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구상흑연주철의 수축결함생성에 미치는 주조방안 및 합금원소의 영향

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Effects of Risering Design and Alloying Element on Formation of Shrinkage Cavity in Ductile Cast Iron

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Abstract The effects of risering design and alloying element on the formation of defects such as external depression, primary and secondary shrinkage cavities in ductile 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 six different alloy compositions were casted. In the No. 1 risering design, external depression or primary shrinkage cavities due to liquid contraction were observed in all the specimens from SG 10 to SG 60. The defects caused by liquid contraction seemed to be more affected by risering design than alloying elements. The secondary shrinkage cavities were also observed in all the specimens but a swollen surface was not observed in all the castings. The primary shrinkage cavities were located right under the top surface or connected to the top surface, and were characterized by smooth surfaces. On the other hand, the secondary shrinkage cavities were positioned in the thermal center of the specimen steps 3 and 4, and characterized by rough surfaces. In the No. 2 risering design, no external depression or primary shrinkage cavities due to liquid contraction were observed in all the specimens from SG 10 to SG 60. However, the secondary shrinkage cavities were formed in the thermal center of specimens SG 40, 50 and 60. Like the No. 1 risering design, a swollen surface was not observed in all the castings.

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

1. Introduction

After pouring into the mold, the volume changes with temperature that take place in most cast metals and alloys are in the order of liquid contraction, solidification contraction and solid state contraction. However, the shrinking behavior of ductile cast iron is very different from the above conventional pattern. The major difference is in the fact that after liquid contraction, ductile cast iron expands during the first stage of the solidification and followed by a secondary contraction while the iron is still in the process of solidification. This expansion has been mainly ascribed to the difference in density between liquid iron and spheroidal graphite that precipitates during solidification. 1) When a relatively heavy section ductile casting is poured into a soft green sand mold, the casting after solidification shows a swollen surface which proves the existence of the expansion. A multitude of small and contraction-induced cavities are also observed in the thermal center of the casting. No such cavities would have been formed if the expansion continued all the way to the end of solidification. Depending on the strength of the mold, this expansion will be suppressed to various degrees and converted into pressure used to compensate for the secondary contraction. Therefore, when designing the risering system of 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 ductile 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

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solidification behavior of ductile cast iron.[2-10] Nevertheless, the research on the effects of risering design and alloying element on the formation of shrinkage cavity in ductile cast iron has not been conducted systematically. Therefore, the objective of this research is to investigate the effect of risering design(with directional or progressive solidification) and alloying element(graphitizing or carbide stabilizing element) on the formation of defects such as external depression, primary and secondary shrinkage cavities in ductile cast iron.

2. Experimental Procedure

2.1. Preparation of Test Specimen

Six different alloy compositions of ductile cast iron were prepared as listed in Table 1.

SG 10 iron has a standard chemical composition of C ; 3.50%, Si ; 2.65%, Mn ; <0.1%, P ; <0.25%, S ; <0.1%. In SG 20, 30, 40, 50 and 60 irons, 1.0% of graphitizing elements(Cu, Ni) or carbide stabilizing elements(Mo, Cr, V) were added to the standard chemical composition to observe their effects on the shrinking behavior during solidification. All the heats were produced in a 15 kg-capacity high frequency induction furnace. Initial charge materials were clean pig iron and steel scrap. Alloying elements were added to a slag-free molten iron so as to minimize the oxidation loss and slag formation. The melt was heated to 1550°C when a chilled sample was taken to obtain the base iron analysis. Then, the heat was subsequently heated to 1600°C, and transferred into well heated teapot pouring ladle in which magnesium and inoculation treatments were conducted concurrently. After removal of any dross and slag, the melt was 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.

