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RESEARCH ARTICLE OPEN ACCESS

Studying the Rheo and Thixo-routes processing for the semi-solid metals and its effect on the mechanical properties

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ABSTRACT:
Semi solid metals forming is a technique for metals processing that involves semi-solid fabrication and forming between the liquefaction and solidus states. For successful forming, the semi-solid metal micro structure has to consist a globular grains of solid in the liquid matrix. This behavior is called thixotropically where when the metal is sheared, it moves and when it is at rest, it solidify again. There are two main categories; rheo-routes and thixo-routes. The rheo-route is one process step where the semi-solid metal slurry is prepared with globular grains microstructure by stirring and cooling, which is pressed into die for shaping without solidification stage. The thixo-route is the process where the melted material is passed through solidification stage which tend the material in the form of a billet and treated when it is heated into the semi-solid state it has a non-dendritic grains "globular" microstructure and is then pressed into the die. To stand on the change in mechanical properties changing with each process technique; 6 samples will be prepared for brass alloy Cu- Zn with a different weight percentage; (75%-25%), (70%-30%), and (65%-35%). 3 out of 6 will be prepared by rheo-casting technique while the other 3 will be prepared by Thixo-casting technique. Tensile, shear strengths and hardness tests will be implemented to relate the change in microstructure of semi-solid metals with the mechanical properties changing. High tensile strength and hardness was achieved by rheo-casting process while high shear strength was achieved by thixo-casting process.

Key words: Semi-solid metals "SSM", rheo-casting, thixo-casting, casting, viscosity, shear rate, mechanical properties.

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I. INTRODUCTION

Semi-solid metal processing is one of the recent technologies for metal processing and forming. It differs from the conventional techniques which use casting method as liquid forming technique or forging as solid forming technique. Semi-solid metal processing involves the processing of alloys between liquefaction state and solid state in order to produce superior mechanical properties.

For successful processing and enhanced mechanical properties, the microstructures should have solid near-spherical or globular grains with a wide transition area from solidus to liquidus. The material behavior became thixotropically.

Thixotropically behavior is the property of the flow behavior in semi-solid processing and it relates the non-Newtonian fluid. Where, when the material state is 50% solid and is applied to shear force, the cohesive force between molecules will break up, its viscosity will decrease, and it will flow like a liquid. On the other hand, if it is at rest for a certain time, globular cohesive will increase the metal viscosity of the material and it can be handled as a solid. Thixotropically behavior is an advantage to have a high quality product shape.

Otherwise, in conventional casting, the dendritic microstructure traps the liquid inside between the dendritic arms and it is difficult to flow it freely, Moreover, segregation, agglomeration, and shrinkage during solidification may be occurred. This causes low quality in the final product.

Today, non-ferrous metals, such as aluminum, copper, and magnesium are examples of semi-solid metals casting.

SSM processing technologies can be categorized based on the state of the starting material: rheo-routes and thixo-routes. Rheo-route tends to the slurry preparation of semi-solid metals with globular grains microstructure by stirring from a liquid state, which is pressed into a die for shaping without an solidification process as shown in figure 1.1.

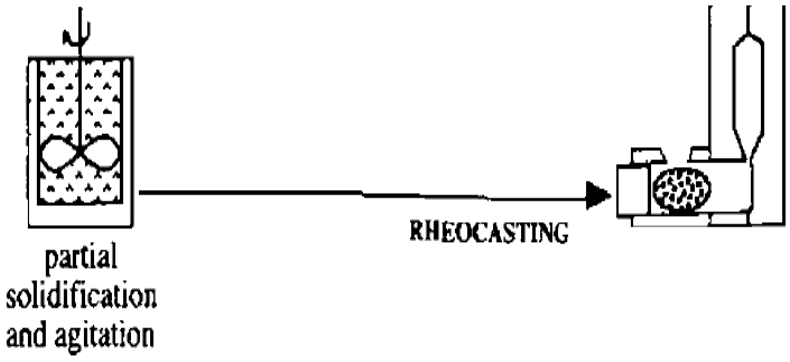

Figure I-1 Rheo-casting process of SSM

So, this is important to use stirrer or agitator in rheo-route forming to apply the shear force and break the dendritic structure to spheroidal grains during cooling process. Stirring angular velocity and blade angle affect on the spheroidal grains size and the enhanced mechanical properties. Difference between the dendritic casting and periodical microstructure that formed by rheo-casting is shown in figure 1.2.

