論 文

Effects of Riser Design and Chemical Composition on the Formation of Shrinkage Cavity in Gray and Ductile Iron Castings

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Abstract

회주철 및 구상흑연주철에 있어서 압탕방안 및 합금원소가 수축결함의 생성에 미치는 영향을 연구하였다. 두 종류의 압탕방안으로 실린더형상의 계단상시편을 제조하였으며 회주철의 경우 5조성(ISO 150, 200, 250, 300, 350), 구상흑연주철의 경우 6조성(SG 10, 20, 30, 40, 50, 60)을 사용하였다. 회주철 및 구상흑연주철 공히, 1차 압탕방안의 경우 액상수축에 의한 1차수축결함이 후육부의 표면에 발생하였으며 수축결함의 내면은 매끄러웠다. 회주철의 경우 응고수축에 의한 2차수축결함은 생성되지 않았으나 구상흑연주철의 경우 모든 시편의 내부열점에 2차수축결함이 발생하였고 그 내면은 거칠었다. 2차압탕방안의 경우 회주철의 모든 시편에서는 1차 및 2차수축결함이 발생되지 않았다. 그러나 구상흑연주철의 경우 탄화물 생성원소가 첨가된 SG 40, 50 및 60의 3조성에서 2차수축결함이 열점에 생성되었다. 견고한 펠센주형을 사용하였기 때문에 주형벽이동으로 인한 표면팽창은 어느 경우에도 관찰되지 않았다.

Key words: Gray and ductile cast iron, Riser design, Primary and secondary shrinkage cavity, Swollen surface

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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 gray and ductile cast irons is very different from the above conventional pattern. The major difference is in the fact that after liquid contraction, they expand during the first stage of solidification and followed by a secondary contraction while the melt is still in the process of solidification. This expansion has been mainly ascribed to the difference in densities between liquid iron and graphite that precipitates during solidification. When a relatively heavy section casting is poured into a soft green sand mold, the casting after solidification shows a swollen surface which proves an 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 the riser systems of gray and ductile iron castings are designed, 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 might be formed in the casting. The amount of liquid contraction, solidification expansion and secondary contraction in gray and ductile cast irons 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 reported the effects of some processing variables on the solidification behavior

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of gray and ductile cast irons[1-10]. Nevertheless, the researches on the effects of riser design and chemical composition on the formation of shrinkage cavity in gray and ductile cast irons have not been conducted systematically. The objective of this research is to investigate the effect of riser design(induced for directional or progressive solidification) and chemical composition(with addition of graphitizing or carbide stabilizing element) on the formation of defects such as external depression, primary and secondary shrinkage cavities in gray and ductile cast irons.

