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Forming of a cylindrical cup in 7075-T6 under warm temperature conditions

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Abstract. The high mechanical properties of aluminum alloys are very interesting for reducing the weight of parts in the automotive sector. However, a formability issue prevents the use of these alloys at room temperature especially for complex shapes where part failure occurs before full drawing. The use of a warm forming process, which consists of heating the part between 150°C and 250°C for aluminium alloys, allows to increase formability and therefore to perform complex shapes. In this study, the forming of a cylindrical cup in 7075-T6 is carried out at 200°C in two steps by two successive reductions in the diameter of the blank. Numerical simulations of these two forming steps are performed with Abaqus. The influence of friction coefficient is analysed in these two forming steps by comparing the evolutions of punch force.

1. Introduction

High-strength aluminum alloys, including the 7xxx series, have emerged as a promising alternative to conventional steels in the automotive and aerospace sectors due to their lightweight and strong characteristics. However, their poor formability is a major obstacle to their widespread use in the production of complex lightweight components. Increasing the temperature between 150°C and 250°C is a solution to significantly improve the formability of these aluminum alloy sheets. However, most existing studies have focused on one-step production processes and used heating methods that are not compatible with current industry standards [1, 2, 3].

Most of the studies on high temperature forming on the 7075-T6 alloy, consists in forming the sheets by carrying out heat treatments under the tools as for hardening steels [4, 5]. Only a limited number of studies have examined the multi-stage warm forming of sheets to assess the improvement in formability of these aluminum alloys [6, 7]. Additionally, it is crucial to preserve the T6 state of these alloys, which has been found to exhibit optimal performance. In our previous study [8], we showed that warm temperature forming should last between 10s and 20s at 200°C to maintain the T6 state. Prolonged heating can lead to the formation of precipitates which do not maintain the T6 state and then require additional heat treatment costs to recover them.

The aim of this study is to investigate the warm formability of a 7075-T6 alloy using a new process for forming a cylindrical cup in two successive steps by approaching industrial stamping conditions. Numerical simulations of these two-step forming processes at 200°C are performed in Abaqus. The punch force is compared with the experimental results during these two stages by changing the friction coefficient.



2. Material and methods

2.1. Material

Aluminum alloy sheet AA7075-T6 with a thickness of 0.8,mm1 mm is considered in this work. Table 1 presents the chemical composition of this alloy and its mechanical properties in the T6 receiving state is listed 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	$R_{p0.2\%}$ [MPa]	R_m [MPa]	$A\%$
Receiving	500	557	14.6

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

2.2. Warm forming and reforming of a cylindrical cup

The warm forming and redrawing tests are performed successively on a press with two specific tools developed by the CETIM. Figure 1 shows the layout of the two stamping tools.

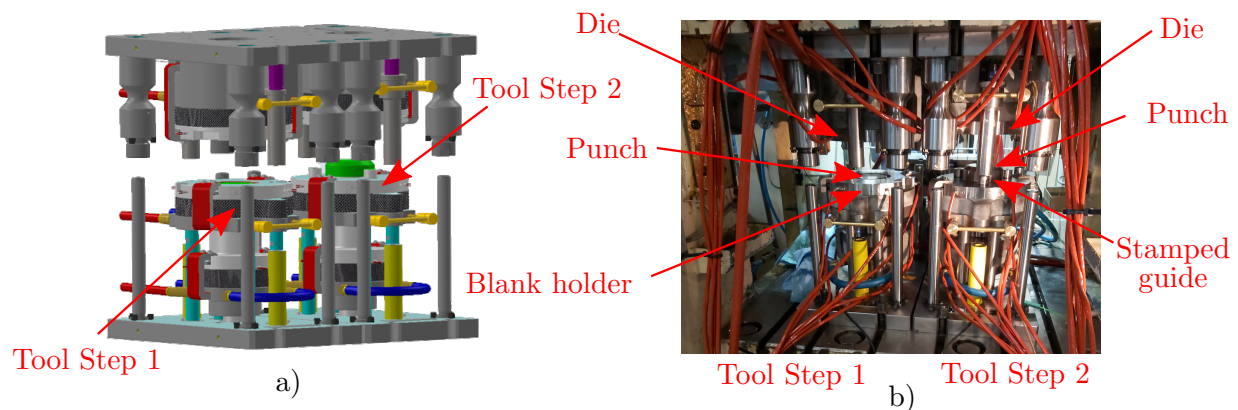


Figure 1. a) Schematic representation of the tools and b) their arrangements in the press.

