© 2018 IJSRST | Volume 4 | Issue 5 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Understanding of Rheology of Semisolid A356 Alloy during Isothermal Deformation – An Overview

Sudip Simlandi
Department of Mechanical Engineering, Jadavpur University, Kolkata, West Bengal, India

ABSTRACT

In recent days, semisolid metal forming (SSF) is a developing casting technique for producing critical aerospace, military and automotive components. The importance of the SSF process relies primarily on distinct rheological behaviour of the semisolid alloy during casting. For successful implimentation of the SSF technique, the rheology of semisolid slurries has to be properly studied. Thus, in the present work, the author offered an overview of the rheological behavior of A356 alloy in semisolid state. The author discussed on models for evolution of apparent viscosity of the semisolid slurry during isothermal deformation.

Keywords: Isothermal deformation, Stirring, Semisolid slurry, Rheology and Apparent viscosity

I. INTRODUCTION

It is observed that the dendritic microstructure in casting is not desirable as it results in poor mechanical properties. The way to avoid this dendritic growth is to enhance the fluid flow in the mushy zone by stirring (Spencer *et al.* [1], Vives [2], Joly and Mehrabian [3], Flemings [4]). The enhanced fluid flow detaches the dendrites from the solid-liquid interface and carries them into the melt to form slurry. This slurry having globular solid phase consists of fragmented dendrites, instead of the conventional dendritic structure, immersed in liquid. The globular microstructures in the semisolid range provide less resistance to flow even at high solid fraction. This property has a great potential in the casting applications. The above principle is the basis of a new manufacturing technology called the semisolid forming (SSF). The new SSF process provides considerable benefits in product quality and productivity, primarily because of the non-turbulent filling of the die, which results from controllable viscosity of the semi-solid slurry. As flow shrinkage porosity, stress and thermal stress are also lower; the SSF process has the capability of forming intricate and near-net-shaped parts. Recently, the SSF process is a developing technique in India and much effort has been given to commercialise the technique. There are two basic forming methods of the SSF process, namely Rheocasting and Thixocasting (Flemings [4]). In a typical rheocasting process, the semi-solid slurry is prepared in presence of stirring directly beside a die and the slurry is immediately cast into parts in the die. On the other hand, in the thixocasting process, the billets having non-dendritic microstructure are first produced through a direct chilled (DC) casting operation along with stirring. These non-dendritic billets are called ‘raw materials’ for further processing. Subsequently, this raw material is reheated to a temperature in the “mushy” zone and processed into final parts using a die-casting machine. The continuous casting in presence of stirring involves cooling, solidification of the melt, fragmentation of dendrites at the solid-liquid interface and the transport of fragmented dendrites in the bulk liquid, and finally the formation of semi-solid slurry which have distinct rheology. The transport phenomenon during the solidification process in presence of stirring is fairly complex because of the movement of fragmented dendrites and the distinct rheological behaviour of the slurry. The rheological behaviour of the slurry and the transport phenomena during solidification are not well known. It is also found that the numerical models related to the SSF process are less developed and the experimental prediction is more expensive. Therefore, in this review, the author presents literature on evolution of apparent viscosity and shear rate during isothermal deformation and subsequently on the modeling of rheology.

II. MODELLING OF RHEOLOGY OF A356 ALLOY SLURRY DURING ISOTHERMAL DEFORMATION

It is already discussed that, in thixocasting, the alloy is deformed isothermally at semi-solid state. Therefore, a review on rheological behaviour is necessary for understanding of the above process. The modelling based rheological behaviour is reviewed during isothermal deformation. For understanding the modelling of the thixotropic behavior of alloys in semisolid state, related research works are reviewed. Burgos *et al.* [5] reported that there exists a shear-dependent finite yield stress which is modeled using the Herschel-Bulkley fluid model and introducing a structural parameter to describe the kinetics of the agglomeration and de-agglomeration phenomena. Koke and Modigell [6] found that the yield stress is strongly depends on the microstructure and the degree of agglomeration of the solid phase and increases strongly with rest time because of the agglomeration of the suspended solid particles. They also found that the steady-state rheological behavior is shear thinning. Gautham and Kapur [7] presented a model for unsteady state shear stress of the semi-solid metal suspensions by introducing a structural parameter. Dullaert and Mewis [8] presented a general structural kinetics model to describe the flow behavior of thixotropic systems. A model proposed by Alexandrou [9] is able to predict the flow behavior of the semi-solid slurries. In that work, the variation of an apparent viscosity demonstrates the complexity of the flow behavior of slurry. Alexandrou *et al.* [10] presented the rate of breakdown and rate of buildup in semi-solid slurry during shearing. They used the Herschel-Bulkey model as a standard thixotropic model for modeling of the semi-solid metal suspensions. However, the semisolid alloys show a complex and distinct flow behavior during semisolid processing. This complex flow behavior during processing changes the process variables and conditions continuously in a way that is very different than the convectional processing. Simlandi *et al.* [11] investigated numerically the thixotropic property of a semisolid aluminium alloy (A356) under deformation where the flow between two parallel plates is considered. In the work, author represented the flow field by the momentum conservation equation where the non Newtonian behavior of the semisolid alloy is incorporated considering the Herschel–Bulkley model as

