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RESEARCH

Tribological Properties of Steel and Al-Alloys Sheet Metals Intended for Deep Drawing

During the last few years, aluminium alloys are increasingly more used in production of light constructions, especially for manufacture of light car bodies of passenger cars. From the aspect of tribological factors influence, experience in application of low-carbon steel sheet metals in manufacture of car body parts by deep drawing procedures up to now differs significantly regarding the application of Al-alloys. The paper presents the experimental results of tribological investigations of specified materials properties at sliding tests, as well as results at deep drawing with variable blank holding force. The combination of unfavourable formability parameters and sensitivity to tribological conditions at application of Al-alloys requires a particular approach to tools and technology designing in comparison with classic forming procedure.

Keywords: *Deep drawing, Tribology, Sheet metal*

1. INTRODUCTION

Deep drawing of parts with complex geometry may be considered in different aspects and by different manners. On the one hand computer simulations of forming process may be applied, and on the other hand experimental research may be employed. One of possible experimental approach is illustrated in Figure 1 [1], and part of these results is given in present paper. Complexity of plastic forming and tribological effects, according to Figure 1., may be considered by use of five physical models: a) sheet stripers sliding between flat contact surfaces, b) sliding over draw bed, c) sheet slippers sliding during bending and tension, d) model of two sided stretching, e) model of pure deep drawing. In present paper are given results obtained by employment of model a) [1, 2]. Special attention is devoted to application of two materials with two main influence factors: contact pressure and lubricant. Output parameters are coefficient of friction and change of sliding force. Applied materials are aluminum alloys AlMg4,5Mn0,7 (according DIN EN 573-3) [3, 4] and conventional car body tin Č0148 P5 (DC04 according DIN EN 10130).

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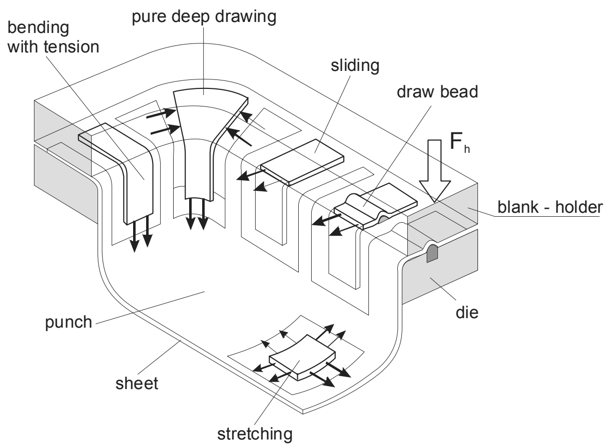

Fig. 1 Tribo-models scheme in deep drawing

In second part of paper influences of complex friction conditions, on the model of pure deep drawing dictated by variable blank holding force during forming process, are pursued. In this case both mentioned materials are used at the same time. Output parameters are depth of deep drawing and deformations distribution.

2. EXPERIMENTAL TESTING

Al alloy used in present paper is recognized as alloy from so called series 5000. They basic property is that they do not request thermal pre - treatment before and during forming. Main properties are given in Table 1. It may be seen low value of r factor which indicates lower formability during deep drawing. It should be noted that formability of Al alloys is significantly influenced by state. In this case alloy state was determined by annealing on 350 ^{o} C during three hours period. Low hardness and stick to tool surface tendency in tribological sense complicate forming process.

Characteristics of steel sheets are given in Table 2. Formability and tribological behavior leads to conclusion that this material is more suitable in comparison to Al alloy, which is clear from Table 2.

Table 1: Al alloy properties

A. Mechanical properties, AlMg4,5 Mn0,7							
	R_p, MPa	R_m, MPa	A_{80}, %	n	r		
0	278	153	19	0,252	0,55		
45	267	145	21	0,258	0,859		
90	272	150	23	0,258	0,592		
$\overline{X}$	271	148	21	0,26	0,715		
Strengthening curve (0^{o}) : $K = 152{,}9 + 305{,}9\,\varphi^{0{,}312}$, MPa							
B. Chemical composition							
element	M_g	M_n	S_i	F_e	T_i	C_u	Z_n	C_r
%	4,20	0,57	0,0869	0,29	0,013	0,007	0,068	0,092

