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# THIXOFORMING – CONSIDERATIONS ABOUT A NEW SOLUTION FOR THE FUTURE

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**ABSTRACT:** The aim of this paper is to present some general problems about THIXOFORMING - a semi-solid process - and a few methods to obtain the thixotropic structure. The effective use of the semisolid process presumes good knowledge of the material behavior. Even the process implicate a series of economical investment, the THIXOFORMING technology proposes itself as one of the best to produce components with the mechanical properties required by their use, with costs industrially acceptable.

**KEYWORDS:** Thixoforging, thixotropy, semisolid metal alloy, microstructure, mechanical properties.

## 1. INTRODUCTION

**Thixoforging** is the forging of metals in the temperature range between their solid and liquid states. In this range, there exist both, fluid and solid components in the structure.

The Thixoforging consists of four modules. Starting from the production of the raw material by casting, this material is reheated to semi-solid state in a specially designed thermal pre-processing line. After semi-solid forming in a Thixoforging press, the properties of the final parts are adjusted by thermal treatment during post-processing. Normally, the cast billet is forged when 30 to 40% is liquid; in the slurry process, 60 to 70% of the material is liquid.

The semisolid metal forming process (SSM) is developed like an eficient alternative of manufacturing parts to forms and dimensions more and more near to the final functional form, as result of the thixotropic behaviour, obtained by using special melting processes. Forming in the semisolid state requires that the metal or alloy have a roughly spherical and fine grain microstructure in the moment when it enters in the forming die.

Semisolid forming can be applied for all alloys that have a solidifying range in which solid and liquid phase can coexist. A lot of metallic alloys were studied, for example, zinc, aluminum, magnesium, copper, but also iron alloys were tested [1]. The results were significant and carried out commercial progresses especially in non-ferrous alloys domain in particular aluminum and magnesium alloys.

As a result of the coexistence liquid + solid in slurry state, the metal has totally different properties respect to the solid state.

- The forming stress of the metal in slurry state is very low. The forming stress depends on the liquid amount present in the metal, and by reason of its appearance on the grains edges, the binding forces between grains are very low or even zero. Consequently, the relative movement between the grains in slurry state can be easily realized. In conclusion, it can be said that metal flow and forming is produced under low stress.

- The solid state content $f_s$ defined in percent, is an important parameter, which express the state of slurry material. When $f_s$<80% the slurry is consistent and easy to form and stirred. When $f_s$<60 the slurry flow under gravitation force [2].
- The slurry with a reduced solid content, can be agitated and mixed with other materials like: different metal powders, ceramic particles, graphite powder and so can be obtained diverse mixtures.
- The metal in slurry state can be easily separated because of the low inter-grains binding forces. Two slurry state metals can be easily combined thanks to the liquid diffusion phase of the two metals one each other and then their solidification together.

## 2. MICROSTRUCTURE EVOLUTION

In the case of most non-ferrous alloy types, the solidifying structure remains the same, so that the phase and structure changes through thermal treatment and plastic forming are produced in the environment of primary structure. So, the effects of this technologic process are strongly influenced by the primary structure properties.

Refering to the fact that non-ferrous metals have tendency to crystallize during solidification with large grains, the question to influence crystallization processes to obtain fine grains and an advanced rate of dispersion, decides the properties of the product. The reduction of the grains dimensions increase mechanical characteristics and ensure their value uniformity, emphasizeing the quasiisotropy of the material.

THIXOTROPY is a physical state in which a solid material gets more fluid (modifies its viscosity), when constrained on shearing stress in a specific direction. Viscosity increases when the shearing stress stops. After reaching a critical shearing stress, the material starts to flow.

In certain processes that works with a low solid phase content, that are semi-liquid state, thixotropic phenomenon is less present then in semi-solid state. This property is very important for semisolid or semi-liquid metal forming process and it permits to avoid turbulence (which can be a source of internal porosity) during liquid casting state, using classical casting processes. This turbulence is the source of great porosity that influence mechanical properties of classical cast pieces or weldability.

To obtain this thixotropic effect, it was developed and patented some methods that allow to obtain the mixture of a solid phase formed by degenerate dendrite with round shape, dispersed in a liquid state (inter-grain eutectic).

This slurry mixture is determined by the content of solid phase $f_s$. To obtain this non-dendritic structure, there are used different stirring methods during the casting process, to break the dendritic structure and obtain a poly-crystalline structure with solid rounded grains $\alpha$ and inter-granular eutectic. As long as the intensity of stirring is increased, the grains and the liquid between grains will decrease. Also, the increasing of the casting speed leads to decreasing of the grain size.

