THE INFLUENCE OF THE COMPONENTS OF THE CHARGE ON THE PROPERTIES AND MICROSTRUCTURES OF HIGH FREQUENCY INDUCTION FURNACE IRONS

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THE INFLUENCE OF THE COMPONENTS OF THE CHARGE ON THE PROPERTIES AND MICROSTRUCTURES OF HIGH FREQUENCY INDUCTION FURNACE IRONS

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INTRODUCTION

Many variables control the structure and the physical properties of cast iron, among these are chemical composition, rate of cooling, pouring temperature, temperature to which the melt is heated, type and amount of inoculants. Even though all these conditions are thought to be equal, irons made from different sources are found to differ significantly from one another in their structure and physical properties. There may be a tendency for the components of the charge to affect the structure and properties of the iron. So many cases of this sort have been recorded that the term "Heridity" is often applied by foundrymen to this condition.

For example, Piwowarsky (1) reported greater strength in sand castings when using chilled pig than using the same iron as sand cast pig.

Allen (2) reported that pieces from the same mine car wheel were remelted in a high-frequency furnace and poured into test bars under identical conditions. The remelt of the chilled tread was white, that from the gray hub was gray and the mixtures of the two were mottled.

Wagner (3) claimed that repeated remelting vastly improved the properties even when no change in composition occurred.

Jominy (4) has shown a marked difference in the behavior of coke iron and charcoal iron of the same chemical analysis. The primary graphite of charcoal iron tends to be more finely divided and nodular, while that of the coke iron tends to separate in long, thick flakes.

Hurst (5) and Levi (6) are convinced that there is a phenomenon of heridity while Portevin (7) is skeptical and is afraid that the idea of heridity could be overdone and be invoked to cover up the existence of controllable variables.

Thus, there seems to be much evidence for the existence of heredity and many theories as to its cause have been expounded.

For example, Johnson (8) ascribed the difference to the presence of oxygen to varying extent, but this is not yet proven correct.

The graphite nucleus theory is held by many writers like Moldenke (9) and Meyer (10), but Rosenhain (11) has commented on the shakiness of the graphite nucleus theory.

Gillett (12) pointed out that alleged heridity is not entirely tied up with the initial structure of pig iron or with the content of oxygen or other factors not shown by the usual analysis, but resides largely in the melting conditions, to changes in which different irons do not respond the same.

Many foundrymen are inclined to believe that when instances of heridity are quoted, the difference in properties are in fact due to the existence of a difference in composition, and hesitate to accept the findings in the absence of analytical evidence that all the irons had the same composition.

Thus, heridity presents itself as a fascinating problem. This research is an attempt to determine whether the components of the charge have any influence on the physical properties and the microstructures of cast iron when the chemical analysis and other variables are kept as constant as possible under experimental conditions. Four different irons were made in a high frequency induction furnace, of very nearly the same chemical composition, starting with widely different charges, and their micro-structures and physical properties are compared.

2. SCOPE OF INVESTIGATION

The investigation was carried out in a 20 K.W. high frequency induction furnace of 30 lbs. capacity. The composition aimed at in each case was as follows:

Carbon	-	2.95%
Silicon	-	2.15%
Manganese	-	0.70%
Sulphur	-	0.08%
Phosphorus	-	0.10%

Irons of the above composition were made in four different ways, utilizing four different types of charges:

1. Steel and Graphite
2. Steel and Pig Iron
3. Grey Cast Iron
4. White Iron and Ferro-Silicon

A small casting 1-1/4" in diameter and 2-1/2" long was poured from each heat before inoculation. This was done for the purpose of determining the microstructure before inoculation. After inoculation with Calcium-Silicon two chill tests and three 1.2" standard test bars were poured. These test bars were tested for transverse breaking load and deflection. From the broken test bars, specimens for tensile strength, hardness and micro-structure were obtained. Chemical analysis for carbon and silicon were carried out for all the heats.

3. MELTING PRACTICE

A. Preparation of Moulds:

All moulds were made from Lake core sand. They were washed with a commercial non-carboneous wash.

