論 文

# Effects of Control Factors on the Morphology of Compacted/Vermicular Graphite ( II )

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# C/V 흑연의 형상에 미치는 공정요소의 영향( II )

예 병 준

## 개 요

C/V 흑연주철의 흑연형상에 미치는 응고인자들의 영향을 알아보기 위해 시편의 단면적, 첨가재, C/Si의 비 등을 변화시켜 보았으며 구상흑연화율과의 관계도 고찰하였다.

50% 이하의 구상화율과 단면적의 차이는 흑연 형상에 영향을 준다고 볼 수 없었으며 첨가재와 C/Si의 비는 알려진바와 같이 기지조직에 영향을 주었으나 C/V 흑연의 형상과는 무관한 것으로 보여진다.

## 1. Introduction

Compacted/vermicular graphite was introduced due to the properties of compacted graphite cast iron such as high tensile strength with high thermal conductivity and good machinability.[1,2]

It is well known that the major properties of cast iron depend upon the shape of graphite. The high tensile strength and ductility of ductile iron come from the shape of graphite of ductile iron-spheroidal graphite cast iron. The good thermal conductivity and good machinability of gray cast iron come from flake shaped that the morphology of graphite in cast irons is important to their properties.

Cooling rate which can be controlled by section size is known as the most influential factor to the morphology of the cast iron especially when it is a spheroidal graphite cast iron. The types of the treatments for C/V graphitization are another important factor on the morphlolgy but has not been studied with this respect.[5~12]

Different treatments may result the morphology in another trend because of their different fading characteristic.[9,13,14] Carbon-silicon ratio with a fixed carbon equilibrium[15,16] is another control factor should be considered when the C/V cast iron is manufactured.

The solidification factors-cooling rate(section size), treatment for c/v graphitization and C/Si ratio were studied to define the change in the morphology of compacted/vermicular graphite in this research. The thickness-length ratio of compacted graphite vs. percent spheroidal graphite was also investigated.

## 2. Experimental procedures

The experimental procedures of this research are identical with the part( I ) of this research except the variables to be considered as the objectives and the experimental design factors. Those variables are as follows :

