STUDY OF THE FORMABILITY OF LIGHT METALLIC MATERIALS

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ABSTRACT: This paper aims to evaluate the forming capacity of lightweight metallic material. The main disadvantages of these materials are their low plasticity. Among this category of materials, the AZ31B magnesium alloy has been chosen for study. In order to evaluate its forming capacity, tensile tests, forming limit curves tests and cylindrical drawing tests were performed. The tests were made for AZ31B magnesium alloy specimens in non treated state and also after heat treatment at a temperature of 250^{o}C with a maintaining period of one hour. The tests performed have targeted the determination of the mechanical characteristics and of the properties of the AZ31B magnesium alloy. In order to evaluate the tensile behaviour of both non-treated and heat treated AZ31B magnesium alloys, the yield, the difference between tensile strength and yield and specific elongation at failure were compared. Also, the plane anisotropy coefficients were determined. The forming limit curves were plotted for the AZ31B magnesium alloy in non treated and heat treated state using the Nakajima test. All these results were used to apply the finite elements method for evaluating the failure moment of the drawn parts.

KEY WORDS: lightweight material, uniaxial tensile test, forming limit curves, cylindrical deep drawing, AZ31B

1 INTRODUCTION

The current tendencies worldwide determine the aeronautic and automotive industry to manufacture planes, helicopters and cars as light, as ecological, as safe and as cheap as possible. Due to the laws and customers demands for safer and less polluting vehicles, the most important manufacturers focus on reducing the weight of the vehicles and limiting the quantity of pollutants. Fuel efficiency led to the extension of possible applications of parts made of lightweight materials. The main drawback of these lightweight materials consists in their low plasticity at room temperature. The researches made both by theoretical and experimental methods, e.g. by means of the finite element method, have shown that lightweight materials may be easily processed by plastic forming, if heated at temperatures between 200^{0}C and 300^{0}C. Among the lightweight materials, which also have a low plasticity, used for reducing the weight of different parts, one can mention magnesium and its alloys, aluminum and its alloys, titanium and its alloys, but also the composite materials.

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2 MATERIALS USED IN THE RESEARCHES

The experimental researches were made in order to evaluate the forming capacity of low plasticity alloys. Among this category of materials, the AZ31B magnesium alloy has been chosen, a representative alloy for magnesium-zinc-aluminum systems.

The main advantage of this alloy is its very low density (1.74g/cm^3), it is used for automotive industry and aeronautic industry parts, parts which have to have a reduced height.

The mechanical characteristics of the magnesium alloy AZ31B are presented in table 1.[Ambrogio, 2008]

Table 1 The mechanical characteristics of the magnesium alloy AZ31B

Mechanical characteristics	Values
Density [kg/mm^3]	1.74x10^{-6}
Young's modulus [GPa]	45
Yield strength [MPa]	150
Tensile strength [MPa]	255
Elongation [%]	10
Anisotropy [-]	1,91
Poisson coefficient [-]	0,35

3 EXPERIMENTAL RESEARCHES

The research directions are, consequently, the following ones:

- the determination of the mechanical parameters and the characteristic properties using the tensile test;
- the plot of the forming limit curves using the Nakajima test;
- the plastic deformation behavior at cylindrical drawing.

The tests were made for AZ31B magnesium alloy samples in two different states, respectively:

- non treated state, corresponding to the material delivered without incurring any thermal or mechanical treatment;
- treated state, corresponding to the heat-treated material prior to applying the plastic deformation process, at 250^{o}C temperature with one hour maintaining period.

The tests were carried out using test samples made of AZ31B magnesium alloy, of 1 mm thickness, using the following experimental layouts:

- the mono-axial tensile layout consisting of the tensile testing machine Instron 5587 and the optical strains measurement system Aramis (fig. 1);
- the forming limit curves and drawing layout consisting of the modular deep drawing device, with exchangeable active elements, and optical strain measurement systems Aramis („on-line”) and Argus („off-line”), respectively (fig. 2);
- the Nabertherm L15/11/P320 furnace for heat treatment of the magnesium alloy AZ31B.

