

Experimental and Numerical Investigation into the Effect of Strain Rate Changes on Failure of AA7075 at the Elevated Temperatures

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Abstract. This paper represents the temperature-dependent study which is performed on AA7075. This was performed through the application of deep drawing experiments at high temperature of 250, 300, 350, 400, 450 and 500°C and different forming speeds. FEM study is applied at room and 300 and 400 °C temperature with different strain rates. Softening model is used to model the thermo-mechanical constitutive equation. Forming limit curve models (based on M-K model) were used in the analysis of simulation results in order to predict the onset of necking. Simulation results were compared with experimental data to evaluate the accuracy of onset of necking simulation and failure location prediction

1. Introduction

The 7XXX aluminum series (Al-Zn-Mg-Cu alloy system) are very attractive materials in automobile and aerospace industries [1]. But the notable drawback is their formability which is significantly lower than traditional steel alloys at room temperature. Nevertheless, the formability of them increases significantly with increasing forming temperature up to the recrystallization temperature [2, 3]. In this study, a direct hot forming process has been examined, where blanks are heated up in high temperature die, and the effects of strain rate at seven different temperatures from 25 to 500°C, which cover both warm and hot temperatures, have been investigated. Forming speed is varied from 5 to 200 mm/min in order to evaluate the effect of strain rate on failure mechanism. FEM study has been performed where M-K based FLD failure criteria has been considered in order to predict the failure. In order to model the constitutive behavior of AA7075 at higher temperature and calculating forming limit curve, the softening model has been used.

2. Experimental procedure

Specimens of AA7075-T6 with same dimensions were considered for different strain rates and temperatures. Samples are formed in die which consists of six main parts: 1. Punch, 2. Blank Holder, 3. Heat controller equipment, 4. Heat isolation system, 5. Upper die, 6. Heat condenser system. Forming system is presented in Fig.1. Because onset of necking is investigated in this study, the



forming test continued to the point that no drastic change in trend of required force for forming process was observed. Samples are circular blanks with 140 mm in diameter and 3.2 mm in thickness.

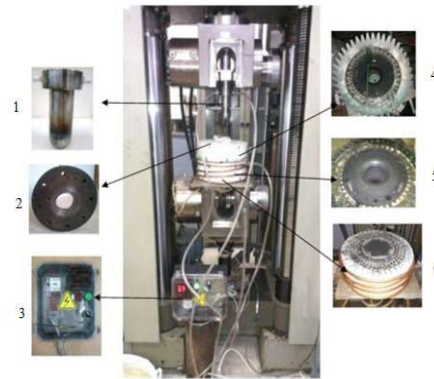


Fig.1. Hot forming die and its main parts.

3. Numerical Model

In order to model 3D finite element simulation, after modeling of all geometries in Fig. 1 and taking advantage of having symmetric die, three sets of uniaxial tensile tension tests have been accomplished. Anisotropic coefficients of this material along different direction proportional to rolling direction are shown in Table.1. To investigate the mesh sensitivity, some simulations based on the different size of elements vs. punch load were done and element size 0.0015 mm shows a good correlation with experimental data, thereby 0.0015 (m) size of element considered as a suitable element size for blank in simulation.

Table 1. Mechanical property of AA7075

Temperature	R ₀	R ₉₀	R ₄₅	σ ₀ - MPa
25	0.45	1.72	1.24	503
300	2.3	4.2	4.7	72
400	2.9	5.11	5.73	66.3

In order to model the softening phenomenon, a modified equation has been considered. General form of this equation is shown below,

$$\sigma_f(T, \dot{\epsilon}) = C(T, \dot{\epsilon}) \epsilon^{n(T, \dot{\epsilon})} \exp(\lambda \log(T) - T_h \epsilon) \quad (1)$$

Where λ is the fitting parameter and it is taken 10-8 for Aluminum alloys. T_h is defined as the absolute temperature $T_a(K)$ divided by absolute melting temperature $T_m^a(K)$. Parameters C and n are improved as below:

$$C(T, \dot{\epsilon}) = C_0 + a_1 [1 - \exp(a_2 \frac{T-273}{T_m})] + a_3 \log(1 + \frac{\dot{\epsilon}}{\epsilon_{ref}}), n(T, \dot{\epsilon}) = n_0 + b_1 [1 - \exp(b_2 \frac{T-273}{T_m})] + b_3 \log(1 + \frac{\dot{\epsilon}}{\epsilon_{ref}}) \quad (2)$$

Above two equations include constants where can be calculated using the least square approximation. Calculated parameters are shown in table 2. [4]

Table 2. Fitting parameters for Softening model, T>300

T _m	C ₀	n ₀	a ₁	a ₂	a ₃	b ₁	b ₂	b ₃
920 K	120.2 MPa	0.09	32.1 MPa	31	0.264	0.121	0.01	-0.0248

4. Results and Discussions

Fig.2 demonstrates the effect of temperature on stress-strain curve and formability at elevated temperature. As it can be seen, the alloy softens by increasing temperature, while showing the hardening behavior in higher strain rate magnitudes. As it's been argued, DRV is the main cause of softening behavior of this alloy at higher temperature below 0.4 s⁻¹ strain rates. [5]

