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Numerical simulation on thixocasting process of auto box-like

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Abstract. Semi-solid metal processing (thixoforming) is a potential forming technology, which can realize near-net-shape forming process with good quality in one forming step. In this study, semi-solid casting (thixocasting) was used to form the auto box-like. Based on Power Law Cut-Off (PLCO) model and finite element code Procast software, the thixocasting process was modeled and simulated. The impact of main process parameters such as initial billet temperature, ram speed as well as die temperature on the thixocasting process was studied. The results show that thixocasting process can be used in forming auto box-like.

Introduction

Semi-solid metal (SSM) processing is a promising technology which combines the advantages of conventional hot forging and casting [1-4]. The metal forming itself takes place in the range of temperatures where the alloy is in a semi-solid state. The thixotropic material behaviour leads to material flow with low forces. This makes it possible to produce complex geometry parts in one forming step with loads much lower than in conventional hot forging. Comparing thixoforming with conventional casting, the forming temperatures are lower leading to porosity and shrink reduction [5]. At present, thixoforming of low melting point alloys as aluminum or magnesium alloy is extensively used in automotive, electric and aerospace industries [1-3].

The aluminum alloy box-like is widely used in auto industries. At present, conventional casting is generally used to form the auto box-like. But by using this method, due to low material usage efficiency, numerous amount of post machining procedures and low mechanical properties lead to low production efficiency and high production cost. In this study, thixocasting was used to replace the conventional casting to form the auto box-like. However, the consequences of such behaviour on the flow during thixoforming, is still neither completely characterized and nor fully understood [6]. Therefore, a clear understanding of thixoforming process is much more essential to support necessary foundation for forming the auto box-like by this method. Hence, in this work, the PLCO model and Procast2008 software were used to simulate the auto box-like thixocasting process, and then, the impact of main process parameters on the thixocasting process was investigated.

Modelling

Thixotropic materials have very complex thermo-mechanical behaviour because they are temperature dependent [6-8]. Depending on the thermo-mechanical loading condition, the deformation of the liquid and solid phases can be either homogenous or heterogeneous. Modelling and simulation of SSM processing have been achieved with essentially two different approaches: two-phase and one-phase approaches. In one phase approach, the SSM is supposed to behave like a homogeneous medium in which the solid and liquid phases move at the same velocity. This method has a wider solidification interval from a volume solid fraction of zero up to one and is implemented in the Power Law Cut-Off model (PLCO) of Procast. The PLCO model is based on the assumption that the material model is isotropic, its behaviour is purely viscoplastic and independent on pressure, and that deformation is homogenous [6-8].

During a thixoforming process, no significant macroscopic liquid segregation occurs. The thixotropic material which consists of a partially solid and partially liquid phase can therefore be treated as a one phase model. The fluid flow is described by a Navier-Stokes model with a non-Newtonian viscosity function. The temperature dependent shear thinning is approximated by a power law function as shown in equations (1) and (2) where μ is the local viscosity, μ_0 is the temperature dependent base viscosity, $\dot{\gamma}$ is the local shear rate, $\dot{\gamma}_0$ is the cut-off shear rate and n is the shear thinning exponent [7].

$$\mu(\dot{\gamma},T) = \mu_0(T)\dot{\gamma}_0^{\,n(T)} \qquad \text{if} \quad \dot{\gamma} \le \dot{\gamma}_0 \tag{1}$$

$$\mu(\dot{\gamma},T) = \mu_0(T)\dot{\gamma}^{\,n(T)} \qquad \text{if} \quad \dot{\gamma} \ge \dot{\gamma}_0 \tag{2}$$

The shear history of the fluid is taken into account in this model by using a simple cut-off method. The latter is applied onto different identified shear regions. In such regions shear thinning will only occur if the shear rate cut-off value, $\dot{\gamma}_0$, is exceeded. On the other hand, if it is not exceeded, the viscosity is not affected by local shearing and is calculated using $\dot{\gamma}_0$ [6, 7].