B. Charges:

Every attempt was made to keep the melting ~~paactice~~ practice constant for each of the 4 heats poured. In each case a total charge of about 29½ lbs. was melted. The induction furnace was filled with as much of the charge as it would hold, and the remainder of the charge was added gradually as the furnace melted down the charge. At 2720°F. suitable amounts of FeMn, FeP and FeS were added to bring the chemical analysis to the desired level, and the temperature was raised to 2820°F. The power was switched off and a small casting of 1-1/4'' in diameter and 2½'' in length was poured. The remaining melt was inoculated with 90 grams of Calcium Silicon. The power was turned on immediately at reduced level for 3 minutes and then turned off. When the temperature dropped to 2650°F. the two chill tests and then the three test bars were poured. The melting records of all the four heats are included to provide more information. The components of the charge in each case are discussed briefly below.

1. Steel and Graphite: Heat No. K3. The steel used was of the following analysis:

Carbon	-	0.10%
Silicon	-	0.15%
Manganese	-	0.35%
Sulphur	-	0.02%
Phosphorus	-	0.02%

Heat K3 Date I-30-47

Finish 4:44

Start 3:15

Total KWH

	C.	Si.	Mn.	P.	S.		
Desired Composition	2.95	2.15	.70	.10	.08		
Actual Analysis	2.96	2.17	.70	.10	.08		

Project Heredity Type of Lining Magnesia

Time	Temp.	Addition	Weight	Lot	
3:15	cold	steel	26#	.01c	
"	"	FeSi	2#202	27%	
"	"	graphite	460gm		
4:26	2720	FeMn	54.29 gm	.80%mn	Load reduced to 15 kw - 4:26
"	"	FeP	42.0 gm	.25%P	Load increased to 20 kw - 4:32
"	"	FeS	16.2 gm	.50%S	Poured Slug at 4:37 - Temp. 2820
4:38		CaSi	90 gm	61.5%Si	Power on at 15 kw at 4:38
					Power off at 4:41. Poured at 4:44. Temp.
					2650°

Melted by Kurien

Ladle	Time Tapped	Tapping Temp.	Pouring Temp.	Additions	

[illegible]

Heat K4 Date 2-6-48

Finish 3:38

Start 2:06

Total KWH

	C.	Si.	Mn.	P.	S.		
Desired Composition	2.95	2.15	.70	.10	.08		
Actual Analysis	2.91	2.17	.70	.10	.08		

Project Heredity Type of Lining Magnesia

Time	Temp.	Addition	Weight	Lot	
2:06	cold	Novo Pig	14 lbs.		
		Hanna Pig	7 lbs		
		Steel	9 lbs		
		FeSi	236 gm	27%	
3:19	2725	FeS	15.7gm	50%	
3:31	2820				Poured Slug
3:32		CaSi	90 gm	61.5%	Power reduced to 15 kw.
3:35					Power off
3:38					Poured

Melted by Kurien

Ladle	Time Tapped	Tapping Temp.	Pouring Temp.	Additions	

Heat K7 Date 6-3-48

Finish 3:51

Start 1:45

Total KWH

	C.	Si.	Mn.	P.	S.		
Desired Composition	2.95	2.15	.70	.10	.08		
Actual Analysis	2.93	2.22	.70	.10	.08		

Project Heredity Type of Lining Magnesia

Time	Temp.	Addition	Weight	Lot	
1:45	cold	c.l	$15\frac{1}{4}$ lbs.	KLC	
	"	c.l	8-3/4lbs.	KHC	
	"	FeSi	197 gm	25%	
			$5\frac{1}{4}$ lbs	KLC	
3:29	2720	FeS	3 gm	50%	
3:45	2820				Poured Slug
3:46		CaSi	90 gm.	61.5%	Power reduced to 15 KW
3:48					Power off
3:51	2650				Poured

Melted by Kurien

Ladle	Time Tapped	Tapping Temp.	Pouring Temp.	Additions	

Heat K12 Date 7-6-48

Finish 4:48

Start 2:45

Total KWH

	C.	Si.	Mn.	P.	S.		
Desired Composition	2.95	2.15	.70	.10	.08		
Actual Analysis	2.94	2.19	.70	.10	.08		

Project Heredity Type of Lining Magnesia

Time	Temp.	Addition	Weight	Lot	
2:45	cold	White iron	$22\frac{1}{4}$lbs.	KW6	
"	"	" "	$4\frac{1}{2}$ lbs.	KW3	
"	"	FeSi	1lb14oz.	25%	
4:23	2720	FeMn	54.2 gms.	80%	
"	"	FeP	42 gms.	25%	
"	"	FeS	16.2 gms.	50%	
4:42	2820				Poured Slug
4:43		CaSi	90 gms.	61.5%	Power reduced to 15 KW
4:46					Power off
4:49	2650				Poured

Melted by Kurien

Ladle	Time Tapped	Tapping Temp.	Pouring Temp.	Additions	

[illegible]

The carbon used was in the form of Mexican Graphite. The steel was in small bits about 1'' square and 1/8'' thick.

