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Numerical Simulation of Mechanical Wave Propagation in Casting Solidification Process

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This paper is mainly devoted to the numerical simulation of mechanical wave propagation in casting solidification process. Firstly, this paper found the mathematical physics model of elastic wave propagation in the elasticity, viscosity and viscoelastic medium. Then, the above equation were solved by finite difference method. Finally, the boundary conditions of casting/mold interface, to realize the mechanical wave propagation in the alloy melt numerical simulation. To achieve the numerical simulation of mechanical waves propagating in the alloy melt. Studied mechanical wave propagation in the alloy melt solidification process. Research shows that mechanical wave propagation attenuation trend in a casting. The site of minimum vibration of the mechanical wave is not the center of the casting in the process of solidification, but the position between the center and the reflection surface.

Keywords: *mechanical wave, casting, solidification process, propagation.*

1. Introduction

An effective measure to improve the solidification structure, eliminate or reduce the casting defects has been recognized by applying an external field in the metal solidification process. It has been 100 years to improve the microstructure and mechanical properties by means of vibration solidification [1-4]. The scientific problem of the impact of vibration on metal solidification is the problem how the elastic wave propagate in viscoelastic two-phase media. In this paper, the author uses the numerical simulation technology to study the propagation of vibration wave in the alloy melt, and the influence of vibration wave in the solidification process.

2. Mathematical physics model

2.1 Constitutive relation

We used the liquid-solid two phase region rheometer by self-designed to measure rheological model of ZL205A in liquid-solid phase and solid alloy. It is showed that the rheological characteristics of ZL205A can be described by the five element model (H1- (N1|S1) - (H2|N2)) in the whole temperature ranges below the liquidus.

In this paper, we consider the force of the alloy does not exceed the yield stress during the metal solidification process. In this case, the constitutive relation of the alloy is H1- (H2|N2).

2.2 Wave equation

According to the "corresponding rule" of the elastic medium and the viscoelastic medium suggested by Auld in 1990, we can obtained 1D (one dimensional) wave equation.

$$\begin{cases} \dfrac{\partial v_x}{\partial t} = \dfrac{1}{\rho}\dfrac{\partial \tau_{xx}}{\partial x} \\ \left(\mu_1+\mu_2\right)\dfrac{\partial \tau_{xx}}{\partial t} + \mu^{'}\dfrac{\partial^2 \tau_{xx}}{\partial t^2} = \left(\mu_1\lambda+\mu_2\lambda+2\mu_1\mu_2\right)\dfrac{\partial v_x}{\partial x} \\ +\left(\mu_1\lambda^{'}+\mu_2\lambda^{'}+\mu^{'}\lambda+2\mu_1\mu^{'}\right)\dfrac{\partial^2 v_x}{\partial x \partial t} + \mu^{'}\lambda^{'}\dfrac{\partial^3 v_x}{\partial x \partial t^2} \end{cases} \qquad (1)$$

2.3 Boundary conditions

The boundary of the wave field calculation in the casting solidification process can be divided into three categories:

(1) Mold / air interface
The interface only have speed without stress,

$$\sigma_x = \tau_{xy} = \tau_{xz} = 0 \qquad (2)$$

(2) Mold / earth interface
The casting of the interface only transmitted stress without speed.

$$u_x = u_z = 0 \qquad (3)$$

(3) Casting/ Mold interface
When the wave transmits to the interface, the velocity and stress at the two sides of the interface are distributed. It is decided by the relative size of the wave impedance (ρv) between the two sides. The interface does not need to do special treatment.

3. Propagation simulation and experiment

The propagation law of the mechanical wave in a 1D high temperature solid metal was obtained by the numerical simulation of the wave equation with MATLAB. We used Ricker wavelet as pulse source, frequency is 780Hz, and calculating time is 12.5ms. The length of the rod is 2.8m, and the measuring temperature is 490 ℃. The simulation result and the experiment result are showed in Fig.1.

