International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-5, March 2019

Comparative Ways and Means for Production of Nondendritic Microstructures

N. K. Kund

***Abstract:** For best casting practices, dendritic microstructure is not preferred as it results in poor mechanical properties. The practices like mechanical stirring, electromagnetic stirring (EM stirring) and cooling slope method (CS method), have demonstrated to be effective in generating nondendritic microstructures. But, the current studies include the micrographs of the samples observed from the semisolid cast billets molded through both EM stirring and CS method. It also encompasses the relative microstructural characteristics like grain size and shape factor of the samples relating to both EM stirring and CS method. It is perceived that the grain size varies from 60 µm to 70 µm, while, the shape factor varies from 0.7 to 0.8. Hence, it is pretty flawless to say that the microstructural characteristics like grain size and shape factor are very much comparable with each other. However, the CS method is the most ideal one on account of simplicity, low equipment together with running/maintenance costs and ease of control/handling, besides, the near net shape components production, and so bears the maximum potential for commercialization in a wide range.*

***Index Terms:** EM Stirring, CS Method, Nondendritic Microstructures, Mechanical Stirring.*

I. INTRODUCTION

Rise in responsiveness about green guidelines results in greater demand of materials and products which are environmental ecofriendly with ecologically sustainable as well. This leads to search for materials and products which are physically realizable from the standpoint of economic and environmental feasibility. In this perspective, some metal alloys, which have the potential to meet most of the stated requirements, are found to be extremely vital for our society. As some metal alloys are used in almost all industrial sectors including safety-critical applications, there is a continuous need for innovation of defect free and robust production processes. Some of these methods related to casting practices are pressure die casting, gravity die-casting, squeeze casting, liquid metal forming etc. Although the components thus manufactured are within the acceptable cost limit with enhanced mechanical properties, a common problem encountered in these processes is the evolution of dendritic microstructure morphology of the cast products, resulting in defects and cracking. In addition, some other problems faced by these casting practices are shrinkage, porosity, and turbulent filling of mould. Search for new techniques to surmount these problems paved the way for a novel forming practice, termed as the semisolid casting, for manufacturing of commercial products with defect free microstructure and excellent properties.

II. SEMISOLID PROCESSES

Normally, metal alloys are cast beyond liquidus temperature, thus producing dendritic microstructure. However, semisolid casting of alloys (occurring between liquidus and solidus temperatures) result in globular and non-dendritic microstructure morphology. The semisolid casting is advantageous in many senses over the conventional metal alloy casting processes. A few of these are, high production rate thus used for mass production, excellent resistance to high pressures caused by hydraulic and pneumatic means, enhanced mechanical properties like strength, elongation, etc. leading to material saving and cost reductions, negligible shrinkage and porosity with low forming efforts, very high formability can fill easily even intricate and complex cavities of die with better accuracy and precision, reduced machining costs due to near net shape, negligible residual stresses, products can be easily heat treated for further improvement in strength, hardness, globularity etc., components produced can be joined together by LASER, TIG, MIG or WIG welding, to produce a bigger and sizable product. Though there are several advantages of semisolid casting, however, it still suffers from few drawbacks such as high equipment costs, high running/maintenance costs, besides, the need for skilled, trained and experienced operators. There are several ways of classifying semisolid processes depending upon the means of slurry preparation, kind of application and so on. A broad way of categorizing the same is as illustrated in figure 1.

III. FUNDAMENTALS OF SOLIDIFICATION

It is meaningful to have a delve into a representative binary eutectic alloy system (with a partition coefficient $k_p < 1$ as demonstrated in figure 2) for understanding the physics of solidification of any binary alloy. The solidification of a binary alloy of initial composition C_i begins with the formation of a small amount of solid having composition k_pC_i at temperature T_L, in the very first instance of onset of solidification. On account of difference in solubility of the solute in the solid and liquid phases (solubility of solute in solid is much smaller compared to that of liquid), the balance solute is rejected (at the solid-liquid interface) to the surrounding liquid matrix. As solidification progresses, the remaining liquid keeps getting enriched with solute, and the composition approaches the eutectic, as illustrated in figure 2. Hence, the solid that forms in a later stage of solidification contains more amount of solute.

Manuscript published on 30 March 2019.
***Correspondence Author(s)**
N. K. Kund, Department of Production Engineering, Veer Surendra Sai University of Technology, Burla, Sambalpur (Odisha), India.

