[논 문] 한국재료학회지
Korean Journal of Materials Research
Vol. 12, No. 7 (2002)

GC150 회주철의 수축결함생성에 미치는 주조 및 설계공정인자들의 영향

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Effects of Processing and Designing Variables on Formation of Shrinkage Cavities in GC150 Gray Cast Iron

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(2002년 6월 19일 받음, 2002년 7월 10일 최종수정본 받음)

Abstract The effect of processing and designing variables such as pouring temperature(1400 or 1500℃), inoculation and risering design(T and H type) on the formation of defects such as external depression, primary and secondary shrinkage cavities in GC150 gray cast iron was investigated. In T type risering design, external depression or primary shrinkage cavity due to liquid contraction was formed in all of the eight cases. Regardless of its modulus value, the riser could not function properly in T type risering design because directional solidification was not promoted toward the riser. On the other hand, the four cases of H type risering design in which thermal sleeves were set onto the risers produced defect-free castings. In both types of the risering designs, secondary shrinkage cavity caused by solidification contraction was not observed in the casting because of the expansion pressure due to graphite precipitation and the application of rigid pep-set mold. The degree of external depression or primary shrinkage cavity was reduced with lowered pouring temperature. The effect of inoculation was diminished because of the high carbon equivalent of GC 150 gray cast iron.

Key words : external depression, primary shrinkage cavity, expansion pressure, inoculation, carbon equivalent

1. Introduction

Gray cast iron is produced in the greatest quantity of all of the cast metals because of its unique characteristics such as excellent castability, good machinability, good wear resistance and high damping capacity that make it as a popular engineering material. However, the shrinking behavior of gray cast iron after pouring is more complicated than the conventional pattern of other alloys. After liquid contraction gray cast iron expands during part of the solidification. This expansion is followed by a secondary shrinkage while the iron is still in the process of solidification. Once the casting is completely solid, no contraction-induced shrinkage defects can be caused by the solid state contraction. Therefore, when designing the risering system of gray cast iron, the above fact must be considered otherwise external depression by liquid contraction or shrinkage cavity by solidification contraction can be formed in the casting. The amount of liquid contraction, expansion and secondary contraction in gray cast iron is known to be dependent upon factors such as type of melting equipment, quality of charge material, melt history, degree of oxidation, chemical composition, type of inoculant, method of inoculant addition, pouring temperature and type of mold material. Many published papers described the effects of processing variables on solidification behavior of gray cast iron.[1~5] Nevertheless, the research on the relationship between processing variables and shrinking behavior in GC 150 gray cast iron has not been conducted systematically. Therefore, the objective of this research is to investigate the effect of processing and designing variables such as pouring temperature, inoculation and risering design on the formation of defects such as external depression, primary and secondary shrinkage cavities in GC150 gray cast iron.

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2. Experimental Procedure

2.1 Preparation of Test Specimen

The grade GC150 gray cast irons were prepared in a 15kg-capacity high frequency induction furnace. The chemical composition of this alloy is C : 3.55%, Si : 2.35%, Mn : 0.65%, P : 0.2%, S : 0.1%.[6] Initial charge materials were clean pig iron and steel scrap. Ferro-alloys such as Fe-75%Si, Fe-60%Mn were added to a slag-free molten iron so as to minimize the oxidation loss and slag formation. The melts were heated to 1550℃ when eutectometer samples were taken to obtain the base iron analysis. Minor additions to effect a constant base iron chemistry were made at this stage. These heats were subsequently heated to 1600℃, samples taken for chemical analysis, and transferred into well heated teapot pouring ladle. After inoculating with(or without) 0.6% of Fe-75%Si in the ladle, the melts were poured at 1400 or 1500℃ into pep-set mold.

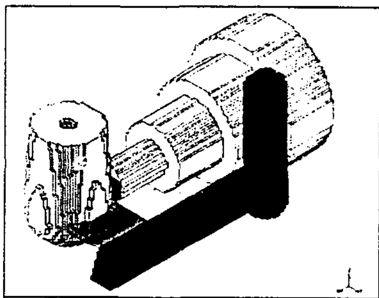
2.2 Shape of Specimen and Risering Design

Two types of risering design of cylindrically step-shape specimens were prepared for this research as shown in Fig. 1.