1. Different section sizes.
2. Ratio of carbon/silicon.
3. Different treatment for c/v graphitization.

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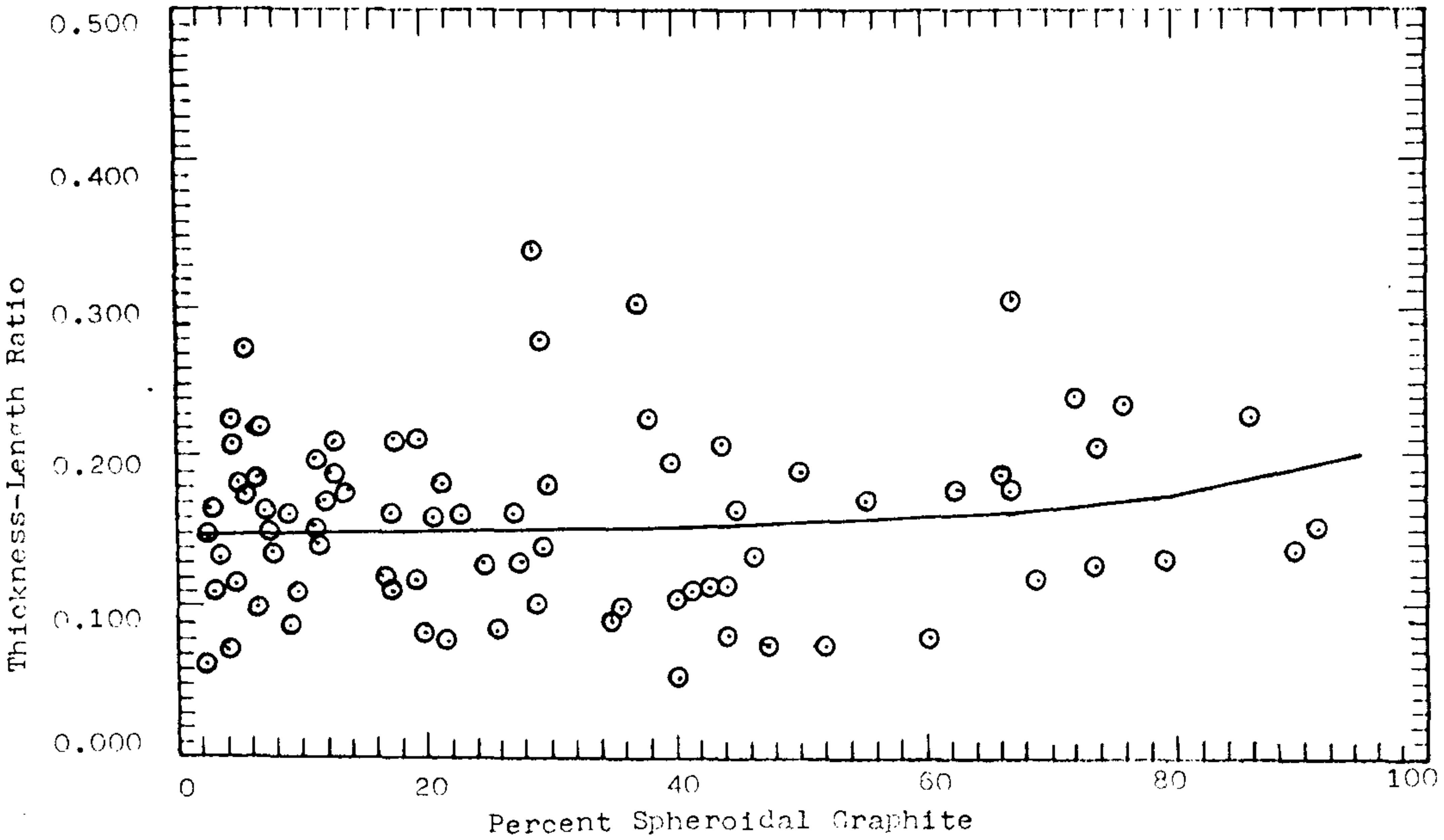

Fig. 1 Thickness-Length Ratio with Different Percent Spheroidal Graphite

4. Percent spheroidal graphite.(as an objective only)

## 3. Results

The relationship between spheroidal graphite and the thickness-length ratio is shown in Fig. 1. The regression line shows almost no difference in the thickness-length ratio of compacted graphite in the range of 0 to 50 percent spheroidal graphite. The plotted result of the two differently treated compacted graphite cast iron is shown in Fig. 2. Very few data which show more than 50% of spheroidal graphite were eliminated in this analysis for the reason that more typical compacted/vermicular-like graphite which is usually presented in a microstructure showing high percent spheroidal graphite should be chosen.

Fig. 6 of part( I ) shows typical examples of the shape difference of the graphite between the heats with 3.8% C/1.8% Si and the heats with 3.4% C/3.0% Si. No significant difference in the shape of the compacted graphite is found in those figures even if the matrix looks different due to the difference of carbon-silicon ratio.