Table 2: Steel sheet properties

A. Mechanical properties, Č0148 P5					
	R_p, MPa	R_m, MPa	A_{80}, %	n	r
$\overline{X}$	179,9	314,6	36,06	0,235	1,51
Strengthening curve (0^{o}) : $K = 177 + 388{,}29\,\varphi^{0{,}448}$, MPa					
B. Chemical composition					
element	C	Mn	Si	P	S	Al
	0,005	0,21	≈0	0,012	0,019	0,07
C. Roughness properties					
R_a , μm	R_t , μm	Rz , μm	Rp, μm	peak/mm	
1,81	12,40	10,89	6,19	≈10	

2.1. Experimental results

During testing of stripes sliding between flat contact surfaces, which models sliding of sheet on flat matrix surface, influence of pressure and state of contact surfaces on intensity of sliding force (Figs. 2 and 3) is considered. Pressure increase leads to increase of necessary sliding forces in both tested materials. During testing of Al – alloy, in all contact conditions (Fig. 4), it has been noticed stick tendency of particles from sheet surface layer to contact pair, and rapidly rise of sliding force. Stick tendency of particles to contact pair has been noticed even with use of lubricants, but it was in significantly smaller volume.

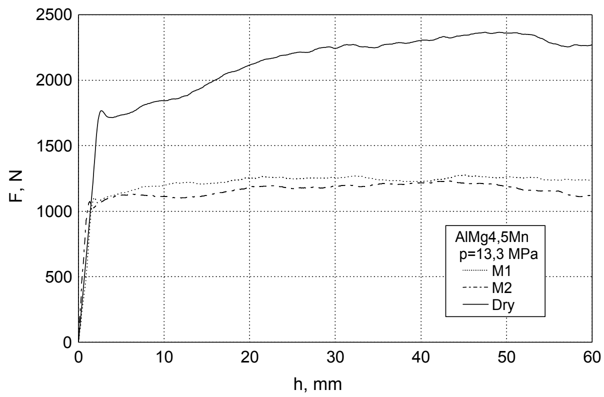

Fig. 2 Force-sliding path dependence for alloy AlMg4,5Mn at 13.3 MPa contact pressure

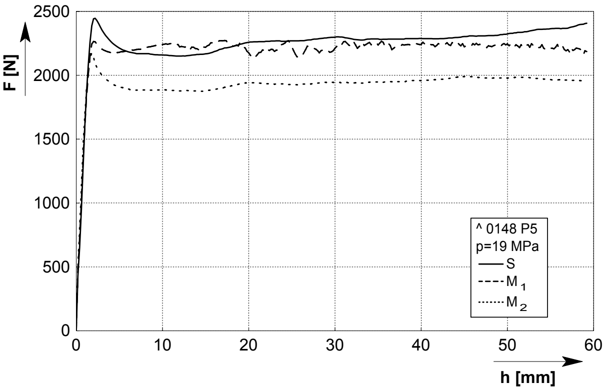

Fig. 3 Force-sliding path dependence for Č0148 at 19 MPa contact pressure

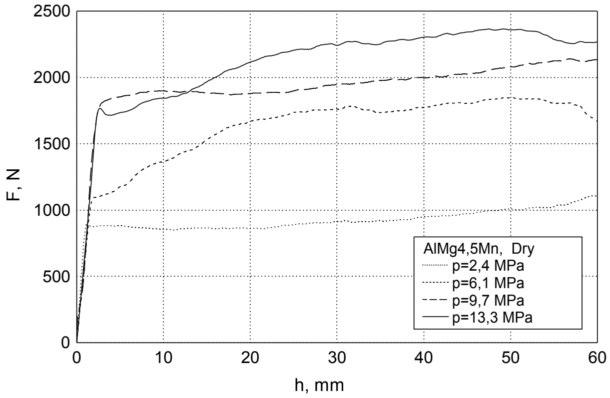

Fig. 4 Force-sliding path dependence for alloy AlMg4,5Mn without lubricants (sign Dry)

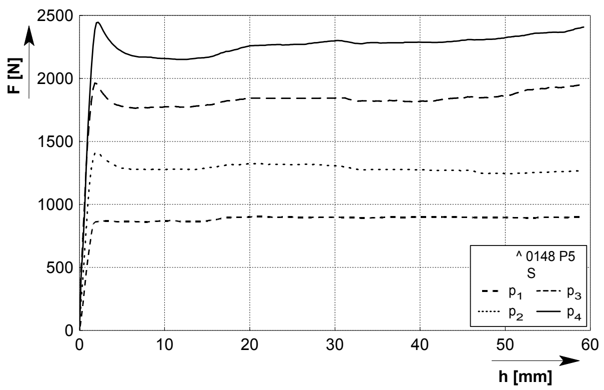

Fig.5 Force-sliding path dependence for alloy Č0148 without lubricants (sign S)

