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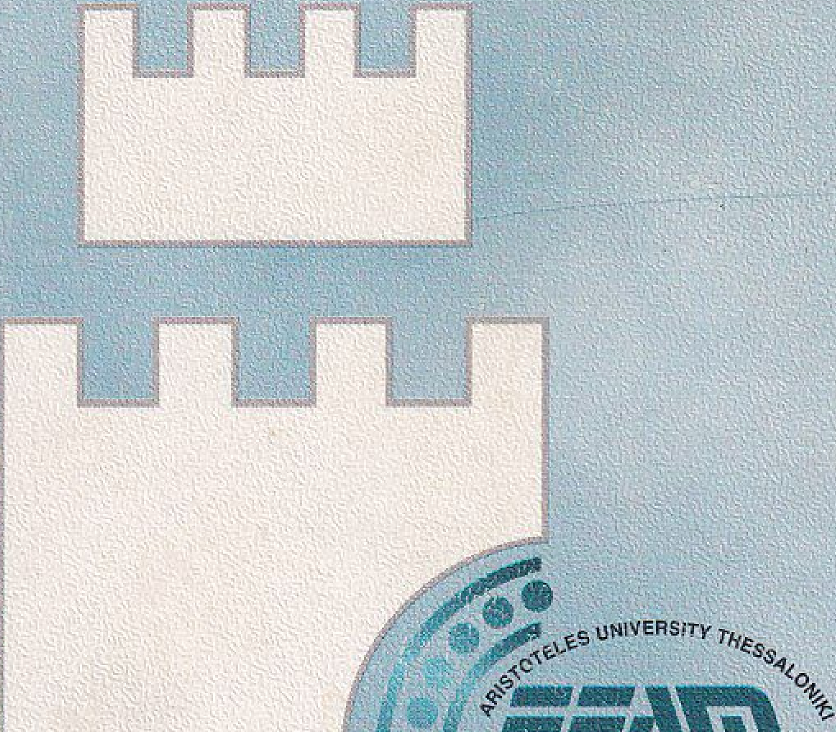

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LABORATORY FOR MACHINE TOOL
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MECHANICAL ENGINEERING DEPARTMENT

Complex approach to tribo-modeling in deep drawing of thin sheets

Prof. dr. ***Stefanovic M.***, *Mr. sci.* ***Aleksandrovic S.***
Faculty of Mechanical Engineering Kragujevac, Yugoslavia

ABSTRACT
In the paper is presented the general approach to modeling of characteristic tribological areas in deep drawing of parts with complex geometry. For particular models are defined the input parameters, the testing procedure, specific criteria and possible outputs. The parameters that represent the particular models are systematized into three groups; the most complete are those indicators which are related to the elements of deformation distribution, namely to realized deformation fields, and show the connection with the limiting formability. In this way, influences of speed, pressure, geometry, tribo-pairs, lubricants, etc., can be expressed through classical and specific parameters and indicators of the limiting formability.

KEYWORDS: sheet metal, deep drawing, tribology, formability

1.INTRODUCTION

Influence of tribological parameters in the forming by deep drawing is equally important with the influence of other central factors - machine, tool and material. The quality working piece is possible to obtain exclusively by convenient combination of the mentioned elements, where their interactions are extremely complex (e.g. influence of the die geometry in changing the holder force and ratio Rp/Rm, namely the lubrication scheme, etc.). The reliable production assumes obtaining of parts without cracks, wrinkles, zones of extreme thinning, corresponding dimensional accuracy and surfaces without scratches and damage (especially in thin sheets with coatings).

The main difficulty in modeling and studying of tribological processes in deep drawing of complex parts is multitude of possible local deformation schemes. Different stress - strain relations require selective approach in studying the formability and investigation of influence of tribological factors (different are basic friction influences - speed and pressure, in some zones of the piece friction is positive, and in some it is not, etc.). In accordance with different forms of deformation developed are simulation procedures for evaluation of corresponding machinability parameters, namely convenient tribological models and the foundation is created for reliable choice of lubricants .

