Extrusion tests of 7075 aluminium alloy at high solid fraction

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ABSTRACT: Thixoforging is a type of semi-solid metal processing at high solid fraction (0.5<fs<1). 7075 aluminium alloy has been used as a feedstock for thixoforging in order to investigate thixoformability of a high performance aluminium alloy at high solid fraction. Higher solid fraction of 7075 alloy is less sensitive to a drop in temperature, avoids metal splash at high speed, allows laminar flow at high speed. Hot tool is used to slow down the solidification rate of the high solid fraction metal by decreasing thermal exchanges. To determine the best parameters to achieve maximum mechanical properties in thixoforging of 7075 aluminum alloy, we need to consider the impact of some parameters such as tool temperature, shear rate. For this, we use extrusion tests with constant speed [1] where these parameters are known. The result of this study is that each parameter has its level of impact on the thixoforging: the temperature of the tool and the deformation rate shouldn't be high to avoid cracks. Thermal exchanges between the material flow and the tool have to be reduced to avoid high solidification rate [2].
Keywords: Extrusion, thixoforging, thermal exchange, hot tool, 7075, aluminium.

1 INTRODUCTION

1.1 Thixoforging process

Thixoforming process is a semisolid metal processing route (SSM), which involves forming of alloys in the semisolid state to near net shaped products [1]. For this to be possible, the microstructure of the semisolid must be globular solid grains surrounded by a liquid matrix. It will then behave thixotropically: if it is sheared, the viscosity falls and it flows like a liquid, but if allowed to stand it thickens again. Thixoforging is a thixoforming process at high solid fraction. With such a process, parts are shaped in one step and their mechanical properties are near those from forging process with complex geometry possibilities [2].

1.2 7075 aluminium alloy

The required microstructure can be obtained by several routes. In the present work, alloy 7075 (Al – (5.1-6.1)Zn – (2.1-2.9)Mg – (1.2-2.0)Cu – 0.5Fe – 0.4Si – (0.18-0.28)Cr -0.3Mn – 0.2Ti, all composition in wt-% unless otherwise stated [3]) is studied. The 7075 aluminium alloy is a wrought alloy that shows, by DSC analysis, less sensitivity to temperature variation at high solid fraction (Fig. 1); this is why we are going to focus here on solid state route to obtain small solid globular grains surrounded by a liquid matrix. This solid route is the recrystallisation and partial melting (RAP) route [4].

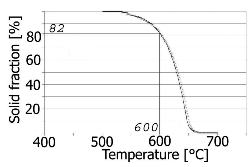

Fig. 1: Solid fraction vs. temperature obtained by DSC analysis at a heating rate of 15°C/min

1.3 Forming parameters

In the thixoforging process, some critical parameters have to be optimised to reduce the solidification rate of the semisolid material flow and keep it laminar. This will lead to high quality parts.

2 EXPERIMENTAL INVESTIGATIONS

The goal of these experiments is to improve forming parameters. Four main parameters are studied: 1. semisolid material temperature, 2. tool lubricant coating, 3. material flow speed, 4. tool temperature.
To show easily the influence of each parameter on the process, the material flow is at constant speed with 15% decreasing speed for last 2mm.

2.1 Equipment

High flow material speed is reached with high variation of sections. One way to do this kind of experiment is to use extrusion test: the material flows through a funnel with a smaller section.

We use an X38CrMoV5 tool steel with an extrusion ratio of 12/40 = 0,3 to perform extrusion experiments. Because of the regulation mode of hydraulic presses, the forming speed decreases at the end of the piston stroke (Fig. 2b). To avoid this decreasing, we are going to form the part before the end of the piston stroke.

For this, the tool is used with stops and gas actuators (Fig. 2a). The tool axis from the slide of the press goes down to extrude the slug. During the extrusion, gas actuators don't move because the tool axis pressure is lower than the actuators pressure. The extrusion of the slug finishes when the superior stop pushes on the inferior one: no more load is on the semisolid material. The load is now on gas actuators. The tool axis pressure has to increase to exceed gas actuators pressure in the goal to reach its final position. So the extrusion test is done at constant speed before the decreasing speed of the punch in the actuators (Fig. 2b). As shown on figure 2b, extrusion curve represents the displacement of the tool relative to the slug (tool axis curve minus actuators curve). We notice that only the last 2mm of the extrusion is extruded at lower speed (15% slower).

