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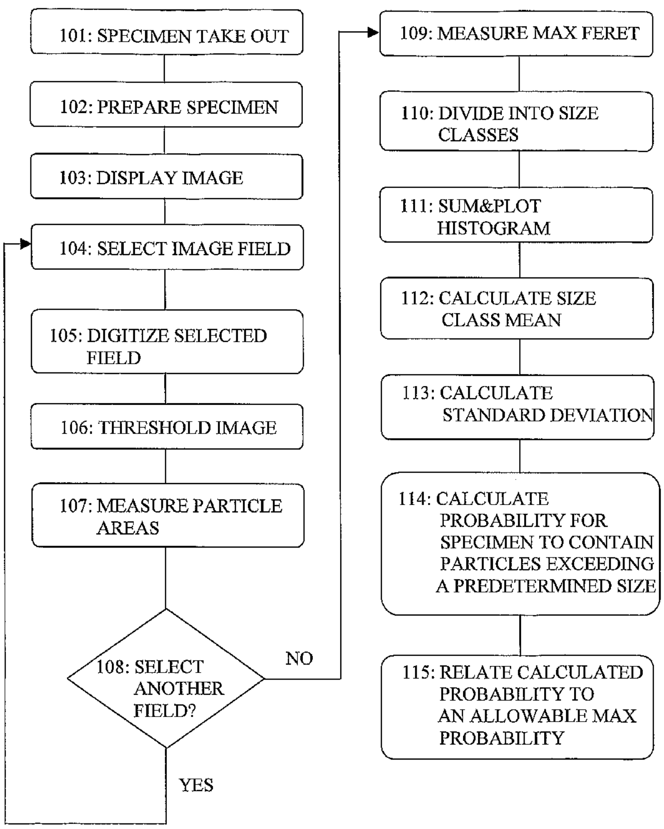
[Continued on next page]

(54) Title: METHOD OF CHARACTERIZING CAST IRON



(57) Abstract: In a method of characterizing cast iron with respect to its content of graphite particles, a specimen (1) of cast iron is metallographically prepared. An image of the microstructure of the specimen is displayed and fields of the image to be studied are selected. The selected fields are digitized and thresholded to obtain an image with distinguishable graphite particles, the area of which is measured. The maximum feret length is measured of the graphite particles having an area larger than a predetermined value. The measured graphite particles are divided into a number of feret length classes and the graphite particles of the same feret length class in all selected fields are summed. The feret length distribution of the graphite particles is calculated and from the calculated feret length distribution the probability for the specimen to contain graphite particles that are of a size that exceeds a predetermined size is calculated.

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METHOD OF CHARACTERIZING CAST IRON

TECHNICAL FIELD

The invention relates generally to the characterization of cast iron and more specifically to a method of characterizing cast iron with respect to its content of graphite particles. The invention also relates to a computer program product, a computer and a computer program for performing a part of the method.

BACKGROUND OF THE INVENTION

European Standard EN ISO 945:1994 specifies a method of designating the microstructure of graphite in cast iron.

According to the Standard, by visually examining iron-carbon alloys under a microscope, the graphite occurring in these alloys is classified by its form, its distribution and its size. The form, distribution and size of graphite particles observed by an operator are determined by comparison with reference images from the Standard and the same classification is allocated as that of the images that resembles them most closely.

A disadvantage of this method is that it is operator-dependant in that different operators, independent of their experience make different determinations when they compare the reference diagrams with what they see. Thus, there is a need of a more accurate method.

SUMMARY OF THE INVENTION

The object of the invention is to bring about a method of characterizing cast iron that is operator-independent and thereby more accurate.

This is attained by the method according to the invention of characterizing cast iron with respect to its content of graphite particles, comprising metallographically preparing a specimen of cast iron, displaying an image of the microstructure of the specimen, selecting at least one field of the image to be studied, digitizing the selected at least one field, thresholding each selected field to obtain an image with distinguishable graphite particles, measuring the area of a plurality of graphite particles in the respective selected field, measuring a maximum feret length of the measured graphite particles having an area larger than a predetermined value in the respective selected field, dividing the graphite particles for which the maximum feret length has been measured into a number of feret length classes, summing the number of graphite particles in the same feret length class in all selected fields, calculating the feret length distribution of the graphite particles, and calculating from the calculated feret length distribution the probability for the specimen to contain graphite particles that are of a size that exceeds a predetermined size.