In already realized manufacturing processes, by variation of tribological factors, is possible to very efficiently influence the machining process; change of material or machine, as well as the tool reconstruction are significantly more complicated. Frequently, due to insufficient knowledge, the broader tribological problems are reduced to choice of lubricants and the application zone. In that one neglects the essential influence of tribo - conditions in machining process on deformation force, loading and working life of the tool, achievement of successful forming (convenient stress and strain distribution without high local strain gradients, etc.), reduction of the energy consumption, etc.

2.SYSTEMATIC APPROACH IN TRIBO - MODELING

From studying the formability of thin sheets, it is known that the simulation tests can not satisfy completely the conditions of physical modeling. Due to geometric similarity, modeling conditions require application of original and model materials of different thicknesses and same characteristics of hardening and anisotropy, as well as identical surface characteristics. One also must take into account also the tool geometry, strain rate, etc.

Development of the so called complete modeling of the process is enabled by production of the modern computers on which the drawing operations are simulated. For numerical modeling is most frequently used the finite elements method. It is common that the tribological conditions are

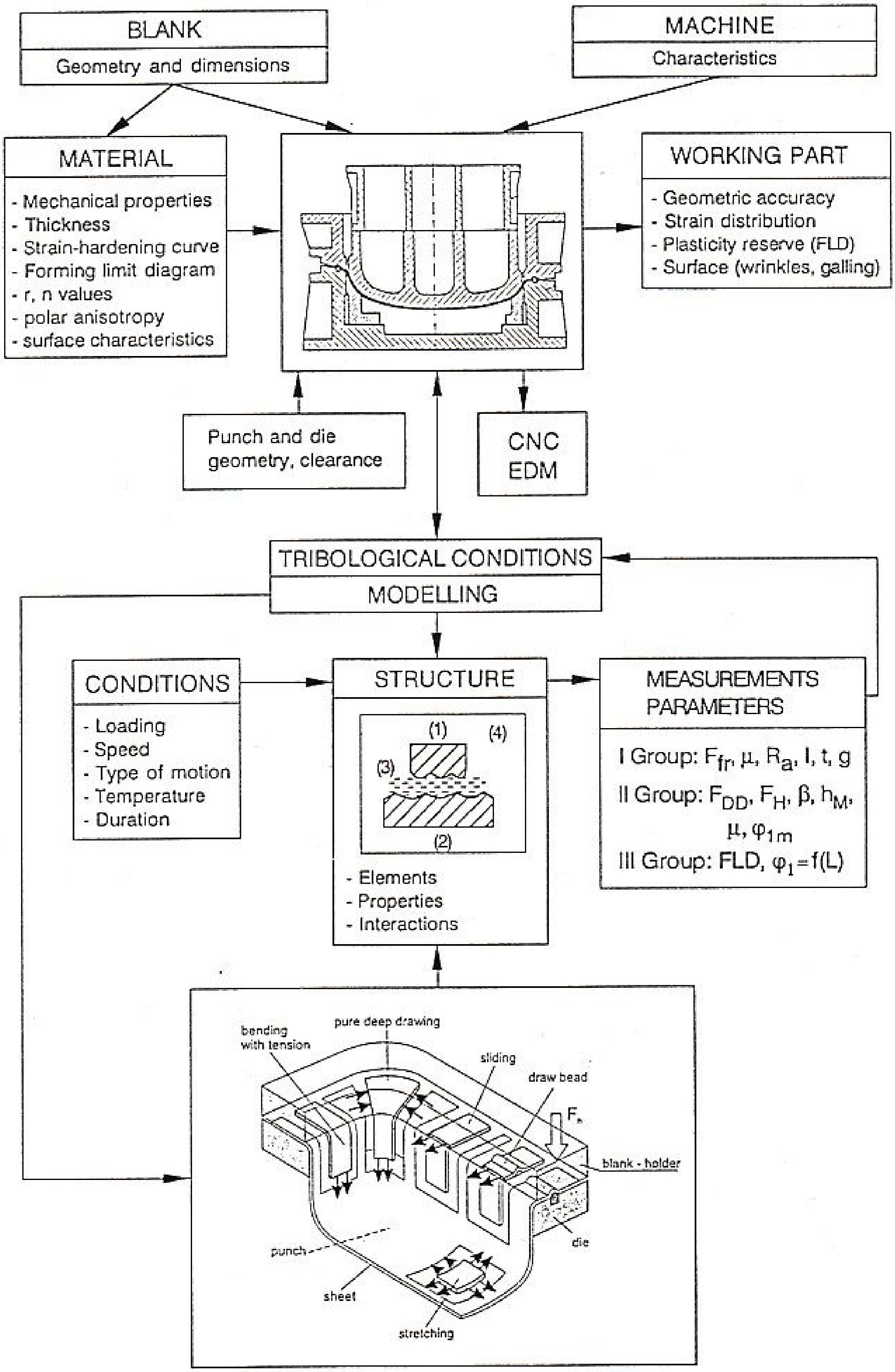

Figure 1. Tribo - modeling in general structure of the CAE system in deep drawing /1/.

described in somewhat simplified manner, as a given function of distribution of the friction coefficient on the contact surfaces, in the phase of prediction and forming of the strain distribution model. The second phase assumes investigation of limiting relations in full development of the process .

In this paper will be considered the physical modeling of characteristic zones in complex drawing, which can be also accepted as a basis for complete tribological modeling. In that the approach in studying can be different and include the following:

a)Local zone, in which forming depends on its shape and metal plasticity characteristics. Obtained elements are basis for the so called local strain analysis.

b)Several local zones, which make the area in which the machining conditions depend on the shape of that area, type of straining (accumulated strain, relaxation, asymmetric appearance of wrinkles).

c)Complete piece, which can be considered through averaging of characteristics of different zones with their mutual influences. The foundation is formed for the so called integral strain analysis.