Increase of pressure leads to decrease of friction coefficients in both tested materials, (Figs. 6 and 7) [5]. Values of friction coefficients depend on roughness of sheet surfaces apart to experimental conditions. Very important is material property during transition of lubrication regime from mixed to boundary. It is more significant in steel sheets. Such situation exists during successive sliding, that is during multiphase deep drawing, when tribological influences on Al – alloys become dominant and significantly limit formability.

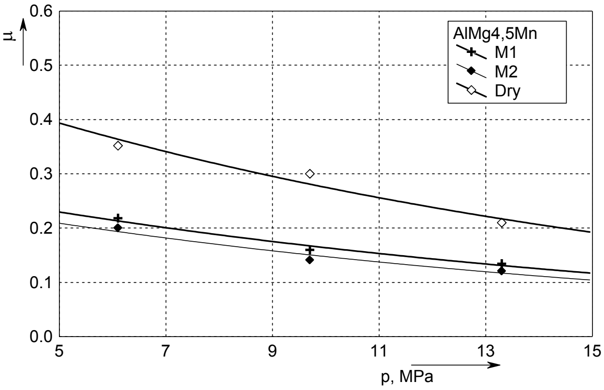

Fig. 6 Friction coefficient dependence on pressure for alloy AlMg4,5Mn

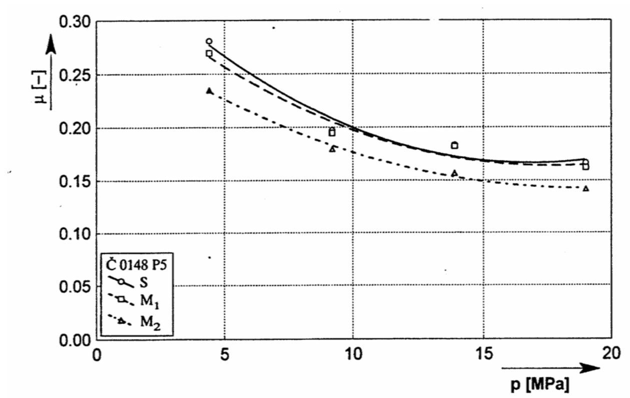

Fig. 7 Friction coefficient dependence on pressure for Č0148P5

In figures 2, 3, 6 and 7 signs M_1 and M_2 mean two different lubricants.

Variation of blank holding force (BHF) during forming process generates complex influences on friction between sheet and tool on the periphery of piece obtained by deep drawing. To analyze these influences 5 ways of prescriptions of BHF, in dry friction conditions [6], have been defined:

a) Constant intensity (F_D = const.),
b) Increasing dependence (F_D INC),
c) Decreasing dependence (F_D DEC),
d) Combined decrease – increasing (F_D COMB),
e) Pulsating dependence (F_D PULS).

Functional dependence of BHF has been defined with help of computerized device [6] applied to cylindrical part made of Al alloy (drawing degree 2.2; D_0=100 mm, d=50 mm).

In Figure 8 is shown experimental accomplished dependences of BHF for steel sheets Č0148, and in Figure 9 for sheet of alloy AlMg4,5Mn.