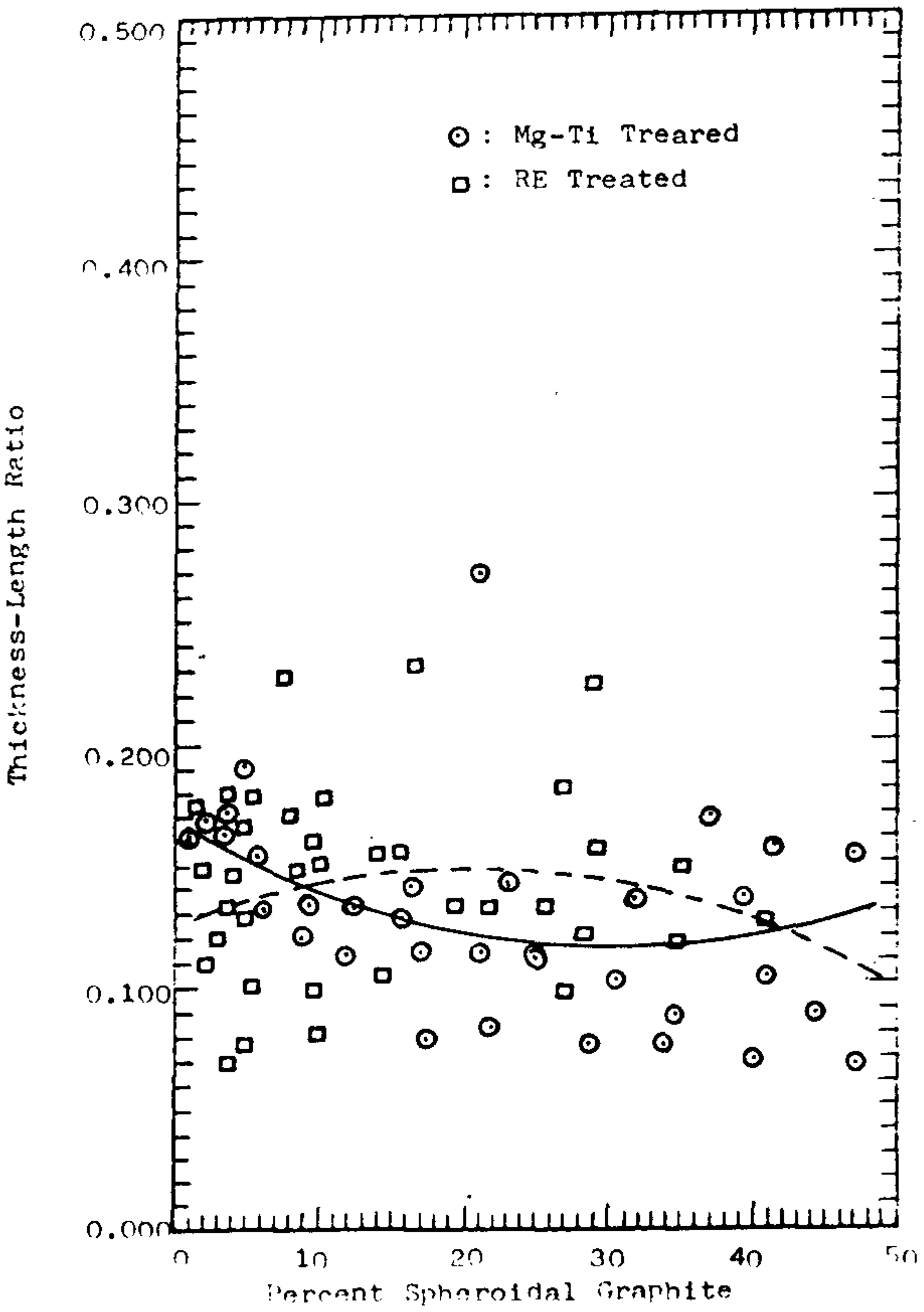

Fig. 2 Difference between Two Different Alloy Treatment for Compacted/Vermicular Graphitization

