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# ANALYSIS OF THE FRICTION INFLUENCE ON CHANGE OF SURFACE TOPOGRAPHY IN STRIP DRAWING TEST

## ANALIZA WPŁYWU TARCIA NA ZMIANĘ TOPOGRAFII POWIERZCHNI WYTŁACZANYCH BLACH

**Key words:**

friction, coefficient of friction, sheet metal forming

**Słowa kluczowe:**

tarcie, współczynnik tarcia, kształtowanie blach

### Summary

In the article, topographical and tribological analysis of the surface of steel sheets is presented. Strip drawing tests were used to describe the friction phenomenon in sheet metal forming processes. The topographical analysis of tested samples was carried out by using the Alicona InfiniteFocus measurement system. The results of strip drawing tests were used as input variables in a mathematical model of friction. The friction tests were carried out in order to determine the influence of the surface parameter values of the sheets, the surface parameters of the rollers, and the pressure force on the friction coefficient value.

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## INTRODUCTION

Friction in sheet metal forming processes is a complex function of material properties and process variables, including forming speed, temperature, lubricant composition and application method, tooling and sheet geometry, and surface topography. All can influence friction conditions in sheet metal forming operations to a significant extend [**L. 4**]. Moreover, resistance to friction depends on physical and chemical factors acting on the contact surface, dynamics of loads and temperature [**L. 3, 4**]. In majority of sheet metal forming processes, the existence of friction resistance is an undesirable phenomenon due to the following [**L. 4**]: strain non-uniformity (especially in thin-walled drawpieces), the increase in forming forces, the decrease of tool life, and the quality of product conformance.

Many friction test for the simulation of friction conditions in different regions of the formed drawpiece were developed and tested [**L. 3, 10, 12**]. In the sheet metal forming process, strip-drawing tests simulate the friction phenomenon that exists between the punch and the wall of the drawpiece. During friction tests, a strip of sheet metal is pulled between two rollers. The parameters influencing the change of frictional resistance during strip drawing tests are the clamping force of the rollers, lubrication conditions, pulling speed, and the surface roughness of the rollers.

Macrogeometry and microroughness of contact surfaces have an important influence on friction resistance during the processes of sheet metal forming with the help of rigid rollers. Microroughness is defined as surface roughness components with spaces between irregularities (spatial wavelength) less than about 100 micrometers [**L. 1**]. Under the influence of pressure force, the peaks of microroughness are deformed and come into surface contact is sufficient to load transfer. During the contact of rough surfaces, smoothing of surface asperities and the evolution of topographic parameters of the top layer occur [**L. 2**]. The elasto-plastic deformation of surface asperities causes an increase in the real area of contact. The value of frictional resistance depends on the real area of contact, rather than the nominal area of contact (**Fig. 1**).

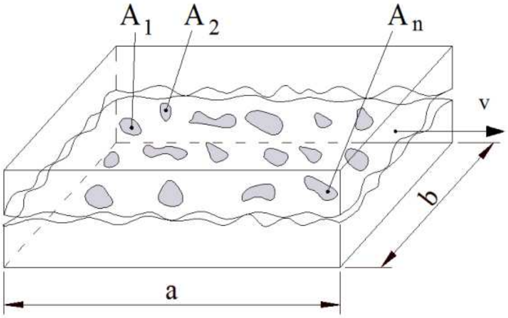

**Fig. 1. Real contact area of two surfaces being in contact**
Rys. 1. Pole rzeczywistego styku dwóch powierzchni będących w kontakcie

The real area of contact is equal to:

$$A_r = \sum_{i=1}^{n} A_i \tag{1}$$

and is smaller than nominal area of contact which equals $A_n = a \cdot b$.

The real area of contact between solid surfaces in contact is proportional to loading force $F_N$:

$$A_r = C_r \cdot F_N \tag{2}$$

where $C_r$ – proportionality coefficient depends on material, surface roughness, lubrication conditions, and the type of loading (static or dynamic). Except stochastic methods allowing to estimate a value of $C_r$ coefficient, any other methods enabling determination of an accurate value of $C_r$ have not been yet found.

Two main factors that have an influence on the increasing real area of contact in cold metal forming processes are

- macroscopic plastic deformations of the analysed element and
- contact stress that causes the mutual action of the deformation field of roughness peaks (**Fig. 2**).