An initial step of heating of the blank with a circular diameter 157mm is performed by a tool located behind the tools 1 and 2 (not shown in figure 1) in order to reach a temperature of 200°C in 0.45s. The blank is then manually transferred under the first stamping tools. Then, the cup is again manually transferred to the second stamping operation. The dimensions of the tools of the first and second steps are shown in figures 2-a and 2-b, respectively. Due to the proximity of the tools, the transfer time is reduced and the two forming steps are assumed to be performed under isothermal conditions. The total time (heating, first and second forming) is less than 20s to guarantee the mechanical characteristics of the T6 state.

Both stamping tools are heated to the target temperature using a heating cartridges. The tools temperature is controlled by K-type thermocouples located in each element that composes the tools. In addition, the temperature of the blank is monitored during the two stamping steps

with a pyrometer located at a constant distance of 20mm from the blank. A clamping force of 41kN is applied on the first stamping step to the blank holder and no clamping force is applied on the second forming step. The reaction forces during both drawing processes are measured by a force sensor located under the punch.

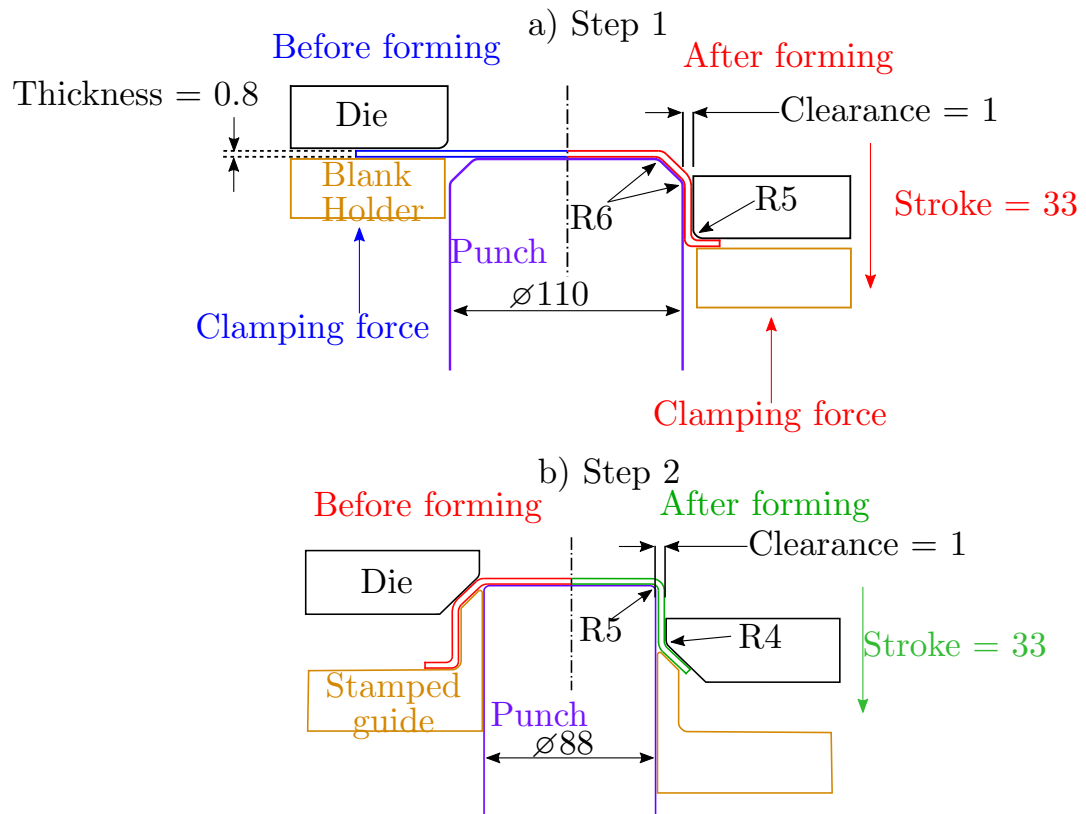


Figure 2. Dimensions and movements of tools (in mm) during a) the first and b) the second step of forming.

Forming tests are performed at RT and 200°C with a JELT 5411 lubricant. At RT, forming is impossible because the sheet breaks under the tools during the first step, so the results at RT are not presented here. At 200°C, four tests are performed to check the reproducibility but the average results is used as a representative. Figure 3 presents the theoretical dimensions of the part after the two stamping operations and pictures of the parts obtained at the end of these two operations at 200°C.

