M.Stefanović, S.Aleksandrović, Tribo-modeling in Stetching of thin Sheets, Symposium on Computational and Experimental Methods in Mechanical and Thermal Engineering, Gent, 1998. Proceed., pp. 85-89.

TRIBO-MODELLING IN STRETCHING OF THIN SHEETS

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1. Introduction

Stretching of sheet metal is a typical stress-strain scheme characterized by positive values of principal normal stresses, one contact surface between the sheet metal and the tool, and relatively small sliding speed at that zone. Strain occurs only in the hole of the die, while the work piece flange is held firmly between the holder and the die. In course of forming the outer area of the work piece is free – not in contact, and so for sufficiently large ratio of punch radius and sheet metal thickness, the conditions of the plain stress state can be applied.

In deep drawing of parts of complex geometry, parts of car body for example, such stress- strain scheme exists under the punch face and in the zone of punch rounding. In laboratory conditions the stretching has been used for years in the evaluation of the sheet metal formability for deep drawing (Erichsen' s test, Olsen' s test).

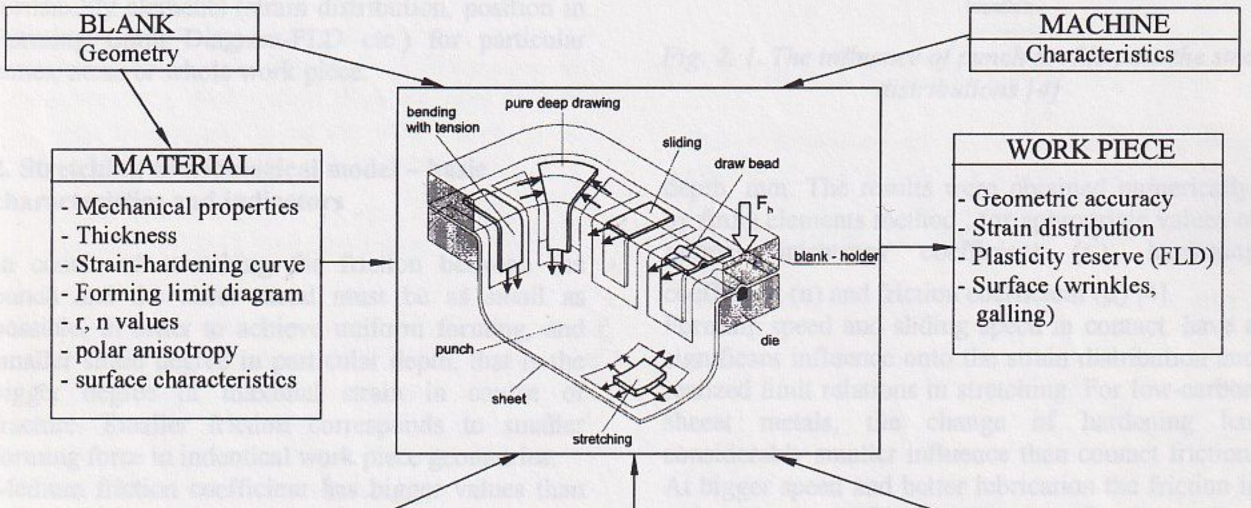

Fig. 1.1. Tribo model of stretching in global scheme of tribo-modelling of deep drawing

For different stress-strain schemes which regularly exist in deep-drawing of parts of complex geometry, the influence of tribological conditions can be different. There are differences in value of local pressures and speeds; also, in some work piece zones friction should be increased, in other zones decreased. Figure 1.1 shows, in more details, the tribo-model of streching in global survey of other models significant in deep drawing. Basic tribo models are – sliding between flat surfaces, bending with tension and sliding across the draw bead (strip draw tests), and complex tribo-models are – stretching and pure deep drawing [1].
According to the size of the examined work piece zones and characteristics of the measuring parameters, the results of tribological researches can be divided into three groups [2]: physical indicators (friction coefficient, friction force, sliding distance etc), macro indicators for whole work piece (force and depth of drawing, limiting drawing ratio etc.) and indicators of strain analysis with limit formability elements (strain distribution, position in Forming Limit Diagram-FLD etc.) for particular zones, areas or whole work piece.

