MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

FACTORS AFFECTING SHRINKAGE CAVITY FORMATION IN GREY IRON CASTINGS

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ABSTRACT

Shrinkage cavity formation in grey iron castings was investigated using special mould arrangement allowing easy determination of the shrinkage volume after solidification. The effect of melt chemistry was studied by variation of carbon equivalent from 3.59% to 4.59% and determination of the corresponding change in shrinkage volume. The effect of silicon content in the melt for the same carbon equivalent C_E is also tested to show the effect of silicon content on shrinkage amount. The relation between eutectic graphite content and the shrinkage volume in grey cast iron ingots was evaluated. Low shrinkage values were observed at high eutectic graphite contents. Effect of pouring temperature on the shrinkage volume was evaluated using five different pouring temperatures 1180 C°, 1200 C°, 1250 C°, 1285 C° and 1320 C° while keeping all other casting conditions constant. Shrinkage volume of grey cast iron was found to increase by increasing pouring temperature. The effect of mould rigidity on grey iron shrinkage was evaluated using different moulding materials. High shrinkage volumes were observed at low rigidity moulds. The control of phosphorous content in the melt was found to reduce the sensitivity of measured shrinkage volumes to variation of mould rigidity.

INTRODUCTION

Grey cast iron is characterized by separation of carbon in the form of graphite flakes which have higher specific volume if compared with other phases in its matrix structure. Amount of eutectic graphite in grey cast iron governs the increase in volume during solidification (1,2). The effect of silicon on the solidification process of grey cast iron can be observed from the vertical section of the ternary equilibrium diagram Fe-C-Si at 2% Si Fig.1, where the eutectic reaction takes place between T_{E1} and T_{E2}. The amount of eutectic graphite in the final structure depends upon the Si% and C% in grey cast iron alloys as shown in Fig. 2, where the solubility of carbon in the austenite

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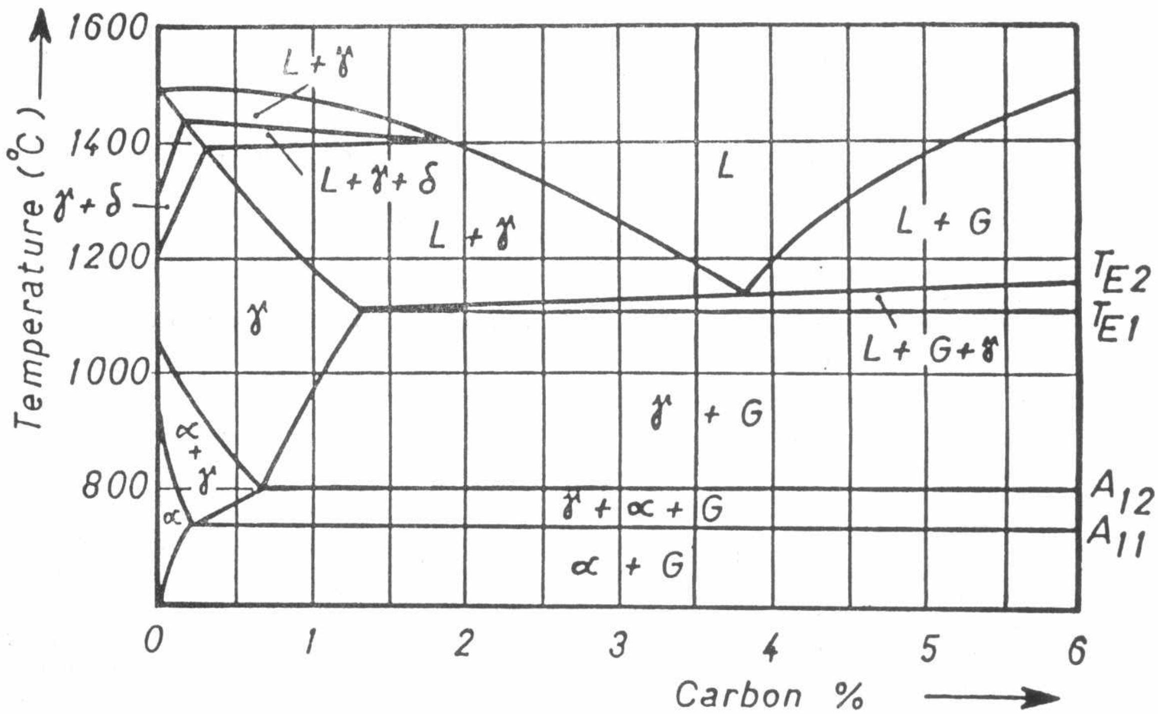

Fig.1. Vertical section in the ternary equilibrium diagram Fe_C_Si at 2% Si(stable system).

