[논 문] 한국재료학회지
Korean Journal of Materials Research
Vol. 13, No. 5 (2003)

회주철의 수축결함생성에 미치는 주조방안 및 화학조성의 영향

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Effects of Risering Design and Chemical Composition on Formation of Shrinkage Cavity in Gray Cast Iron

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(2003년 4월 1일 받음, 2003년 4월 26일 최종수정본 받음)

Abstract The effects of risering design and alloying element on the formation of defects such as external depression, primary and secondary shrinkage cavity in gray cast iron were investigated. Two types of risering design for the cylindrically step-wise specimen, No. 1(progressive solidification) and No. 2(directional solidification) risering designs, were prepared and five different alloy compositions were casted. In the No. 1 risering design, external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from ISO 150 to ISO 350. The primary shrinkage cavity was located right under the top surface or connected to the top surface, and was characterized by smooth surface. Its size increased with an increase in ISO number. However, neither secondary shrinkage cavity nor swollen surface was observed in all the castings. In the No. 2 risering design, neither primary shrinkage cavity nor secondary shrinkage cavity was observed in all the specimens due to proper risering design. A swollen surface was also not observed in all the castings with the application of pep-set mold.

Key words external depression, shrinkage cavity, progressive and directional solidification, swollen surface

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, high damping capacity, excellent compressive strength and good tensile strength.[1)] However, the shrinking behavior of gray cast iron after pouring into the mold is more complicated than the conventional pattern of other alloys except for ductile cast iron. After liquid contraction gray cast iron solidifies with the precipitation of graphite flakes in the matrix. As the graphite forms during solidification, an expansion of the metal takes place. 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 ductile cast iron, the above solidificaion pattern must be recognized; otherwise external depression or primary shrinkage cavity by liquid contraction, swollen surface by solidification expansion and shrinkage cavity by secondary contraction may be formed in the casting. The amount of liquid contraction, solidification expansion and secondary contraction in gray cast iron are known to be dependent upon the factors such as type of melting equipment, quality of metallic charge, melt history, degree of oxidation, chemical composition, type of inoculant, method of inoculant addition, pouring temperature, type of mold material and risering design. Many published papers described the effects of some processing variables on the solidification behavior of gray cast iron.[2-8)] Nevertheless, the research on the effects of risering design and chemical composition on the formation of shrinkage cavity in gray cast iron has not been conducted systematically. Therefore, the objective of this research is to investigate the effect of risering design(with directional and progressive solidification) and chemical composition on the formation of defects such as external depression, primary and secondary shrinkage cavities, and swollen surface in gray cast iron.

2. Experimental Procedure

2.1. Preparation of Test Specimen

Five different alloy compositions of gray cast iron were prepared and compared with the actual analysis as listed in

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Table 1.[9)]

Initial charge materials such as clean pig iron and steel scrap were melted in a 15 kg-capacity high frequency induction furnace. 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. These heats were subsequently heated to 1600 and transferred into well heated teapot pouring ladle. After inoculating with 0.6% of Fe-75%Si in the ladle, the melts were poured at 1400°C into pep-set mold. A chilled sample was also obtained for final chemical analysis.

2.2. Design of Risering System

Two types of risering design for the cylindrically step-wise specimen, No. 1 and No. 2 risering designs, were prepared as shown in Fig. 1.

In the No. 1 risering design, the riser is attached to the thinnest section of casting to promote a progressive solidification toward center of each specimen step. However, the No. 2 risering design reveals that the riser is attached to the

Table 1. *Five different alloy compositions of gray cast irons*

Grade		Elements (%)				
		C	Si	Mn	P	S
ISO 150	Target	3.65	2.55	0.65	<0.25	<0.1
	Actual	3.60	2.47	0.87	0.02	0.01
ISO 200	Target	3.45	2.05	0.75	<0.20	<0.1
	Actual	3.40	1.96	0.94	0.02	0.01
ISO 250	Target	3.35	1.95	0.75	<0.15	<0.1
	Actual	3.35	1.85	0.92	0.02	0.01
ISO 300	Target	3.20	1.85	0.75	<0.12	<0.1
	Actual	3.25	1.83	0.97	0.02	0.01
ISO 350	Target	3.5	1.75	0.85	<0.10	<0.1
	Actual	3.07	1.80	1.13	0.02	0.01

