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# INFLUENCE OF EXPERIMENTAL CONDITIONS ON MATERIAL RESPONSE DURING THIXOEXTRUSION PROCESS

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**Abstract:** *The behavior of aluminum alloy to deformation is strongly influenced by the morphology of the microstructure. This paper illustrates several experimental research activities for thixoextrusion of 7075 aluminum alloy being carried out within the “Arts et Métiers ParisTech” of METZ. Inductive re-heating of the aluminum billet is the method to enable the desired liquid fraction for thixoextrusion. Experimental results show that after induction reheating the solid particles obtained has globular shape and homogeneous dimension. A sample obtained from a direct extruded bar is inserted in a die and thixoextruded after reheating in semisolid state. In laboratory experiments the temperature it was directly controlled applying thermocouples for temperature measurements in the slug and also in the die. The experimental tests were made for two different working speeds on the mechanical eccentric press. The preliminary experimental results on extrusion load and microstructure evolution of the product are reported. These results will contribute to implementing the specific boundary condition of the manufacturing process to the future numerical analysis of the current project activities.*

**Key words:** *Semi-solid, thixoextrusion, 7075, aluminium, solid fraction*

## 1. INTRODUCTION

In the current year, considerable effort has been devoted to research to minimize time and manufacturing costs while maximizing the quality of the products. To increase geometry complexity, the resistance of the material during deformation can be reduced by using shear thinning and thixotropic forming [1–2]. Since its discovery, semisolid metal processing has been developed to become a new technology for forming complex near-net-shape components, competing with conventional casting and forging technologies and opening new opportunities [3]. Thixoextrusion is one of the thixofforming processes, which combines the elements of both casting and forging. In comparison with the conventional hot-extrusion process, the load required to deform material by thixoextrusion is much lower than in the case of conventional hot forging due to smaller resistance and good fluidity of the material.

Thixoextrusion, has the advantages of extension of the die life and cost saving due to low energy consumption compared with conventional extrusion processes. Forming at semi-solid temperatures (between liquidus and solidus) offer significant advantages to the final part, such as reducing macrosegregation and porosity at lower forming efforts[3]. In general, that parts exhibits better mechanical properties than conventional casting or forging. As same as any thixo-process, the thixoextrusion is composed of three steps: feedstock manufacturing, reheating and forming by extrusion. The key of the process is to obtain semi-solid slurry free of dendrites, with the solid being present as non-agglomerated, fine and spherical particles, and with minimum entrapped liquid in the solid, to obtain the necessary thixotropic flow behaviour. Now are several methods for obtaining this microstructure. The RAP (recrystallisation and

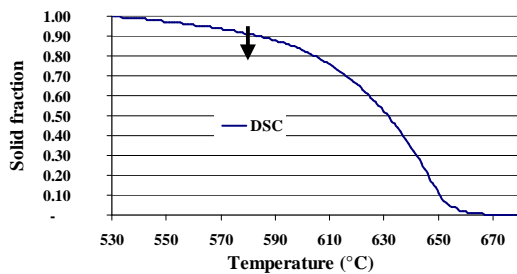
partial melting) method [4-5] has the advantage that some alloys are supplied in the extruded state. Reheating to the semisolid temperature range for a certain period of time, recrystallisation occurs and the liquid penetrates the recrystallised boundaries resulting in the spheroids surrounded by liquid [3]. The semi-solid processing had a significant impact in a number of industries including aerospace, automotive and electronic components.

The purpose of the present study is to report the results of experimental method based on backward extrusion test and to examine the rheological behaviour of a semi-solid 7075 aluminum alloy extruded at high speed.

## 2. MATERIAL AND EXPERIMENTAL PROCEDURES

### 2.1 Material

The material used for thixoextrusion was a commercially aluminium alloy type 7075. The chemical composition of used alloy is indicated in the table 1. The 7075 wrought aluminium



**Fig.1** Solid fraction vs. temperature curves of the 7075 alloy obtained by DSC analysis (heating rate 15°C/min) alloy has good plastic deformation properties and is heat treatable. This material is typically used for aerospace and automotive applications.

Table 1

**Chemical composition of 7075 aluminum alloy used for experiments**

Zn	Mg	Cu	Fe	Si	Mn	Cr	Ti	Al
%	%	%	%	%	%	%	%	%
5,1	2,1	1,2	max	max	max	0,18	max	Bal
6,1	2,9	2	0,5	0,4	0,3	0,28	0,2	

The 7075 aluminium alloy is an aluminium alloy that shows, by differential scanning calorimetry (DSC) analysis, more sensitivity to temperature variation for 5%–60% of solid fraction (Fig.1).