The riser is attached to the heaviest section of the casting in H type design while the thinnest section is attached to the riser in T type design. In both designs, the melts flow into the casting through sprue, runner, riser and riser neck.

2.3 Processing and Designing Variables

Of the various processing and designing variables, pouring temperature(1400 or 1500℃), thermal sleeve (application onto riser or not), inoculation(addition of 0.6% of Fe-75%Si into ladle or not) and risering design(H type design for directional solidification and T type design for non-directional solidification) were considered to investigate their effects on shrinking behavior of gray cast iron. Sixteen combinations of


T type

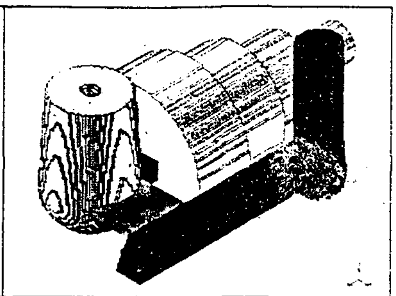

H type

Fig. 1. Two types of risering design of cylindrically step-shape specimens employed in this research.

Table I. Sixteen Combinations of the Processing Variables.

Case No. \ Variable	Pouring Temperature(℃)	Thermal Sleeve	Inoculation	Risering Design
T-1	1400	×	×	T type
T-2		○	×	
T-3		×	○	
T-4		○	○	
T-5	1500	×	×	
T-6		○	×	
T-7		×	○	
T-8		○	○	
H-1	1400	×	×	H type
H-2		○	×	
H-3		×	○	
H-4		○	○	
H-5	1500	×	×	
H-6		○	×	
H-7		×	○	
H-8		○	○	

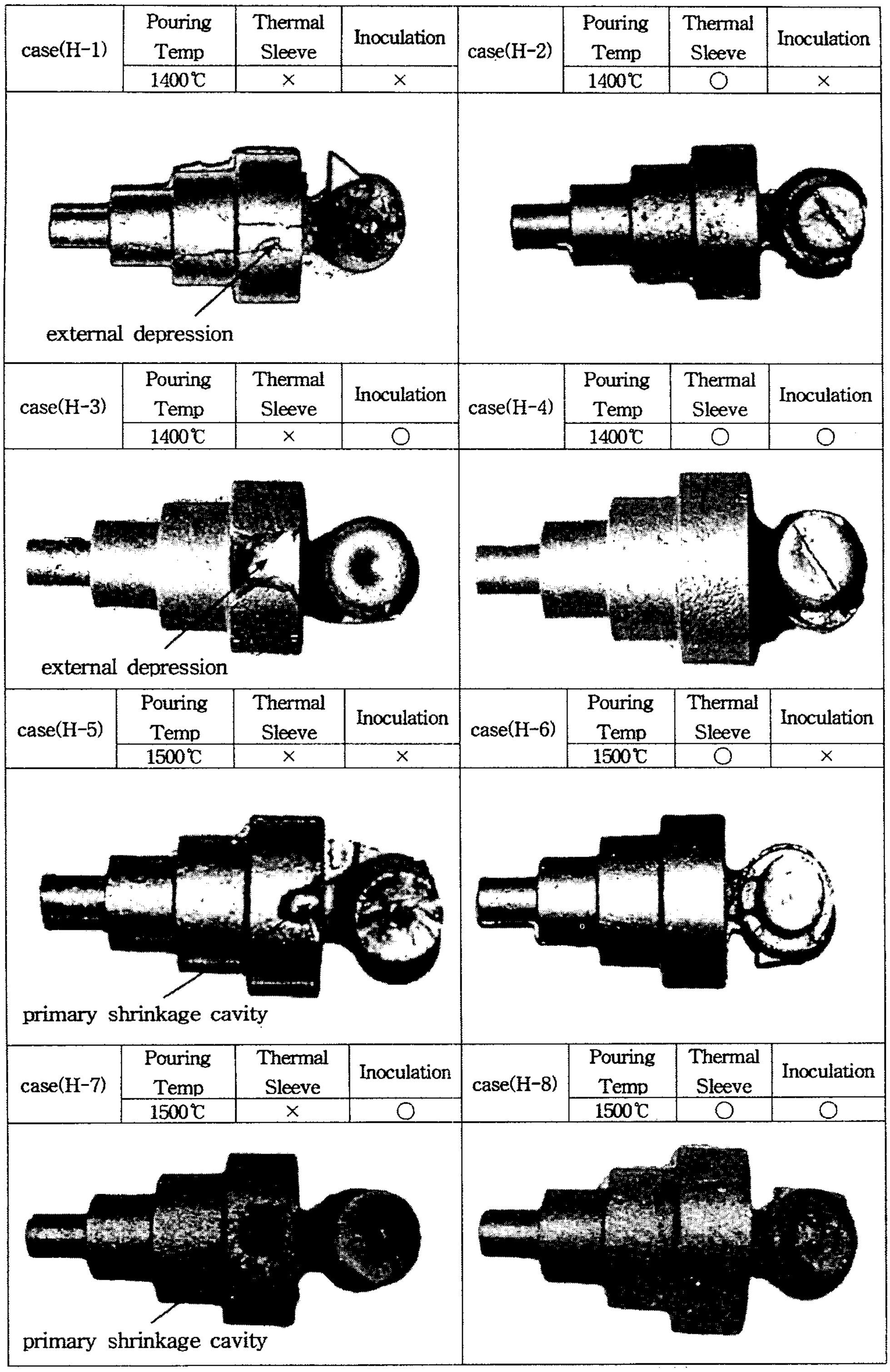
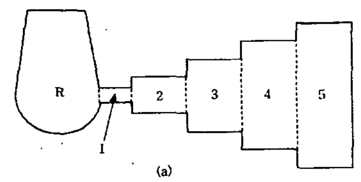