The new concept of design of the deep drawing technology and introduction of the CIM strategy elements, assumes also the systematic approach to studying the tribological problems. In Figure 1 is presented the concept of the CAE system which includes also the tribological modeling. Such a presentation of deep drawing as a multi-parameter model, enables, via relations by which it is described, studying of input / output variables, criterion for checkups, analysis and control is manufacturing of parts with given performances. Relations shown in Figure 1 represent synthesis of classical design, tribo system structure, and types of elementary and complex tribo - models /1/.

Natural order in studying the mentioned processes in deep drawing of more complex parts is: choice of the zone - area, identification of straining scheme (association of some of the known stress - strain schemes), forming of the corresponding tribological model, realization of the simulation procedure, parametric, local or integral strain analysis, interventions into the machining system or the tool design procedure in the appropriate manner.

As it is presented in Figure 1, results of tribological investigations can be divided into three groups, in accordance with the nature of parameters which represent measurements variables for different models.

I group of parameters - those are the physical variables, frequently presented in the form of graphs, the most frequently as a function of pressure, speed and temperature: Ffr - the friction force, μ- the friction coefficient, R_a,R_z-roughness arameters, l - the sliding length (galling tests), t - temperature, g - weight amount of wear.

II group of parameters - represents the outer indicators*f* of the forming process, the most frequently for the whole piece (procedure c): F_{DD} - total drawing force, F_H - holder force, β-limiting degree of drawing, h_M - the largest depth at failure, μ- the friction coefficient.

Parameters of this group are frequently of the complex character, e.g. relation of the drawing depth and holder force for variable contact conditions, or friction coefficient distribution in the main cross - section of the piece for individual phases of drawing, etc.

III group of parameters - represents the interior indicators of the forming process (procedure b,c) and it requires knowledge of the critical forming zone. Parameters of this group are being determined graphometrically and they require complex experimental approach and complex analysis. Those are: strain distribution in the form $\varphi_1, \varphi_2, \varphi_3 = f(location)$ with indicators of the distribution uniformity, strain gradient, etc., strain distribution in the forming limit diagram (reserve of plasticity, local necking zones), elements of the straining history, trajectories slopes, etc.

