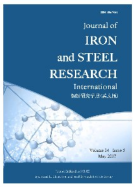
Journal of Iron and Steel Research, International 24 (2017) 495—500

Contents lists available at ScienceDirect

Journal of Iron and Steel Research, International

journal homepage: www.chinamet.cn



Application of insulation padding in a heavy turbine guide vane casting

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ARTICLE INFO

Key words:
Heavy steel casting
Insulation padding
Metal padding
Modulus
Expansion
Shielding

ABSTRACT

To replace metal padding by insulation padding for castings can save the melt and reduce cleaning work of castings. The design of insulation padding was investigated. The equation of the modulus extension factor for insulation padding and the ratio of its thickness over the modulus of a casting were improved to determine the thickness of insulation padding. The insulation padding was designed for a turbine guide vane casting weighing 3. 5 t. A sound casting was obtained with 750 kg steel saved. On the other side, the casting obviously expanded at the interface with the insulation padding, which is perhaps the reason that the use of insulation padding has been suspended for many years. To avoid the expansion of insulation padding, a shielding layer made of a kind of material of good fire resistance was adopted to prevent the insulation layer from touching the melt. The shielding layer serves as a cushion of heat and expansion during solidification process so as to resist the expansion of castings and guarantee the feeding effect at the same time. Furthermore, insulation padding can be placed by a certain offset into the mold cavity so as to counteract the expansion of castings.

1. Introduction

In the production of castings, especially steel castings, risers are necessary to compensate the contraction of the melt during solidification. In most cases, it is required to design metal padding for the area connecting a riser to its corresponding hot spot of a casting to realize a smooth feeding channel. To increase the feeding effect of risers during casting production, insulation materials have been used since 1940s. At the beginning, the insulation materials were just used as riser sleeves to prolong the solidification of risers which serve as the feeding source during solidification[1-4]. Then exothermic insulation materials were developed to further postpone the solidification time of risers[5-7]. In 1980s, foundrymen from USA, UK, Japan and China tested insulation materials to replace metal padding to directly enhance the feeding channel connecting with risers[7-16]. That is because metal padding causes problems. One problem is that the removal of metal padding is a tough work. The second one is that defects sometimes appear as the padding is cut off. The third one is that metal padding needs extra liquid metal, which consumes more energy during melting. Thus, the replacement of metal padding by insulation padding drew foundrymen′ interest. Zhou et al. [9] deduced an equation to determine the thickness of the insulation layer based on the modulus corresponding to metal padding. Zeng[12] and Mao et al. [13] studied the relationship of the thickness of insulation padding and the enhanced modulus of test castings. Meanwhile, efforts were devoted to developing new insulation materials capable to replace metal padding[14,15,17,18]. Some took application of this method into real castings and obtained sound castings[19,20]. However, there has been no more research since 1990s. And actually, up to date, metal padding is still popularly used in casting process. The reason is not yet clear. Zhao et al. [14] mentioned that there is dilation of castings at the interface in contact with the insulation padding. However, no

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Received 14 July 2016; Received in revised form 24 October 2016; Accepted 8 November 2016

more details were given. In this paper, insulation padding was used in a turbine guide vane casting and the expansion problem which may be the main reason of the suspension of the application of insulation padding is addressed.

2. Improvement of E-(δ/M) Relationship for Insulation Padding

Zhou et al.[9] deduced the following equation based on one-dimensional heat transfer differential equation.

$$\frac{b_2}{b_1}=E+\frac{q}{M}\sum_{n=1}^{\infty}\left(\frac{b_2-b_1}{b_2+b_1}\right)^n\int_0^{\frac{(EM)2}{q2}}\frac{1}{\sqrt{\tau}}\mathrm{e}^{\frac{-n2\delta2}{a1\tau}}\mathrm{d}\tau \tag{1}$$

where, E is the modulus extension factor; δ is the thickness of insulation padding; M is the modulus of a casting; b_1, b_2 are the thermal capacity of molding sand and insulation material, respectively; a_1 is the thermal dissipative coefficient of insulation material; q is the solidification coefficient; and τ is time.

The above equation contains E and δ, but they are included in the integral; thus, it is hard to directly get their simplified relationship. Zhou et al.[9] used the Newton-Cotes formula to simplify the integral, then Eq. (2) was obtained.

$$E=E_0\left[1+\sum_{n=1}^{\infty}\left(\frac{E_0-1}{E_0+1}\right)^n\sum_{k=1}^{N}C_k^{(N)}\sqrt{\frac{N}{k}}\mathrm{e}^{-\frac{Nn2q2\delta2}{ka1E2M2}}\right]^{-1} \tag{2}$$

where, E_0 is the maximum modulus extension factor, $E_0=\sqrt{\lambda_1\rho_1c_1/\lambda_0\rho_0c_0}$; λ_0, λ_1, ρ_0, ρ_1, c_0, c_1 are the thermal conductivity, density and specific heat of the sand mold and insulation material, respectively; and $C_k^{(N)}$ is Newton-Cotes coefficient.