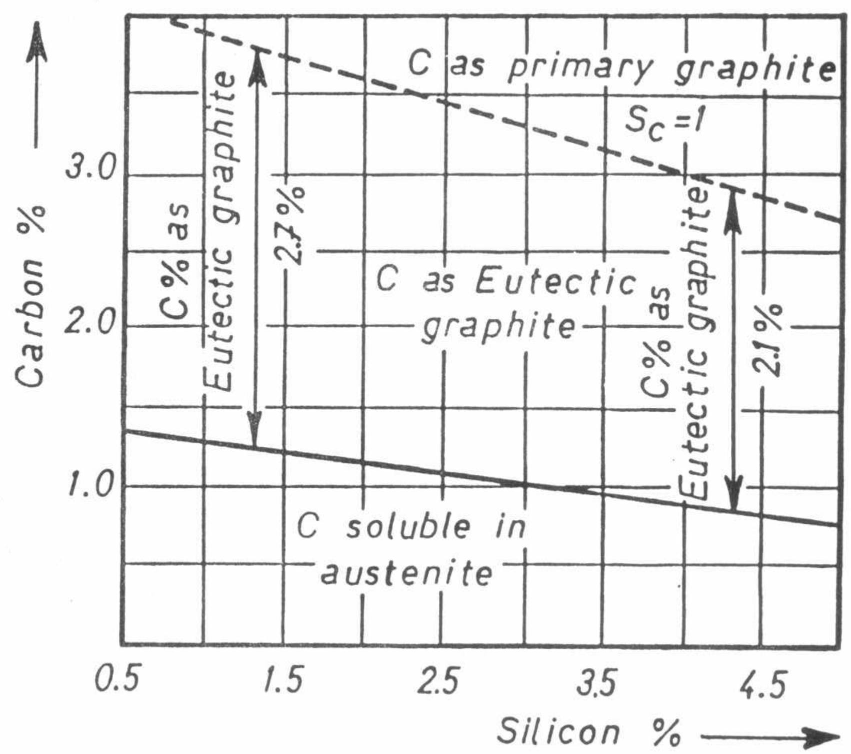

Fig.2. Effect of silicon on carbon content as eutectic graphite.

decreases by the increase of silicon content and consequently the amount of carbon in eutectic graphite decreases from 2.7% to 2.1% for saturation coefficient S_c=1 (3,4).

In case of hypoeutectic grey cast iron alloys solidification starts with spongy type of austenite dendrites as leading phase then continues by pasty type of eutectic liquid. The two types of crystallization change their relative ratio according to the value of carbon equivalet $C_E = C\% + 1/_3\ (Si\% + P\%)$ (5,6). **Fig. 3,** shows the effect of variation of carbon equivalent on the relative solidification time of both austenite dendrites and eutectic transformation. The time of eutectic transformation increases by the increase of the value of carbon equivalent (6,7). The graphite formation in grey cast iron is governed by the kinetic diagram of eutectic transformation shown in **Fig. 4.** The graphite formation takes palce only if the cooling rate is lower than the critical value V_1(7).

Shrinkage of grey cast iron during solidification is conpensated partially or completely by the evolution of eutectic graphite (8). The increase of volume due to graphite formation may cause pressure on mould walls and enlarge the mould cavity if the rigidity of the mould material is low. In case of high rigidity mould material the increase of volume due to graphite formation will reduce the total shrinkage observed in grey iron castings. Therefore a distinct mechanical interaction between solidifying casting and its mould determines the shrinkage behaviour (9,10). This work aimed to evaluate a number of variables which may exert a significant influence on shrinkage behaviour of grey cast iron such as melt chemistry, amount of superheat and rigidity of mould material.

EXPERIMENTAL PROCEDURE

A special test mould was designed for easy and accurate determination of shrinkage volume in grey iron casting. The shrinkage volume was collected on the top surface of the cast ingot with the aid of a ceramic sleeve located above the upper surface of casting cavity to insure directional solidification. The resulting shrinkage volume after solidification was evaluated by determination of the water volume required to complete the depression on the casting surface. **Fig.5,** illustrates the mould arrangement of the testing ingot before pouring. The used melts were prepared in an induction melting furnace of 20 Kg. capacity using steel scrap and grey cast iron retruns as a charge.

The test programme was divided into four groups of melts. The first group comprised nine melts with different chemical compositions to investigate the effect of carbon equivalent C_E on the shrinkage volume. These melts were poured at the same pouring temperature T_p = 1300 C° in identical moulds prepared from synthetic sand chemically bonded by water glass and hardened by CO_2 gas. The second group comprised five melts with the same carbon equivalent but with different degrees of superheating to study the effect of pouring temperature on shrinkage volume. These melts were poured at 1180 C°, 1200 C°, 1250 C°, 1280