Presentation of characteristics and results of particular tribo - models are in the paper given in the order related to their degree of complexity, which takes into account the following: nature of deformation, stress - strain state, influence of macro - geometry, complexity (enhancement of simpler models). Those are, according to Figure 1, strip draw tests, bending with tension, sliding over the draw bead, stretching and pure deep drawing.

3.BASIC MODELS AND MAIN INDICATORS

According to the general scheme of tribo-modeling of parts with the complex geometry, *sliding of the sheet between the plane surfaces of the holder and die* corresponds to those zones on the piece which are not subjected to tangential compression, but only to tension in the radial direction. Due to the low values of pressure in the holder zone, the plane part of the flange slides freely and deforms elastically. During sliding the normal and sliding (double the friction force) forces are measured, so the friction coefficient is relatively easily determined; the main deficiency of such a procedure is absence of permanent deformations in tension, namely the different change of surfaces in contact and the role of lubricant. .

In conditions of expressed adhesive wear, regularly appears the phenomenon of galling, which can be defined as seizure of the thin sheet surfaces, what has as a consequence the transfer of sheet metal material to the tool. Without going into details of the material transfer mechanism origination, it is important to mention that the galling phenomenon renders more difficult the deep drawing of thin sheets with anti-corrosive coatings and lowers their formability. As the basic procedure for studying the galling is regularly used the strip draw test, with basic indicators that are taking into account the micro geometry, speed and other tribological characteristics /2,3/. In the paper /4/ is shown that there is no reliable correlation between the critical pressure at which the galling occurs and standard roughness indicators Ra, Rz, number of peaks per length unit, carrying curves, etc., but relevant parameter is *surface waviness* - undulations of surface, of which the period of repetition is greater than of the surface roughness, but smaller than length of the entire surface, Figure 2.

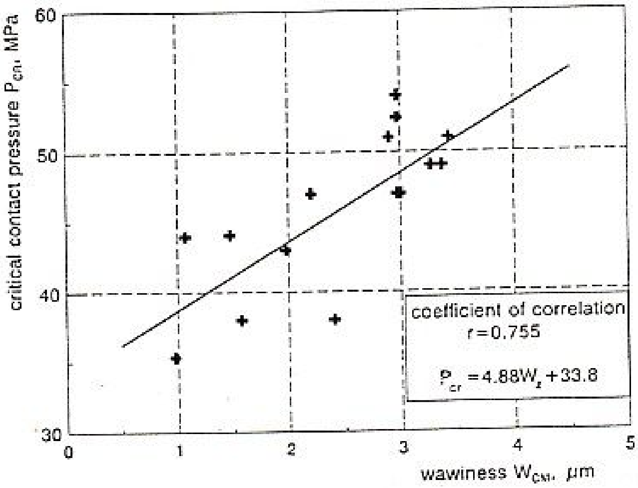

Figure 2. Relationship between critical pressure and waviness /4/

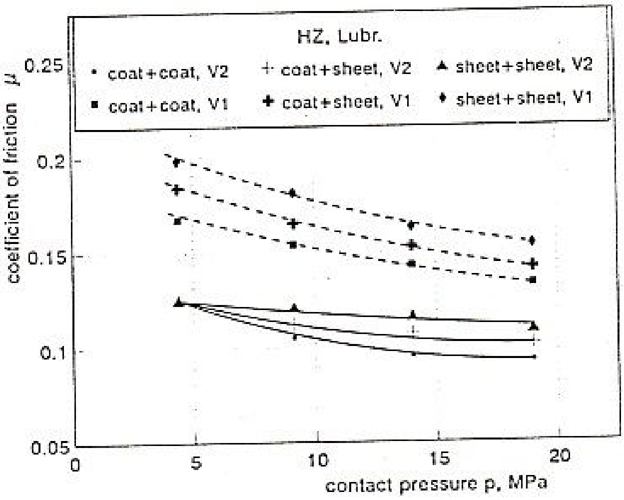

Figure 3. Friction coefficient change for thin sheet with coating

Experimental investigations, whose results are presented in the further text, were conducted under the following conditions: materials were the low carbon rested steel thin sheets, of nominal quality C0148 without coating (UC), hot zinc-plated (HZ) and with the zinc and chromium coating (ZC); deformation speeds were v1= 0.33 mm/s and v2= 3.33 mm/s, lubrication conditions - no lubrication (dry - D), lubrication with oil for deep drawing (L), lubrication with polyethylene foil (P). Mechanical characteristics and surface roughness indicators have values prescribed by the corresponding standards for this kind of material.