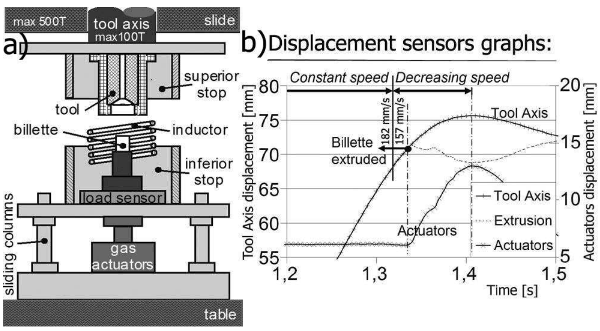

Fig. 2: a) Extrusion test device mounted in the press; b) extrusion tests at constant speed

To obtain a high solid fraction, with homogeneous globular recrystallised grains, a five steps heating cycle of 2,5 minutes is used. The slug is heated directly on the ceramic support to decrease thermal losses before extrusion. At the end of the heating cycle, the tool axis goes down through the inductor and extrudes the slug.

2.2 Extrusion tests

Two speeds are used for these experiments: the slow one (41mm/s) and the fast one (182mm/s). With such tool geometry and such speeds, the deformation rates are: $d\varepsilon/dt = v/L*\ln(S1/S2) = 182/7*\ln(3,33) = 31,3s^{-1}$ for the fast speed, $7,1s^{-1}$ for the slow one, where ε is the deformation, v is the tool axis speed in mm/s, L is the converging length in mm, S1/S2 is the section ratio of the extrusion.

2.2.a Semisolid material temperatures

We have to determine the semisolid material temperature that gives laminar flow without ejection of liquid under a high deformation rate.

For this, we realize partial filling to avoid compression of the material during filling. The extrusion tool is at room temperature, high speed is used because we would like to determine the highest temperature before liquid ejection and the lowest one without material waves (stick-slip phenomena due to friction and solidification). With such kind of material temperature, the flow should stay laminar if the speed is low.

2.2.b Tool lubricant coating

Applying lubricant on the tool decreases the load of the forming and helps to protect against wear.

Two lubricants are tested: Ceraspray, containing ceramic powder, decreases thermal exchanges between the material and the tool; Boron Nitride, containing hexagonal Boron Nitride and binding agents, highly decreases the load of the forming.

2.2.c Material flow speeds

The material flow speed influences thermal exchanges and rheology of the semisolid material because of the thixotropic behaviour.

Two speeds are used to observe thermal exchanges between the semisolid material and the tool.

2.2.d Tool temperatures

To have a variation of thermal exchanges between tool and semisolid material, two speeds and different tool temperatures are tested. Quality of the part is observed.

3 RESULTS AND DISCUSSION

During extrusion tests at constant speed, the slug, of 30 mm diameter for 45 mm length, is first compressed to reach a diameter of 40 mm and then extruded in a 12 mm diameter. At the end of the

compression phase, the top of the slug is cooled down because of the full contact with the cold tool. At the beginning of the funnel, the solidified skin forms a stopper that the flow will push through the funnel. This creates compression-traction efforts.
The influence of each parameter on the external quality and the microstructure of the part is described below.

3.1 Semisolid material temperatures

By using induction heating, it is quite difficult to reach homogenous temperature in the slug. The temperature that we talk about is measured in the centre of the slug. By using five steps heating cycle, we manage to keep a lower temperature difference than 5°C between the centre and the side of the slug. Different convection rates between the bottom, in contact with ceramic stuck, and the top of the slug, in air, imply a temperature difference of 20°C. Different temperatures were tested (Table 1) at high speed.

Table 1. Extrusion tests done with different semisolid material temperatures

Semisolid material temperatures					
580°C	→	600°C	→	→	610°C
Test 07	Test 13	Test 14	Test 11	Test 12	Test 08

The goal of this experiment is to find the range of temperatures where the flow is laminar, the extrusion is done without ejection of liquid and with a good surface quality. Ceraspray lubricant helps, because of decreasing thermal exchanges between the cold tool and the semisolid material, to slow down the solidification rate and then increase the quality of the surface of the part by decreasing the material waves phenomena (see Test 07 on Fig. 3). The external quality of these two parts shows that the Test 07 is too cold because of the high solidification rate of the material that allows to create material waves. It also shows that Test 08 is too hot because of liquid ejection. The observation of these different samples reveals that Test 14 exhibits the best external quality showing smooth and homogeneous material along the sample with some material waves (Fig. 4). Solid fraction was determined by image analysis. Few porosity is observed at the bottom of Test 14: gas comes inside the high solid fraction material by cracks during compression. Cracks at the top are due to the compression-traction efforts because of the stopper. Test 07 shows the ejection flow of the stopper.
600°C is used for next experiments.

