EXPERIMENTAL DETERMINATION OF PROCESS PARAMETERS FOR SUPERPLASTIC FORMING FROM AA7075 ALUMINUM ALLOY

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Abstract

In this study, experimental processes are presented to determine the process parameters for superplastic forming (SPF) AA7075 aluminum alloy. The thermomechanical method is performed to prepare the fine stable grain microstructure for AA7075 alloy. Subsequently, the tensile tests and the free bulging tests were carried out under different conditions for the alloy sheet with a thickness of 1.2 mm. The results determine the process parameter ranges of the SPF including deformation temperature of 500-530°C, forming pressure of 0.6-0.8MPa, and forming time of 20-40 minutes. The strain rate sensitivity is also calculated with values in the range of 0.3-0.6. The obtained results are an important basis for designing the technological process for the SPF of the studied alloy.

Keywords: **Superplastic Forming, Free Bulging Test, Tensile Test, Strain Rate Sensitivity, AA7075 Alloy**

Introduction

Improving the deformability of high-strength materials has always been a research problem with many published works. (Aoura *et al*., 2004; Smolej, 2009; Babu *et al*., 2014). This trend is growing more and more because of the spacious application of these materials in key industries such as aerospace, aircraft, automobile, shipbuilding One of the alloys mentioned in many studies are high strength aluminum alloys, which has outstanding properties such as high strength, lightweight and good corrosion resistance. (Holt, 1970; Dorward *et al*., 1988; Dieguez *et al*., 2012). However, the deformability of materials depends not only on their characteristic but also on their states. The research results show that tensile tests under the specified strain rate and temperature conditions can obtain large strain levels up to several hundred, even thousands of times, and small yield stress values of the material. That is the SPF state of the material. (Giuliano, 2011; Babu *et al*., 2014; Eswara Prasad *et al*., 2014). The SPF occurs only under limited conditions: low strain rate from 10^{-4} to 10^{-2} s^{-1}, high forming temperature from 0.5 to 0.9 T_{nc} (T_{nc} is the melting point in degrees Kelvin), and average grain size below 15µm of the microstructure. (Horita *et al*., 2001; Giuliano *et al*., 2008). Thus, it can be seen that the preparation of the fine stable grain microstructure and the determination of process parameters are the decisive conditions for the appearance of the SPF state.

Many studies have provided experimental methods to determine the parameter ranges of

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superplastic forming for certain alloys. In general, these methods include tensile tests and free bulging tests. (Kim *et al*., 2002; Kumaresan *et al*., 2014; Laxman Bhatta *et al*., 2020). Test specimens are machined from structurally prepared alloy sheets. Experimental results are evaluated through the degree of deformation of the tensile specimens or the products of the free bulging process. The degree of deformation of the specimens will vary with different process parameters and there is an optimal value for each kind of alloy. The process parameters determined by tensile tests include deformation temperature, initial strain rate, and forming time. (Ma *et al*., 2009). The free bulging tests allow further determination of the forming pressure, which cannot be determined by the tensile tests. (Nieh *et al*., 2005). This study proposes to use a combination of both methods to determine the range of process parameters including deformation temperature, forming pressure, and forming time. The sheet specimens are used for both tensile and free bulging tests. It is found that the stress state of the deformed specimens in the tests is similar to the stress state in the SPF for the sheet alloy. This allows improving the reliability of experimental results.

In addition, the superplasticity of the alloy is evaluated by the value of the strain rate sensitivity, which has a value between 0.3 and 0.8. (Horita *et al*., 2001; Picu *et al*., 2005 Giuliano *et al*., 2008). A larger value of the strain rate sensitivity represents a better SPF ability of the alloys. In many studies, the strain rate sensitivity was determined to confirm the SPF ability of the alloy. For the case of the sheet metal SPF process, the free bulging method is suitable for determining the strain rate sensitivity. (Starke *et al*., 1996; Sahraoui *et al*., 2003).

In this work, experimental processes are presented to determine the process parameters for the SPF of AA7075 aluminum alloy. The thermomechanical method is performed to prepare the fine stable grain microstructure for AA7075 alloy. Subsequently, the tensile tests and free bulging tests were carried out under different conditions for the alloy sheet. The results determine the process parameter ranges of the SPF including deformation temperature, forming pressure, and forming time. The strain rate sensitivity is also calculated to confirm the accuracy of the studied results. The obtained results are an important basis for designing the technological process for the SPF of the studied alloy.

