

Comparison of the techniques to produce non-dendritic feedstocks for thixoforming

Kawan M. Abdulrahman* **, Viktor Gonda*, and Mihály Réger*

*Óbuda University, Bánki Faculty of Mechanical and Safety Engineering,
Népszínház u. 8, 1081 Budapest, Hungary

** Sulaimani Polytechnic University, Technical College of Engineering, Department of Production
Engineering & Metallurgy, Iraq

kawan.abdulrahman@bgk.uni-obuda.hu, gonda.viktor@bgk.uni-obuda.hu,
reger.mihaly@bgk.uni-obuda.hu

Abstract — Preparation methods of feedstock billets for thixoforming including Semi-Solid Rheocasting (SSR), Cooling Slope (CS), Magneto-Hydrodynamic stirring (MHD) and Semi-Solid Rheocasting with Cooling Slope (SSR+CS) are studied in this paper. On the base material of aluminum A201, non-dendritic feedstocks for thixoforming were prepared and compared by analysing their microstructures. The main variation between the microstructure provided by these technologies are presented, and a comprehensive review is made of the potential mechanisms that lead to microstructural alterations during the preparation of feedstocks.

Keywords: Semi-solid metal; thixoforming; Semi-Solid Rheocasting; Cooling Slope; Magneto Hydrodynamic stirring; microstructural properties.

1 INTRODUCTION

Semisolid metal (SSM) processing, otherwise thixoforming is usually known as a technology that includes the forming of metal alloys between solidus and liquids temperatures. Currently, this process is industrially successful, generating a variety of products with high-quality parts in various industrial sectors. During the years since its inception, a number of technologies to produce the appropriate globular microstructure have been developed and applied worldwide. The success of Semi-Solid Metal (SSM) forming is dependent on a globular solid grain formation within a liquid phase. The microstructure of the starting material must consist of solid near globular grains surrounded by a liquid matrix and a wide solidus-to-liquidus transition area (Fig. 1) [1].

There are four possible methods which are used in this processing consist of Semi-Solid Rheocasting, Cooling Slope, Magneto Hydrodynamic stirring and Semi-Solid Rheocasting with Cooling Slope [1]. Microstructure analysis results also revealed the formation of more globular and larger α -Al solid grains in the same feedstock billets. The grain size and shape in semi-solid slurries differ irrevocably with time. Growing shear degree breaks down dendrites and the discount in viscosity and shear stress joined with slow cooling results in acceptable and

spheroidal atoms to move past one additional in the liquid matrix [1].

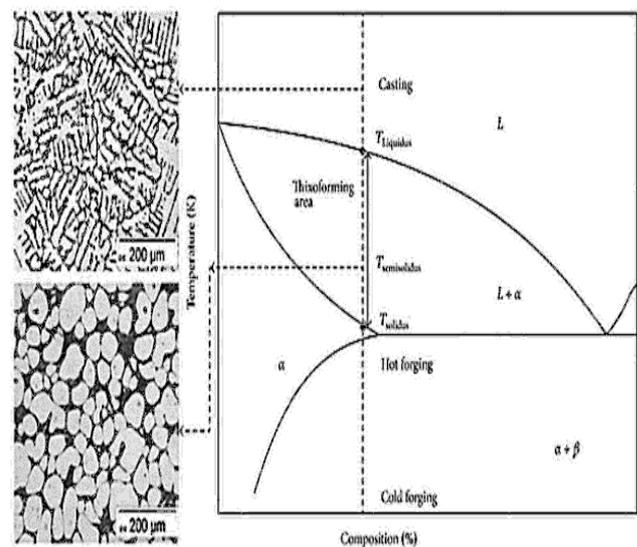


Figure 1. Micrographs of dendritic and globular structures in a semisolid alloy [1].

2 TECHNOLOGIES FOR PRODUCTION OF NON-DENDRITIC FEEDSTOCK

The feedstock materials could be used in two different techniques that are depending on the route: rheo-route or thixo-route. The slurry used is either a liquid-like slurry or solid-like slurry. The liquid-like slurry has consistently discrete solid particles besides exhibits fluid behaviour below exterior forces. The solid-like slurry requires unified solid phases and proves well-defined yield strength [2] (Fig. 1). Regardless of which route is used, processes need the structure to be non-dendritic or near globular, therefore feedstock production is crucial [2]. The four methods which are used in this processing consist of Semi-Solid Rheocasting, Cooling Slope, Magneto Hydrodynamic and Semi-Solid Rheocasting with Cooling Slope.