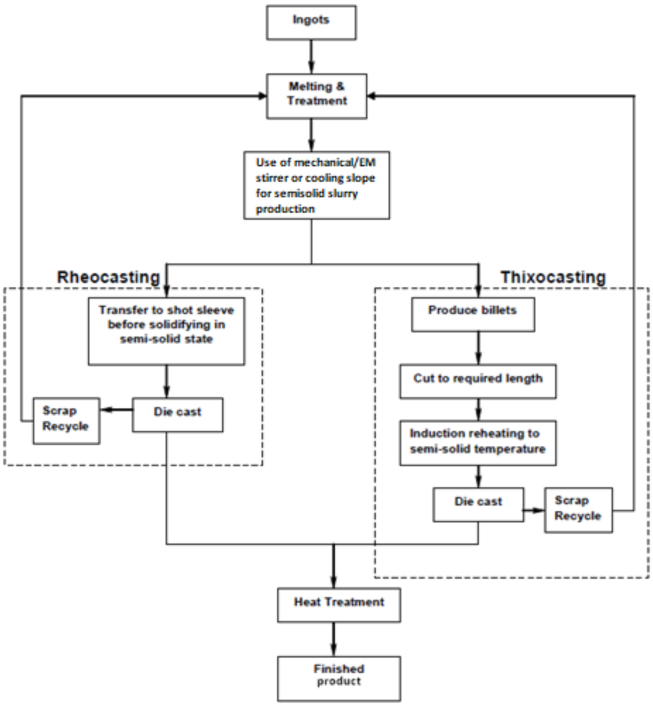

Figure 1. Classification of semisolid processes

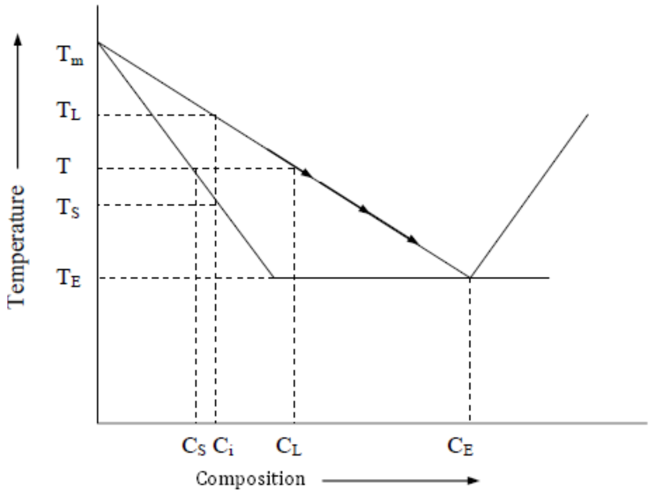

Figure 2. Typical phase diagram of a binary alloy

An overview of a solidification process accompanying appearance of different phenomena along with solid phase movement by melt convection is demonstrated in figure 3.

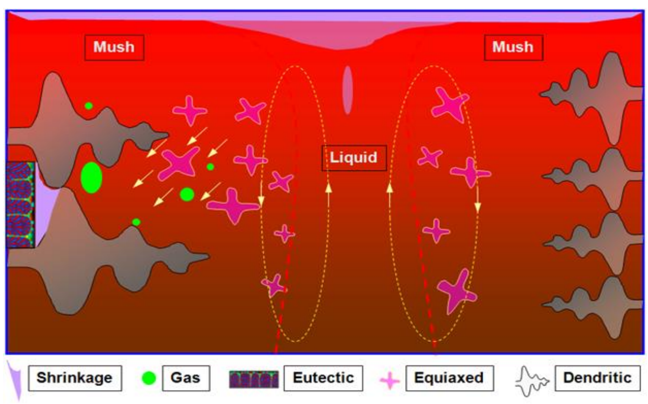

Figure 3. Schematic of an overview of a solidification process

Figure 4 demonstrates the schematic of mechanism of shearing of dendrites (i.e. dendrite fragmentation) caused by dendrite arm bending and dendrite arm root remelting.

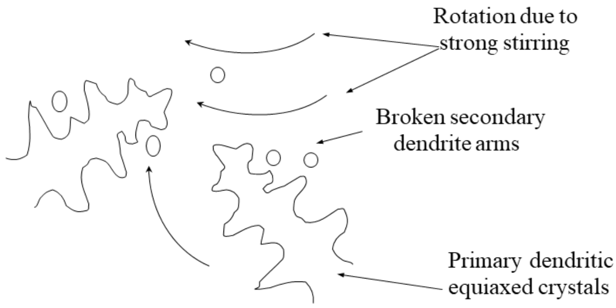

Figure 4. Schematic of mechanisms of shearing of dendrites by melt stirring

IV. METHODS OF PRODUCING NONDENDRITIC MICROSTRUCTURES

It is obvious form the earlier description that globular non-dendritic microstructure morphology can be achieved by forced convection caused by vigorous agitation. Some of the slurry production methods are described below briefly.