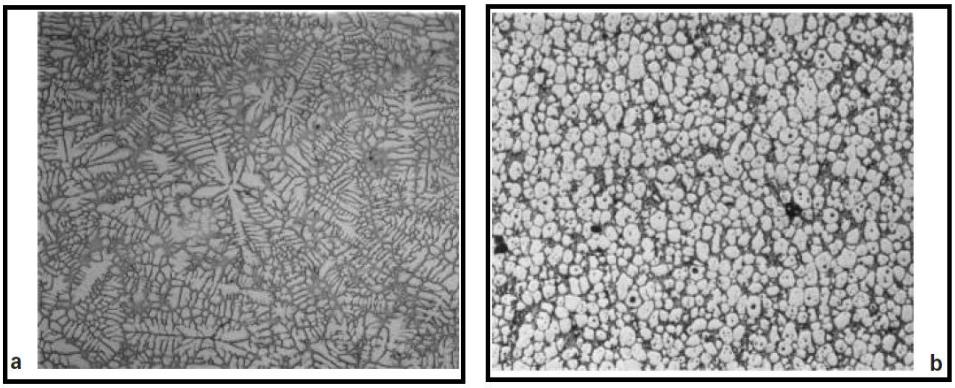

Figure I-2 (a) dendritic cast microstructure – (b) spheroidal microstructure

While, the thixo-route is the process where the melted material is passed through solidification stage which tend the material in the form of a billet and treated when it is heated into the semi-solid state it has a non-dendritic grains "globular" microstructure and is then pressed into the die. Thixo-forming process is shown in figure 1.3.

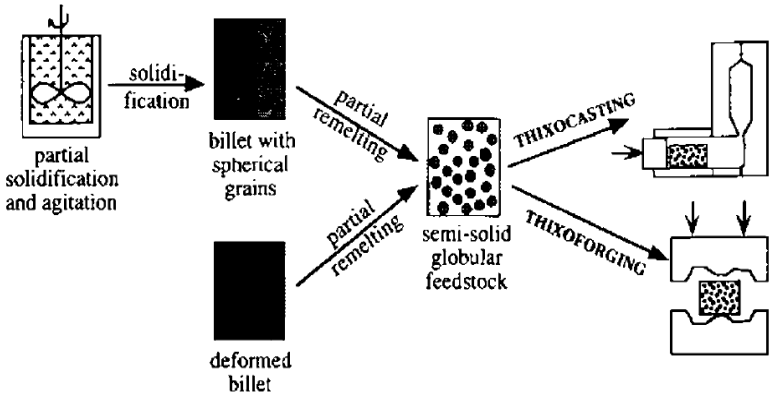

Figure I-3 Thixo-forming SSM process

Thixoforming process has several applications because of it has high ability to produce the high-quality parts with lower cost compared with those of conventional forming techniques such as casting or forging. Differences between rheo-casting and thixoforming are illustrated in Figure 1.4.

