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Effect of Aluminum in Cast Iron

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1. Introduction

It is well known that systematic studies on the cast iron had already been started from the end of 19th centry. In early stage of the works chemical analysis of the composition and microscopic examinations of the structure were realized. Thereafter a study on the silicon addition initiated by keep (1) and on the pearlitic casting by Goerens (2). After-wards a classification of the type of graphite in cast iron, so called A, B, C, D, and E type (3) had been authorized by AIME which threw some light on the correct understanding of the importance of graphite in cast iron. All of these works plus many others had contributed to the remarkable progress in the field of ordinary cast iron, and to the invention of current malleable cast iron and spheroidal graphite cast iron as well. Nonetheless ordinary cast irons are still prevailing in general uses and consequently in the amount of production. In this respects the authors have continued a series of research to develop the ordinary cast irons which have more improved properties and strength. Aluminum is by nature one of the powerful graphitization promoting elements, so that one can expect in might play a similar role as silicon does in cast iron. Besides it would be hoped that small addition of aluminum to cast iron gives a positive influence on the type of graphite. It was also thought that supplementary strength might be resulted through the solution hardening effect due to the aluminum dissolved in the iron matrix. The present study was thus designed to investigate how and why the addition of small amount of aluminum would alter the properties of cast iron.

2. Experimental Methods

The chemical analysis of the starting pig iron material and final specimens used in this study are listed in Table 1, 2, and 3. The method of preparing these are as follows.

Table 1

Chemical Composition of Materials (wt %)

Comp. mat.	*C*	*Si*	*Mn*	*P*	*S*	Remarks
Pig Iron	4.1	1.6	0.15	0.05	0.03	
Electro Iron	0.015	0.15	0.05	0.008	0.001	
Fe-Si	—	70-75	—	—	—	
Fe-Si-Mg	—	60-65	—	—	—	Mg: 25%

Table 2

Chemical Composition of Samples

Sample No.	*C*	*Si*	*Mn*	*P*	*S*	Remarks
1.	3.176	2.437	0.181	0.032	0.042	
2.	3.423	2.536	0.177	0.040	0.047	
3.	3.576	2.582	0.180	0.044	0.037	
4.	3.785	2.743	0.169	0.047	0.042	
5.	3.806	2.891	0.170	0.046	0.034	
6.	3.032	2.264	0.160	0.030	0.024	
7.	3.143	2.047	0.159	0.028	0.030	
8.	3.379	2.375	0.174	0.030	0.026	
9.	2.998	1.932	0.161	0.029	0.027	
10.	3.679	3.114	0.175	0.051	0.029	
11.	3.112	2.731	0.158	0.046	0.038	
12.	3.754	2.237	0.178	0.044	0.030	
13.	3.298	2.413	0.166	0.037	0.026	
14.	3.599	2.272	0.155	0.047	0.029	
15.	3.676	2.536	0.158	0.036	0.031	
16.	3.787	2.359	0.172	0.039	0.023	
17.	2.945	2.313	0.163	0.529	0.021	

Table 3

Chemical Composition of Samples (Add. Al)

Sample No.	*C*	*Si*	*Mn*	*P*	*S*	*Al*	Remarks
1.	2.877	2.505	0.198	0.030	0.052	0.846	
2.	3.028	2.722	0.174	0.025	0.056	0.635	
3.	3.348	2.615	0.151	0.028	0.050	0.686	
4.	3.023	2.319	0.198	0.054	0.025	0.743	
5.	3.519	2.420	0.154	0.048	0.025	0.789	
6.	2.998	2.354	0.165	0.052	0.033	0.726	
7.	3.847	2.329	0.176	0.055	0.031	0.752	
8.	3.284	2.678	0.198	0.063	0.026	0.832	
9.	2.958	2.119	0.165	0.066	0.024	0.880	
10.	3.508	2.370	0.176	0.062	0.027	0.798	
11.	2.846	2.576	0.176	0.065	0.029	0.824	
12.	3.263	2.387	0.169	0.045	0.023	0.676	
13.	3.516	2.634	0.177	0.039	0.034	0.799	
14.	3.700	2.542	0.159	0.056	0.027	0.754	
15.	3.914	2.313	0.189	0.029	0.045	0.842	
16.	3.888	2.275	0.167	0.060	0.021	0.782	
17.	3.085	2.731	0.192	0.033	0.037	0.765	
18.	2.998	2.454	0.175	0.047	0.028	0.697	
19.	3.416	2.130	0.160	0.051	0.036	0.888	
20.	3.599	2.594	0.191	0.029	0.025	0.732	
21.	3.020	2.280	0.170	0.036	0.020	0.223	
22.	3.040	2.330	0.179	0.032	0.021	1.572	
23.	2.960	2.280	0.160	0.041	0.027	2.540	