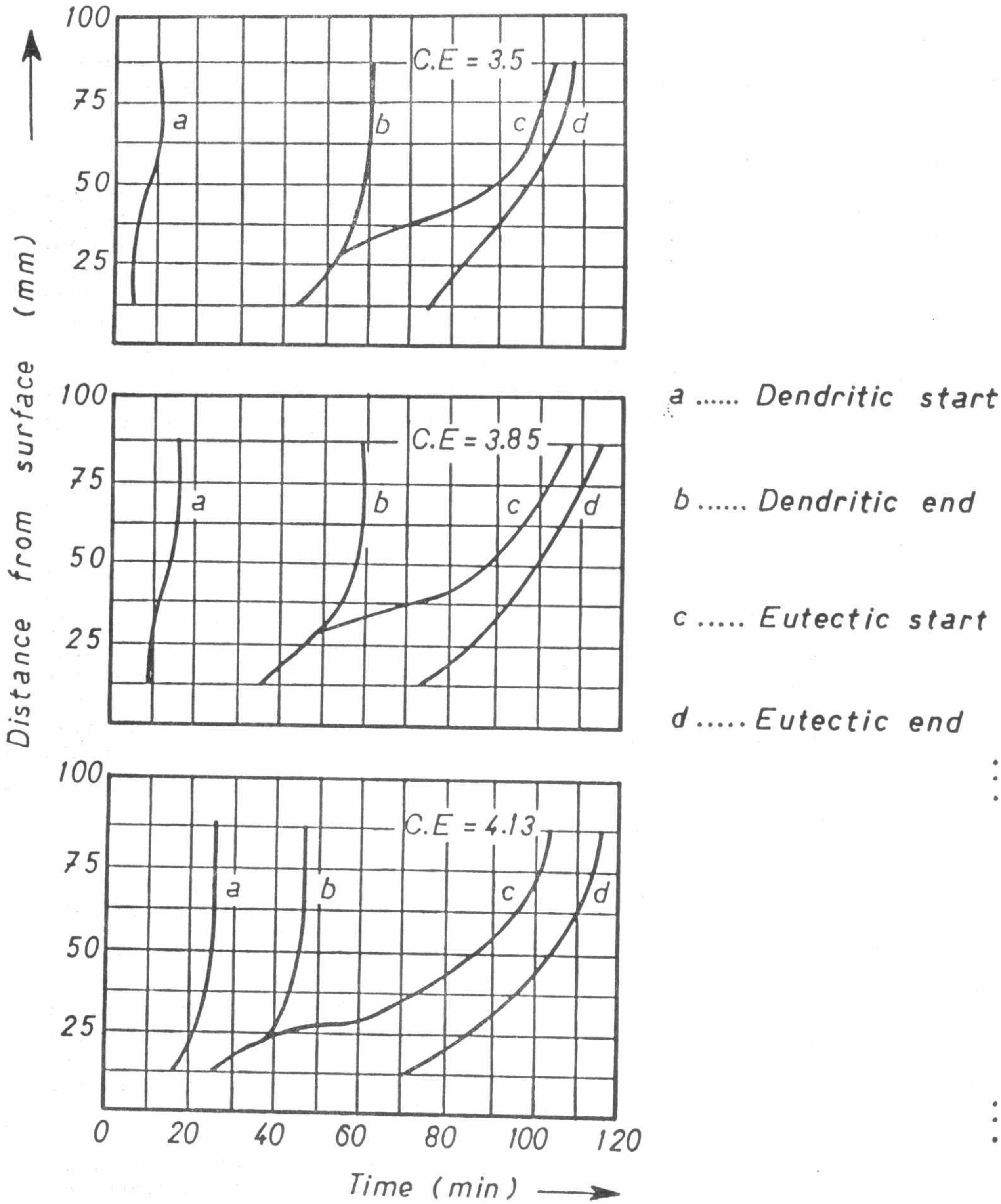

Fig.3. Effect of variation of carbon equivalent on the relative solidification time of austenite dendrites and eutectic transformation.

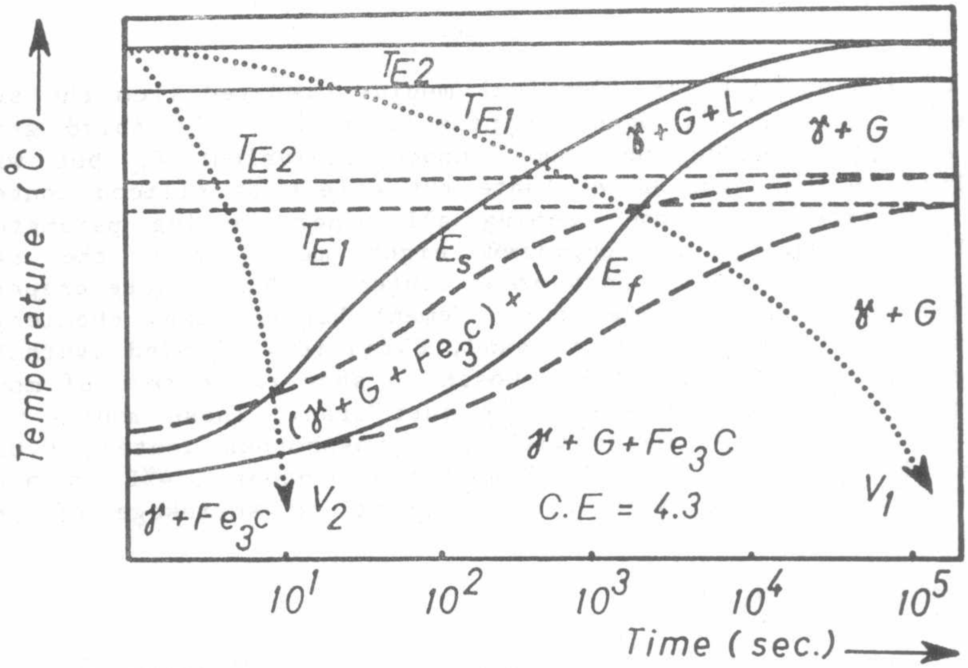

Fig.4. Kinetic diagram for eutectic transformation.
—— stable system
---- metastable system