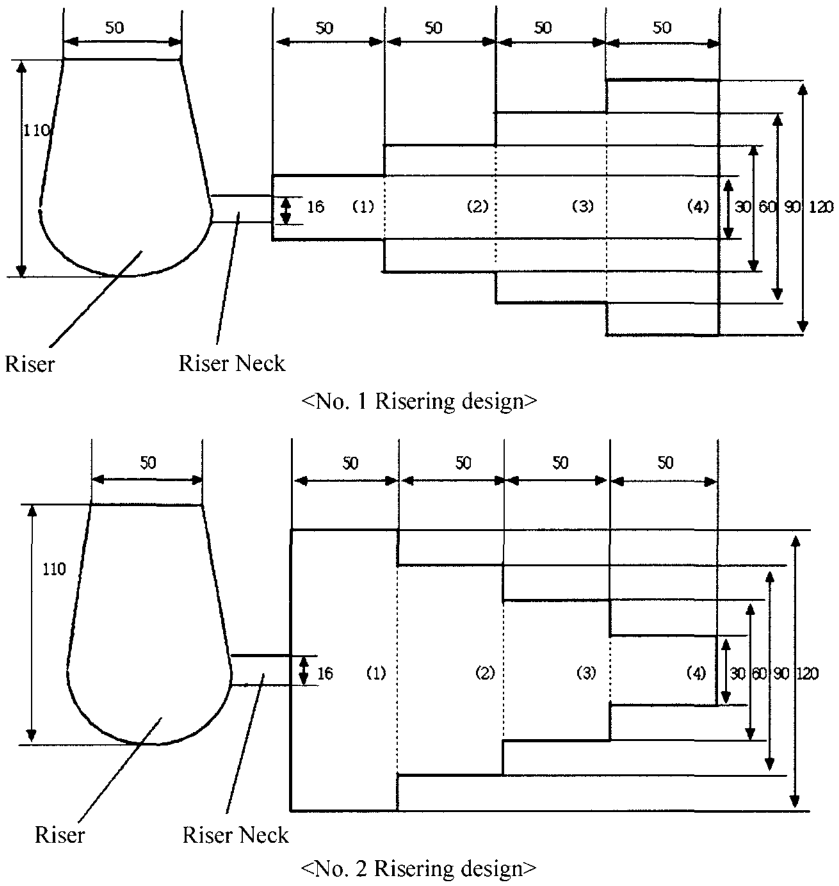

Fig. 1. Two types of risering design for cylindrically step-wise specimen.

heaviest section of casting to promote a directional solidification toward riser.

2.3. Observation of Defects

External depression and swollen surface were observed from outside appearance with naked eyes. However, the specimens were sectioned transversely to observe the primary and secondary shrinkage cavities.

3. Results and Discussion

The effect of chemical compositions on the behavior of liquid contraction after pouring into the mold in the No. 1 risering design is shown in the five top views of Fig. 2.