In that the method according to the invention is operator-independent, it is more accurate than known methods. At the same time, the method according to the invention is less time consuming than previous methods. Furthermore, based on the calculated feret length distribution and the calculated probability the operator can estimate e.g. the existence of large graphite particles in the specimen without having actually seen any of those large graphite particles in any of the selected fields. This helps the operator to improve the characterization of the cast iron.

The invention also relates to a computer program for characterizing a metallographically prepared specimen of cast iron with respect to its content of graphite particles. The computer program comprises computer useable code means for causing a computer to

- display an image of the microstructure of the specimen,
- digitize at least one selected field,
- threshold each selected field to obtain an image with distinguishable graphite particles,
- measure the area of a plurality of graphite particles in the respective selected field,
- measure a maximum feret length of the measured graphite particles having an area larger than a predetermined value in the respective selected field,
- divide the graphite particles for which the maximum feret length has been measured into a number of feret length classes,
- sum the number of graphite particles in the same feret length class in all selected fields,
- calculate the feret length distribution of the graphite particles, and

- calculate from the calculated feret length distribution, the probability for the specimen to contain graphite particles that are of a size that exceeds a predetermined size.

The feret length distribution of the graphite particles may be calculated by feret length class mean value and its standard deviation.

Furthermore the invention relates to a computer program product comprising a computer readable medium and the computer program, wherein the computer program is comprised in the computer readable medium.

Moreover the invention relates to a computer for characterizing a metallographically prepared specimen of cast iron with respect to its content of graphite particles. The computer comprises a processing unit, a storage unit, the computer program comprised in the storage unit and means adapted for communication with an image generating means and an image display unit.

BRIEF DESCRIPTION OF THE DRAWING

The invention will be described more in detail below with reference to the appended drawing on which Fig. 1 is a flow diagram illustrating an embodiment of the method according to the invention of characterizing cast iron, Fig. 2 is a schematic illustration of a setup for implementation of the method according to the invention, Fig. 3 is a schematic illustration of an embodiment of a computer to be used in the setup in Fig. 2, Fig. 4 shows the typical microstructure of a specimen of grey iron with graphite flakes to be characterized, Fig. 5 illustrates how maximum feret length is defined for a graphite particle, and Fig. 6 is an exemplary diagram illustrating the length distribution of graphite particles in a specimen of grey iron.

DESCRIPTION OF THE INVENTION

Fig. 1 is a flow diagram illustrating steps of an embodiment of the method according to the invention of characterizing cast iron with respect to its content of graphite particles.

In Step 101, a specimen of a casting, e.g. a cylinder block, is taken. When taking a specimen, it is essential that attention be paid to the location, to the wall thickness, to the distance from the surface and to the presence of chills, shrinkage, slag and the like.

In Step 102, the specimen is metallographically prepared. This involves grinding and polishing of the specimen down to a 3 μm diamond grinding paste in order that the graphite particles appear in their true form and size.

In Step 103, an image of the microstructure of the specimen is displayed on a display unit. The image can be produced at a magnification of 100 times by a microscope with a video camera connected to a video display unit connected to a computer having a computer program for image analysis.

In Step 104, a field to be studied of the image of the microstructure of the specimen is according to one embodiment carefully selected manually by an operator. According to another embodiment the field to be studied is selected by the computer through the computer program.

In Step 105, the selected field of the image of the microstructure is digitized in order to obtain a digital version thereof that can be processed by the computer through the computer program.

In Step 106, in order to make the graphite particles of the specimen distinguishable, the digitized image field is thresholded at a predetermined level. By thresholding is to be understood that the digitized image field is converted to just two colors, e.g. a black-and-white image, where black represents the graphite particles of the specimen.

