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A NEW FRICTION TEST METHOD

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ABSTRACT

The process deep drawing is influenced by several parameters: one of the most important is the friction at the flange as well as the radius of the die. This friction is also effected by the size-effects. This paper describes a new friction test method for deep drawing applications, which is suited for investigations in different dimensions. Thus this method can be used to study the size-effects. The FC function (friction coefficients function) was derived from the results of strip drawing investigations to describe the friction behaviour in the whole deep drawing process.

1 INTRODUCTION

There's a growing demand on micro technical products, which is mainly driven by a rising trend of miniaturisation of products. As a basic process of production, deep drawing provides a great application potential for the manufacturing of parts with complex shapes, even the dimension of the workpiece is minimised. However, due to the size-effects the technology of the macro forming can not be directly translated to the micro forming [1, 2]. These size-effects affect the friction behaviour too, which plays a great role in the deep drawing process. So the friction behaviour was investigated in this paper, not only in macro forming but also in micro forming.
A new friction test method in deep drawing was developed in this investigation, which takes the effect of the normal pressure on the contact area into account, because the normal pressure on the contact area affects the friction too [3, 4]. Hence inconstant friction coefficients are obtained with this method, which differs from the conventional methods summarised in [5] and [6]. This method is scalable. It is suited not only for macro forming but also for micro forming. Through the comparison of the results from macro and from micro forming the tribological size-effects can be discovered. This is helpful for the translating of the forming technology from the macro to the micro forming.

2 INVESTIGATION

2.1 Strip drawing

During deep drawing the workpiece is drawn by the punch into the die. In the deep drawing of circular blank there is a tangential pressure in the workpiece. In order to avoid this tangential pressure a right-angled strip instead of a circular blank was drawn within the experimental and analytical investigations[7], so that the calculation of friction coefficients in this investigation is simplified. Two materials in two different forming dimensions were applied in this investigation, see Table 1.

Table 1: Materials and peometry of the strips used in this investigation

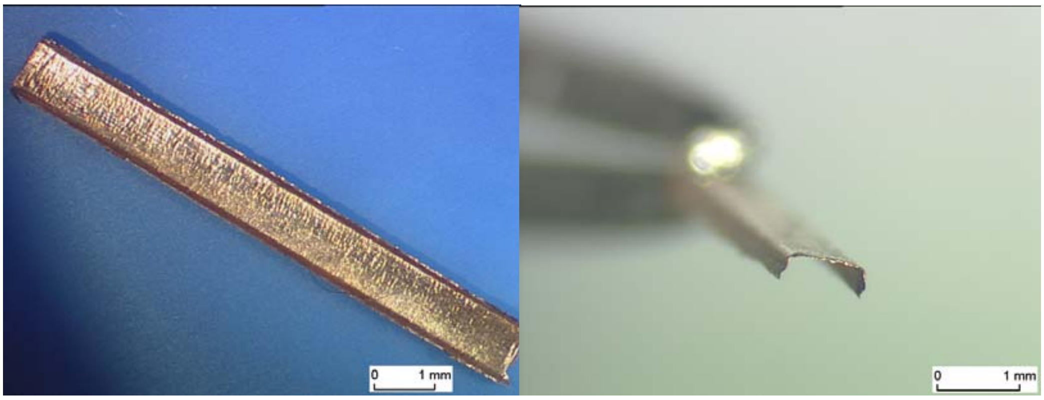
Material	Thickness [mm]	Yield stress [N/mm^2]	Punch length [mm]	Strip breadth [mm]	Strip length [mm]
St14	1	216.65	120	5	215
E-Cu58	0.02	30.3	1	10	1.8

For macro strip drawing mild steel St14 was used as workpiece material. In order to avoid a big punch force, which is meaningless for the investigation, the used strip had a narrow width (5 mm). The length of the strip was equivalent to a drawing ratio of 1.8 in this investigation. Macro strip drawing were carried out with lubricant (mineral oil HBO 947/11) in different amounts (0 g/m^2, 2 g/m^2, 4 g/m^2) and different blank holder forces (BHF) (4 kN und 3.2 kN). The corresponding punch force vs. stroke curves were achieved. *Fig. 1* shows a macro drawn strip.