2. Steel and Pig: Heat No. K4. The steel used was the same as in the previous heat. Two types of pig iron were used. Their analysis are given below.

	Novo Pig	Hanna Iron
Carbon	4.26 %	4.19 %
Silicon	2.03 %	2.11 %
Manganese	0.91 %	0.83 %
Sulphur	0.023%	0.018%
Phosphorus	0.130%	0.173%

14 lbs. of Novo pig and 7 lbs. of Hanna pig each in one large piece made up the pig portion of the charge.

3. Grey Cast Iron: Heat No. K7. A heat of 240 lbs. of grey cast iron was made in an indirect arc type rocking furnace. The charge used to make this heat was made up of 135 lbs. of Novo pig, 35 lbs. of Hanna pig and 70 lbs. of Steel. About 120 lbs. of this was cast into 4'' diameter and 3'' diameter bars and to the rest Graphite was added to raise the Carbon content and then similarly cast. Before casting each ladle was inoculated with Calcium-Silicon. Thus two different Carbon content grey cast Iron were obtained and they were analyzed for Carbon and Silicon.

Heat No.	Carbon	Silicon
KHC	3.41%	1.62%
KLC	3.00%	1.62%

By adjusting the proportion of KHC to KLC in the induction furnace charge, it was possible to control the Carbon content. KHC was added in one large piece of 8-3/4 lbs. and KLC in two pieces of 15-1/4 lbs. and 5-1/4 lbs.

4. White Iron: Heat No. K12. Six heats of white iron were made in the induction furnace of varying carbon content from Steel and Graphite. These were cast in the form of thin discs about 4" in diameter and 1" thick. Since white iron is very hard, it was impossible to obtain drillings from it for analysis. So a small amount of the melt — about 3 lbs. — was left in the furnace in each case and graphitized by addition of 20 grams of Ferro-Silicon (80%) and then poured into the form of a small slug 2" in diameter and 2" high. Drillings were obtained from this slug and analyzed for Carbon. This would be very nearly equal to the carbon content of the white iron. The carbon content of the six different white iron heats are given below:

Heat No.	Carbon Content
KW1	2.92%
KW2	3.44%
KW3	3.20%
KW4	3.00%
KW5	3.68%
KW6	3.47%

The charge for heat K12 consisted of 22-1/4 lbs. of KW6 and $4\frac{1}{2}$ lbs. of KW3 and 1 lb., 14 oz. of Ferro-Silicon (27.4% Si).

C. Inoculation:

Research on inoculants conducted at the Engineering Experiment Station of Michigan State College during the summer of 1947, showed that in the case of high strength irons a heavy inoculation of Calcium Silicon is desirable for obtaining the optimum properties from the iron.

This is in agreement with the results reported by Pearce (13).

It was therefore decided to add about 0.4% of Silicon of the total amount present in the form of Calcium-Silicon addition. This innoculant was added at about 2800°F. with the power on at the reduced level of 15 K.W. for 3 minutes. Then the power was shut off and the metal poured when the temperature dropped to 2650°F. It will be noted that the time interval between the addition of the inoculant and the pouring of the heat was the same for all the four heats. All temperatures were measured by means of an optical pyrometer.

D. <u>Metal Casting</u>:

All castings were allowed to cool down completely to room temperature before they were knocked out of the flasks. The castings were cleaned by wire brush before testing.

5. INVESTIGATION

A. Procedure:

1. Chemical Composition: For making the chemical analysis drillings were obtained from the basin of the test bars of each heat. While all irons were analyzed for Carbon and Silicon, the analysis for Manganese, Sulphur and Phosphorus were not undertaken. These would suffer no appreciable loss in the induction furnace. Knowing the analysis of the components of the charge, the amounts of these three elements that went into the charge were calculated and brought up to the desired level by suitable alloying additions. Table I shows the analysis of the four heats.