If a color video camera is used to display the image of the specimen, thresholding would involve converting the digitized image field to two different colors, one of which would represent the graphite particles.

In Step 107, the area of each graphite particle in the selected field is measured.

In Step 108, the computer program queries whether or not another field to be studied of the image of the microstructure of the specimen is to be selected.

If the answer in Step 108 is YES, Steps 104, 105, 106 and 107 will be repeated.

If the answer in Step 108 is NO, the method according to the invention will continue with Step 109.

In Step 109, the maximum feret length of each graphite particle that has an area that is larger than a predetermined value in the respective selected field is measured. By maximum feret length is meant the maximum linear distance within one and the same graphite particle or the logest side of a projected rectangular frame that precisely surround the graphite particle. The predetermined value of the area can be set to e.g. 80 μm^2. In that case, the maximum feret length will be measured only for graphite particles having an area $\geq 80\ \mu m^2$.

In Step 110, the measured graphite particles are divided into a number of feret length classes. The number of feret length classes can be selected to be e.g. eight, e.g. according to the European Standard EN ISO 945:1994.

In Step 111, the number of graphite particles within the respective feret length class is summed and a histogram is plotted.

In Step 112, the size class mean value (i.e. the feret length class mean value) of the feret length classes is calculated. The size class mean value shall be interpreted as a weighted mean value of the feret length classes, where each value contributed by each feret length class is dependent on the number of the feret length class itself and the number of measured graphite particles in that class. See below for a mathematical definition of the size class mean value.

In Step 113, supposing that the feret length classes are normal distributed the standard deviation of the distribution is calculated.

In Step 114, from the calculated standard deviation and the feret length class mean value, the probability for the specimen to contain graphite particles of a size class that exceeds a predetermined size class is calculated.

In Step 115, the calculated probability for the specimen to contain graphite particles of a size class that exceeds the predetermined size class is related to an allowable maximum probability of the graphite particle size class for the casting in question.

Occasional large graphite particles are more detrimental to the strength of the casting than a number of smaller graphite particles.

Fig. 2 is a schematic illustration of a typical known setup for implementing the method according to the invention of characterizing cast iron with respect to its content of graphite particles.

In Fig. 2, 1 denotes a metallographically prepared a specimen of cast iron to be characterized. The specimen 1 is viewed by a combined microscope/video camera 2 that is connected via a so-called frame grabber 3 to a video display unit 4 connected to a computer 5 having a computer program for image analysis and calculations. The frame grabber 3 digitizes images, i.e. converts analogue images to digital images, upon request.

Fig. 3 is a schematic illustration of an embodiment of the computer 5 in Fig. 2.

The computer 5 comprises a central processing unit (CPU) 51 that is connected via a first bus 52 to a computer readable medium in the form of a storage unit 53. The storage unit 53 can be a hard disk, a flash memory, a ROM or any other computer readable computer program product. A computer program 54 for image analysis and calculations is installed in the storage unit 53.

The CPU 51 in Fig. 3 is connected to a port 55 via a second bus 56 for communication with an image generating unit, i.e. the combined microscope/video camera 2 in Fig. 2, and to a port 57 via a third bus 58 for communication with an image display unit, i.e. the video display unit 4 in Fig. 2. Although not shown, the computer 5 may comprise other ports adapted for connection with e.g. a pointing device and a keyboard.

Fig. 4 is a typical image of the microstructure of a specimen of grey iron with graphite flakes to be characterized by means of the setup in Fig. 2 in accordance with the method according to the invention described in connection with Fig. 1.

Fig. 5 illustrates how maximum feret length, Fmax, is defined for a graphite particle.