It was noticed that a reheated structure of an alloy obtained by classic casting, without refining grains, it is not a poly-crystalline structure and in conclusion it can not be thixoformed [3].

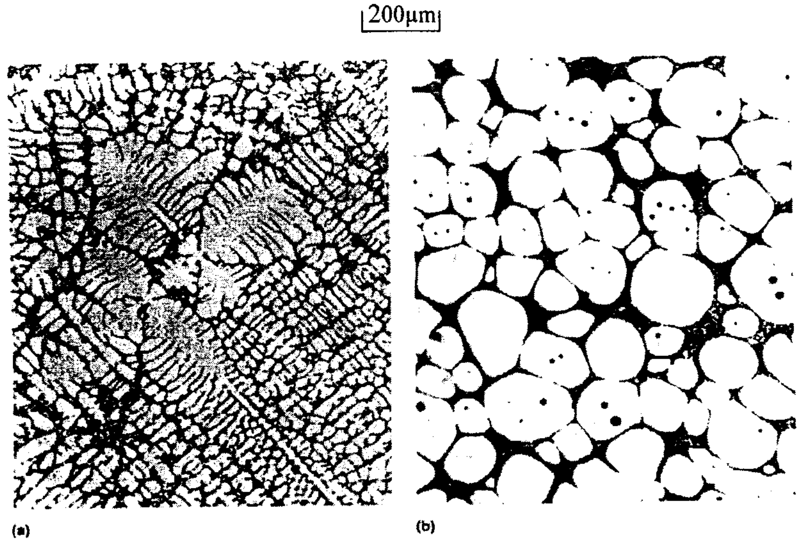


***Figure1.** Microstructures of aluminum alloy Al-7Si-0,5Mg (357) (a) dendritic conventionally cast and (b) ) nondendritic semisolid formed*

## 3. METHODS TO OBTAIN A THIXOTROPIC STRUCTURE

At present, there are eight basic methodes which are used to obtain a thixotropic structure. These methodes are: mechanical stirring, electromagnetical stirring, magnetohidrodynamichal stirring MHD in continuous casting, through vertical or horizontal stirring (work carried out by Aluminium Pechiney), ultrasonic stirring (which is not very effcient in obtaining thixotropic structure, but permit fine-grained microstructure), passive stirring (M.I.D.A.S method), extrusion (S.I.M.A. method), continuous casting with grain refining and PID process. There are some other methods of producing billets with thixotropic structure by stirring: FIAT WEBER, ALLURES, STAMPAL, VIVEZ, etc. [3].

It is found that the cooling rate of the melt during solidification under stirring is the most important factor influencing the microstructures of the billets [4]. The average cooling rate T, during the continuous casting can be approximately expressed as :

$$\dot{T} = \frac{\pi}{4}\frac{D^2}{hA}(T_o - T_s)V \tag{1}$$

where $\dot{T}$ is the average cooling rate; **h**-the effective height of the melt; **A**-the cross sectional area of the melt in the crystallizer; **D**-the diameter of the billet; **V**-the continuous casting speed; $\mathbf{T_0}$-the temperature when the melt enters the stirring region ; $\mathbf{T_S}$-the solidus temperature.

The cooling speed influences the primary grains size; their sizes decrease if cooling speed increase. In the same time, the amount of liquid between grains raise.

The average speed of shearing stress has a very low influence on the primary grain size; if speed increase, grain size gets homogenized and they become better separated.

A thixotropic aluminum alloy, with a liquid phase content of 50 %, presents three major physic differences in comparison with the 100 % liquid, die-casting or obtained by squeeze casting process [3]:

- A superior viscosity, even after fluidization through shearing stress produced during injection. This permits injection of the thixotropic metal with relatively high speed, maintaining a laminar flow and so, realizing thinner parts respect to those obtained by die forming using liquid metal, having the same metallurgic quality: inclusion absence, thermal treatment and welding possibilities, high resistance and elongation values.
- Lower temperature; solidification enthalpy is almost twice lower. This permits the increase of productivity and service life of dies.
- Lower solidification shrinkage, which reduces feeder difficulties, without a complete elimination of them.

In conclusion, solidifying structure is finer and more uniform in the whole part, independent of the local differences of the wall thickness. This gives to the parts special mechanic properties, if the defects like oxides or shrink holes are not present.