In Figure 3 is shown the dependence of the friction coefficient on contact pressure for different combinations of contact surfaces, in conditions of preserved coating. Both sides coatings and increase of the sliding speed significantly decrease the friction in contact.

At the pressure increase over 40 MPa the braking of the sub layer occurs, absence of sliding and specimen tearing. The pressure increase at thin sheets with coatings leads to smaller change of the medium roughness, but the intensity of the friction coefficient change is much more emphasized, Figure 4.More realistic relations can be obtained by consecutive sliding - pulling of the same specimen, without additional lubrication.

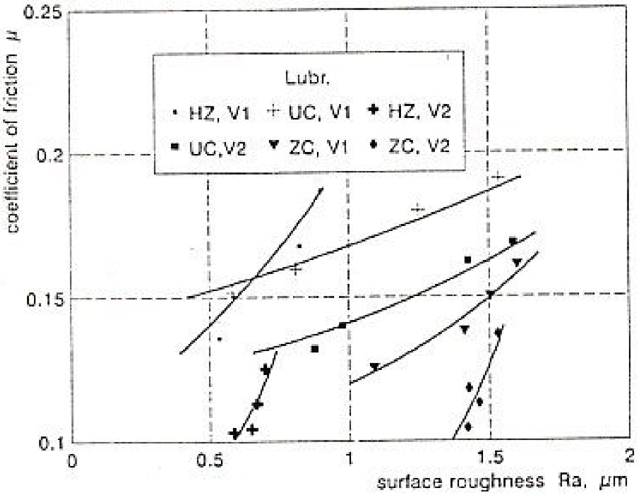

Figure 4. Friction coefficient as a function of medium roughness

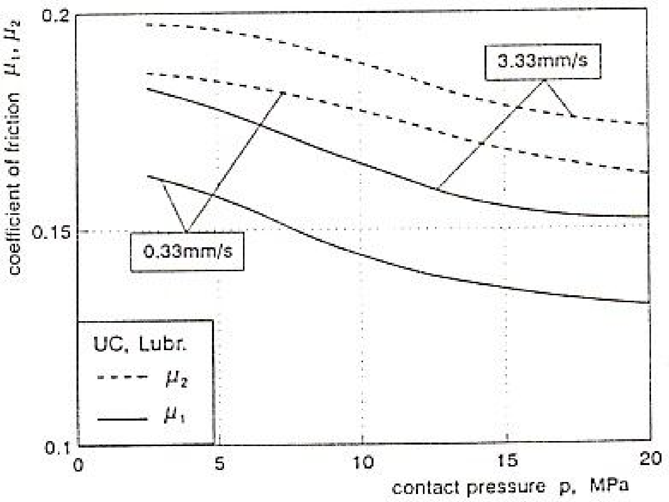

Figure 5. Friction coefficient as a function of the contact pressure

Sliding of the thin sheet over the holders surface and edge of the die, in absence of tangential stresses can be modeled completely by bending with tension, Figure 1. Straining is in the plastic domain, it takes into account the bending geometry, where the stress and strain states are plane, without change of the strip width and stress in the direction of the sheet thickness. The friction coefficient in the zone of the matrix rounding can be determined by knowing the relations on the plane part of the matrix, Figure 5 /5/, or by application of the special bending devices, which make possible the separation of the friction force from the forming force /6/. Due to significantly higher values of the contact pressures in the zone of the die edge rounding, in that area are also the values of the friction coefficient lower than on the plane surfaces of the die.