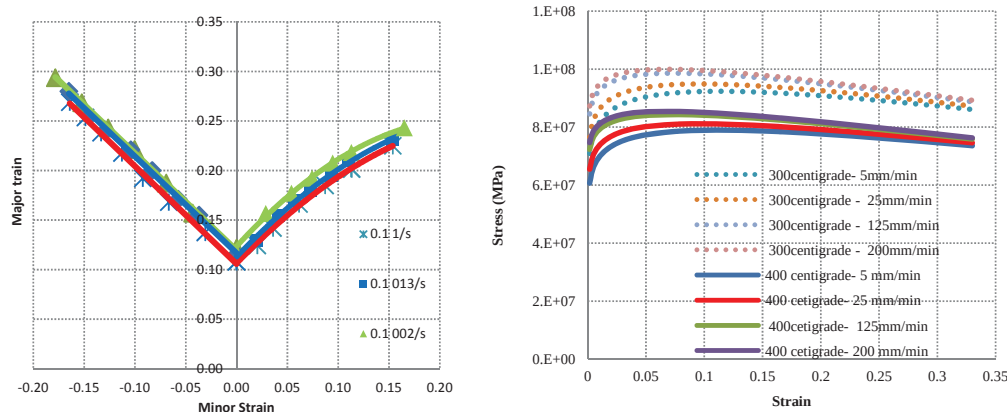


Fig. 2. Numerical assumption of Mechanical behavior of AA7075 at different strain rates

Fig.3 demonstrates the effect of temperature and strain rate on the maximum height of samples. As it can be seen, the maximum height increases markedly with an increase in temperature. Moreover, this amount decreases while the strain rate increases. In addition, the crack type changes from the brittle to ductile while temperature is increasing. Meanwhile, the failure position relocates from the top of the sample, near the punch radius, at room temperature to around die radius at higher temperatures which is correlated with the past studies [5, 6, and 7]. The effect of temperature on required force is considerable. Fig. 4 shows the force changes with temperature. Heating to higher temperatures causes significant reduction in amount of ultimate stress, and subsequently according to the Fig. 4-A, the required force will decrease in forming process. Moreover, increasing strain rate causes the slight increase in stress throughout the hardening phenomenon of material. As a result, the required force

increases with the strain rate increase. Fig. 4-B illustrates the effect of temperature and strain rate variation on maximum height of samples.

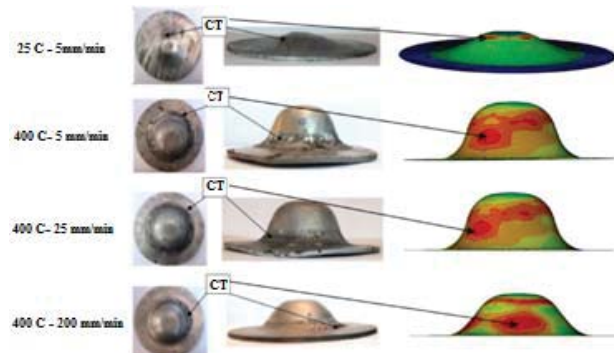


Fig.3. Samples through different strain rates. (CT: Crack Tip)

As it can be seen, increasing in temperature to below 300°C, results in a significant increase in formability of AA7075. Ironically, this trend changes after temperatures over 300°C, causing reduction to just a few millimeters at 450°C, and drops off markedly in 500°C. The main reason of this trend can be the increasing in friction between die and blank throughout the changes of blank state from solid to semisolid condition, variation in surface topology, removal of oxide layers and wear of the tool [5]. In addition, the maximum height increases as well as the reduction of strain rate. The main reason of increase in height between room temperature and elevated temperatures is the softening of sheet under this condition. As shown, the height of samples decreases, while the strain rates rise steadily and much higher reduction is shown at higher temperatures throughout the strain rate hardening of sheet metals.

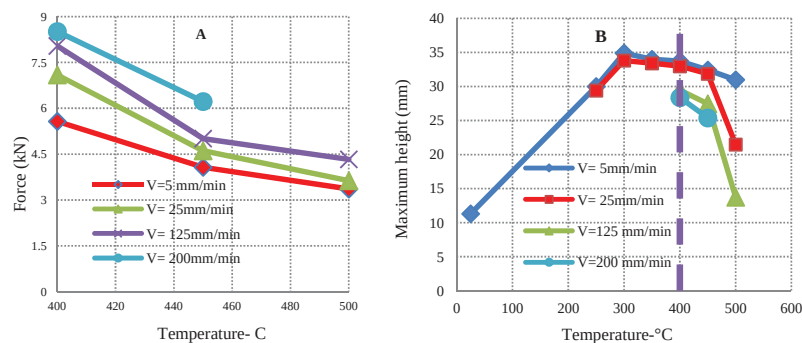


Fig.4. combined effects of temperature and forming velocity on A: required force, B: maximum height of cups

5. References

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