2.1 Semi-Solid Rheocasting [3]

In Semi-Solid Rheocasting (SSR), raw material is taken which is originally from ingot processes without an intermediate solidification step. The molten metal which is slightly above the liquidus temperature is poured into a steel crucible and then treated to form a globular microstructure. The molten metal is detained above the liquidus temperature and a cold finger (copper or graphite) is presented into the pool.

This rod, being at a much lower temperature than the liquid, comes into interaction with the liquid metal and a temperature incline exists amid the melt and the rod and partial solidification of the melt on the rods surface begins. As a result of the rotating motion of the cold finger, nuclei consequently shaped are sent into the melt, resulting in a globular microstructure of fine grains.

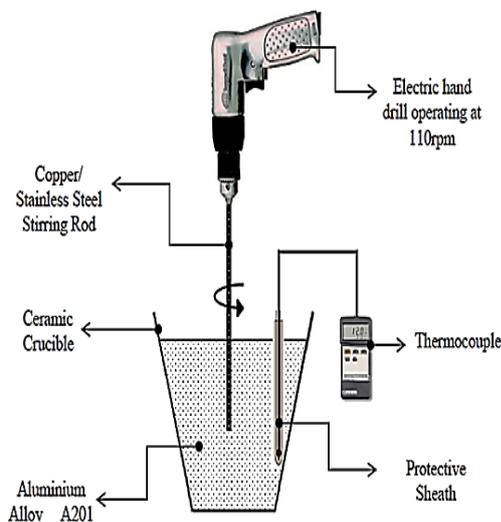


Figure 2. Schematic of Semi-Solid Rheocasting [3].

2.2 Magneto Hydrodynamic Stirring Procedure [4]

The Magneto Hydrodynamic (MHD) procedure was initially established by International Telephone and Telegraph (ITT) company in the USA. In MHD way, a dynamic electromagnetic field is applied to the melt to produce high local shear. There are three methods for this technique: horizontal agitation, vertical agitation and helical agitation.

The resulting effect is to produce non-dendritic microstructure slurry which is cast into billets. The billets could be then cut into slugs of the required size, re-heated to the semi-solid state and shaped or cast into the obligatory shape. The rate of solidification could be additionally controlled by coolants about the mould wall.

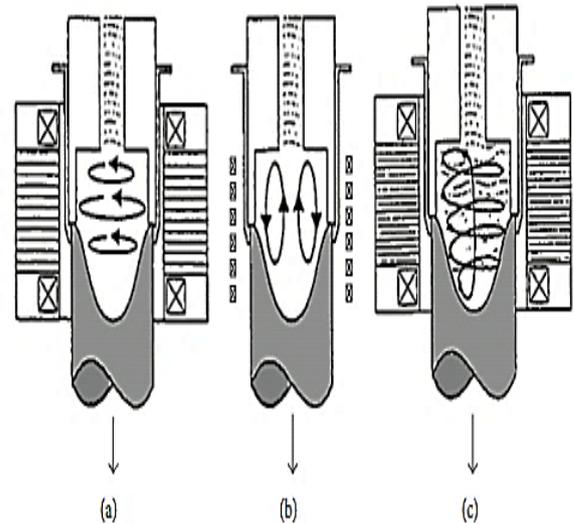


Figure 3. Schematic diagram of dissimilar flow modes: (a) horizontal agitation, (b) vertical agitation and (c) helical agitation [4].

2.3 Cooling Slope Technique [4]

The cooling slope was established to overcome the limits of the Magneto hydrodynamic method of not having the obligatory size ingot. It basically consists of a water-cooled plate situated over a mould. Through a cooling slope of 60° incline to the mould, the semi-solid slurry is produced. Also the cooling slope introduces nucleation of granular crystals that are eroded away by the fluid motion. With that a great number of these nuclei are approved by the melt that solidifies in the mould, concisely it is resulting in a globular microstructure.

The mould diameter besides the weight of the molten metal determines the size of the slab. The ingot is formerly heated to the appropriate semi-solid temperature and thixoformed, depending on the type of metal used. The total length of the slope, the correct angle of slope and the cooling system have a direct effect to the solidification of the molten metal that the quantity of superheat. In this process, the cooling rate of the ingot is contingent on the mould material.

