Proceedings IRF2018: 6th International Conference Integrity-Reliability-Failure
Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid
Publ. INEGI/FEUP (2018); ISBN: 978-989-20-8313-1

PAPER REF: 7222

DETERMINATION OF ALUMINUM ALLOY EN AW-1100 LIMITING DRAWING RATIO AT DIFFERENT TEMPERATURES THROUGH PRACTICAL EXPERIMENTS AND NUMERICAL SIMULATION USING FINITE ELEMENT METHOD

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ABSTRACT

Widely used in industry and academia to evaluate the drawability of a material, the Swift cup test provides as a result value known as limiting drawing ratio (LDR), which quantifies the maximum reduction between the initial and final diameters of a metal sheet, in the deep drawing process. This work aims to determine the Aluminum Alloy EN AW-1100 limiting drawing ratio at different temperatures (25° C, 220° C and 350° C). For this purpose, it was used numerical simulation of the Swift cup test.

Keywords: limiting drawing ratio, swift cup test, sheet metal forming, finite element method.

INTRODUCTION

The sheet metal forming process called deep drawing has become a studying target, due to its wide possibilities of application and reproducibility. Reasons by which it is characterized as an ideal process to a large-scale production. It can be used from producing simple household utensils (pots, pans, etc.), to manufacturing car body parts in the automotive industry. Intending to measure materials drawability and simulate the industrial production conditions, were run some tests. Among them may be highlighted Erichsen Cupping Test, Olsen Cup Test and Swift Cup Test.

Swift Cup Test consists of pulling a sheet metal blank into a die cavity, using a drawing force, which is applied by a tool called punch. The die and punch diameters are 52.5 mm and 50 mm, respectively (Boljanovic, 2003; Button; Bortolussi, 1999; Dieter, 1984). The blank diameter is increased until the material failure. It is taken the last diameter, that can be drawn successfully, and the diameter of cup made in the process (Rodrigues; Martins, 2005). The obtained value is known as limiting drawing ratio (LDR), which is calculated by the following relation:

$$LDR = D/d \qquad (1)$$

Where:

D = the maximum blank diameter;

d = the diameter of cup made.

Various parameters can modify the value of LDR in the Swift cup test. This work aims at studying the LDR variation, of the Aluminum Alloy EN AW-1100, as a function of the process temperature, using finite element methods.

METHODOLOGY

Tensile tests were performed on Aluminum Alloy EN AW-1100 samples, using a universal machine for mechanical testing INSTRON/EMIC 23-300 and in accordance with ASTM-E8M standard. To maintain the test specimens at the desired temperature during the entire test, an electric resistance with a power of 550 W (220 V voltage) was used as shown in Figure 1. The temperature control was implemented with the use of a universal controller with PID Auto-adaptive Fuzzy C100.

Fig. 1 - Resistance for heating in the tensile test

Tool components (punch, die and blank holder) were designed in the Autodesk Inventor®. A fixed blank holder was used instead of movable. The drawn components are shown in Figures 2A, 2B, 2C.