The iron raw material was melted in the No. 20 graphite crucible employing a 20 KVA cryptol furnace. In the ensuing step 1 wt% of CaC_2 was put in over the surface of molten iron, simultaneously agitating it, to remove the dissolved sulfur and oxigen as their slags. And then it was casted into an iron mould to obtain the starting pig iron ingots. To prepare the final specimens these ingots were remelted and composition controlled in the No. 6 graphite crucible inserted into the above No. 20 crucible. Carbon content was first controlled by the addition of electrolytic iron. Fluxing and slagging out with CaC_2 as before, silicon content was then adjusted with *Fe-Si* alloy crushed to 6 mesh size. In case of the specimens aluminum being added to, the designed amount of aluminum was put in the melt before the slagging out. Finally the melts with and without the added aluminum was inoculated with 0.5% of *Fe-Si* alloy and casted into a mould to prepare the final specimens. For the specimens of spheroidal graphite cast iron the inoculation was conducted after the addition of aluminum with 2% of *Fe-Si-Mg* alloy. Pouring temperature was fixed at about 1400º C and considering the contraction of the melt during the solidification Y type green sand mould was used. Specimens thus prepared were used for the optical microscopic examination of the structure and for EPMA.

3. General Trend with the Variation of the Amount of Aluminum Addition

Fig. 1 shows the variation of tensile strength with the amounts of aluminum addition.

As can be seen from the figure, the tensile strength comes to the highest, 33 kg/mm^2 in case with the 0.7% of aluminum being added. For the specimens with the aluminum content more or less than the 0.7% of values of the tensile strength tend downward. It is interesting in Fig. 1 that in the range of aluminum content exceeding 0.7% the tensile strength decreases by 0.6 kg/mm^2 with increase of aluminum content by 0.1%. At present the reason of this is not clear-cut, but it was thought that addition of aluminum more than certain limit might have so changed the type of graphite as to exhibit such a constant reduction ratio. Microscopic examination of the specimen illustrated later supported this thought might be correct. That is, it revealed that the type and the size of graphite had formed in the best condition for the specimen with 0.7% aluminum content. For the specimens with aluminum content more or less than the 0.7% the suitable type of graphite did not occured; type of graphite was getting larger with the aluminum content increased and it went into finely dispersed form and

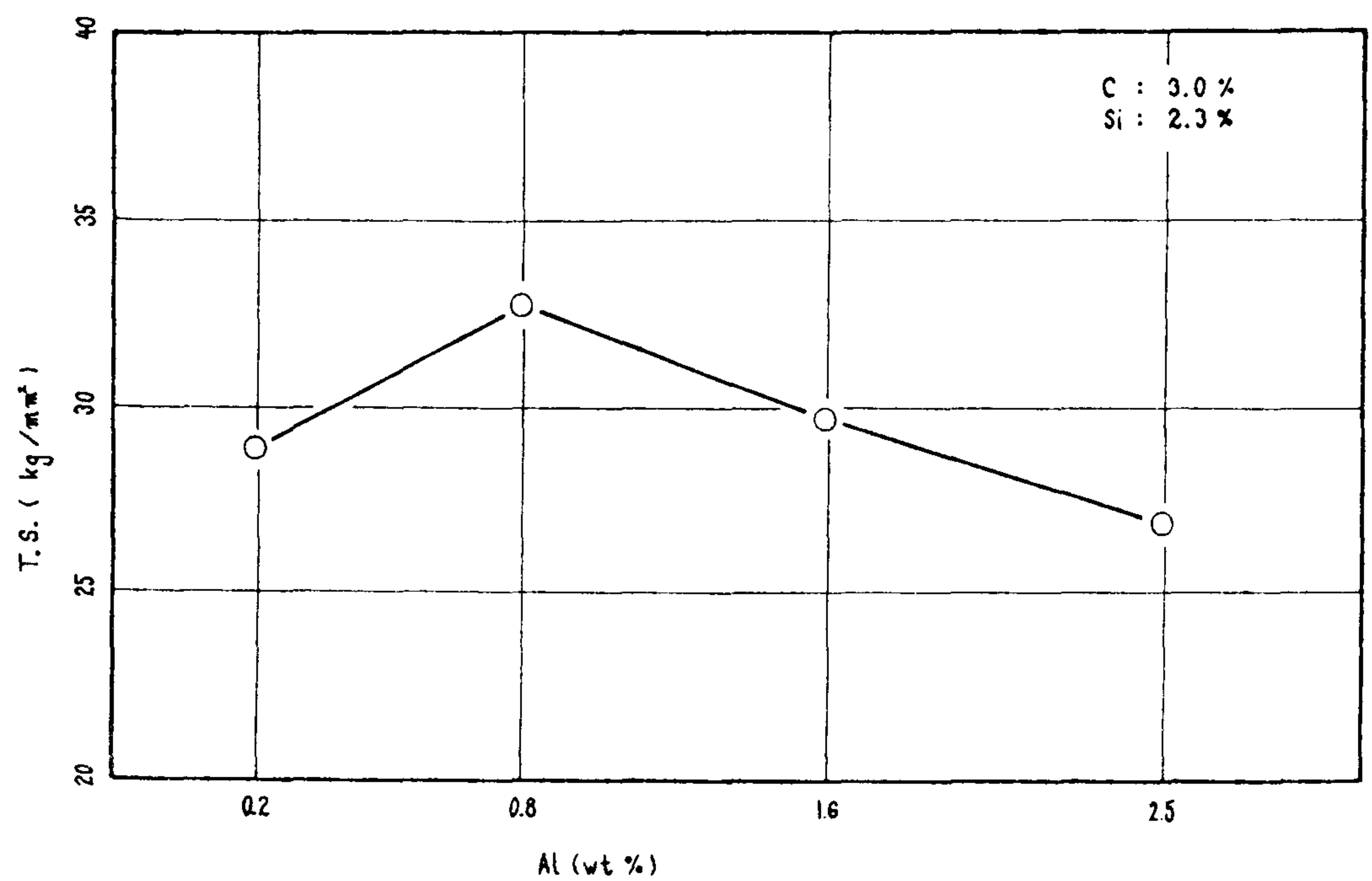


Fig. 1. The variation of tensile strength due to the change of aluminium contents.