Table I

Chemical Analysis of Heats

Heat No.	C	Si	Mn	P	S	Carbon Equivalent C + 1/3 Si.
K3	2.96	2.16	0.70	0.10	0.08	3.68
K4	2.91	2.11	0.70	0.10	0.08	3.61
K7	2.93	2.22	0.70	0.10	0.08	3.67
K12	2.94	2.19	0.70	0.10	0.08	3.67

The Carbon equivalent was calculated on the basis of C + 1/3 Si. It was found necessary to repeat each heat several times in order to get their chemical analysis within a narrow range so that it was possible to compare their physical properties and microstructures. In all 12 heats were poured. It will be noted that the four heats chosen have their carbon equivalents very close to each other; this is particularly true of heat numbers K3, K7 and K12.

2. Transverse Strength: Three test bars of 1.2'' diameter and 21'' long, from each heat were broken according to A. S. T. M. Specifications. Breaking load and maximum deflection at that load were recorded for each bar.

Table II

Transverse Test Result

Heat No.	Transverse Load in lbs.	Deflection in inches	Remarks
K3 (steel & graphite)	1. 3255	.500	?
	2. 2977	.397	
	3. 3170	.434	
K4 (steel & pig)	1. 2780	.351	
	2. 2575	.289	Defective
	3. 2777	.362	
K7 (grey cast iron)	1. 2630	.360	
	2. 2685	.378	
	3. 2725	.392	
K12 (white iron)	1. 2750	.308	
	2. 2950	.360	
	3. 2950	.376	

3. Tensile Strength: Tensile test specimens were cut from the top of the lower half of the broken test bars. In each case specimens were machined from the center of the bar. Two test specimens were made from each heat. Each specimen was pulled in a tensile testing machine.

The results are recorded in Table III.

Table III

Tensile Test Results

Heat No.	Breaking Load in lbs.	Diameter in inches	Tensile Strength in lbs./sq. inch
K3	1. 26,310	.798	52,600
(steel & graphite)	2. 26,220	.798	52,500
K4	1. 25,150	.799	50,200
(steel & pig)	2. 25,290	.799	50,500
K7	1. 23,360	.798	46,700
(grey cast iron)	2. 23,560	.800	46,800
K12	1. 27,120	.799	54,100
(white iron)	2. 26,550	.799	53,100

4. Hardness: Hardness specimens of about one inch in thickness were cut out of the test bars from which the tensile test specimens were obtained. All specimens were well polished before any Brinell hardness reading was taken. Readings were obtained from both sides of the specimen. The results obtained are given in Table IV.

Table IV

Hardness Results

Heat No.	Readings on Scale	Brinell Hardness
K3 (steel & graphite)	1. 4.10 2. 4.10	217
K4 (steel & pig)	1. 4.15 2. 4.15	212
K7 (grey cast iron)	1. 4.25 2. 4.25	201
K12 (white iron)	1. 4.10 2. 4.10	217

5. Chill Test: The results of the chill test on these four irons are shown below. These readings are the average of the results of two chill tests per heat.

Table V

Chill Test Results

Heat No.	Clear Chill in inches	Total Chill in inches
K3 (steel & graphite)	0.219	0.344
K4 (steel & pig)	0.328	0.438
K7 (grey cast iron)	0.375	0.469
K12 (white iron & FeSi)	0.313	0.406

6. <u>Microscopic Examination</u>: Samples of about 3/8'' x 3/8'' x 1/4'' were cut from the samples poured before inoculation as well as from the test bar pieces from which the tensile test and the hardness specimens were obtained. All samples were cut from the center and care was taken to see that they were cut from corresponding places for all the four heats, so that their microstructures could be compared. The results of the microscopic examination is shown in Table VI.