Fig. 6 is an exemplary diagram illustrating the distribution of graphite flakes in a specimen of cast iron. In Fig. 6, the X-axis represents the size or feret length of the graphite flakes divided into eight size classes according to the European Standard EN ISO 945:1994 mentioned above in the introductory portion, the left-hand Y-axis represents the number of graphite flakes in the respective size class, i.e. the respective shaded bars, and the right-hand Y-axis represents the normal frequency distribution function

$$f_x(GC) = \frac{1}{s \cdot \sqrt{2 \cdot \pi}} \cdot e^{-(GC-\bar{x})^2 / (2 \cdot s^2)} ,$$

where GC corresponds to the graphite size class number, i.e. the feret length class, while $\bar{x}$ and s are the feret length class mean value and the standard deviation, respectively.

The latter two parameters can be calculated as follows:

$$\bar{x} = \frac{1}{n} \sum_{0}^{k} (f_i \cdot y_i),$$

$$s = \sqrt{\frac{S}{(n-1)}}$$

, where the square sum around the arithmetic mean value

$$S = \sum_{0}^{k} f_i \cdot y_i^{2} - \frac{1}{n}\left(\sum_{0}^{k} f_i \cdot y_i\right)^2 .$$

In the above equations, n is the total number of measured graphite flakes, f_i is the number of graphite flakes in class i, and y_i represents the class mean equal to size class (i.e. feret length class) in this case. In the embodiment of the method according to the invention described above, the number of feret length classes is eight. Thus, in this case $k = 7$.

CLAIMS

1. A method of characterizing cast iron with respect to its content of graphite particles, comprising

- metallographically preparing a specimen (1) of cast iron,
- displaying an image of the microstructure of the specimen (1),
- selecting at least one field of the image to be studied,
- digitizing the selected at least one field,
- thresholding each selected field to obtain an image with distinguishable graphite particles,
- measuring the area of a plurality of graphite particles in the respective selected field,
- measuring a maximum feret length of the measured graphite particles having an area larger than a predetermined value in the respective selected field,
- dividing the graphite particles for which the maximum feret length has been measured into a number of feret length classes,
- summing the number of graphite particles in the same feret length class in all selected fields, **characterized by**
- calculating the feret length distribution of the graphite particles, and
- calculating from the calculated feret length distribution the probability for the specimen (1) to contain graphite particles that are of a size that exceeds a predetermined size.

2. The method according to claim 1, **characterized in** that the feret length distribution of the graphite particles is calculated by feret length class mean value and its standard deviation.

3. A computer program (54) for characterizing a metallographically prepared specimen (1) of cast iron with respect to its content of graphite particles, comprising computer useable code means for causing a computer (5) to

- display an image of the microstructure of the specimen,
- digitize at least one selected field,
- threshold each selected field to obtain an image with distinguishable graphite particles,

- measure the area of a plurality of graphite particles in the respective selected field,
- measure a maximum feret length of the measured graphite particles having an area larger than a predetermined value in the respective selected field,
- divide the graphite particles for which the maximum feret length has been measured into a number of feret length classes,
- sum the number of graphite particles in the same feret length class in all selected fields,

characterized by computer useable code means for causing the computer (5) to
- calculate the feret length distribution of the graphite particles, and
- calculate from the calculated feret length distribution, the probability for the specimen (1) to contain graphite particles that are of a size that exceeds a predetermined size.

4. The computer program (54) according to claim 3, **characterized in** that the feret length distribution of the graphite particles is calculated by feret length class mean value and its standard deviation.

5. A computer program product (53) comprising a computer readable medium and a computer program (54) according to claim 3, wherein the computer program (54) is comprised in the computer readable medium.

6. A computer (5) for characterizing a metallographically prepared specimen of cast iron with respect to its content of graphite particles, comprising a processing unit (51), a storage unit, a computer program (54) according to claim 3 comprised in the storage unit and means adapted for communication with an image generating means and an image display unit (4).