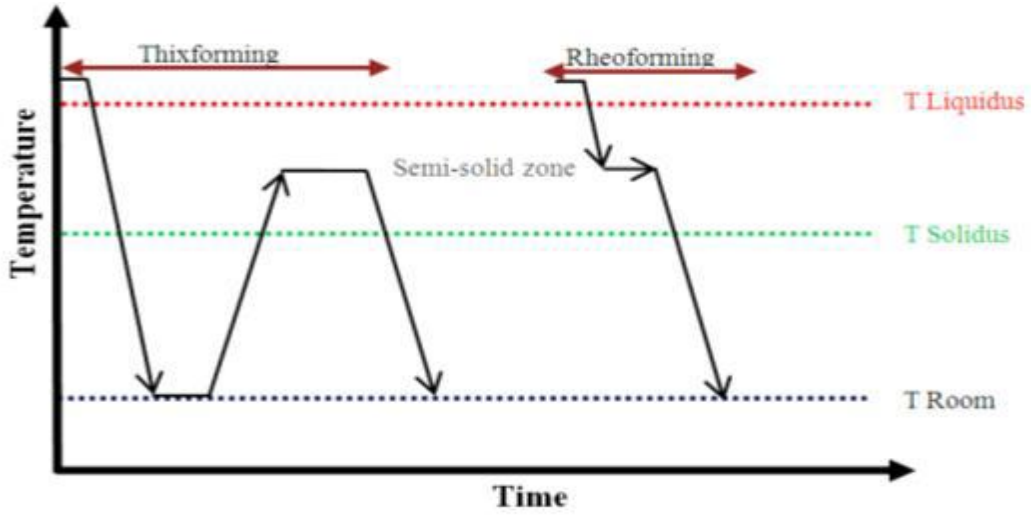

Figure I-4 Difference between Rheo-routes and Thixo-routes for SSM

II. MATERIAL AND METHODS

Rheo-route and Thixo-route process of semi-solid metals have different ways to create globular grains which enhance the mechanical properties. So, samples were prepared by each process technique for copper – zinc alloy with different compositions. Mechanical properties were measured for each sample and compared with each other.

2.1. Samples Description

Six samples were prepared for brass alloy "copper-zinc" with different weight percentage. Three out of six samples were prepared by rheo-route while the other three samples were prepared by thixo-route processing technique. Samples were names as shown in table 2.1.

Table 2.1. Samples description

Sample	Sample Symbol	Cu-Zn composition %	SSM processing technique
1	B-1r	75-25%	Rheo-route
2	B-2r	70-30%	Rheo-route
3	B-3r	65-35%	Rheo-route
4	B-1t	75-25%	Thixo-route
5	B-2t	70-30%	Thixo-route
6	B-3t	65-35%	Thixo-route

2.2. Instrumentations Used

The melting temperature range and liquid-solid fraction were determined by differential scanning claromity (DSC). High temperature DSC "Pegasus 404F3" that has an operating temperatures -150°C to 2000°C. The Cu-Zn alloy was heated up to 900°C. '

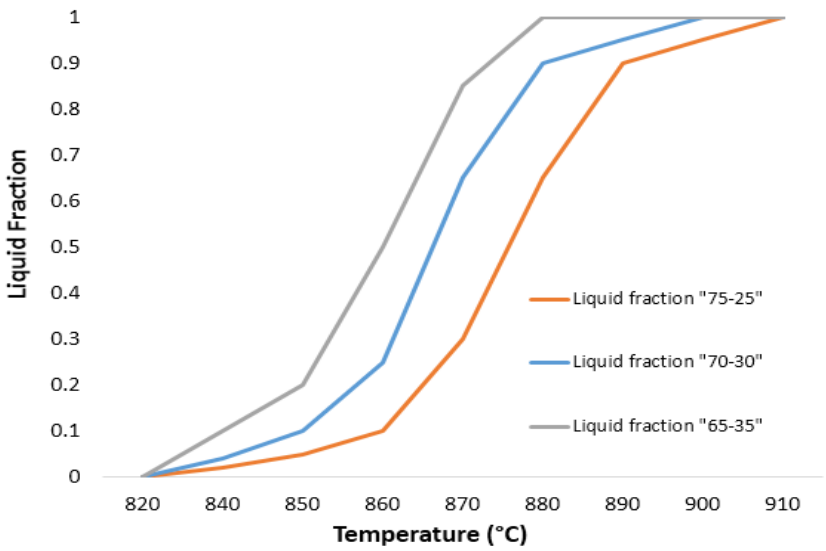

Figure II2-1 DSC for three different Cu-Zn composition

For rheo-route casting; mechanical stirrer is used. It consist of an electric motor that rotate the vanes or blades "made of stainless steel" immersed in the mixed liquor. Mechanical stirrers are commonly used in industrial mixing or dispersing solid and liquid material. All samples were stirred at 350 RPM for all samples.