Table VI

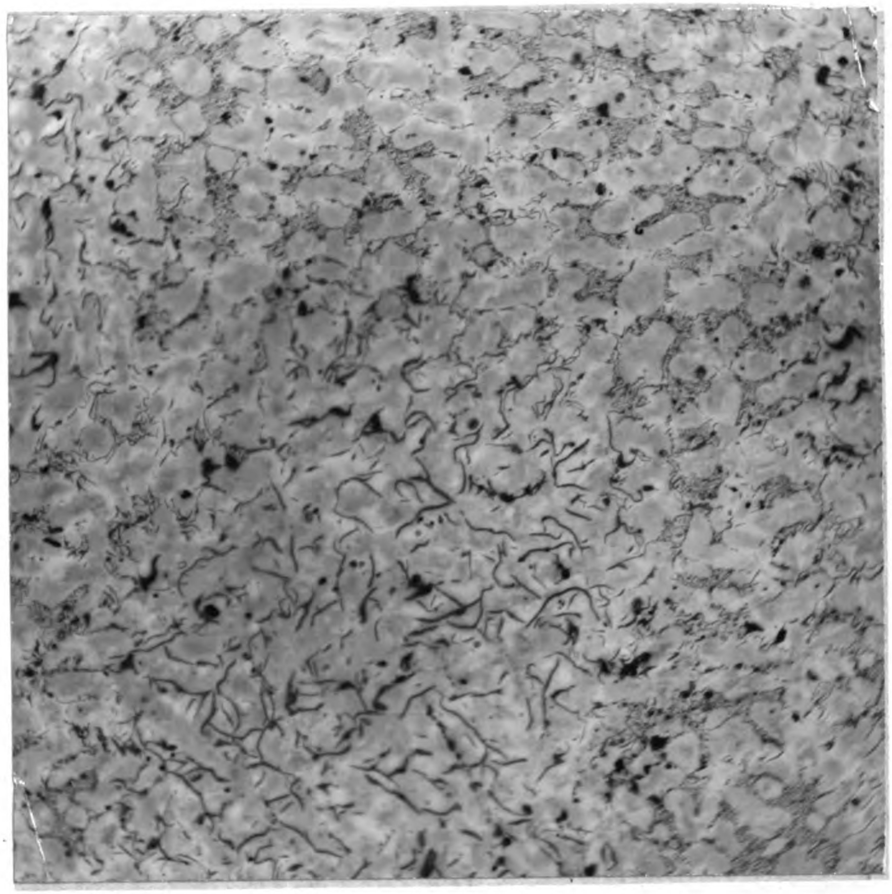
Microscopic Examination Results

K3 (Steel & Graphite)	
Before Inoculation - K3	**After Inoculation - K3**
Normal and abnormal graphite distribution. Some cementite in the structure. See photo-micrograph No. 1.	Completely normal distribution of graphite. Pearlitic matrix. See photo-micrograph No. 2.
K4 (Steel & Pig Iron)	
Before Inoculation - K4	**After Inoculation - K4**
Completely abnormal distribution of graphite. Also some cementite.	Completely normal distribution.
K7 (Grey Cast Iron)	
Before Inoculation - K7	**After Inoculation - K7**
Completely abnormal distribution of graphite. No cementite. See photo-micrograph No. 3.	Normal graphite distribution. Some Ferrite around the graphite flakes. See photo-micrographs 4 & 5.
K12 (White Iron)	
Before Inoculation - K12	**After Inoculation - K12**
Abnormal graphite distribution. Considerable cementite in the structure.	Normal graphite distribution.

Photo-micrograph No. 1.

Specimen No. K3.

(Steel and Graphite - Un-inoculated)



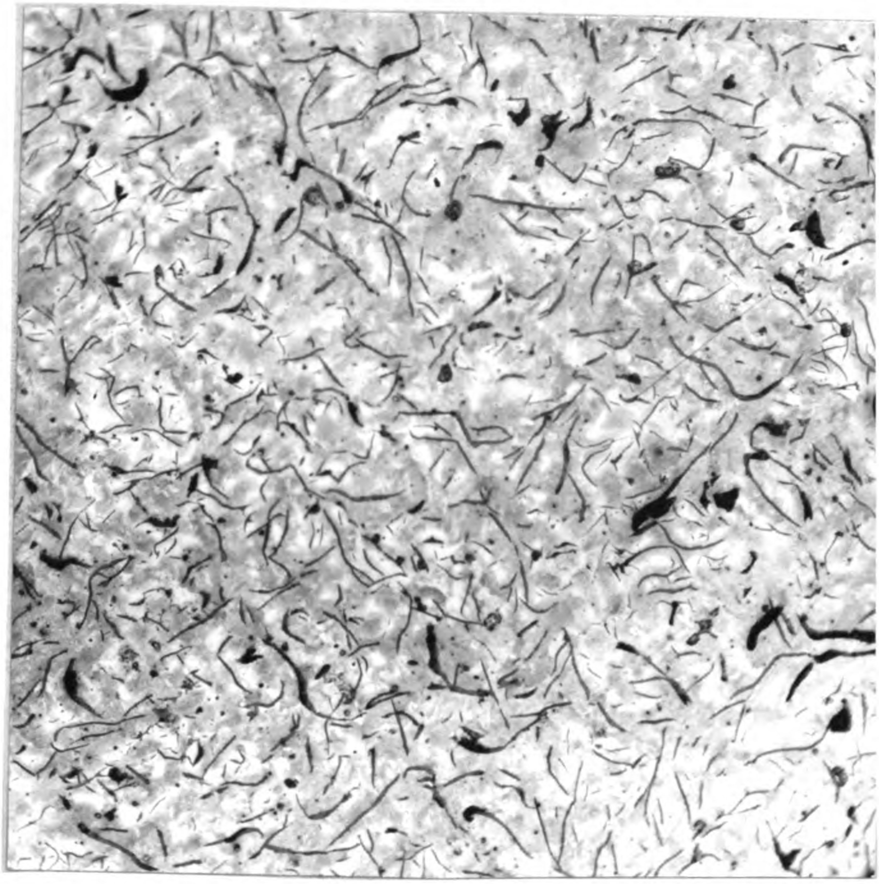
Etched with 2% Nital for 1 sec.