The volume of the slug is chosen to fully fill the extrusion tool. For these tests the slug dimensions are 35 mm in diameter and 37 mm high, cut from an extruded bar of 35 mm diameter with an extrusion ratio of 1:16.

### 2.2 Experimental procedure

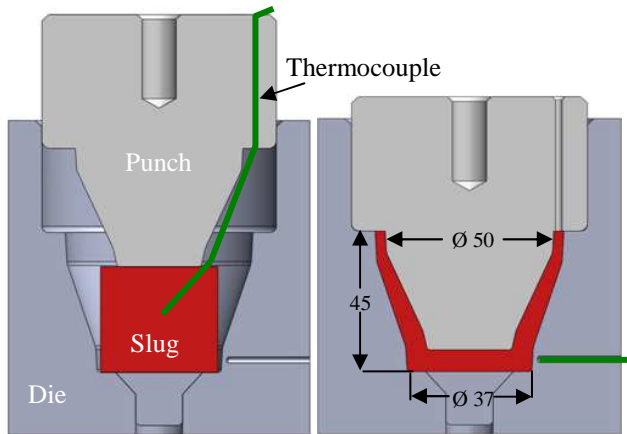
Semisolid manufacturing requires heating the slug to the semisolid state with coexisting liquid and solid phases. To heat at the semisolid temperature, an induction heating method was used because it is non-contact, compact and fast method and the input power can be easily controlled. In our work a Fives Celes MP50 generator was used (Fig.2). The parameters of the slug heating are reached using the induction heating to a maximum power of 50 kW and a frequency between 20-100 kHz. The heating process must be accurately controlled to achieve a uniform temperature distribution in the slug, so the heating cycles are programmed and applied on our equipment and these cycles are repeatable.



**Fig.2** Induction heating system (left), and thixo-extrusion test device mounted on the press (right)

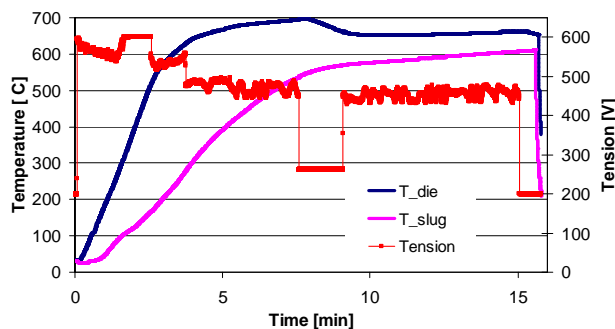
To obtain a uniform temperature in the slug, it was heated into the extrusion die at four different temperatures 605, 610, 615, 620°C and the corresponding solid fraction for these temperatures was 0,80, 0,76, 0,71, 0,66.

The die (Fig. 3) was designed to reduce the heat losses between the heating and the forming stages, allowing to control the filling of the die. The die with the slug are positioned in the axis of the inductor and stands on a special ceramic support which resist to thermal stresses, and is thermal insulated (Fig.2). A hole of 2 mm in diameter was drilled into the center of each sample in order to insert a thermocouple for controlling the temperature (Fig.3).



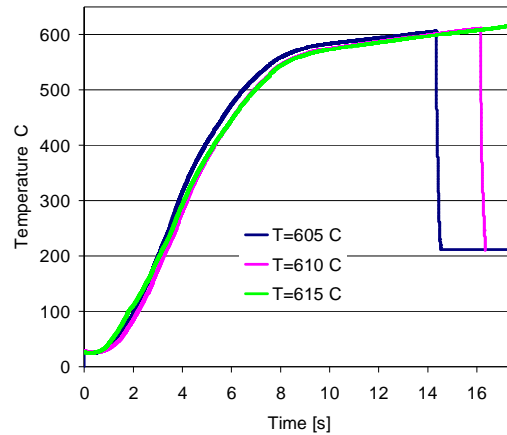
**Fig.3** The assembly die-slug-thermocouples

Two „K” type thermocouples were inserted to control the temperature evolution: one into the centre of the slug and other into the die, at less than 5mm from the slug surface. In order to obtain a homogeneous slug temperature, heating cycles consisting of several power stages separated by dwell time were used (Fig.4).



**Fig.4** Heating cycle of 7075 aluminium alloy slug in a die

In the figure 4 it can be observed a relative homogenization of the temperature in the slug for the last 5 min of the heating. The heating process is relatively rapid and allows obtaining and maintaining the globular microstructure. It was used the same parameters for the heating cycle, except the duration of the last stage of the cycles, which is different, depending on the temperature needed in the slug (Fig.5). The die was cooled between each experiment. The heating efficiency and the temperature distribution inside the billet depend on the design and position of the induction coil. After heating, the die assembly and the slug are transfer from the induction box to the mechanical eccentric Press X50CNR4.