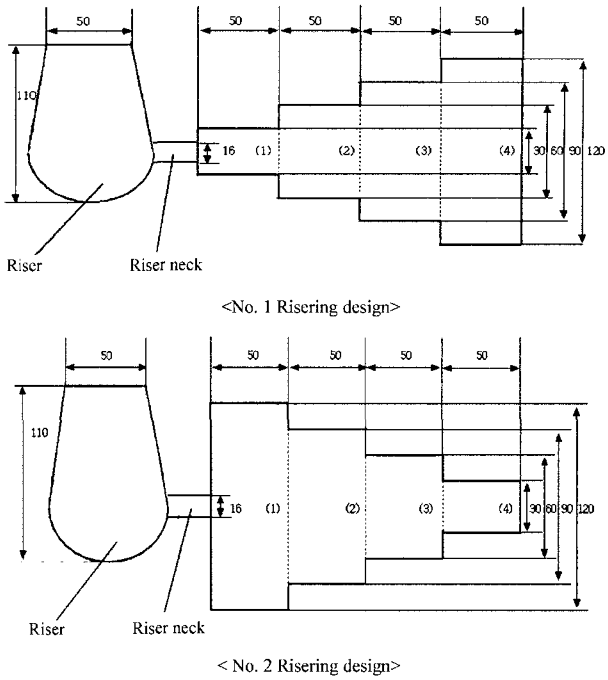

Fig. 1. Two types of risering design for cylindrically step-wise specimen.

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 heaviest section of casting to promote a directional solidification toward riser. In both risering designs, the thermal sleeve was inserted on the top of the riser for maximum efficiency.

3. Results and Discussion

The effect of alloying elements on the behavior of liquid contraction after pouring in the No. 1 risering design is shown in the six top views of Fig. 2.

External depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from SG 10 to SG 60. Shortly after completed pouring, there is no solid present other than the thin layer frozen next to the

Table 1. Six different alloy compositions of ductile cast irons.

Grade	Elements (%)					
	C	Si	Mn	P	S	Other
ISO 10	3.50	2.65	< 0.1	< 0.25	< 0.1	-
SG 20	〃	〃	〃	〃	〃	Cu: 1.0
SG 30	〃	〃	〃	〃	〃	Ni: 1.0
SG 40	〃	〃	〃	〃	〃	Mo: 1.0
SG 50	〃	〃	〃	〃	〃	Cr: 1.0
SG 60	〃	〃	〃	〃	〃	V: 1.0