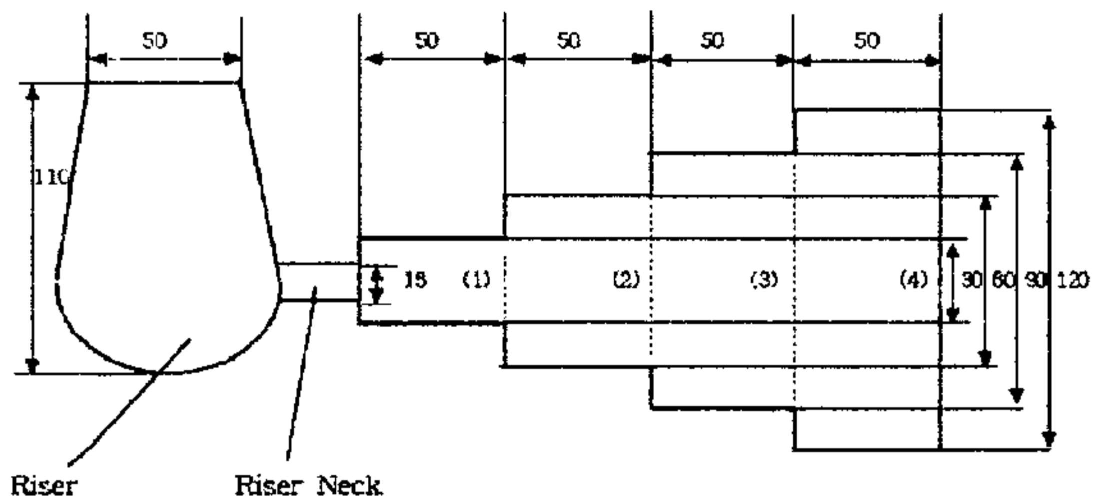
2. Experimental

Five different ISO specifications(ISO 150, 200, 250, 300, 350) of gray cast iron and six different chemical compositions (SG 10, 20, 30, 40, 50, 60) of ductile cast iron were prepared and their chemical compositions are shown in Table 1. Initial charge materials such as clean pig iron and steel scrap were melted in a 15 kg-capacity high frequency induction furnace. Alloying elements were added to a slag-free molten iron so as to minimize the oxidation loss and slag formation. This melt was subsequently heated upto 1600°C and transferred into well heated teapot pouring ladle. After Mg treatment and/or inoculation, the melt was poured at 1400°C into pep-set mold.

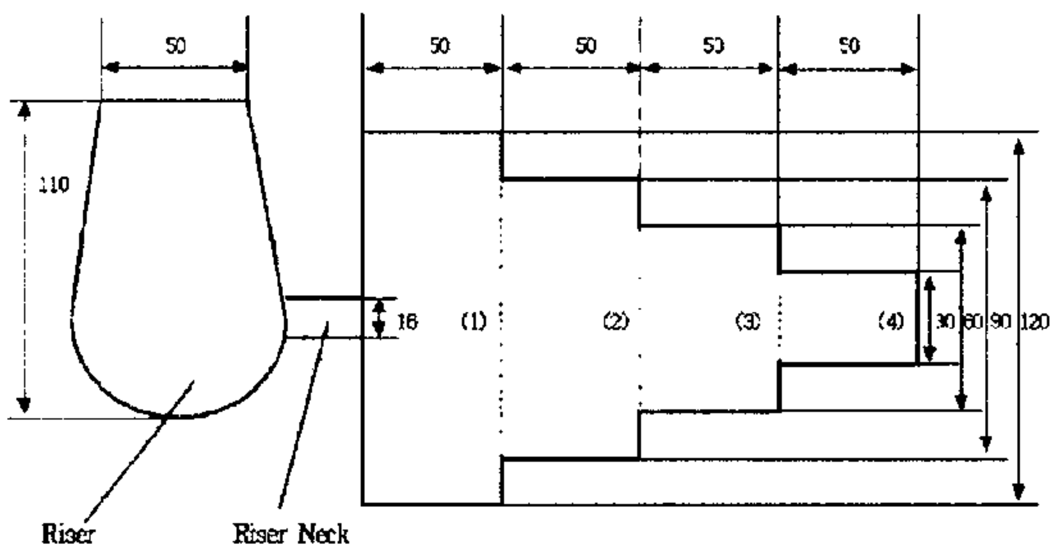
Two different types of riser design for the cylindrically step-wise specimen, No. 1 and No. 2 riser designs, were prepared as shown in Fig. 1. In the No. 1 riser design, the riser is attached to the thinnest section of casting to promote a progressive solidification toward center of each specimen step. On the other hand, the riser in the No. 2 riser design is attached to the heaviest section of casting to induce a directional solidification toward riser. External depression and swollen surface were observed from outside appearance with naked eyes. And, the specimens were sectioned transversely to observe the primary and secondary shrinkage cavities.

Table 1. Chemical compositions of gray and ductile cast irons.

Grade	Elements(%)					
	C	Si	Mn	P	S	Other
ISO 150	3.65	2.55	0.65	< 0.25	< 0.1	CE: 4.50
ISO 200	3.45	2.05	0.75	< 0.20	< 0.1	CE: 4.13
ISO 250	3.35	1.95	0.75	< 0.15	< 0.1	CE: 4.00
ISO 300	3.20	1.85	0.75	< 0.12	< 0.1	CE: 3.82
ISO 350	3.05	1.75	0.85	< 0.10	< 0.1C	E: 3.63
SG 10	3.50	2.65	< 0.1	< 0.25	< 0.1	CE: 4.38
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



(a) No. 1 Riser Design



(b) No. 2 Riser Design

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

3. Results and Discussion

The effect of chemical composition on the behavior of liquid contraction in the No. 1 riser design of gray cast iron is shown in Fig. 2. External depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from ISO 150 to 350 specification. 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.[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 riser design are shown