Fig. 1: Macro drawn strip

Micro strip drawing with foils of 0.02 mm in thickness required a low punch force. Making the measurement of the punch force easier and more precise the width of the strip (10 mm) used in this investigation was magnified. The width of the strip was explicitly wider than the length of the strip. A micro drawn strip is shown in top view and cross section, *Fig. 2*.

Micro strip drawing tests were carried out with different BHFs of 18 N und 10 N, equivalent to initial blank holder pressure of 3.6 Mpa and 2 Mpa respectively. Considering that the effect of lubricant on micro forming maybe different from that on macro forming, the micro strip drawing tests were firstly carried out without lubricant, so that the boundary friction between workpiece and tool can be precisely investigated. In the future lubricant will be also applied in micro investigations.



Top view Cross section

Fig. 2: Micro drawn strip

Through strip drawing the punch force vs. stroke curves were obtained. Due to the great difference of the punch forces between macro and micro strip drawing, a normalised punch force, a ratio F/(B·t·k_f) depending on the s/d_0 is described in Fig. 3 for both macro and micro strip drawing without lubricant. Where F means the punch force, B means the width of the strip, t means the original thickness of the strip, s means the punch stroke and d_0 means the punch diameter. For simple bending the bending force F_B is proportional to width of the strip B, original thickness of the strip t and the yield stress of the material σ_s respectively. Due to that, the punch force F was normalised by B·t·σ_s, this normalised punch force F/(B·t·σ_s) should be constant, if no friction or other additional forces occur during the bending. In the strip drawing tests the punch force consists of the bending force and the friction force. The ratio of the punch force F to the term B·t·σ_s shows, how much is the portion of bending force F_B in the whole punch force F. On the other hand the portion of friction force F_R in the whole punch force F can also be shown through this ratio. The bigger F/(B·t·σ_s), the smaller the portion of the bending force F_B and the bigger the portion of the friction force F_R respectively. The results of macro and micro strip drawing are compared in *Fig. 3*.