Materials and Methods

The AA 7075 aluminum alloy was used in this study. The chemical composition of the analyzed AA7075 alloy (in wt%) of 5.35 Zn, 2.34 Mg, 1.32 Cu, 0.3 Fe, 0.22 Cr, 0.04 Ti, 0.0027 Zr, 0.024 Mn with the balance being aluminum. The initial specimens with 5 mm thickness were used for the experiments. The thermomechanical method is performed to prepare the fine stable grain microstructure. (Valiev *et al*., 1998) The thermomechanical process for AA7075 alloy is shown in Table 1. (Vasin *et al*., 1998; Yang *et al*., 2002; Kumaresan *et al*., 2014; Wang *et al*., 2018).

Table 1. Thermomechanical process of AA7075 alloy

Step	Temperature (°C)	Time (h)	Conditions
Solution treatment	500	1.0	Furnace cooling to 380°C
Overaging	380	2.0	Furnace cooling to 190°C
Warm rolling	180		Reduction of thickness
Recrystallization	500	0.5	Water quenched
Aging	180	0.5	Water quenched

The AA7075 aluminum alloy sheet after the thermomechanical process has a thickness of 1.2 mm. with an average grain size of 13 µm., manufactured according to ISO 6892-1:2016 standard for tensile tests in superplastic deformation conditions. The tensile specimens have some basic dimensional parameters such as a thickness of 1.2 mm. and an initial length of 10 mm. The tensile tests are conducted at temperatures from 470 to 550°C and strain rate from 10^{-4} to 10^{-3} s^{-1} (Table 2). The Devotrans DVT FU/RDNN 50kN-CKS testing machine and the heating resistance furnace are experimental equipment. The range of values of the reasonable deformation temperature is determined from the results of the tensile tests.

The free bulging tests are carried out after the tensile tests when the deformation temperature range has been determined. The test specimens have a diameter of 50 mm. and a thickness of 1.2 mm. The forming pressure ranges from 0.4 to 1.2 MPa. The experimental equipment system is shown in Figure 1. The argon pressure system includes high pressure Argon gas tank, gas pressure control valve assembly, gas pressure duct. The furnace system includes high temperature resistance furnace and furnace temperature display system. The system for measuring displacement of deformation specimen includes stroke sensor, display and data collector connected to the computer, displacement test data collection software. The strain rate sensitivity is calculated based on the results of the free bulging tests. Based on the experimental results, it is possible to determine the reasonable value of forming pressure and forming time. A detailed diagram of the experimental steps is shown in Figure 2.

Results and Discussion

The specimens after the tensile tests are shown in Figure 3. The elongations of the tensile specimens are determined based on the stress-strain curve and measured directly on the deformed specimens to achieve high accuracy. Figure 4 and Figure 5 show the relationship between elongation and varying initial strain rates at different temperatures of AA7075 aluminum alloys.

Figure 3. The specimens after tensile tests

Table 2. The process paramaters of the tensile tests

Specimens	Strain rate (s^{-1})	Deformation temperature (°C)
1	5.10^{-4}	470
2	10^{-3}	470
3	$1.5.10^{-3}$	470
4	5.10^{-4}	500
5	10^{-3}	500
6	$1.5.10^{-3}$	500
7	5.10^{-4}	530
8	10^{-3}	530
9	$1.5.10^{-3}$	530
10	5.10^{-4}	550
11	10^{-3}	550
12	$1.5.10^{-3}$	550

Figure 1. The equipment system for free bulging tests

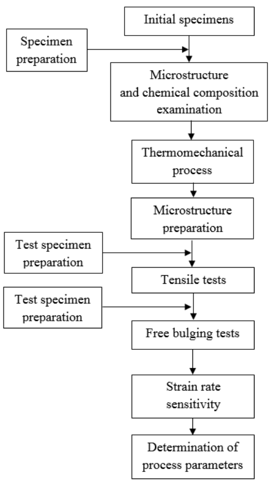


Figure 2. The detailed diagram of the experimental steps

Based on tensile test results, it was found that the cross-section of the tensile specimens decreased evenly along the length of the specimens, which caused the appearance of the neck to be delayed. Therefore, the specimens can obtain a large degree of deformation compared to the normal tests. (Horita *et al*., 2001; Giuliano *et al*., 2008).