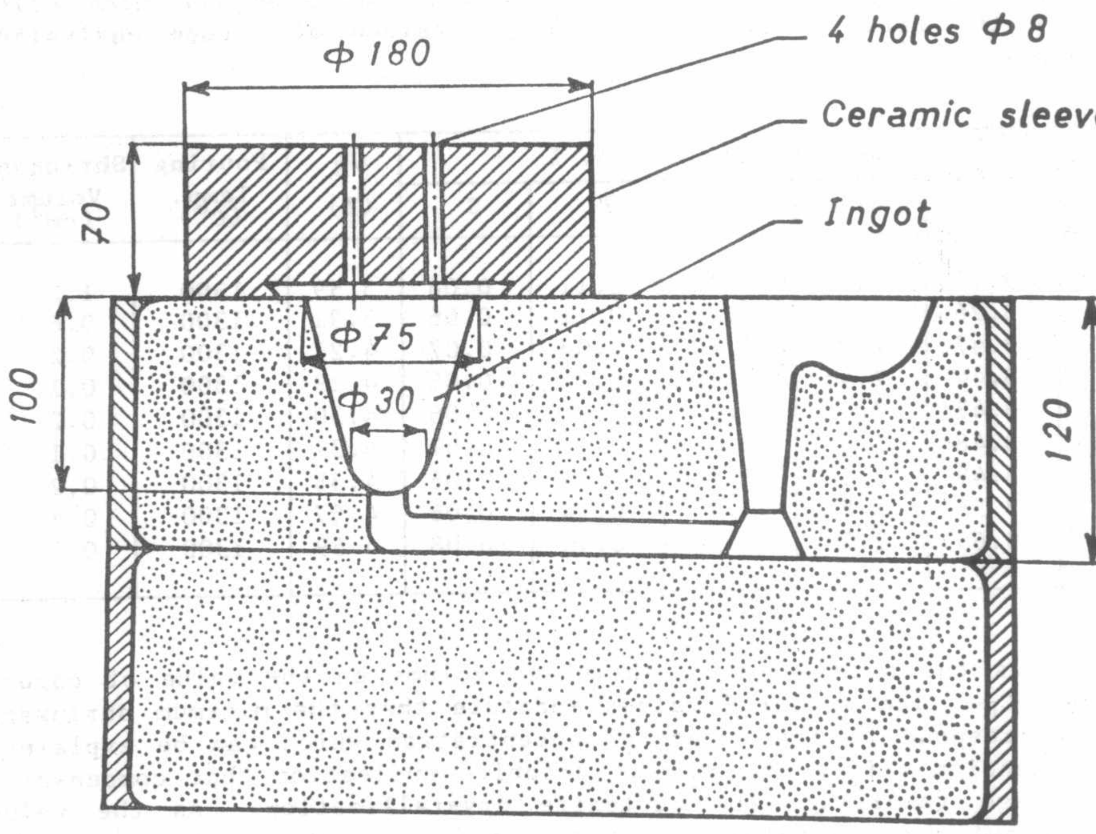

Fig.5. Mould arrangement before pouring.

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C° and 1320 C° respectively in identical moulds prepared from the same moulding material (chemically bonded synthetic sand). The third group comprised five melts having the same carbon equivalent C_E but with different silicon percentages to evaluate the effect of silicon content on shrinkage of grey cast iron keeping all other casting parameters constant. The fourth group comprised eight melts with the same superheating but with different phosphorous content. Moulds were prepared from four different moulding materials. Cement bonded sand, chemically bonded CO_2- sodium silicate synthetic sand, Furan resin bonded synthetic sand and green sand clay bonded were chosen to show the effect of mould rigidity on the shrinkage volume of grey cast iron. These moulds were prepared two times, one for melts with low phosphorous content 0.09%P and the other for melts with high phosphorous content 0.4%P in order to determine the effect of phosphorous content on shrinkage of grey iron castings.

RESULTS AND DISCUSSION

The values of shrinkage volume measured on the first group of melts poured at 1300 C° are illustrated in table 1, where the chemical compositions are determined by the chemical analysis of chilled samples taken from each melt before pouring.

Table 1. Shrinkage volume in grey cast iron measured on the nine melts of the first group with different values of carbon equivalent C_E.

Melt No.	Chemical Composition %					C_E (%)	Pouring Temp. (C°)	Shrinkage Volume (cm^3)
	C	Si	Mn	P	S			
01	3.04	1.55	0.51	0.11	0.06	3.59	1300	1.2
02	3.26	1.85	0.74	0.11	0.06	3.91	1300	0.6
03	3.47	2.34	0.40	0.08	0.07	4.27	1300	0.2
04	3.44	2.45	0.49	0.11	0.06	4.29	1300	0.1
05	3.47	2.32	0.50	0.16	0.06	4.30	1300	0.2
06	3.48	2.50	0.61	0.17	0.07	4.37	1300	0.1
07	3.49	2.55	0.71	0.14	0.06	4.38	1300	0.2
08	3.58	2.85	0.47	0.14	0.06	4.57	1300	0.4
09	3.65	2.73	0.50	0.10	0.08	4.59	1300	0.5

Fig. 6 shows the dependence of shrinkage volume on the value of carbon equivalent C_E. The measured values indicate that the minimum shrinkage volumes correspond to the eutectic concentration which can be explained by the expansion effect of eutectic graphite nucleation that compensates the shrinkage resulting from austenite crystallization. As the value of carbon equivalent increases the relative portion of eutectic structure increases at the expense of hypoeutectic austenite. For hypereutectic compositions the nucleation of primary graphite presedes the nucleation