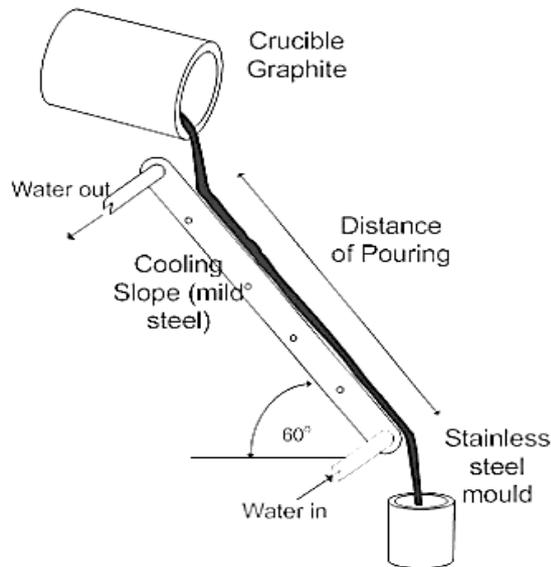


Figure 4. Schematic of cooling slope method [4].

2.4 The Semi-Solid Rheocasting Processes with the Cooling Slope Technique

In the Semi-Solid Rheocasting processes with the Cooling Slope processes, the raw material is heated to molten temperature [4]. The molten material is restless mildly with a thermocouple at the same time as slowly cooling down to Semi-Solid temperature. It is stirred vigorously using rotating rod attached to an electric hand drill for 10 seconds, followed which, the melt is decanted down the Cooling Slope, finally collected at the bottom of the device in a mould and left to cool [4].

3 MATERIAL AND PROCEDURES

Aluminium A201 alloy was used as a base material, its chemical composition is shown in Table 1. The (2xx) series aluminium contains copper as the principal alloying element [3]. This alloy has great mechanical properties, machinability, and good formability [5].

Table 1. Chemical composition of Aluminium A201 alloy [3].

wt%	Al	Cu	Ag	Mn	Mg	Si	Fe	Ti
A201	Bal.	4.7	0.59	0.31	0.28	0.10	0.05	0.21

It has high strength properties for components especially in military aircraft, impellers for gas turbine engines and arms equipment [5].

Mechanical properties are similar to, and sometimes exceed, those of low-carbon steel. The corrosion resistive properties are suitable for structural mechanisms and fittings [5].

Aluminium alloy A201 is also a good applicant for semi-solid forming requests due to it is varied solidification choice [5]. Feedstock were prepared from the alloy. Samples were prepared for metallographic analysis.

In the microstructural images, the shape factor and grain size were determined to characterize the non-dendritic structure. The shape factor (SF) of the grains is measured by:

$$SF = 4\pi \frac{A}{p^2} \quad (1)$$

Where A is the average area of the grains and p is the average perimeter of the grains [6].

If SF approaches 1, then the morphology turns into a spherical shape, and when SF is below 0.3 the morphology can be considered as dendritic, also when $SF=0$ the morphology is actual complex [6].

Moreover, the maximum performance in the semisolid creating then the highest mechanical properties were displayed by the structure that was small grain size, the shape factors above (0.6-0.7) then the maximum homogeneous besides globular size of the primary phase [6].

Table 2. Variation of microstructure in standings of shape factor [6].

No.	Shape Factor (S.F.)	Classic particle shape
1.	$SF < 0.3$	
2.	$0.3 \leq SF \leq 0.5$	
3.	$SF \leq 1$	

4 RESULTS

4.1 Semi-Solid Rheocasting

The value of the average SF is about 0.67 and the grain size is about $47 \mu\text{m}$ (Fig. 5). The SF values in the Semi-Solid Rheocasting are high caused by the dendrites breaking up through the agitation imposed on the melt by the hand drill.

This value is lesser than that of CS process [7], due to the general metal disturbance time is somewhat lower. The spherical particles are mainly created throughout stirring but the process starts when the stirring rod was dipped in the cooling molten alloy, interfering the nucleation surface and the rotation of the surface sending nucleated sites into the melt, henceforth stopping branch of dendrites developing fully [8, 9].