Fig. 2. Effects of processing and designing variables on shrinking behavior of T type risering design.

the processing variables are listed in Table 1.

3. Results and Discussion

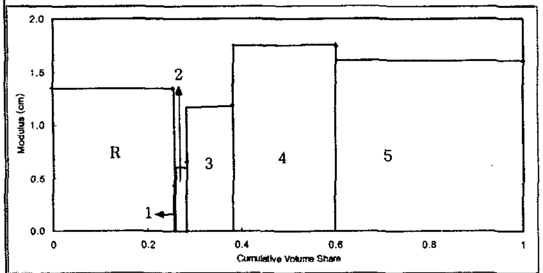
The effect of processing variables on shrinking behavior of T type design is shown in Fig. 2. As shown in Fig. 2, external depression or primary shrinkage cavity is observed in all the cases from (T-1) to (T-8). It is known that the shrinking behavior of gray cast iron is very different from that of other alloys and metals with the exception of ductile cast iron. The general pattern for volume change after completed pouring is in the order of liquid contraction, solidification contraction and solid state contraction. On the other hand, after liquid contraction, gray cast iron expands during part of the solidification because the carbon dissolved in the molten iron comes out of solution and precipitates as graphite flakes in a matrix of solidified iron alloy. This expansion is followed



(a)

T type Specimen					
Factor / Segment	Volume (cm^3)	Surface Area (cm^2)	Volume Share	Cumulative Volume Share	Modulus (cm)
R	361.33	269.33	0.253	0.253	1.342
1	4.60	10.625	0.003	0.256	0.433
2	35.34	53.83	0.025	0.281	0.657
3	141.37	119.46	0.099	0.380	1.183
4	318.09	182.45	0.223	0.603	1.743
5	565.49	354.19	0.396	1	1.597
Total	1426.22	989.89	1		1.441

(b)



(C)

Fig. 3. Cumulative volume share vs. modulus diagram in T type risering design.

by a secondary shrinkage while the iron is still in the process of solidification. The pattern of solid state contraction is the same as the other alloys.

The observed external depression or primary shrinkage cavity in Fig. 2 is the defect caused by liquid contraction just after pouring. Shortly after completed pouring, there is no solid present other than the thin layer frozen next to the mold wall, which causes the internal liquid pressure below that of the atmosphere.[7] Therefore, the atmospheric outside pressure can easily deform the solid skin, pushing it toward the inside at its weakest points, usually at the top or internal corners where the solidification process is slowest. This mechanism, by decreasing internal volume, can restore atmospheric pressure inside the liquid. The properly designed riser can deliver a liquid volume in order to compensate for liquid contraction. In Fig. 3, the specimen, riser and riser neck in T type risering design are divided by imaginary surfaces into six segments and a modulus for each segment vs. cumulative volume share is constructed from the calculated values.