Also, a universal testing machine (UTM) is the machine used to measure the mechanical properties (tension, compression etc.) of a test specimen by applying variable tensile and compressive.

Moreover, hardness Brinell tester is used to measure the hardness of each sample. In the Brinell hardness test, an optical method, the size of indentation left by the indenter (hard ball) is measured. As increasing the indent in the surface of the work piece, the tested material is considered softer.

2.3. Samples preparation

From DSC curve; it is shown that the semi-solid Cu-Zn alloy had to be processed between 870 to 880°C to be between solid and liquidus states. For samples "B1-r", "B2-r", and "B3-r"; raw materials were prepared with the predetermined compositions and one by one was melted in graphite crucible by induction and the near liquidus slurry (880C) of alloy was stirred at 350 RPM for 10 minutes using stirrer. Then, it was poured in the rheo-casting die with cooling to form the final sample shape. Rheo-casting process is shown in figure 2.2.

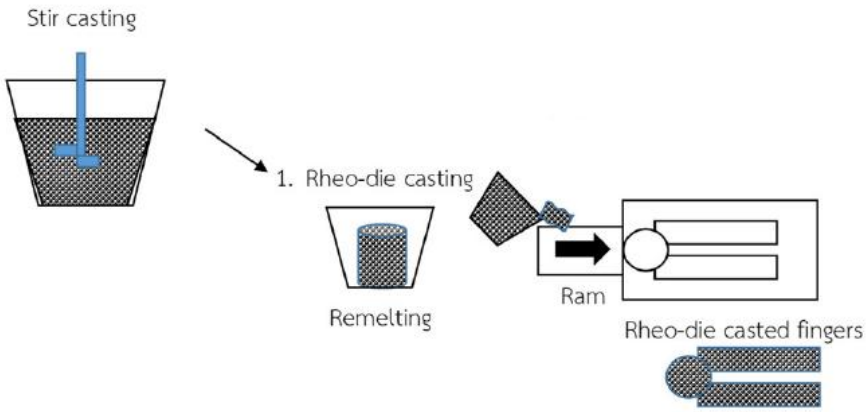

Figure II2-2 Samples B1-r, B2-r, and B3-r preparation "Rheo-casting"

On the other hand; samples "B1-t"," B2-t", and "B3-t" raw materials were prepared and melted in graphite crucible by induction. Then it was solidified in order to create the globular grains in microstructure in the room temperature. To form the final product, it was reheated again and casted in the die to have the final sample shape as shown in figure 2.3.

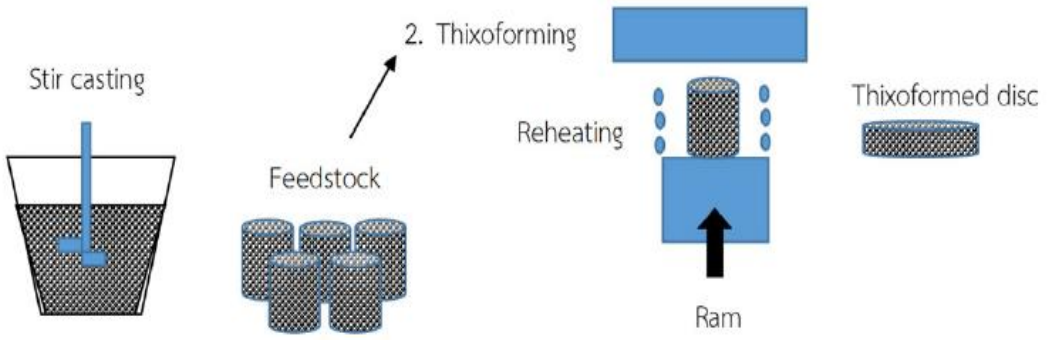

Figure II2-3 Samples B1-t, B2-t, and B3-t preparation "Thixo-casting"

III. RESULTS AND DISCUSSION

Tensile, shear, and hardness tests were performed for each sample. Comparisons were prepared to show the effect of the SSM process technique in the mechanical properties.

