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THE EFFECTS OF LADLE ADDITIONS OF ACTIVE METALS ON THE PHYSICAL PROPERTIES, MICROSTRUCTURE AND CHEMICAL COMPOSITION OF CAST IRON

Thesis for the Degree of M. S.

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Aman Ullah Khan

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THESIS

This is to certify that the

thesis entitled

EFFECT OF LADLE ADDITIONS OF ACTIVE METALS ON THE CHEMICAL COMPOSITION, MICROSTRUCTURE AND PHYSICAL PROPERTIES OF CAST IRON

presented by

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THE EFFECTS OF LADLE ADDITIONS OF ACTIVE METALS ON THE PHYSICAL PROPERTIES, MICRO-STRUCTURE AND CHEMICAL COMPOSITION OF CAST IRON

By

AMAN ULLAH KHAN

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INTRODUCTION

The technique of inoculating cast Iron has been known to the foundrymen for the past fifteen years. Although some work has been done in this field, it is still far from complete. Occasionally a new inoculatent has been discovered but no work has been done to show the comparative effect of innoculents. New theories have been presented but none has been able to explain all the phenomenon of inoculation.

Inoculation, as it is used today means addition of small amounts of other metals or alloys to the ladle or to the stream of metal flowing from the copula to bring about different effects in graphite formation and distribution.

Ordinarily, uninoculated, low carbon, electric furnace Cast Iron microstructures consist of type D or E or denderetic graphite with traces of ferrite, non metallic inclusions of Pearlite background, as shown in Fig. 1. The Carbon Content of these Iron varies between 2.6 to 3 percent and the Silicon between 1.25-2.75 percent. During the solidification of the metal the Carbon which has a limited solubility in Iron starts to leave the solution and solidifies as graphite flakes.

These flakes break the continuity of the structure, thus their shape, size and distribution as a marked effect upon the physical properties of grey Cast Iron.

R. Schemdewind and C.D. D'Amico[5] have shown the difference in Physical properties in iron having the same amount of graphite but having a difference in the size, shape and distribution of the graphite flake. They have shown that irons with flakes randomly oriented have the best physical properties but the same kind of flakes if arranged in a lacey pattern around the primary dendrites of austenite weaken the structure considerably.

Inoculation produces flakey graphite randomly oriented which increases the strength of the iron as there are no continuous lines of weakness across the micro-structure. The microstructure of flaky graphite randomly oriented is shown in Fig. 2. The microstructure is also freer from ferrite which is formed by the under-cooling of the metal during solidification.

Until recently inoculation has been regarded as primarily a process of addition of silicon or various high silicon alloys to the molten metal. Most important of these alloys have been Ferro-silicon, Calcium-silicon and Silicon-Manganese-Zinconium type. Although these alloys have been used extensively as late additions for improving the physical properties during the past several years, nothing has been available in the literature regarding the relative effectiveness of these alloys or regarding the mechanism of the process. In 1945 a general program of research was initiated in the Engineering Department at Michigan State College for the purpose of determining the relative effectiveness of the various innoculents and for the purpose of throwing some light on the mechanism of the process. Unpublished work by Womochel, Harvy and McClune has indicated that Calcium silicon is markedly more effective than Ferro silicon as an innoculent. Data from their work is presented in Table No. 1 showing the different effects produced by these two alloys when added to the ladle in amounts to give the same silicon pick up.

The difference in the effects of the two alloys suggests that the active metal, Calcium, plays an important role in the process and also suggests that other active metals might be useful as innoculents.

SURVEY OF LITERATURE

Survey of the literature gives no information on the effects of the active metals with the exception of the work done by Womochel, Harvey and McClune. Data from their work is presented in the following table:

Table 1 - Comparative effect of FeSi and CaSi additions in grey Cast Iron.

	%C	%Si	Trans.	Deflec.	Ten.	Chill
.6 FeSi	2.8	2.17	2905	.261	51470	20
.6 CaSi	2.84	2.21	3728	.394	59200	8

This marked difference in the relative effectiveness of the two silicon alloys suggest that the active metal content of the Calcium alloy is important in the mechanism of inoculation.

