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COMPUTER SUPPORTED RECOGNITION OF GRAPHITE PARTICLE FORMS IN CAST IRON

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ABSTRACT

The paper analyzes the microstructure of cast iron by the aid of a computer-supported image analyzer. The possibilities of distinguishing graphite particles forms by a new form factor method are studied. The form factor is defined as a simple ratio between the graphite particle measured parameters and its actual area, perimeter and maximum size D_{max}. The results are presented graphically and prove that this new method can be successful in classifying graphite particles forms existing in ductile iron and gray iron.

Key words: form factor, graphite, ductile iron, gray iron.

INTRODUCTION

It is known that the shape and size of graphite particles in the matrix have a strong influence on heat conductance of cast iron. Therefore it is desirable to know more about the graphite particle size and shape distribution. Backed by this knowledge we can predict the response of the material to surface heat treatment by laser beams. Long graphite flakes prevent the conductance of heat into the deeper layers of the material and thus increase heat accumulation in the surface layer of the workpiece.

In cast iron, graphite can be clearly seen on the polished surface of the prepared specimen. During specimen preparation, it is necessary to take great care not to spoil its correct shape. In preparing the specimen for optic microscopy, the use of an automatic grinding and polishing machine is recommended. In this way the specimens are always equally well prepared, which is especially important in computer aided analysis of the structure taken by a CCD scanner camera. The software package for image analysis includes a procedure which provides the possibility of presenting the observed object by morphological attributes describing their size and shape. Our investigation will be directed into the measurements of area, perimeter and maximum length of the graphite particle.

EXPERIMENTAL PROCEDURE

The measurements were carried out at a magnification of 100x in a rectangular field with an area of 0.2269 mm^2. On each material at least 30 fields were analyzed thus ensuring a sufficient level of results reliability. Measurements were made on only those graphite particles whose surface was greater than 30 μm^2. We analysed different qualities of cast irons. The chemical composition of two most significant cast irons in percent is shown in Table 1.

Table 1. The chemical composition of two characteristic cast irons.

	ISO	C	Si	Ni	Cr	P	Cu	Mg	S	Mn	CE
SL200	Grade 200	3.406	1.95	0.175	0.183	0.07	0.459	-	0.083	0.302	4.079
NL400	400-12	3.649	2.372	0.08	0.011	0.013	0.161	0.04	0.008	0.213	4.438

The main data used to characterize the microstructure of cast iron are the size, number and form of graphite particles. For the characterization of the microstructure, reference is mostly made to quantitative measurements of graphite particles. In the literature you cannot find any generally accepted method for measuring the graphite particle form which would be suitable for later classification of a wide variety of these forms found in cast iron. To characterize graphites in a cast, the shape and the size of the graphite particles are fundamental data for its classification into form groups or classes. The method of form measurement that we used had to ensure, among other things, that the calculated form factor was independent of the size, and possible graphite particle displacement or rotation.

In the analysis of the form factor, the following criteria were considered:
1. The form factor values should range within 0 and 1, where the value of 1 is reserved for a disc.
2. The method should be most sensitive to any variation from circularity.
3. The form factor has to be calculated from easily obtainable geometric properties of the structure.
4. The calculated form factor has to be independent of possible rotation or translation motion of graphite particles in the microstructure.

Considering these requirements, we established a new form factor which should fully meet our needs in classifying the graphite structure in the ductile iron and gray iron.
To the generally known form factors $\frac{A}{\pi \cdot r^2}$ (Karsay, 1992) and $\frac{4 \cdot \pi \cdot A}{p^2}$ (Pavešič, 1992, Serra, 1982) a new relationship was added, describing the ratio between the graphite particle perimeter and the circumference of the circle circumscribing this particle: $\frac{p}{2 \cdot \pi \cdot r}$.
Then all these factors were multiplied by one another, and the result that we obtained was called the new form factor:

$$\frac{A}{\pi \cdot r^2} \cdot \frac{4 \cdot \pi \cdot A}{p^2} \cdot \frac{p}{2 \cdot \pi \cdot r} = \frac{2 \cdot A^2}{\pi \cdot p \cdot r^3} \quad (1)$$

where:

A .. the surface of the graphite particle cross section,
p .. the perimeter of the graphite particle cross-section,
r .. maximum graphite particle radius.

