Proceedings of the 15th International Conference on Manufacturing Systems – ICMaS
Published by Editura Academiei Române, ISSN 1842-3183

"Politehnica" University of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania, 26–27 October, 2006

DETERMINATION METHODS OF THE FORMABILITY OF METALLIC MATERIAL WITH LOW PLASTICITY

Claudia GÎRJOB, Octavian BOLOGA, Gabriel RACZ

Abstract: *The work presents the possibilities to realize the dies to processing by metal forming of some metallic material with low plasticity like magnesium alloys AZ31B, AZ61B and MN150 and the aluminium alloy AlMg4.5Mn0.4. This materials are used often especially in aeronautical industry and in the automotive industry because of their low density of approximately 1.74 g/cm*^{3}*. This density is about 75% lower than the density of steel, which leads to a considerable decrease of the weight of the metallic constructions. However, because of their low plasticity at room temperature, the process must be realized at temperature between 200 °C and 250 °C, range of temperature for which a considerable increase of the plasticity of the above mentioned alloys occurs without influencing the mechanical proprieties. Thereby, the metallic materials with low plasticity and light weight at the same time would possible substitute successfully conventional sheet materials.*

Key words: *metal forming, magnesium alloys, aluminium alloy, heating, formability, low plasticity.*

1. INTRODUCTION

In the automotive industry, especially, nowadays became very important to obtain light metallic structures which leads to fuel consumption reduction. A way to decrease the weight of automobile constructions is to use lightweight metallic material such the magnesium alloys AZ31B, AZ61B and MN150 and aluminium alloy AlMg4, 5Mn0,4. The major disadvantage of these materials is their low plasticity at room temperature. A considerable increase in formability of the above mentioned metallic materials can be obtained for a process of metal forming realized in the temperature range from 200°C to 250°C [3]. Thereby, the manufacturing of these metallic materials cannot be performed by classical cold forming technology. The dies used for processing these materials must be adapted to the specific conditions of forming the low plasticity metallic materials.

Comparing, the proprieties of the magnesium alloys with other metallic materials one could observe that these materials offer a series of advantages such as low yield elongation and high stiffness at room temperature but this characteristics increases with the temperature increase, resulting light weight components. With a density of 1.74 g/cm^3, the magnesium is over 75% lighter then steel and over 35% lighter then aluminium. The specific stiffness (E/ρ) for magnesium is similar with the specific stiffness for aluminium and steel. The specific elongation (R_{p02}/ρ) of magnesium is much bigger compared with the specific elongation for steel and aluminium.

2. DETERMINATION METHODS OF THE DEFORMABILITY

To determine the mechanical proprieties of the magnesium alloys, the uniaxial test is realized. The characteristic values, determined at room temperature ($T = 25°C$), are presented in Table 1. An improvement of the formability proprieties appear at temperature over 200°C.

The flow limit diagram for this material is first considerably increasing slower with the increase of temperature and secondly placed in the lower stress level for high temperature. This indicates the accuracy of the active thermal process of the temperature that reduces the material cohesion. This is the reason for improving the deformability and for reducing the flow limit at high temperature. Fig. 1 shows the temperature limit drawing ratio for magnesium alloy AZ31B ($g_0 = 1$ mm).

Significant for the determination of the sheet plasticity are the deep drawing tests realized with cylindrical die at different forming temperatures [1].

Table 1

Characteristic values determined at room temperature

Mechanical characteristics	AZ31B	AZ31B	AZ61B	MN150	AlMg4.5Mn0.4
Sheet thickness [mm]	1.3	1.0	1.0	1.0	1.0
Ultimate tensile strength R_m [MPa]	256.3	251.2	289.8	222.2	279.5
Yield strength R_{p02} [MPa]	187.2	168.7	189.7	143.2	146.0
R_{p02}/R_m [–]	0.73	0.672	0.655	0.644	0.522
Elongation ε [%]	21.4	17.8	19.0	12.9	26.3
Hardening coefficient n [–]	0.17	0.216	0.197	0.097	0.317

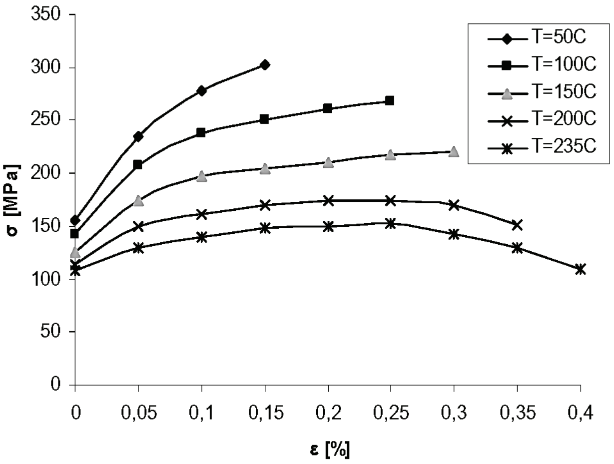

Fig. 1. Temperature dependent limit drawing ratio for AZ31B ($g_0 = 1.0$ mm).