directional for the specimens with lesser aluminum than the 0.7%.

It is worthy of notice here that the above results were obtained with such specimens as aluminum was added to before inoculating. Should the sequence of aluminum addition be altered a different result might come out. The data presented from now on are for the specimens aluminum content of which was fixed to about 0.7%, based on the results of Figure 1.

4. Effects of Aluminum on Strength

4.1. *Flake graphite Cast Iron*

a) Tensile Strength

Fig. 2 shows the relation between the degree of carbon saturation and the tensile strength for the specimens concerned. Solid line drawn through mark (•) represents the tensile strength of the specimens containing 0.7% aluminum and that connecting mark (o) corresponds to the tensile strength of the specimens not containing aluminum at all. As can be seen in the figure all the specimen containing aluminum have about 15% higher values in tensile strength than those not containing aluminum. Besides, the difference in the tensile strength between these two kinds of samples appears larger in the hypoeutectic composition range where the degree of carbon saturation is low, while smaller in the hypereutectic range where the degree of carbon saturation is high. For one thing, at the 0.85 degree of carbon saturation, the difference is 4.5 kg/mm^2 while it is only 3.0 kg/mm^2 at the 1.15 degree of carbon saturation. The reason of this may again be attributed to the condition of graphite which had occured in the matrix after solidification. It is imagined that variation of the shape of graphite due to the addition of aluminum would be more conspicuous in the hypoeutectic composition range than in the hypereutectic, because in the latter primary carbon might have already been precipitated. Therefore, it can be said that the effect of aluminum addition on the final shape of graphite might be of minor importance in the hypereutectic composition range resulting the less distinct difference in tensile strength.

In short, effect of aluminum addition to the flake cast iron is more distinct in the hypoeutectic composition range where the shape of graphite can be altered in proper condition to effect the strength.

b) Hardness

Fig. 3 shows the relation between the degree of carbon saturation and the hardness of the specimens mentioned above in part 1). The addition of aluminum increases the hardness of the flake cast iron by 10-15%.