EXPERIMENTAL PROCEDURE

The general procedure was as follows: To melt dawn 200# heat in indirect arc rocking furnace to the following composition:

Carbon 2.8 -3.0 percent Silicon 2.0-2.5 percent
Manganese 0.9-1.0 percent Sulphur 0.05-0.068 percent
Phosphorous 0.06-0.1 percent

Metal was tapped to pairs of 50# ladles. Metal in one ladle was treated in each case with active metal and the iron from the two ladles poured into chill test specimen and standard 1.2 inch A.S.T.M. transverse test bar moulds.

The metal from the untreated metal served as a control or blank for determining the effect of the active metal. The metals used in this experiment were Calcium, Sodium, Magnesium and Aluminium.

<u>Preparation of Test Bar Moulds:</u> The moulds were made from Lake Michigan sand with oil and cereal binder. Moulds were washed with a commercial non-graphitic core wash. The diameter of the bars were approximately 1.2 inches.

<u>Charge and Charging Practice:</u> A typical charge is

tabulated in the following table:

Mays Pig	125#
Ingot Iron	27#
Steel Strip	25#
Silveny Pig	25#
Fern-Manganese	1.7#
Iron Sulphide	110 grams.

A Detroit indirect arc rocking furnace with silminite lining was used during this investigation. The capacity of the furnace was 250#. Silveny pig was first placed on the bottom of the furnace. It was covered with ingot iron and steel strip. Pig was finally placed over the steel strip. Ferromanganese and iron sulphide were added to the furnace when iron was partially molten. The tapping temperature for all heats was 2850°F and was poured at 2600 to 2650°F.

<u>Method of Inoculation:</u> Provision was made to weigh the ladle during pouring. Fifty# of metal was tapped in each ladle. Additions of Calcium and Sodium were made by means of an inoculating bar about ten feet long. Each end of which carried a cage in which inoculent was placed. A guard was provided for the inoculater. A quick check was made for the temperatures by optical pyrometer

after the ladles were poured and skimmed. The cage containing the inoculent was then plunged below the surface by manipulating the opposite end of the bar. An orange flame was produced of a violent nature. Sodium addition was tried in the same way but the moment sodium comes in contact with molten metal it explodes. Part of the metal was thrown out of the ladle in the form of mist. Magnesium additions cause a white glare with splatter more violent than Calcium. The Aluminium and Magnesium additions were made by dropping the metal through a tube suspended above the ladle on to the molten cast iron as opposed to the Sodium and Calcium additions which were made by plunging and holding them beneath the surface. Aluminium does not glow or spatter when added to the ladle.

Casting Procedure : Part of a steel bar was melted in the untreated ladle to compensate for the addition of about one half # of steel in the treated ladle by the melting of the cages. One rectangle chill test and five vertical arbitration bars-mould were poured from each ladle. Increasing amounts of inoculating agent were added to the successive group during the experiment. The rectangle chill tests were obtained by pouring

3 7/8" by 2 1/4" by 7/8 " section.
A Cast Iron chill block was placed inside the mould adjacent to 2 1/4 by 3/8" 1face.

<u>Chemical Analysis:</u> Samples for chemical analysis were obtained by drilling the chill test half way across the length. Great precautions were taken to eliminate any external source of addition of Silicon and Carbon.

Carbon determinations were made by the combustion method. Sulphur by the combustion of Silicon by the perchloric acid method. The accuracy of the methods was checked by running standard samples.

<u>Transverse Strength and Deflection:</u> A hand operated Olsen lester was used to break the bars. A dial guage was set up to record the deflection midway between the supporting end. The supporting ends were eighteen inches apart and the lead was applied at the midpoint. The transverse test data is tabulated in Tables No. 2,3,4,5 and 6.

<u>Chill Test:</u> Rectangular chilled test specimen 3 7/8 by 2 1/4" by 7/8" size were moulded. One of the 2 1/4" by 7/8" faces was poured in contact with cast iron. chill placed inside the mould. The clear chill included the white iron fracture only while

the total chill included both the white and mottled fracture.

The chill test data is tabulated in Table 7.

Hardness Test: Brinell hardness samples were taken adjacent to the fracture of each bar and about 3/4" thick. The Brinell impressions were made after they were grounded on both sides. A three thousand Kg. load on a ten millimeter steel ball was utilized. The test results are tabulated in Table 8.

Microscopic Examinations: Samples for microscopic examinations were cut from the test bars adjacent to the fracture. The samples were 1/4" thick and represented more than half the cross-section. They were polished and etched with two percent nital. As the structure did not contain any extraordinary constituent, only the amount of ferrite and graphite distribution were recorded.