Significantly more complex model with respect to the previous ones is *pulling - sliding of the strip over the draw - bead*, primarily due to the exceptional influence of the macro-geometries of the die and the bead. The draw beads are being placed on the surfaces of the die or the holder in drawing the parts of different shapes. They increase the tensile, and decrease the compressive stresses at the flange, they increase the material hardening in the central zone of the piece and, by that, they decrease the possibility of the appearance of wrinkless. The basic geometry of the draw - bead (height - h and radius - r), namely the braking force at the flange, does not have to be the same in particular zones of the holder.

In pulling over the draw - bead the alternative bending and flattening of the thin sheet occur, with simultaneous realization of high local pressures. Same as previous tests, this one is very frequently used basic tribo - investigations; obtained results can be used in design of tools, in definition of the limiting conditions in numerical modeling of deep drawing, in studying the galling - effect, behavior of coatings on thin sheets, evaluation of lubricants for deep drawing, etc., /7, 8 /.

In Figure 6 is shown the dependence of the pulling force on the friction coefficient on the draw bead, where the special device was used for separation of the friction from the bending force /9/.

Variation of the pulling force as a function of the draw - bead rounding radius, for different draw - bead heights and speeds is given in Figure 7.

Two - sided tension - stretching is typical stress - strain scheme in metal forming by deep drawing, which is characterized by positive values of the principal normal stresses, by one contact surface between the tool and the sheet, and by relatively small sliding speed in that zone. Deformation occurs only in the die opening, while the opening in the piece is firmly pressed towards the matrix surface. Besides the drawing tool geometry, in stretching are of the utmost influence the strain rate and the contact conditions. The basic indicator of the II group is the depth at fracture (Olsen, Erichsen).

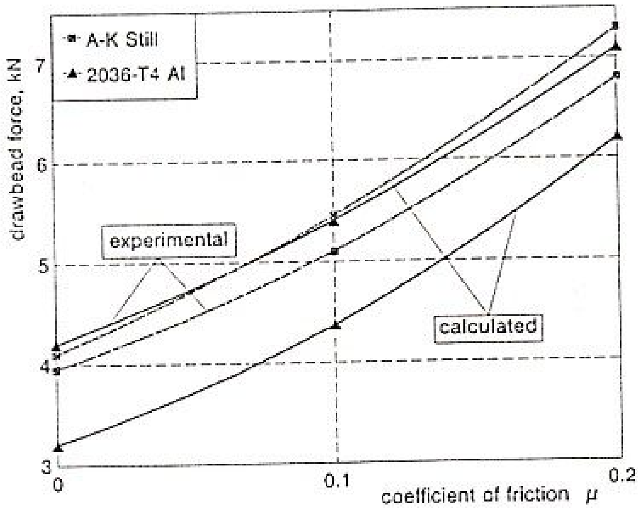

Figure 6. Draw - bead restraining force as a function of the friction coefficient /9/

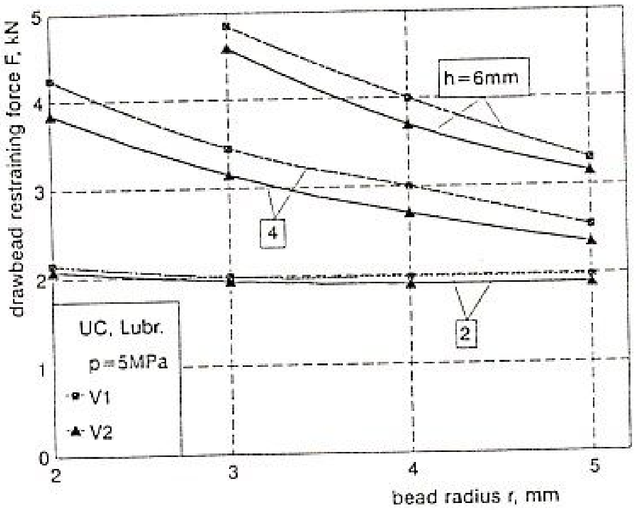

Figure 7. Draw - bead restraining force as as a function of bead penetration /7/

Application of the grapho - metric procedure of the measuring meshes for determination of strains in characteristic cross - sections of the drawn pieces, enables the more qualitative approach in studying the thin sheets formability, especially the influence of the tribo - conditions.

