Study on X60 Micro Alloy Steel'S Solidification Characteristics Based on Linea Contraction-thermal Stress Measuring

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Keywords: micro alloy steel, In situ measurement, thermal stress, linear contraction, solidification.

Abstract. Based on the difficult technical defect, measuring the amount of solidification shrinkage and the stress, we use the linear contraction-thermal stress In situ measurement equipment, designed independently by shanghai university, to study the solidification characteristics, such as linear contraction, thermal stress, thermal cracking, of X60 steel. Acquiring and disposing the temperature, stress and shrinkage simultaneously in solidification process, depicting correlation curves, are suit for further study on X60 steel solidification characteristics. This paper mainly discussed the methods of design and analyses, given the results we got and analyzed during the study. The linear contraction-thermal stress in situ al device captures the stress and shrinkage of X60 steel during the solidification process accurately. Both stress and shrinkage have a high consistency with the temperature curve. The amount of shrinkage is 0.96% and the shrinkage stress is 28Mpa after the whole process.

Introduction

Thermal cracking is a kind of common defects in the metal solidification process, especially in the crack sensitive steel. From the liquid metal to room temperature in the cooling process, the change of status and crystal structure during the solidification process will lead to stress of contacted objects or metal itself, always lead to thermal cracking[1]. Different steel, the performance is different and each steel has its own characteristics, have its own rules. We can analyze and judge the existence of metal under different temperature conditions, the impact leaded by the change of structure, exploring the mechanism of steel thermal cracking and controlling the thermal cracking effectively, once depict the solidification shrinkage characteristics quantificationally and dynamically. It is significance to theoretical research, improving the casting quality, professional teaching and producing process and improving related equipment parameters.

The thermal cracking of aluminum alloy and other low melting point alloy is mainly measured by casting hot cracking method. This method, usually using the pouring hot metal into casting mold to solidification, is easily fulfill the measurement of thermal cracking and shrinkage during the solidification[2]. It is difficult to control the temperature precisely because of the steel's characteristic of high melting point. And it is more difficult to accurately measure the thermal cracking and linear shrinkage and it is impossible to despite the thermal cracking quantitatively because of the sample has higher axial temperature gradient. The existing studies of the steel solidification behavior always use the calculation and numerical simulation. The constant calculation results may not apply the complex solidification process duo to the structure evolution during solidification process and the association between transition of solid phase and cooling rate. A unified mathematical model, considering flow field, temperature field, stress field, thermal physical properties and high temperature properties, during alloy steel's solidification has not yet established. A reasonable mathematical model should be established in precise measurement of solid mechanics behavior. This is the foundation to established the model of cracking formation and

carried on the numerical simulation for stress, strain and thermal cracking during the solidification[3-5]. So it is necessary, to find an effective method, which can evaluate the tendency of steel thermal cracking quantitatively, to study the steel solidification behavior.

According to the existing technological defect, this study use the shanghai university "linear contraction-thermal stress in situ al instrument" rely on the national major special instrument, to fulfill in situ measurement, such as temperature, linear shrinkage and thermal stress, during the solidification for micro alloy steel X60. Then using those date to study the solidification characteristics.

Experimental materials and methods

The main chemical composition of X60 micro alloy steel used for this experiment was shown in table 1-1. The sample size is 20mmx10mmx9mm.

Tab. 1 Chemical compositions of tested steel (%)

C	Mn	S	P	Si	Cr	Ni	Nb	V	Ti
0.08	1.30	0.001	0.01	0.09	0.15	0.01	0.031	0.003	0.015

According to the steel composition, we can calculate the temperature of liquidus and solidus. The formula was shown as follows[6-8]:

The liquidus:

$$T_L = 1536 - \{90[\%C] + 6.2[\%Si] + 1.7[\%Mn] + 28[\%P] + 40[\%S] + 2.6[\%Cu] + 2.9[\%Ni] + 1.8[\%Cr] + 5.1[\%Al]\}$$ (1)

The solidus:

$$T_S = 1536 - \{415.3[\%C] + 12.3[\%Si] + 6.8[\%Mn] + 124.5[\%P] + 183.9[\%S] + 4.3[\%Ni] + 1.4[\%Cr] + 4.1[\%Al]\}$$ (2)

Using the formula 1.1, 1.2, we can calculate the X60 micro alloy steel's liquidus and solidus. The liquidus is 1525℃ and the solidus is 1482℃. According to this steel, the transformation temperature A_{r3} is 780℃, $\gamma \to \alpha$ transition completely temperature is 718℃.