The result is tabulated in Table 9.

Table 2- Actual Data

Specimen	Load	Deflection	Specimen	Load	Deflection
Addition of .21 percent Calcium					
T9B1	2647#	.265"	T9C1	3098#	.292"
T9B2	2570#	.228"	T9C2	2868#	.268"
T9B3	2691#	.247"	T9C3	3000#	.291"
T9B4	2699#	.242"	T9C4	2831#	.269"
Addition of .44 percent Calcium					
T9B5	2689#	.260"	T9C5	3262#	.339"
T9B7	2718#	.270"	T9C6	2898#	.269"
T9B8	2640#	.252"	T9C7	3345#	.374"
T9B9	2662#	.252"	T9C8	3178#	.318"

Table 3- Heat No. 10

Addition of .63 percent Calcium

Specimen	Load #	Deflection "	Specimen	Load	Deflection
T10B1	2280#	.192"	T10C1	2980	.304"
T10B2	2225#	.196"	T10C3	3170	.335"
T10B3	2245#	.182"	T10C3	3120	.358"
T10B4	2245#	.198"	T10C4	3075	.312"
T10B5	2340#	.210"	T10C5	3060	.310"

Addition of .87 percent Calcium

T10B6	2150	.187	T 10C6	3275	.397
T10B7	2180	.188	T10C7	3180	.358
T10B8	2180	.190	T10C8	3230	.387
T10B9	2315	.200	T10C9	3290	.367
T10B10	2245	.187	T10C10	3200	.375

Table 4- Heat 11

Addition of 0.68 percent Calcium

Specimen	Load #	Deflection "	Specimen	Load #	Deflection "
T11B1	2290	.251	T11C1	2890	.346
T11B2	2240	.247	T11C2	2940	.359
T11B3	2390	.271	T11C3	2975	.359
T11B4	2145	.216	T11C4	2880	.328
T11B5	2400	.264	T11C5	3125	.366

Addition of 1.11 percent Calcium

Specimen	Load #	Deflection "	Specimen	Load #	Deflection "
T11B6	2270	.243	T11C1	2770	.287
T11B7	2190	.232	T11C2	2780	.283
T11B8	2225	.244	T11C3	2780	.292
T11B9	2115	.203	T11C4	2280	.204
T11B10	-	-	T11C5	2610	.239

Table 5- <u>Heat 12</u>

<u>Addition of .55 percent Sodium</u>

Specimen	Load #	Deflection inch	Specimen	Load #	Deflection inch
T12B1	2100	.180	T12S1	2430	.223
T12B2	2215	.192	T12S2	2420	.222
T12B3	2020	.155	T12S3	2340	.208
T12B4	2165	.185	T12S4	2320	.204
T12B5	2335	.210	-	-	-

Table 6- Heat 13

Addition of 1.1 percent Magnesium

Specimen	Load	Deflection	Specimen	Load	Deflection
T13B1	2210	.176	T13M1	2395	.206
T13B2	2155	.172	T12M2	2270	.186
T13B3	2160	.169	T13M3	2295	.190
T13B4	-	-	T13M4	2320	.182
T13B5	2200	.173	T13M5	2270	.194
Addition of 1.1 percent Aluminium					
T13B6	2220	.189	T13A6	2650	.239
T13B7	2180	.172	T13A7	2430	.200
T13B8	2265	.179	T13A8	2110	.162
T13B9	2270	.189	T13A9	2365	.200
T13B10	2315	.186	T13A10	-	-

Table 7- Data on Chill Test

Blank Specimen	Chill Total 1/32" A	Chill Clean 1/32" B	Treated Specimen	% add.	Chill total 1/32" C	Chill clean 1/32" D	Ratio C/A	Ratio D/B
T9B1-5	22	7	T9C1-5	0.21	17	5	.79	.71
T9B6-10	17	1	T9C6-10	0.44	4	1	.23	1.0
T10B1-5	31	9	T10C1-5	0.63	11	3	.35	.33
T10B6-10	29	7	T10C6-10	0.87	3	.5	.102	.071
T11B1-5	20	13	T11C1-5	0.68	8	1.5	.40	..115
T11B6-10	16	7	T11C6-10	1.11	1	.5	.062	.071
T12B1-5	30	12	T12S1-5	0.55	16.5	4.5	.55	.375
T12B1-5	35	21	T12M1-5	1.1	17.5	7.5	.50	.348
T12B6-10	24	7	T13A6-10	1.1	1	0	.041	0