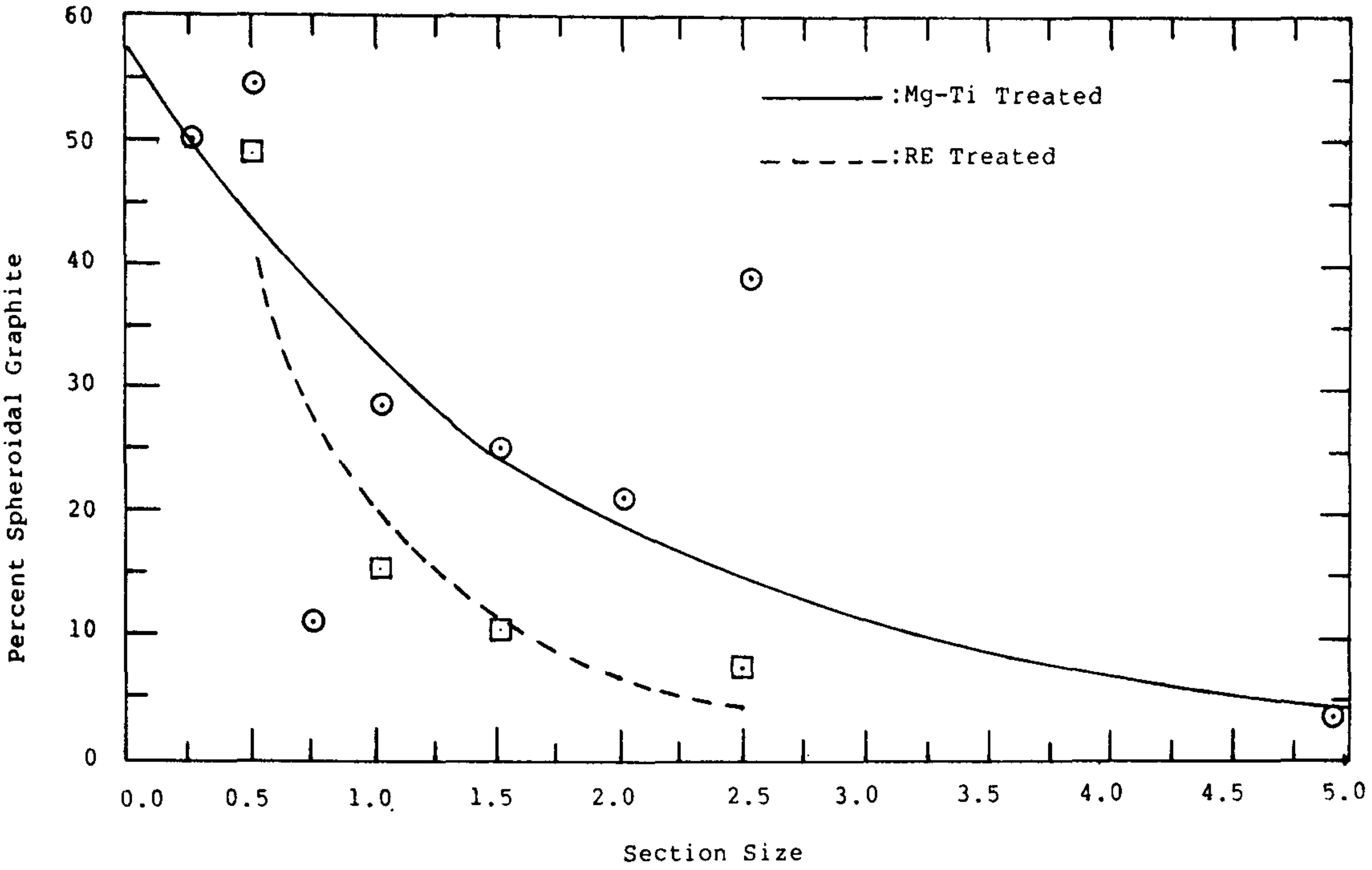

Fig. 3 Effect of Section Size on Percent Spheroidal Graphite

The shape of spheroidal and compacted graphite of rare earth silicide treated irons changes more than that of Mg-Ti alloy treated irons as shown in Fig. 6 of part( I )

Fig. 3 shows the relationship between section size and percent spheroidal graphite. The thickness-length ratio of compacted graphite with different section sizes is shown in Fig. 4. Percent sheroidal graphite decreases continuously with increasing section size as shown in Fig. 3. The thickness-length ratio of compacted graphite does not change with different section sizes except in the case of 6mm and 13mm section sizes as shown in Fig. 4.

## 4. Discussion

A prior study[17] shows that the thickness-length ratio of compacted graphite varies generally from 0.5 to 0.1. However, the ratio of this study has a range of 0.065 to 0303. The reason for this difference could be that type I (similar to the ASTM-D type, so called "chunky graphite") was not considered as compacted graphite in the study.

Type Ⅱ was not found even though those are treated by rare earth silicides as shown in Fig. 6 and Fig. 8 of part( I ).