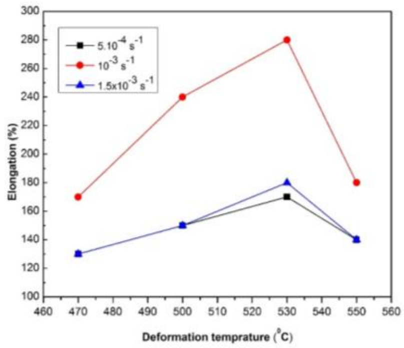


Figure 4. The relationship between superplastic elongation and temperatures with different strain rates

In Figure 4, as the temperature increases from 470 to 530°C, the elongation of the tensile specimens increases (the maximum elongation of 280%). However, if the temperature continues to increase to 550°C, the elongation tends to decrease (the minimum elongation of 140%). This phenomenon is explained as follows: As the temperature increase, the viscous forces in the grain boundary gradually decrease and the grain boundary becomes more and more unstable. The grain boundaries begin to slide with relative ease, causing the tensile specimens to show a better elongation. However, if the temperature continues to increase too high, grain boundaries softened excessively and the binding capacity of grain boundaries is significantly reduced, resulting in less elongation. Also at high temperature is the cause of the growth of the crystalline grains leading to a decrease in the grain border area, the reduction of the sliding surface area, making the alloy less deformable. (Giuliano, 2011; Babu *et al*., 2014). Thus, it is found that the temperature range from 500 to 530°C shows the good SPF ability for AA7075 aluminum alloy with elongation reaching 280%.

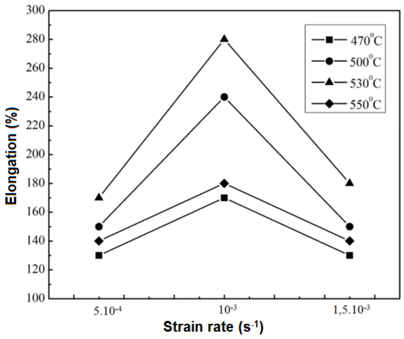


Figure 5. The relationship between superplastic elongation and strain rates with different temperatures

In Figure 5, when the strain rate increases from 5.10^{-4} to 10^{-3} s^{-1}, the elongation of the tensile specimen increases, but when the strain rate continues to increase to $1.5.10^{-3}$ s^{-1}, the elongation of the tensile specimen decreases, which can be explained by the strain rate is large, there is not enough time for the diffusion process to occur. Therefore, there are no favorable planes for sliding, so the stress increases, the elongation of the tensile specimens decreases. (Giuliano *et al*., 2008; Giuliano, 2011; Babu *et al*., 2014). In the range of studied parameters, the elongation is greatest at the deformation temperature of 530°C and the initial strain rate of 10^{-3} s^{-1}.

The specimen shape and experimental results after the free bulging tests with different deformation temperatures and forming pressures are presented in Figure 6 and Table 3. The results obtained include the maximum height of the specimens and the forming time, at which time the deformed specimens were destroyed.

Based on the data in Table 3, it can be seen that the experiments performed at temperatures of 500°C and 530°C together with forming pressures of 0.6MPa and 0.8MPa show good forming ability. The forming time is valid between 20 and 40 minutes. The specimens Nº1 and Nº6 are deformed at a forming pressure of 0.4MPa for poor deformability. This can be explained because the strain rate is too small, it will increase the material deformation time, the grain size will be enlarged due to the recrystallization process, thus increasing the yield stress. Besides, when the strain rate is too small, the strain rate sensitivity will be reduced, leading to a decrease in the deformation degree of the studied alloy. (Giuliano *et al*., 2008; Babu *et al*., 2014). The specimens Nº4, Nº5, Nº9, and Nº10 were deformed but destroyed with small height in a short time. This phenomenon can be explained by the large forming pressure, so the high strain rate leads to the reduction of the superplastic deformation ability of the alloy. From the above analysis, the next experimental processes were carried out to determine the strain rate sensitivity for SPF at 500°C and 530°C with forming pressure of 0.6MPa and 0.8MPa.

Table 3. The results of the free bulging tests

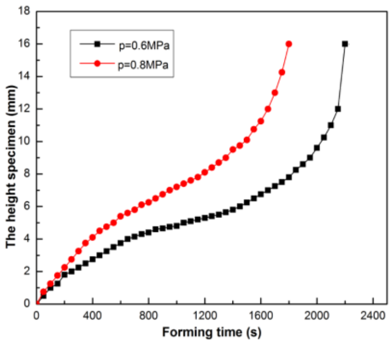
Symbol	Deformation temperature (°C)	Forming pressure (MPa)	Height of specimens (mm)	Forming time (s)
Nº1	500	0.4	4	-
N_o2	500	0.6	16	2200
Nº3	500	0.8	16	1800
Nº4	500	1.0	8	1100
Nº5	530	1.2	8	960
Nº6	530	0.4	4	-
Nº7	530	0.6	16	1800
Nº8	530	0.8	16	1400
Nº9	530	1.0	8	900
Nº10	530	1.2	8	850

The graphs of the hemispherical convex peak height of the deformed specimens overtime at deformation temperatures of 500°C and 530°C and forming pressures of 0.6 MPa and 0.8 MPa are determined and shown in Figure 7. The strain rate sensitivity for SPF is shown in Figure 8 and Figure 9.