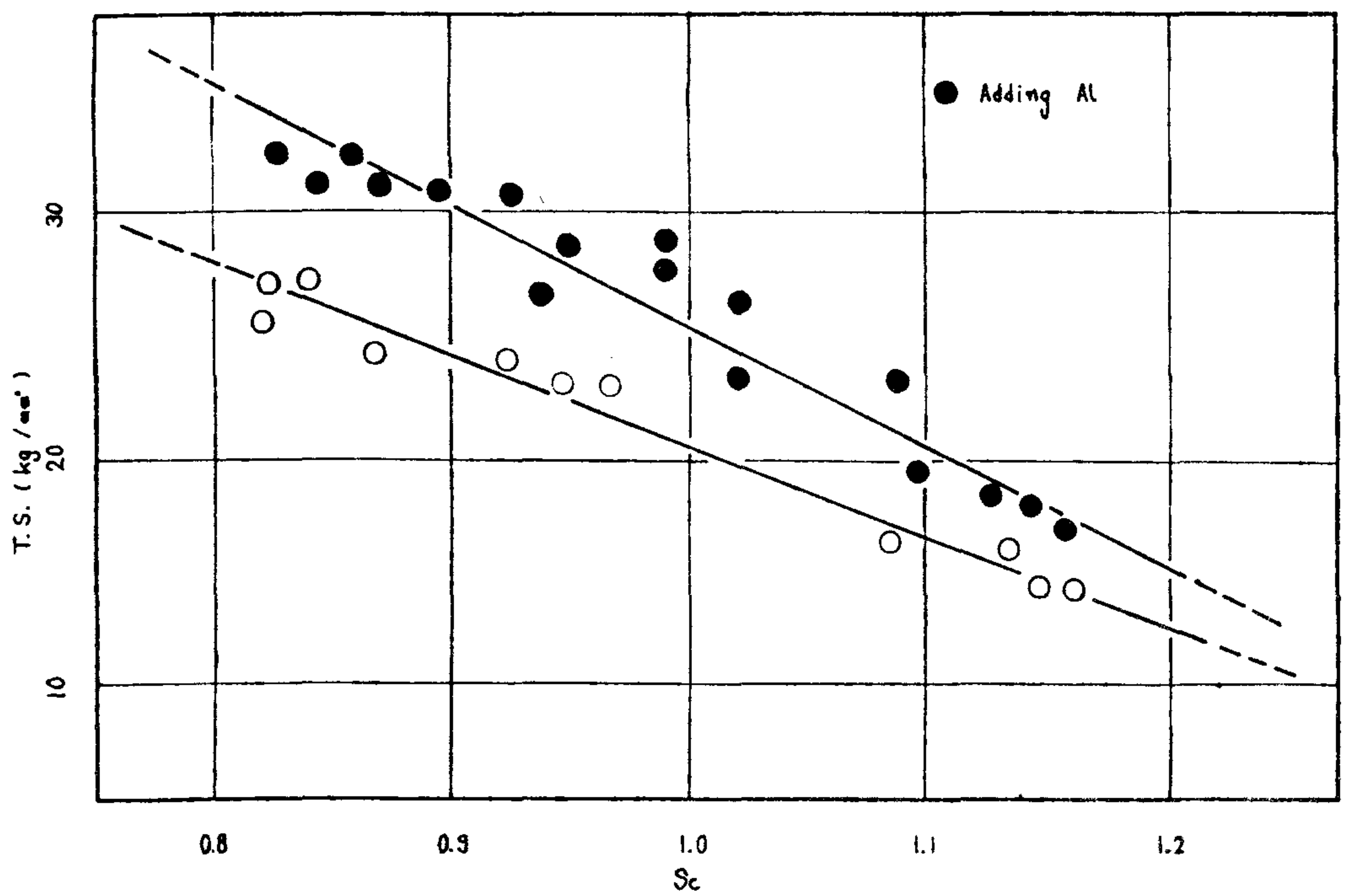


Fig. 2. Relation between Sc and T.S. in gray cast iron.

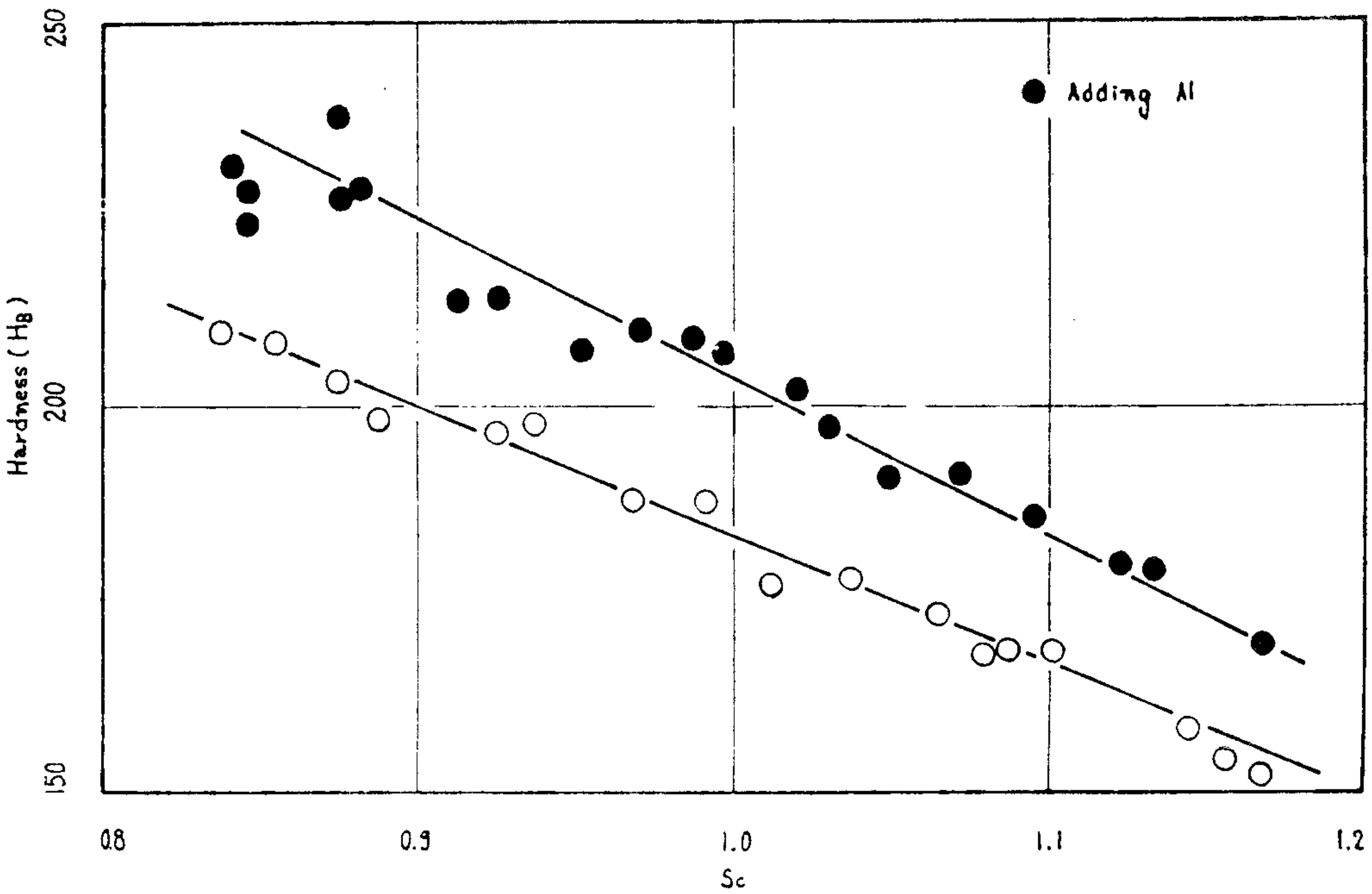


Fig. 3. Relation between hardness and saturated carbon in cast iron.