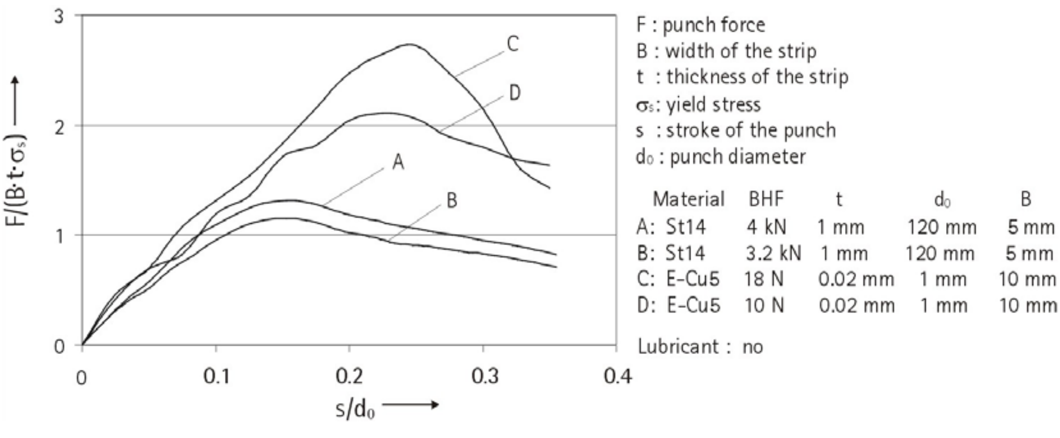


Fig. 3: F/(B·t·k_f) depending on s/d_0 of macro and micro strip drawing

The curves in *Fig. 3* show a good agreement: a lower BHF resulted in a lower friction force, thus the curve with the lower BHF lays below the curve with a higher BHF. The curves of micro strip drawing lay above the curves of macro. This means the portion of friction force F_R in punch force F in micro strip drawing is bigger than that in macro strip drawing. This is maybe due to the difference in the material (copper for micro, steel for macro) or/and size-effects. Due to the different friction coefficients distributions in the drawn strip the shapes of the curves are a little different from each other. All curves have a maximum. But the force of macro strip drawing increases steeper than the force of micro strip drawing. The maximum of the punch force in macro forming is at the stroke of about 17 mm, that is about 40% of the total stroke. However in the micro forming the maximum of the punch force is at the stroke of about 0.25 mm, that is about 70% of the total stroke.

2.2 Calculation of the friction coefficients

Based on experiments the friction coefficients will be determined from the measured punch forces. The relationship between the punch force and the bending forces is required. The acting forces during the process is shown in *Fig. 4* [6].

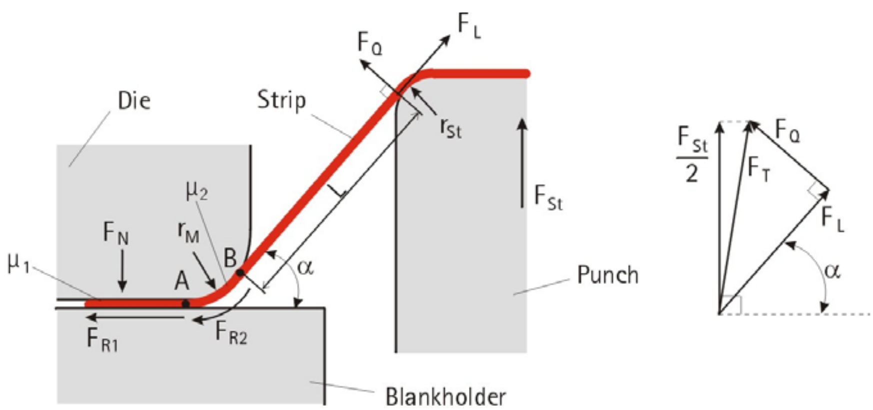


Fig. 4: Stresses in the strip drawing

Due to the effect of normal pressure on friction coefficient, friction coefficients at planes with different normal pressures should not be considered as same. The friction coefficient at flange (μ_1) and at radius of die (μ_2) are respectively given, because the normal pressures at flange and at radius of the die are not always same during the process. In [8] these forces are analysed and the relationship between the acting forces is acquired. A calculation method was developed. The main equations are shown in the following.