2. Stretching as tribological model – basic characteristics and indicators

In course of stretching the friction between the punch and the sheet metal must be as small as possible, in order to achieve uniform forming, and smaller strain degree in particular depth, that is the bigger degree of maximal strain in course of fracture. Smaller friction corresponds to smaller forming force in indentical work piece geometries.
Medium friction coefficient has bigger values than in pure deep drawing (μ=0.2-0.3). At the place where new sheet metal zones make contact in course of lubrication, the oil film is formed and it can remain stable or be disturbed, depending on conditions of contact surfaces. Considering the relatively low values of surface pressure, in conditions of boundary lubrication, the adhesive-chemical qualities are more important than reological qualities of a lubricant [3].
Besides the lubrication conditions, geometry of stretching and punch speed also significantly influences the forming process. In course of investigation of geometry of streching it is necessary to observe separately the punch shape in the plane of tool travel and in the level of die.
In axis-symmetrical stretching, each work piece element moves only in radial direction. However, in non symmetrical forming there is the displacement in tangential direction. The deacrease of friction increases the tangential displacement from bigger radius zone into the zone with smaller curve radius. For example, for elliptic punches bigger stress appears, directed towards the bigger axis which moves the place of fracture. In conditions of complex configuration of punch face, it is necessary to have knowledge of strain history in order to control the friction in an appropriate way. Fig. 2.1 shows the basic distribution of main strain for three relations R/r, R – the radius of the punch face rounding , r - the punch radius and h_m – limiting

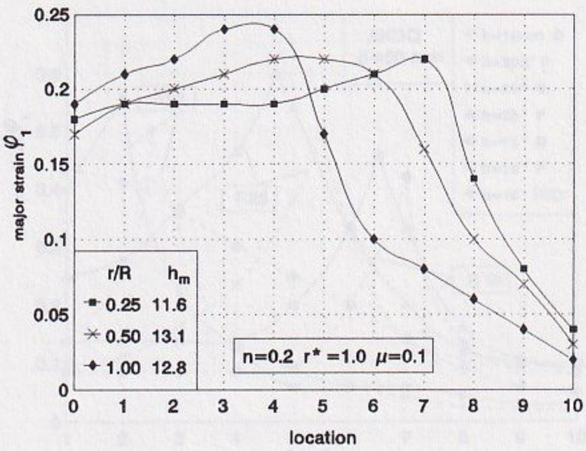

Fig. 2. 1. The influence of punch profile onto the strain distributions [4]

depth, mm. The results were obtained numerically, by finite elements method , for appropriate values of normal anisotropy coefficient $(\bar{r})$, hardening coefficient (n) and friction coefficient (μ) [4].
Forming speed and sliding speed in contact, have a significant influence onto the strain distribution and realized limit relations in stretching. For low-carbon sheeet metals, the change of hardening has considerably smaller influence than contact friction. At bigger speed and better lubrication the friction is reduced, more uniform forming is realized as well as bigger depths and strain degrees in fracture and the displacement of fracture location towards the work piece pole.
The increase of friction brings along the opposite appearances – sheet metal braking in the punch zone, localization of strain, and realization of high distributions gradient with prominent unhomogeneity of the strain field. The fracture zone is displaced towards the die edge.
According to fig. 1.1, the output indicators of modelling, according to the first and second group of the results, are both, fracture force and depth. In comparative investigations, such as evaluation of techinical qualities of the lubricant for deep drawing for example, it is convinient to work at the same drawing depths.
The usage of grid strain analysis procedure of measuring grids for determining strain distributions in characteristic areas or in sections of deformed work pieces make possible more qualitative approach in tribological researches. By using new procedure of measuring grids elements and by