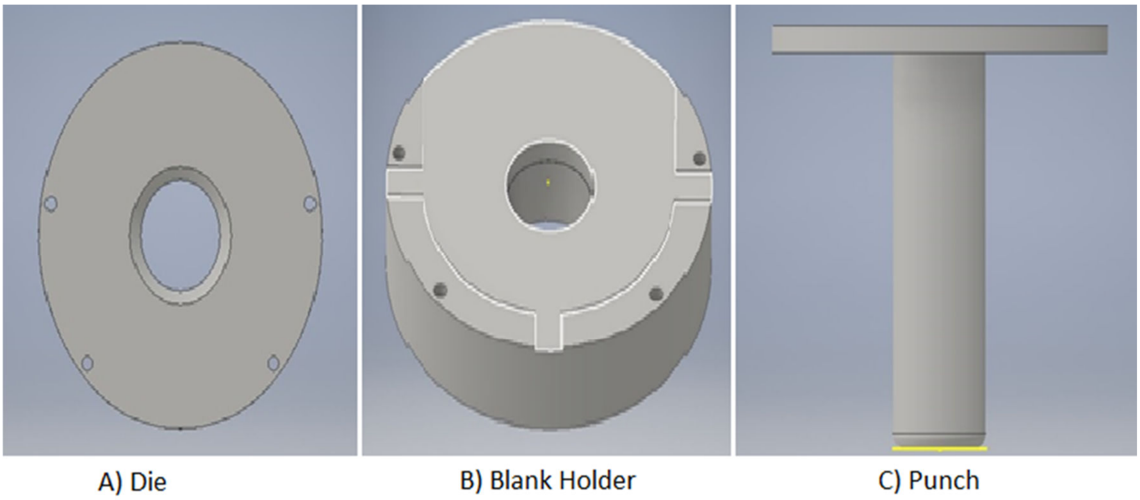

Fig. 2 -A) Die B) Blank holder C) Punch

It was decided to use the fixed blank holder in the matrix. The blank holder has a thickness of 1 mm feature (exactly the thickness of the plate), which allowed the positioning of the plates in the center of the tool, and exerted on it a force, keeping it parallel to the surface of the matrix until the end of the test. In the present study, the blank holder also had the purpose of allocating the ceramic strength to keep the plate heated throughout the test. The die and die set and their respective base plates were screwed using M6 screws. Four slits were opened in the plate blank holder, one to allow the positioning of the plates in the center of the matrix, and the other three to allow the entry of three rulers, which serve to centralize the plates to be tested.

The process simulations were made through ABAQUS/CAE® Software. Parameters of the simulation were considered the matrix, and punch and the plate press as rigid elements and the plate as flexible element (Azevedo, 2003). With all parameters in place, the diameter of the test plate was gradually increased until rupture, thus allowing the calculation of the LDR of the material and the comparison with the practical tests.

The values of the parameters used in the simulations are shown in Table 1.

Table 1 - Parameters used in the simulations

Parameter	**Value**
Thickness of the blanks	1.2 mm
Coefficient of friction	0.1
Diameter of the punch	50 mm
Diameter of the die throat	52.5 mm
Diameter of the blanks	80 - 120 mm
Punch and die corner radius	6.36 mm
Poisson's ratio	0.33
Coefficient of thermal expansion	23×10^{-6} °C

The coefficient of friction, diameter of the punch, diameter of the die throat and punch/die corner radius values were found in the Kumar and Reddy (2014) article.

RESULTS AND DISCUSSION

The simulations at different temperatures (25°C, 220°C and 350°C) were performed, resulting in a LDR value, for the Aluminum Alloy EN AW-1100, of 2.2. It was observed that was no difference in the LDR values with the temperature variation. This LDR value (2.2) was compared to the value obtained by Kumar and Reddy (2014), which was 1.904, and it was observed that these values were not so close. One of the factors that help to explain the difference found is the use of a fixed blank holder, instead of movable, like the authors.

The stress-strain curve of the material was obtained at predetermined temperatures (25°C, 220°C and 350°C). These tests were performed in order to obtain some mechanical properties of the material, such as elastic modulus and the plastic range as well, to be used in the simulations. Table 2 shows the values of the modulus of elasticity of the material for each temperature and Table 3 shows the values of the tensile strength limit of the material as a function of the test temperature.

The results from the tensile tests are shown in Figure 3.