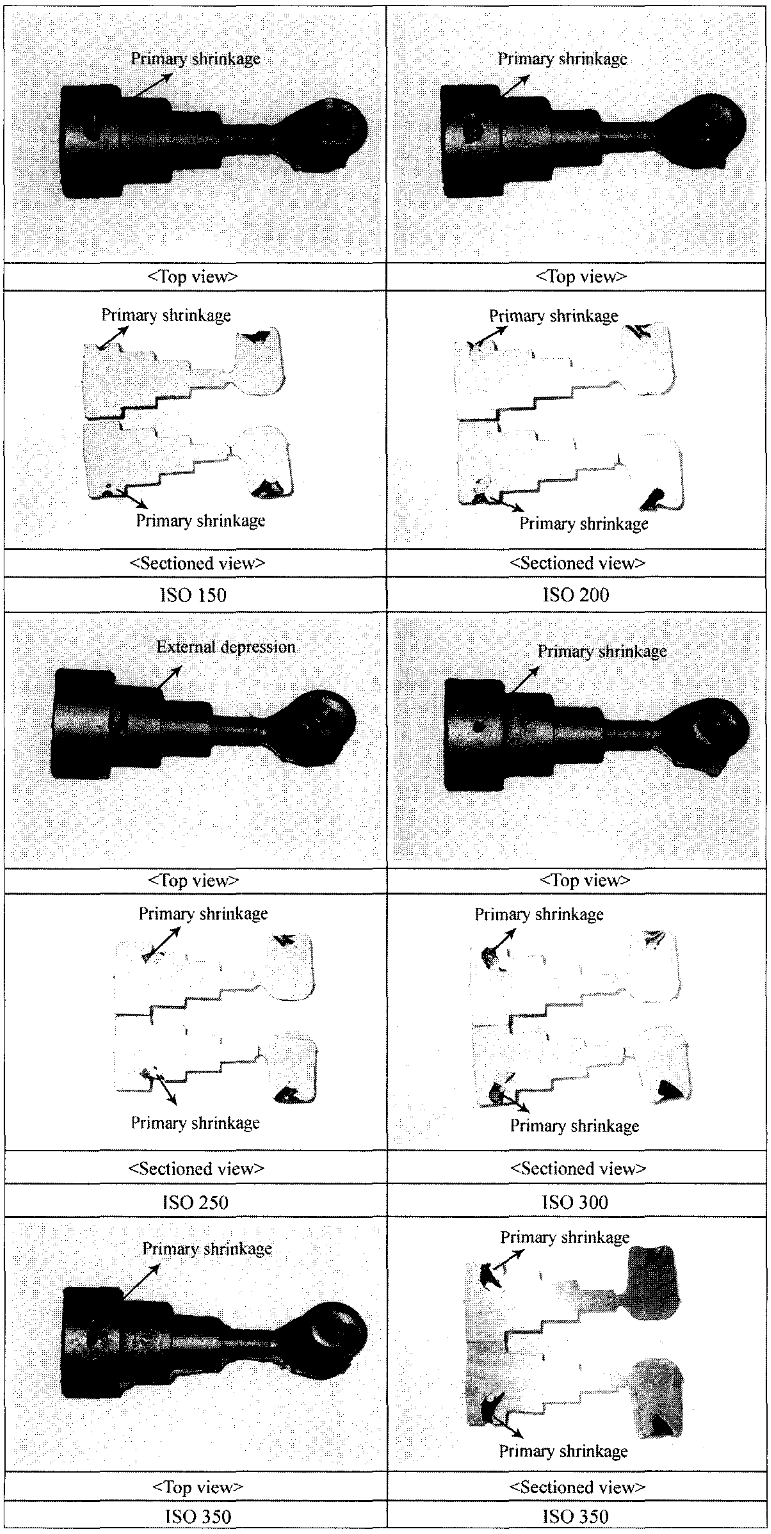

Fig. 2. Top and sectioned views of the five specimens in the No. 1 risering design.

External depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from ISO 150 to ISO 350. 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 atmospheric pressure.[10-11] Therefore, the atmospheric outside pressure can easily deform the solid skin by pushing it toward the inside at its weakest points, usually at the top or internal corners where the solidification process is the slowest. This mechanism, by decreasing internal volume, can restore atmospheric pressure inside the liquid. A properly designed riser can deliver the liquid metal in order to compensate for this liquid contraction. The modulus values of riser, riser neck and four specimen steps in the No. 1 risering design are shown in Table 2.

By comparing Fig. 2 with Table 2, it is evident that external depression or primary shrinkage cavity was formed on the top of specimen step 3(modulus: 1.743 cm) or step 4(modulus: 1.597 cm) having higher modulus value than that of the specimen step 1(modulus: 0.657 cm) and 2 (modulus: 1.183 cm), which is consistent with the above theory. In all the five specimens, the riser did not feed a liquid metal equaling to that of the liquid contraction, which resulted in defects such as external depression or primary shrinkage cavity. The occurrence of these defects is attributed to the nature of the No. 1 risering design. From Table 2, it can be recognized that the solidification pattern of the No. 1 risering design is not directional toward riser but progressive toward center of each specimen step : after mold filling, the specimen steps 1 and 2 with smaller modulus values solidified earlier and blocked the flow channel of liquid metal from the riser to the specimen steps 3 and 4. As shown in the five sectioned views of Fig. 2, all the specimens were also cut transversely for the revelation of primary and secondary shrinkage cavities formed during liquid and solidification contractions. The primary shrinkage cavities were located right under the top surface or connected to the top surface, and were characterized by smooth surfaces. The size of the primary shrinkage cavities increased with an increase in ISO number. As shown in Fig. 3, ISO 350 gray cast iron has the highest liquidus temperature and ISO 150 has the lowest one. Because of the fact that the best fluidity results when the liquidus temperature is at the minimum, ISO 150 gray cast iron produced the specimen with lowest amounts of primary shrinkage cavities.