## 4. ADVANTAGES

Advantages of the thixoforming process for production cycle and finite products, respects to the traditional die casting and forging are:

- Lower volumetrical contraction during solidification;
- Lower risk of micro shrinkage appearance;
- Lower heat cracking;
- The solidified microstructure is homogeneous and uniform in the whole part, even different dimensions, resulting a good mechanical properties;
- It can be obtained parts in final form, with complex geometry and good dimensional precision, reducing the costs with the mechanical manufacturing of the parts;
- Heat treatment possibility for higher mechanical characteristics and welding;
- The evacuated heat is reduced, related to die casting; for a part with the same geometry, results a decrease of 20-25% of the part manufacturing and increases the life expectancy for the die;
- Energy saving (40%) to the final user;
- A better environment conditions for workers without excessive heat because the material is just reheated and not melted;
- Avoiding the risk of ignition caused by magnesium in liquid states, if not working in protective gases atmosphere (expensive, toxic or ozone-layer threatening protective gases), by decreasing the injection temperature corresponding to a mushy consistency.

Anyway, the main advantage is the high and controllable viscosity of the semi-solid material; witch determines a laminar flow, avoiding turbulent flow, sours of internal porosity.

Table 1 presents some aluminum alloys, witch the specific heat treatment, used in thixoforging and the Table 2 compares the characteristic of aluminum automobile wheels produced by thixoforming and permanent mold casting.

## 5. APLICABILITY

The main aplicability fiels are :

- parts with high mecanical characteristic;
- parts that need high tightness, wich actually aren't produced through die casting;
- parts of hipereutectic alloys needed to resist to friction ;
- some parts made with die casting, but with high loss caused by the local porosity, etc.

***Table1.*** *Mechanical properties resulted by thixoforming (Source Aluminum Pechiney).*

| Aluminum alloy | Temper | Ultimate tensile strength (Mpa) | Tensile yield strength (Mpa) | A % | HB |
|---|---|---|---|---|---|
| AlSi7Mg0,3 (356) | F | 230 | 105 | 18 | 60 |
| | T5 | 260 | 170 | 15 | 80 |
| | T6 | 300 | 230 | 14 | 95 |
| AlSi7Mg0,6 (357) | F | 240 | 110 | 17 | 65 |
| | T5 | 275 | 205 | 10 | 90 |
| | T6 | 345 | 290 | 10 | 110 |
| AlSi5CuMg | F | 270 | 130 | 7 | 80 |
| | T5 | 320 | 225 | 7 | 100 |
| | T6 | 405 | 320 | 5 | 130 |
| AlSi6Cu4 | F | 270 | 130 | 7 | 80 |
| | T6 | 405 | 320 | 5 | 130 |
| AlSi17Cu4Mg | F | 220 | 185 | 1 | 115 |
| | T5 | 270 | 270 | <0,2 | 140 |
| | T6 | 350 | 350 | <0,2 | 165 |

***Table 2.*** *Comparation of thixoforming and permanent mold casting for the production of aluminum automobile wheels [5]*

| Process | Aluminum alloy | Weight direct from die or mold kg | Finished part weight kg | Production rate per die or mold, pieces/h | Heat treatment | Ultimate tensile strength Mpa | Yield strength Mpa | A % |
|---|---|---|---|---|---|---|---|---|
| Thixoforming | 357 | 7,5 | 6,1 | 90 | T5 | 290 | 214 | 10 |
| Permanent mold casting | 356 | 11,1 | 8,6 | 12 | T6 | 221 | 152 | 8 |

## 6. CONCLUSION

In conclusion, it can be said that the THIXOFORMING became an industrial reality and the fields of application of the process seems to become clearer. The remarkable properties of the semi-solid gel (slurry) permit to obtain finite parts with thin wall thickness and without defects.

The THIXOFORMING industry should focus on applications that really take the advantages of its specificities and the rapid growth of the use of aluminum in the automobile, military and aerospace industry offers numerous opportunities. The fundamentals of this new technology require further investigation.

## REFERENCES

1. K. Young, P.Eisen, 6$^{th}$ International Conference on semi-solid processing of alloys and

composites, Turin, (2000), 97.
2. M. Kiuchi, Plasticity and modern metal-forming technology, Edited by T.Z.Blazynski, 289.
3. J.Collot, 64th World Foundry Congress, (2000), Paris.
4. Z. Kui, 6th International Conference on semi-solid processing of alloys and composites, Turin, (2000), 115.
5. ASM Specialty handbook Aluminum and aluminum alloys, The Materials Information Society, 102.