So, the graphite found in these microstructures was rather long, thin and vermicular shaped. The average thickness-length ratio of this compacted graphite is approximately 0.15. More than 80% of the thickness-length ratio data of compacted graphite samples are located between 0.09 and 0.21.

As to the effect of percent spheroidal graphite on the thickness-length ratio of compacted graphite, there is no effect as shown in Fig. 2. But the opinion that the intermediate form of graphite between spheroidal graphite and compacted graphite may influence the measurement of the thickness-length ratio of compacted graphite can not be denied. So, it could be resonable that the thickness-length ratio of compacted graphite

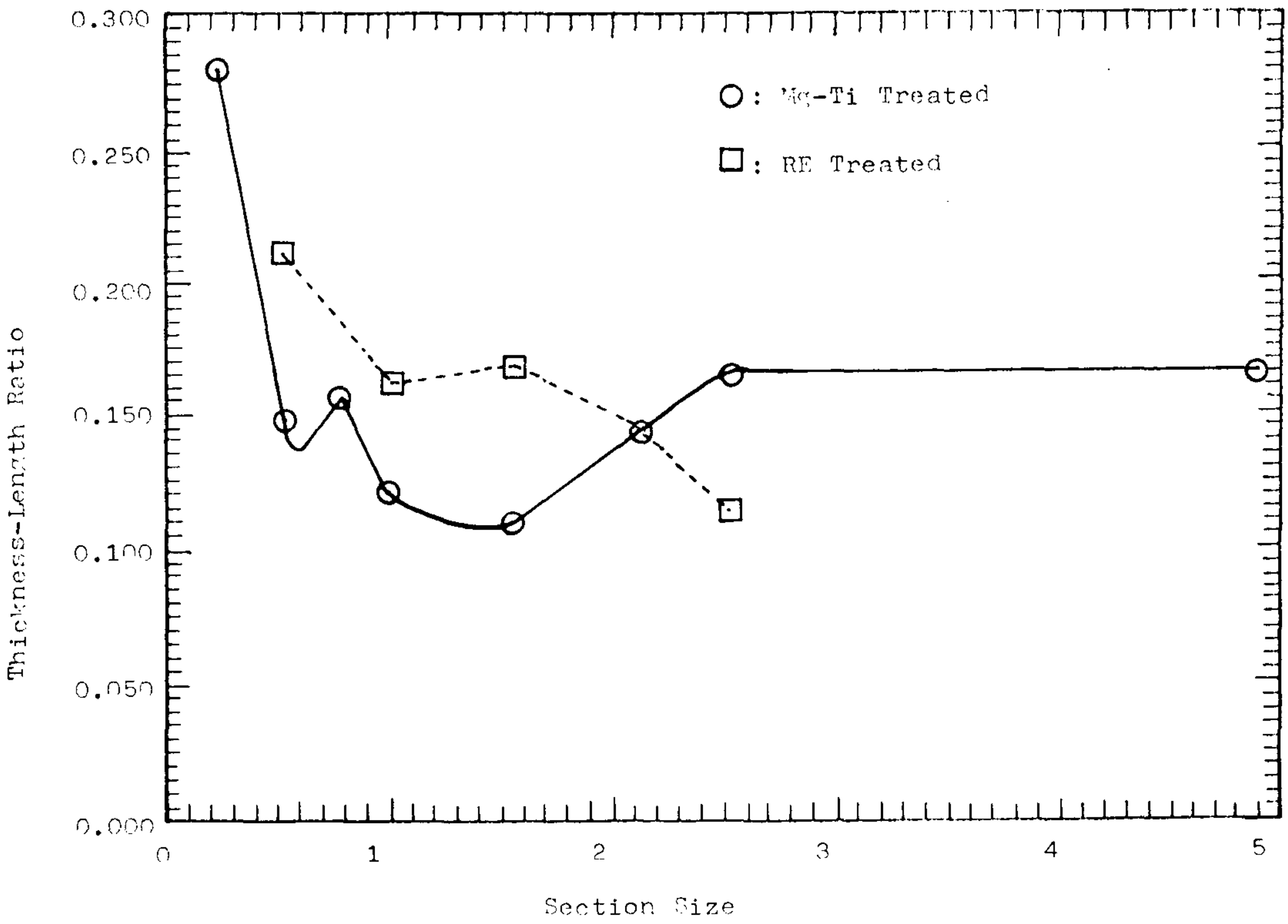

Fig. 4 Effect of Section Size on Thickness-Length Ratio of Compacted Graphite

slightly increases when the ratio increases by adding the intermediate form of graphite in the range of more than 50% spheroidal graphite. This phenomenon can easily happen in thin sections less than 13mm in diameter as shown in Fig. 4.

The more silicon content, the less carbide in the microstructure due to the property of ferrite promotion of silicon. In the Fig. 6 of part( I ) as cast C 3.8%/Si 1.8% shows that some carbide was formed as a result of the solidification procedure of the 13mm bar. Meanwhile as cast C 3.4%/Si 3.0% shows that few carbides were formed as a result of the solidification procedure of the same size bar. For the rare earth silicide treated samples a similar situation occurred. But no compacted graphite could be found in cases of low silicon content(C 3.8%/Si 1.8%).

The percent spheroidal graphite decreased remarkably and continuously with increasing section size in both kinds of compacted graphite (Mg-Ti alloy and rare earth silicide treated) as shown in Fig. 2.

But the thickness-length ratio of compacted graphite with increasing section size decreased rapidly from 6.5mm to 19mm. section size. Then there is no marked change in the thickness-length ratio up to 127mm section size. This is shown in Fig. 4. Some sets of optical photomicrographs which are in Fig. 6, 7 and 8 of part ( I ) show this phenomenon.

Comparing different C/Si ratios of rare earth treated photographs in Fig. 6 of part( I ) (both "as cast" and "after annealing"), microstructures of "after annealing" are different from each other. And there is no compacted graphite in the figure of C 3.8%/Si 1.8%. So it could be said that "annealing" does not generate compacted graphite by itselt.