The form of the contact surface has an influence on the nominal area of the contact surface and value of unit pressure. In recent research [**L. 8**], it was found that the dependence between the friction coefficient value and normal pressure is non-linear. The Microgeometry of contact is characterised by 2D and 3D roughness parameters and has an essential influence on the nature of tribological phenomena in the contact zone and the friction force value. The value of 2D roughness parameters depends on the direction of their measurement in relation to the rolling direction of the sheet. Frictional resistance measured along rolling direction is lower than measured perpendicularly to rolling direction [**L. 9**].

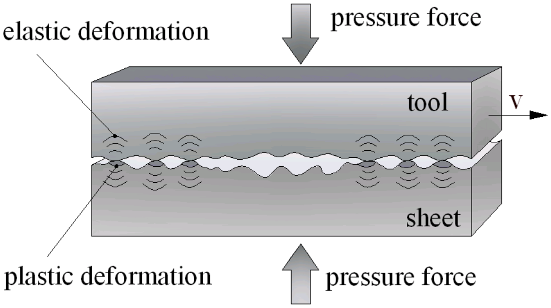

**Fig. 2. Plastic and elastic deformation of roughness asperities**
Rys. 2. Plastyczne i sprężyste odkształcenia wierzchołków nierówności

## MATERIAL AND TEST METHOD

Sheets made of deep drawing quality (DDQ) steel used in the automotive industry were selected as a testing material. The values of mechanical properties of the tested material (**Table 1**) were determined in the uniaxial tensile test. Tensile specimens of 240 mm gauge length and 20 mm width were prepared from strips cut at $0^0$, $45^0$ and $90^0$ to the rolling direction of the strip. Standard surface roughness 3D parameters (**Table 2**) were measured by using a Rank Taylor Hobson Subtronic 3+ instrument. The measured area is then 1.4301x1.0849 $mm^2$ with the point size 438x438 $nm^2$. The surface roughness was measured in the middle part of the specimen. Three measurements were done and average value of parameters was determined. After the strip drawing test, the surface was measured in the same places. The parameters for study were selected on the basis of the literature review [**L. 5–7**].

**Table 1. The mechanical properties of the tested sheets**
Tabela 1. Właściwości mechaniczne badanych blach

| Specimen orientation according to rolling direction | Yield point | Ultimate strength | Ultimate elongation | Strain hardening parameters | |
|---|---|---|---|---|---|
| | $R_{eL}$ MPa | $R_m$ MPa | $\varepsilon_u$ | C MPa | n |
| 0° | 162 | 310 | 0.42 | 554 | 0.21 |
| 45° | 163 | 320 | 0.38 | 542 | 0.20 |
| 90° | 163 | 312 | 0.41 | 530 | 0.21 |
| Mean value | 162.7 | 315 | 0.40 | 542 | 0.205 |

**Table 2. The surface roughness parameters of the tested sheet**
Tabela 2. Parametry chropowatości powierzchni badanych blach

| Material | Average absolute deviation of the surface | Root-mean-square deviation of the surface | Root-mean_square surface slope | Surface bearing index | Valley fluid retention index |
|---|---|---|---|---|---|
| | Sa µm | Sq µm | Sdq µm/µm | Sbi | Svi |
| DDQ | 1.54 | 1.89 | 0.103 | 0.913 | 1.56 |

The friction tests were realised using strip-drawing test (**Fig. 3**). Samples were prepared as a strip having a 20 mm width and about 200 mm length, cut along transverse direction of the sheet. A strip was clamped with a specified force between two cylindrical rollers with diameter of 20 mm made of cold-work tool steel.

Various tribological conditions were obtained by using rollers with different values of surface roughness parameters Ra: 0.32, 0.64 and 1.25 µm. These parameters were measured along generating line of rollers. Values of

