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Studies of Wheel Center Castings*

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Casting of wheel center of rolling stocks was experimented as an example for studies of sound steel castings.

Risering considering the fundamental experiments of risering steel castings for simple shapes developed by Pellini and others was provided for this experiment which aimed both to study the thermal analysis of riser and to measure feed metal flow in mold. Casting process in the mold was analysed and thermal gradient promoting the directional solidification in molten steel comprehended which was needed for sound casting.

The conclusions from this experiment are as follows, considering the result of γ -ray inspection.

(1) Casting designs for complex castings considering Pellini's experiments for simple castings can give optimum or minimum adequate riser only under the correction which is given when the influences of molding conditions and of the delayed solidification at corner are fully investigated and taken into consideration.

(2) Based on (1), the better casting design with riser dimensions enlarged by 15% was determined for wheel center when any exothermic compound was not used.

(3) Through the author's analysis of the feed metal flow and the thermal gradient of metal in mold, further casting experiments applying chills to promote directional solidification will become easier to execute.

Introduction

For the study on preventing shrinkage cavity which is very common in steel castings, a wheel center with eight arms for rolling stocks used in Japanese National Railways, shown in Fig. 1, was applied.

Risering and casting design

(1) Location of risers

As hot spots which produce gross shrinkage cavities are predicable in boss and in T joining section where arm and rim are joined, risers or chills were applied as shown in Fig. 2. The gates of No. 1 and No. 3 were located tangential to the rim at T section and the gates of No. 2, No. 4, and No. 5 were located at the bottom of the boss. This time in this study No. 1 design was adopted because it seemed to keep riser hotter than the case of bottom casting, while study of chill action at corner was not yet satisfactory.

(2) Feeding range of riser

By the Pellini's studies for the prevention of

centerline shrinkage, the maximum feeding distance between the neighbouring risers in the case of plate castings is shown about $4T$ wherein T is the thickness of plate. Each riser of the proposed casting design seems to have a sufficient feeding range according to the above formula.

(3) Riser dimensions

Shape of riser was determined as cylindrical considering that the riser must solidify later than the casting which was to be fed by the riser during solidification. Because the ratio of solidification time or freezing ratio between riser and casting relates to the ratio of geometric ratios of volume to cooling surface area between them⁽¹⁾.

Fig. 1 Pattern dimensions of wheel center

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Values of height and diameter were determined by the Pellini's simplified method⁽²⁾ which was experimented with the steel having a nominal composition of 0.20/0.30%C etc. poured at 2950~2975° F using a mildly exothermic antipiping compound as a cover.

And it was assumed that riser on boss could feed all eight arms as well as boss and each riser on *T* section of rim could feed the half distance between neighbouring risers and also between each *T* joint and boss. Then boss and rim were assumed as parent castings while arm as appendage. Each percentage of appendage volume to be added to parent volume is 50% for boss and 100% for rim as the result of calculation. And for the calculation of riser on boss, boss thickness was multiplied by the correction factor 1.1 which was calculated considering the solidification delayed

by the core inserted. By the same reason, for the determination of riser dimensions on *T* section of rim the thickness of rim was multiplied by the correction factor $\sqrt{1.5}$ considering the influence of hot corner effect⁽³⁾.

The definite dimensions of risers were calculated as follows.

For riser on boss, volume is $462 \times 10^4 \text{ mm}^3$,

Consequently

height 180 mm × diameter 180 mm
or 145 mm × 200 mm
or 110 mm × 230 mm

For riser on rim, volume is $80 \times 10^4 \text{ mm}^3$

Consequently

height 115 mm × diameter 95 mm
or 100 mm × 100 mm
or 85 mm × 110 mm
or 70 mm × 120 mm

H_1 : Riser on boss, H_2 : Riser on rim except H_3 , H_3 : Riser on rim at gate,
C : Chill between risers round rim at *T* section

Fig. 2 Casting designs

(a) Thermocouple setting in riser

(b) Measurement by oscillograph and millivoltmeter

Fig. 3 Illustration of thermal analysis procedures for risers

● : Location of wire in drag (1~16)
○ : Location of wire in cope (17~21)
▲ : Location of wire in riser (22~26)
+ : Location of thermocouple in riser
Fig. 4 Measuring locations of riser temperature and feed metal flow

Fig. 5 Measurement of riser temperature

Fig. 6 Thermal data of risers

Riser sizes in Fig. 2 were so modified as to be applied to the actual molding flask, eliminating the exothermic compound or any vent core. All risers on rim were covered with molding sand and padded to the rim and only the riser sizes at gate were multiplied by about 1.1 considering the influence of runner on corner effect.

