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The analysis of forming process for bimetal materials

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Abstract

The paper presents the concepts of solving of deep drawing process for bimetal elements of sheet materials. For this, the elementary theory of plasticity as: inertia forces, plastic hardening behaviour of the deformed material and dynamic stress are utilized in the problems of plasticity. Known formulations for calculation of the drawing load for cylindrical parts can be applied to a large spectrum of geometry by a local way of looking at single critical deformation zones of a drawn component. The idea of designing a new construction of a die, the experimental results and general conclusion is presented in the paper.

1 Introduction

The object of this study is to define the forming conditions of a bimetal material composed of two dissimilar sheet metals. The ever increasing industrial demand for more sophisticated composites, which, in addition to the required physical and mechanical properties, would also show a reasonable degree of homogeneity, calls often for the use of unconventional methods of manufacture.

Deep drawing of sheet metal is an important manufacturing technique. In deep drawing process, a blank of sheet metal is clamped against a die by a blankholder. A punch is then moved against the blank, which is thus drawn into the die. The ratio of drawing depends on the force on the blankholder and the friction conditions at the interface between the blank and the blankholder and die. The force and the friction at the blank-die-blankholder interface limit the slip at the interface and increase the radial stretching of the blank.

In many investigations that are based on the use of mechanical energy considerations logarithmic stress distributions are assumed in the flange. This is provided by the simplifying assumptions of: lack of friction, constant sheet

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thickness, Tresca yield criterion, isotropic material properties, rigid-plastic material behaviour without work hardening.

The significant results in investigations of mechanical and technological parameters of a sheet metal shaping have been done by Kuczyński and Marciniak. The interesting information on that subject is contained in papers [1-8].

To obtain a successful deep drawing process it is essential to control the slip between the blank and its holder and die. If the slip is restrained too much the material will undergo severe stretching, thus potentially causing necking and rupture. If the blank can slide too easily the material will be drawn completely and high compressive circumferential stresses will develop causing wrinkling in the product. For simple shapes, like the cylindrical cup here, a wide range of interface conditions will give satisfactory results. For more complex, three-dimensional shapes, the interface conditions need to be controlled within a narrow range in order to obtain a good product. During the drawing process the response is primarily determined by the membrane behaviour of the sheet. For axissymmetric problems, the bending stiffness of the metal yields only a small correction to the pure membrane solution. In contrast, the interaction between the die, blank and blankholder is critical.

2 Theoretical principles

The predetermination of parameters of the shaped in deep drawing process is essential aspect of the optimisation technology. Very expensive tools are needed, for the deep drawing process, usually quite complicated parts (for instance - autobody parts). In manufacturing, these complicated parts, failures like wrinkles or ruptures often occur. The causes of the appearance of deep drawing defects (the ruptures and wrinkles) can have many reasons. For instance, the parameters influencing deep drawing process are: tool geometry, blank geometry, blankholder pressure, forming stages, lubricant, tool-abrasion, forming machine. Therefore the practice-related investigation on deep drawing should try to supply the designer pieces or tool with information that help to detect failure of a deep drawing part already during the designer phase. The consequences of mistakes committed during the construction period of the tool geometry can rarely be completely rectified as production of the part commences.

The axissymmetric shape of drawpiece can be an example of solving the problem of drawing process.

The equilibrium equation of the material element in yield plasticity state is given in the form (Fig. 1)

$$\frac{d\sigma_r}{dr} + \frac{dt}{dr}\frac{\sigma_r}{t} + \frac{\sigma_r - \sigma_\theta}{r} = \rho V \frac{dV}{dr} \tag{1}$$

where: σ_r - tensile radial stress, r - radius of the material element,

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σ_θ - compressive tangential stress, ρ - mass density, V - velocity of the material element, t - thickness of the material.

The equation of plasticity for axissymmetrical co-ordinates can be expressed as (Hill)

$$\sigma_y^2 = \frac{\sqrt{3}}{2\sqrt{2R+1}}[(R+1)\sigma_r^2 - 2R\sigma_r\sigma_\theta + (R+1)\sigma_\theta^2] \tag{2}$$

where: R - anisotropy parameter of material, $R(\theta) = \frac{\varphi_2}{\varphi_3}$.