Figure 1, 2 are the linear stress-thermal shrinkage situ al device's structure and real figure respectively used for this experiment. This device can accurately measure the change of temperature and linear contraction during the process of solidification. The device include atmosphere protection system, temperature control system, transmission system, dates acquisition system, dates display and dispose system.
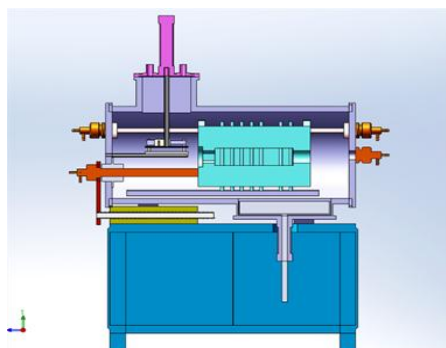
Fig. 1 Linear contractive -thermal stress instrument structure

Fig. 2 Linear contractive-thermal stress device

The equipment's subject is silicon molybdenum box type resistance furnace under the argon atmosphere protection. The heating curves can be set arbitrary within the temperature that the scope of the heating body can withstand. The resistance furnace was installed on the guide rail. It was driven by a transmission system to fulfill level movement. This makes the crucible installed on the

bracket of crucible move into and out of the resistance furnace. Temperature control system is composed by the thermocouple and the temperature control part. Writing programs through the temperature control part to control the furnace temperature accurately and collecting the thermocouple temperature. Detection system was main composed by transducer, control circuit and collection agency. It was shown in figure 4. This system, conclude stress sensor, displacement sensor, filter, amplifier, date acquisition, hardware and some related software, can measure the linear shrinkage and the thermal stress simultaneously. The transmission system includes the vertical lift system measured by sensor and the level braking system.
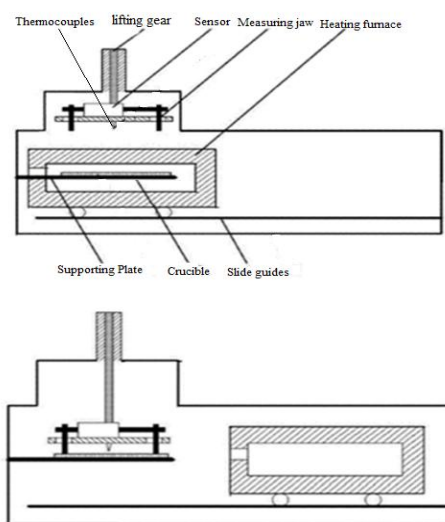

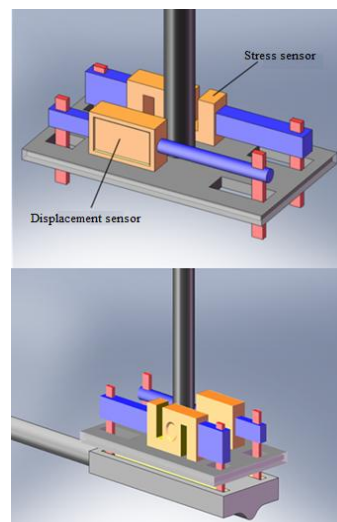Fig. 3 The experimental principle diagram

Fig. 4 Measuring principle diagram

Figure 3, 4 are the experimental theory picture. Put the cured steel sample into a corundum crucible which supported by a graphite plate. Melting the sample under the atmosphere of argon protection, and move away the resistance furnace after completely melt. Using the lifting rod controlled by a cylinder stator to drop four measuring claws, connected by displacement sensor and stress sensor, into the molten steel. At the same time, the B-type thermocouple, installed on the below of the sensor, insert into the molten steel. The sensors will collect the dates of stress and shrinkage during the solidification continuously, and put the dates to acquisition system through the filter and amplifier. Through the acquisition system record the stress, linear shrinkage and temperature simultaneously.