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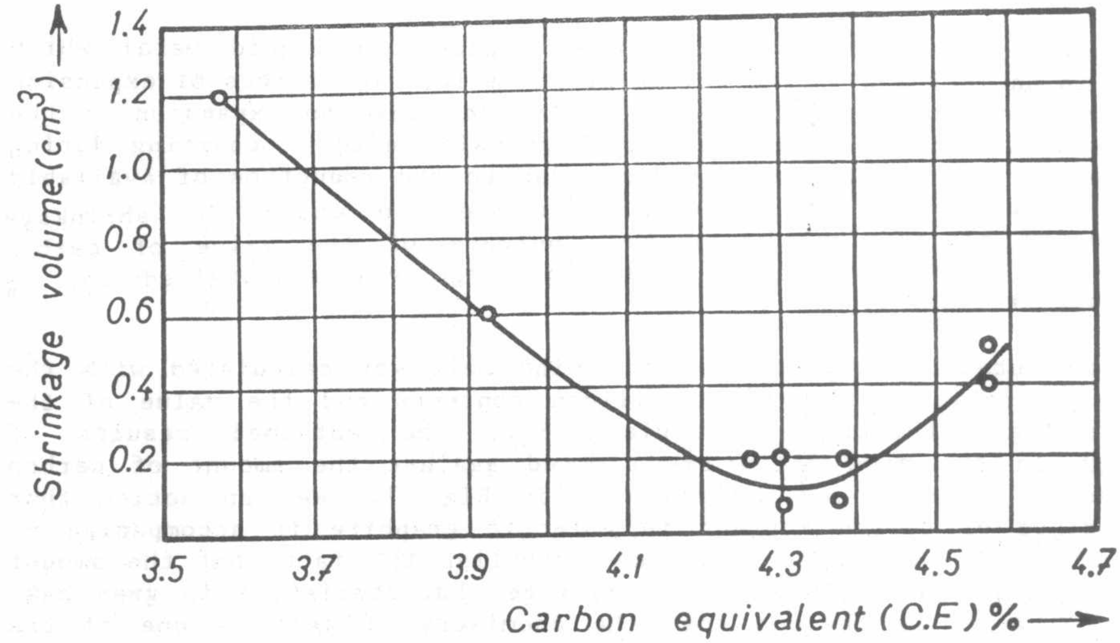

Fig.6. Dependence of the shrinkage volume on the carbon equivalent.

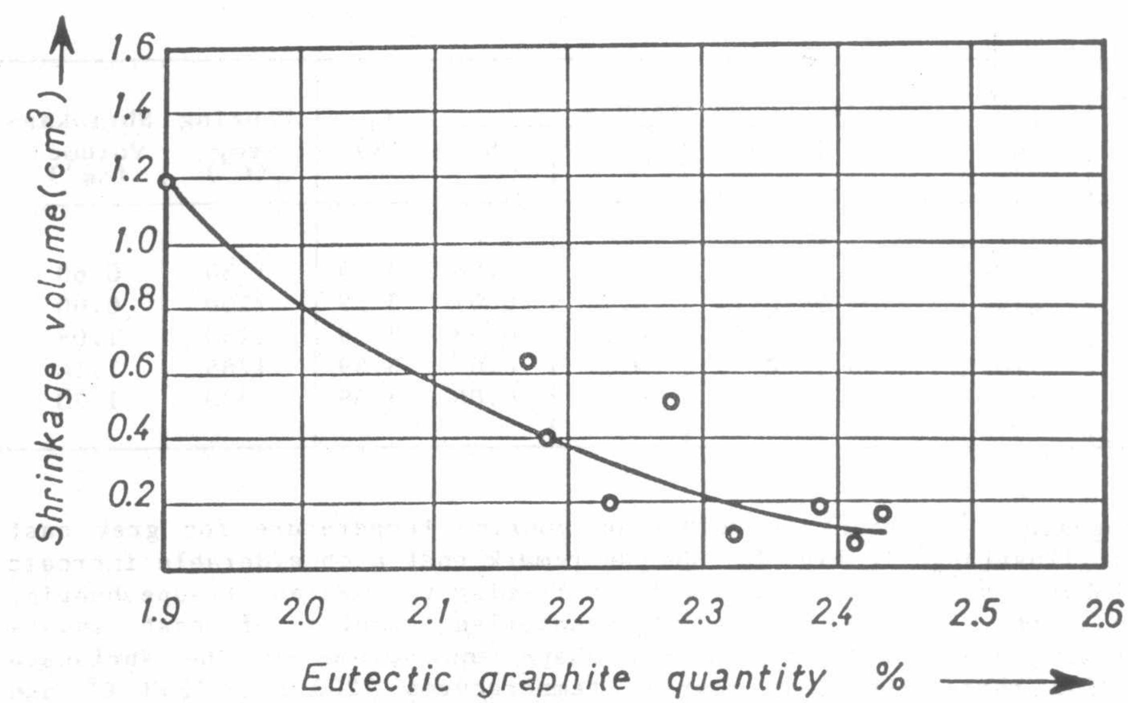

Fig.7. Dependece of the shrinkage volume on the eutectic graphite quantity.

of austenite and its growth continues inside the liquid metal which results in an increase in the volume of the melt. The forces of expansion of the molten metal push the mould walls and cause an expansion of the mould cavity. On the other hand the expansion effect occurring during the eutectic solidification is reduced due to the reduction of available amount , of carbon for eutectic structure, to which the shrinkage compensation is attributed, by the increase of the value of carbon equivalent. This justify the high shrinkage volume obtained for C_E values higher than 4.3 %.

Carbon in eutectic graphite for the nine melt was calculated with the aid of the relative carbon and silicon contents and the value of the corresponding saturation coefficient S_c. The obtained results of shrinkage in the nine melts are plotted against the amount of carbon as eutectic graphite and demonstrated in **Fig. 7**. We can notice that the increase of carbon content in eutectic graphite is accompanied by lower values of shrinkage. This may establish the fact that the amount of eutectic graphite governs the shrinkage characteristics in grey cast iron . Then it is obvious that the chemistry of melt is one of the main factors affecting shrinkage in grey iron casting.