The trend in Fig. 3 can be seen to be very similar with that shown in Fig. 2. Such a similarity may easily be understood because hardness and tensile strength are the interrelated properties. In the introductory part it was remarked that solution hardening effect due to the addition of aluminum might be expected. This possibility was checked through EPMA described later.

However such effect could not be detected only with the result of EPMA. Further investigation would be needed about this point.

4.2. *Spheroidal Graphite Cast Iron*

a) Tensile Strength

Fig. 4 shows a relation between the tensile strength and the degree of carbon saturation for the spheroidal graphite cast iron specimens. Solid line drawn through small open circle (•) represents, as before, the tensile strength of the specimens containing aluminum and the others for the specimens not containing aluminum. As can be seen from the Figure, tensile strength is dropped in this case with the addition of aluminum. This phenomenon is dramatically opposed to that observed in the flake graphite cast iron specimens. For example at the 0.9 degree of carbon saturation, tensile strength of the specimen containing aluminum is 64 kg/mm², while it attains to 70 kg/mm² for the specimens not containing aluminum giving a difference of 6 kg/mm².

As a rule aluminum is regarded as impurities in manufacturing of spheroidal graphite cast iron and many investigators have reported it is one of the harmful elements spoiling the spheroidization of graphite. From this point of view it is imagined that the incomplete spheroidizing of graphite due to the added aluminum brought about the decrease in tensile strength of the specimens containing aluminum. Type of the graphite occured in the cast iron containing aluminum will be discussed in some detail in the following section. Needless to say, the addition of aluminum will cause the decrease in hardness in spheroidal graphite cast iron.

5. Effect of Aluminum Addition on the Type of Graphite

5.1. *Flake Graphite Cast Iron*

Fig. 5 shows the microstructures of unetched specimens both with and without aluminum added, carbon content of which are within the hypoeutectic composition range. It can be seen that the type of graphite in the specimens without aluminum is directional radiating from certain specific center. On the other hand the type of graphite in the specimens with aluminum is