computer treatment, strain analysis has become more reliable and considerably quicker [5], [6]. Strain distribution in the basic showing or in the system of main strains, connection with FLD, strain paths as elements of strain history, etc [7], can be used as indicators of the third group of results.
The distribution of the largest linear strain in meridian section in function of the location of measuring place in relation to the axis of drawing, represents the basis for more complete analyses and quatification of geometry parameters and tribological conditions. It is possible, for example, to introduce characteristic strain indicators: strain gradient in the critical zone, coefficient of strain suitability [8], i.e. the position of strain pick, the width of strain medium field etc [9]. By having knowledge of strain history one can determine the so called reseve of plasticity in FLD [10].

3. Some results of researches

The basic experimental scheme is given in fig. 1.1, and it consists of – the punch of circular section with diameter d=2r, with radius of punch face rounding R, - the holder, and – the die with radius r_M. The tools of following characteristics were used:

d=50 mm; R=10;18;25;50; ∞ mm, r_M=5 mm
d=100 mm; R=25;37.5;50;62;75 mm, r_M=8 mm.

In course of examination, materials intended for forming by deep drawing were used: 1) low carbon killed steel sheet metal (AKDQ-aluminium killed drawing quality), 2) steel sheet metal of the same category, with zinc coating (AKDQZn) and 3) stainless steel sheet metal (AISI 304). Mechanical characteristics and the characteristics of surface of these materials correspond to standard references.

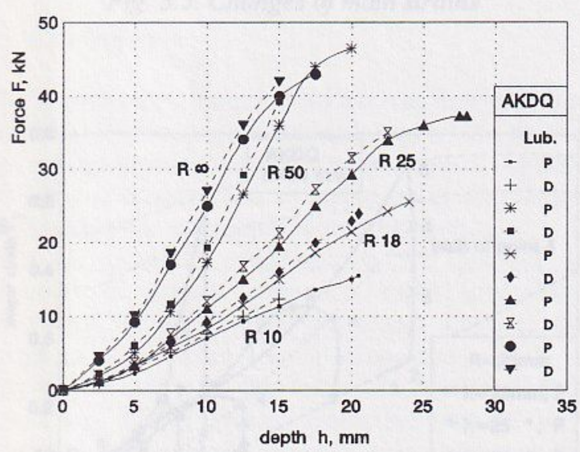

Fig. 3.1. Punch load dependence on drawing depth

Lubrication conditions provided limit conditions: technicaly dry contact surfaces (D) and "quasi-hydrodynamic" lubrication by using polyethylene foil (P). The punch speed was $3.33 \cdot 10^{-4}$ m/s.

In case of variable strain history two-phase trajectory is used: single-axis tension, in the first phase and stretching in the second phase.
Fig. 3.1 shows the stretching force dependence on the punch travel at different contact conditions and punch shapes. Geometrical relations influence the value of the forming force directly and analogously.

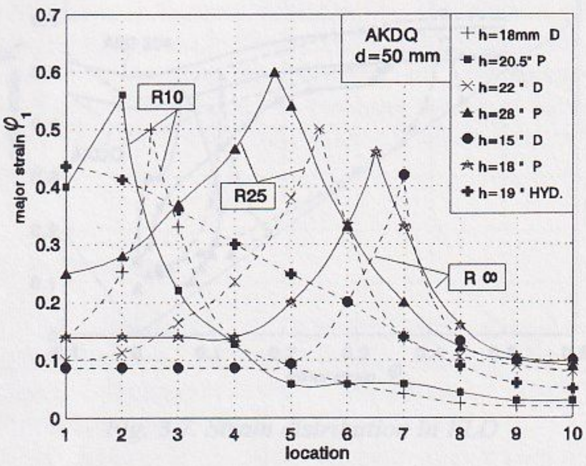

Fig.3.2. Strain distribution for d=50 mm

The distribution of main strains for different experimental conditions is given in fig. 3.2 and fig. 3.3. With the increase of punch diameter, smaller limiting degree of strain and larger depth are realized.
Comparative showing of realized limit depths in

