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# Numerical and experimental forming of a cylindrical cup in 7075-T6 under warm temperature conditions

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**Abstract.** The use of aluminium alloys with high mechanical properties is very interesting to reduce the weight of parts, especially in the automotive industry. However, forming of these alloys at room temperature (RT) is difficult, especially for complex parts where fracture often occurs before the end of the forming process. The warm forming process, which consists of heating aluminum alloys to a temperature between 150 and 250°C, increases formability and thus allows complex shapes to be formed. In this study, forming of a cylindrical cup using a specific two-step drawing device by two reductions of the blank diameter is performed at RT and 200°C for a 7075-T6 alloy. These two forming steps are also numerically simulated using Abaqus. Forming at RT leads to the failure of the cup in the first stage, which is also obtained by numerical simulation with plastic deformations higher than what the material can support. At 200°C, the cylindrical cup can be formed in two steps, which results experimentally and numerically in a significant reduction of the forming forces.

**Keywords:** Warm forming · Aluminium Alloy · 7075-T6 · Two-step forming

## 1 Introduction

High strength aluminum alloys, such as the 7xxx series, are an attractive alternative to conventional steels in the automotive and aerospace industries. However, the poor formability of these aluminum alloy sheets is a serious obstacle to their use in the manufacture of complex lightweight components. This disadvantage can be reduced with the increase of the temperature which leads for temperatures higher than 150°C to a strong increase of the formability. Nevertheless, most of the studies carried out concern a part made in a single step and use heating methods which are not necessarily compatible with the current industrial environment [?, ?, ?]. Only a few studies focus on multi-stage warm forming of sheets to analyze the improvement of formability of high strength aluminum alloys [?, ?]. It is also important to keep the best performing T6 state of these

alloys and in our previous study [?], we showed that that temperature forming should be performed for times between 10 and 20s at 200°C. A longer duration leads to the formation of precipitates that no longer maintain the T6 state and then requires additional heat treatment costs to recover this state. The objective of this study is to investigate the warm formability of a 7075-T6 alloy using a new drawing and redrawing test configuration of a cylindrical cup. The simulation of these two-step forming at RT and 200°C is also numerically simulated using Abaqus and the forming forces are compared to the experimental during these two steps.

## 2 Material and methods

### 2.1 Material

AA7075-T6 sheet aluminum alloy with 0.8mm thickness is used in this work. Commercially purchased aluminum was directly received in T6 state. The chemical composition of this alloy is presented in table 1. Its mechanical properties measured in the T6 receiving conditions are given in table 2.

Zn	Mg	Cu	Si	Cr	Fe	Mn	Ti	Al
5.1-6.1	2.1-2.9	1.2-2.0	0.4	0.18-0.28	0.5	0.3	0.2	Balance

**Table 1.** Chemical composition of AA7075-T6 sheet in %wt.

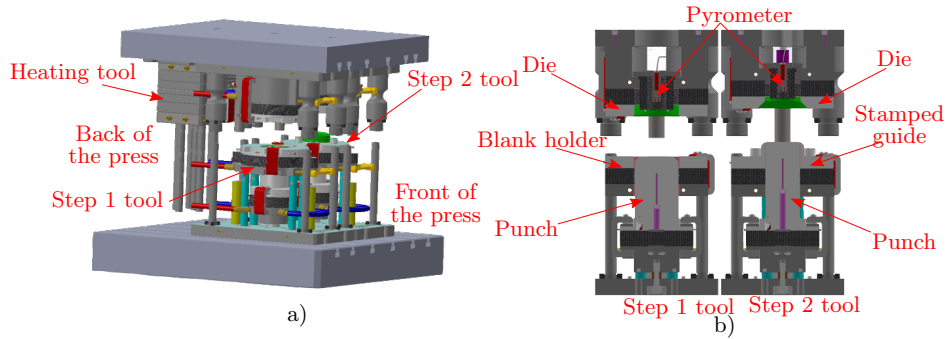
Conditions	$Rp_{0.2\%}$ [MPa]	$R_m$ [MPa]	$A\%$
Receiving	500	557	14.6