$$\tau = \left[\frac{\tau_0(\lambda)}{\dot{\gamma}} + K\dot{\gamma}^{n-1} \right] \dot{\gamma} \qquad (1)$$

where the rate of strain ($\dot{\gamma}$) is given as $\dot{\gamma} = \frac{\partial u}{\partial y}$ and $\tau_0(\lambda) = \lambda \tau_0$. The structural parameter (λ) represents the time dependent semisolid behavior, which is first introduced by Burgos *et al.* [12]. In their work (Burgos *et al.* [12]), the evolution of the structural parameter (λ) with time (*t*) is considered as

$$\frac{D\lambda}{Dt} = \alpha_0(1-\lambda) - \alpha_1 \lambda \dot{\gamma} \exp(\alpha_2 \dot{\gamma}) \qquad (2)$$

They predicted the thixotropic behavior of A356 alloy in transient and steady state conditions. Hence, to incorporate the sudden change in velocity of the moving plate and for the simplicity in solution, an apparent viscosity (μ_a) of the semisolid alloy is considered. The sudden increase or decrease in the velocity (U_{LP}) of the lower plate is considered as $U_{LP} = U_{steady} + U_{increament}$, where U_{steady} is the steady velocity and $U_{increament}$ is the increment in velocity.

The corresponding time dependent velocity distribution is given as

$$u = U_{steady}\left(1-\frac{y}{H}\right) + U_{increament}\left[\left(1-\frac{y}{H}\right) - \frac{2}{\pi}\sum_{k=1}^{\infty}\frac{1}{k}\exp\left(-k^2\pi^2\frac{\mu_a t}{\rho H^2}\right)\sin\left(\frac{k\pi y}{H}\right)\right] \quad (3)$$

$$\dot{\gamma} = -\frac{U_{steady}}{H} - U_{increament}\left[\frac{1}{H} + \frac{2}{\pi}\sum_{k=1}^{\infty}\frac{\pi}{H}\exp\left(-k^2\pi^2\frac{\mu_a t}{\rho H^2}\right)\cos\left(\frac{k\pi y}{H}\right)\right] \quad (4)$$

In the Eqs. (3 and 4), an approximate value of the apparent viscosity (μ_a) is assumed. They predicted the apparent viscosity by using the Herschel-Bulkley model (Eq. 1) and the evolution of the structural parameter (Eq. 2). The evolution of structural parameter at different shear rates is shown in Figure 1. Whereas, figures 2 and 3 show variation of shear rate and apparent viscosity during isothermal deformation of A356 alloy respectively.

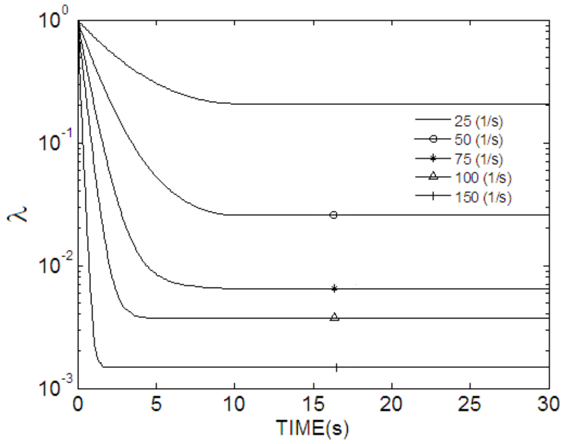

Figure 1. Evolution of λ with time under different shear rates [$\alpha_0 = \alpha_1 = \alpha_2 = 0.01$] (Simlandi et al. [13])