The ratio between stress and strain state is given in the form (Levy-Mises)

$$\frac{d\varphi_r}{(R+1)\sigma_r - R\sigma_\theta} = \frac{d\varphi_\theta}{(R+1)\sigma_\theta - R\sigma_r} = \frac{d\varphi_z}{-\sigma_r - \sigma_\theta} = \frac{d\varphi_i}{2\sqrt{\frac{2R+1}{3}}\sigma_y} \tag{3}$$

where: (4)

$$d\varphi_r = \frac{dV}{dr}, \quad d\varphi_\theta = \frac{V}{r}, \quad d\varphi_z = \frac{V}{t}\frac{dt}{dr}, \quad d\varphi_i = \sqrt{\frac{2}{3}}\sqrt[4]{\frac{3}{2R+1}}\sqrt{d\varphi_r^2 + d\varphi_\theta^2 + d\varphi_z^2}.$$

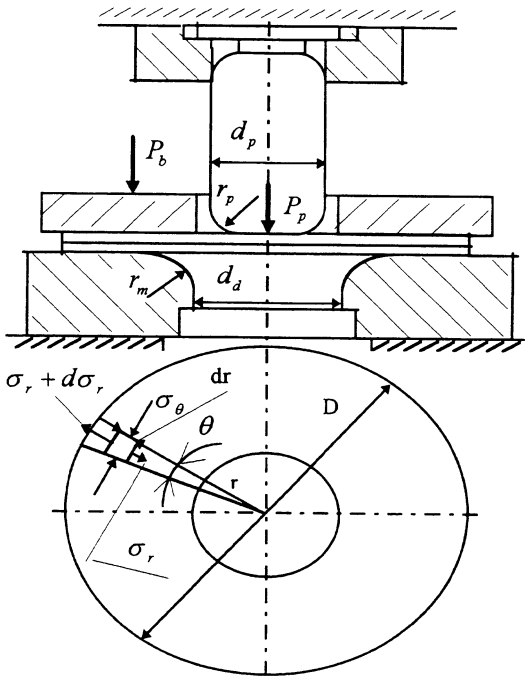

Figure 1: Geometry for the deep drawing problem of bimetal plate.

The incompressibility of the material is given in the form

$$\varphi_r + \varphi_\theta + \varphi_z = 0 \tag{5}$$

The hardening equation is written in the form

$$\sigma_y = C(\varphi_0 + \varphi_i)^n \tag{6}$$

where: C, φ_0, n - material parameters.

If it is assumed that the incompressibility criterion applies then it is possible to find, with the help of the continuity condition, the relationship between the location of a material element on the initial disk and on the formed component as a function of the punch displacement. The appropriate reference deformation of the element is calculated assuming that work hardening takes place and taking into account the flow conditions. The flow conditions have been converted to a form suitable for the numerical calculation. The equilibrium condition can be used to perform an iterative determination of the stress distribution. The equations (1-5) have determined the values of stress, strain and change of the thickness on the radius r for the punch displacement. In the shells the thickness change is calculated from the assumption of incompressible deformation of the material. This simplifying assumption doesn't allow for the development of stress in the thickness direction of the shell, thus making it difficult to model the contact pressure between the blank and die and blankholder. A similar method is used to determine the strains and displacements with the help of the curvatures or finite element method.

The deformation stress is the sum of flow and friction stresses of the material formed which in deep drawing may attain 30 up 40% of the total deep drawing stress [1]. A diminishment or elimination of detrimental friction forces' results in the diminishment of the maximum deep drawing force exerted by the punch upon the drawpiece cup. The friction force increment at the metal-punch contact surface is quite beneficial for the course of the process. It ensures better strain homogeneity and relieves in some extend the cross-section that transfers deep drawing force exerted by the punch unto the drawpiece cup. Quite often this friction does not occur altogether because of the elastic outwards camber of the cup. On the other hand the friction at the metal-die-flange-blankholder contact surface should be eliminated as far as possible since its occurrence increases deformation irregularity and implies a significant increment of the force P_p (Fig. 1) required for deep drawing. The most objectionable effects are provoked by flange-tool friction. The part of losses due to friction on die cylindrical part is the smallest and slightly higher at the rounded corner of the die.