The auto box-like geometry is shown in Fig. 1. It is made by A356 aluminum alloy. For A356 alloy, its chemical composition and thermal properties came from the database of Procast2008, as shown in Tab. 1 and Fig. 2.

Table 1. A356 alloy chemical composition (%)

Si	Mg	Al	T_S (°C)	T_L (°C)
7.0	0.3	Bal.	556	616

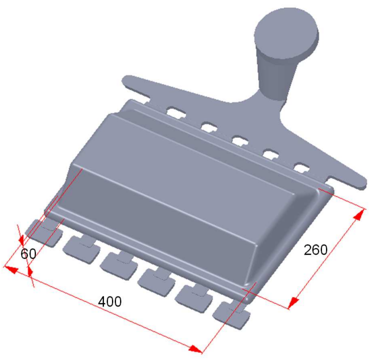


Fig. 1 The auto box-like

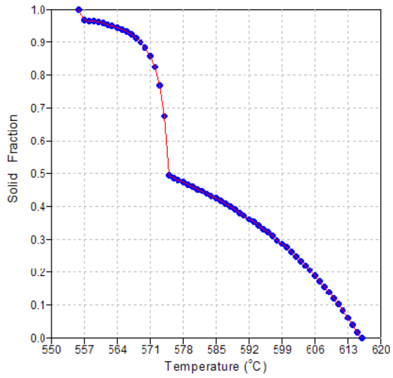


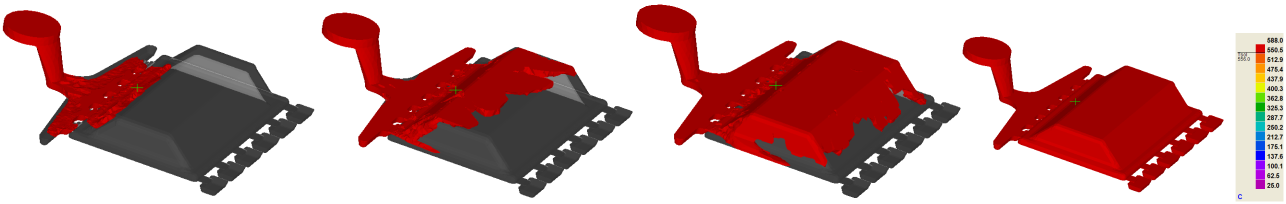
Fig. 2 Liquid fraction vs. temperature

Identification of parameters for simulation of the auto box-like thixocasting process: In this study, three main process parameters were investigated, viz. initial billet temperature (T_{billet}), ram speed (v_{ram}) and die temperature (T_{die}), which were specified as follows: T_{billet}=574~592°C, v_{ram}=0.5~10m/s and T_{die}=25~300°C.

Result and analysis

The auto box-like thixocasting process can be divided into two stages: first stage is the die cavity filling process and second stage is cooling and solidification process.

The first stage, die cavity filling process is shown in Fig. 3. It can be seen that, material flows quite steadily. During filling process, total filling time is very short, so that, billet temperature is nearly unchanged.



(a) 18% filling (b) 42% filling (c) 75% filling (d) full filling

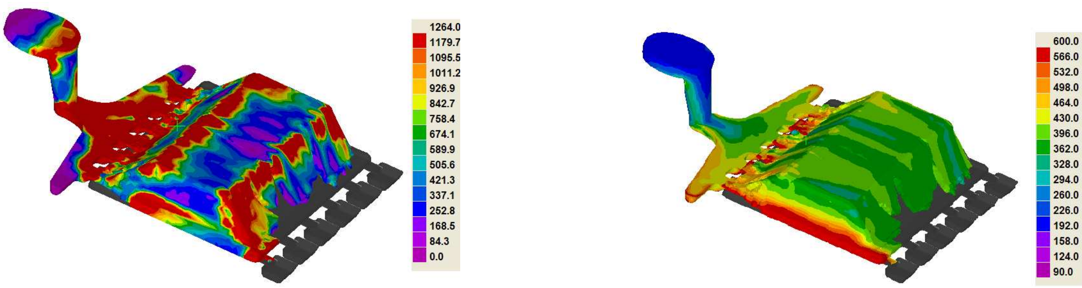
Fig. 3 The filling process, corresponding to T_{billet}=582^{o}C, T_{die}=200^{o}C, v_{ram}=2m/s