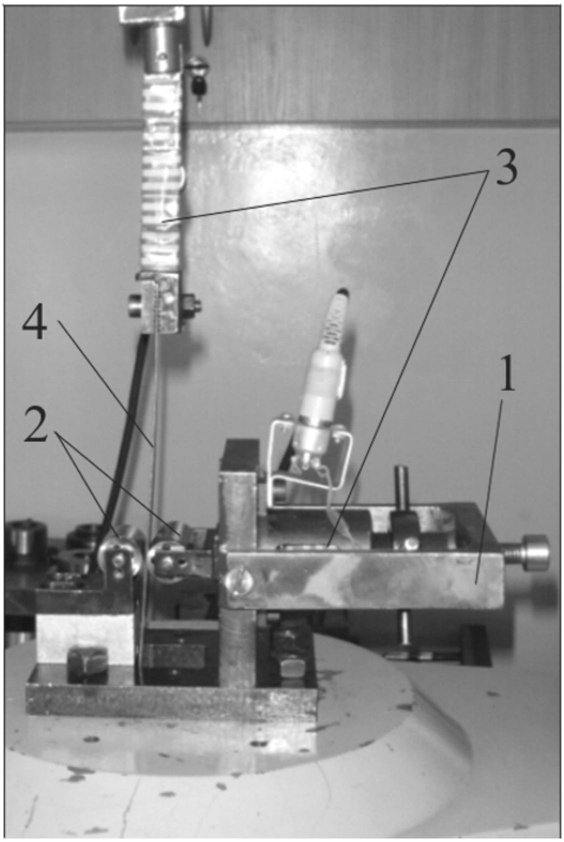

**Fig. 3. View of device for strip drawing test: 1 – frame, 2 – working rollers, 3 – load cells, 4 – sample**

Rys. 3. Widok przyrządu do realizacji próby przeciągania paska blachy: 1 – korpus, 2 – wałki robocze, 3 – czujniki, 4 – próbka

both forces, the clamping force $F_C$ and the pulling force $F_P$, were constantly recorded using the electric resistance strain gauge technique, 8-channel universal amplifier of HBM's QuantumX data acquisition system and a PC. The tests were conducted under the following values of clamping force: 0.4, 0.8, 1.2, 1.6 and 2 kN. To realise various friction conditions, both rollers and specimens were degreased by using acetone for "dry" conditions, and LAN-46 oil was used for "oil" conditions. The mean value of the friction coefficient is determined according to Eq. (3) for the stabilised range of values of $F_P$ and $F_C$:

$$\mu = \frac{F_P}{2 \cdot F_C} \tag{3}$$

where: $F_P$ – pulling force, $F_C$ – clamping force.

## RESULTS

The influence of different friction conditions on the change of the surface parameter values of tested sheets was determined. The general relationship was that the friction coefficient decreases as the clamping force value increases for both “dry” and “oil” conditions (**Fig. 4**). It can be explained by the fact that, after exceed a certain value of normal pressure, the relationship between the friction force and pressure force is non-linear. Consequently, the friction coefficient value is not constant and changes as the pressure force increases.

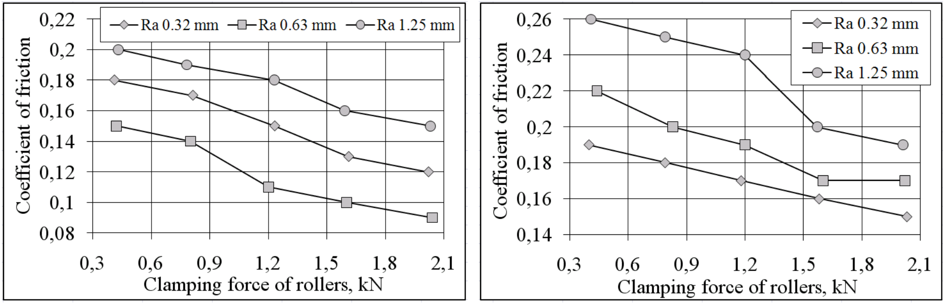
a)
b)

**Fig. 4. Value of friction coefficient versus the value of clamping force of rollers in lubrication (a) and dry friction (b) conditions**

Rys. 4. Zależność wartości współczynnika tarcia od siły docisku wałków wyznaczonego w warunkach smarowania (a) oraz tarcia suchego (b)

The variations of friction conditions determine the variation of the surface topography of sample surface [**L. 11, 12**]. Topographical analysis of samples was carried out by using optical 3D surface measurement systems (Alicona InfiniteFocus). The measurements of the functional parameters of surface microgeometry after strip drawing tests (**Table 3**) do not give an unequivocal response to how the change of friction conditions influence the variation in surface topography of sheets.