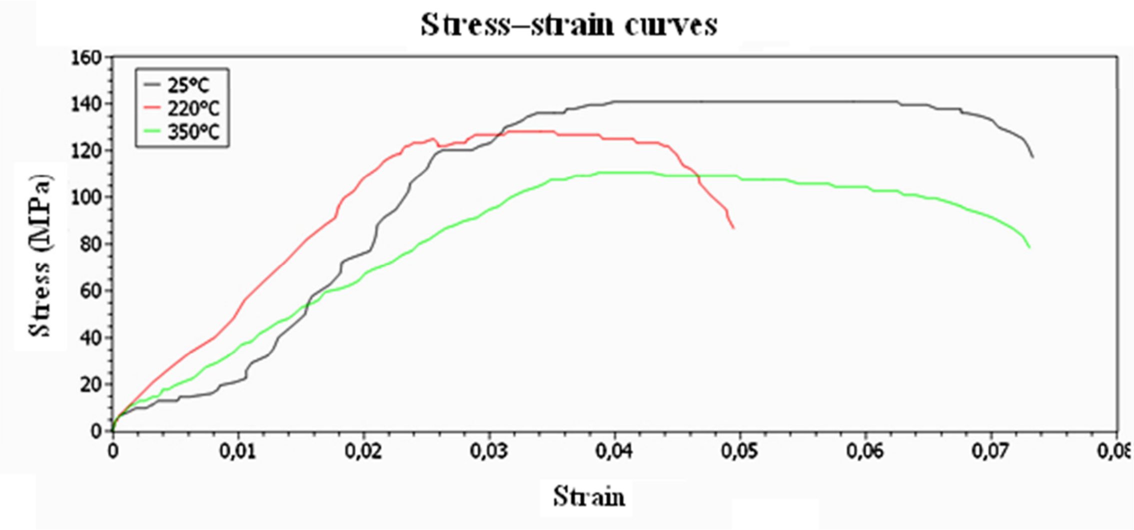

Fig. 3 - Tensile test results

As expected, there was a drop in the value of the material modulus as the temperature of the test increased.

Table 2 - Aluminum modulus as a function of temperature

Temperature (°C)	Modulus of elasticity (MPa)
25	61183
220	53113
350	32781

The values of the tensile tensile strength tensions were observed to fall as the test temperature increased, as expected, as the strength of the material fell when heated.

Table 3 - Tensile strength of aluminum as a function of temperature

Temperature (°C)	**Tensile Strength Limit (MPa)**
25	149,52
220	132,5
350	112,95

With the data of the tensile tests, the design performed in Autodesk Inventor® software, the Poisson modulus of the material (0.33) and its coefficient of thermal expansion ($23\ x\ 10^{-6}$ ° C) the simulations of the Swift Test of the Aluminum EN AW-1100 at each pre-set temperature. Observing the work of Kumar and Reddy (2014), a coefficient of friction (μ) equal to 0.1 was used.

The Swift test simulations were started at a temperature of 25° C with a plate of 80 mm diameter, and the initial diameter of the plate was gradually increased until rupture. This procedure was repeated for temperatures of 220 and 350° C. After the rupture, the last plate was taken in which there was no failure and the ratio between the initial diameter (before the test) and the final diameter (50 mm) was made, this value being the LDR of the material.

Figures 4 and 5 present the test simulation at 25° C, with diameters of 110mm (no rupture) and 112 mm (rupture), respectively.