Experimental results and analysis

We can see that the sample's surface is bright and clean, the friction resistance between crucible and steel is small during the solidification. So, the frictional resistance's effect, shrinkage and stress, is small. And thus the dates are precise enough. Figure5 shows the metallographic structure at room temperature after solidification. We can see that the metallographic structure is uniform relatively. The sample has not any void. The sample solidifies equably during the cooling process, and the axial temperature gradient is low. So, the linear shrinkage and the thermal stress we measured are accurate.
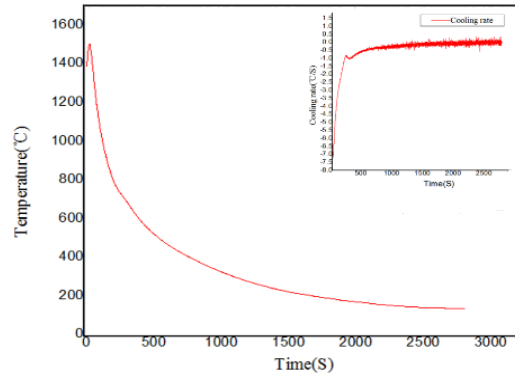
Fig. 5 Curve of dynamic cooling

Figure5 shows the cooling curve during the dynamic linear shrinkage test. We can find that through using the horizontal transmission device to removing heating furnace and descending the vertical measurement device and inserting into the hearth to fulfill the in situ measure. Then we can use high sensitive thermocouple—B type to measure current temperature immediately. Because of the thermocouple is placed in the center of the hearth, there is low temperature gradient because no rapid chill caused by low temperature sand, so the temperature did not descent rapidly. When the temperature reaches to 153℃, far above the solidus temperature of 1482℃ and near to the liquidus temperature of 1525℃, the solid phase began to precipitation. We can confirm from the cooling curve that the temperature decrease slower at about 850℃. We can presume firstly that because of the potential heat of crystallization during crystallization process, decreased the cooling rate. After the steel solidified completely, it tends to cooling uniformly.
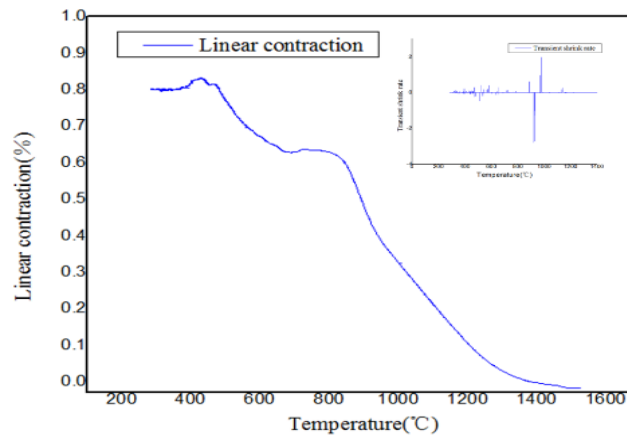
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Fig. 6 X60 steel's curve of cooling-contraction in dynamic test

Figure 6 shows the cooling-contraction curve of X60 steel in dynamic test. The contraction of the casting usually includes three stage: liquid contraction, solidification contraction, solid contraction. Solid contraction always presents a size reduction. We usually use the linear shrinkage to express the solid contraction.

$$\varepsilon_l = \frac{l_0 - l_1}{l_0} \times 100\% = \frac{180 - 178.27}{180} \times 100\% = 0.96\%$$
(3)

ε_1 is longitudinal shrinking ratio, I_1 is the sample original length, I_0 is the length of the sample after solidification.

From the shrinkage-temperature curve, we can see that the sample shrinkage changes rapidly during high temperature. With the decrease of temperature, the shrinkage rate gradually decreased. The curve is smooth and there has a turning point. From figure 8, we can see that the metal is not has strength in the early solidification, so the amount of shrinkage is not measured. In the early