A blankholder that is held down on the sheet disk with a force P_b would be lifted by amount equal to the height of the folds as a result of folding of the flange. The force P_b would be enough, that folding hasn't been existed in the

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flange. The blankholder force alone has only a small effect on the internal stress state and the thickness distribution of forming material. However, the normal force, which the blankholder exerts, provides a friction force component parallel to the plane of the flange. During the deep drawing process the flange section adopts a wedge shape which changes continuously. As a result of the tangential compressive stresses the edge of the flange thickens whereas the radial tensile stresses in the vicinity of the drawn radius cause a reduction in the sheet thickness. As the depth of drawing is increased both the regions in which thickening occurs and the extend of thickening increase. Every position of the flange exhibits a thickness greater than that of the original sheet, when the maximum force is attained. The new idea of construction of a die improves conditions of realisation deep drawn flange. The idea of construction is presented in Fig. 2.

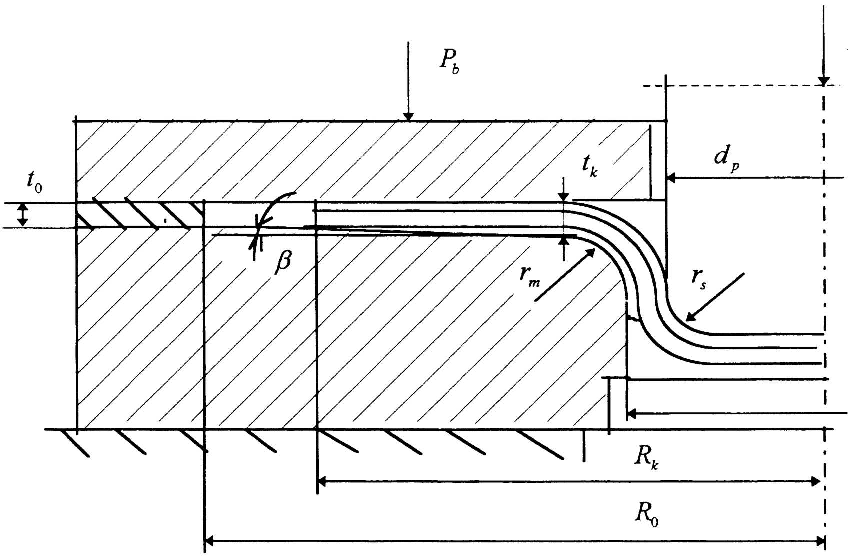

Figure 2: Illustration of the deep drawing process with using a new construction of a die.

The value of angle β may be written from geometrical principles

$$\tan\beta = \frac{t_k - t_0}{R_0 - [R_m + r_m(1-\sin\beta)]} \tag{7}$$

The value t_k may be written down as follows:

$$t_k = t_0\sqrt{\frac{R_0}{R_m + r_m(1-\sin\beta)}} \tag{8}$$

The value R_m we can express as

$$R_m = m_1 R_0 \tag{9}$$

From (7), (8) and (9) we have:

$$\frac{\{[R_0(1-m_1)-r_m(1-\sin\beta)]\tan\beta+t_0\}^2}{t_0^{\,2}}-\frac{R_0}{m_1R_0+r_m(1-\sin\beta)}=0 \tag{10}$$

where: m_1 - deep drawing coefficient.

The value β has been calculated from equation (10). The results of calculation are presented in Table 1.

TABLE 1: Calculation results of angle β.