The flow velocity field distribution in the filling process is shown in Fig. 4. The results have shown that during filling process, flow velocity is quite low and quite homogeneous distribution, so that, material is still in laminar flow state. However, ram speed and initial billet temperature have strong impact on the velocity field. When ram speed increases, it induces increment in flow velocity and level of inhomogeneous velocity field distribution. If ram speed and initial billet temperature are too high, turbulence flow state may occur due to higher flow velocity and low viscosity, which may have bad impact on part quality.

(a) when 35% filling (b) when 72% filling

Fig. 4 Flow velocity field distribution, corresponding to T_{billet}=582^{o}C, T_{die}=300^{o}C, v_{ram}=3m/s

Fig. 5 shows the non-Newton shear rate and non-Newton viscosity. It can be seen that shear rate and viscosity is quite great. These values mainly depend on ram speed and initial billet temperature. The greater ram speed and higher initial billet temperature induce increase in shear rate and decrease in slurry viscosity resulting in increase filling capability, but also might reduce the part quality.



(a) (b)

Fig. 5 Non-newton shear rate (a) and non-newton viscosity distribution (b), at the time of 80% filling, corresponding to Tbillet=582oC, Tdie=200oC and vram=3m/s

During filling process, the total filling time is very short and mainly depend on ram speed. When ram speed increases, filling time decreases. Fig. 6 shows the filling time distribution. It has shown that, the last filling positions are the pouring ladles. However, filling time distribution depends on ram speed and initial billet temperature. When ram speed and initial billet temperature are higher, due to high flow velocity and low viscosity it induces turbulence flow state which may lead to non-uniform distribution of filling time in the billet.

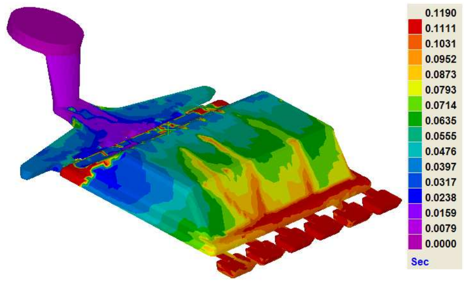


Fig. 6 Filling time distribution, corresponding to vram=2m/s, Tbilet=582oC, Tdie=200oC

The filling capability mainly depends on the initial billet temperature and ram speed. The higher initial billet temperature and ram speed induces good material fluidity and fine filling capability, but it has bad influence on part quality. On the contrary, too low initial billet temperature and ram speed induces high viscosity, bad fluidity and bad filling capability, which might lead to incomplete filling defects. Simulation results show that, if initial billet temperature is lower than 572°C (corresponding solid fraction is higher than 0.63) or ram speed lower than 0.5 m/s, die cavity can not be filled full.