Fig. 2 shows the rate of the limit drawing ratio depending of the temperature for magnesium sheet alloy (AZ31B, AZ61B, MN150) and for aluminium alloy (AlMg4.5Mn0.4) with thickness $g_0 = 1.0$ mm. From this chart, it is obvious that the plasticity of magnesium and aluminium mentioned is low at room temperature but it is increasing with the increase of temperature.

The maximum of the limit drawing ratio for AZ31B is $\beta_0 = 2{,}52$ at temperature $T = 200$°C, for AZ61B is $\beta_0 = 2.20$ at temperature $T = 220$°C, for MN150 is $\beta_0 = 2.25$ at temperature $T = 220$°C and for aluminium alloy AlMg4.5Mn0.4 is $\beta_0 = 2.40$ at temperature $T = 200$°C.

An exact evaluation for the deformability of the magnesium and aluminium sheet alloys requires the determination of the material's characteristic values like anisotropy or flow curves [4, 5]. The flow curves of the metallic material with low plasticity are determined as the result of the tensile test at different temperatures. Fig. 1 shows the flow curves for a magnesium sheet alloy AZ31B, thickness $g_0 = 1$ mm, at different temperatures between 50°C and 250°C [2]. It is obvious that the stress and logarithmic strain largely depend on temperature. Similar flow curves present also the magnesium alloys AZ61B and MN150.

All tests performed on the magnesium and aluminium alloy confirm the low plasticity of these metallic materials at room temperature but also a significant improvement for temperatures over 200°C. In addition, for the determination of the formability characteristic of the metallic materials with low plasticity the Erichsen test may be performed. Fig. 3 shows the maximum stretching height $h_{\max}$ for magnesium and aluminium alloy at three different temperatures 150°C, 200°C respective 250°C.

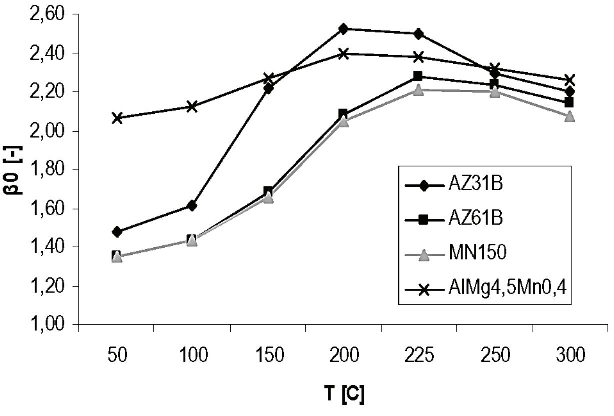

Fig. 2. Temperature dependent limit drawing ratio.

It is obvious that the maximum stretching height for magnesium and aluminium alloys decreases with increasing the temperature. The values for aluminium alloy AlMg4.5Mn0.4 and for magnesium alloy AZ31B are comparable over the investigated temperature range.

As a result of analyzing the behaviour of the materials with low plasticity, especially the magnesium sheet alloys AZ31B, AZ61B, MN150 and the aluminium alloy AlMg4.5Mn0.4, it can be observed that from this material it is possible to obtain metal parts by forming only on temperatures close to 200°C.

The heating of the blank from the metallic material mentioned represents an additional process compared to the conventional sheet metal forming at room temperature.

Possible alternatives for the heating of the blank are:

- the external heating of the blank in an oven with followed by transportation to the processing die;
- the heating of the blank during the deep drawing process.

The external heating of the blank in the oven guarantees the obtaining of a homogenous temperature of the blank but the great disadvantage is that during the transport from oven to pressing machine a loss of heating occurs. Theses losses can be reduced using an automat transfer system of the blank from oven to the machine press in heated boxes. The results are still not very good because of the quick heat transfer from heated blank to the unheated blank and so it is not possible to assure the deformation temperature. Thus, this method is not very recommended [7].