A. Mechanical Stirring

Figure 5 illustrates schematic sketch of a mechanical stirring system. This method is simplest and oldest, but it suffers from some drawbacks such as unwarranted reaction between the mechanical impeller and the corrosive liquid metal, and entrapment of gases due to the direct melt agitation.

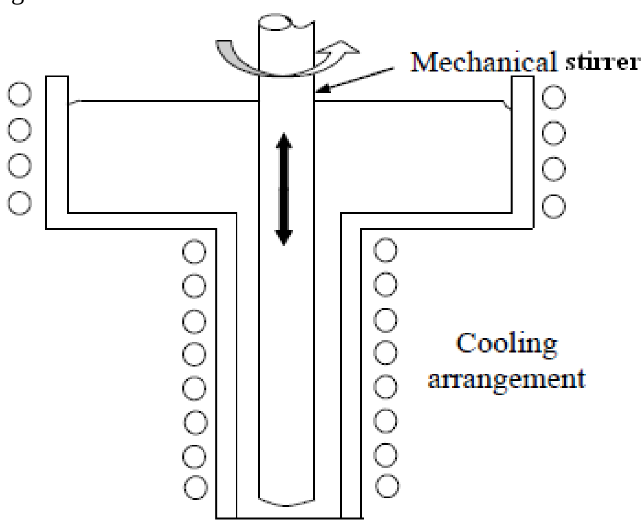

Figure 5. Schematic of mechanical stirring system

B. Electromagnetic Stirring

It is a non-intrusive method which involves subjecting the melt to undergo partial solidification in presence of a strong electromagnetic force field. The vigorous stirring by the electromagnetic force field creates the necessary circulation which causes shearing of dendrites formed at the solid-liquid interface.

Retrieval Number: E3178038519/19©BEIESP
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-5, March 2019

Figure 6 depicts a schematic sketch of a typical electromagnetic stirring (EM stirring) system in the context of direct chilled (DC) casting. Since there is no physical contact between the melt and the device, it is advantageous compared to the mechanical stirring system. However, it is a relatively more expensive process because of high equipment cost and electric power consumption.

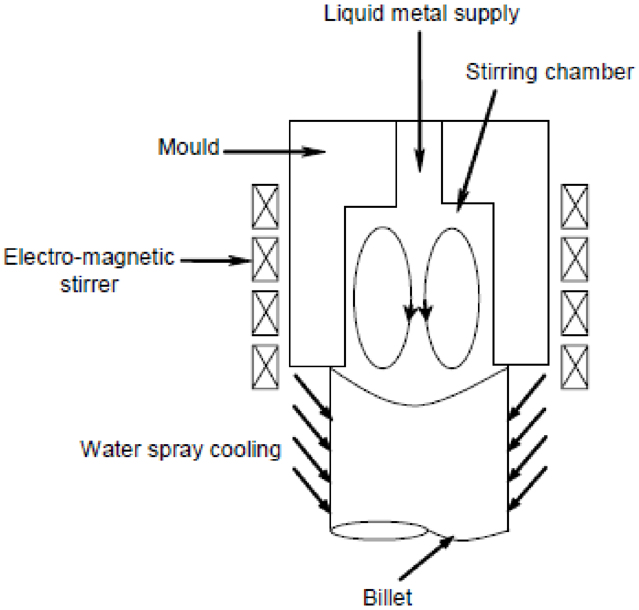

Figure 6. Schematic of an electromagnetic stirring system

C. Cooling Slope Method

It is a simple but effective method of semisolid slurry preparation to produce globular, non-dendritic microstructure morphology. In this method, the melt is poured down an inclined plate which is cooled from the bottom by counter flowing water. The melt, while flowing down, solidifies partially on the plate causing dendrite formation on slope wall. The plate inclination, along with gravity, provides the necessary inertia to the flowing liquid for dendrite breaking and to form slurry of non-dendritic microstructure at the slope exit. A schematic sketch of the cooling slope setup is portrayed in figure 7.