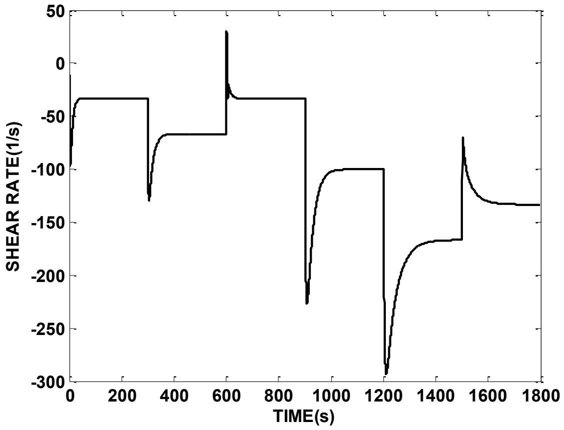

Figure 2. Variation of the shear rate with time at Y= 0.001m (Simlandi et al. [11])

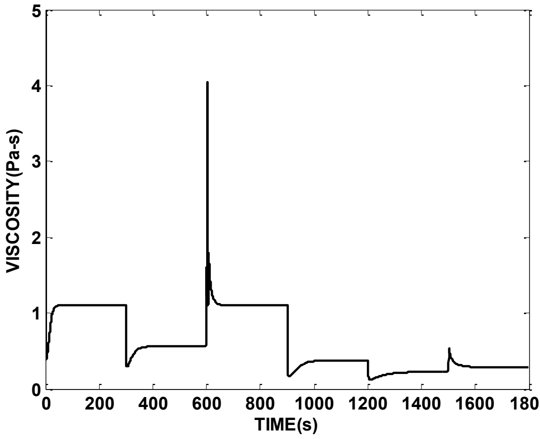

Figure 3. Evolution of apparent viscosity with time at Y= 0.001m. (Simlandi et al. [11])

III. CONCLUSION

In this work, the authors presented an overview of the rheological behavior of alloy in semisolid state during isothermal deformation. It is concluded from the above review during isothermal deformation, apparent viscosity decreases with increasing shear rate due to the agglomeration of the suspended particles.

IV. REFERENCES

[1]. D. B. Spencer, R. Mehrabian, M. C. Flemings. 1972. "Rheological behavior of Sn–15%Pb in the crystallization range", Metallurgical and Materials Transactions, vol. 3, pp.1925-1932.

[2]. C. Vives. 1992. "Elaboration of semisolid alloys by means of new rheocasting processes", Metallurgical and Materials Transactions , vol. B 23, pp.189–206.

[3]. P. A. Joly, R. Mehrabian. 1976. "The rheology of a partially solid alloy", Journal of Materials Science vol. 11, pp.1393-1418.

[4]. M. C. Flemings. 1991. "Behavior of metal alloys in the semisolid state", Metallurgical and Materials Transactions A. vol. 22, pp.957–981.

[5]. G. R. Burgos, N. Andreas, A. N. Alexandrou and V. Entov. 2001. "Thixotropic rheology of semisolid metal suspensions". Journal of Materials Processing Technology, vol.110, pp.164-176.

[6]. J. Koke and M. Modigell. 2003. "Flow behaviour of semi-solid metal alloys". J. Non-Newtonian Fluid Mech., vol. 112, pp.141–160.

[7]. B. P. Gautham and P. C. Kapur. 2005. "Rheological model for short duration response of semi-solid metals", Materials Science and Engineering A, vol. 393, pp. 223–228.

[8]. K. Dullaert and J. Mewis. 2006. "A structural kinetics model for thixotropy", J. Non-Newtonian Fluid Mech., vol.139, pp. 21–30.

[9]. A. N. Alexandrou. 2008. "On the Modeling of semisolid suspentions". Solid State Phenomena, vol.141-143, pp. 17-23.

[10]. A. N. Alexandrou and G. Georgiou. 2007. "On the early breakdown of semisolid suspensions", Non-Newtonian Fluid Mech., vol.142, pp. 199–206.

[11]. S. Simlandi, N. Barman and H. Chattopadhyay. 2013. "Study on Thixotropic Property of A356 Alloy in Semi-Solid State". Solid State Phenomena, vol.192-193, pp. 335-340.

[12]. G. R. Burgos, N. Andreas, A. N. Alexandrou and V. Entov. 2001. "Thixotropic rheology of semisolid metal suspensions". Journal of Materials Processing Technology, vol. 110, pp. 164-176.

[13]. S. Simlandi, N. Barman and H. Chattopadhyay. 2012. "Study on Rheological Behavior of Semi-Solid A356 Alloy during Solidification", Transactions of Indian Institute of Metals, vol. 65(6), pp. 809-814.