Table 8- Brinell Hardness Data

Blank Specimen	B.H.N.	Treated Specimen	B.H.N.
T9B1	205	T9C1	217
T9B2	217	T9C2	217
T9B3	217	T9C3	217
T9B4	214	T9C4	216
T9B5	207	T9C5	217
T9B6	-	T9C6	223
T9B7	207	T9C7	223
T9B8	212	T9C8	219
T9B9	209	T9C9	227
T10B1	214	T10C1	217
T10B2	199	T10C2	217
T10B3	226	T10C3	219
T10B4	208	T10C4	209
T10B5	199	T10C5	-
T10B6	209	T10C6	214
T10B7	207	T10C7	207
T10B8	202	T10C8	217
T10B9	205	T10C9	219
T10B10	223	T10C10	199

Table 9- Data on Microscopic examination

T9B1-5	T9C1-5
Abnormal structure, lots of ferrite at the surface, lacey graphite distribution	More normal structure, ferrite at the surface, less lacey graphite, smaller cell size.
T9B6-10	T9C6-10
Abnormal structure, same as T9B1-5.	Normal structure, with very little ferrite at the surface. smaller cell size.
T10B1-5	T10C1-5
Abnormal structure	Smaller cell size and normal structure with little ferrite at the surface.
T10B6-10	T10C6-10
Abnormal structure	Completely normal structure and smaller cell size.
T11B1-5	T11C1-5
Abnormal structure	Smaller cell size, normal structure.
T11B6-10	T11C6-10
More massive ferrite and abnormal graphite than in Calcium treated iron.	Almost completely normal structure with no massive ferrite. Smaller cell size.

Table 9- Continued

T12B1-5

Highly abnormal structure with lacy graphite in some areas. Shows lacy graphite at surface with considerable ferrite

T12S1-5

Slightly less abnormal than blank. Very little graphite. Shows lacy graphite at surface with somewhat more ferrite than in blank. More ferrite in specimen generally than in blank. Smaller cell size.

T13B1-5

Microstructure about like other blank. Heats with areas of large flakes and abnormal graphite.

T13M1-5

Much more abnormal than blank. Cell size smaller and the boundaries much less evident in this sample.

T13B6-10

Less ferrite of somewhat more normal than aluminium treated iron. Cell boundaries more evident in this one than in the aluminium treated sample.

T13A6-10

Appears to have more ferrite and to be somewhat less normal than the corresponding blank. Cell size is smaller.

Table 10- <u>Data from Carbon Determination</u>

Blank Specimen	% Carbon	Treated Specimen	% Carbon	Difference %
T9B1-5	3.075	T9C1-5	3.040	-.035
T9B6-10	3.090	T9C6-10	3.000	-.090
T10B1-5	2.960	T10C1-5	2.800	-.160
T10B6-10	2.995	T10C6-10	2.830	-.165
T11B1-5	3.100	T11C1-5	2.920	-.180
T11B6-10	3.085	T11C6-10	2.845	-.240
T12B1-5	2.900	T12S1-5	2.920	+.020
T13B1-5	2.935	T13M1-5	2.940	+.005
T13B6-10	2.950	T13A6-10	2.900	-.050

Table 11- <u>Data from Sulphur Determination</u>

Blank Specimen	% Sulphur	Treated Specimen	% Sulphur	Difference %
T9B1-5	.063	T9C1-5	.062	-.001
T9B6-10	.066	T9C6-10	.057	-.009
T10B1-5	.065	T10C1-5	.056	-.009
T10B6-10	.065	T10C6-10	.058	-.007
T11B1-5	.063	T11C1-5	.052	-.011
T11B6-10	.064	T11C6-10	.050	-.014
T12B1-5	.057	T12S1-5	.057	-
T13B1-5	.066	T12M1-5	.029	-.037
T13B6-10	.068	T12A6-10	.067	-.001