By comparing Fig. 2 with Fig. 3(c), it is evident that external depression or primary shrinkage cavity was formed on the top of the segment 4(modulus: 1.743 cm) or segment 5(modulus: 1.597 cm) having higher modulus than other segments, which is consistent with the above theory. In all the eight cases, the riser did not deliver a liquid volume equaling that of the liquid contraction resulting in defects such as external depression or primary shrinkage cavity. This might be attributed to T type risering design. From Fig. 3(a), it can be known that the solidification pattern of T type risering design is not directional toward the riser: (1) After mold filling, smaller modulus values of the segments 2(modulus: 0.657 cm) and 3(modulus: 1.183 cm) hindered liquid flow from the riser to the segments 4 and 5. (2) The riser neck between casting and riser froze during liquid contraction because of its small modulus(modulus: 0.433 cm), which prevented the riser from compensating for external depression or primary shrinkage cavity. (3) The modulus of thermal sleeve-free riser(modulus: 1.342 cm) is smaller than those of the segment 4(modulus: 1.743 cm) and segment 5(modulus: 1.597 cm). (4) Even the thermal sleeve-attached riser having larger modulus value than that of the segment 4 or 5 failed to eliminate such defects.

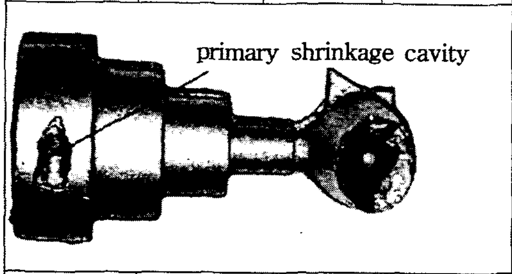
Therefore, it can be postulated that regardless of its modulus value, the riser can not function properly in the casting design system which does not lead to directional solidification toward the riser.

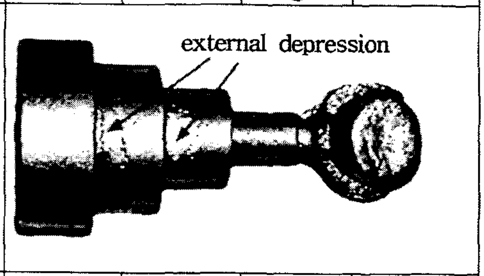
The effect of pouring temperature on liquid contraction is also shown in Fig. 2. When compared the cases of (T-1), (T-2), (T-3) and (T-4) with those of (T-5), (T-6), (T-7) and (T-8), it can be known that the degree of external depression or primary shrinkage cavity was reduced with lowered pouring temperature. The greater the gap between the temperature of pouring and onset of solidification, the more compensation is required for the volumetric contraction of the liquid. The carbon equivalent(CE) of GC 150 gray cast iron is 4.33, which solidifies at eutectic temperature of 1130℃. Therefore, the temperature gap between pouring point and onset of solidification is 370℃ in pouring at 1500℃, and 270℃ in pouring at 1400℃, which can explain the effect of pouring temperature on the degree of defects caused by liquid contraction.

For the observation of secondary shrinkage cavity formed during solidification, all the specimens were sectioned but revealed no shrinkage cavity in all the cases. Unlike primary shrinkage cavity, secondary shrinkage

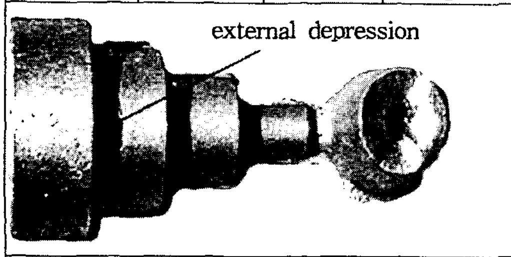
cavity is located in the thermal center of casting during solidification. Therefore, it has been expected