**Fig.5** Temperature-time evolution during the reheating process for various slug temperatures

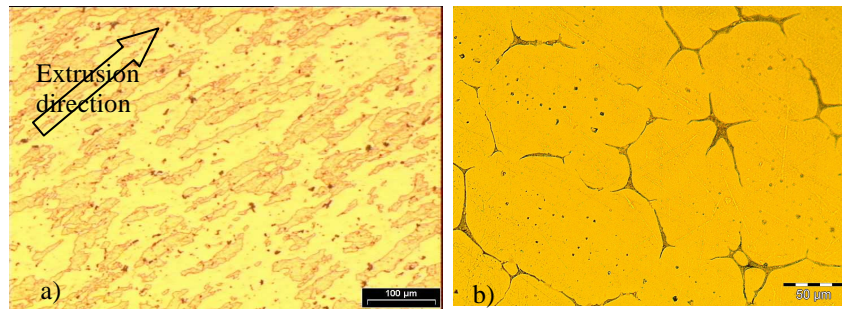
A Nefacier1500©disc (based on ceramic fibres with low content of non-fibrous ceramic particles) was placed between the piston and the die to reduce heat losses during the forming step. A tool protection coating is sprayed before each extrusion test to protect tool surface against wear and chemical attack of aluminium on steel. Acheson Pulvegraph D31A which is a graphite base lubricant was used as tool thermal protector agent to limit thermal exchanges with the extrusion tool and to limit aluminium chemical attack.

The extrusion is done in about 0,3s depending on piston speed. The maximum working ram speed applies in our experiments was 416 and 235 mm/s. The whole equipment is controlled through load and displacement sensors and the physical parameters are recorded by data acquisition boards. The load sensor is placed above the piston and measures the loads involved in the thixoextrusion process. The transfer time of the reheated assembly to the mechanical press is about 5s.

### 3. Results and discussions

#### 3.1 Microstructural evolution during partial remelting

An important aspect in the semi-solid processes is the microstructure. It is well known that the cast aluminium alloy it is characterized by a dendritic microstructure which is very difficult to eliminate.



**Fig.6** Type of microstructures of 7075 aluminium alloy: a) before reheating [7], after reheating at b) 605°C

Figure 6a shows the microstructure of 7075 samples before reheating which consist on primary  $\alpha(\text{Al})$  elongated phase particles, aligned in the extrusion direction, with the grain boundaries well delineated [7]. Samples used to analyze the microstructure were ground with grit paper, polished using diamond paste, etched using Nital 2% etch and optical micrographs were taken. After a reheating time of 15 min at 605°C, the recrystallisation occurred and it can be observed that the system evolves to a globular structure (due to the liquid diffusion at the limit of the grains). In the figure 6b, it can be clearly seen in the cross section, the light primary solid phase and the dark eutectic phase, corresponding to the solid phase and to the liquid phase, which is supposed to be present in the semisolid state. The variation of the shape factor after induction reheating was studied. The shape factor  $F=4*\pi*A/P^2$  was calculated with ImageJ analyzer, where A and P are area and perimeter of the globule respectively. The average shape factor obtained on the samples reheated to 605°C was 0,80.

### 3.2 Impact of the temperature parameter on the extrusion process

Figure 7 shows two thixoextruded parts extruded at two different working ram speed and at the same slug temperature 615°C. After the first stage of filling the liquid phase tries to skip away from the solid skeleton and in his ascent the liquid phase takes away the graphite based lubricant. The extruded parts surface display white “V” trail which is probably the effect of the fact that in this zone the graphite is entrapped during the extrusion step by the liquid phase. More the working ram speed is greater, the surface of white "V" trails zone created by the liquid splash is smaller, but the number of the white “V” trails is major.



**Fig.7** Parts thixoextruded at 615°C: working ram speed a)  $v=235$  mm/s; b) 416 mm/s.

The part presented in the figure 8 was axial cut and through the white "V" trail zone. The porosities displayed on the surface probably appears because of the lubricant, which, during the reheating stage of the slug, contaminate the surfaces and in the filling stage is engaged in the part by the liquid phase. Other cause could be the shrinkage porosity which appears during the solidification phase. A composition analyze in this zone will be realized it in our future study. As depicted in fig.8, the defects are on the shearing plane, and they were formed exactly in the white “V” trail but they could be wherever in the part.