In order to be able to automate the procedure, we had to simplify the identification of the size of the maximum graphite part diameter which was done by circumscribing a circle around the particle, that is:

$$r = \frac{D_{max}}{2} \quad (2)$$

where D_{max} is the maximum size of the graphite particle in 2D.

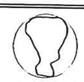
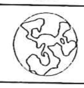
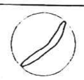
Thus by rearranging equation (1), we get as the final result a new form factor:

$$\text{form} \cdot \text{factor} = \frac{16 \cdot A^2}{\pi \cdot p \cdot D_{max}^3} \quad (3)$$

ranging from 0 to 1.

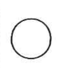
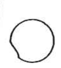
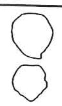
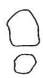
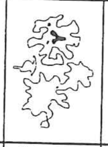
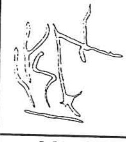
In Table 2 we have four different shapes of graphite particles presented and calculated their corresponding form factors. We chose five form factors and numeric description of graphite shape particles in the ductile and gray iron, where the last form factor represents our proposal. On the basis of the results in Table 2 it can be stated that the first four methods very badly distinguish particular shapes of graphite particles, what confirm equally calculated values of form factors for different particle shapes. The calculated results of the new suggested form factor confirm good distinction for different graphite particle shapes.

Table 2. Comparing the distinction of different form factors.

Graphite particle shape	Form factor				
	$\frac{A}{\pi \cdot r^2}$	$\frac{4 \cdot \pi \cdot A}{p^2}$	$\frac{2 \cdot A}{p \cdot r}$	$\frac{8 \cdot \pi \cdot A^2}{p^3 \cdot r}$	$\frac{2 \cdot A^2}{\pi \cdot p \cdot r^3}$
	**0.41**	0.52	0.46	0.24	0.18
	**0.41**	**0.06**	**0.15**	**0.007**	0.06
	0.19	**0.06**	0.1	**0.007**	0.02
	0.1	0.2	**0.15**	0.03	0.015

In Table 3, you can see the forms of graphite particles presented by the new form factor according to equation (3) for the ductile iron and gray cast, while in Fig. 1 this distribution is shown by a graph. All the possible graphite particle forms in the ductile iron and gray iron were classified into 12 classes. In the next step, the graphite particle forms were divided into 6 major groups based on the value of the form factor. This classification into form groups is presented in Table 4.

Table 3. Classification of particle forms in the ductile iron and gray iron in a 2D cross-section based on the proposed form factor.

Graphite structure							
Form factor	1	1 - 0.9	0.9 -0.8	0.8 - 0.7	0.7 - 0.6	0.6 - 0.5	0.5 -0.4
Class	1		2	3	4	5	6
Graphite structure							—
Form factor	0.4-0.3	0.3 - 0.2	0.2 -0.1	0.1 - 0.05	0.05 - 0.01	0.01 - 0	0
Class	7	8	9	10	11	12	

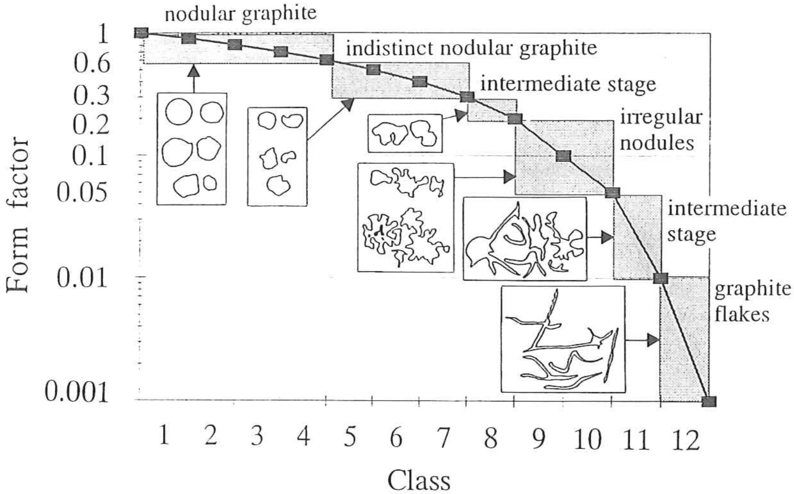


Figure 1. Classification of particle forms into 12 classes based on the proposed form factor.