Magnification 75 X.

Photo-micrograph No. 2.

Specimen No. K30.

(Steel and Graphite - Inoculated)



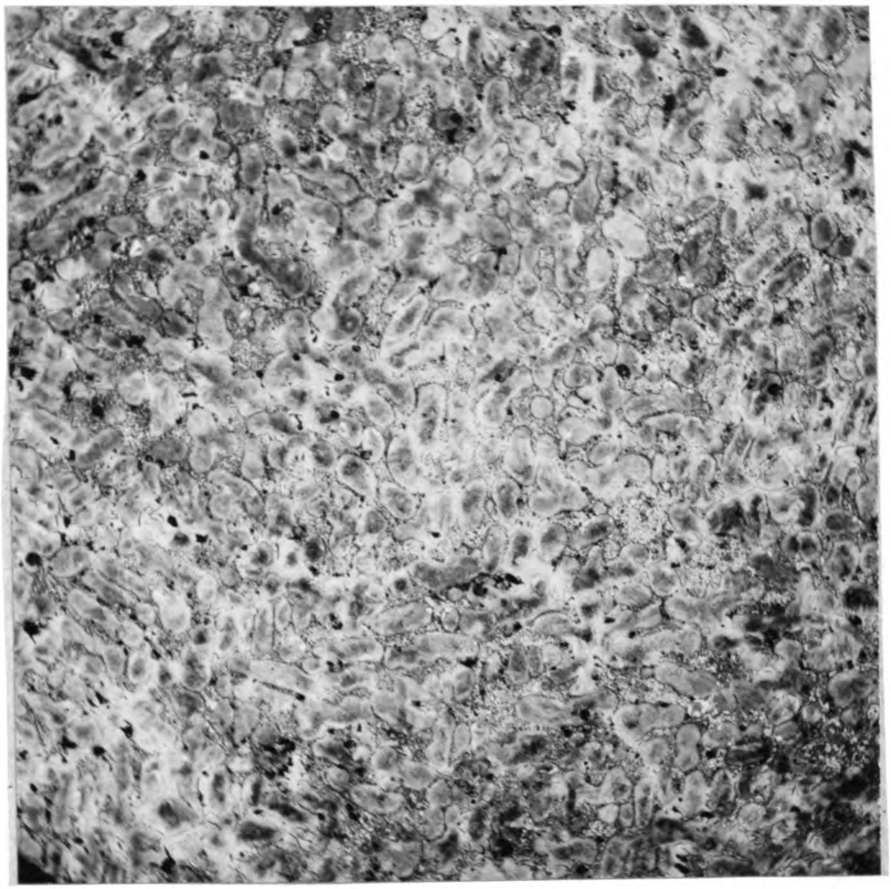
Etched with 2% Nital for 1 sec.

Magnification 75 X.

Photo-micrograph No. 3.

Specimen No. K7.