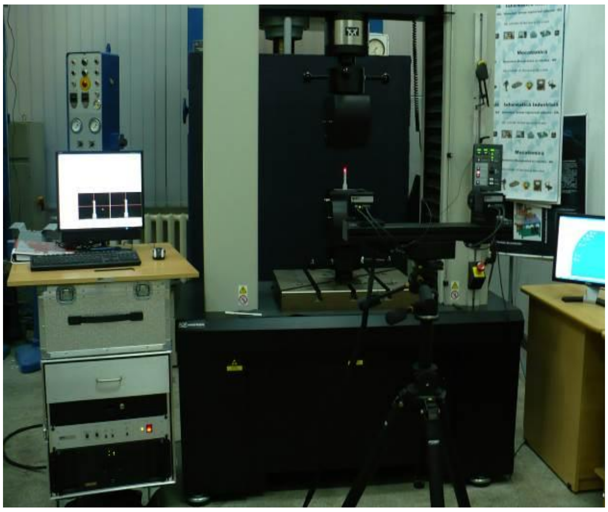

Figure 1. The experimental layout used for tensile test

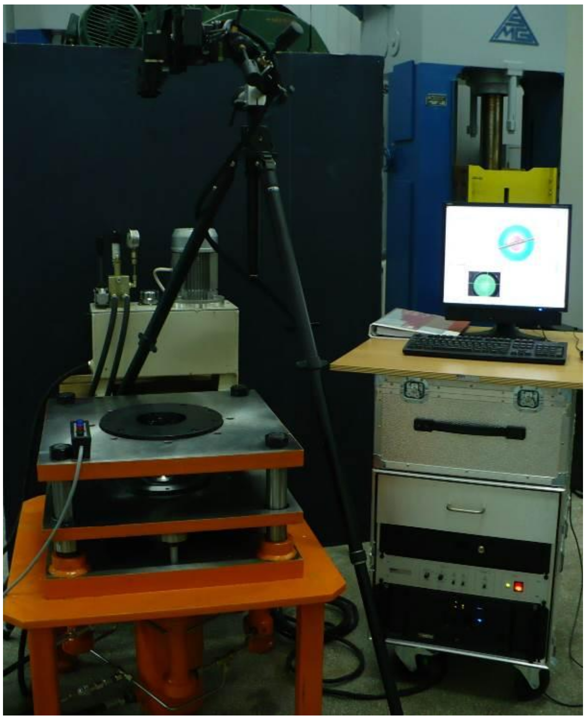

Figure 2. The experimental layout used for the tensile test and for the forming limit curve test

The mono-axial tensile tests performed have targeted the determination of the mechanical characteristics and the properties of the AZ31B magnesium alloy. In order to evaluate the tensile behavior of both nontreated and heat treated AZ31B magnesium alloy, the yield, the difference between tensile strength and yield and specific elongation at failure were compared. Also, the plane anisotropy coefficients were determined. The determination of the plastic anisotropy coefficients r_0, r_{45} and r_{90} respectively was realized according to the SR ISO 10113:1996 standard.

Forming limit curves can be determined experimentally by means of points with the coordinates (ε_1, ε_2) where ε_1 and ε_2, are the limit strains corresponding to a certain loading mode of the test sample (equibiaxial, biaxial, uniaxial etc.). Consequently, in order to determine a forming limit curve, the material has to be subjected to several loading modes, comprised between the biaxial stretching ($\varepsilon_1=\varepsilon_2$) and pure shearing ($\varepsilon_1=-\varepsilon_2$).[Engel, 2012]

3.1 Employed test samples

As test sample type for mono tensile test there was chosen a proportional sample with the dimension of the calibrated zone 75*12,5 mm*mm. (fig. 3), according to the standard SR EN 10002-1:2002.

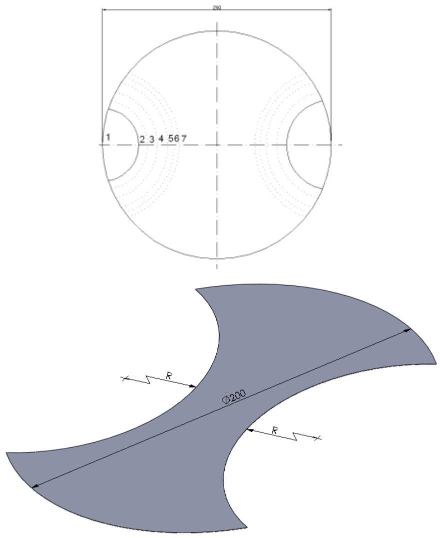

Figure 5 The shape of the test samples used for determining the forming limit curves

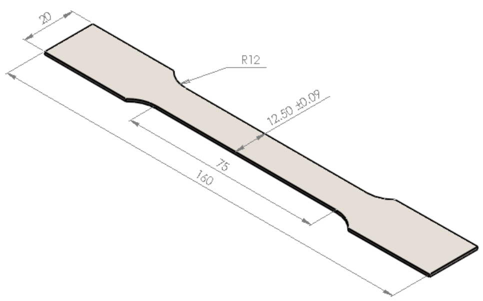

Figure 3 Proportional test sample

To study the anisotropy of the material for the sample sets, the sample were extracted at angles of 0^0, 45^0 and 90^0 respectively to the sheet rolling direction (fig. 4).