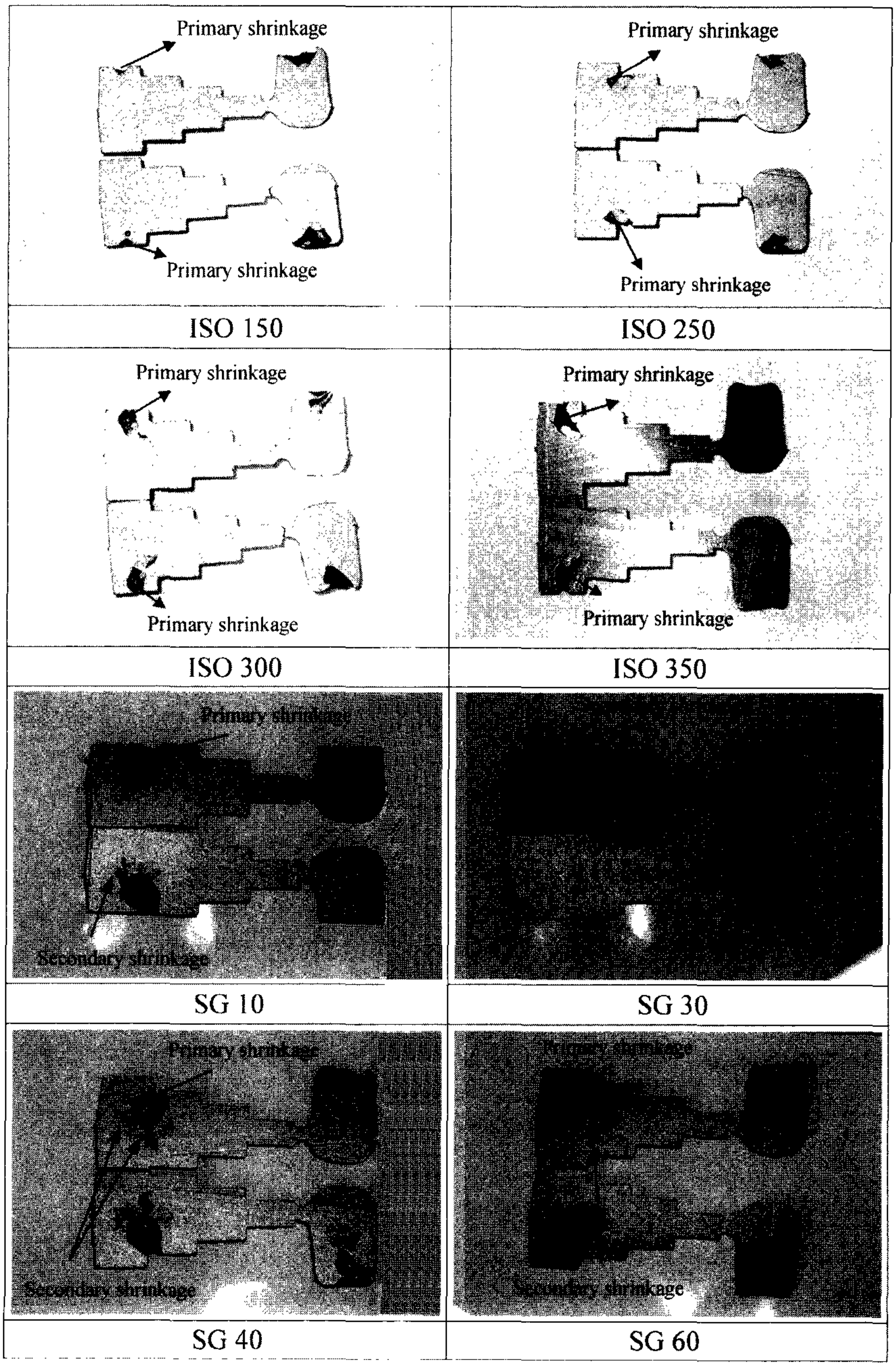


Fig. 2. Sectioned views of some specimens in the No. 1 riser design.