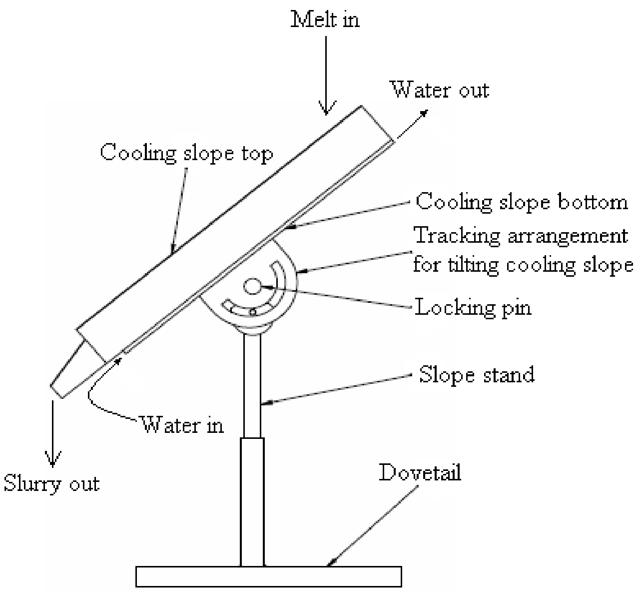

Figure 7. Schematic sketch of the cooling slope setup

Besides the methods already cited, there are some other methods of producing non-dendritic microstructures, either by melt agitation processes such as mechanical and ultrasonic vibration, or by dendritic growth control process such as low superheat, stress-induced and melt-activated (SIMA) process and addition of chemical refiners.

V. RESULTS AND DISCUSSIONS

Figures 8 and 9 illustrate the micrographs of the samples obtained from the semisolid cast billets produced through both electromagnetic stirring (EM stirring) and cooling slope method (CS method), respectively. In addition, figure 10 depicts the comparative microstructural properties (both grain size and shape factor) of the samples pertaining to both EM stirring and CS method.

It is witnessed that the grain size ranges between 60 µm and 70 µm, whereas, the shape factor ranges between 0.7 and 0.8. Thus, it is quite obvious that the microstructural properties like grain size and shape factor are very much comparable with each other. However, the cooling slope method is the most preferred one because of simplicity, low equipment along with running/maintenance costs and ease of control/handling.