EXPERIMENTAL RESULTS

Having defined the form factor of the graphite particles, we wanted to verify how the latter changes in terms of the particle area and maximum diameter D_{max}. Fig. 2 shows the cumulative frequency of the distribution of graphite particle areas for the ductile iron and gray iron based on the proposed form factor. From the graph, we can see that in gray iron SL200 almost 90% of the graphite particle area lies within 0 and 0.05 of the form factor. This means that in the majority of cases the graphite particles have the form of flakes or a transitional form between flakes and irregular nodules. In the ductile iron NL400 the frequency distribution is quite the opposite to the gray iron SL200. The results of the analysis show that more than 80% of graphite particle areas take a distinct nodular form whereas the remaining 20% have a less distinct nodular shape. Thus, based on the form factor from Fig. 1 we can classify different kinds of casts into classes or form groups.

Table 2. Classification of graphite structure based on the type of graphite particle form.

FORM FACTOR	FORM GROUP
0.6 - 1	nodular graphite
0.3 -0.6	indistinct nodular graphite
0.2 - 0.3	intermediate stage nodules / irregular nodules
0.05 - 0.2	irregular nodules
0.01 - 0.05	intermediate stage irregular nodules / flakes
0 - 0.01	graphite flakes

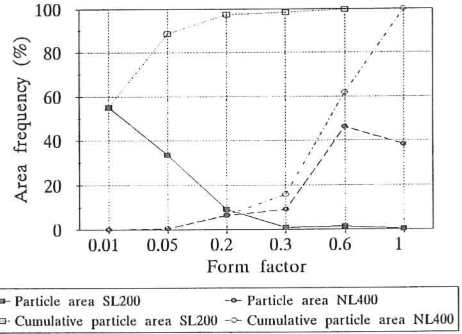


Figure 2. Graphite particle areas frequency versus form factor.

A very important piece of information for the quality of casts is also the graphite particle area. Therefore an analysis was also made to see how the size of the average form factor varies with the graphite particle area. From Fig. 3 we can note that the form factor profile of the ductile iron differs greatly from that of the gray iron. In Fig. 3 two relations are shown, i.e. :

- the form factor size versus the size grade of graphite particle area,
- graphite particle area frequency (particles weighted according to the areas) versus size grade of graphite particle area.

In the ductile iron NL400, the form factor ranges within 0.4 to 0.7. The values of these form factors present some characteristic forms of nodular graphite structures as classified in Table 4. On the other hand, in the gray iron SL200, there are big differences in the form factor values in terms of the size grade of graphite particle area. The results have shown that large particles have a distinct shape of flakes with form factor values within 0 and 0.01 or have a transitional shape between flakes and irregular nodules with form factor values within 0.01 to 0.05. The bar chart in Fig. 3 presenting the area frequency also shows that in the case of the gray iron SL200 around 10% of the graphite particle area have the form factor value greater than 0.05 rising upto 0.16, and that this decreasing form factor is reverse proportional to the size grade of the graphite particle area. This means that the shape of the particle at small area sizes approaches an indistinct spherical shape of irregular nodules. Another important data is the maximum size of the circumscribed circle of the graphite particle in terms of its area. This is illustrated in Fig. 4 which shows two relationships, i.e.:

- the average form factor value versus the maximum cross-section size of the graphite particle,
- the particle area frequency (particles weighted according to the areas) versus the maximum cross-section size.

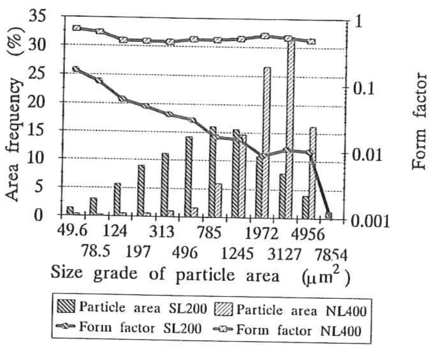


Figure 3. Form factor and area frequency versus graphite particle size grade.