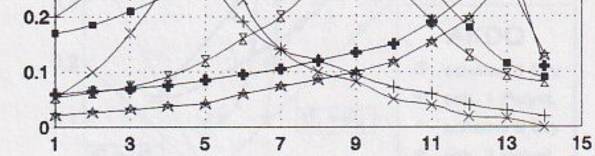

Fig. 3.3. Strain distribution for d=100 mm

stretching by punches of different geometry and in different contact conditions is given in fig. 3.4. More prominent influence of lubrication is relized at semi-spherical punch face shapes (R=r).
The differences in values of the largest main strains, which are realized in different contact conditions, are not the most important indicator. The tangential strain φ_2 has the basic influence onto the strain homogeneity and increase of fracture depth. Fig.3.5 shows the intensity of change of main strains in

special investigation conditions, and fig. 3.6 shows the strain distribution in FLD – so called constitutive diagrams.
The increase of the second main strain moves the

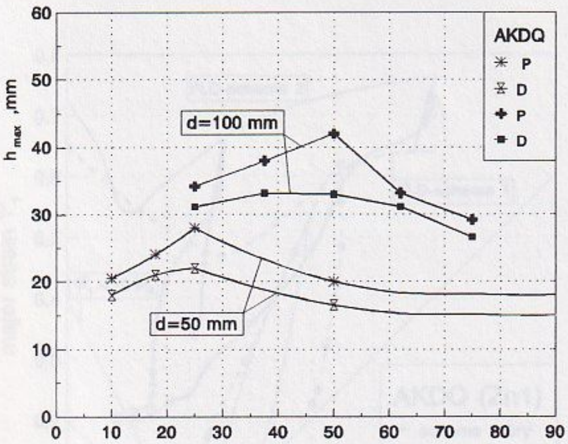

Fig. 3.4. The maximal depths in stretching

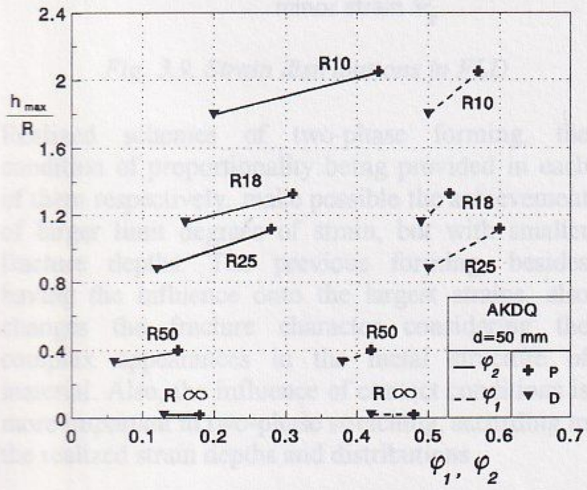

Fig. 3.5. Changes of main strains

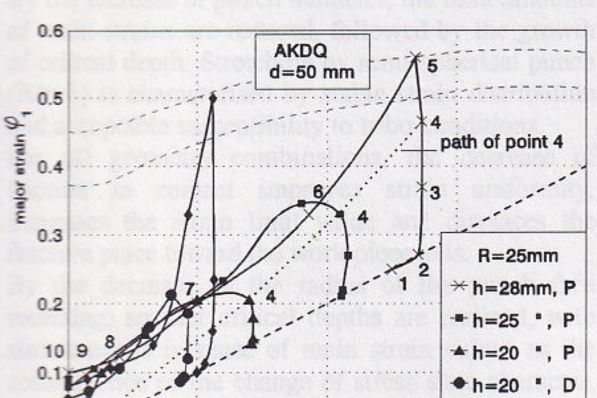

Fig. 3.6. Deformation constitutive diagram in FLD

strain trajectories in direction $\varphi_1=\varphi_2$ which realizes larger limit strain at the lifted part of FLD curve. Strain proportionality exists until the strain