$$F_{R1} = 2F_N \mu_1(P)$$

$$F_{BA} = \frac{M_{BA}}{r_M + \frac{s}{2}}$$

$$F_{R2} = (F_{R1} + F_{BA})EXP(\mu_2(P)\alpha)$$

$$F_{BB} = \frac{M_{BB}}{r_M + \frac{s}{2}}$$

$$F_{BSt} = \frac{M_{BSt}}{L}$$

$$F_{st} = 2[(F_{R2} + F_{BB})\sin\alpha + F_{BSt}\cos\alpha]$$

whereby

F_{st} : punch force

F_{R1} : friction force at flange

F_{R2} : friction force at radius of die

F_{BA} : bending force at point A

F_{BB} : bending force at point B

F_{BSt} : bending force at the radius of the punch

α : bending angle

M_{BA} : bending moment on point A

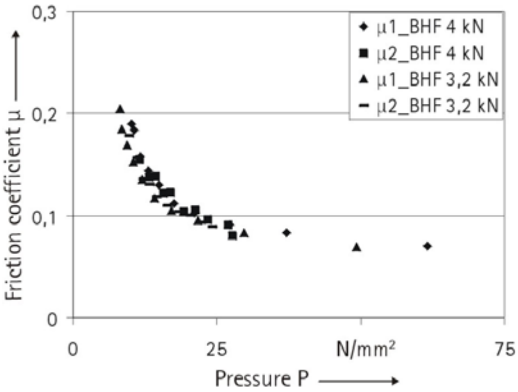
M_{BB} : bending moment on point B

M_{BSt} : bending moment on the radius of the punch

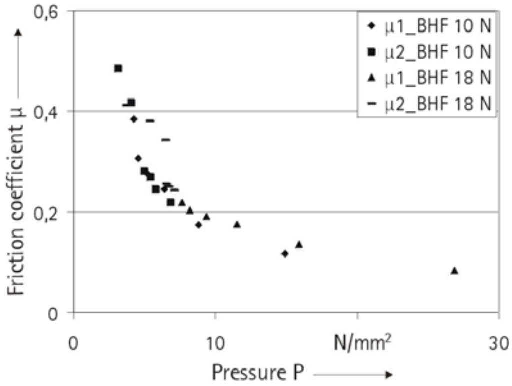
For the simplifying of the calculation three assumptions are applied [8]:

- The Coulomb's Law is valid in consideration of $\mu = f(P)$, whereby P is the normal pressure on the contact area.
- The normal pressure at the radius is uniform.
- Under the same forming condition (same material, same amount of lubricant and same roughness of surface) and same normal pressure the friction coefficient on a plane surface is equal to the friction coefficient on a round surface.

With the described method the friction coefficients at the flange (μ_1) and at the radius of the die (μ_2) were calculated from the punch force vs. stroke curves achieved in experiments. The acquired friction coefficients in dependence of normal pressure are shown in Fig. 5.



(a) Macro



(b) Micro

Fig. 5: Friction coefficients of macro strip drawing without lubricant

2.3 Determination of the FC function

The friction coefficients in each diagram shown above lay in a narrow band, which shows the trend of the calculated friction coefficients depending on the pressure. This trend can be described by a function in the following form:

$$\mu = a + b * EXP[(d - P)/e] + c * EXP[(d - P)/f]$$

whereby

μ : friction coefficient.

P : normal pressure on the contact area.

a, b, c, d, e, f : the numerical coefficients of the function without physical meaning.

But there are more than one mathematical description for a band. *Fig. 6* shows three typical curves through a same friction coefficients band (A goes through the top of the band, B goes through the middle of the band and c goes through the bottom of the band).

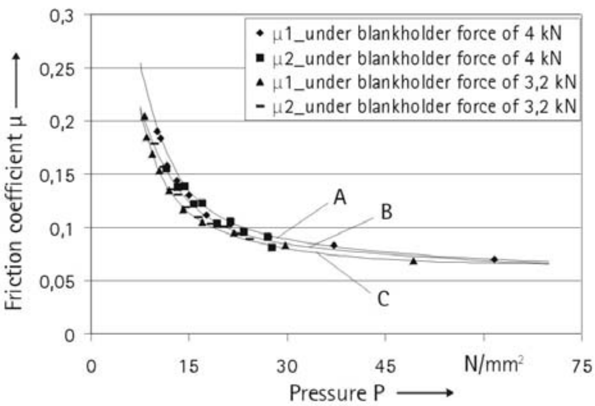


Fig. 6: Different curve described by different functions for the points cloud

These curves are described by three different functions respectively. Applying these functions back to the relationship between the acting forces three calculated punch force vs. stroke curves are acquired. The comparison of them with the experimental one is shown in Fig. 7. Obviously the curve B can at best correspond to the experimental one. The corresponding function for curve B is named as FC function. In each friction coefficient diagram a FC function can be obtained. The numerical coefficients of the FC functions for macro and micro strip drawing without lubricant are listed in Table 2. In order to certify these FC functions they are applied back into the relationship between the acting forces during the process. In this way a calculated punch force vs. stroke curve can be acquired.