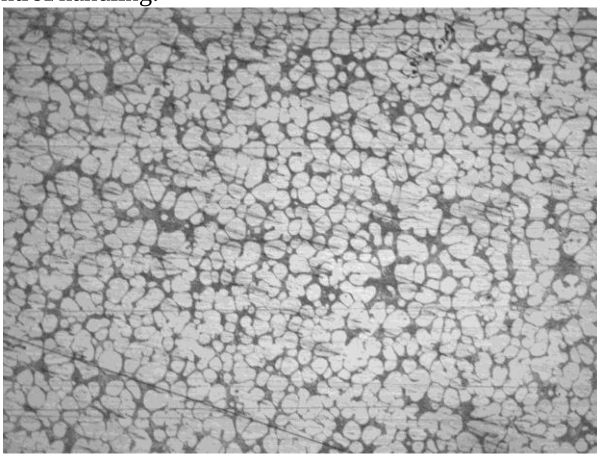

Figure 8. Micrograph of sample involving EM stirring

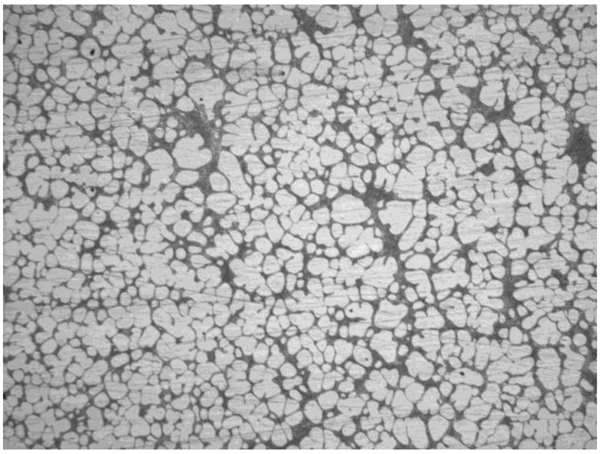

Figure 9. Micrograph of sample involving CS method

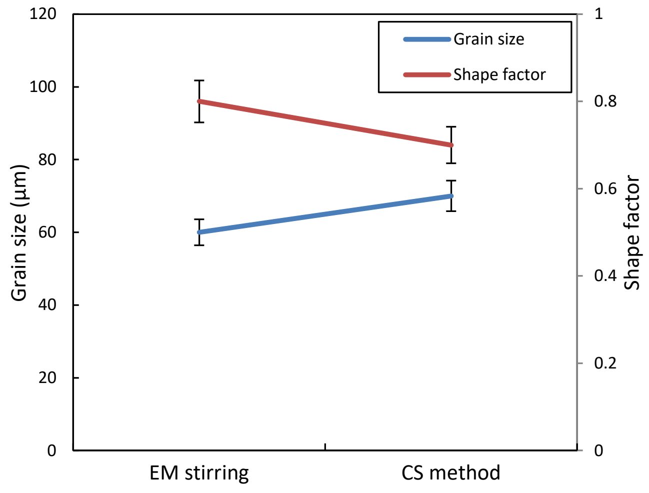

Figure 10. Comparative microstructural properties of samples involving both EM stirring and CS method

VI. CONCLUSION

The techniques like mechanical stirring, electromagnetic stirring (EM stirring) and cooling slope method (CS method), have proved to be effective in producing nondendritic microstructures. However, the present investigations encompass the micrographs of the samples found from the semisolid cast billets formed through both EM stirring and CS method. It also involves the relative microstructural properties like grain size and shape factor of the samples concerning both EM stirring and CS method. It is observed that the grain size ranges between 60 µm and 70 µm, while, the shape factor ranges between 0.7 and 0.8. Therefore, it is pretty clear that the microstructural properties like grain size and shape factor are very much comparable with one another. Nevertheless, the cooling slope method is the most favored one owing to simplicity, low equipment together with running/maintenance costs and comfort of control/handling, in addition to the near net shape components manufacturing, and therefore holds the maximum potential for commercialization in a vast range.

ACKNOWLEDGMENT

The essential support from VSSUT Burla for this text is greatly acknowledged. The author is certainly grateful to the journal editorial and review board for their encouraging and productive reviews to this article.

REFERENCES

1. Kund N. K., Dutta P., 2010, Numerical simulation of solidification of liquid aluminium alloy flowing on cooling slope, Trans. Nonferrous Met. Soc. China, Vol. 20, pp. s898-s905.
2. Kund N. K., Dutta P., 2012, Scaling analysis of solidification of liquid aluminium alloy flowing on cooling slope, Trans. Indian Institute of Metals, Vol. 65, pp. 587-594.
3. Kund N. K., 2014, Influence of melt pouring temperature and plate inclination on solidification and microstructure of A356 aluminum alloy produced using oblique plate, Trans. Nonferrous Met. Soc. China, Vol. 24, pp. 3465−3476.
4. Kund N. K., 2015, Influence of plate length and plate cooling rate on solidification and microstructure of A356 alloy produced by oblique plate, Trans. Nonferrous Met. Soc. China, Vol. 25, pp. 61−71.
5. Kund N. K., Dutta P., 2015. Numerical study of solidification of A356 aluminum alloy flowing on an oblique plate with experimental validation, J Taiwan Inst. Chem. Ers., Vol. 51, pp. 159−170.
6. Kund N. K., Dutta P., 2016, Numerical study of influence of oblique plate length and cooling rate on solidification and macrosegregation of A356 aluminum alloy melt with experimental comparison, J. Alloys Compd., Vol. 678, pp. 343−354.
7. Kund N. K., 2018, Effect of tilted plate vibration on solidification and microstructural and mechanical properties of semisolid cast and heat-treated A356 Al alloy, Int. J. Adv. Manufacturing Technol., Vol. 97, pp. 1617−1626.
8. Kund N. K., 2019, EMS route designed for SSM Processing, International Journal of Engineering and Advanced Technology, Vol. 8, pp. 382−384.
9. Kund N. K., 2019, Cooling slope practice for SSF Technology, International Journal of Engineering and Advanced Technology, Vol. 8, pp. 410−413.

AUTHORS PROFILE

Dr. N. K. Kund has completed Ph.D. in Mechanical Engineering from Indian Institute of Science Bangalore. He has also obtained M.Tech. in Mechanical Engineering from Indian Institute of Science Bangalore. Furthermore, he has obtained B.Tech.(Hons) in Mechanical Engineering from IGIT Sarang, Utkal University Bhubaneswar. He has published several research papers in international journals and also having more than 20 years of both teaching and research experience. He is currently working as Associate Professor in the Department of Production Engineering, Veer Surendra Sai University of Technology Burla (A Government Technical University).

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)