

Experimental Investigation of Frictional Resistances in the Drawbead Region of the Sheet Metal Forming Processes

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Abstract. Drawbeads are used in sheet metal forming to restrain the sheet from flowing freely into die cavity, especially in the case of forming unsymmetrical drawpieces. This process is necessary to produce an optimal stamped part without wrinkles and cracks. In this paper, a special tribological simulator is used to evaluate the frictional resistances during flowing the sheet through the circular shape bead. The tests were conducted on DC04 carbon steel sheets with a sheet thickness of 0.8 mm. Experiments were carried out at different process parameters: friction conditions, specimen widths, heights and surface roughness of drawbead. The results obtained in the drawbead friction test show that the value of friction coefficient depends on the width of the sample. The character of sheet deformation during bending and reverse bending on the sheet thickness over the drawbead changes the surface topography and real contact area of sheet and tool.

1. Introduction

Sheet metal forming processes are influenced by many parameters such as friction and lubrication conditions, die geometry, shape of drawpiece, blank holding force and draw-bead force. In the case of forming drawpieces with complex shape, the material flow into die cavity must be controlled to prevent a drawpiece against defects such as wrinkling, galling, and tearing. Prevention of wrinkling of large complicated shapes like automobile body panels is based on the use of drawbeads in suitable regions of the drawpiece flange. The other means of applying a restraining force to control the material flow is application of higher blankholder pressure. However, this process may cause excessive wear of the tools and galling the sheet metal, especially in the case of aluminium alloys. The drawbeads play an important role in sheet metal forming and cause an increase in radial tensile stresses and a decrease in compressive stresses in drawpiece material. The number and arrangement of the drawbeads in stamping tool depends on the shape of the workpiece, and the drawing depth. They are placed in the locations subjected to small deformations, in which the hamper of the material flow and an increase in tensile stress are required. High blankholder pressure forces and drawbeads, however, increase the risk of sheet fracture. So, the determination of the frictional resistances that arise in drawbead is a crucial task in the process of producing an optimal stamped part with minimum material usage.

An analytical, experimental and numerical investigations of material flow controlled by the restraining force of the drawbead have been the subject of extensive studies in the past few decades. Firstly, Nine [1] developed a drawbead simulator which has been used by several researchers for



further investigations. The draw-bead test allowed the simulation of the bending and unbending in a sheet metal forming process and measurement of the friction coefficient during the sliding of the sheet against a drawbead [2]. Cao and Boyce [3] analyzed the restraining force with respect to the depth of drawbead. Triantafyllidis et al. [4] considered the effects of the drawbead in sheet forming using experiments and numerical modelling. The effects of friction coefficient, bead geometry, and material properties were investigated. Smith et al. [5] developed a novel device for obtaining pulling and holding forces for drawbead tooling on inclined binder surfaces.

Keum et al. [6] developed an expert database system that computes the drawing characteristics of different kinds of drawbead: the circular drawbead, stepped drawbead, and squared drawbead. The predictions obtained from this expert system agreed well with the experiments. The experimental and numerical research on the effect of sheet metal surface roughness, sample orientation according to sheet rolling direction and lubricant conditions on the value of friction coefficient in the drawbead region conducted by Trzepieciński and Lemu [7] have shown that the sample orientation and the lubrication conditions are crucial parameters influencing the value of the coefficient of friction. Firat and Cicek [8] applied numerical modeling of drawbead to improve the accuracy of finite element simulations in terms of part draw-in and thickness distribution predictions. The results of the modeling have been validated with channel drawing experiments of high-strength low-alloy steel.

The use of expert systems and numerical simulations to predict frictional resistances in mass production is limited due to the high costs. Furthermore, accurate prediction using these systems requires the knowledge of many parameters that must be determined and often have to be verified experimentally. So, better understanding of the evolution of friction coefficient at drawbead still demands experimental testing. In this paper, the drawbead apparatus is used to evaluate the frictional resistances in drawbead region in forming of DC04 carbon steel sheets that are widely used in automotive industry.