The external heating has an advantage: the forming time for this case is not greater relative the conventional forming.

The second alternative consists in building of a die who realizes the heating of the blank during the metal forming process.

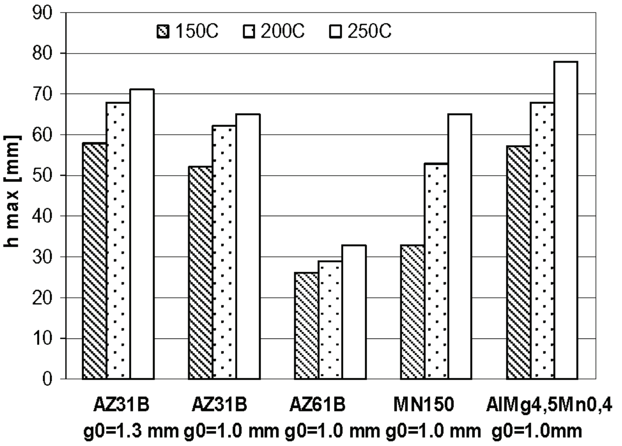

Fig. 3. Maximum stretching height $h_{\max}$ for different sheet materials and temperatures.

At this kind of die, the blank is clamped for a short time before processing between the blank holder and the die. Due to the high coefficient of thermal conduction and the low heat capacity of magnesium and aluminium sheet alloys this time is very short. Comparative to the external heating in an oven this forming process is longer but the process control is more accurate.

Another advantage of the heating of the blank during the process is the uniform distribution of the temperature all over the blank area. This uniform heating of the blank can be obtained by realizing different temperatures in different tool areas. Thus, good results where obtained if the punch has a lower temperature then the blank holder and the die. In order to heat the die, the electrical elements within the punch, the blank holder and the die are used. Insulation layers prevent the heat transmission from these elements into the tool frame, the pressing machine and additional water-cooled plates.

3. TEORETICAL AND EXPERIMENTAL RESERCHES

In order to determinate, the influence of the different factors upon the deep drawing process of the metallic material with low plasticity a numerical simulation using the finite element method was used. The numerical simulation consists in deep drawing of a cylindrical part using the following parameters:

- punch diameter D_0 = 100 mm,
- sheet thickness g_0 = 1 mm,
- punch radius and die radius r = 12 mm,
- drawing ratio β_0 = 1.8,
- friction quotient.

The deep drawing simulation was made at different deformation temperatures for aluminium alloy AZ31B.

The model with finite element is presented in Fig. 4.

The geometrical model was generated in a parametric way so by parameters transformation the simulation of the deep drawing can be realized for different input parameters. The parameters represent the geometrical size for process elements like sheet thickness g_0, the punch radius r and the die radius, the blank diameter d_{sf} and process size like temperature and deformation process speed.

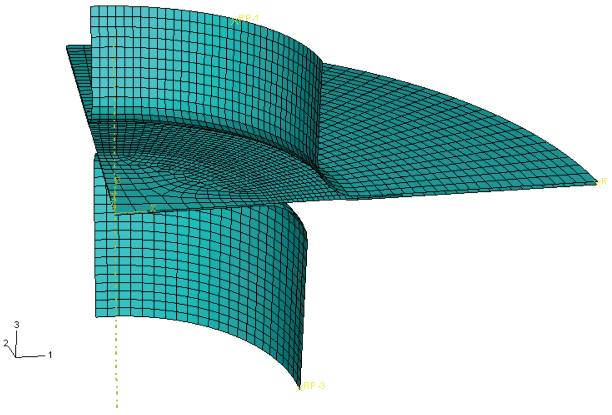

Fig. 4. Finite element model.

In finite element simulation the flow curve for AZ31B at temperature T = 50°C and 1 mm thickness was used.

The deep drawing simulation allowed the obtaining of the stress, and strain distributions shown in Figs. 5 and 6.

The deep drawing equipment is realized in modular way and it allowed the determination of the formability of the material by Marciniak and Nakajima methods, respective to carry out the deep drawing tests for cylindrical and rectangular shape of the parts. This equipment will be installed on a hydraulic press by 630 kN. The acquisition and automated data handling (force and displacement) are realized by means of an acquisition and control board Keithley KPCI 3108 and by displacement and force transducers. The equipment allows keeping out the working temperature by heating the blank holder and the active plate. In order to visualize the piece fracture moment, at the formability tests, the equipment is endowed with a video camera. The camera was mounted on the superior plate of the equipment and using a mirror the exact fracture time is surprised. The equipment allows the arrangement and control of the hold force, by using four hydraulic cylinders. The hydraulic installation is endowed with valves and pumps.