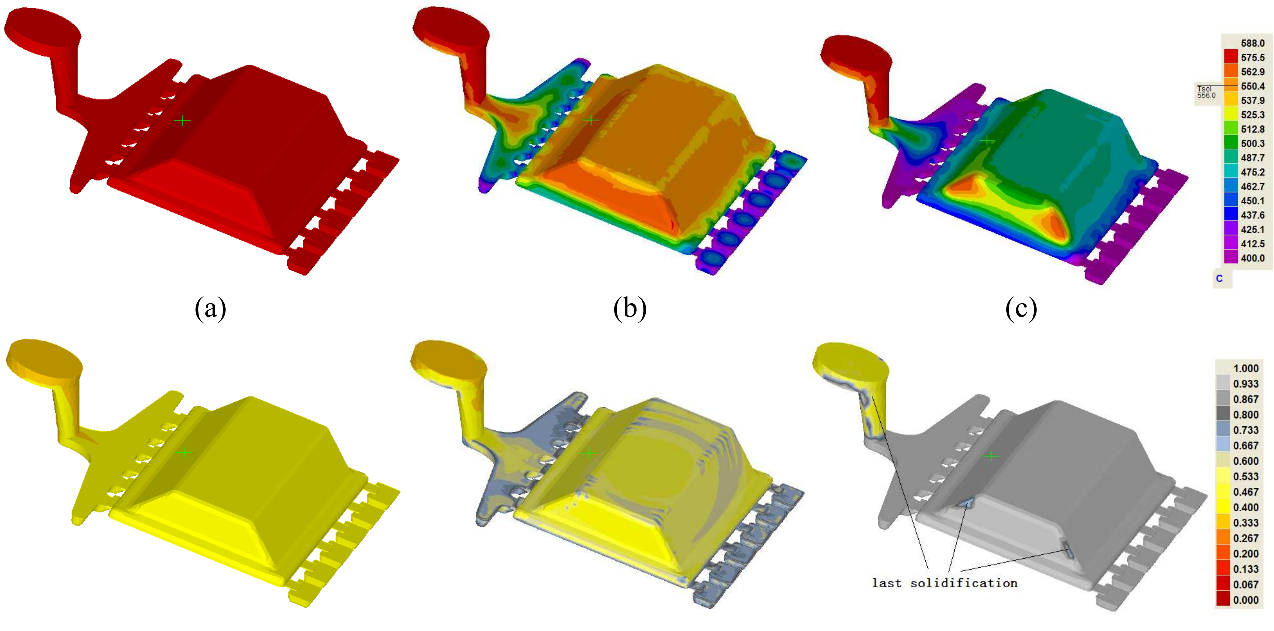


Fig.7 Temperature field distribution (a, b, c) and solid fraction (d, e, f) when cooling process, corresponding T_{billet}=582°C, T_{die}=200°C, v_{ram}=2m/s; (a) and (d) t=0.112 s, (b) and (e) t=6.54s; (c) and (f) t=12.68s

The second stage, cooling and solidification process, is shown in Fig. 7. The temperature field distribution is shown in Fig 7(a~c), and solidification process is shown in Fig. 7(d~f), respectively. It could be observed that during cooling process, the temperature field is non-uniformly distributed, which lead to non-uniform distribution of solid fraction. The last solidification position might lead to concentration of defects.

Fig. 8 shows the distribution of solidification time. It can be seen that solidification time is not-uniformly distributed, some positions have quite long solidification time. Besides, the total solidification time mainly depends on die temperature and initial billet temperature. The simulation results show that the total solidification time decreases measurably as die temperature and initial billet temperature decrease. However, die temperature should not be too low, which might cause cold shut problem [7, 8].