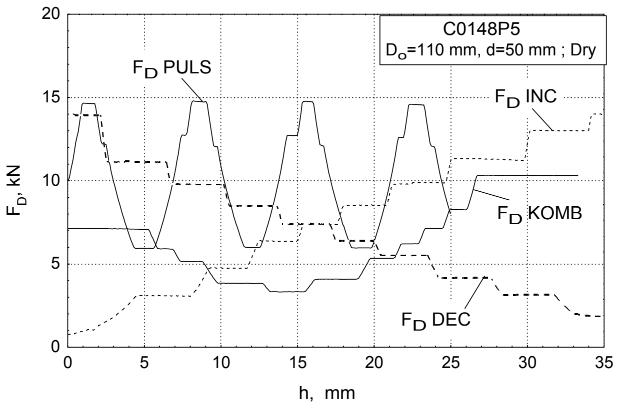

Fig. 8 Blank holder force dependences on punch travel

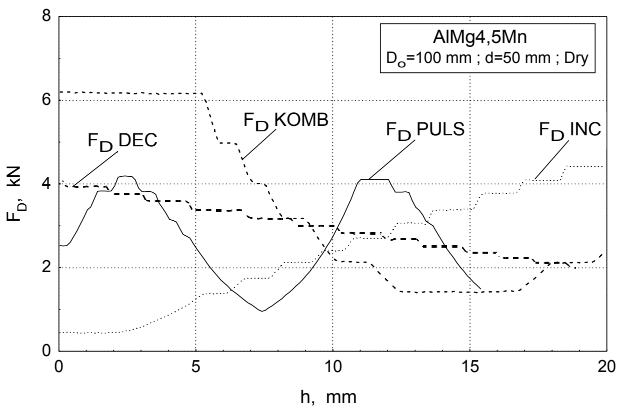

Fig. 9 Blank holder force dependences on punch travel

Effects of considered influences have been followed through deep drawing deformation force (Figs. 10. and 11.), drawing depth (Table 3) and thinning strain (Figs. 12. and 13.).

It is obvious, from Figures 8. and 9., that force intensities for steel sheets are greater, as well as drawing depths, as it was expected. In both cases deformation process progress with difficulties caused by dry friction (contact surfaces complete degreased and cleaned with acetates). Obtained final drawing depths were relatively small. Full depth for steel sheet is about 54 mm, and for Al sheet is about 39 mm. Variable friction conditions which BHF dictates lead to quantitative changes. Growing dependence of BHF, in steel sheets, allows significant growth of item depth (61.3 %) in comparison to usual constant values. In Al sheets described effect is bit smaller, but still observed when combined decrease - increase BHF dependence. Explanation of such effect is the most probably in complex regime of load or in relieving of critical zones of piece created by variable friction on the edges caused by variable normal force (i.e. BHF).

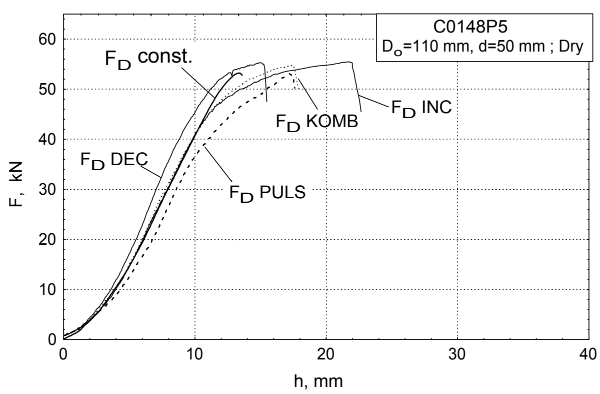

Fig. 10 Forming force dependences on punch travel

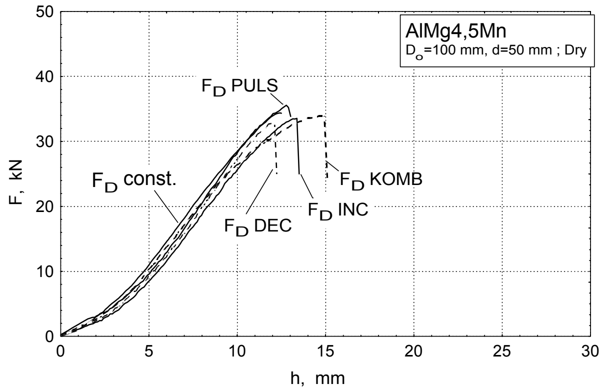

Fig. 11 Forming force dependences on punch travel

Although it may be seen on Figures 10 and 11, Table 3 shows quantitatively values of achieved depths of deep drawing for both materials and for all 5 types of BHF. It was given percentage increase of deep drawing depth when variable BHF are applied in comparison to constant BHF. In steel sheets all types of variable BHF lead to significant increase of deep drawing depth but the most significant influence is caused by increasing dependence (INC) of variable BHF, when increase reach 61,3%. With Al alloys there is different situation. In spite of decreased level of deep drawing, hard friction conditions and well known poor formability lead to small increase of deep drawing depth. In the case decreasing BHF (DEC) reduction of depth was measured, which makes evident that such type of BHF is disadvantageous in comparison to constant. Nevertheless, combined decrease – increase dependence (COMB) leads to significant increase of depth of 19.2%.