solidification, at the beginning shrinkage of 1480℃, the amount of shrinkage of X60 steel in the early solidification is bigger. Because of the volume expansion when the austenite transformed to the ferrite, the amount of shrinkage increase slow and almost platform when the temperature reaches to 750℃. The amount of shrinkage began increase slowly after the austenite transformed to the ferrite completely. The amount of shrinkage is at about 1.73mm and the rate of shrinkage is at about 0.96% finally.
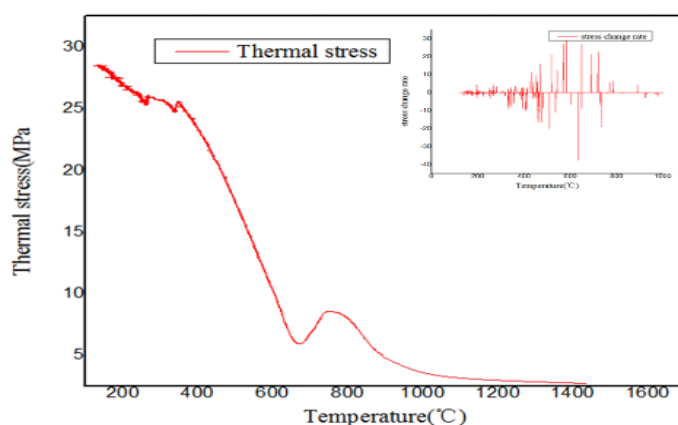
Fig. 7 curve in X60 steel's dynamic test of cooling-thermal stress

From the figure 7, we can see that the metal is not has strength in the early solidification, so the cast steel is not has stress now. the zero-strength temperature (ZST)[9] at about 1460 ℃.The stress began to increase slowly at about 1450℃. Combined with the temperature curve we can see that the X60 steel has strength when the temperature is 1450℃. At the temperature of 890℃, the stress began to generate and increase rapidly because of the transformation of austenite tend to its terminate. When reached to the temperature of 750℃, the stress began to decrease because of the volume expansion when the austenite transformed to the ferrite. At around 680℃, when the austenite transformed to ferrite completely and the expansion is finished, the stress began to increase. The stress value is about 24Mpa. But considering the inverse pre-stress of 4Mpa, the whole shrinking process of stress is about 28Mpa.
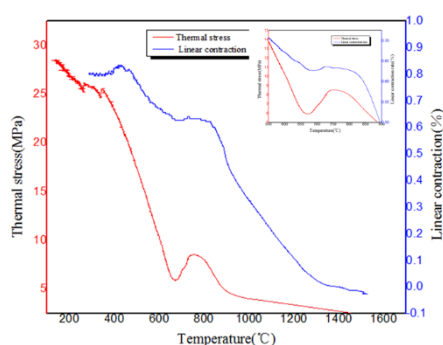

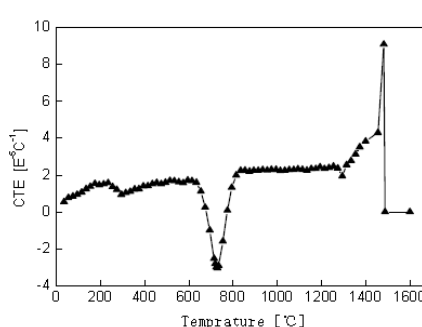| Fig. 8 Curve in X60 steel's test of cooling Thermal stress | Fig. 9 Coefficient of thermal expansion of steel X60 |

Figure 10 shows the curve in X60 steel's cooling-stress. From the table we can see that the linear shrinkage and the stress value have synchronicity with the decrease of temperature in the process. So the dates have certain scientific nature. The stress value in high temperature has a certain error because there have a preloaded stress in early time and the small change of stress value in liquid contraction and solidification contraction.

Conclusions

The linear shrinkage-stress in situ device captured the X60 micro alloy steel's stress and shrinkage during the solidification accurately. And they have a high degree of consistency between temperature curve and above two parameters. Both thermal stress and linear shrinkage rate are increased with the temperature drops. But they are not a simple linear relationship obviously. Because liquid contraction, solidification contraction and solid contraction are different, the shrinkage rate in early time is bigger but the change of stress is lower in early time. Because of the expansion of X60 steel when austenite transform into ferrite, shrinkage and stress will decrease. Actual test shows that can not only measure the micro alloy steel's linear shrinkage, stress and other parameters like thermal cracking, providing many useful information for the study on X60 micro alloy steel, but has a better follow-up function.

Actual test results show that the system can not only accurate determination of micro alloy steel line parameters such as shrinkage, stress and cracking, for the study of micro alloy steel X60 solidification feature provides a large number of useful information, but has a good follow-up function expansibility and extensibility.

Acknowledgments

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