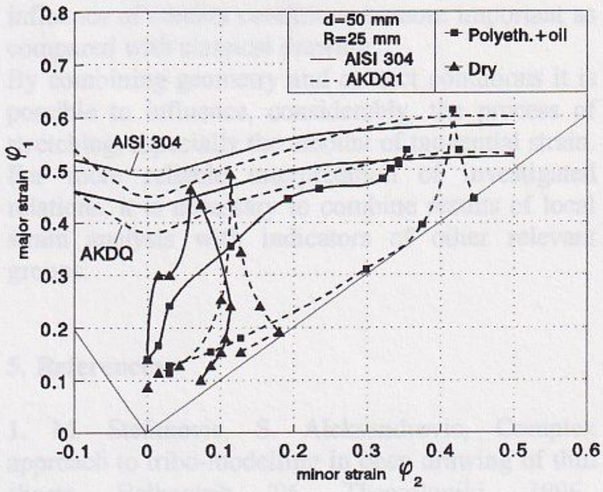

Fig. 3.7. Strain distribution in FLD

φ_2 becomes constant, and strain φ_1 enlarged to fracture.
In streching of stainless steel sheets metals, the qualitative lubrication moves the fracture place to the work piece center, fig. 3.7. Strain distribution in FLD is analogous to the case of using AKDQ sheet metals.

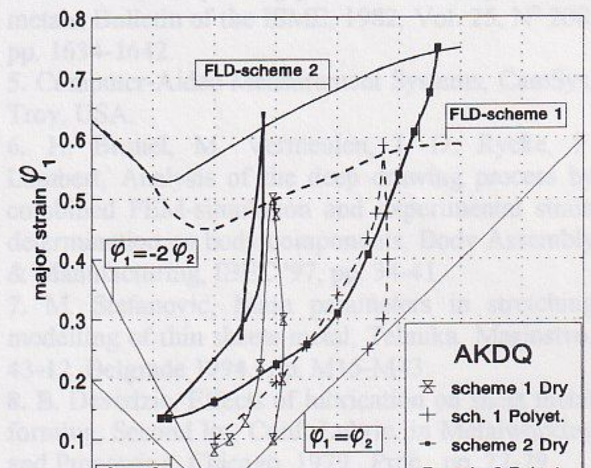

Fig. 3.8. Strain distributions in FLD

In using the FLD, the condition of indentical strain histories must be provided. Classical two-phase forming applied in this paper, is realized by previous single-axis tension, and then by stretching (scheme 2). Such previous strain lifts the FLD curve in the area $\varphi_2>0$. In investigation of sheet metals of ordinary quality, distributions are realized according to fig. 3.8. Previous tension corresponds to the initial point of distribution curves, with coordinates

φ_1=0.138 and φ_2=–0.083.
In case of stretching of sheet metal with zinc coating, tension to amount φ_1=0.2 is previously realized, fig. 3.9.