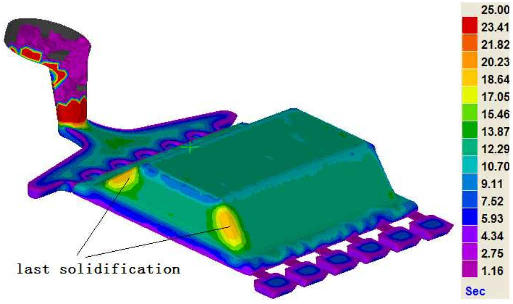
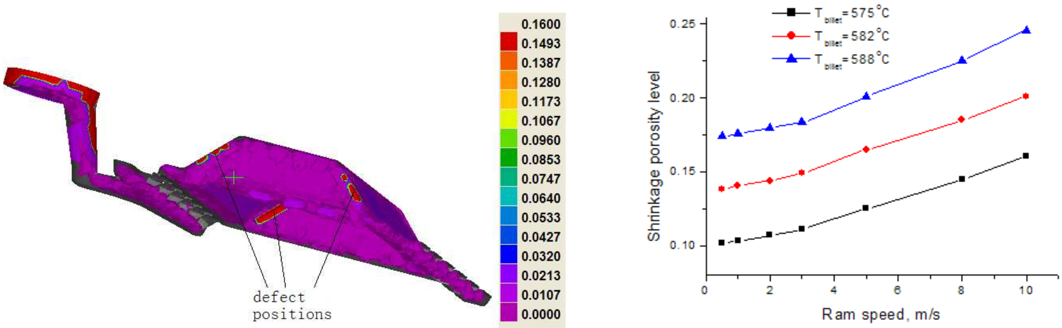


Fig. 8 Solidification time distribution, corresponding to Tbillet=582oC, vram=2m/s, Tdie=200oC

In the box-like thixocasting process, defect may also exist, such as shrinkage porosity and gas porosity [7, 8]. Fig. 9(a) shows the distribution of shrinkage porosity. It could be observed that the shrinkage porosity only exist on the three last solidification positions (Fig. 7 and Fig. 8). The level of shrinkage porosity (LOSP) is quite small and mainly depends on initial billet temperature and ram speed (Fig. 9b). From Fig. 9(b) it can be seen that, the LOSP increases rapidly as initial billet temperature increases. Besides, when ram speed is below 3 m/s, LOSP slightly increases as ram speed increases. But when ram speed is above 3 m/s, LOSP measurably increases as ram speed increases.



(a) (b)

Fig. 9 The distribution of shrinkage porosity corresponds to T_{billet}=582^{o}C, v_{ram}=2m/s, T_{die}=200^{o}C (a) and the curves of LOSP-T_{billet}-v_{ram} corresponds to T_{die}=200^{o}C (b)

In summary, initial billet temperature, ram speed and die temperature have strong impact on box-like thixocasting process. The high initial billet temperature induces good material fluidity that leads to fine filling capability, but it has bad influence on microstructure and increases defect level. However, low initial billet temperature due to decrease in material fluidity might lead to incomplete filling defect. Besides, low ram speed induces slurry steady flow that might improve product quality. But too low ram speed might lead to incomplete filling defect. However, high ram speed induces high metal flow velocity that might lead to turbulence flow, as a result, increases air-entrapment and shrinkage porosity level. In addition, low die temperature might cause cold shut problem. But too high die temperature might lead to significant increase in solidification time, as a result, product quality decreases and production efficiency reduces. Therefore, these parameters need to be reasonably chosen. In this study, by changing the process parameters and analyzing simulation results, the reasonable parameter for the thixocasting of auto box-like were obtained, viz. initial billet temperature 578~582^{o}C, die temperature 200~250^{o}C and ram speed 0.5~3.0m/s.

Conclusions

Replacing the conventional casting by thixocasting to product the auto box-like has many advantages such as good quality, high usage efficiency, high production efficiency, less defect, high mechanical properties etc.

Based on the PLCO model and Procast2008 software, the auto box-like thixocasting process was modeled and simulated. The impact of main process parameters on the flow velocity field, filling time, filling capacity, temperature field and defect during forming process were investigated.

During auto box-like thixocasting process, initial temperature, die temperature and ram speed have strong impact on forming process. The high initial billet temperature, ram speed and die temperature induces good material fluidity and increase in filling capability, but have bad influence on the microstructure and product quality. However, too low initial temperature, ram speed and die temperature might lead to incomplete filling defect.

The simulation on auto box-like semi-solid casting process can provide relevant data for designer to choose appropriate process parameters and die structure. The simulation results are important foundations for applying thixoforming process to form auto box-like.

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