3.1. Tensile strength comparison

From figure 3.1; it is shown that rheo-route technique increase the alloy tensile strength at the same alloy composition compared with thixo-route. This is due to the stirring effect that cause less globular grain size and less segregation and agglomeration. Also, it was noted that increasing in zinc weight percentage; the tensile strength decreased, where the tensile strength of zinc is lower than the copper.

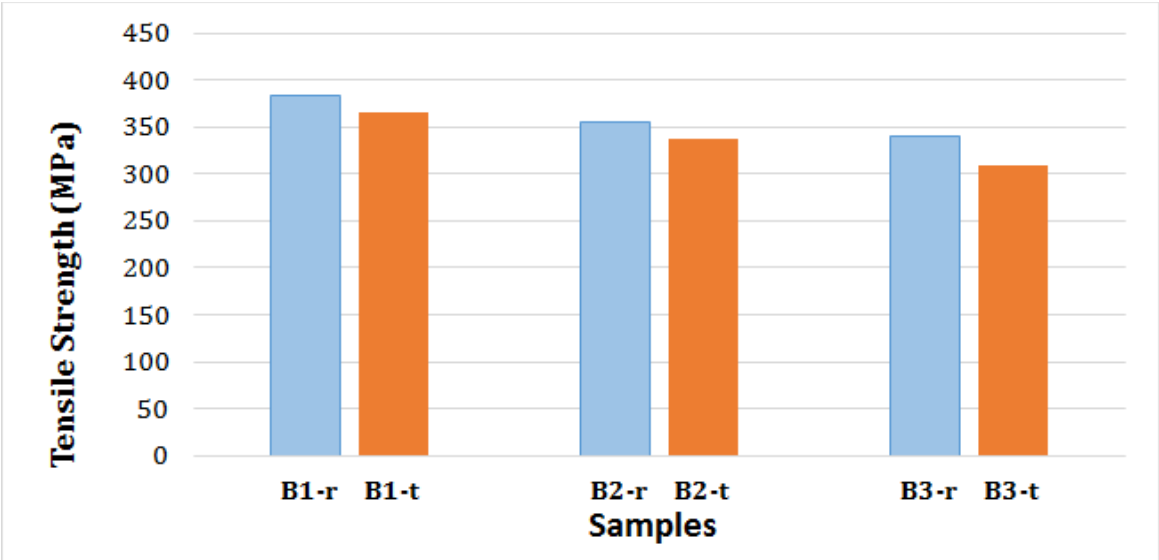

Figure III3-1 Tensile strength comparison for Samples whether Rheo or Thixo routes

3.2. Shear strength comparison

From figure 3.2; it is shown that thixo-route technique increase the alloy shear strength at the same alloy composition compared with rheo-route technique. This is due to high rheological property and low cohesive force in the microstructure that decrease the viscosity and the shear strength.