2. Material and method

The experimental works were conducted at different process parameters, including specimen widths, drawbead penetrations (figure 1a) and drawbead surface roughness. Drawbead simulator (figure 1b) that was mounted on the Zwick/Roell Z030 tensile testing machine was employed. In this setup, the wrap angle of middle roll may be changed by a nut. During the test, the pulling (vertical) force and clamping (horizontal) force were measured and registered simultaneously using tension gauges and computer program respectively. The friction test consisted of two stages: (1) pulling the specimen between freely rotating cylindrical rolls, and (2) measuring the pulling force and the clamping force that gave the bending and unbending resistance of the sheet under “frictionless” conditions, respectively. The sheet was displaced between the rotating rolls in order to minimize the friction between the sheet and rolls, while the second specimen was pulled between the fixed rolls [7]. The coefficient of friction (COF) value is then calculated according to the following expression:

$$\mu = \frac{\sin\theta}{2\theta} \cdot \frac{F_P^{\text{fix}} - F_P^{\text{free}}}{F_C^{\text{fix}}} \quad (1)$$

where θ is the quarter contact angle of actual engagement of the strip over the bead, and F_C^{fix} is the normal force or clamping force obtained with the fixed beads, F_P^{fix} is the pulling force obtained with the fixed rolls, and F_P^{free} is the pulling force obtained with the freely rotating rolls.

The test material was a DC04 steel sheet ($R_{p0.2} = 187$ MPa, $R_m = 307$ MPa, $A = 22.5\%$) with a thickness of 0.8 mm. The basic roughness parameters of the sheet determined using the Talysurf CCI Lite 3D instrument are as follows: $Sa = 1.178$ μm , $Sq = 1.467$ μm , $Sp = 8.628$ μm , $Sz = 17.902$ μm , $Ssk = -0.128$, $Sdq = 2.97$, $Sdr = 0.265\%$. Three sets of rolls with different surface roughness values ($Ra = 0.32, 0.64$ and 1.25 μm) were used. Machine oil lubrication L-AN46 was used for the friction tests.

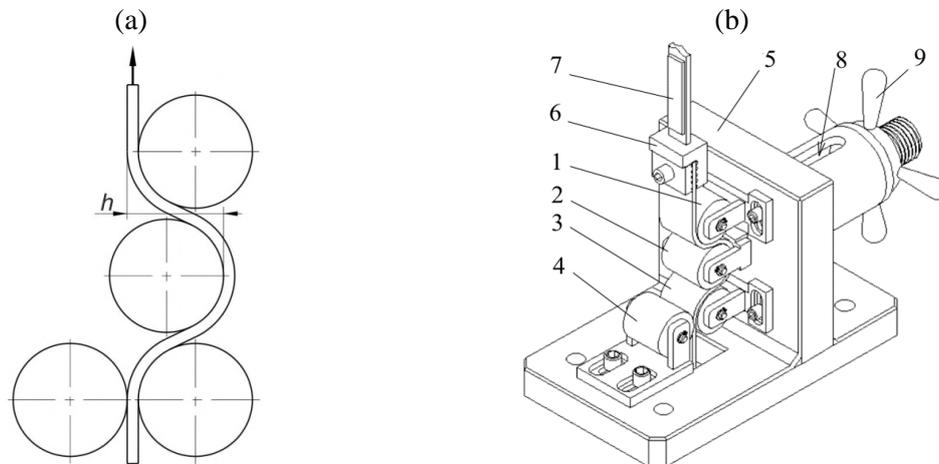


Figure 1. (a) The model of drawbead and (b) measurement system used for friction testing; 1 – front roll; 2 - middle roll; 3 – back roll; 4 – supporting roll; 5 – frame; 6 – tension member; 7 and 8 – extensometers; 9 – nut.

3. Results and discussion

As depicted in figure 2, the highest values of COF, for all sample widths, are observed at the penetration depth of middle roll $h = 12$ mm. Results of the statistical analysis showed that standard deviation of the registered experimental data did not exceed ± 0.016 . The effect of rolls surface roughness value on the friction coefficient value is also clearly visible. In the case of the smallest sample width (figure 2a) the highest COF is observed for surface roughness of $Ra = 1.25 \mu\text{m}$. The lowest friction coefficient value is observed for the rolls with surface roughness of $Ra = 0.63 \mu\text{m}$. However, for the highest tested sample width $w = 20$ mm (figure 2c) the situation is the contrary. This can be explained by the effect of sample width on the character of sheet deformation. The bending and reverse bending of the sheet during pulling the sheet through the drawbead caused that the initial rectangular section of the sample is changed into concave-convex section after leaving the drawbead. The contact of the sheet and front roll exists only at the edges of the sample (figure 3), where the roughness asperities are more flattened than in the middle area of the sample width. This effect is not indicated by previous researches that were conducted to investigate frictional resistances based on the idea of Nine's simulator [1].