During the process, the tool component drawing die and blank holder will be heated by integrated, electric heating elements to the target temperatures T = 200°C and T = 250°C. The temperatures of the tool component and the material will be recorded with a thermo graphic

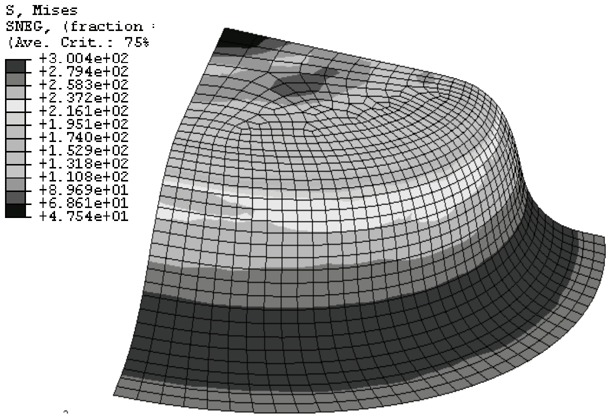

Fig. 5. Stress distribution.

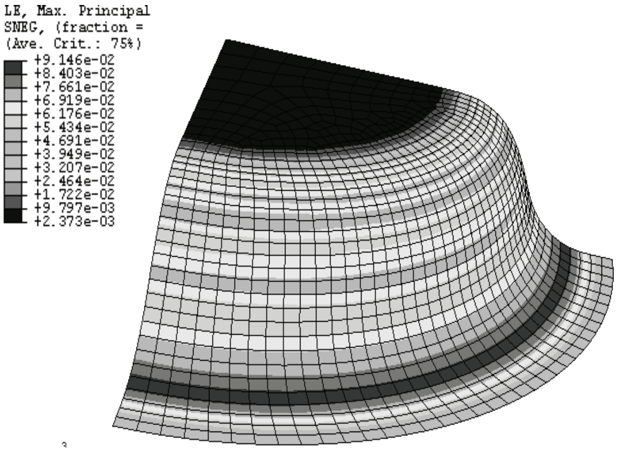

Fig. 6. Strain distribution.

camera and the punch will be keep at room temperature, which will indicate the temperature distribution in the drawing tool at different points in time during the process.

The processing tool was designed based upon the maximum force determined by means of numerical simulation, presented in Fig. 7.

Fig. 8 shows the designed tool.

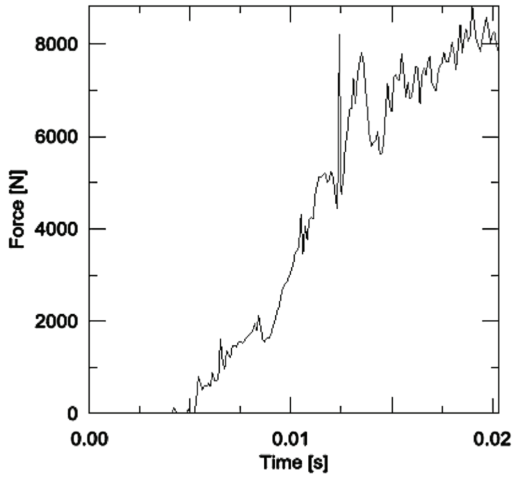

Fig. 7. Deformation force.