**Table 2.** Mechanical properties at RT of the AA7075-T6 measured at receiving condition.

### 2.2 Warm deep drawing and redrawing of a cylindrical cup

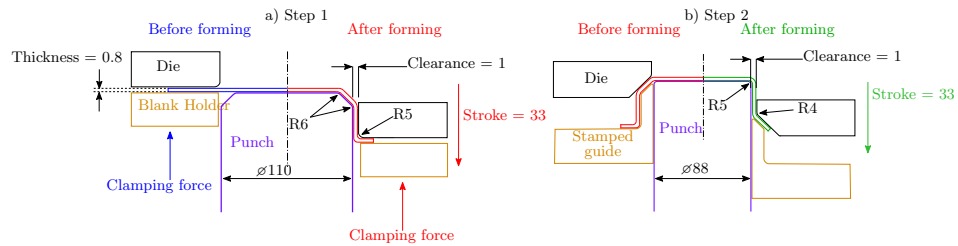
The warm forming and redrawing experiments were carried out separately in two stages on a press equipped with several heating and forming stages with a specific device manufactured by CETIM. Figure 1 presents the schematic of the arrangement of the heating station and the two forming stages stations in the press.

The blank initial diameter is 157mm. The device consists of a first stage of heating the blank by clamping contact to reach a uniform temperature of 200°C in 0.45s. In the next stage, the blank is manually transferred to the first forming



**Fig. 1.** a) Schematic of the press setup with the heating station and the two forming stages, b) Cutting view of the two forming tools.

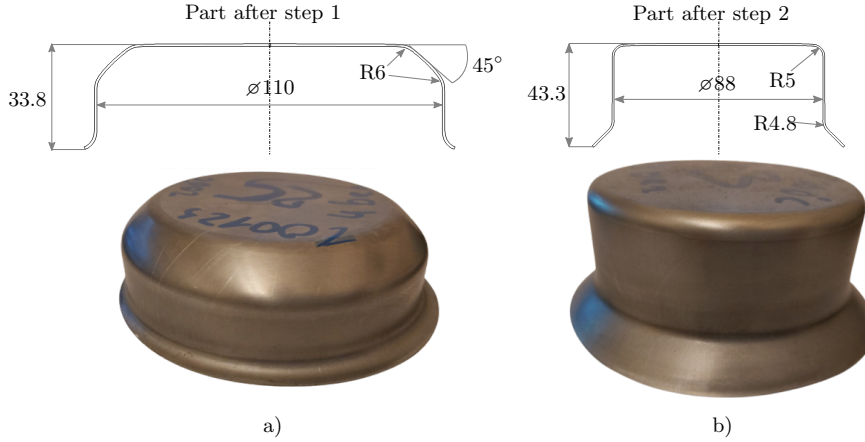
station as presented in figure 2-a and once the stamping is done, the blank is manually transferred to the second drawing station presented in figure 2-b. These two forming stations are placed next to each other to limit the transfer time. All tools are heated with heating cartridges and their temperature is controlled by K-type thermocouples. A clamping force of 66kN is applied on the first stamping step to the blank holder and no clamping force is applied on the second forming step. The reaction force during both drawing processes is measured by a force sensor under the punch and the temperature of the blank is monitored by a pyrometer located at 20mm from the blank.



**Fig. 2.** Dimensions and movements of tools (in mm) during a) the first step of forming and b) the second step of forming

It is assumed that all the stamping and transfer stages are carried out under isothermal conditions. The three steps (heating, first and second forming) are carried out in less than 20s to maintain the mechanical characteristics of the T6 state [?].

Forming test are performed at RT and 200°C with a JELT 5411 lubricant. At RT, forming is impossible and causes the blank to break during the first drawing. At 200°C, four tests are performed to check the reproducibility but the average result will be used as a representative. Figure 3 presents the theoretical dimensions of the part after the two stamping operations and a picture of the parts obtained at the end of these two operations at 200°C.



**Fig. 3.** a) Dimensions (in mm) of the part after step 1 a) and b) after step 2.

### 2.3 Numerical simulations of the warm forming process

Isothermal numerical simulations of the forming process are conducted with Abaqus/Standard. A 2D axisymmetric model is used with tools modeled as rigid surfaces. A section of the blank is meshed with 2D quadratic quadrilateral elements CAX4. A mesh size of approximately 3.5mm is used in the punch zone before the punch radius whereas the size decrease to approximately 0.5mm after this radius. Moreover, 11 elements are used through the thickness. The tensile tests show little striction and therefore a Swift law has been chosen to identify the behavioral laws. Several Swift law (1) are identified by tensile tests at room temperature and 200°C for strain rates of  $2 \times 10^{-4}$ ,  $2 \times 10^{-3}$ ,  $2 \times 10^{-2}$  and  $0.2s^{-1}$ . The blank has therefore a strain rate dependent elastic-plastic behavior. The parameters of the hardening law at RT and 200 °C are summarized in table 3.