The values of shrinkage volume measured on the second group of melts poured at different pouring temperature are shown in table 2, where the chemical compositions of melts are controlled so that the value of carbon equivalent is kept constant C_E= 3.59%.

Table 2.Shrinkage volume in grey cast iron measured on the five melts of the second group with different pouring temperature.

Melt No	Chemical Composition %					C_E (%)	Pouring Temp. (C^o)	Shrinkage Volume (cm^3)
	C	Si	Mn	P	S			
10	3.04	1.55	0.52	0.11	0.06	3.59	1180	0.60
11	3.06	1.50	0.51	0.10	0.07	3.59	1200	0.80
12	3.08	1.45	0.50	0.12	0.08	3.59	1250	1.08
13	3.07	1.46	0.51	0.11	0.07	3.59	1285	1.14
14	3.05	1.52	0.52	0.11	0.06	3.59	1320	1.20

The dependence of shrinkage volume on pouring temperature for grey cast iron is illustrated in **Fig. 8**. We can remark that a considerable increase in shrinkage volume is recorded when increasing the degree of superheating of the melt. **Fig. 9**, shows representative samples of cast ingots illustrating the variations of the shape and volume of the shrinkage cavity for three different pouring temperatures 1200 C°, 1250 C° and 1320 C°. It is clear that the depth of shrinkage cavity increases by increasing the pouring temperature of the melt. This can be attributed

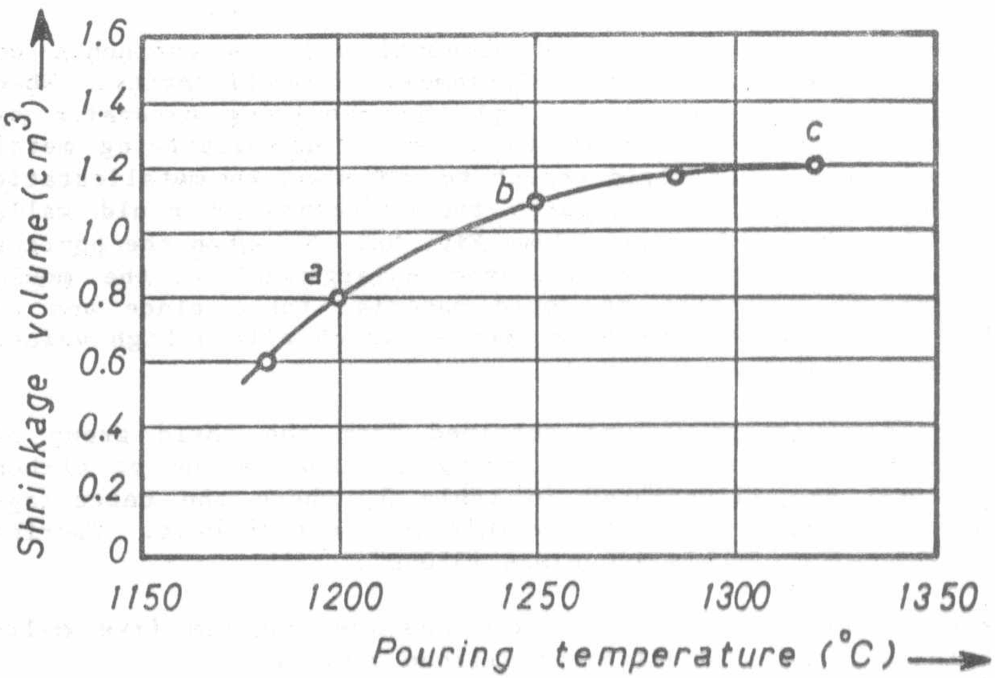

Fig. 8. Effect of pouring temperature on shrinkage volume.

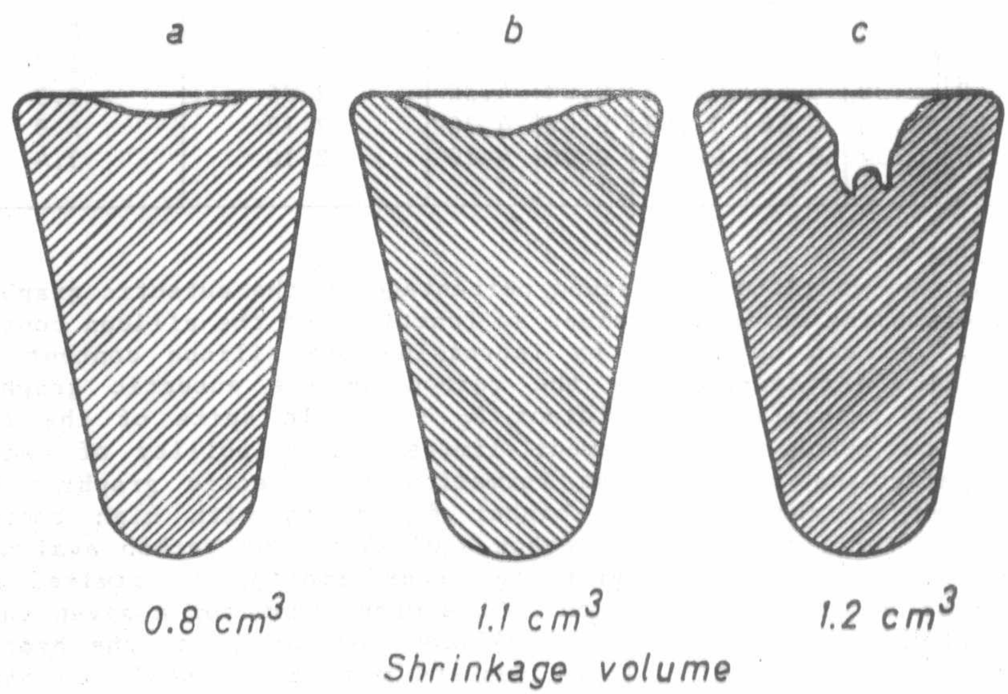

Fig. 9. Shrinkage cavities of ingots poured at different pouring temperaturs.
(a) 1200 °C (b) 1250 °C (c) 1320 °C