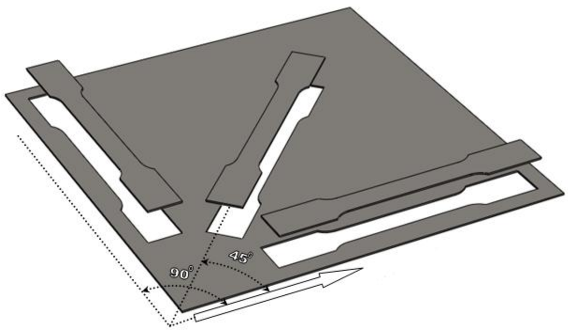

Figure 4 Proportional test samples extracted at 0^0, 45^0 and 90^0 to the rolling sheet direction

As test sample type for forming limit curves there was chosen the type suggested by Hasek in 1978, namely circular-shaped test samples with a diameter of 200 mm, with lateral cutouts symmetrical to the rolling direction (fig. 5), with various radii as presented in table 2.

By using this type of test samples, there can be obtained forming paths comprised between the uniaxial stretching and the equibiaxial stretching. This means that the whole variation domain of the forming states encountered in the metal sheet forming processes is covered. [Hsu, 2008]

Table 2 Cut out radii at the test samples used for determining the forming limit curves

Specimen	1	2	3	4	5	6	7
r [mm]	0	40	50	57.5	65	72.5	80

3.2 The determination of the mechanical characteristics and of the properties

The tests performed have targeted the determination of the mechanical characteristics and of the properties of the AZ31B magnesium alloy, presented in table 3.

Table 3 The mechanical characteristics of the AZ31B magnesium alloy

Mechanical characteristics	AZ31B	
	Non treated (20^oC)	**Heat treated (250^oC - 1h)**
Yield strength $R_{p0,2}$ [N/mm^2]	161.94	156.67
Tensile strength R_m [N/mm^2]	261.06	265.42
(R_m-$R_{p0,2}$) [N/mm^2]	99.12	108.74
Yield strain, A_r ,%	12.37	25.03

Figure 6 presents comparatively strain hardening curves for the AZ31B magnesium alloy in heat treated and non treated state.

The determination of the plastic anisotropy coefficients r_0, r_{45} and r_{90}, respectively, for the AZ31B magnesium alloy for the non treated and heat treated state, was realized according to the standard SR ISO 10113:1996 and the results are presented in table 4.

For the AZ31B magnesium alloy a significant increase of the anisotropy coefficient for the heat treated samples compared to the non treated samples may be observed, which indicates an increase of the formability of the AZ31B magnesium alloy that was heat treated at 250^oC temperature for a maintaining period of one hour.

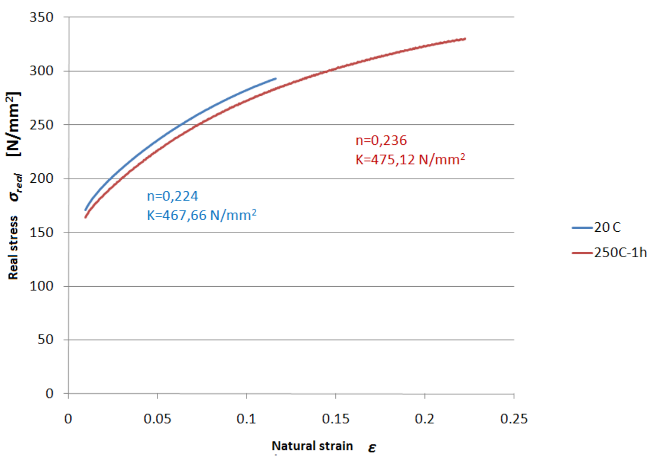

Figure 6. Strain hardening curves for the AZ31B magnesium alloy in heat treated and non treated state

Table 4 Determination of the plastic anisotropy coefficients

Material	Cut out rolling direction [0]	Plastic anisotropy coefficients r_0, r_{45}, r_{90}	Normal anisotropy coefficients $\bar{r}$	Planar anisotropy coefficients Δr
AZ31B non treated	0	1.40	2.91	1.45
	45	2.63		
	90	4.97		
AZ31B heat treated	0	3.18	4.67	2.34
	45	6.37		
	90	2.76		

3.3 The determination of the forming limit curves

In order to determine the forming limit curves for the AZ31B alloy sheet metal in nontreated and heat treated state, there was chosen the Nakajima test.