Table 12- Data from Silicon Determination

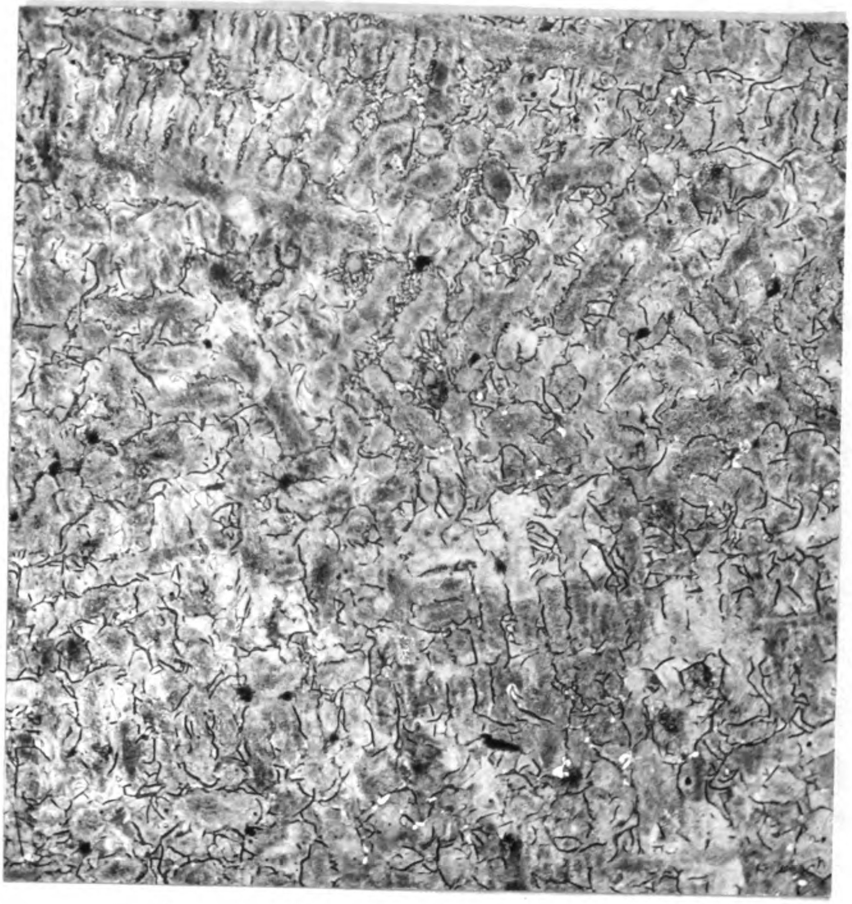
Blank Specimen	Percent Silicon	Treated Specimen	Percent Silicon
T9B1-5	2.30	T9C1-5	2.29
T9B6-10	2.30	T9C6-10	2.30
T10B1-5		T10C1-5	
T10B6-10		T10C6-10	
T11B1-5	2.28	T11C1-5	2.31
T11B6-10	2.25	T11C6-10	2.24
T12B1-5	2.23	T12S1-5	2.24
T13B1-5	2.26	T13M1-5	2.26
T13B6-10	2.26	T13A6-10	2.23

Table 13- Condensed Data on Transverse Test

Blank No.	Load #	Deflection inches	Treated No.	Load #	Deflection
T9B1-5	2679	.251	T9C1-5	2988	.283
T9B6-10	2656	.261	T9C6-10	3261	.343
T10B1-5	2288	.194	T10C1-5	3121	.335
T10B6-10	2246	.192	T10C6-10	3265	.384
T11B1-5	2360	.262	T11C1-5	3013	.361
T11B6-10	2228	.239	T11C6-10	2776	.287
T12B1-5	2202	.196	T12S1-5	2396	.217
T13B1-5	2188	.173	T13M1-5	2333	.199
T13B6-10	2280	.184	T13A6-10	2481	.213