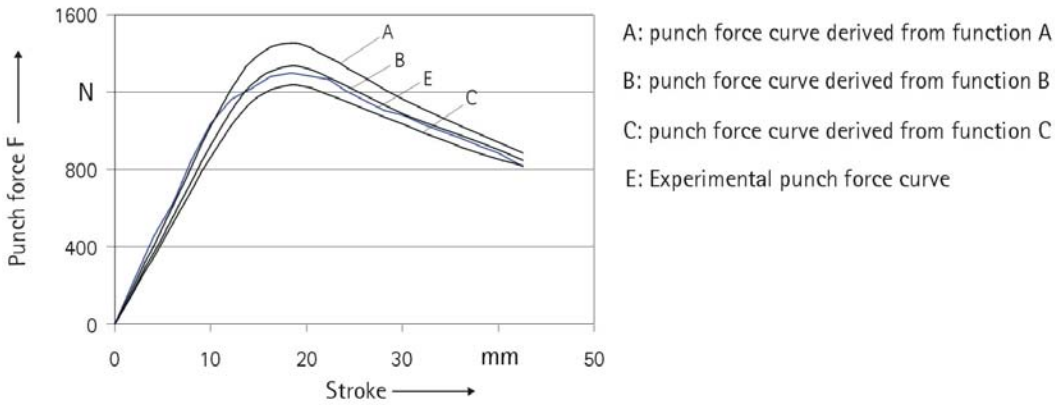


Fig. 7: Comparison of calculated punch force vs. stroke curves derived from different funtions

Table 2: FC functions of macro and micro strip drawing

Forming type	Material	Coefficients of the FC function					
		a	b	c	d [N/mm^2]	e [N/mm^2]	f [N/mm^2]
Macro	St14	0.05132	0.10353	0.04645	8.13	5.81127	53.64356
Micro	E-Cu58	0.06383	0.30634	0.1698	2.66	2.37327	13.34402

The calculated results from these FC functions for macro and micro strip drawing are shown in Fig. 8. The calculated curves agree with the experimental ones very well. The workpiece material, the blank holder force and the lubricant amount were varied, whereas the other parameters like drawing velocity and forming temperature were kept constant. With a series of experiments, in which only the lubricant amount is changed and the other two kept unchanged, the effect of the changing lubricant amount on the process can be displayed. These FC functions can be easily used in the integration of size dependent FEM-simulation.

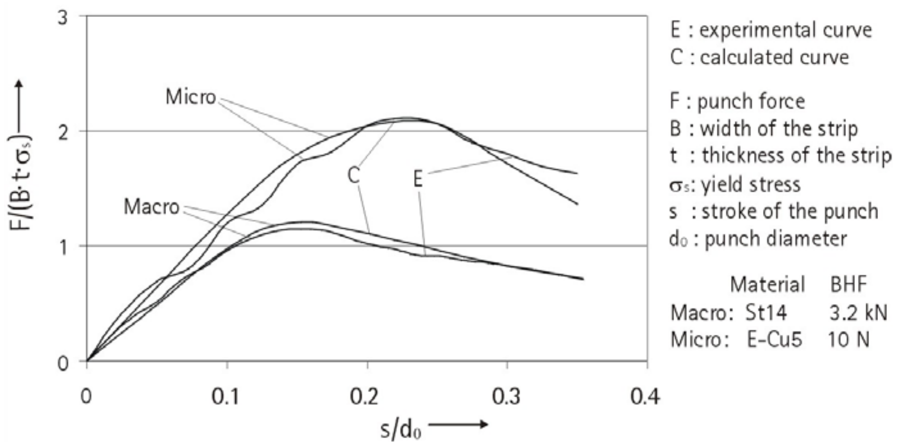


Fig. 8: Comparison of the experimental and calculated punch force vs. stroke curve of macro and micro strip drawing

3 CONCLUSIONS

The new friction test described in this paper enables a new description of the friction within strip drawing. This method is not only suited for the macro but also for the micro strip drawing.