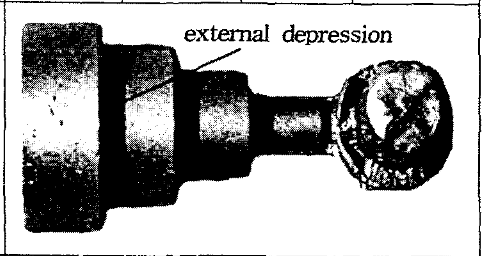
case	Pouring Temp	Thermal Sleeve	Inoculation	case	Pouring Temp	Thermal Sleeve	Inoculation
case(T-1)	1400℃	×	×	case(T-2)	1400℃	○	×



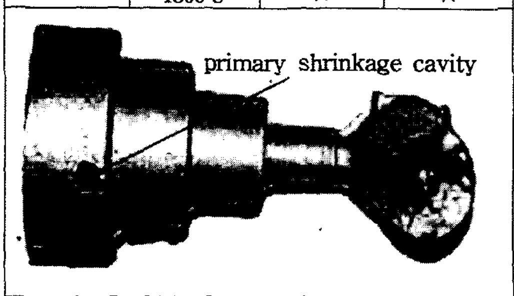


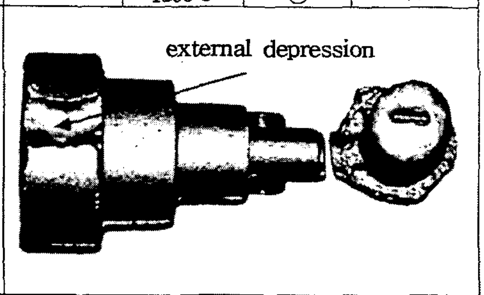
case	Pouring Temp	Thermal Sleeve	Inoculation	case	Pouring Temp	Thermal Sleeve	Inoculation
case(T-3)	1400℃	×	○	case(T-4)	1400℃	○	○



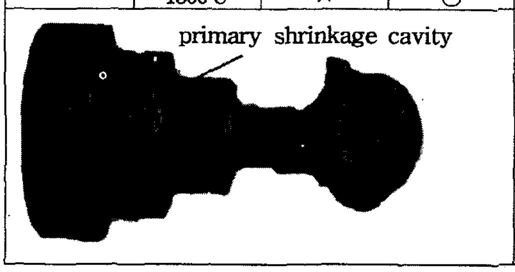


case	Pouring Temp	Thermal Sleeve	Inoculation	case	Pouring Temp	Thermal Sleeve	Inoculation
case(T-5)	1500℃	×	×	case(T-6)	1500℃	○	×





case	Pouring Temp	Thermal Sleeve	Inoculation	case	Pouring Temp	Thermal Sleeve	Inoculation
case(T-7)	1500℃	×	○	case(T-8)	1500℃	○	○



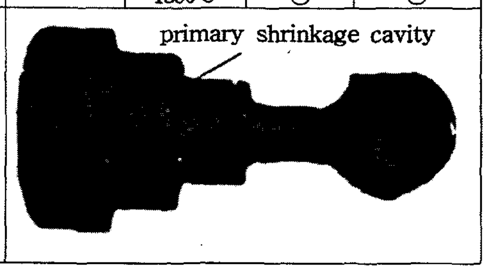
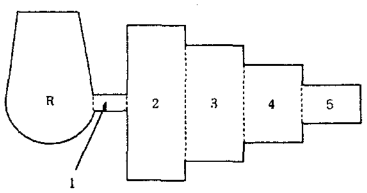


Fig. 4. Effects of processing variables on shrinking behavior of H type specimen.

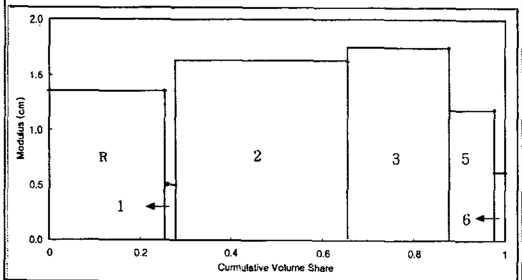
that secondary shrinkage cavity might be formed in the segment 4 because the thermal center of T type risering design lies in the segment 4 and the solidification pattern is not directional toward the riser. From the above results, it can be postulated that after liquid contraction, the expansion due to graphite precipitation built up pressure which counteracted the secondary shrinkage cavity. It is reported that the expansion pressure is maximum at the eutectic chemical composition which is equal to that of GC 150 gray cast iron and decreases in both directions away from the eutectic.[8] The use of rigid mold such as pep-set mold also played a role in resisting the forces of expansion otherwise swelling would occur and the casting would not be sound internally. The effect of inoculation on the formation