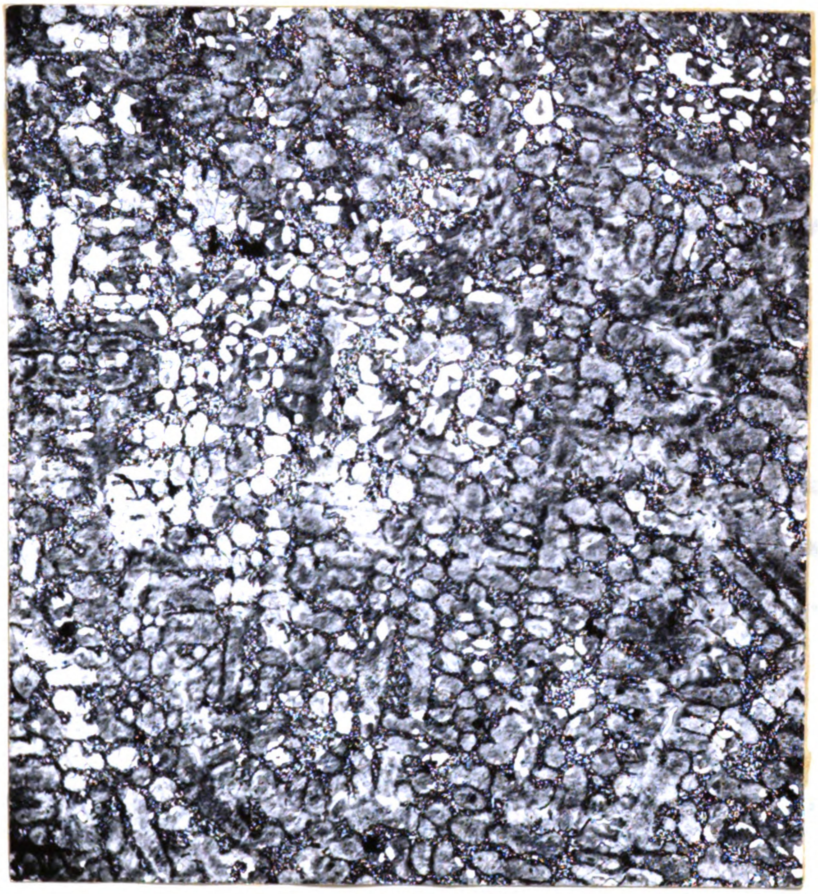
Table 14- Comparative effects on the Physical Properties for same Carbon and Silicon Pick up

Specimen	Carbon	Silicon	Transverse	Deflec-tion	chill ratio total 1/32"	chill ratio clear 1/32"
T12B1-5	2.90	2.23	2202	.196	30	12
T11C1-5	2.92	2.31	3013	.361	8	1.5
T12B1-5	2.90	2.23	2202	.196	30	12
T12S1-5	2.92	2.24	2396	.217	16.5	4.5
T13B1-5	2.935	2.26	2188	.173	35	21
T13M1-5	2.94	2.26	2333	.199	17.5	7.5
T12B1-5	2.90	2.23	2202	.196	20	12
T13A6-10	2.90	2.23	2481	.213	1	0



Photomicrograph 1- 2% Nital etch. Showing Abnormal structure with type D graphite. (Blank for Magnesium inoculation).

Photomicrograph 2- 2% Nital etch. Showing normal graphite pattern.



Photomicrograph 3- 2% Nital etch. Showing abnormal structure after Magnesium inoculation.

DISCUSSION OF RESULTS

Chemical Composition- Calcium decarborizes the metal as it is clear from Table 10. Increasing amount of Calcium has brought about a corresponding decrease in the Carbon content of the final inoculated metal. With the addition of one percent of Calcium the Carbon has decreased by o.24 percent.

Mg, Na apparently do not affect the carbon content of the metal. It could not be said here with confidence that sodium does not have any affect on Carbon, as the amount of sodium which went into the metal was very small for drawing any conclusions. It does have a little effect but is very small as compared to the effect of Calcium.

Sulphur- During the whole experiment the sulphur content did not change very much. From Tables 11, it is clear that Aluminium and Sodium do not affect the sulphur content of the final metal. Calcium does have some effect on desulpherising. The sulphur decreased 0.014 percent by the addition of 1.11 percent of Calcium to the charge.

Magnesium- Magnesium disulpherises the metal considerably. The addition of 1.1 percent of Mg reduces the Sulphur content by 0.037.

Silicon- Silicon content was within close limits. It varied between 2.23 to 2.30. Silicon content of the final composition is not effected by inoculation. Equivalent ladles have very little difference in Silicon contents as such a comparison would be very accurate.

Transverse Strength and Deflection:

It is clear from Tables 2,3,and 4 that increasing the amount of Calcium improved the transverse properties. An addition of 0.21 percent Calcium showed the increase in transverse load from 2679 to 2988 pounds and the deflection increased from 0.251 to 0.283 inches.