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 4(modulus: 1.597 cm) having higher modulus values than those of the specimen steps 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 the 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 riser design. From Table 2, it can be recognized that the solidification pattern of the No. 1 riser 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 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 specification number. ISO 350 gray cast iron has the highest liquidus temperature and ISO 150 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 the 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 to the formation of the secondary shrinkage cavities. The use of rigid pep-set mold also played a significant role in resisting the forces of expansion; otherwise a swollen surface might have resulted and the casting would not be sound internally.

The effect of chemical composition on the behavior of liquid contraction in the No. 2 riser design is shown in Fig. 3. Unlike the No. 1 riser design, no external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens. This might be due to the different riser design of the two systems. The modulus values of riser, riser neck and four specimen steps in the No. 2 riser design are shown in Table 3. After mold filling, a directional solidification is expected to occur toward 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 those of the specimen steps 1 and 2, it can become greater with the application of thermal sleeve onto it. Therefore, regardless of the chemical composition,

Table 2. Factors of each segment in the No. 1 riser design.

Riser Design No. 1					
Segment \ Factor	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

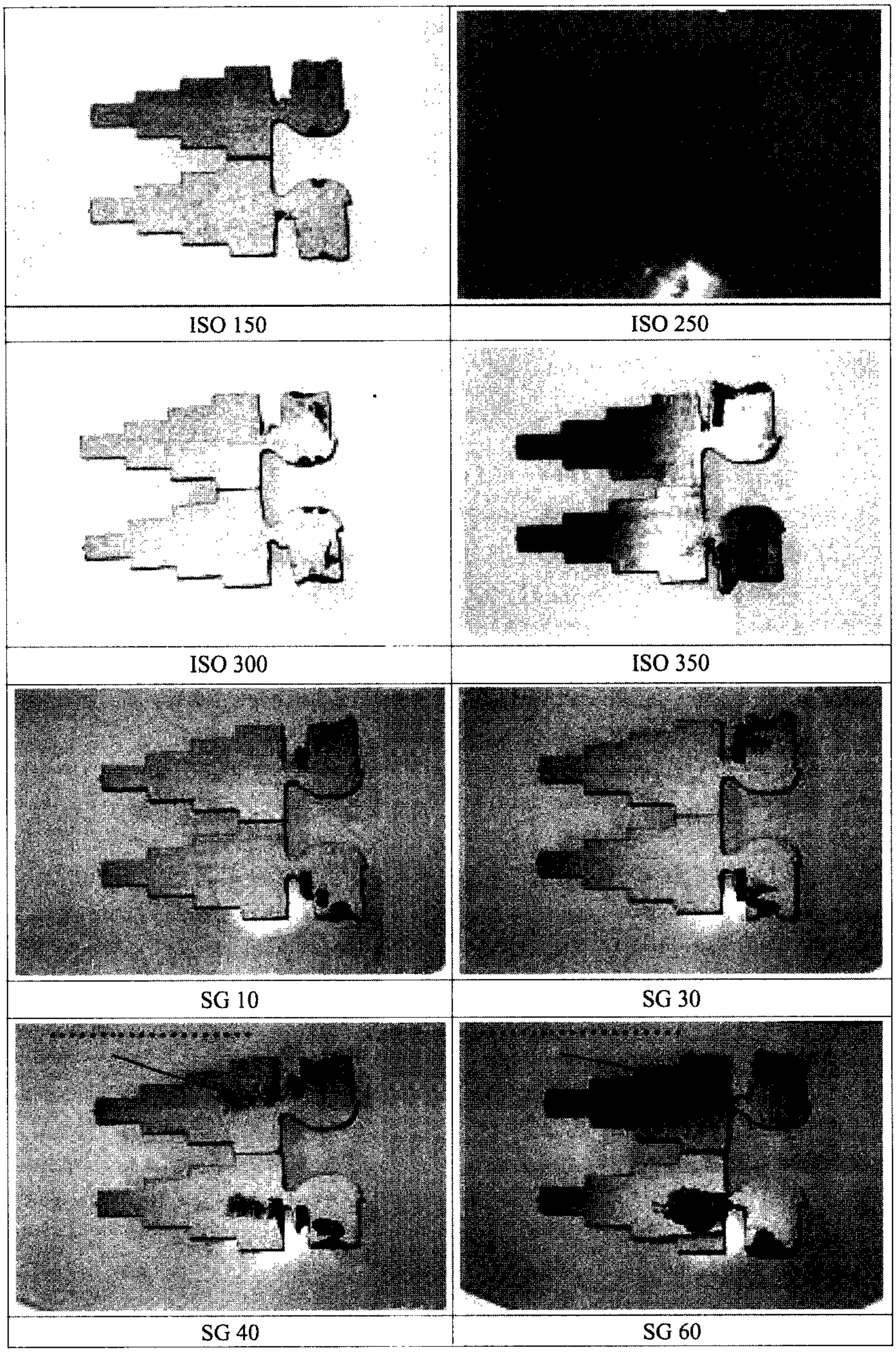


Fig. 3. Sectioned views of some specimens in the No. 2 riser design.

the formation of defects caused by liquid contraction was prevented with the riser design induced for directional solidification. As shown in Fig. 3, the primary and secondary shrinkage cavities were not observed in all the specimens. As far as the secondary shrinkage cavity and swollen surface are concerned, the same

Table 3. Factors of each segment in the No. 2 riser design.

Riser 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

theory applied to the No. 1 riser design can also be applied here to explain the results.

The effect of alloying elements on the behavior of liquid contraction in the No. 1 riser design of ductile cast iron is also shown in Fig. 2. As observed in the gray cast iron, external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from SG 10 to 60. But, unlike the gray cast iron, a multitude of small and contraction-induced cavities, the secondary shrinkage cavities, were also observed in the thermal centers of the specimen steps 3 and 4, and characterized by rough surfaces. In spite of the fact that CE values(CE:4.38) of the six ductile cast irons were higher than those of ISO 200(CE:4.13), 250(CE:4.00), 300(CE:3.82) and 350(CE:3.63), all the sectioned specimens of ductile cast iron revealed secondary shrinkage cavities. This might be due