Radius	Parameters of forming process				
	t_0 [mm]	$w=\frac{t_0}{2R_0}100$	m_1	r_m [mm]	β [°]
$R_0 = 35$	1.40	2.00	0.48	6	1.579
	1.00	1.43	0.50	5	1.137
	0.70	1.00	0.53	4	0.793
	0.40	0.57	0.55	3	0.457
	0.20	0.29	0.58	2	0.228
	0.10	0.14	0.60	2	0.112
	0.05	0.07	0.63	1	0.056
$R_0 = 30$	1.00	1.67	0.48	5	1.322
	0.70	1.17	0.50	4	0.938
	0.40	0.67	0.53	3	0.537
	0.20	0.33	0.55	2	0.273
	0.10	0.17	0.58	2	0.138
	0.05	0.08	0.60	1	0.067

3 Tests and experimental results

For any deep drawing process of bimetal elements, the bending is necessary test, which allow to predict the technological parameters such as: maximum tensile and spring-back. The spring-back angle is defined as the difference of the bend angles measured on load and unload. The bend angle refers to the angle involved between the two straight arms of a bend.

It is known that spring-back vary with material properties, die geometry and punch pressure. The combination of various material parameters and process parameters makes it extremely difficult to predict theoretically with desirable accuracy. It is possible to define approximately the spring-back parameter β of monolithic material with formula

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$$\beta = \operatorname{arctg}[0.375\frac{L}{(1-x)t}\frac{R_y}{E}] \tag{7}$$

where: x - the geometrical parameter of bending surface, of the element where stress doesn't exist (Fig. 4), L - geometrical parameter of die (Fig. 3), E - Young's modulus, R_y - parameter of the material.

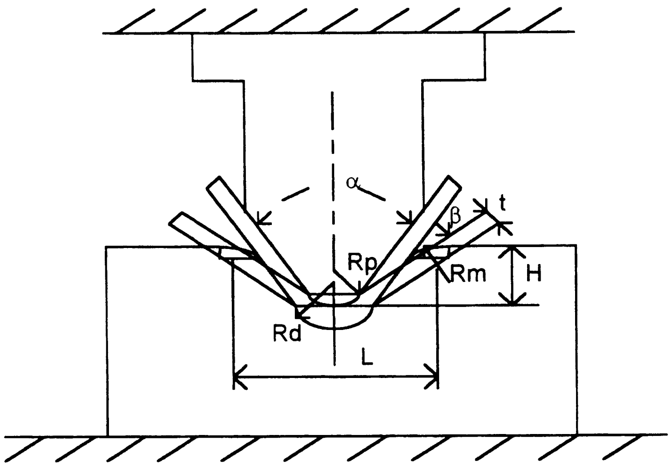

Figure 3: Schematically presentation of bending process.

The formula isn't true for bimetal materials, because spring-back for these kinds of elements depends on situation of material and tools in the bending process and relation of thickness between materials of bimetal structure. The series of experiments have been carried out to study the influence of various parameters such as: yield strength, thickness, punch radius and die opening width on spring-back. Parameters involved in bending are: punch radius Rp, die corner radius Rd, rounded off at the side of die Rm, die opening width L, sheet thickness t, bend angle α and punch insertion depth H.

The situation of neutral surface is very important technological parameter in bending process (Fig. 4). Parameter ρ can be calculated from formula

$$\rho = R + xt \tag{8}$$

where: $\rho = f(\frac{R}{t})$ - coefficient of bending process.

For bimetal elements it can be calculated as follow

$$\rho = R + (x + x_b)t \tag{9}$$

where: x_b - correction parameter for kind of bimetal element.

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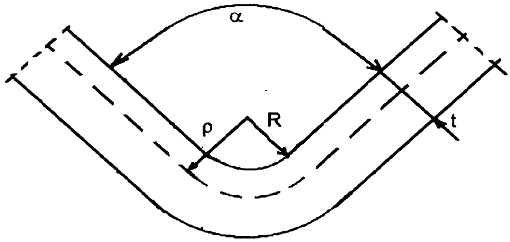

Figure 4: Geometrical parameters of material in bending process.

Schematically presentation of the tools for experiments is shown in Fig. 5. The results of experiment are shown in Fig. 7.

The object of this study is to define the forming conditions and plastic deformation of a bimetal cylindrical cup that consists from two dissimilar and similar kinds of metals. The geometry of the problem is shown in Fig. 1.