More complete picture of analyzed influences may be acquired by inspection of thinning strain parallel to achieved deep drawing depths. In figures 12. and 13. comparatively are given thinning distributions for all types of BHF and both materials. Entire effect of process improvement in technological sense may be achieved only if simultaneously both, enough large deep drawing depth and thinning distribution without large local gradients, are realized. In steel sheet such condition satisfies variable BHF of INC and PULS types. Decreasing dependence (DEC) allows suitable thinning distribution, but with relatively small increase of depth. In Al alloy sheets local gradients are large. Only for BHF of COMB type significant increase of depth with decrease of local gradient is achieved (location 8 in Fig. 13.).

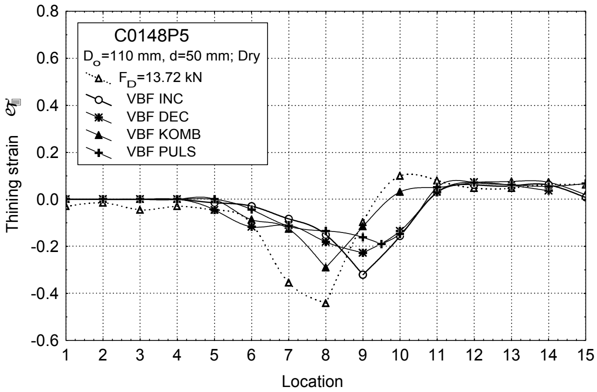

Fig. 12 Thining strain distributions

In Figures 12. and 13. dependence of depth change (third proper deformation, thinning) on location on piece is given. Location is placed on the line obtained as intersection of piece surface and vertical plane which include piece axis. Locations 1 to approximately 5 are on bottom and 11 to 15 on periphery of piece. Deformations are measured by employment of measure grids. Nominal initial diameter of measure grid circle was 3 mm.

Reading was performed by optical way. After reading of proper deformations in sheet plane, deformations of thickness were calculated.

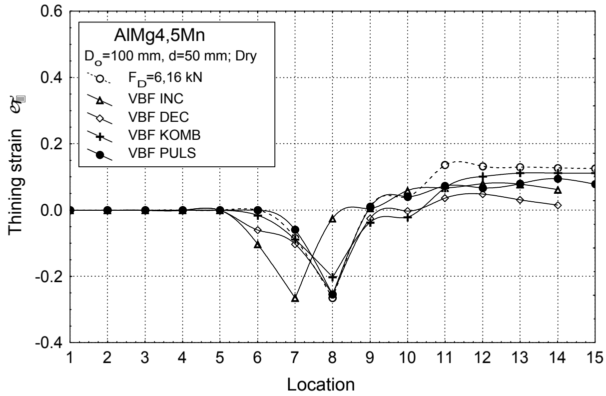

Fig. 13 Thining strain distributions

Examination of Figures 10. and 13., and Table 3, leads to conclusion that macro effects of variable holding friction force (conduction during process) during deep drawing of cylindrical pieces may be significant. It has been shown possibility of identification of the most suitable type of variation BHF to achieve maximal deep drawing depth and the most suitable thinning distribution. Complete analysis was performed in pure dray friction conditions, which indicates possibility that suitable variation of holding force, as normal force for friction on the edge, make possible correction of lubricants in industrial conditions [7]. Fundamental nature of achieved influences lies, probably, in coupling of complex loads in certain zones of piece and friction on one side and deformability of materials on the other side.

Table 3. Drawing depths

Drawing depth					
Č0148			AlMg4,5Mn		
F_D	h, mm	% of increasing	F_D	h, mm	% of increasing
Const.	13.7	-	Const.	12.5	-
INC	22.1	61.3	INC	13.4	7.2
DEC	15.2	10.9	DEC	12.2	-2.4
KOMB	17.6	28.5	KOMB	14.9	19.2
PULS	17.5	27.7	PULS	12.8	2.4

3. CONCLUSIONS

Weight reduction and anticorrosive resistance are main motives for growing usage of Al alloys sheets. However, both formability aspect and tribological effects lead to problems that must be solved. Low values of r factor lead to difficulties during deep drawing forming. Sliding test, in present paper, demonstrated tendency of Al alloys to tear of particles and stick these on the tool. This tendency may be in certain amount corrected by applying of suitable lubricant. Increase of contact pressure in both materials leads to decrease of friction coefficient.

Obtained results, also, show that optimization of holding force during deep drawing may influence process and deep drawing depth.

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