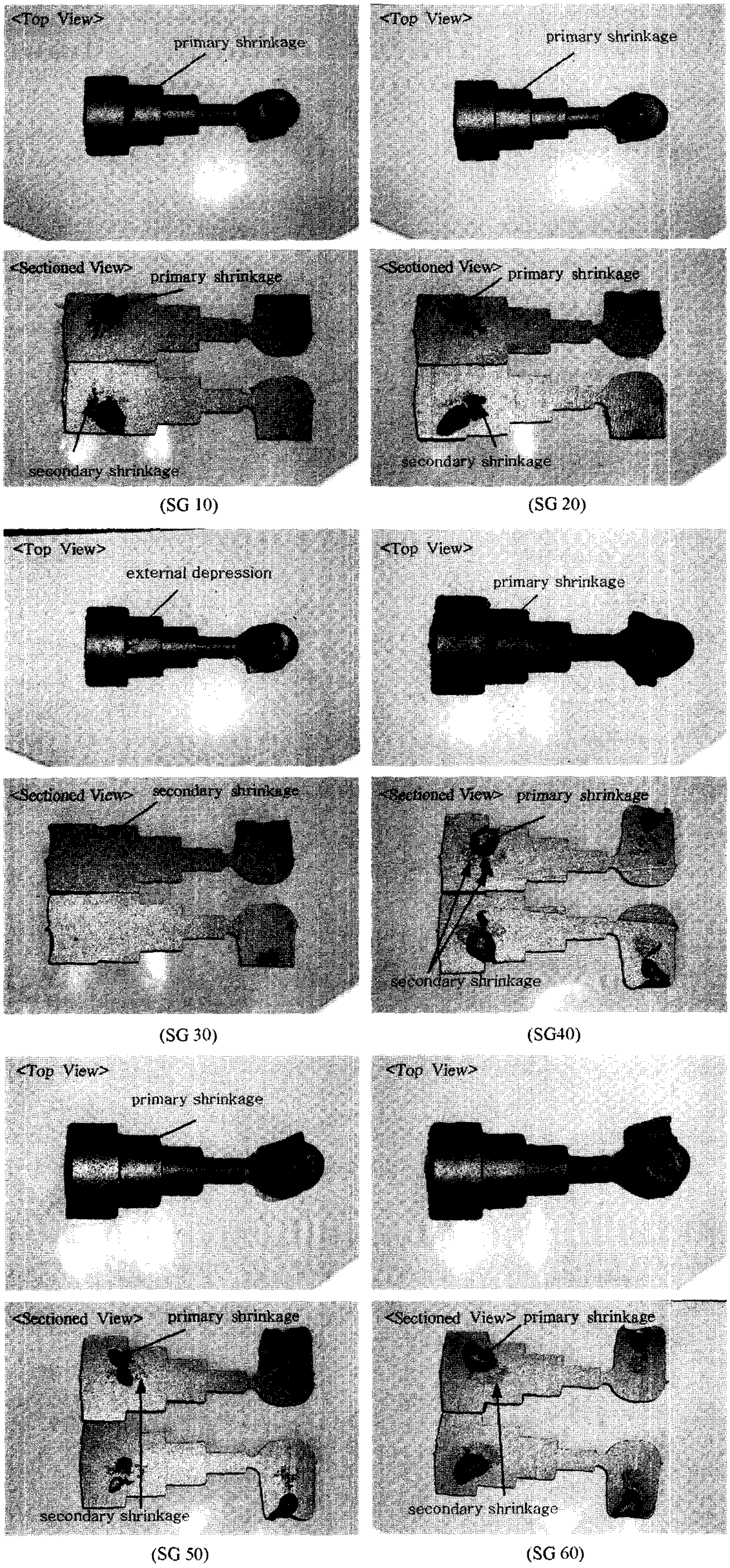

Fig. 2. Top and sectioned views of the six specimens in the No. 1 risering design.

mold wall, which causes the internal liquid pressure below atmospheric pressure.[11,12] 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 six 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. Therefore, the defects caused by liquid contraction seem to be more affected by risering design than alloying elements.

As shown in the six sectioned views of Fig. 2, all the specimens were also cut 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. A multitude of small and contraction-induced cavities, the secondary shrinkage cavities, were also observed in all the specimens. But, they were positioned in the thermal center of the specimen steps 3 and 4, and characterized by rough surfaces. It is known that the shrinking behavior of ductile cast iron is very different from that of other alloys and metals with the exception 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, ductile cast iron expands during the first stage of the solidification because the carbon dissolved in the molten iron comes out of solution and precipitates as graphite nodules in the matrix. This expansion is followed by a secondary shrinkage while the iron is still in the process of solidification. However, a swollen surface was not observed in all the specimens. This might be due to the fact that the rigid pep set mold was capable of resisting the forces of expansion by graphite precipitation. Therefore, it

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

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

Risering Design No. 2					
Factor Segment	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