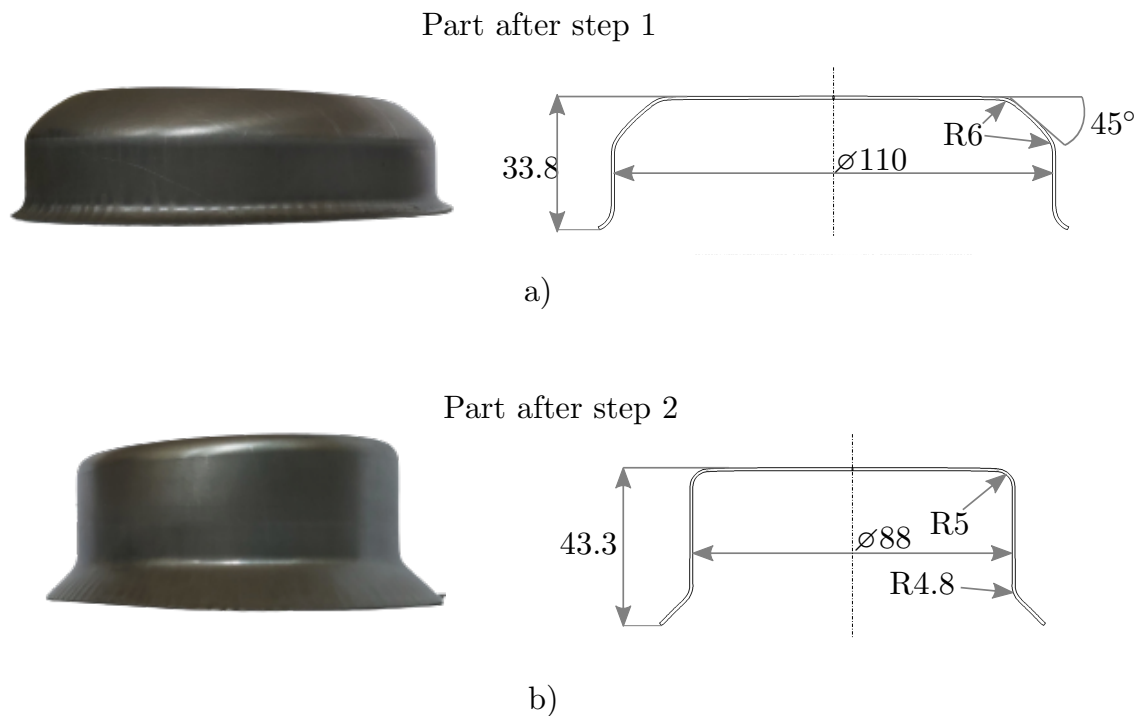


Figure 3. a) Dimensions (in mm) of the part after step 1 a) and b) after step 2.

2.3. Numerical simulations of the warm forming process

The two forming processes are simulated with Abaqus/Standard assuming isothermal conditions. A 2D axisymmetric model is used with tools modeled as rigid surfaces. A mesh size (2D quadratic quadrilateral elements CAX4) 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. A strain rate dependent elastic-plastic behavior of the blank is simulated with a Swift law:

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

K , ε_0 , n are material parameters and $\bar{\varepsilon}$ is the equivalent plastic strain.

From results presented in [8], these material parameters are identified by tensile tests at RT and 200°C for strain rates of 2×10^{-4} , 2×10^{-3} , 2×10^{-2} and 0.2s^{-1} .

3. Results and discussion

The numerical and experimental results of the reaction force of the punch of the first stamping stage are presented in figure 4 with different friction coefficient as well as the temperature of the blank measured by the pyrometer during the stamping at 200°C. The blank temperature during this first step is 194.8 ± 1.47 which is acceptable compared to the target temperature of 200°C. The error bar on the force curve at 200°C gives the variation in force over the four tests performed. The small force jump obtained numerically at about 16mm displacement is due to the contact of the blank on the second punch radius. At the end of the forming, the force is not zero when the press reaches bottom dead center but it is gradually cancelled when the press is raised. Only the forming sequence is analyzed here and thus the force after the bottom dead center is not simulated.

