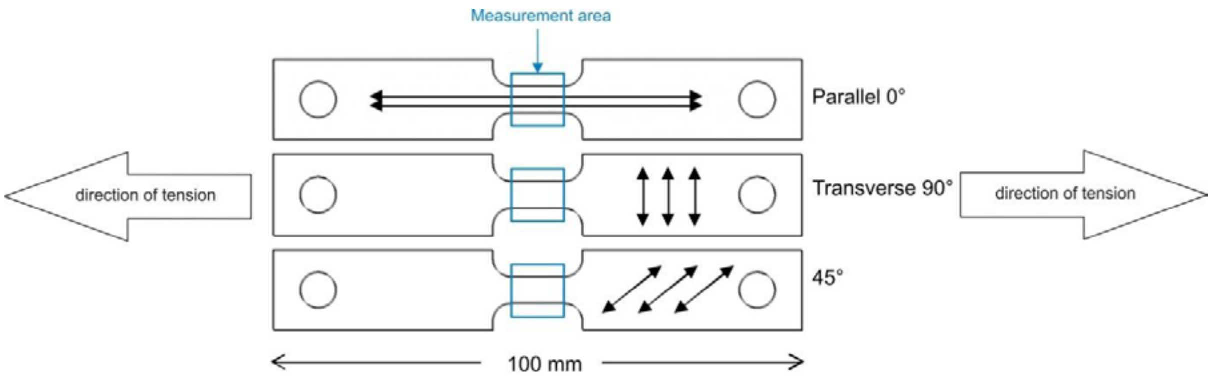


**Figure 3**: Dilatometer samples with different rolling directions

The results of the changes in surface roughness of the samples extended in different angles to rolling directions (0°, 90° and 45°) are presented in Figure 4a-c. The increase in roughness from the initial roughness (without tension) is expressed as a percentage above the bars. The $R_a$-values measured in rolling direction are smaller than the ones measured in 90° to rolling direction because of the surface structure formed by the rolling process.

A strong anisotropic behavior was found out: Tension applied in different angles to rolling direction causes dissimilar evolutions of surface topography. The measurement in 90° to rolling direction (blue bars) as well as the measurement in rolling direction (red bars) shows dissimilar increases. Especially the 45°-samples (Figure 4c) show a demonstrative behavior in roughness evolution: Whereas the roughness measured in 90° to rolling direction (blue bars) increases least, the roughness measured in rolling direction (red bars) shows the strongest increase.

The samples extended in rolling direction (Figure 4a) show less increase in the roughness measured in rolling direction (red bar) than the other samples. The influence of the rolling process on the roughness remains obvious when the sample is extended in this rolling direction.