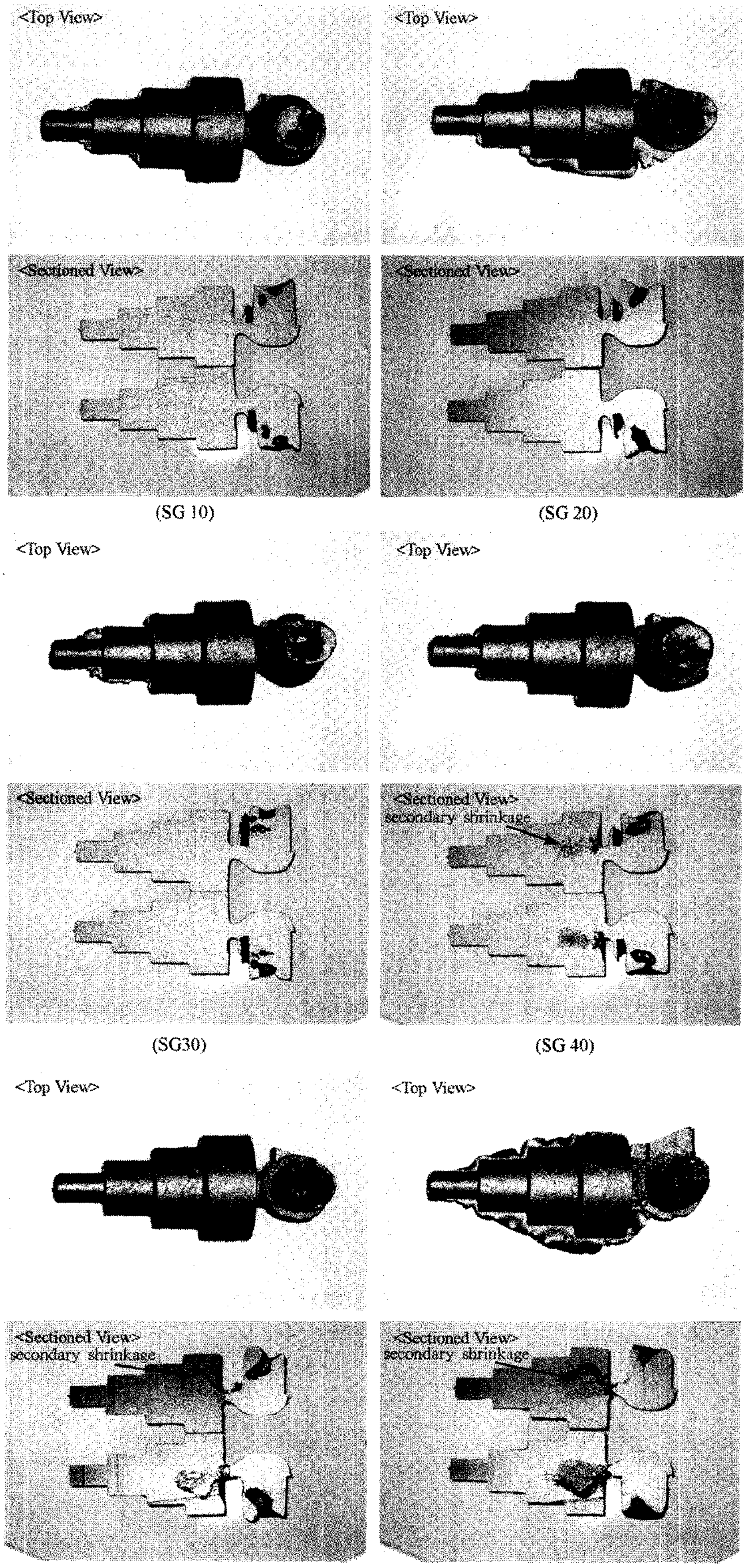

Fig. 3. Top and sectioned views of the six specimens in the No. 2 risering design.

can be postulated that during solidification contraction, the feeding channel from the riser to the specimen steps 3 and 4 has been already frozen, which resulted in the formation of secondary shrinkage cavities.

The effect of alloying elements on the behavior of liquid contraction after completed pouring in the No. 2 risering design is shown in the six top views of Fig. 3.

Unlike the No. 1 risering design, no external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from SG 10 to SG 60. 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.

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). Even if the modulus of riser is smaller than that of the specimen steps 1 and 2, it can become larger with the application of thermal sleeve onto it. Therefore, regardless of the type of alloying elements added, the formation of defects caused by liquid contraction was prevented through proper risering design.

As shown in the six sectioned views of Fig. 3, all the specimens were also cut for the revelation of primary and secondary shrinkage cavities formed during liquid and solidification contractions. While the primary shrinkage cavities were not observed in all the sectioned views, the secondary shrinkage cavities were observed in the thermal centers of specimens SG 40, 50 and 60. The alloying elements such as Mo, Cr and V are called as carbide stabilizing elements which promote carbide eutectic rather than graphite eutectic. And carbide eutectic temperature is about 10°C lower than graphite eutectic temperaure.[12] With the addition of carbide stabilizing elements, the gap between the two eutectic temperatures becomes narrow causing less solidification time. Therefore, the fact that feeding channel from the riser to the casting is frozen off earlier than that with graphitizing elements might be responsible for the formation of secondary shrinkage cavities in the specimens SG 40, 50 and 60. Like the No. 1 risering design, a swollen surface was not observed in all the castings.

4. Conclusion

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

1) In the No. 1 risering design, external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from SG 10 to SG 60. The defects caused by liquid contraction seemed to be more affected by risering design than alloying elements. The secondary shrinkage cavity was also observed in all the specimens but a swollen surface was not observed in all the castings.

2) In the No. 2 risering design, no external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from SG 10 to SG 60. However, the secondary shrinkage cavity was formed in the thermal centers of specimens SG 40, 50 and 60. A swollen surface was not observed in all the castings.

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