In stretching (deep drawing) one determines the distribution of the principal meridian strain, with respect to the character of straining and orientation of the point of localization and fracture.In Figure 8 are shown distributions of the principal strains for different combinations of punch geometry and contact conditions /10/. The punch diameter is 50 mm, and distributions are related to critical depths, denoted in the figure legend. The semi-spherical drawing tool (R = 25 mm) enables stable distribution and the largest critical depth. The basic characteristics of the shown distributions is: by lowering the friction in the contact of the tool and the thin sheet the uniformity of straining is improved, the value of critical depth is increased, and the zone of gracture is being moved towards the center of the piece.

Due to possibility of realization of the proportional straining, the stretching model is exclusively used in numerical modeling; it enables reliable selection of lubricants via the quantitative indicators of the strain distribution /11/.

The localization and realization of the limiting relations in stretching are significantly influenced by the amount of the second principal strain. Combination of the corresponding values of the principal strains in particular measurements fields enables forming of the specific indicators in the system of the principal strains. By monitoring the deformation path, namely by entering the distributions for different forming phases, the so called constitutive diagrams are obtained, Figure 9 .

Model of pure deep drawing is the most complex, with respect to the fact that it, in the indirect way, includes all previously mentioned models. Due to possible expressed sliding in the zone of the punch edge rounding, and appearance of the strain localization, it is desirable that, exactly at that point, the friction should be stronger. On the contrary, the friction on the rim and die edge rounding needs to be as decreased as possible.

Besides the usual indicators of the II group, it is necessary also in this case to use elements of the strain analysis, namely to compare realized with limiting strains. In that sense it is convenient to use strain distributions in the forming limit diagram (FLD), what creates the foundation for determination of the plasticity reserve in drawing /12/.