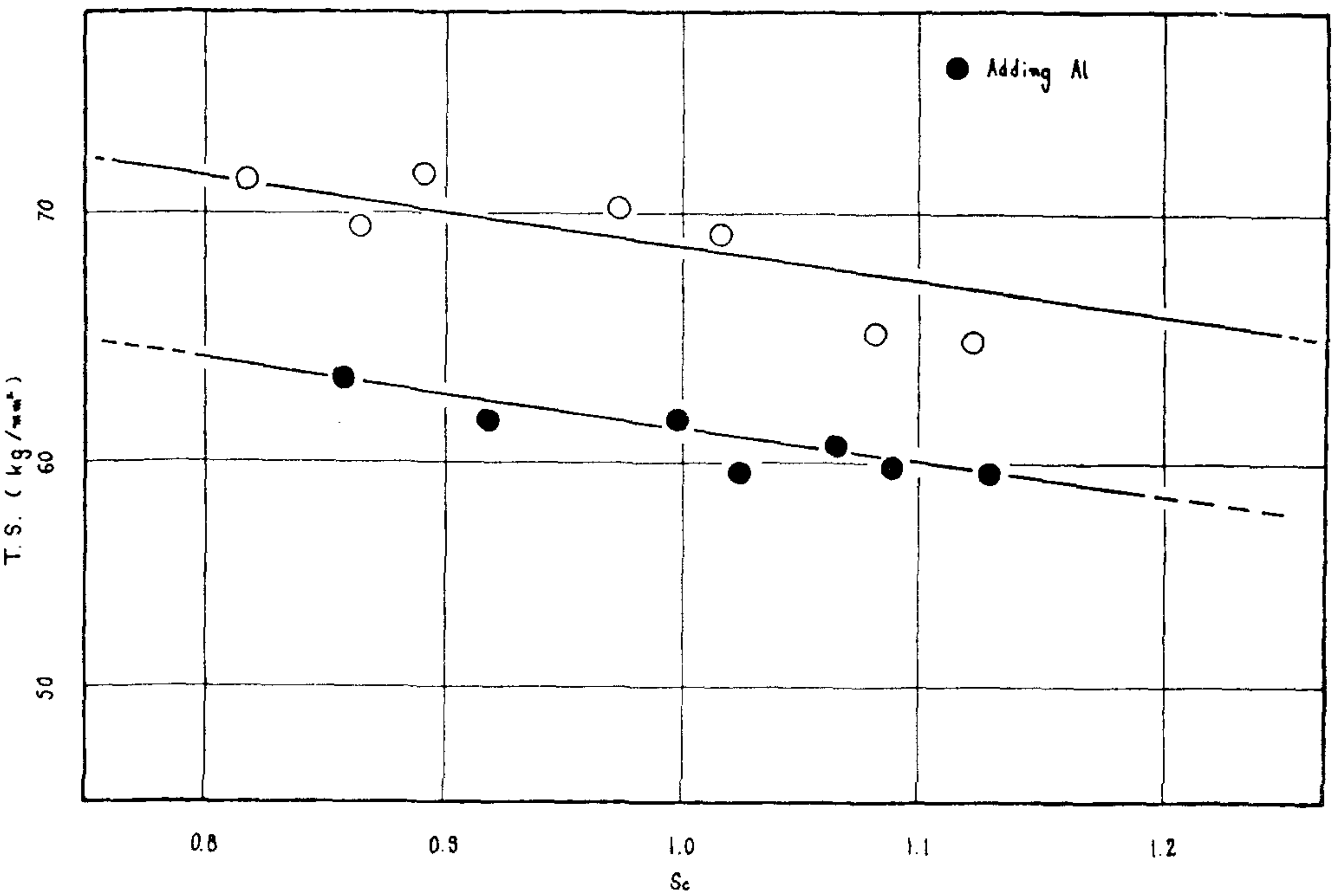


Fig. 4. Relation between Sc and T.S. in spheroidal graphite cast iron.

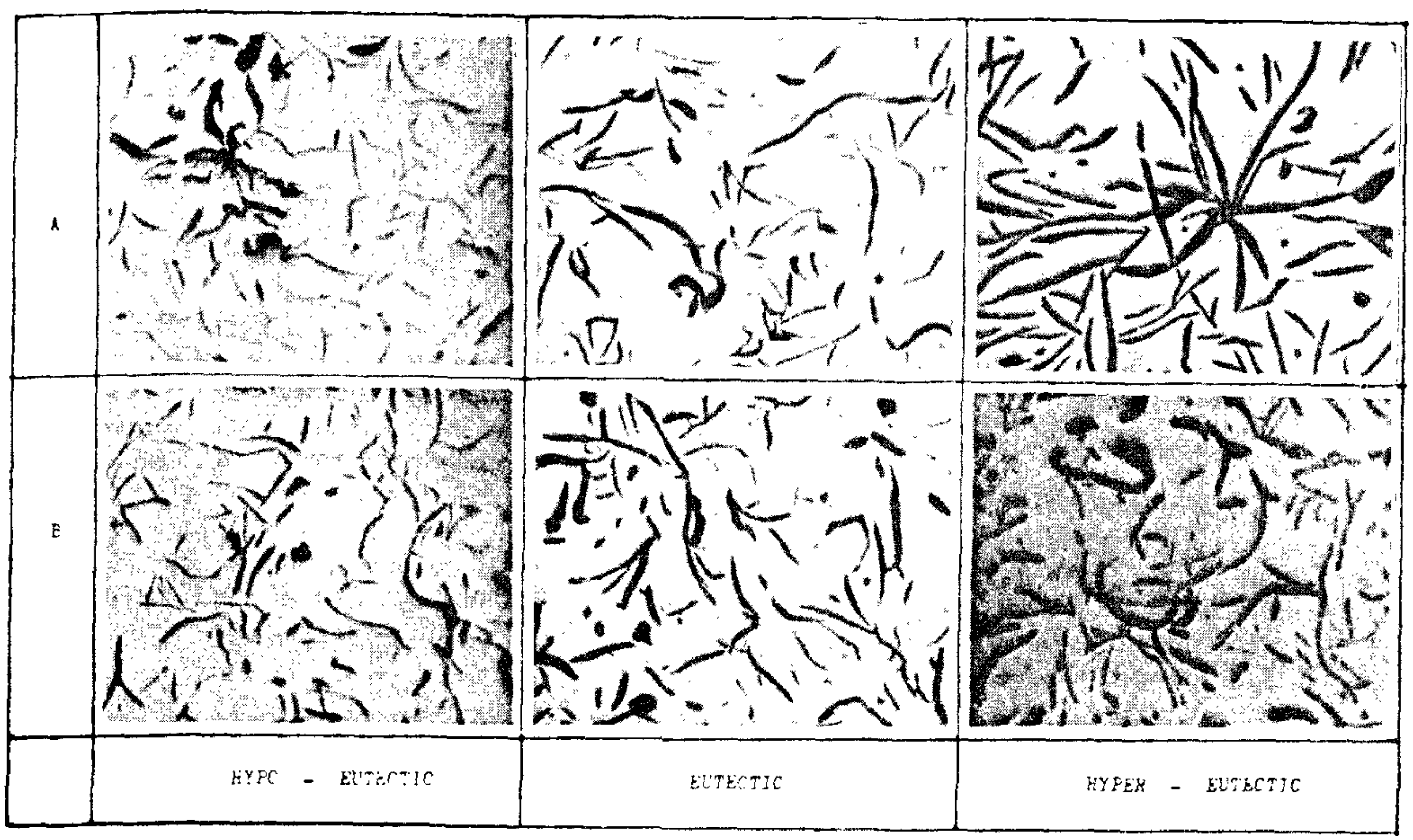


Fig. 5. Microstructure of Cast Iron (X 100)