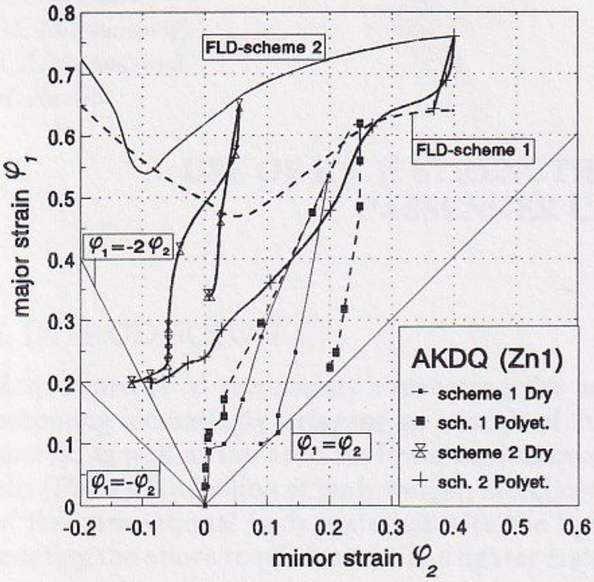

Fig. 3.9. Strain distributions in FLD

Realized schemes of two-phase forming, the condition of proportionality being provided in each of them respectively, make possible the achievement of larger limit degrees of strain, but with smaller fracture depths. The previous forming, besides having the influence onto the largest strains, also changes the fracture character considering the complex appearances in the metal structure of material. Also, the influence of contact conditions is more important in two-phase stretching, according to the realized strain depths and distributions

4. Conclusion

By the increase of punch diameter, the limit amounts of main strains are reduced, followed by the growth of critical depth. Stretching by semi-spherical punch (R/r=1) is characterised by stable strain distribution and acceptable susceptibility to tribo-conditions.
For all geometry combinations, the decrease of friction in contact improves strain uniformity, increases the strain limit value and displaces the fracture place toward the work piece axis.
By the decrease of the radius of the punch face rounding, smaller critical depths are realized, with simultaneous increase of main strain values as the consequence of the change of stress state character. With the increase of the radius of rounding, differences in distributions for different friction conditions are reduced; therefore, such forms can be used in the evaluation of sheet metals formability.
By the demonstrated change of strain history, the larger amount of local strains can be realized, but on the account of decrease of whole work piece formability. The realized limit strains are bigger, but the largest depths are reduced. In case of stretching of previously deformed by tension sheet metal (the first scheme of non proportional forming) the influence of contact conditions is more important as compared with classical drawing.
By combining geometry and contact conditions it is possible to influence, considerably, the process of stretching, especially the amount of tangential strain. For more reliable interpretation of investigated relations, it is necessary to combine results of local strain analysis with indicators of other relevant groups.

5. References

1. M. Stefanovic, S. Aleksandrovic, Complex approach to tribo-modelling in deep drawing of thin sheets, Balkantrib '96, Thessaloniki, 1996., Proceedings, pp. 214-221.
2. M. Stefanovic, S. Aleksandrovic, Importance of strain analysis in tribo-modelling in deep drawing, 1st World Tribology Congress, London, 1997., Abstracts of papers, pp. 626.
3. B. Fogg, Modern developments in lubrication theory and practice for deep drawing, Sheet met. ind., 6, 1976, pp. 294-304.
4. M. Kobayashi, Y. Kurosaki, N. Kawai, Working conditions for improving pure stretchability of sheet metals, Bulletin of the ISME, 1982, Vol. 25, N° 208, pp. 1634-1642.
5. Computer-Aided Measurement Systems, CamSys, Troy, USA.
6. H. Brunel, M. Vermeulen, I. D. Rycke, F. Lambert, Analysis of the deep drawing process by combined FEM-simulation and experimental strain determination on body components, Body Assembly & Manufacturing, IBEC '97, pp. 34-41.
7. M. Stefanovic, Main parameters in stretching modelling of thin sheets metal, Tehnika, Masinstvo, 43-12, Belgrade 1994., pp. M15-M43.
8. B. Devedzic, Effects of lubrication on sheet metal forming, Second Int. Conf. Lubric. in Metalworking and Processing, Chicago, 1979., Proc. pp. 27-29.
9. E. Schedin, A. Melander, On the strain distribution during the stretch forming of low and high-strength steels, Journal of Mechanical Working Technology, 15, 1987., pp. 181-202.
10. B. Devedzic, M. Stefanovic, On the influence of the lubrication in sheet metal forming on the variation in the "plasticity reserve", Int. Mach. Tool Des. and res., Swansea, 1980., Proc. pp. 397-403.