(a)

H type Specimen					
Factor / Segment	Volume (cm^3)	Surface (cm^2)	Volume Share	Cumulative Volume Share	Modulus (cm)
R	361.33	266.52	0.253	0.253	1.356
1	9.02	17.85	0.006	0.259	0.505
2	565.49	348.14	0.395	0.655	1.624
3	318.09	182.45	0.222	0.877	1.743
4	141.37	119.46	0.099	0.976	1.183
5	35.34	57.07	0.025	1	0.619
합 계	1,430.64	991.49	1		1.443

(b)



(c)

Fig. 5. Cumulative volume share vs. modulus diagram in H type risering design.

of secondary shrinkage cavity is not evident in T type risering design. The main reason for conducting inoculation is the formation of small, uniformly dispersed Type A graphite flakes by providing more nucleation centers for eutectic cells to form. The smaller the cell size, the more will be the graphite flakes, by which more expansion forces can be exerted. But, it is thought that this effect was faded because of the carbon equivalent of GC 150 gray cast iron which has the highest expansion forces.

Unlike T type risering design, H type risering design showed a different shrinking behavior as shown in Fig. 4.

Regardless of pouring temperature and inoculation, the specimens with thermal sleeve-attached riser showed no external depression or primary shrinkage cavity while those defects were produced in the specimens with thermal sleeve-free riser. Therefore, it can be postulated that the riser modulus had a dominant effect in eliminating the defects caused by liquid contraction. In Fig. 5, H type risering design is divided by imaginary surfaces into six segments and a modulus for each segment vs. cumulative volume share is constructed from the calculated values.

From the arrangement of the segments shown in Fig. 5(a), a directional solidification is expected to occur toward the riser. But, because the modulus of thermal sleeve- free riser (modulus: 1.356 cm) is smaller than that of the segment 2 (modulus: 1.624 cm) or 3 (modulus: 1.743 cm), the riser could not deliver the molten iron to compensate for liquid contraction resulting in the formation of external depression or primary shrinkage cavity in the cases of (H-1), (H-3), (H-5) and (H-7). However, this phenomenon was eliminated with the application of thermal sleeve onto riser. With the aid of exothermic reaction during risering, the modulus of riser became greater than that of the segment 2 or 3 which promoted the directional solidification toward the riser. Therefore, no defects due to liquid contraction were observed in the cases of (H-2), (H-4), (H-6) and (H-8).

When compared the cases of (H-1) and (H-3) with those of (H-5) and (H-7), the effect of pouring temperature on shrinking behavior is evident. As observed in T type risering design, the degree of defects was reduced with lowered pouring temperature. Therefore, the same explanation can be applied here.

For the observation of secondary shrinkage cavity formed during solidification, all the specimens were sectioned but revealed no shrinkage cavity in all the cases, which can be explained as in T type risering design.

4. Conclusion

In GC 150 gray cast iron, the effect of some processing and designing variables such as pouring temperature, inoculation and risering design on the formation of shrinkage cavities was investigated and the following conclusions were obtained:

1) Regardless of its modulus value, the riser can not function properly in the casting design system which does not lead to directional solidification toward the riser. While external depression or primary shrinkage cavity was formed in all the cases in T type risering design, only four cases were observed in H type risering design.

2) In both types of risering designs, the degree of external depression or primary shrinkage cavity was reduced with lowered pouring temperature.

3) In both types of risering designs, secondary shrinkage cavity was not formed during solidification by the expansion pressure due to graphite precipitation and rigid pep-set mold employed.

4) The effect of inoculation was faded because of the carbon equivalent of GC 150 gray cast iron.

Acknowledgements

This work was supported (in part) by the Korea Science and Engineering Foundation(KOSEF) through the Center for Automotive Parts Technology (CAPT) at Keimyung University.

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