However, the secondary shrinkage cavities were not observed in all the specimens. This might be attributed to the shrinking behavior of gray 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 the first stage of solidification because the carbon dissolved in the molten iron comes out of solution and precipitates as graphite flakes in the matrix. This expansion is followed by a secondary shrinkage while the iron is still in the process of solidification. Therefore, the expansion due to graphite precipitation might have built up a pressure which counteracted a formation of the secondary shrinkage cavities. The use of rigid pep-set mold also played a significant role in

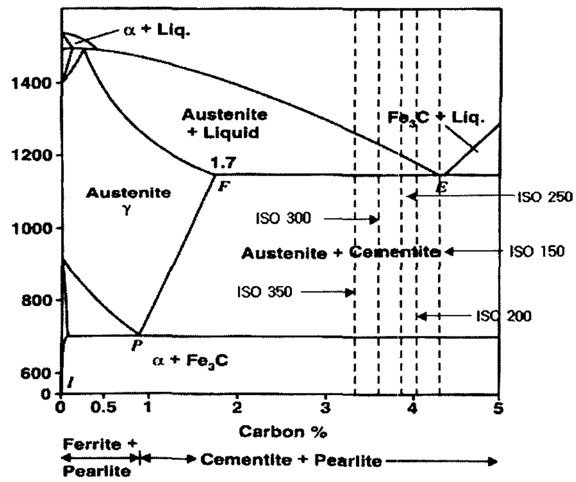

Fig. 3. Phase diagram of gray cast iron showing five ISO grades.

Table 2. Modulus values of each part in the No. 1 risering design

Risering Design No. 1					
Factor / Segment	Volume (cm^3)	Surface Area (cm^2)	Volume Share	Cumulative Volume Share	Modulus (cm)
Riser	361.33	269.33	0.253	0.253	1.342
Riser Neck	4.60	10.625	0.003	0.256	0.433
1	35.34	53.83	0.025	0.281	0.657
2	141.37	119.46	0.099	0.380	1.183
3	318.09	182.45	0.223	0.603	1.743
4	565.49	354.19	0.396	1	1.597
Total	1,426.22	989.89	1		1.441

resisting the forces of expansion; otherwise a swollen surface might have resulted and the casting would not be sound internally.

The effect of chemical compositions on the behavior of liquid contraction after completed pouring in the No. 2 risering design is shown in the five top views of Fig. 4. Unlike the No. 1 risering design, no external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from ISO 150 to ISO 350. This might be due to the different risering design of the two systems. The modulus values of riser, riser neck and four specimen steps in the No. 2 risering design are shown in Table 3.