**Fig.8** Macro views on the part thixoextruded at 590°C

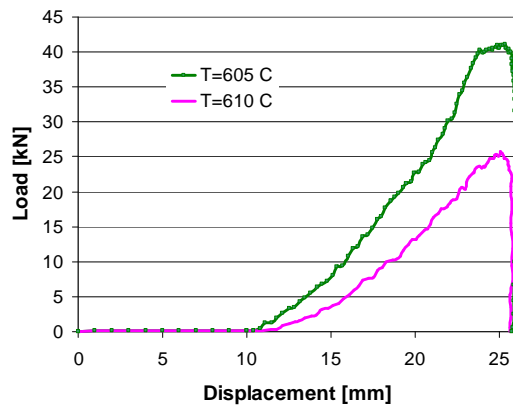
A bad filling was obtained between 590°C and 610°C (between 0,88 and 0,76 solid fraction determined by DSC) and a complete filling at 615°C and 620°C (0,70 and 0,66 solid fraction) when the parts shows the exact shape with 2 mm flash thickness.





**Fig.9** Parts thixoextruded at 590 °C and 620 °C

Figure 10 show typical diagram of extrusion force vs. ram displacement associated with the experiments mentioned above. First, the load very slowly increases with the displacement: this step is not recorded by the load sensor because the sensitivity of the sensor we used was lower then the loads that appeared in the slug in this stage.

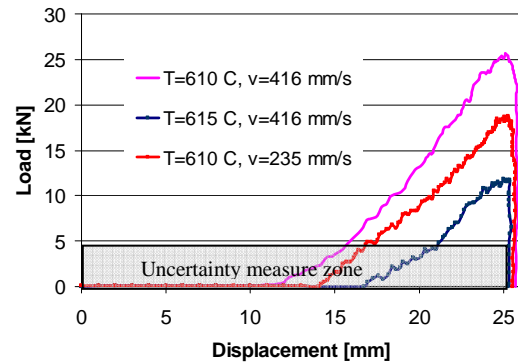


**Fig.10** Load-displacement evolution during the thixoextrusion process for various slug temperatures

Then the load swiftly increases, up to a maximum value: this step corresponds to the filling of the die conical cavity. We observed that the load level clearly increases when the slug temperature decreases mainly because of the increase of the consistency of the semisolid.

### 3.3 Impact of the working ram speed on the extrusion process

The load is strongly influence by the working ram speed. Figure 11 presents the load-displacement evolution during the thixoextrusion process for two slug temperatures and two values of the working ram speed. We found that the load decrease with the decrease of the ram speed. We explain the load decrease by the liquid segregation that is present in low forming speed.



**Fig.11** Load-displacement evolution during the thixoextrusion process for two slug temperatures and two ram speed

We suppose that using a low extrusion speed that gives the liquid phase enough time to skip away from the solid skeleton.

## 4. CONCLUSION

Reheating by induction at a semisolid temperature, a slug cut from an extruded bar, after a period of time promotes globular solid particules surrounded by liquid film, with a significant degree of spheroidization. To minimize the heat losses the initial extruded sample was heated into the thixoextrusion die and after 15 min it has a thixotropic state. In our conditions the process has a limit which gives a good flow and a good quality parts to 0,70 solid fraction. In semisolid range, a medium temperature is preferred in order to get a good filling in the die. The experiments described above clearly showed that the slug temperature, the working ram speed and the presence of the graphite lubricant strongly impact the load required for filling as well as the shape of the extruded part and on the integrity of the microstructure.

This observation could help us to implementing the specific boundary condition of the manufacturing process to the future numerical analysis of the current project activities.

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## INFLUENTA CONDITIILOR EXPERIMENTALE ASUPRA COMPORTAMENTULUI MATERIALULUI LA TIXOEXTRUDARE

**Rezumat:** Comportamentul la deformare al aliajelor de aluminiu este puternic influențat de morfologia microstructurii. Lucrarea prezintă câteva din rezultatele încercărilor experimentale de tixoextrudare a aliajului de aluminiu 7075 realizate la "Arts et Métiers Paristech" METZ. Reîncalzirea prin inducție a semifabricatelor de aluminiu este o metodă care permite obținerea cantității de lichid necesare pentru tixoextrudare. Rezultatele experimentale arată că după reîncalzirea prin inducție particulele solide obținute au o formă globoidala și dimensiuni omogene. Semifabricatul obținut din bara extrudată este introdus în matrită și tixoextrudat după reîncalzirea în stare semisolidă. Temperatura a fost controlată direct, cu termocuple montate în semifabricat și în matrită. Testele experimentale au fost făcute la două valori ale vitezei de lucru pe o presă mecanică cu excentric. Au fost prezentate rezultatele preliminarilor asupra evoluției forței de extrudare și microstructurii. Aceste rezultate vor contribui la implementarea condițiilor specifice al procesului în analiza numerică prevăzută în proiectul curent.

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