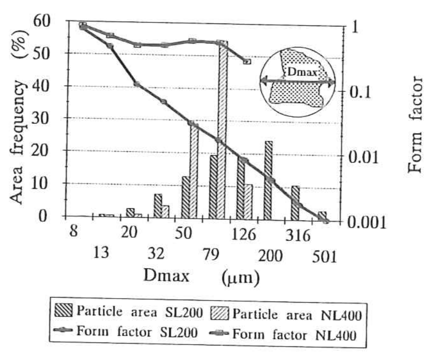
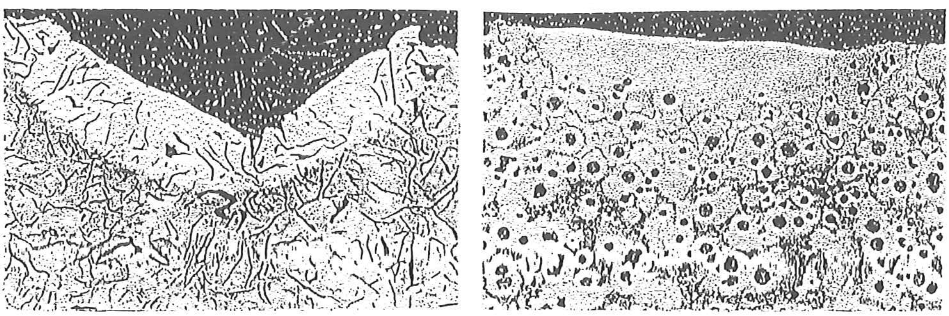


Figure 4. Form factor and area freqency variation versus maximum cross-section size of the graphite particle.

The maximum cross-section size of the particle is the diameter of the circle circumscribed to the particle in 2D. From the Fig. 4 we can see that the form factor of the ductile iron differs greatly from that of the gray iron. This confirms the findings about the form factor as shown in Fig. 3, i.e. that the form factor and thus the form of the graphite structure in the ductile iron NL400 does not change with the size of the maximum diameter of the graphite particle. On the other hand, in the gray iron, the form factor value depends on the maximum diameter of the graphite particle, the decreasing maximum size of the diameter causing an increase in the value of the form factor. At smaller maximum dimensions of the graphite (8 - 13 μm) we can find form factor value so large that they may even stand for the nodular form of the particles. An explanation for this can be found in studying the place where the flake is cut across. If the flake is cut somewhere on its edge or if only its peak is cut off, we get a shape that is not at all characteristic of this kind of microstructure. This becomes obvious at larger particle area sizes when almost all the observed particles display a form factor value close to the reference value for flake-shaped forms.

CONCLUSIONS

The proposed new form factor is a highly reliable method for recognizing and classifying graphite particles in ductile iron and gray iron matrices. Considering the graphite particle distribution in terms of their maximum diametre and shape, we can predict the behaviour of the material in laser heat treatment. The nodular shape of graphite has a very positive effect on heat conductivity whereas the shape of flakes when the latter have large dimensions hinders heat transfer into the inner layers of the material. Therefore, on the grounds of graphite particle statistical analysis and form factor measurements, it is possible to prescribe the right conditions for laser heat treatment of casts. An example confirming this fact is shown in Fig. 5.a from which we can see that in equal machining conditions the gray iron SL200 suffers an increased concentration of energy on the workpiece surface resulting in burning-off of the material. Thus we can say that, in the gray iron, a preferable microstructure is the one composed of small graphite flakes whereas in the ductile iron, the size of the graphite nodules does not exert any essential influence on heat conductivity and after hardening the desired shape of the surface profile is obtained as shown in Fig. 5.b.



a) gray iron SL200 b) ductile iron NL400
Figure5. Laser hardening by surface melting. P=500 W, v_b = 2 mm/s, z_s = 10 mm, magnification 40x.

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