$$\bar{\sigma} = K(\varepsilon_0 + \bar{\varepsilon})^n \quad (1)$$

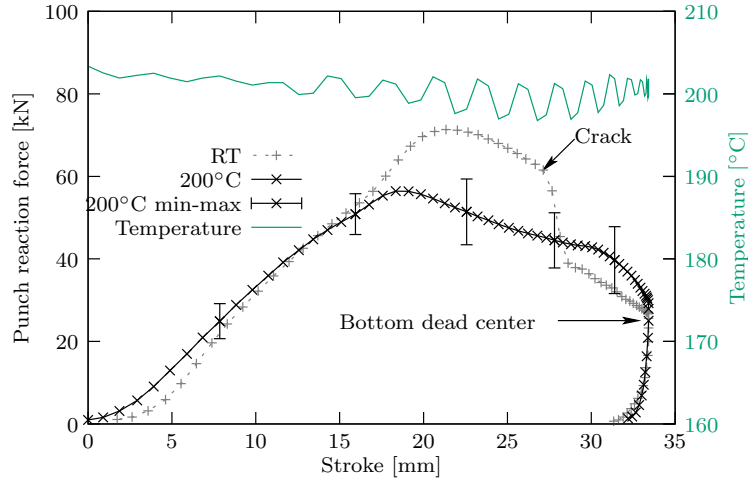
$K$ ,  $\varepsilon_0$ ,  $n$  are material parameters and  $\bar{\varepsilon}$  is the equivalent plastic strain

Temperature [°C]	Strain rate [s <sup>-1</sup> ]	K [MPa]	$\epsilon_0$ [-]	n [-]
20	$2 \times 10^{-4}$	841.7	0.0405	0.1410
	$2 \times 10^{-3}$	869.4	0.0457	0.1590
	$2 \times 10^{-2}$	859.2	0.0468	0.1530
	$2 \times 10^{-1}$	859.4	0.0458	0.1523
200	$2 \times 10^{-4}$	300.3	0.0114	0.0077
	$2 \times 10^{-3}$	431.1	0.1695	0.1497
	$2 \times 10^{-2}$	479.9	0.2378	0.1713
	$2 \times 10^{-1}$	500.5	0.0401	0.0680

**Table 3.** Swift's law parameters at RT and 200 °C identified through tensile tests at different strain rates.

### 3 Results and discussion

The experimental results of the reaction force of the punch at RT and 200 °C during the first step forming are shown in figure 4 as well as the temperature measured by the pyrometer during the forming at 200 °C.



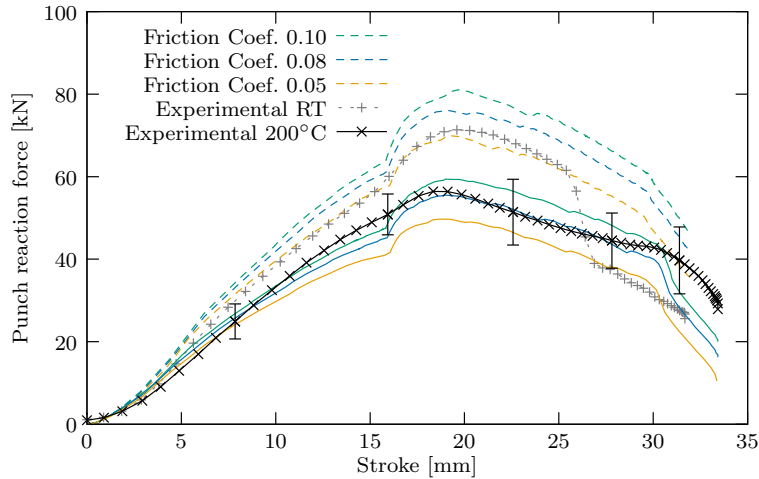
**Fig. 4.** Experimental punch force as a function of punch displacement at RT and 200 °C with a clamping force of 66kN during the first stage of drawing and temperature of the blank during forming measured by pyrometer for the target temperature of 200 °C.

The temperature measured during forming is  $201 \pm 1.67^\circ\text{C}$  and thus confirms that the drawing is indeed performed at the target temperature. Oscillations in the temperature measurement may be due to slight vibrations during the drawing process and the fact that the lubricant generates some bubbles during heating, which may slightly disturb the measurement. The error bar on the force

curve at 200°C represents the variation of the force over the four tests performed, while at 20°C the force is similar for all tests.