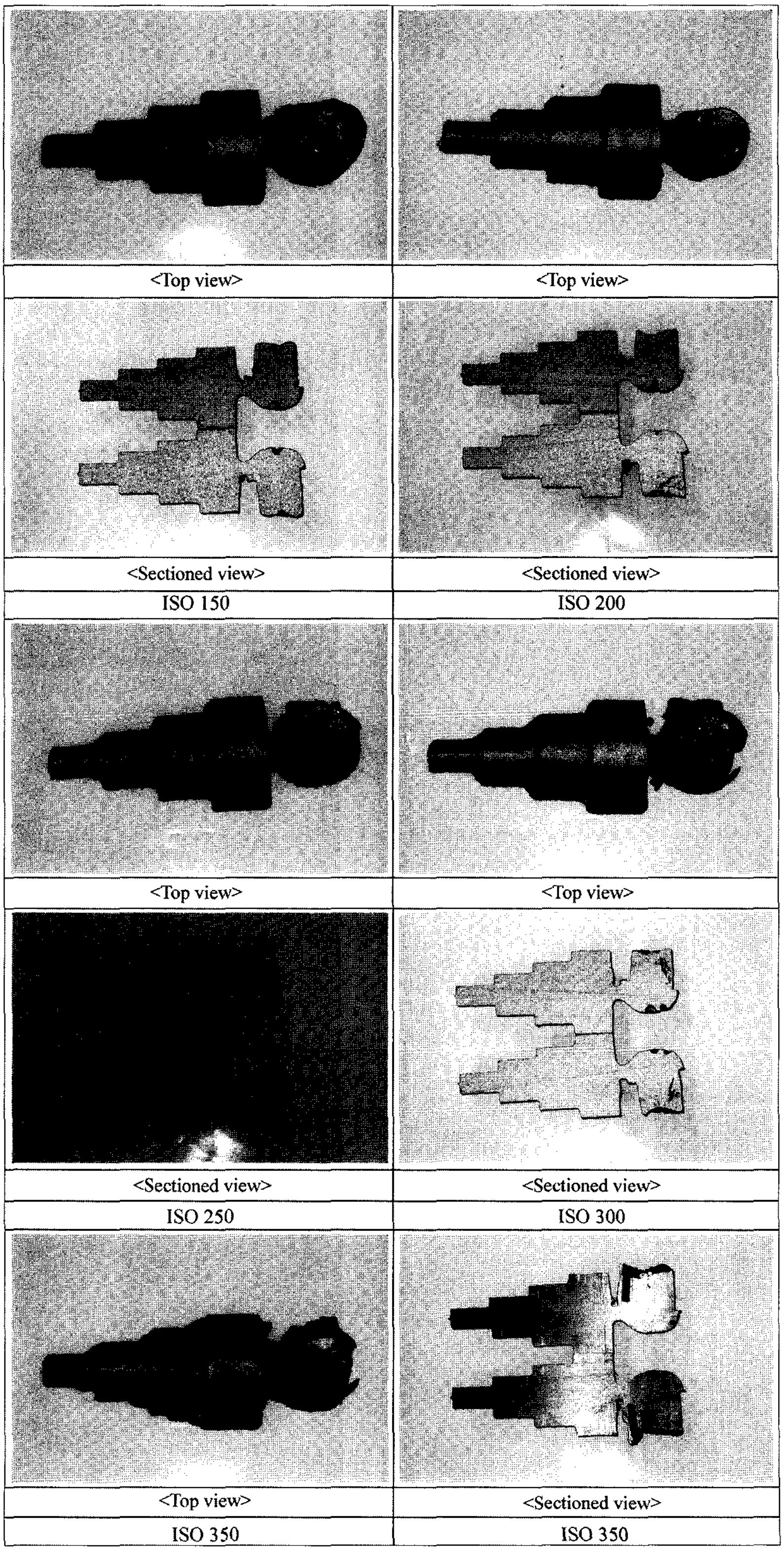

Fig. 4. Top and sectioned views of the five specimens in the No. 2 risering design.

Table 3. Modulus values of each part in the No. 2 risering design

Risering Design No. 2					
Segment \ Factor	Volume (cm^3)	Surface Area (cm^2)	Volume Share	Cumulative Volume Share	Modulus (cm)
Riser	361.33	266.52	0.253	0.253	1.356
Riser Neck	9.02	17.85	0.006	0.259	0.505
1	565.49	348.14	0.395	0.655	1.624
2	318.09	182.45	0.222	0.877	1.743
3	141.37	119.46	0.099	0.976	1.183
4	35.34	57.07	0.025	1	0.619
Total	1,430.64	991.49	1		1.443

After mold filling, a directional solidification is expected to occur toward the riser: it solidifies from the specimen step 4(modulus: 0.619 cm), 3(modulus: 1.183 cm), 2 (modulus: 1.743 cm), 1(modulus: 1.624 cm) to riser (modulus: 1.356 cm). Enen if the modulus of riser is smaller than that of the specimen steps 1 and 2, it can become greater with the application of thermal sleeve onto it. Therefore, regardless of the chemical compositions, the formation of defects caused by liquid contraction was prevented through proper risering design.

As shown in the five sectioned views of Fig. 4, the primary and secondary shrinkage cavities were not observed in all the specimens.

4. Conclusion

In gray cast iron, the effect of risering design and chemical composition on the formation of defects such as external depression, primary and secondary shrinkage cavities was investigated and the following conclusions were obtained:

1) Risering design played an important role for the formation of shrinkage cavities.

2) In the No. 1 risering design, external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from ISO 150 to ISO 350. The size of the primary shrinkage cavity increased with an increase in ISO number. However, the secondary shrinkage cavity was not observed in all the specimens. A swollen surface was also not observed in all the castings with the adoption of pep-set mold.

3) In the No. 2 risering design, neither primary shrinkage cavity nor secondary shrinkage cavity was observed in all the specimens from ISO 150 to ISO 350. A swollen surface was also not observed in all the castings.

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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