The curves plotted based on Eq. (2) for a kind of insulation material is shown in Fig. 1. It can be seen that there is deviation as the curve approaches point (0, 1). It is supposed to pass through point (0, 1). Now, by the software MATLAB, the original function can be transformed to Eq. (3).

$$\begin{aligned}E_0=&E-2.1\times10^{-3}\frac{\delta}{\sqrt{a_1}}\mathrm{erfc}\left(\frac{q\delta}{\sqrt{a_1}ME}\right)+1.2\times10^{-3}\times\\&\frac{ME}{q}\mathrm{e}^{\frac{-\delta2q2}{a1M2E2}}-1.5\times10^{-3}\frac{\delta}{\sqrt{a_1}}\mathrm{erfc}\left(\frac{2q\delta}{\sqrt{a_1}ME}\right)+\\&4.1\times10^{-4}\frac{ME}{q}\mathrm{e}^{\frac{-4\delta2q2}{a1M2E2}}-5.9\times10^{-4}\lim_{\tau\to0+}[2\sqrt{\tau}\mathrm{e}^{\frac{-\delta2}{a1\tau}}-\\&2\delta\sqrt{\frac{\pi}{a_1}}\mathrm{erfc}(\frac{\delta}{\sqrt{a_1\tau}})]-2.1\times10^{-4}\lim_{\tau\to0+}[2\sqrt{\tau}\mathrm{e}^{\frac{-4\delta2}{a1\tau}}-\\&4\delta\sqrt{\frac{\pi}{a_1}}\mathrm{erfc}(\frac{2\delta}{\sqrt{a_1\tau}})]\end{aligned} \tag{3}$$

The curve based on Eq. (3) for a kind of insulation material is plotted in Fig. 1. Its original position is very close to point (0, 1). That means the new equation is more accurate.

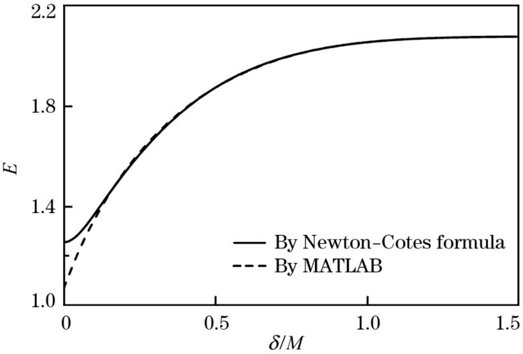

Fig. 1. Comparison of E-(δ/M) curves.

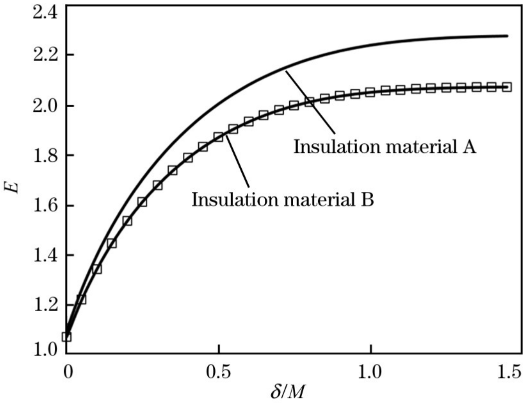

Fig. 2. E-(δ/M) curves for two different insulation materials.

The E-(δ/M) curves for two different insulation materials are plotted in Fig. 2. The E-(δ/M) curves are actually the function of the thermal properties of casting, mold and insulation material. Thus, the relationship of the thickness of the insulation layer and the thermal properties of casting, molding sand and insulation, casting modulus and the extension modulus can be represented by a simple form as follows

$$\delta=\left[\frac{30}{\sqrt{\lambda_c c_c}}\ln\frac{M_e(\sqrt{\lambda_0\rho_0c_0}-\sqrt{\lambda_1\rho_1c_1})}{M\sqrt{\lambda_0\rho_0c_0}-M_e\sqrt{\lambda_1\rho_1c_1}}\right]M \tag{4}$$

where, M_e is the extended modulus; and λ_c, c_c are the thermal conductivity and specific heat of casting material, respectively.

From the E-(δ/M) curves in Fig. 2, it can be seen that, as δ/M reaches a certain value, E will increase very slowly and finally reach a fixed value. Thus, there is a limit of the effect of insulation padding, and its maximum thickness is obtained as the E-(δ/M) reaches stable status. For example, it is $2.1M$ for the insulation material B. Beyond this thickness, the insulation effect cannot be improved by increasing its thickness. The relationship of the extended modulus is empirically expressed as,

$$M_e=\left[1+C\frac{H}{M}\right]M \tag{5}$$

where, C is a constant in a range of 0.08－0.10; and H is the height from a hot spot to its corresponding riser. Thus, the critical height of the casting from a hot spot to a riser is