A: None added B: Adding Aluminum

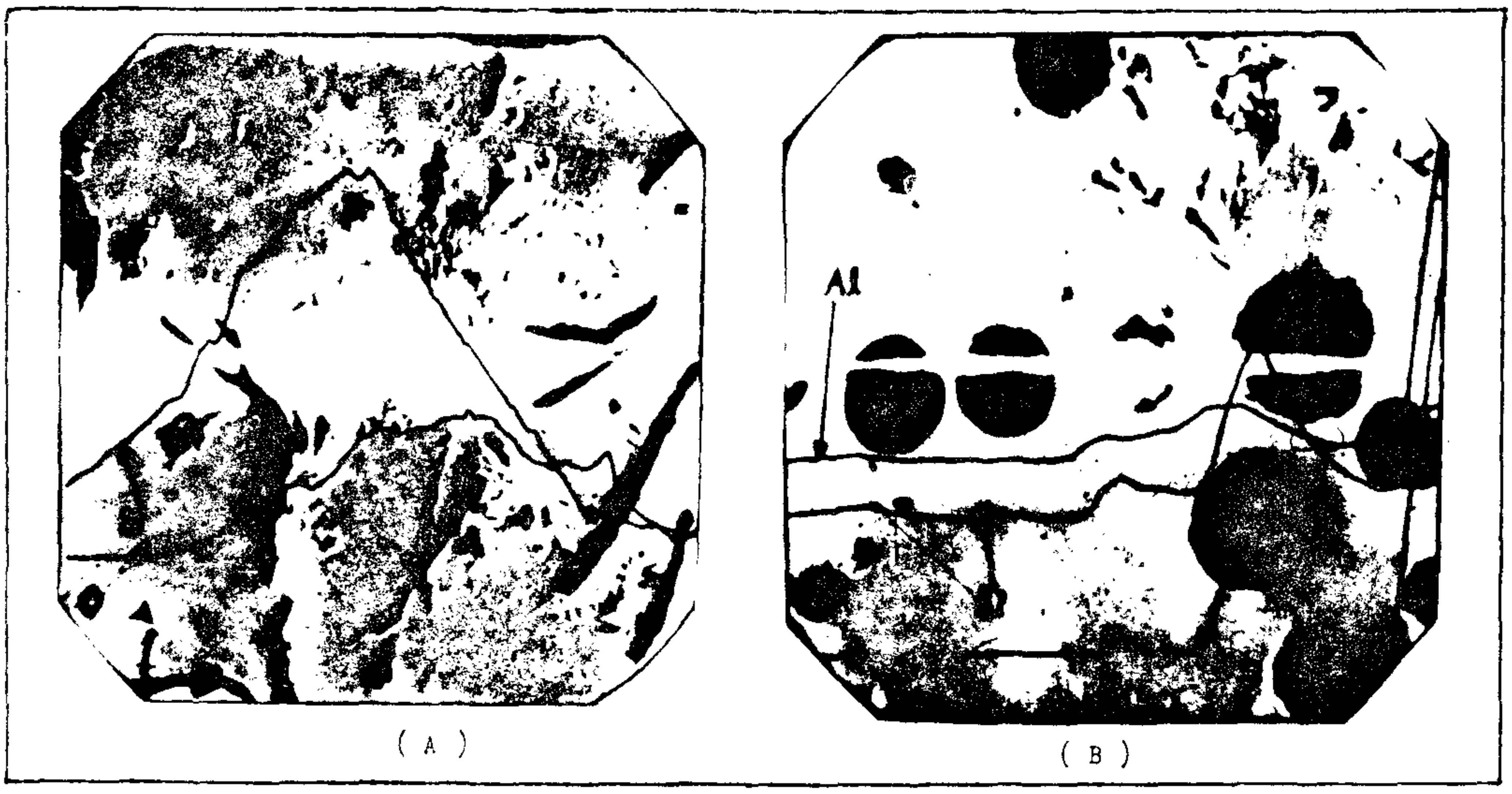


Fig. 6. Line Analysis of Aluminum and Silicon by EPMA.
A: Flake Graphite Cast Iron
B: Spheroidal Graphite Cast Iron

somewhat larger in size, non-directional and curved properly indicating quasi A type graphite. The mechanism why these two kinds of specimens showed the different types of graphite is not clear, but to be sure is that the added aluminum gave certain effect to the graphitization process. Viewed in this light it would be concluded that the previously mentioned result, that is, the increase in tensile strength for the specimens containing aluminum was primarily due to the type of graphite which had been effected by the added aluminum. Possible change in the microstructure of matrix or solution hardening effect through the added aluminum would have only minor importance to the increase in tensile strength.

Relating the tensile strength to the type of graphite in this way it is explained of itself how the highest tensile strength had been obtained when the 0.7% of aluminum was added; it had been effected through the quasi A type graphitization. It seems that in case the portion of aluminum was more or less than the 0.7%, the effect of aluminum on the graphitization was different from the case with the 0.7%.

5.2. *Spheroidal Graphite Cast Iron*

As mentioned before aluminum is regarded as a harmful element in spheroidizing of graphite. Connecting the data in Fig. 4 with this point of view, it is easily understood that the lower tensile strength observed in the spheroidal graphite cast iron containing aluminum was due to the incomplete formation of spheroidal graphite.