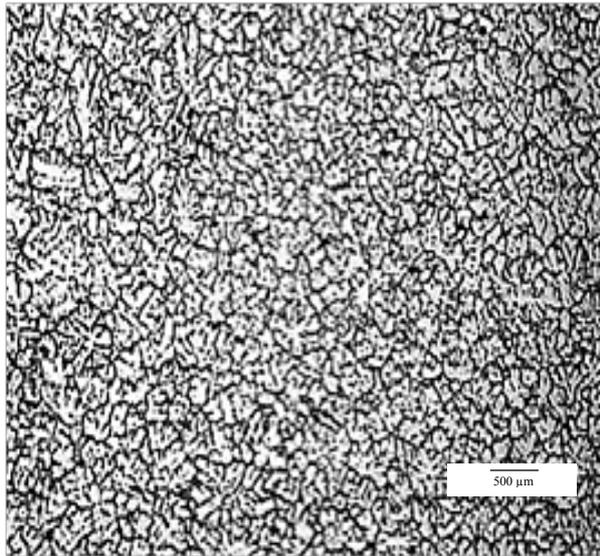


Figure 5. SSR Micrograph

4.2 The Magneto Hydrodynamic Stirring

The *SF* achieved in the Magneto hydrodynamic Stirring is about 0.39 and the grain size is 26 μm. The as-cast MHD sample shown in (Fig. 6) is clearly of dendritic microstructure with well-spaced arms typical of conventionally solidified cast.

The shape factor associated with this structure is not of a suitable size for thixoforming, this could be made better by increasing the holding time [8]. At this circumstance, the interface develops unstable hence formation was more dendritic microstructures [8].

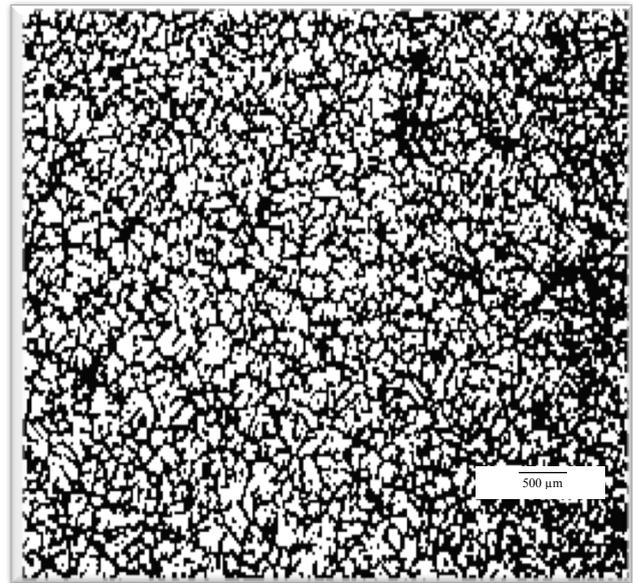


Figure 6. MHD Micrograph

4.3 The Cooling Slope

The Cooling Slope method disrupts the dendrites as they are shaped through the molten metal as it cools flowing down the feed channel [10]. The molten metal in The Cooling Slope method runs down the feed channel for about 8 seconds [10]. Number shape factor could be noted in the result because of the dendrites structure were braked up to became more globular structures when the molten metal runs down the feed channel. The number of shape factor was about 0.7 and the grain size was around 40 μm Table 3 show the structure.

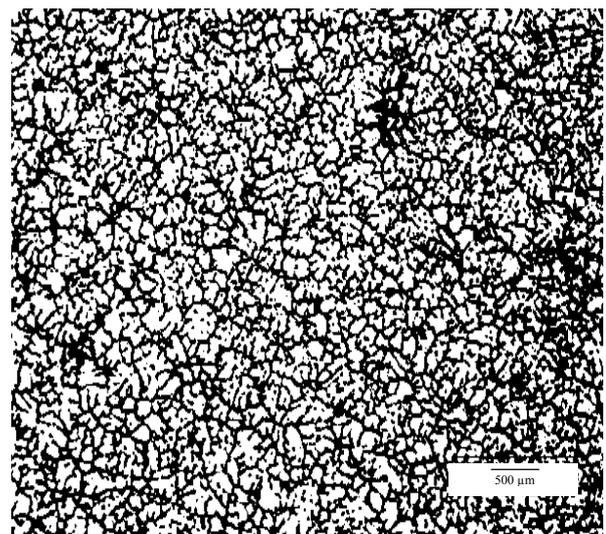


Figure 4. CS Micrograph

4.4 The Semi-Solid Rheocasting with the Cooling Slope

With this process, the overall metal disturbance time is extended, letting more dendrites to be broken up and better

globular structures being formed. The value of the average shape factor is about 0.7 and the grain size $\sim 38 \mu\text{m}$; (Fig. 5) show the structure.