Without considering this matrix change, the morphology of compacted graphite may not be affected by changing the carbon-silicon ratio with the same carbon equivalent.

It has been reported[17] that there is a difference between Mg-Al-Ti alloy treated compacted graphite(type Ⅱ) and cerium treated compacted graphite(type Ⅲ). But, it is hard to tell whether there is a significant difference between compacted graphite of two differently treated irons as shown in Fig. 1.

Statistical analysis shows that there is no difference between the two differently inoculated compacted graphite with 95% confidence. Fig. 6 and Fig. 7 of part(Ⅰ) also support this opinion

As discussed above and in part(Ⅰ), solidification factors(percent spheroidal graphite, treatment, carbon-silicon ratio, section size and holding time) do not significantly affect the morphology of compacted graphite as represented by the thickness-length ratio of compacted graphite. The variables which do not affect the morphology include : percent spheroidal graphite-from 0% to 50%. : inoculation-Mg-Ti alloy and rare earth silicide. : carbon silicon ratio-C 3.8%/Si 1.8% and C 3.4%/Si 3.0%. : section size-13mm, 25mm, 38mm : holding time-0.5 minutes, 2.5 minutes, 4.5 minutes after post-inoculation.

## 5. Conclusions

1. The change of percent spheroidal graphite, in the range of less than 50% spheroidal graphite, does not change the thickness-length ratio of compacted graphite.
2. The carbon-silicon ratio of the iron plays a major rloe in the distribution of the matrix-usually ferrite and carbide but that ratio does not affect the thickness-length ratio of compacted graphite.
3. In a small section size(13mm.), the thickness-length ratio of compacted graphite is slightly greater than that of larger section sizes(25mm and 35mm) due to the presence of an intermediate form of graphite(between spheroidal graphite and typical vermicular shaped compacted graphite). Otherwise, the factor of section size does not affect the morphology of compacted graphite either.
4. The amount of compacted graphite in a microstructure may differ with different treatments, but the actual morphology-thickness-length ratio of compacted graphite-does not change remarkably.

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