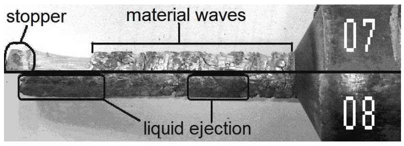

Fig. 3: Comparison between Test 07 and 08

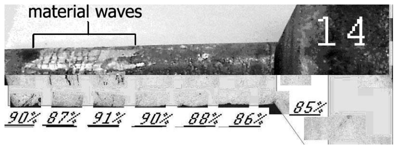

Fig. 4: Evolution of the solid fraction and defects on an extruded sample for Test 14

3.2 Lubricant coating on the tool

Boron Nitride (BN) was used first. BN is not a thermal protector. To decrease thermal exchanges between the tool and the semisolid material in the funnel of 12 mm, high speed and hot tool (140°C) are used. But the solidification rate is still too high and causes material waves with any semisolid material temperatures (Fig 5).

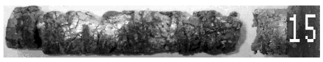

Fig. 5: Slug at 600°C extruded at 31.3s^{-1} with a tool at 140°C coated with Boron Nitride

Better results are obtained with Ceraspray. Ceraspray is therefore used for all experiments.

3.3 Material flow speeds

3.3.a Load

Results (Table 2) show that higher is the speed and the temperature, lower is the load: these are shear thinning benefits.

Table 2. Influence of temperature/speed on the forming load

	Test 01	Test 02	Test 06
Temp.	595°C	605°C	600°C
speed	low	low	high
load	30T	20T	10T

3.3.b External quality

The external quality of the parts shows a higher homogeneity of the material without liquid ejection for Test 06 than for Test 01 and 02. Few material waves remain for these three tests.

3.3.c Microstructures comparison

The tool is heated up for this experiment to decrease the influence of the thermal exchanges between the semisolid material and the tool. We focus on the rheology behaviour of the 600°C semisolid material at different speeds. Test 33 is extruded at low speed with a tool at 125°C. Test 39 is extruded at high speed in a tool at 95°C and 125°C for Test 22. To increase external and internal quality, complete filling is done to have material compression. By increasing the pressure, defects like cracks and porosities decrease.

External quality is quite the same for the three samples but if we look at the section variation, cracks appear for Test 39 due to the high speed flow and not for Test 33 (Fig. 6). Same cracks were observed for all samples at high speed flow (Test 14, 21, 26).

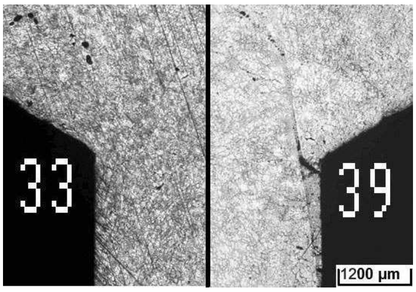

Fig. 6: Comparison between microstructures of Test 33 and Test 39 at the section variation.

3.4 Tool temperatures

3.4.a High speed

Next 600°C slugs are extruded at high speed with different tool temperatures (Table 3):

Table 3: Different tests at 600°C for different tool temperatures

Tool temperature						
24°C	75°C	100°C	125°C	170°C	180°C	240°C
Test 26	Test 20	Tests 21-39	Test 22	Tests 23	Test 24	Test 25

Observations of external quality of extruded samples reveal that the optimal external quality is reached for a tool temperatures range from 75°C to 100°C. For temperatures under 75°C, material waves are still present at the top of the extruded sample: these are due to the high solidifcation rate due to thermal exchanges between material and the tool. For temperatures above 100°C, cracks lead to broken samples around their stopper because of compression-traction efforts due to solidified skin between compression and extrusion: material wave disappear but cracks remain. At 180°C, the extruded sample is broken in two locations: the stopper and the section variation. This last defect can be explained by cracks (Fig. 6) due to lower thermal exchanges that influence the rheology of the semisolid flow.

3.4.b Low speed

A lower speed increases thermal exchanges effects. Test 33 shows few material waves at the top of the part in comparison with Test 39 extruded at lower tool temperature and higher speed. At low speed, tool can be heated until 125°C to decrease the solidification rate without breaking the sample. At 140°C, the sample breaks at the stopper.

4 CONCLUSIONS

Extrusion with such high sections variation is a quite hard geometry for the thixoforging process. Nevertheless, it helps to enlighten the influence of each process parameters on the quality of the part made in 7075. If these parameters should be classified from the major effect to the minor: the order will be: 1) semisolid material temperature to reach laminar flow without liquid ejection: 600°C in our case; 2) tool coating to decrease thermal exchanges; 3) material flow speed to have a compromise between low load for high speed and low cracks for low speed; and finally 4) tool temperature to decrease material waves on surface: around 100°C in our case. By using high solid fraction material, we reach homogeneous (± 5%) solid fraction in all the extruded part.

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