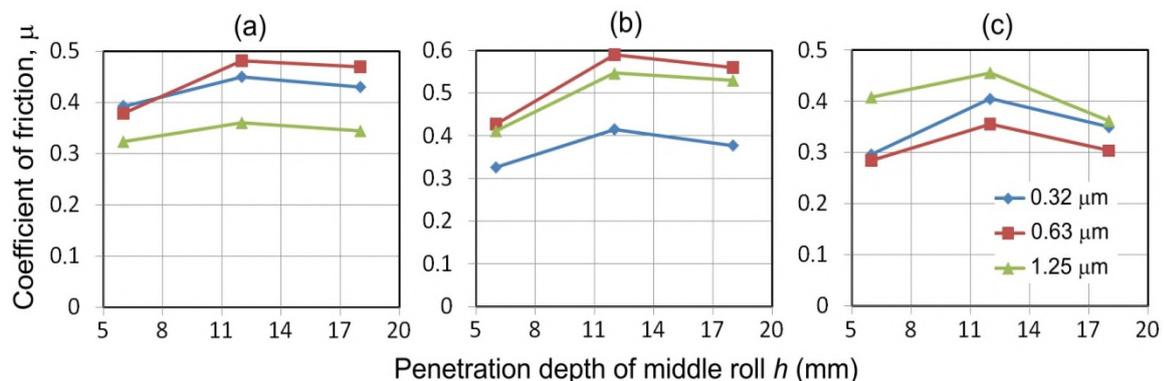


Figure 2. The effect of penetration depth of middle roll on the value of COF for sample widths: (a) $w = 7$ mm, (b) $w = 14$ mm and (c) $w = 20$ mm.

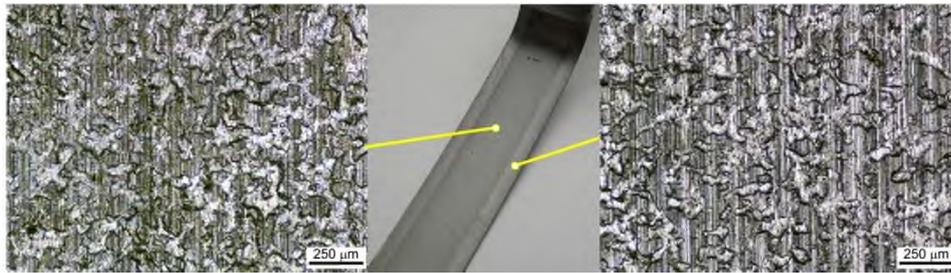


Figure 3. The view of the sample surface after the friction test.

The values of COF determined at lubricated conditions seem to be too high. However, it should be noted that the values determined using drawbead simulator are conventional parameters resulted from the difference of plastic and friction resistance of pulling the sheet through the drawbead. Furthermore, the pulling direction of the sheet is not parallel to the direction of sheet movement around the middle roll. The sheet is subjected to strain hardening phenomenon during friction testing, so the mechanical properties of the sheet greatly influence the COF value than the contact conditions.

Increased sample width leads to decreased COF value only in the case of the roll with surface roughness of $Ra = 0.32 \mu\text{m}$. Furthermore, the values of COF for tested sample widths (figure 4a) are the most similar among all used rolls (Figure 4a-c). The most unfavourable friction conditions are observed in the interaction of the roll roughness $Ra = 0.63 \mu\text{m}$ with the sample width $w = 14 \text{ mm}$ (figure 4b). Further, two-fold increase in roll roughness causes slight decrease in the COF value (figure 4c). To understand the relation between the sample width and COF for roll roughness values of $Ra = 0.63 \mu\text{m}$ and $Ra = 1.25 \mu\text{m}$ (figures 4a and 4b), it must be taken into account that lower surface roughness leads to an increased COF value due to increased contact area. In materials forming, where there exists high contact plastic deformations, according to the friction law of Amontons-Coulomb, the COF, in many cases, does not depend on the area of contact, but this is not satisfied. However, the high surface roughness of the tool causes flattening of the softer sheet material and the frictional resistances increase.