Each test sample was subjected to a deep drawing test with a hemispherical punch, until the fracture occured (fig. 7).

The obtained forming limit curves for the AZ31B alloy sheet metal in nontreated and heat treated state are presented in figure 8.

It can be noticed that the forming limit curve for the heat treated AZ31B magnesium alloy is located in the diagram above the curve corresponding to the non treated state, which indicates a better forming behaviour after heat treatment.

Figure 7 Test samples for forming limit curves

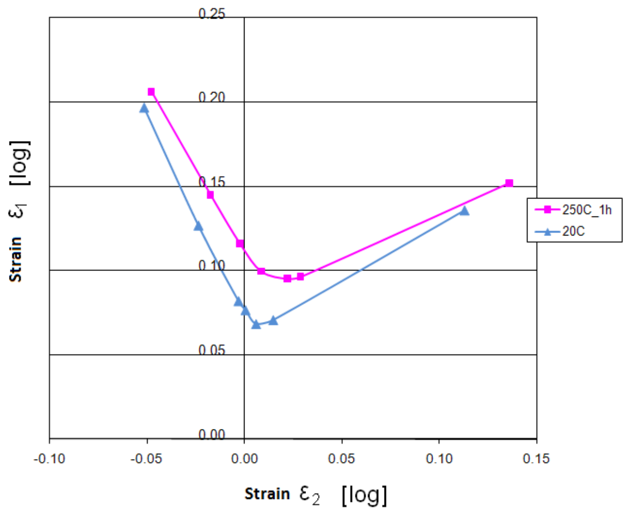

Figure 8 Forming limit curves for the AZ31B alloy sheet metal in non treated and heat treated state

3.4 The cylindrical drawing test

The main objective of this research was to determine the maximum forming degree K, using the cylindrical drawing test for a piece with flange by 100 mm diameter, for the AZ31B alloy sheet metal in nontreated and heat treated state. For the drawing test, the following parameters were varied successively: the holder pressure and the blank diameter. The values of these parameters are presented in table 5.

Table 5 Parameter values for cylindrical deep drawing

Parameter	Value
Blank diameter D [mm]	140; 145
Holder pressure p [MPa]	1.5; 2.5;

The forming degree K is defined as:

$$K = \frac{D}{d}$$

where: D is the blank diameter;

d is the diameter of the cylindrical drawn parts.

For the cylindrical deep drawing tests on circular samples with the diameter values presented in the table above, a calibrated network of circular spots, with 2 mm diameter and 3 mm distance between centers, was printed electrolytically (fig. 9).

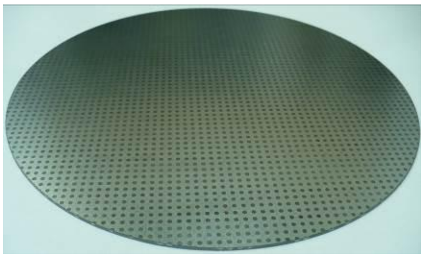

Figure 9 Cylindrical deep drawing sample

For each sample the drawing force, the holder pressure and the main strains in the drawn parts were measured.

The drawing force and the holder pressure were measured „on-line”, during the process by means of pressure transducers mounted in the hydraulic actuation circuits of the punch and the holder ring and connected to the data acquisition system of the experimental setup. The main strains in the drawn parts were measured „off-line”, by means of the optical strains measurement system Argus systems (fig. 10).

Figure 10 Measurement of the strains in the drawn parts

The parts with the maximum height obtained for the magnesium alloy AZ31B in non treated and heat treated state, respectively, are presented in figure 11.

a. b.