to the thermal expansion of the mould material and its influence on the movements of the mould walls and enlargement of mould cavity. When the pouring temperature is relatively low the resulting expansion of the mould cavity is low and on the other hand the solidifying metal will quickly form a skin layer rigid enough to withstand the metallostatic forces on the mould walls which reduces the movements of mould walls and consequently the total shrinkage volume **Fig. 9a.** But when the pouring temperature is relatively high considerable enlargement of the mould cavity due to thermal expansion of mould material takes place and on the other side the skin effect will be reduced which allows high values of total shrinkage **Fig. 9c.**

The results of the shrinkage volume obtained from the thrid group of melts having chemical compositions satisfying the same value of carbon equivalent C_E = 4.3 are illustrated in table 3, where the percentage of carbon in the eutectic graphite is calculated for each melt. Pouring temperature for all melts of this group was 1350 C°.

Table 3.Shrinkage volume in grey cast iron measured on the five melts of the third group with different silicon contents

Melt No.	Chemical Composition %					C_E (%)	Carbon as Eutectic Gr. (%)	Shrinkage Volume (cm^3)
	C	Si	Mn	P	S			
15	3.83	1.35	0.42	0.066	0.07	4.30	2.75	0.5
16	3.67	1.82	0.45	0.072	0.06	4.30	2.50	1.7
17	3.48	2.38	0.51	0.094	0.08	4.30	2.35	2.3
18	3.27	3.03	0.48	0.069	0.07	4.30	2.18	2.9
19	3.15	3.34	0.42	0.110	0.06	4.30	2.10	3.4

Fig. 10 shows the variation of carbon percentage in the eutectic graphite and the corresponding shrinkage values as functions of the silicon content in the melt. We can note that by increasing the silicon content the shrinkage volume increases while the carbon in the eutectic graphite decreases for a saturation coefficient S_C = 1. In spite of the fact that silicon as graphitizing element limits the solubility of carbon in the austenite and promotes the formation of eutectic graphite the measured values of shrinkage are higher for melts with high content of silicon. In fact, at constant carbon equivalent the carbon available in the melt for the eutectic graphite transformation is limited due to the increase of amount of silicon. This means that for a given value of carbon equivalent the increase of silicon content is at the expense of the total carbon content. These results make it possible to state that the decrease in the amount of eutectic graphite can be taken as a measure of shrinkage in grey cast iron.

The chemical compositions of the fourth group which comprises eight

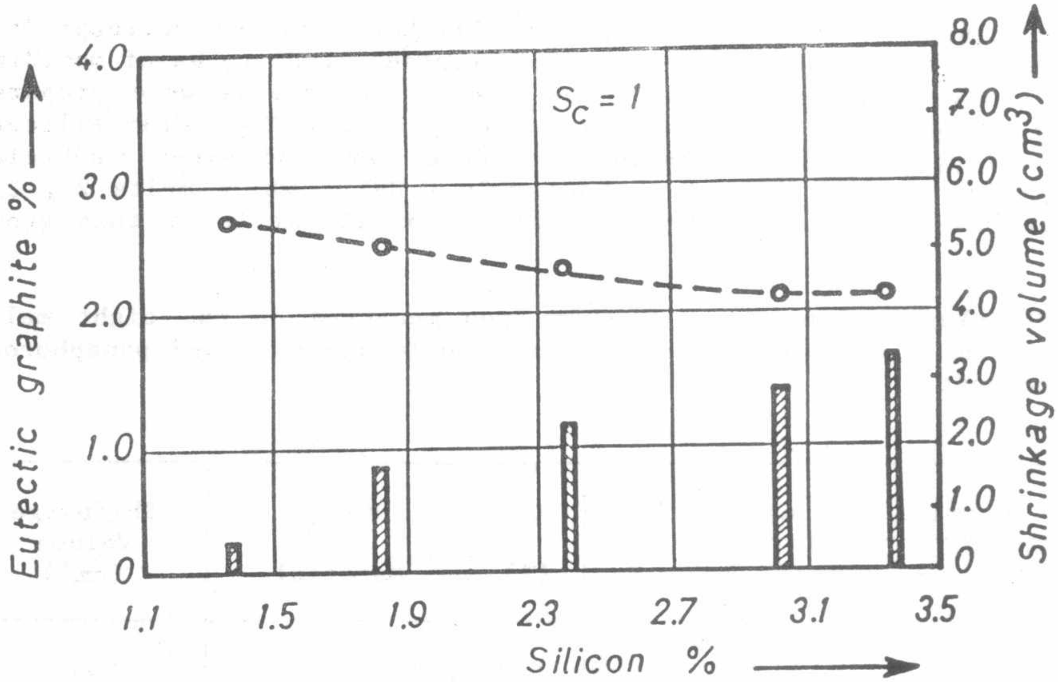

Fig.10. Effect of silicon content on shrinkage volume.