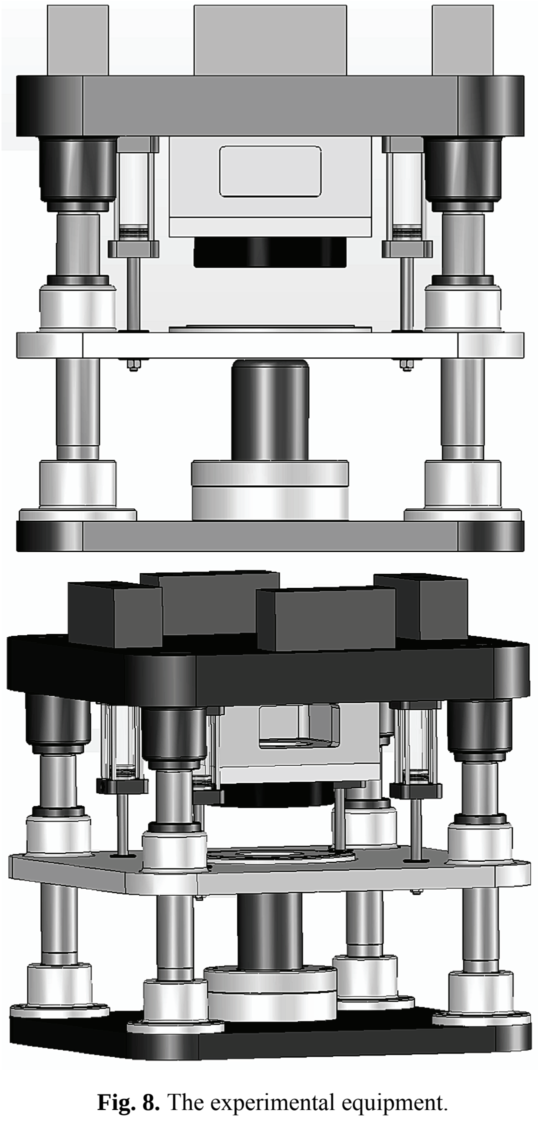

Fig. 8. The experimental equipment.

This equipment will be used, in future researches, in order to perform experimental tests concerning the deep drawing of the metallic material with low plasticity. The processed materials will be aluminium and magnesium alloy for different temperatures ($T = 200°C$, $T = 250°C$, $T = 300°C$), for different sheet thickness ($g_0 = 0.8$ mm, $g_0 = 1$ mm, $g_0 = 1.3$ mm) and for different piece diameter ($D_0 = 60$ mm, $D_0 = 75$ mm, $D_0 = 100$ mm).

4. CONCLUSION

The demands for light metallic construction lead permanently to study the metallic materials proprieties with low densities and to realize their forming.

Such metallic materials are the magnesium alloys AZ31B, AZ61B, MN150 and aluminium alloy AlMg4.5Mn0.4 which have lower densities comparative to conventional metallic materials used in constructions of the automobiles and aircrafts.

Theses materials are not used very often because of their low plasticity at room temperature. However, this inconvenience can be surpassed by heating the blanks at temperatures between 200°C and 250°C. The heating can be realized outside the forming process in an electrical oven or during the process by heating the punch, the blank holder and the die.

Thus, complex and in the same time very light parts can be obtained realizing new dies types specifically to the forming of the metallic materials with low plasticity.

REFERENCES

[1] Doege, E., Droder, K. (2002). *Forming of Magnesium Sheet Metal*, Production Engineering, vol. IX/2, Germany.

[2] Doege, E., Droder, K., Elend L. E. (2000). *Investigations on Formability of Magnesium Sheet Metal Alloys*, Journal of Materials Processing Technology, **115**, pp. 14–19, Germany.

[3] Siebel, G. (1940). *Technology of Magnesium and its Alloys*, Ed. Beck, Hughes, London.

[4] Doege, E., Droder, K. (1997). *Proccesing of Magnesium Sheet Metals by Deep Drawing and Stretch Forming*, Materiaux & Techniques, *7–8*, Germany.

[5] Doege, E., Droder, K., Janssen, St. (1998). *Umformen von Magnesium-werstoffen*, DGM – Fortbilungsseminar, Clausthal - Zellerfeld, pp. 28–30, Germany.

[6] Avedesian, H. M., Baker, H. (1999). *Magnesium and magnesium alloys*, ASM Speciality Handbook, ASM International, Ohio.

[7] Siegert, K., Werle, Th., Hojas, M., Kuhlein, W. (1990). *Herstellung von superplastischen Aluminiumblechen und deren Verarbeitung mit numerisch gesteuerten Pressen Tagungsband*, Seminar Neuere Entwicklungen in der Blechumformung, 08–09 May, 1990, Fellbach.

Authors:

Assistant Professor Claudia GÎRJOB, “Lucian Blaga” University of Sibiu, Department of Machines and Equipment,
E-mail: `claudia.girjob@ulbsibiu.ro`
Professor Octavian BOLOGA, “Lucian Blaga” University of Sibiu, Department of Machines and Equipment,
E-mail: `octavian.bologa@ulbsibiu.ro`
Associate Professor Gabriel RACZ, “Lucian Blaga” University of Sibiu, Department of Machines and Equipment,
E-mail: `gabriel.racz@ulbsibiu.ro`