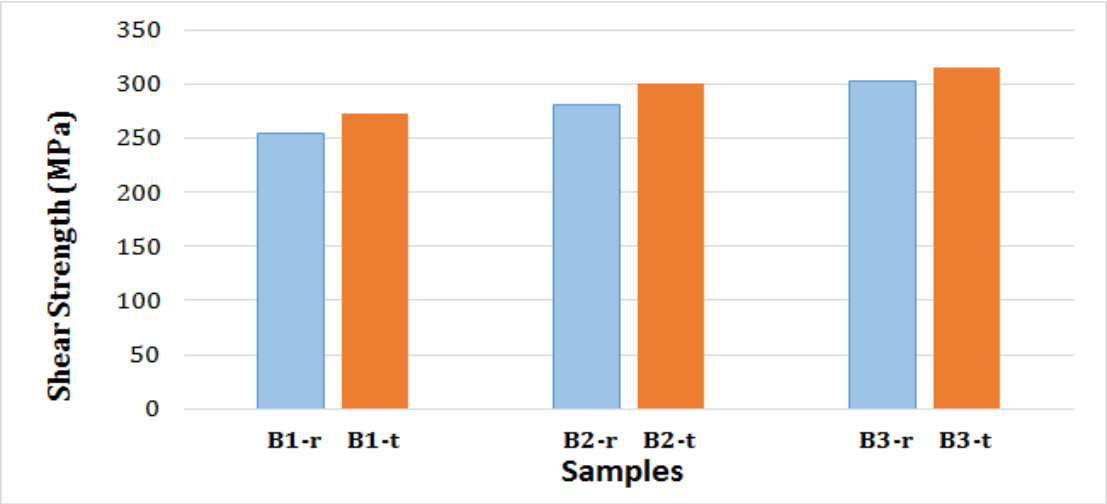

Figure III3-2 Shear strength comparison for Samples whether Rheo or Thixo routes

3.3. Hardness comparison

From figure 3.3; due to less segregation, less agglomeration, and small globular grain size that produced from the stirring effect; the hardness of the rheo-route alloy was increased compared with thixo-route alloy. Also, it was noted that increasing in softer metal "zinc" weight percentage; the alloy hardness decreased.

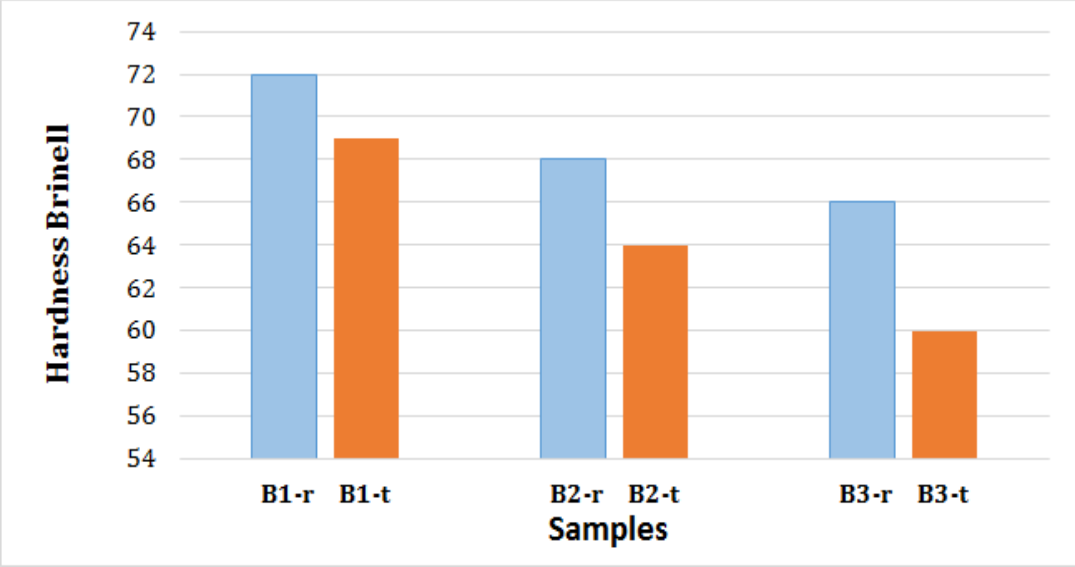

Figure III3-3 Hardness comparison for Samples whether Rheo or Thixo routes

Hence, rheo-casting products have high tensile strength and high hardness compared with thixo-casting products. As increasing the stirring rotational speed or stirring time; the tensile strength and hardness of the product will be improved.

IV. CONCLUSION

Mechanical properties enhancement in semi-solid metals relate with the formation of globular grains in the microstructure that are formed by stirring and continuous cooling in rheo-route process or by cutting in billets and have the non-dendritic structure during the solidification intermediate stage in thixo-route process. It was concluded that each technique has a specific improvement for the mechanical properties as below:

- In order to increase the hardness of the copper zinc alloy; it is recommend to perform rheo-casting with high RPM stirring because of formation of small size slurry.
- In order to increase the tensile strength of the copper zinc alloy; it is recommend to perform rheo-casting with a long time stirring.
- In order to increase the shear strength of the copper zinc alloy; it is recommended to perform thixo-casting.

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