Addition of 0.44 percent Calcium increased the transverse load from 2288 to 3121 pounds and the deflection from 0.194 to 0.335 inches. Maximum increase in the load was obtained by the addition of 0.87 percent of Calcium (See heat T10B9 in Table13). The transverse load increased from 2246 to 3265 pounds and the deflection from 0.192 to 0.384 inches.

The effect seems to decrease by further increase of Calcium. The cause may be due to the increase in defects by the formation of Calcium Carbide, but the holding time seems to have little effect on the difference in the transverse properties.

The addition of 1.11 percent of Calcium reduced the Carbon content by 0.24 percent. The transverse strength increased from 2776 to 3265 pounds in heat No. 10. The deflection also increased from 0.287 to 0.384 inches.

For good comparison Heat No. 12 was proposed to be inoculated by 0.55 percent and 1.1 percent Sodium, but due to the explosion effect of Sodium inoculation the latter additions were called off. Addition of o.55 percent Sodium does increase the transverse load and deflection but to a small extent as shown in Table 5. The transverse load increased from 2202 to 2396 pounds. The deflection increased from 0.196 to 0.217 inches. It was also observed that sodium inoculation produces bars with less defects and of uniform properties. In comparison with Calcium, Sodium has a lesser effect. In fact Calcium is about twelve times as effective as Sodium.

Also, Sodium cannot be added by ordinary means.

Addition of 1.11 percent Magnesium has a very small effect on the transverse properties. The Magnesium inoculated bar had a transverse load of 2333#and a deflection of 0.199 inches as compared to the non-inoculated bar, of 2188 pounds and 0.173 inch respectively.

Aluminium additions have some inoculation effect. The transverse load increased from 2280 pounds to 2481 pounds and the deflection increased from 0.184 to 0.213 inches. It was also observed that Aluminium inoculated bars have more defects. The defects are probably due to the Aluminium oxide trapped during solidification. Table 13 was prepared to show a clear picture of the inoculating effects of these metals. Magnesium and Aluminium slightly improve the physical properties, even though more ferrite is found in the microstructure by their addition. This may be due to the solid solution effect of these inoculants in ferrite. Table 14 was prepared to compare the physical properties for the same Carbon and Silicon pick up. Calcium and Aluminium show considerable increase in the physical properties but Magnesium and Sodium do not have any appreciable effect.

Chill Characteristics:

Aluminium addition has the maximum effect in reducing the chill. Both clean and total chill were reduced considerably. There was practically no clean chill left by the addition of 1.1 percent Aluminium. The total chill was reduced to about twenty-four times in the treated iron. Calcium also reduced the chill to a great extent. Increasing amounts of Calcium reduced the chill till 0.87 percent of Calcium was used, after which no further reduction in chill was obtained by further increase in the inoculent. Magnesium and Sodium additions also reduced the chill but their effect was small as compared to Aluminium and Calcium. Aluminium additions seem to be twice as effective as Calcium from the data in Table 7. It is also clear from this table that any addition of active metals reduces the chill to some extent.

Ease of Inoculation:

Calcium inoculation produces a peculiar orange flame. The Calcium addition causes some splattering of the molten iron from the ladle. The reaction between Calcium and molten metal is violent but it is not as vigorous as those of Magnesium and Sodium. Magnesium has a violent reaction with molten Cast Iron and gives out a white flame with much splatter. Sodium has the most violent reaction with molten Cast Iron. It explodes as soon as it comes in contact with the molten metal. It throws the metal out of the ladle in the form of a fine mist. It also produces black smoke.

Aluminium does not react with the molten metal violently. There is no explosion, flame or splatter during the inoculation procedure. It floats on top of the metal and soon dissolves into the metal. During this investigation, Aluminium was the easiest to be used as an inoculant. Although it imparts a strange appearance to the metal. During pouring the metal looks like an under-cooled brass. It may be caused by Aluminium Oxide floating on top of the metal.

Hardness: The Brinell hardness data is tabulated in Table 8. for the first two heats. This data did not show any significant change for comparing the effects of different inoculants on their physical properties. The variation of hardness was 14 B.H.N. for heat No. 9 and 27 for heat No. 10. This difference does not lead to

any definite conclusion. It is generally understood among grey iron Metallurgists that hardness is not correlated with the other properties of Cast Iron. As such the determination of B.H.N's for the hardness of the rest of the specimens were discontinued.