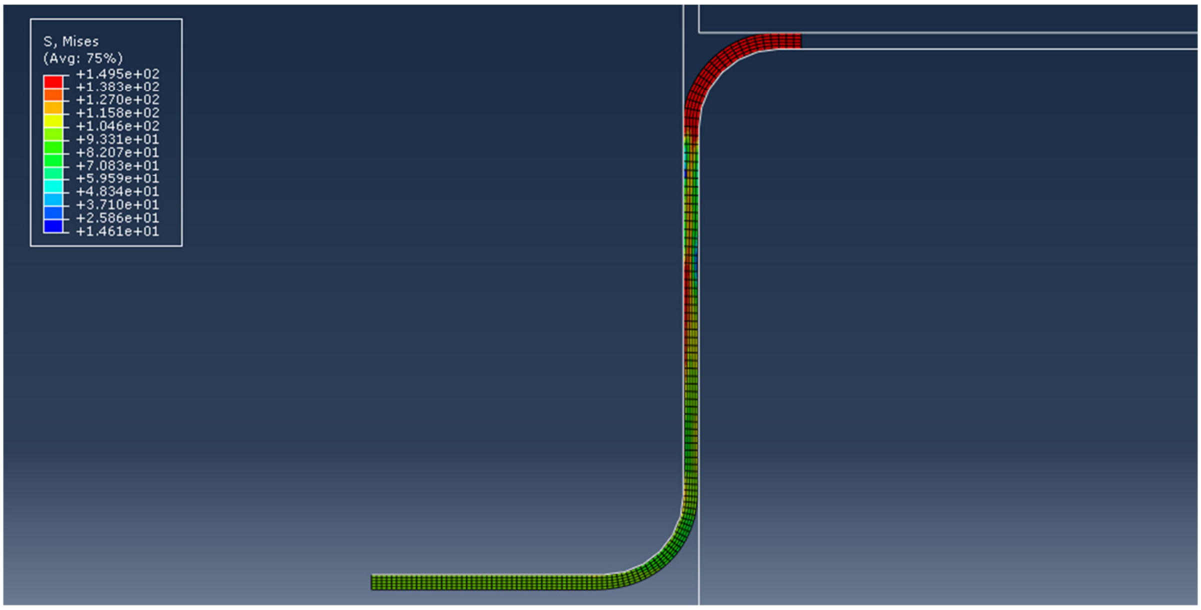

Fig. 4 - Simulation at 25° C and diameter of 110 mm (no rupture)

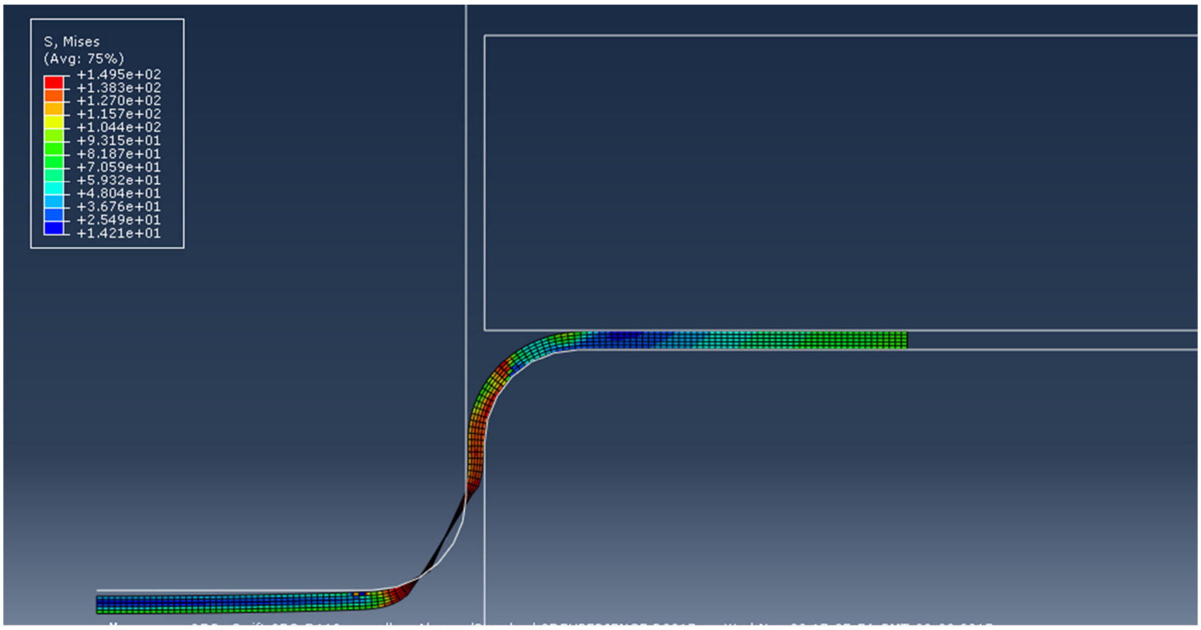

Fig. 5 - Simulation at 25° C and diameter of 112 mm (rupture)

The value of 2.20 was found by calculating the LDR of the material at the temperature of 25° C. Kumar and Reddy (2014) in their simulation, for the same material, found an LDR value equal to 1,904. However, the authors opted for the use of a movable plate press, with a force of 500 N on the plate.

This may be one of the factors that explain the difference in LDR values found. Table 4 shows the values of the initial and final diameters at each test temperature, as well as the LDR calculated for each temperature during the simulations.