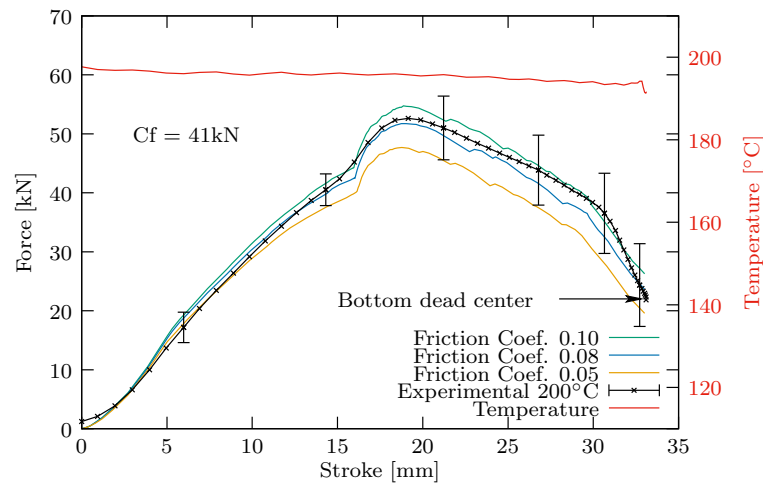


Figure 4. Experimental and numerical punch force as a function of punch displacement at 200°C and influence of friction coefficient and temperature of the blank during forming measured by pyrometer for the target temperature of 200°C.

Different friction coefficients between 0.05 and 0.1 are tested. A friction coefficient of 0.08 seems the closest to the experimental results for this first stamping step but due to the variation of the experimental reaction force a coefficient of friction of 0.10 can also be acceptable.

The numerical and experimental results of the punch force in function of the die stroke during the second step are given in figure 5. The temperature of the blank measured by the pyrometer during the stamping at 200°C is also shown in this figure.

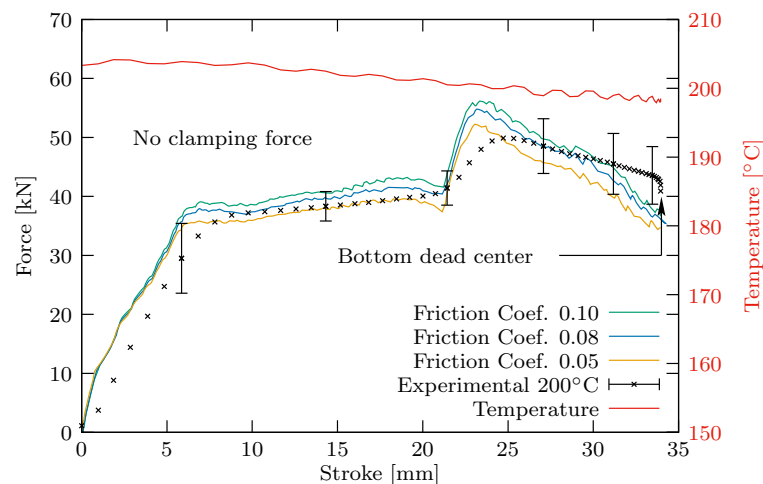


Figure 5. Experimental and numerical punch force as a function of punch displacement for the second step of stamping at RT and 200°C and influence of friction coefficient.

The blank temperature during this second step is 200.2 ± 2.16 indicating that the forming is performed at the desired temperature. The slight variations in the temperature measurement may be due to the vibrations of the press and the lubricant which generate slight bubbles that may disturb the measurement. The stabilization of punch force at about 6mm of displacement

is due to the the wrapping of the blank around the punch radius. The increase in force observed at about 23mm is due to the contact with the lower radius of the blank obtained in the first drawing step that comes into contact with the die during the second step.

A friction coefficient of 0.08 also seems the closest to the experimental results but due to the variation of experimental effort a coefficient of 0.05 or 0.10 might also be acceptable. It appears that determining a friction coefficient on the figures 4 and 5 is difficult due to the experimental variation of the reaction force of the punch.

It is also important to note the presence of wrinkles in the radius die after first step stamping as shown in figure 3-a.

4. Conclusion

Warm forming in two successive forming steps of a cylindrical cup part of 7075-T6 alloy were performed at RT and 200°C with a dedicated process. The punch force in function of die stroke obtained with Abaqus were compared with the experimental results and the influence of friction coefficient was tested. It was observed that a friction coefficient of 0.08 was closest to the experimental results of the first and second stamping steps but the other friction coefficients of 0.05 and 0.10 also gave results in the same order of magnitude as the experimental results which can suggest that the friction coefficient probably evolves during the two forming phases.

Acknowledgments

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