to the difference in solidification morphology between gray and ductile cast iron. While steel solidifies with narrow range of solidification, ductile cast iron freezes in a wide range fashion. Gray cast iron is inbetween. Alloys with a wide solidification range go through three stages in the solidification process, from the liquid to the mushy to the solid. In this case, liquid feeding becomes interdendritic feeding, which makes a supply of liquid more difficult from the riser.[13] However, a swollen surface was not observed in all the specimens because of the fact that the rigid pep set mold was capable of resisting the forces of expansion by graphite precipitation. Therefore, it can be postulated that during solidification contraction, the feeding channel from the riser to the specimen steps 3 and 4 has been hindered because of interdendritic feeding, which resulted in the formation of secondary shrinkage cavities.

The effect of alloying elements on the behavior of liquid and solidification contractions in the No. 2 riser design is shown in Fig. 3. Like the gray cast iron mentioned earlier, no external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens. However, the secondary shrinkage cavities were observed in the thermal centers of specimens of 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. With the addition of carbide stabilizing elements, the gap between the two eutectic temperatures becomes narrow causing more secondary shrinkage cavities to form. Therefore, when designing the riser system of ductile cast iron with carbide stabilizing elements, the riser with more higher modulus is required as compared with the iron alloyed with graphite promoting elements. Like the No. 1 riser design, a swollen surface was not observed in all the specimens.

4. Conclusion

In gray and ductile cast irons, the effects of riser design and chemical composition on the formation of defects such as external depression, primary and secondary shrinkage cavities, and swollen surface were investigated and the following conclusions were obtained:

(1) In the No. 1 riser design of gray cast iron, external

depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from ISO 150 to 350. The size of the primary shrinkage cavity increased with an increase in ISO specification number. However, the secondary shrinkage cavity was not observed in all the specimens due to the solidification characteristics of gray cast iron. A swollen surface was also not observed in all the castings because of the adoption of rigid pep-set mold.

(2) In the No. 2 riser design of gray cast iron, neither primary shrinkage cavity nor secondary shrinkage cavity was observed in all the specimens. A swollen surface was also not observed in all the castings.

(3) In the No. 1 riser design of ductile cast iron, external depression or primary shrinkage cavity due to liquid contraction was observed in all the specimens from SG 10 to 60. The secondary shrinkage cavity was also observed in all the specimens but a swollen surface was not observed.

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

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