(Grey Cast Iron - Un-inoculated)



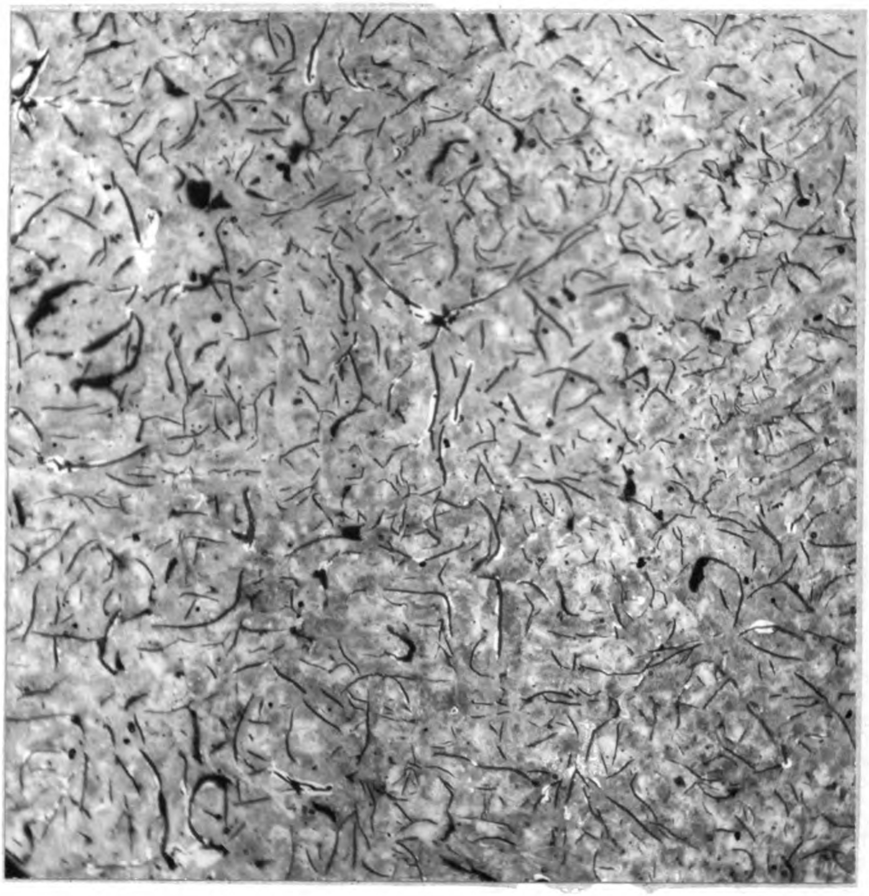
Etched with 2% Nital for 1 sec.

Magnification 75 X.

Photo-micrograph No. 4.

Specimen No. K70.

(Grey Cast Iron - Inoculated)



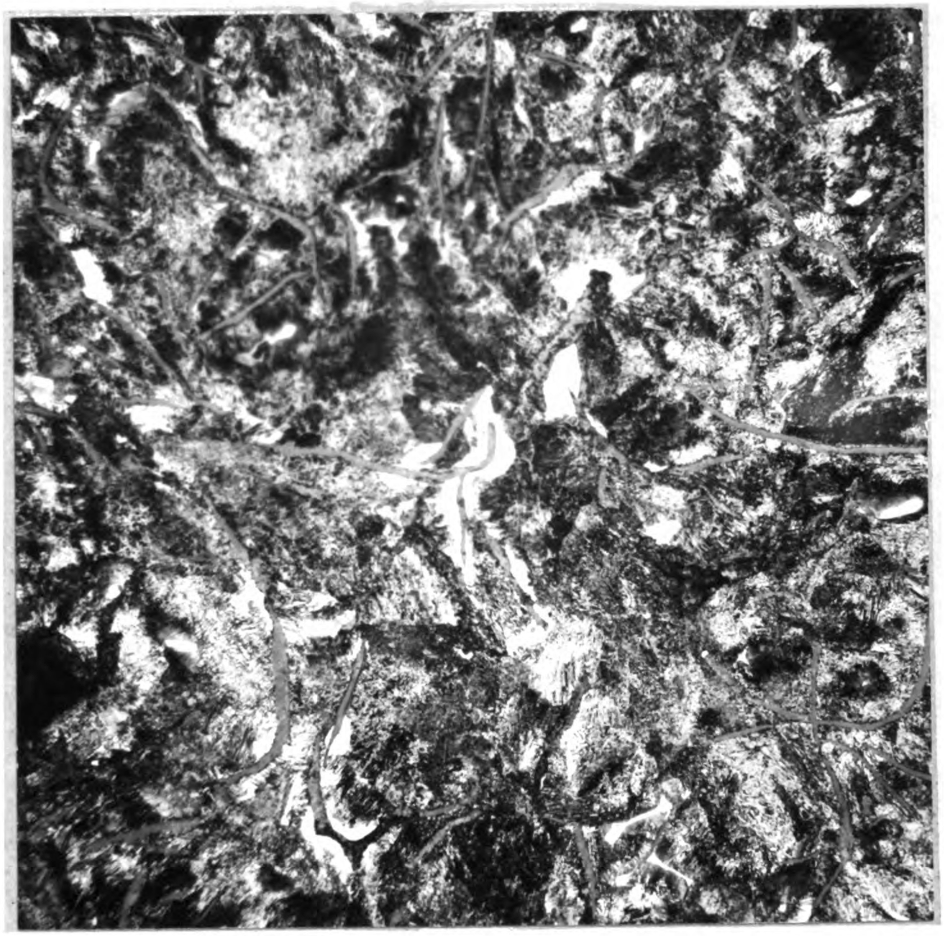
Etched with 2% Nital for 1 sec.