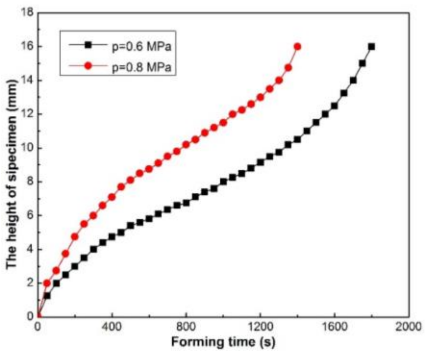
Figure 6. The specimens after the free bulging tests

Found that the first part of the curves in Figure 7 is depicted by a sudden increase in the height of the specimens and where the slope of the curve is larger. The increase in the inclination of this curve corresponds to the increased strain rate values. In the second part of the curve, the increase in the height of the specimens over time is the average, so that the inclination of the curve is smaller and stable, at the end of the curve increases again, so the strain rate also increases. As the pressure increases, the deformation ability of the alloy increases and thus forming time decreases.

According to Figure 8, when the forming pressure increases (from 0.6 MPa. to 0.8 MPa.), the strain rate sensitivity curve shifts to the part with a higher strain rate. As the deformation temperature increases, with the same value of forming pressure, the strain rate sensitivity curve also shifts to the part with a higher strain rate. The strain rate sensitivity has a larger value. In this study, the strain rate sensitivity for the SPF process in the free bulging tests from constant pressure and temperature was calculated to have a value in the range from 0.3 to 0.6. The strain rate has a value between 5.10^{-4} and $1.5.10^{-3}$ s^{-1}. This result confirms the SPF ability of the studied alloy.



(a)



(b)

Figure 7. The height of the specimens after the free bulging tests at forming pressure of 0.6Mpa and 0.8MPa: (A) 500°C, (B) 530°C

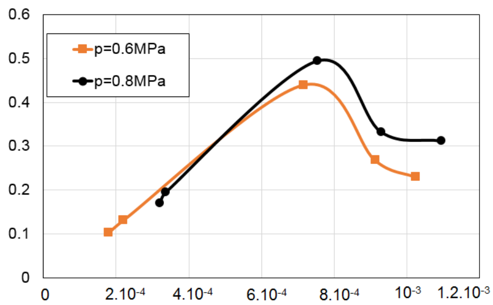


Figure 8. The strain rate sensitivity at forming pressure of 0.6 Mpa. and 0.8 Mpa. at 500°C

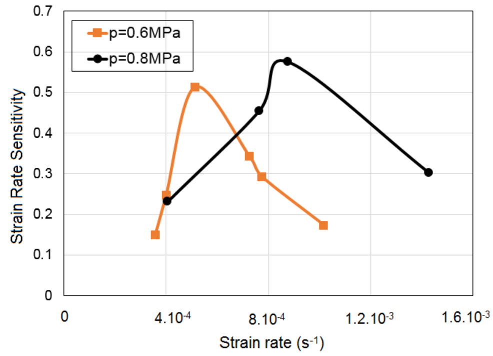


Figure 9. The strain rate sensitivity at forming pressure of 0.6 Mpa. and 0.8 Mpa. at 530°C

Conclusion

The high- strength aluminum alloy AA7075 is prepared to fine stable grain microstructure by thermomechanical method with an average grain size of 13mm. The tensile tests and free bulging tests with specimens of 1.2 mm. thickness were carried out at different deformation temperatures, initial strain rate, forming pressure. Through evaluation and analysis of the obtained experimental results, a range of process parameters has been determined for SPF of AA7075 alloy, including deformation temperature from 500 to 530°C, forming pressure from 0.6 to 0.8 MPa, forming time from 20 to 40 minutes. The strain rate sensitivity was determined to be greater than 0.3, confirming the correctness of the research results. The problem of optimizing the SPF ability of AA7075 aluminum alloy to find a specific set of process parameters will be studied shortly.

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