**Table 3. Roughness parameters of tested samples**

Tabela 3. Parametry chropowatości badanych próbek

| Ra of rollers µm | Friction conditions | Sa µm | Sq µm | Sdq µm/µm | Sbi | Svi |
|---|---|---|---|---|---|---|
| 0.32 | dry friction | 1.16 | 1.46 | 0.090 | 0.928 | 1.31 |
| | lubrication | 1.22 | 1.53 | 0.099 | 0.825 | 1.36 |
| 0.63 | dry friction | 1.29 | 1.62 | 0.088 | 0.898 | 1.36 |
| | lubrication | 1.33 | 1.64 | 0.104 | 0.812 | 1.45 |
| 1.25 | dry friction | 1.34 | 1.68 | 0.096 | 0.892 | 1.26 |
| | lubrication | 1.42 | 1.74 | 0.111 | 0.826 | 1.39 |

The friction process causes a decrease in the value of amplitude parameters Sa and Sq. For all tested sheets, lubrication influences the decrease of these parameters in a lesser degree. It is connected with the "planishing" of the sheet surface (**Fig. 6**) because of plastic squeezing of asperities of microroughness.

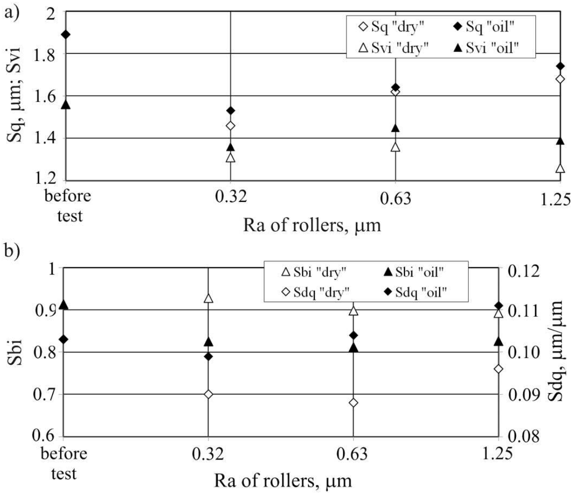

**Fig. 5. Variations of surface parameter values of sheets after friction tests: Sq, Svi (a), Sbi and Sdq (b)**

Rys. 5. Zmiana wartości parametrów chropowatości powierzchni blach po wykonaniu testów tarcia: Sq, Svi (a), Sbi and Sdq (b)

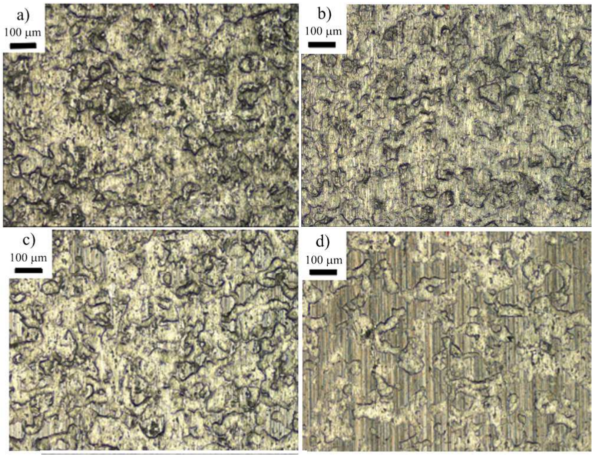

**Fig. 6. Surface topography of the sheet metal before (a) and after friction test under the following conditions: oil lubrication, clamping force $F_C$ 0.8 kN, Ra of rollers 1.25 μm (b), 0.63 μm (c) and 0.32 μm (d). Area 1.4301x1.0849 mm**

Rys. 6. Topografia powierzchni blachy przed (a) i po wykonaniu testów tarcia w następujących warunkach: smarowanie olejem, siła docisku $F_C$ 0,8 kN, Ra wałków 1,25 μm (b), 0,63 μm (c) i 0,32 μm (d). Obszar 1,4301x1,0849 mm

Decreasing of the surface roughness of the sheet causes an increase in the fraction of the load-bearing surface in sheet-roller metallic contact (**Fig. 7**).