Casting experiment

(1) Casting conditions

The composition of this casting steel is 0.27% C, 0.36% Si, 0.72% Mn, 0.049% P, and 0.034% S which is within Pellini's experimental range of composition. The tensile strength is 47 kg/mm², elongation 30%, and hardness 150 HB. Net casting product weight is 190 kg and total poured metal weight 314 kg, consequently the ratio of them is about 60%.

Casting mold was made of synthetic silica sand bonded with 10% clay and 0.5% honey compound and mixed with 6% water in 15 minutes. Then

Locations 1~21 Locations 22~26
(a) Wire setting

(b) Measuring circuit
Fig. 7 Measuring procedures of feed metal flow

it was dried in furnace.

(2) Thermal analysis of riser

Experimental method is shown in Fig. 3 and

the five risers whose temperatures were measured are marked (+) as shown in Fig. 4 i.e. the riser on boss and every other riser on rim from the one next to the gate. These risers on rim are numbered 1, 2, 3, and 4 respectively anticlockwise in the direction of runner, while the riser on boss is No. 5.

The casting steel was poured at 1600°C into the mold of 10°C , and feeding time was over 20 seconds. Fig. 6 shows the cooling temperature curves of each riser. The records which were photographed by the oscillograph till each temperature reached up to the highest are omitted. No. 1, No. 2, and No. 3 already reached down to the liquidus temperature at the highest recorded by the oscillograph, when about 20 seconds passed since the silica tubes of thermocouples had begun to touch the feed metal. And No. 3 started to freeze earlier than No. 1 and No. 2 which were remaining at the

liquidus temperature for a while and solidified at almost the same freezing rate. No. 4 was already freezing from the beginning on the curve, while No. 5 on boss was over the liquidus temperature at the very first and then keeping the liquidus temperature for much longer time than No. 1~No. 3 till the measurement ended. No. 4 and No. 5 were intermitted by the accident of thermocouples. This thermal analysis seems to mean that No. 1 and No. 2 were fed by the last hotter feed metal, while No. 4 by the first feed metal which was cooled through cold mold and No. 3 by the middle feed metal. Of course, No. 5 keeps the liquidus temperature until the start of freezing round the biggest riser reaches the center where the thermocouple is set.

(3) Feed metal flow

Fig. 7 shows the experimental method in which the rotating drum takes a photograph of 26 lamp-lights which light one after another as the feed metal touches each wire located in mold to close electric circuits. Fig. 4 and Fig. 8 show the locations of wires. This experiment traced the tip of the feed metal flow in drag as shown in Fig. 9. And it was assured that the feed metal flowed about half round the rim in cope when the tip of feed metal finished to flow all over the drag in six seconds. Thus the feed metal generally seems to be pushed forth from gate by the later coming and hotter one. And it is considered as the result of temperature measurements of risers and radiographic inspection that this thermal gradient does not change at the solidification.

This is explained the same by the other experiment of coloured paraffine method⁽⁴⁾.

Fig. 8 Drag showing the measuring locations of feed metal flow

Location of feed metal after elapse of various time intervals
Fig. 9 Feed metal flow wetting the drag of wheel center

Fig. 10 Feeding rate of molten steel into mold

Fig. 11 Wheel center in the experiment

Fig. 12 Traces of shrinkage under riser

- A : On arm and T section joined with rim
 B : Outside the rim between T sections
 C : At corner of T section
 D : Inside the boss
 O.K : There is no defect
 Critical : Usable but hardly visible two pin holes were found out

	A	B	C	D
Radio isotope	Co ⁶⁰	Co ⁶⁰	Cs ¹³⁷ Co ⁶⁰	Co ⁶⁰
Intensity of R.I. mC	360	360	6 000 360	360
Distance between R.I. and film mm	850	230	600 300~400	270
Thickness radiated	100	40	80~90	70~90

	A	B	C	D
Radiative time	16h	13min	36~28min 55min~ 1h38min	50min
Film number	400#			
Pb screen	Tried both with and without screen			

Fig. 13 The procedures and results of radiographic inspection.