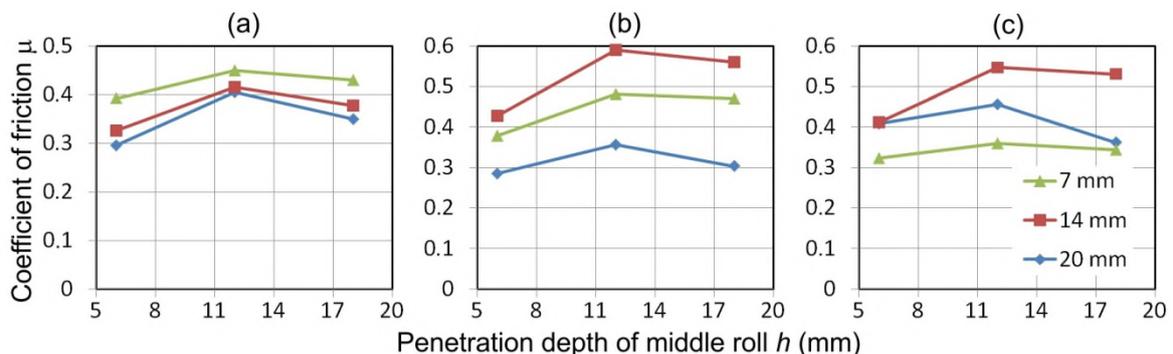


Figure 4. The effect of penetration depth of middle roll on the value of coefficient of friction for surface roughness of rolls: (a) $Ra = 0.32 \mu\text{m}$, (b) $Ra = 0.63 \mu\text{m}$ and (c) $Ra = 1.25 \mu\text{m}$.

The values of the friction coefficient determined for the samples cut according to the rolling direction and cut transverse to this direction (figure 5) are close to the range of the standard deviation of data. So, it can be noted that sample orientation slightly influences the friction coefficient. Considering the sample width $w = 20 \text{ mm}$, the optimal surface roughness ensured the minimal value of COF that is equal to $Ra = 0.63 \mu\text{m}$ (figure 6). As mentioned above, the high surface roughness corresponds to the intensification of flattening mechanism, so the COF value increases. In the case of low surface roughness, the lubricant is squeezed out from the contact interface, so the load is carried out by plastically deformed roughness asperities.

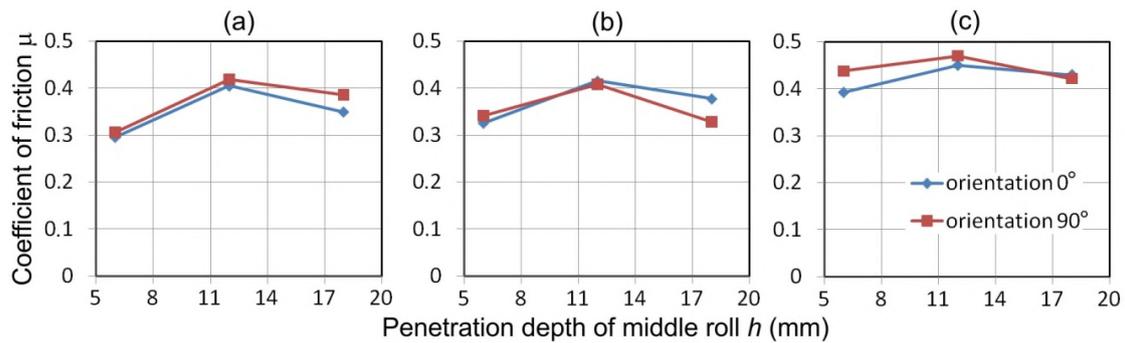


Figure 5. The effect of penetration depth of the middle roll on the value of the coefficient of friction for sample width $w = 20$ mm at: (a) $Ra = 0.32 \mu\text{m}$, (b) $Ra = 0.63 \mu\text{m}$ and (c) $Ra = 1.25 \mu\text{m}$.

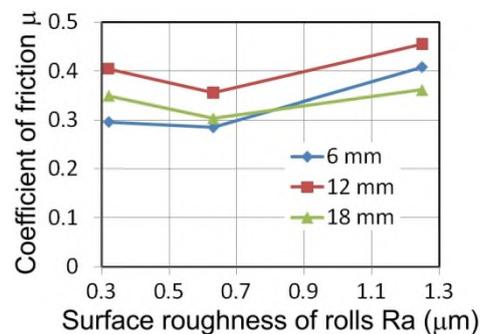


Figure 6. The effect of surface roughness of rolls on the value of the coefficient of friction for sample width $w = 20$ mm.

4. Conclusions

The action of the drawbead changes the stress-strain state in the drawpiece, and this is because of strain hardening phenomenon of the mechanical properties of sheet material. The plastic deformation of the sheet material causes the change of the topography of sheet surface, and as a consequence, the conditions of frictional contact change. Experimental tests using the drawbead simulator showed that the sample width is an essential parameter in analysis of frictional resistance while pulling the sheet through the drawbead. During a series of local bending and reverse bending, the sheet width determines the character of sheet deformation and real area of contact between sheet and rolls. The high surface roughness ensures better lubrication due to high volume of voids. However, high profile height causes the intensification of flattening of roughness asperities. Then, the friction coefficient value increases. In contrast, the low surface roughness of tool ensures worse lubrication due to low volume of open voids, which result in increased COF value.

5. References

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