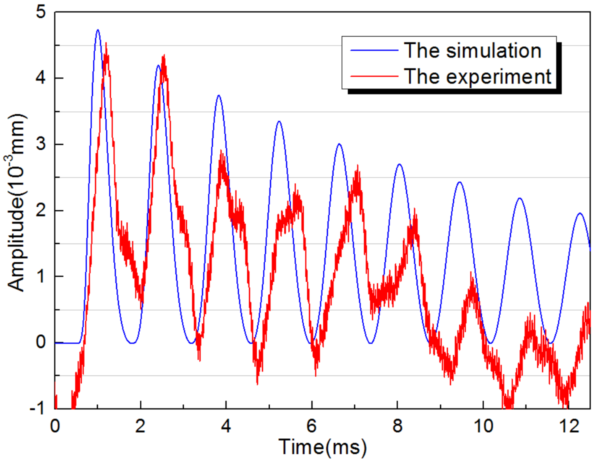

Fig. 1 Numerical simulation and experiment results of wave propagation in high temperature metal rod

We can see that the mechanical wave propagation in the high temperature metal rod is more serious attenuation and the amplitude is becoming smaller and smaller. The velocity of wave in the metal rod is about 4000 m/s when temperature is 490 ℃. By comparing the pulse signal derived from the experimental to detected signal in the experiment, the velocity and the attenuation rate in the simulation conform to the experiment result well.

4. Numerical simulation in 1D casting

In this paper, the author has carried on the numerical simulation of the mechanical wave propagation in the metal solidification process of 1D metal casting. The temperature in the both ends of 1D casting is 550 ℃, and the center is 650 ℃. The gradient temperature is linear from the edge to center. The vibration source was set in the left end. The experimental structure and points distribution showed in Fig.2.

We can see from Fig.3, the initial wave amplitude is small, only 0.3mm, the amplitude of the wave gradually decays in propagation process. But the source continues to provide energy, leading to amplitude get bigger in the casting. The casting center is not the wave amplitude minimum position, although the central part of the decay is the most serious. With the supply of the source energy, the amplitude is not small. The site of the minimum amplitude is located away from the vibration 0.75m. Because of the energy supplement was inadequate from the source, the reflection of the wave was almost completely attenuated, and the site obtained the smallest amplitude in the last.

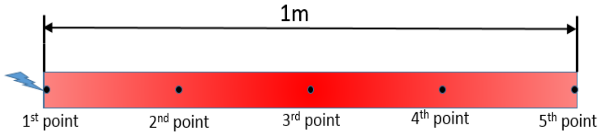

Fig.2 Experimental structure and points distribution

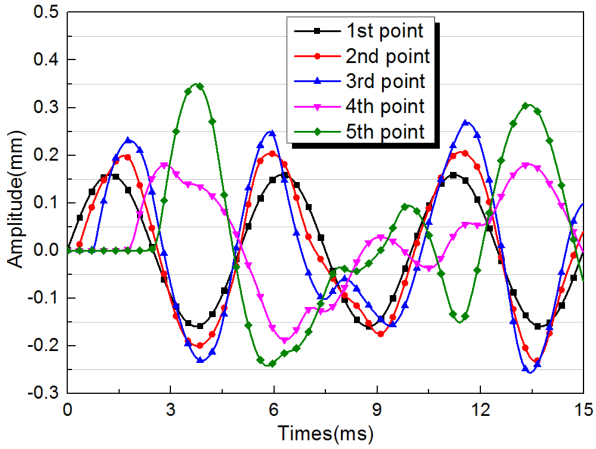

Fig. 3 The amplitude variation with time of each point in 1D metal solidification process

5. Conclusion

In this paper studied the propagation of mechanical waves in the casting solidification process, and obtained the following conclusions :

(1) The rheological characteristics of high temperature solid and solid-liquid phase of ZL205A alloy can be described with the mechanical model of five element (T=H1-(S1|N1) - (H2|N2));

(2) The mechanical wave decays rapidly in the high temperature alloy, and the propagation time is very short.

(3) The site of minimum vibration of the mechanical wave is not the center of the casting in the process of solidification, but the position between the center and the reflection surface.

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