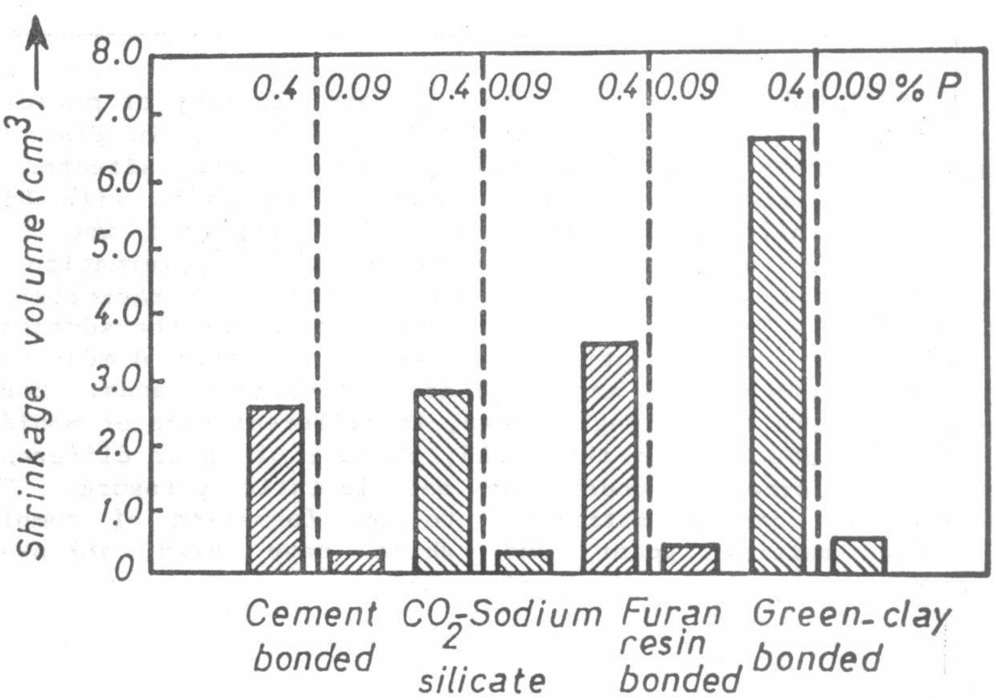

Fig.11. Effect of P content and mould rigidity on shrinkage volume.

melts are given in table 4, where the shrinkage volumes corresponding to each melt after solidification are illustrated. Four types of moulding materials with different rigidity are used. Two moulds were prepared each time using cement bonded sand, chemically bonded CO_2-sodium silicate synthetic sand, Furan resin bonded synthetic sand and green sand clay bonded. Melts 20, 22, 24 and 26 have only 0.09% P while melts 21, 23, 25 and 27 have 0.4%P. Pouring temperature for all metls of this group was 1300.

Table 4 Shrinkage volume in grey cast iron measured on the eight melts of the fourth group for different mould rigidity and phosphorous content.

Melt. No	Chemical Composition %					C_E (%)	Mould Material	Shrinkage Volume (cm^3)
	C	Si	Mn	P	S			
20	3.49	2.35	0.59	0.09	0.06	4.3	Cement	0.2
21	3.38	2.38	0.52	0.40	0.07	4.3	Cement	2.65
22	3.49	2.35	0.59	0.09	0.06	4.3	CO_2 method	0.25
23	3.38	2.38	0.52	0.40	0.07	4.3	CO_2 method	2.80
24	3.49	2.35	0.59	0.09	0.06	4.3	Furan resin	0.40
25	3.38	2.38	0.52	0.40	0.07	4.3	Furan resin	3.50
26	3.49	2.35	0.59	0.09	0.06	4.3	Green Sand	0.50
27	3.38	2.38	0.52	0.40	0.07	4.3	Green Sand	6.50

The dependence of shrinkage volume on the type and rigidity of moulding material for different phosphorous content is demonstrated in **Fig. 11.** We can recognize that the values of shrinkage are greatly affected by the variation of the rigidity of mould material for melts with high phosphorous content while this effect is less recognized when the phosphorous content is low. In fact the mould cavity deformation is directly related to the strength and thermal expansion characteristics of the mould material. The green sand moulding process has the advantage of economy, simplicity and versatility, however, it lacks dimensional stability compared to such mould materials as resin-bonded sands. Mould cavity enlargement occurs in varying degrees, in different type of moulds, when molten metal is poured into the mould, because of their difference in resistance to deformation under the matallostatic pressure. The effect of phosphorous can be attributed to the formation of complex phases with low melting point and which have high shrinkage characteristics.

CONCLUSION

Shrinkage cavity formation in grey iron castings is affected by the carbon equivalent of the melt. Minimum shrinkage values are obtained

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at eutectic composition. The carbon content as eutectic graphite has inverse relation with the resulting shrinkage volume. For saturation coefficient S_c = 1 which yields the best castability, the increase of silicon content increases the shrinkage volume due to the decrease of eutectic graphite percentage. High degrees of superheating promotes the formation of high shrinkage volumes. The higher the rigidity of the mould material and its resistance to deformation under metallostatic pressure the lower the resulting shrinkage volume. The control of phosphorous content in the melt decrease the sensitivity of shrinkage to mould material rigidity. High phosphorous content increases the shrinkage volume specially when using green sand moulding. Resulting shrinkage cavity in grey cast iron can be minimized by the control of melt chemistry, pouring temperature and mould rigidity.

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