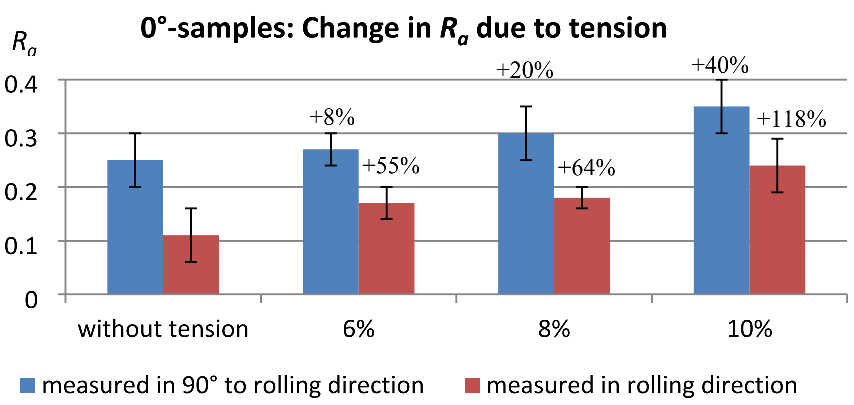


**Figure 4a**: 0°-samples: roughness evolution while tensile test

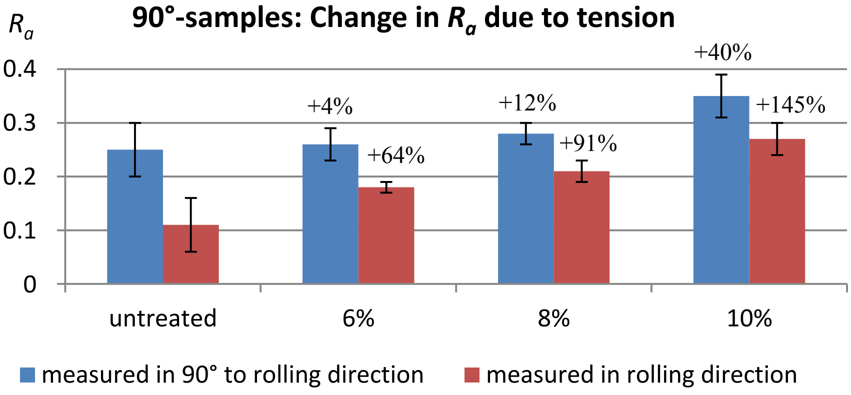


**Figure 4b**: 90°-samples: roughness evolution while tensile test

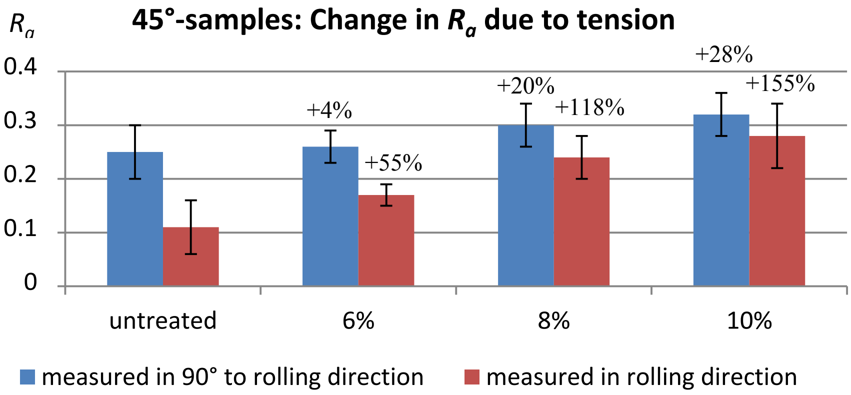


**Figure 4c**: 45°-samples: roughness evolution while tensile test

The highest increase in roughness (155%) is obtained for the measurement in rolling direction (blue bars) if the direction of tension has a 45° angle to the direction of rolling. As mentioned before, the measurements in rolling direction show a stronger increase because of the initial surface structure due to the rolling process. The tensions (8% and 10%) in direction of 45° to the rolling direction result in the most significant growths because this angle combines the roughening effects of both other directions of tensions, 0° and 90°.

In contrast to earlier results [4, 5] from compression experiments, no linear increase in roughness was obtained.

## 4 SUMMARY

As expected, the appearance of only normal pressure without relative motion shows no significant influence on the roughness evolution of the sheet surface: a shear stress on micro contact zones is needed for flattening.

While tension tests aluminum shows a strong anisotropic roughness evolution. Tension applied in different angles to the rolling direction causes dissimilar evolutions of surface topography.

The sheet surface topography which is changing due to contact, tension and sheet deformation is one factor influencing the friction. Therefore, it is important to take into account this anisotropic roughness evolution in friction modeling of deep drawing processes.

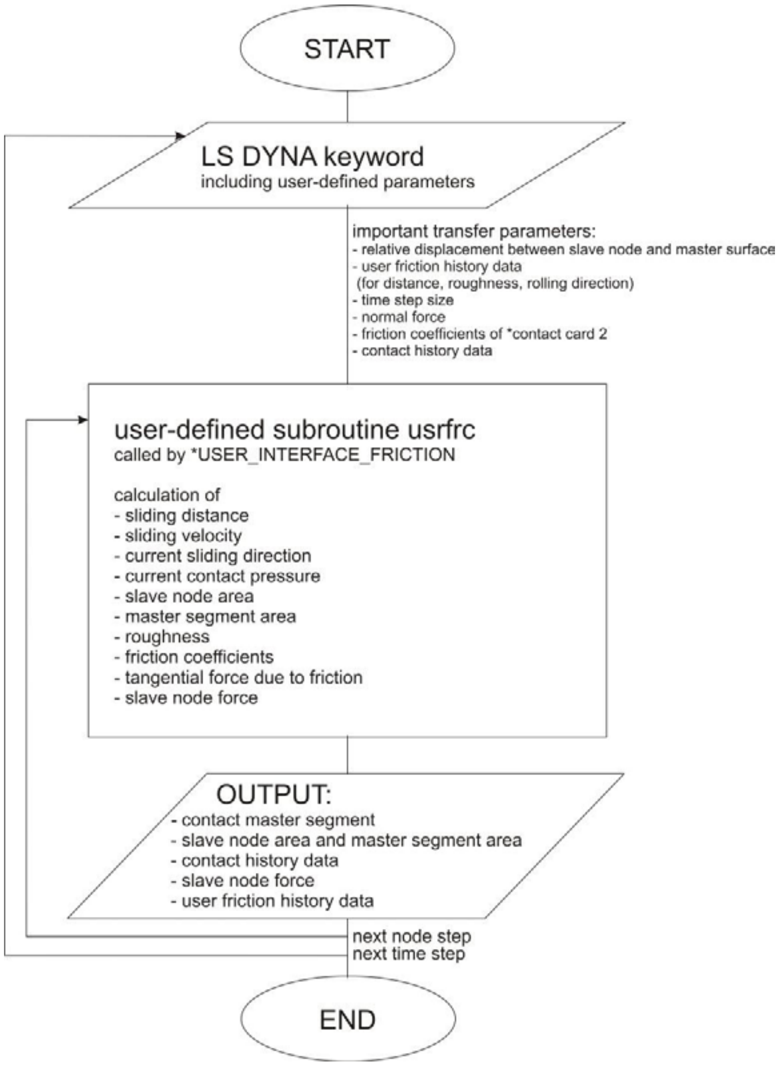


**Figure 5**: Algorithm of the new friction law

## 5 OUTLOOK

### 5.1 Strip Draw Test

Before creating an user-defined friction subroutine, friction tests must be executed. The case of appearance of contact pressure and relative motion has to be considered. Therefore, strip draw tests will be carried out.

The strip draw test offers the possibility to consider the influence of contact pressure and relative motion on the topography evolution of the sheet surface. In addition, the friction coefficient can be obtained.

The intention is to get a correlation between flattening or roughness evolution and the parameters of the deformation. This correlation can be used to improve existing friction models used for the FE analysis of deep drawing processes.

### 5.2 Numerical Modeling

The friction law can be implemented in the commercial finite element software LS DYNA by means of the user subroutine usrfrc in dyn21.F. In LS-DYNA, the friction between two contacting parts is based on a Coulomb friction. This underlying standard algorithm can be modified by the user by writing his or her own Fortran (or C) code [13].

An idea of friction subroutine is schematically presented in Figure 5.

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