The authors think further studies should be made on this subject considering the proper moment of adding aluminum into the molten iron as well as the amount of it.

6. EPMA for the Distribution of Aluminum

Fig. 6 shows the result of EPMA for the regional distribution of aluminum and silicon in the cast iron specimens. It indicates that the majority of silicon are located around the graphite in both the flake and the spheroidal graphite cast iron exposing uneven distribution in general. On the other hand aluminum is not maldistributed either in the matrix or in the graphite side revealing completely inconstant distribution. EPMA also indicates that matrix was not greatly altered by the addition of aluminum.

7. Conclusion

The important results obtained in this study are as follows.

1. Addition of small amounts of aluminum to the flake graphite cast iron increased the tensile strength of cast iron up to 15%.

2. This increase in tensile strength is more effective in the hypoeutectic composition range than hypereutectic.

3. On the contrary addition of small amounts of aluminum to the spheroidal graphite cast iron decreases the tensile strength of cast iron.

4. The reason why the tensile strength is increased by the addition of aluminum might be attributed to the occurrence of quasi A type graphite in the flake cast iron due to the aluminum added.

5. The reason why the increase in the tensile strength is more effective in the hypoeutectic range might be described to that in the hypereutectic range the precipitation of primary carbon precedes the promotion of graphitization by the aluminum added.

6. It is imagined that the reason why the tensile strength is decreased by the addition of aluminum to the spheroidal graphite cast iron might be due to that the added aluminum spoils the spheroidization of graphite.

REFERENCES

1. *Keep:* "Cast Iron" A Record of Original Research, New York (1902).
2. *P. Goerens:* Stahl U. Eisen 26 (1906) 397.
3. Metals Hand Book 8th Edition ASM vol. 7. 82.

鑄物工場 Layout

鑄 鋼 鑄 物 生 產 用 의　自 動 造 型 라 인

鑄鋼工場의 造型라인으로서 炭素鋼밸브, 스라이드밸브 등의 輸送管밸브를 鑄造한다. 表面砂는 CO_2 砂를 사용한다.

이 라인의 仕樣은 다음과 같다.

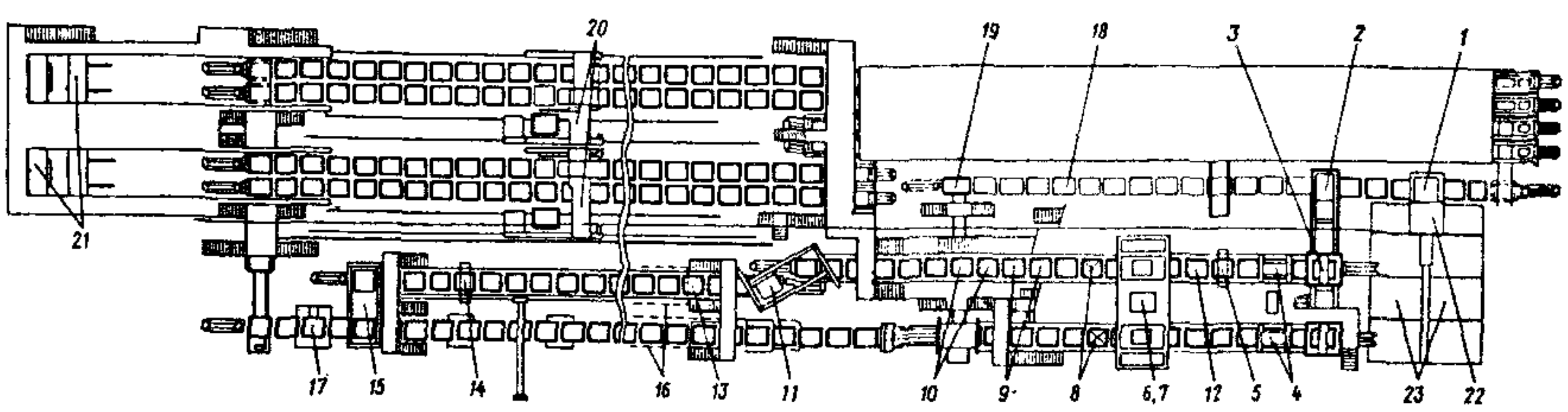
鑄枠칫수 : 1,200×1,000×400/400 ㎜

造型싸이클 : 36 sec

最高時間当生產量 : 100 鑄型

最大鑄込重量 : 350 ㎏

鑄型冷却時間 : 2 hr



1. 枠해체裝置
2. 枠移送裝置
3. 枠分離裝置
4. 枠淸掃用부라쉬
5. 枠反転裝置
6. 3 station 自動造型機
7. CO_2 吹込 station
8. CO_2 追加吹込 station
9. 湯口, 압탕설치 station
10. 湯口押湯설치 station
11. 上型移動裝置
12. 上型 roller conveyor
13. 上型 roller conveyor
14. 上型反転裝置
15. 型合裝置
16. 塗型乾燥機
17. 鑄型크램프 station
18. 運搬裝置
19. 驅動台車
20. 注湯裝置
21. 移動台車
22. Chute
23. 진동 conveyor