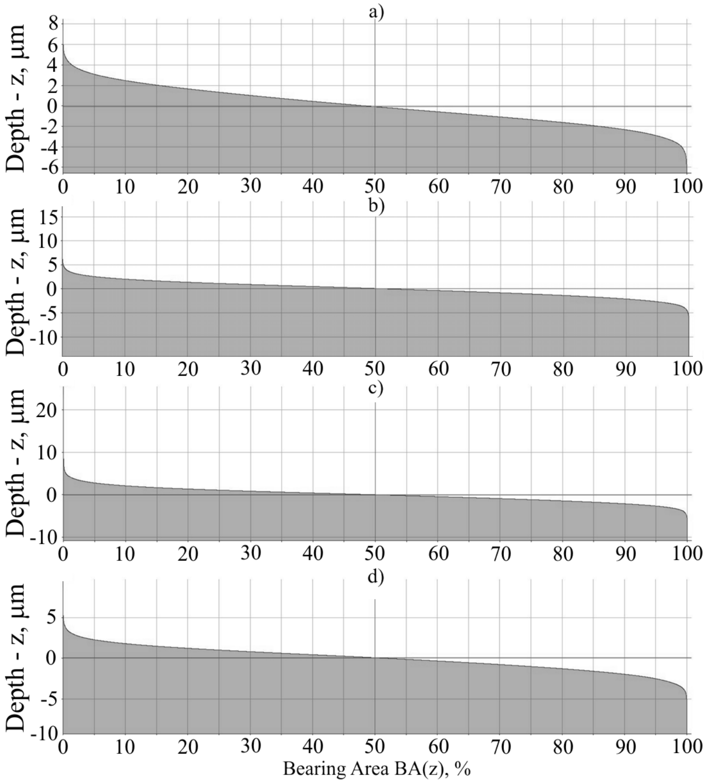

**Fig. 7. The bearing area curve for the sheets before (a) and after friction test under the following conditions: oil lubrication, clamping force $F_C$ 0.8 kN, Ra of rollers 1.25 µm, (b) 0.63 µm (c) and 0.32 µm (d)**

Rys. 7. Krzywa nośności profilu dla blachy przed (a) i po wykonaniu testów tarcia w następujących warunkach: smarowanie olejem, siła docisku $F_C$ 0,8 kN, Ra wałków 1,25 µm (b), 0,63 µm (c) i 0,32 µm (d)

The suitable surface topography determines the occurrence of oil pockets that decrease friction resistance by producing an oil cushion [**L. 10**]. The oil pockets perform as oil reservoirs. This significantly eliminates friction-welded connections and consequently decreases friction resistance.

## CONCLUSIONS

Interdependence between friction force and pressure force determined in strip-drawing tests is non-linear. Consequently, the value of the coefficient of friction is not constant and changes with the increase of the pressure force. Surface roughness of the sheet and the rollers essentially influence the character of tribological changes connected with friction resistance. The changes in the surface roughness of the sheets produce conditions of hydrodynamic lubrication. Furthermore, increasing the surface roughness of the rollers causes a decrease in roughness parameters Sa and Sq of the sheets after friction tests. The change in the surface topography of the sheets in the strip-drawing test was strongly connected with the value of the clamping force of the rollers and friction conditions which resulted from lubrication.

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## Streszczenie

**W pracy przedstawiono analizę topograficzną powierzchni po próbie przeciągania blachy. Analizę wykonano za pomocą systemów pomiarowych Subtronic 3+ Rank Taylor Hobson oraz InfiniteFocus firmy Alicona. Badania mające na celu wyznaczenie wartości współczynnika tarcia dla zmiennych warunków tarcia wykonano na specjalnym przyrządzie umożliwiającym pomiar tensometryczny. Badania zrealizowano dla różnych warunków tarcia wynikających z zastosowania trzech kompletów przeciwpróbek walcowych o różnej chropowatości powierzchni oraz różnych wartościach sił docisku rolek w warunkach tarcia suchego i smarowania olejem LAN-46. Określono wpływ zmiennych warunków tarcia na zmianę wartości parametrów chropowatości przeciąganych blach. Generalną zależnością wynikającą z badań jest spadek wartości współczynnika tarcia wraz ze wzrostem siły docisku dla warunków tarcia suchego oraz przy smarowaniu olejem. Po przekroczeniu pewnej wartości obciążenia zależność między siłą tarcia a siłą docisku jest nieliniowa, a współczynnik tarcia nie ma stałej wartości i zmienia się wraz ze wzrostem nacisku. Ze zmianą warunków tarcia wiążą się zmiany topografii warstwy wierzchniej próbek. Przeprowadzone pomiary parametrów struktury geometrycznej powierzchni blach po wykonaniu prób przeciągania nie dały jednoznacznej odpowiedzi na pytanie o wpływ warunków tarcia na zmianę chropowatości powierzchni blach. Procesowi tarcia analizowanej blachy głębokotłocznej towarzyszy zmniejszenie parametrów amplitudowych Sa oraz Sq. Jest to spowodowane wygładzaniem powierzchni blachy na skutek plastycznego zgniatania wierzchołków mikronierówności. Jednocześnie wraz ze zmniejszeniem chropowatości powierzchni blachy zwiększa się udział powierzchni nośnej.**