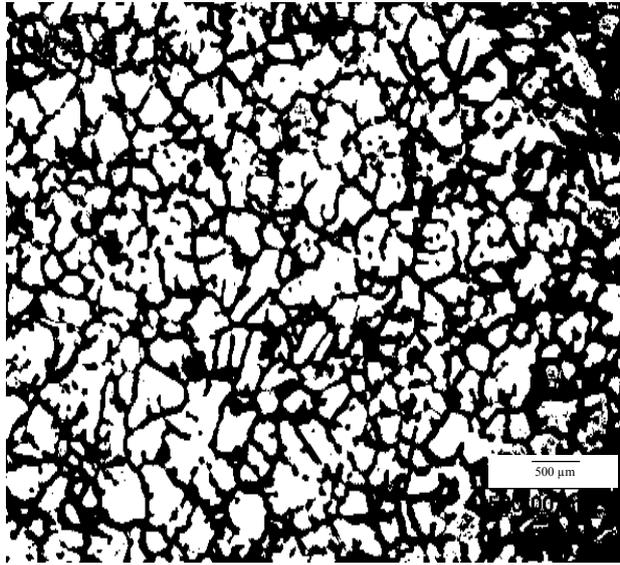


Figure 5. SSR + CS Micrograph

4.5 Microstructure statistic data of Aluminum A201 Alloy billets

Table 3. Solid Fraction and Grain size of variance types of Alloy A201

No.	Samples	Shape Factor	Grain Size μm
1.	CS	0.705	39.64
2.	MHD	0.385	25.85
3.	SSR	0.670	46.95
4.	SSR + CS	0.735	38.32

4 CONCLUSIONS

From this study, the following conclusions can be drawn:

1. There was a clear change in the microstructure of all aluminum feedstocks depending on shape factor and grain size.
2. The nature of final microstructures shaped below Semi-Solid process depends on the shape factor and all feedstock exhibited values that are appropriate for thixoforming.
3. The Semi-Solid Rheocasting feedstock resulted in better microstructures than the other feedstocks because of grain size of around $46.95 \mu\text{m}$ while the second feedstock Cooling Slope sample was around $39.64 \mu\text{m}$.

REFERENCES

- [1] M. C. Flemings: Behavior of metal alloys in semi-solid state. Aluminum Transactions B, 1991 - Springer.
- [2] R. Canyook, S. Petsut, S. Wisutmethangoon, M. C. Flemings, J. Wannas: Evolution of microstructure in semi-solid slurries of rheocast aluminum alloy.
- [3] Z. Fan: Semisolid Metal Processing. International Materials Review, Vol 47, 2002.
- [4] E.T. Budiman: Aluminum: Effect of Water Cooling on the Production of Al-Si Thixotropic Feedstock by Cooling Slope Casting.
- [5] A. Blanco, Z. Azpilgain, J. Lozares, P. Kapranos, I. Hurtado: Rheological characterization of A201 aluminum alloy.
- [6] T. Witulski: The thixofomoability of aluminum alloys. Proceedings of the 5th Int. Semi-solid processing of alloys and composites, Golden, Co. USA, pp. 353-360, 1998.
- [7] E. R. Freitas, E. G. Ferracini, M. Ferrante: Microstructure and rheology of an AA2024 Aluminium Alloy in the Semi-Solid State, and Mechanical Properties of a Back-Extruded Part.
- [8] E. Oberg, F. Jones, H. Horton, H. H. Holbrook: Machinery's Handbook. Industrial Press, 2000.
- [9] P. Kapranos: Course on Semi Solid Metal Processing, Thixoforming Group, University of Sheffield, 1994.
- [10] S. Menargues et al: Simulation of the Semi-Solid Rheocasting process in an Automotive Component, Barcelona, Spain, 2012.