Magnification 75 X.

Photo-micrograph No. 5.

Specimen No. K70.

(Grey Cast Iron - Inoculated)



Etched with 2% Nital for 4 sec.

Magnification 250 X.

Photo-micrographs were taken both in the inoculated and the uninoculated conditions for heats K3 and K7 which were the strongest and the weakest of these four irons as judged by transverse test results. Photo-micrographs 1 to 4 were taken after a slight etch in Nital to show the graphite flake distribution. These were taken at a magnification of 75X. Photo-micrograph No. 5 was taken after a deeper etch at a magnification of 250X to show the ferrite.

B. Discussion:

1. Transverse Strength: The steel and graphite heat — K3 — showed the greatest strength while the cast iron remelt — K7 — showed the least. While the graphite distribution in the inoculated condition showed no marked difference, in the uninoculated condition K3 alone had some areas of normal distribution. While all the other heats showed some cementite in their structure K7 alone had none. Moreover K7 alone had some ferrite around the graphite flakes and its lower strength may be atributed to this cause.

2. Tensile Test: Table III shows that the heat from the white iron — K12 — showed the greatest strength while K7 was again the weakest. The fact that K12 did not come out best in the transverse test may be due to abnormal distribution of graphite around the edges of the bar. These areas were machined out when the tensile test specimens were made.

3. Hardness Test: The Brinell hardness for these irons followed the same pattern set by the two previous tests as shown by Table IV.

K3 and K12 heats showed a B. H. No. 217, K4 of 212 and K7 had a B. H. No. 201.

4. Chill Test: It is interesting to note from Table V that the strongest iron shows the least chill, and the weakest the most chill.

This is not in accord with the usual behavior of normal irons in which the chill ordinarily increases with increasing strength. In addition foundrymen have been of the opinion that increasing additions of steel increase chill. In this case, we have the strongest iron, with an all steel charge, exhibiting the lowest chill.

5. Microscopic Examination: Micro-structures of all the iron were similar after inoculation. But a small portion of the heat, poured before inoculation showed a difference in the graphite distribution. While three heats showed wholely abnormal distribution, the steel and graphite heat showed some areas of normal distribution. The grey cast iron remelt alone did not show any cementite in the inoculated structure; but it alone showed ferrite around the graphite flakes.

It must however be pointed out that additions, made to bring up the composition of the irons to the desired level, though made at the same temperature (2720°F.) in each heat, were naturally different in amount. It is possible to argue that these additions might have an inoculating effect and might therefore account for the difference in properties and structure between the heats. This does not however appear likely. Inoculation effect decreases rapidly with time and since as much as 20 minutes elapsed between these additions and the pouring of the heat. These additions cannot have any significant inoculating effect.

6. CONCLUSIONS

This research has been carried out to determine the influence of the components of the charge on the physical properties and microstructure of induction furnace irons of the following approximate analysis:

Carbon	-	2.95%
Silicon	-	2.15%
Manganese	-	0.70%
Sulphur	-	0.08%
Phosphorus	-	0.10%

Four heats were investigated having widely different components of charge, namely:

1. Steel and Graphite	-	Heat No. K3
2. Steel and Pig Iron	-	Heat No. K4
3. Grey Cast Iron	-	Heat No. K7
4. White Iron	-	Heat No. K12

The following conclusions were reached:

1. The components of the charge has an effect on the transverse strength, tensile strength and hardness of induction furnace irons. The maximum difference in properties was approximately 15%. Irons resulting from steel and graphite charge and from white iron and ferro-silicon charge are superior in properties to irons produced from remelt or from pig iron and steel.

2. The chilling tendency is influenced by the charge. The strongest irons have the least chill.

3. The microstructure is influenced by the components of the charge.

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