Fig. 14 γ -raying radiograph of rim and arm after the riser (1) was cut off.
(Location A in Fig. 13)

Fig. 15 γ -raying radiograph of shrinkage on rim connected with riser (3)
(Location C in Fig. 13)

/// Defect appearing after cut to 25 mm thick slice
 ■ Defect inspected by γ -raying the same slice
 (R.I. : C₉¹³⁷)

	Test slices	Location (cf. Fig.13)
A	Riser on boss	
B	Riser on rim	1'
C	Riser on rim	4'
D	Cross section of wheel center	Boss-4'
E	Rim between risers	4'-4
F	Rim between risers	1'-1

Fig. 16 γ -raying inspection of slices

Fig.10 indicates the change of feed metal flow which was estimated on the results of this experiment.

Radiographic inspection by γ -ray

The wheel center cast in this experiment is shown in Fig. 11. Fig. 13 shows the method of the radiographic inspection and its results. When risers were cut off slight shrinkage cavity was

Fig. 17 γ -raying radiograph of the slice of the riser (1)' on rim at gate

Fig. 18 γ -raying radiograph of the slice of the riser on boss (cf. Fig. 16)

Fig. 19 γ -raying radiograph of the slice of the arm connected with rim fed by the riser (4)' (cf. Fig. 16)

found as the tip of pipe under riser on every T section of rim except at gate as shown in Fig. 12 but there was no defect in boss and arms as shown in Fig. 14~Fig. 19. This may prove that the proposed riser dimensions on rim are not sufficient for eliminating the pipe under riser. However they seem to be almost enough for finished cast products except No. 1 riser whereunder hot spot exists probably because of being next to gate. And it must be also remarked that there are two very small interdendritic shrinkage cavities in the rim whereto gate is attached. They are considered to be caused by the influence of hot corner between rim and runner according to the second experiment. The second experiment was tried assuming that

riser dimensions without exothermic compound should be enlarged by 15% at least for the wheel center castings in comparison with Pellini's data, if any shrinkage under riser should be avoided. It is therefore concluded that Pellini's data should be modified considering the influences of hot spots and change of thermal gradient caused by gate, corner and metal flow.

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Elasticity Problem in the Case a Rigid Sphere is Pressed on the Plane Surface of Semi-Infinite Elastic Solid* (The Effect of Friction on the Contact Surface)

By Bunzai AN**

In recent papers, various methods of analysis, the so-called Bussinesq's problem⁽¹⁾, were given for the distribution of stress in a semi-infinite elastic medium deformed by the pressure of rigid body on a part of the plane boundary, while the remainder of the plane was free. In these papers, a friction on the contact surface in neglected or directly expressed⁽²⁾⁽³⁾.

In this paper, the author proves that the stress distribution and displacements on the surface of semi-infinite elastic solid indented by a rigid sphere are given by applying the Hankel Transform, and that the approximate solutions under the influence of friction on the contact surface are reduced by suitable use of above solutions.

An assumption of friction is made from the well-known fact that u_r of the contact surface decreases by the friction.

1. Introduction

It is already shown that, with axial symmetry, the relation for the biharmonic equation representing the components of displacement and stress may be written in the form⁽⁴⁾

$$\left. \begin{aligned} \sigma_r &= \lambda \nabla^2 \Phi_z - 2(\lambda + \mu) \Phi_{rrz} \\ \sigma_z &= (3\lambda + 4\mu) \nabla^2 \Phi_z - 2(\lambda + \mu) \Phi_{zzz} \\ \sigma_\theta &= \lambda \nabla^2 \Phi_z - \frac{2}{r} (\lambda + \mu) \Phi_{zr} \\ \tau_{rz} &= (\lambda + 2\mu) \frac{\partial}{\partial r} \nabla^2 \Phi - 2(\lambda + \mu) \Phi_{zrz} \end{aligned} \right\} \dots \dots \dots (1)$$

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