The circular blank being drawn has an initial radius of 50 mm and an initial thickness approximately of 1.3 mm. The punch has a radius of 31 mm and is rounded off at the corner with a radius of 6 mm. The die has an internal radius of 34 mm and is rounded off at the corner with a radius of 6 mm. The blankholder has an internal radius of 40 mm. At the start of the analysis, the blank is positioned precisely on the top of the die and the blankholder is precisely in touch with the top surface of the blank. The punch is positioned on the top surface of the blank. The material of plate consists from brass (M90) thickness of 0.3 mm and killed steel thickness of 1 mm connected together.
The chemical compositions, by weight % of material BW14G(M90) are given below.
C - (0.1-0.16), Mn - (0.4-0.65), Si - 0.13 max., P - 0.2 max., S - 0.02 max.,
Cr - 0.15 max., Ni - 0.2 max., Al - (0.03-0.07)

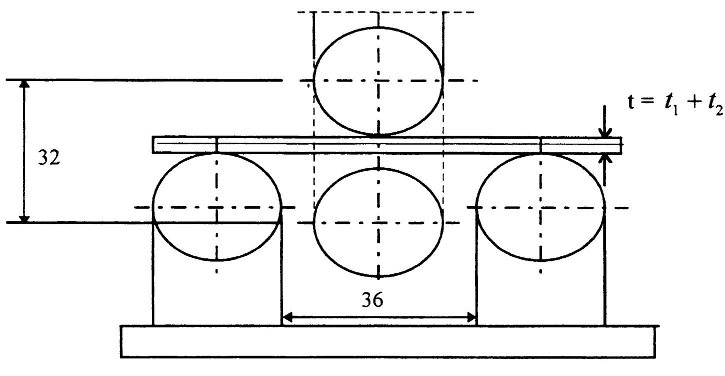

Figure 5: Standard instrument for tests.

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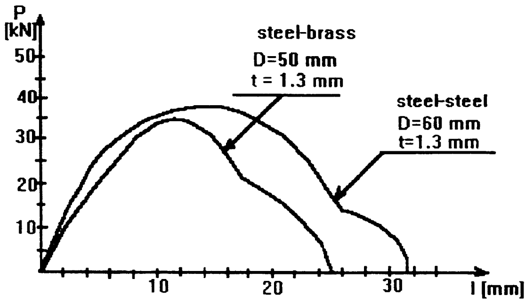

Figure 6: Diagram of force change in deep drawn process of bimetal elements.

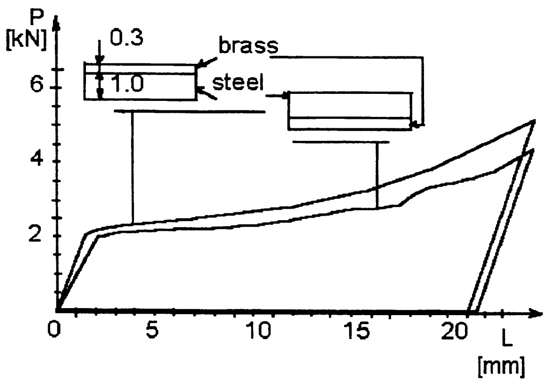

Figure 7: Bending diagram for bimetal elements.

The another material consists from two plates (D=60 mm) of killed steel thickness of 0.5 mm and 0.8 mm connected by glue.

The experiments have been carried out on the laboratory universal testing machine FPZ 100/1. The drawing force has been received on diagram (Fig. 6).

4 Conclusions

Deep drawing process of cylindrical elements is optimal model experiments for the prediction: distribution of stress and strain or frictional behaviour and frictional forces for stamping drawpieces. The frictional forces at the die radius, kinds of lubricate and additionally the forces for bending should be determined,

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exactly. The bimetal materials for drawpieces should be systematic investigated. The investigations carried out in laboratories give important data for optimal parameters of deep drawing process. Specially for drawpieces with bimetal material, which it can be used in autobody parts like: mudguard and elements of chassis. The experimental results are leading to the following conclusions:
- the distribution stress, strain and value of spring-back in a bimetallic sheet material in deep drawing process depends on the layer thickness ratio t_1/t_2 (Fig. 5) and bimetal layer yield stress ratio σ_y^1 / σ_y^2;
- the next series of investigates are necessary.

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