A calculation method was developed within this friction test. With this method the friction coefficients can be directly calculated from the experimental measured punch force vs. stroke curve. Not only the coefficient on the stroke of max punch force but also the friction coefficients on the stroke of the whole process can be calculated.

Furthermore FC functions were derived from the calculated friction coefficients. These FC functions describe a dependence of friction coefficient μ on normal pressure on the contact area P. No relationship between the FC function and the tests dimension appears. Thus this FC function can be used as description of friction coefficients for investigations in different dimensions. The comparison of these FC functions in different tests dimensions is meaningful for the research of size-effects.

With the described calculation method the calculated punch force vs. stroke curves were obtained from the achieved FC functions. These curves show a very good agreement with the experimental ones. The achieved FC functions can be used in the integration of size dependent FEM-simulation.

4 ACKNOWLEDGEMENT

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REFERENCE

[1] F. Vollertsen, Z. Hu, H. Schulze Niehoff, C. Theiler, State of the art in micro forming and investigations in micro deep drawing, Journal of Materials Processing Technology 151 (2004), 70-79

[2] F. Vollertsen, Metal Forming: Microparts, Encyclopaedia of Materials, Science and Technology, Eds.: J. Buschow, R. Kopp et al. Elsevier Amsterdam (2001), 5424-5427

[3] B. Girschweski, M. Pfestorf, Einfluss von Trockenschmierstoff und Oberflächenstruktur auf das Umformverhalten von Aluminium-Blechen, Neuere Entwicklungen in der Blechumformung, 2000, 437-456

[4] S. Wagner, H. Kleinert, R. Zimmermann, Trockenschmierstoffe für die Blechumformung, Neuere Entwicklungen in der Blechumformung, 2002, 437-456

[5] M. Tisza, T. Fülöp, A general overview of tribology of sheet metal forming, Journal for Technology of Plasticity, Vol. 26 (2001), Number 2, 11-25

[6] E. Evin, A. Hrivnák, J. Tkáčová: Measurement and evaluation of friction ratios at deep drawing, Journal for Technology of Plasticity, Vol. 26 (2001), Number 2, 81-87

[7] Z. Hu, F. Vollertsen, Friction Test for Deep Drawing with Respect to Size-effects, New Forming Technology 2004, Proceedings of the 1st ICNFT, 153-158

[8] Z. Hu, H. Schulze Niehoff, F. Vollertsen: Determination of the Friction Coefficient in Deep Drawing, Process Scaling, Eds.: Vollertsen, F.; Hollmann, F., BIAS Bremen, Verlag, 2003, 27-34

NOVI METOD ZA ODREĐIVANJE VELIČINE TRENJA

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REZIME

U radu je prikazan novi metod za određivanje veličine trenja kod dubokog izvlačenja. U analizi je uzet u obzir raspored normalnog napona na kontaktnim površinama alat-materijal. Takav pristup rezultira u promenjivoj veličini koeficijenta trenja uzduž matrice.
Razvijeni metod može se skalirati tj. primeniti za određivanje koeficijenta trenja ne samo u makro nego i u mikro deformisanju. Komponovanjem dobijenih veličina u dve, dimenziono različite oblasti, može se odrediti tzv., "uticaj veličine" ("size effect"). Poznavanje ovog efekta neophono je pri analizi mikro procesa deformisanja.
U eksperimentalnom delu rada realizovano je makro i mikro duboko izvlačenje trake od St14.

Dimenzije trake:

- *makro: 1mm x 5mm x 215mm*
- *mikro: 0,02mm x 1,8mm x 10mm*

Na bazi originalnog matematičkog modela, moguće je odrediti veličinu koeficijenta trenja direktno iz očitane sile dubokog izvlačenja i poznate sile držača lima.
Određena je funkcija zavisnosti između koeficijenta trenja i pritiska koji vlada na kontaktu alat-materijal.