Table 4 - LDR values calculated for each test temperature

Temperature (°C)	**Ø Initial (mm)**	**Ø Last (mm)**	**LDR**
25	110	50	2,200
220	110	50	2,200
350	110	50	2,200

It was observed during the simulations that the LDR values for the EN-AW-1100 Aluminum Alloy did not change, regardless of the test temperature. A factor that helps to explain this behavior is the deformation of the aluminum, observed during the tensile tests, which presented very close values, independent of the test temperature.

TOOL CONSTRUCTION

By observing the design, the components (die, punch and plate press) were machined and Figures 6A, 6B, 6C, 6D shows the components of the tool already machined. With the parts ready, the assembly and the necessary adjustments in the tool were started.

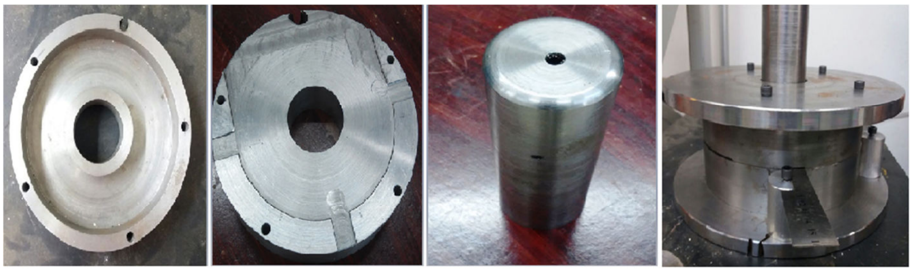
A) Die B) Blank holder C) Punch D) Tool for performing the Swift test

Fig. 6 - A) Die B) Blank holder C) Punch D) Tool for performing the Swift test

SWIFT TEST

The tests were initially carried out at a temperature of 25 °C. According to Kumar and Reddy (2014), the LDR for aluminum EN AW-1100 equals 1,904.

Knowing that the final diameter is constant and equal to 50mm, it was expected that the maximum initial diameter of the plate, without the rupture, was approximately 95mm.

The tests were started with a plate having a diameter of 82 mm and the plate diameters were gradually increased until the specimen was ruptured.

As expected, the material supported the test up to the 95mm diameter, and from the 96mm diameter there was rupture of the specimens, providing an LDR of 1,900 that is practically the same as that found by Kumar and Reddy (2014). Figures 7A, 7B, 7C shows some specimens after the tests.

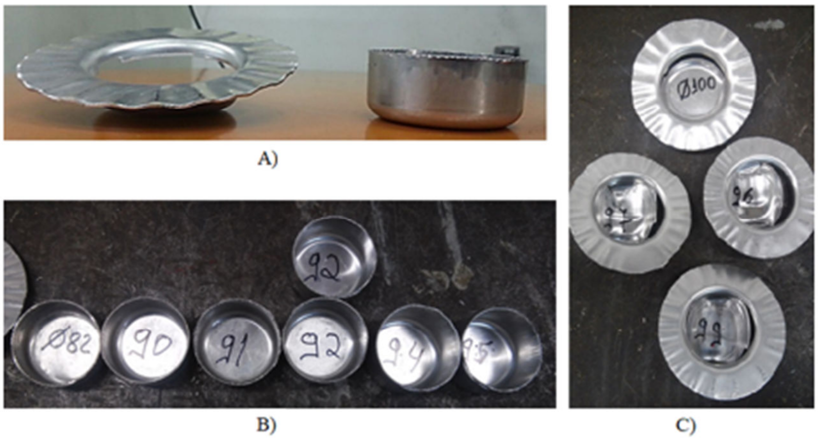

Fig. 7 - A) Specimens after the test; B) Test specimens after the test (without rupture);
C) Test specimens after the test (with rupture)

CONCLUSIONS

According to the present work it is concluded that the Aluminum Alloy EN AW-1100 presents an excellent drawability, with a limiting drawing ratio (LDR) of 2.2. It was also observed, during the simulations, that the process temperature did not influence the value of the limiting drawing ratio for this material. Several parameters influence the value of the limiting drawing ratio, such as: Punch and die corner radius, friction between the blank and the tool, force of the blank holder, etc. These parameters must be observed when comparing the results obtained in the studies of the drawability of a certain material.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), under grants FIP-2017/968.

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