The punch force decreases with the temperature as classically observed by several authors [?,?]. At RT, a fracture of the cup during this first stage of drawing appears at about 26mm of the punch displacement whereas the cup is correctly formed at 200°C. The force is not zero when the bottom dead center of the press is attained, force that is gradually cancelled out when the tools start to move up. No wrinkles appear on the cup at the end of this first drawing with the clamping force of 66kN at 200°C (see figure 3-a).

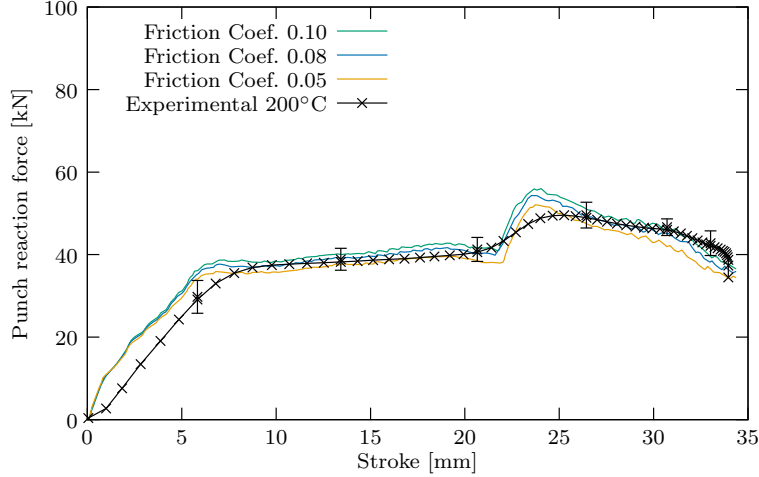
Figure 5 presents the results of numerical simulations of the first drawing stage at RT and 200°C for a friction coefficient of 0.05, 0.08 and 0.1. The small jump in force observed numerically at about 16mm displacement is due to the contact of the blank on the second punch radius. At RT, a coefficient of friction of 0.05 is the closest to the experimental curve until the cup breaks, while at 200°C, a coefficient of friction of 0.08 gives the best result especially after the maximum force. Numerically, the failure of the cup during the first stage is detected with plastic deformations beyond what the material can withstand.



**Fig. 5.** Experimental and numerical punch force as a function of punch displacement for the first step of stamping at RT and 200°C and influence of friction coefficient.

Figure 6 presents the comparison between experimental and numerical results of the punch force in function of the punch displacement during the second drawing stage at 200°C. The punch force is much weaker during this second stage than during the first. The stabilization of punch force at about 6mm of displacement is due to the the blank wrapping around the punch radius. The increase observed at about 23mm is due to the contact with the bottom radius

of the blank obtained during the first drawing stage which comes in contact with the die of the second stage. This evolution of the contact force is more marked numerically. The influence of the friction coefficient is much smaller during this step and the choice of an effective friction coefficient is much more difficult to give.



**Fig. 6.** Experimental and numerical punch force as a function of punch displacement for the second step of stamping at 200°C and influence of friction coefficient.

The friction coefficients found numerically are low compared to the standard value in stamping. Additional simulations are being carried out because it is possible that the clamping force applied is lower than that currently envisaged in the device. This lower clamping force could be explained by the presence of a constant clearance between the die and the blank holder and the total force envisaged of 66kN would not fully apply. Numerical simulations are still in progress to verify this hypothesis both numerically and experimentally. Finally, the chosen behavior law can also influence the numerical results of force-displacement. Thus, a study of the influence of the choice of the constitutive law using a saturating Voce law on the results in force and on the friction coefficients is currently in progress.



## 4 Conclusion

Warm forming in two successive steps of a cylindrical cup part of 7075-T6 alloy was performed at RT and 200°C with a dedicated process. Numerical force displacements were compared with the experimental results and the influence of friction coefficient was tested. It is observed that the cylindrical cup breaks at RT during the first drawing step, whereas at 200°C, it forms correctly in two steps. In addition, the different changes in force direction observed on the force displacement curves at RT and 200°C appear to be much more pronounced numerically. The numerical results obtained are in the same order of magnitude as the experimental results but not for the same friction coefficient in function of temperature. Finally, the various friction coefficients found numerically seem low compared to the standard values. A lower clamping force could allow to find a higher friction coefficient and numerical simulations are still in progress to confirm this hypothesis.

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