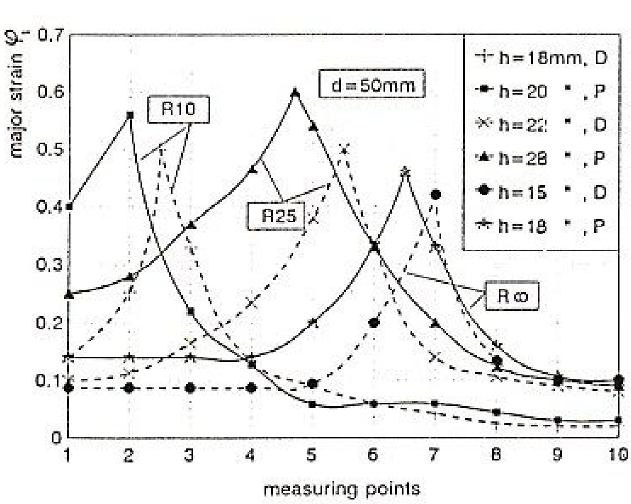

Figure 8. Strain distribution for different tests conditions

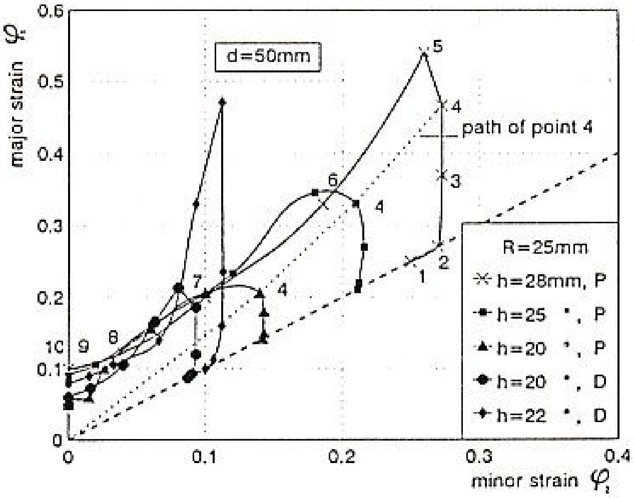

Figure 9. Strain distribution at critical depths

In Figures 10 and 11 are shown the strain distributions for the square cross - sectioned pieces (40 x 40 mm), in the diagonal direction and for different degrees of drawing. In comparison with cylindrical pieces, significantly larger strains are realized, as well as differences, which are the consequence of the conditions on the contact surfaces. The initial localization in the stretching zone is moved from the drawing tool front, so the fracture occurs in the conditions of the plane straining (φ2= 0). The more complete presentations assume multi phase drawing with monitoring the deformation path.

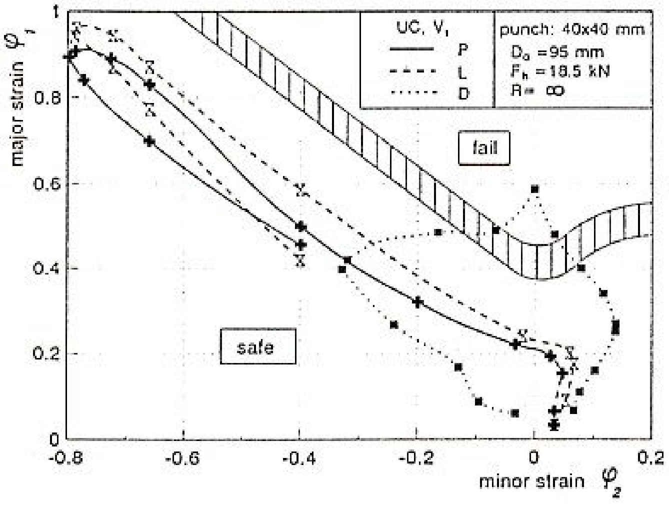

Figure 10. Strain distribution for the square piece (Do = 95 mm)

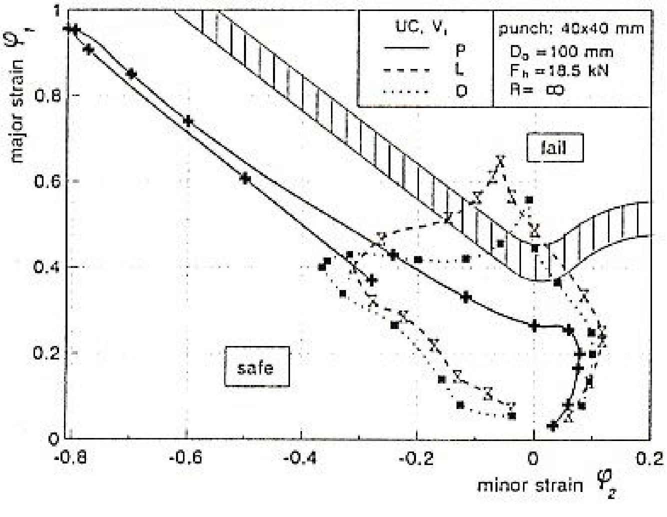

Figure 11. Strain distribution for the square piece (Do = 100 mm)

4.CONCLUSION

The basic tribo - models (strip draw test, bending with tension, sliding over the draw bead), in which exist the plane stress - strain state, can be successfully applied in studying the tribo - phenomena on the long paths of sliding, in conditions of high local pressures (mass transfer, galling, tool wear, micro geometry changes of the contact surfaces, importance of the lubrication regimes, etc.).

Complex tribo - models assume three dimensional straining, where the indicators of the friction on the contact surfaces influence, are being related to limiting forming possibilities. The input parameters in the tribo system must be completely in accordance with the limiting formability, e.g. the holder pressure with the limiting degree of deep drawing, etc. The complete analysis is being realized by application of the forming limit diagrams, with knowing the complete previous deformation history.

Due to relatively complex technique of determination the indicators of the tribo - conditions based on strain analysis, they are usually used in laboratory conditions. However, with development of the computer and video equipment, these methods also become routine and commercially available.

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