Figure 11 The parts of maximum height obtained for the cylindrical deep drawing: a. AZ31B heat treated (K=1.45), b. AZ31B non treated (K=1.45)

Also, there were carried out numerical simulations of the cylindrical deep drawing process for the AZ31B magnesium alloy in the two states, non treated and heat treated. The numerical simulation using the finite elements method was realized using the ABAQUS software. The aim was to determine the maximum height, at failure, of the drawn parts function of the process parameters forming degree K and holder pressure p. For the simulation there was used a parametrized geometric model with finite elements, which included the plastic instability initiation criterion - FLD, which involves indicating the forming limit curve as a table using the limit strain ε_1 at the instability initiation function of the limit strain ε_2, $\varepsilon_1^{FLD}(\varepsilon_2)$.

The experimental results were compared with the ones obtained using the numerical simulation with finite elements in which the plastic instability initiation criterion FLD was used, the values being similar.

The experimental and theoretical results are presented comparatively in figure 12 and table 6.

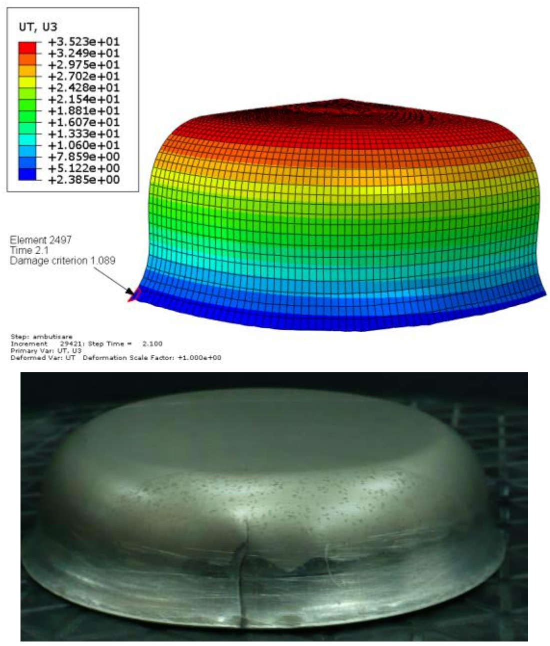

Figure 12 Determination of the maximum height of the part at breaking

Table 6 Maximum failure heights, theoretical and experimental values

Material	Forming degree	Pressure [MPa]	Numerical simulation			Experimental
			Coefficient ω	Time [s]	Maximum height	Maximum height
AZ31B non treated	1.4	1.5	1.013	2.10	29.24	29.88
		2.5	1.010	1.86	28.22	28.72
	1.45	1.5	1.079	2.41	30.57	30.98
		2.5	1.089	2.1	23.67	24.01
AZ31B heat treated	1.4	1.5	1.03	1.98	29.69	29.98
		Eans of 2.5	1.046	1.80	28.85	30.02
	1.45	1.5	1.089	1.92	33.31	33.64
		2.5	1.025	1.80	32.84	33.02

The maximum strength heights, determined by numerical simulation, are presented in figure 13. It should be noted that the corresponding values of the magnesium alloy in heat treated state are better than those for the non treated state in the same conditions, for all tests performed. By increasing the forming degree K respectively the holder pressure the differences between the heights of parts are increasing. The maximum value of this difference is obtained for a forming degree K = 1.45 and a holder pressure p = 2.5MPa, respectively. This shows an improvement of the forming capacity for the magnesium alloy AZ31B after applying the heat treatment.

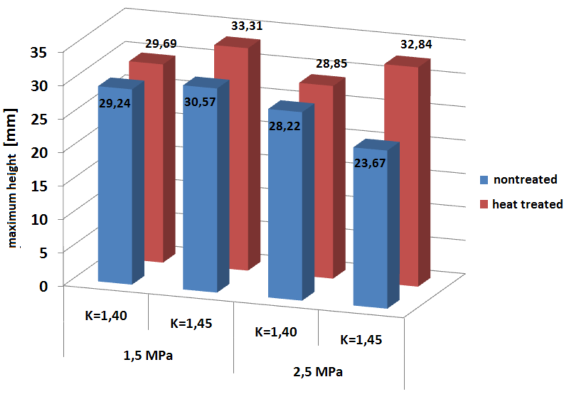

Figure 13 Maximum heights for cylindrical deep drawn parts

4 CONCLUDING REMARKS

The general conclusion of the researches is that the AZ31B magnesium alloy heat treated at 250°C temperature for a maintaining period of one hour may be used for cold forming processes with small forming degrees, its behaviour being better than in non treated state.

5 ACKNOWLEDGEMENTS

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