Microstructure and graphite distribution:

Great difference in microstructure was observed between the corresponding inoculated and uninoculated specimen of Calcium heat. It has already been stated that a change in matrix and graphite shape, size and distribution greatly affects the physical properties of the test bars. The same correlation was obtained during this investigation. Inoculated specimen from heat No. 9 showed an increase in normal graphite. The cell size was smaller and the microstructure was less denderetic than the corresponding blank. There was quite a bit of ferrite and lacy graphite at the surface of the test bars. The corresponding blank also had dendretic structure and lacy graphite but in these uninoculated bars the dendritic structure extended to the center of the section. There was more massive ferrite and abnormal graphite near the suface of the bar. Increasing amount of Calcium in heat No. 10 and 11 has shown corresponding effect in producing normal graphite. A Specimen from Sodium inoculated iron showed slightly less abnormal structure than the corresponding non-inoculated iron. There was smaller amounts of lacy graphite throughout the specimen. The lacy graphite at the surface was associated with somewhat more ferrite than the blank. As a whole the sodium inoculated,iron had more free ferrite than the blank. The blank had highly abnormal stfucture with lacy graphite and more ferrite was associated with the lacy graphite at the surface. Blank for Magnesium inoculated iron was shown to have the same microstructure as other blanks. The flakes were larger and there was abnormal graphite in the structure. Magnesium inoculated iron had more abnormal structure than blank. The cell bounderies were much less evident though the cell size was smaller. There was more free ferrite and lacy graphite than in the blank. This effect of Magnesium on the microstructure may be attributed to the reduction in the Sulphur content brought about by the Magnesium addition. Reference to the table shows that the inoculation reduced the Sulphur from 0.066 to 0.029 percent. Boyles [3] has shown that low sulphur irons tend toward an abnormal structure and has stated that 0.025 S is necessary for a normal structure. Although the Sulphur remaining in the treated iron exceeds this amount, it would appear desirable to control the Sulphur content before reaching a final conclusion regarding the effect of Mg. additions on the microstructure.

Blank for Aluminium treated showed abnormal structure, with ferrite and lacy graphite. The cells were larger and well defined. Ladle treated iron had smaller cell size and the structure was more abnormal than blank.

From the microexamination it has become clear that Calcium has the maximum effect in producing normal graphite. Magnesium and Aluminium apparently have a negative effect in promoting good graphite distribution. Their additions appear to make the iron more dendritic and increase the amount of ferrite. Sodium has some inoculating effect as it helps to produce normal graphite but it is hard to put into the ladle. It increases the amount of ferrite and thus reduces the physical properties of the metal.

SUMMARY AND CONCLUSIONS

An investigation has been carried out to determine the relative effects of Calcium, Aluminium, Magnesium and Sodium as ladle inoculants for gray cast iron on its chemical analysis, physical properties and microstructure.

The base iron has 2.8 to 3.0 percent Calcium, 2.0 to 2.5 percent Silicon, 0.05 to 0.068 percent Sulphur, 0.9 to 1.0 percent Managnese and 0.06 to 0.1 percent Phosphorous, throughout the entire investigation. Comparisons were based on the difference of the final chemical composition, transverse strength and deflection, chill debth, microstructure and graphite distribution between inoculated and uninoculated irons.

The conclusions drawn are as follows:

1- Calcium is effective in improving the graphite distribution and matrix structure when used as a ladle addition in gray cast iron.

2- Magnesium and Aluminium additions to the ladle in amounts of about one percent have an adverse effect on graphite distribution and matrix structure. In the case of Magnesium this effect may be associated with a reduction in sulphur content.

3- The addition of Calcium brings about an improvement in the physical properties as evidenced from the effect on the transverse strength.

4- An addition of about 0.87 percent Calcium seems to have maximum inoculating effect.

5- Calcium decarbonizes the iron.

6- Calcium reduces the chill to a great extent but it is less effective than Aluminium.

7- Magnesium inoculation desulphurises the metal.

8- Sodium seems to promote normal graphilization to some extent but it is very hard to inoculate. It ignites with an explosion the moment it comes in contact with molten metal.

9- Aluminium reduces the chill considerably. It was the best chill reducer among the metals tried in this investigation.

10- Calcium, Aluminium, Sodium and Magnesium do not have any effect on the Silicon content of the final composition of the metal. All these inoculants reduce chill to some extent.

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