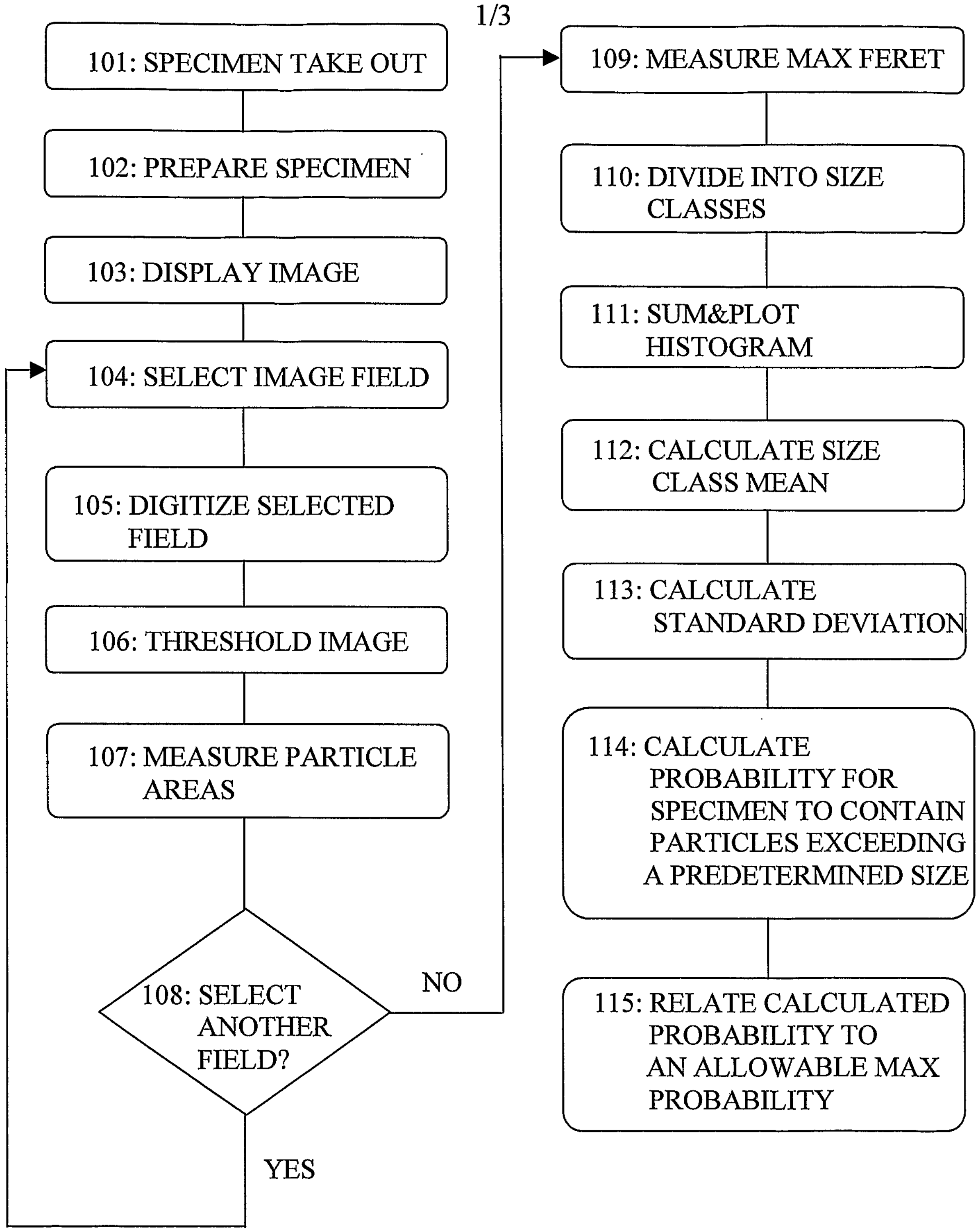
101: SPECIMEN TAKE OUT
102: PREPARE SPECIMEN
103: DISPLAY IMAGE
104: SELECT IMAGE FIELD
105: DIGITIZE SELECTED FIELD
106: THRESHOLD IMAGE
107: MEASURE PARTICLE AREAS
108: SELECT ANOTHER FIELD?
NO
YES
109: MEASURE MAX FERET
110: DIVIDE INTO SIZE CLASSES
111: SUM&PLOT HISTOGRAM
112: CALCULATE SIZE CLASS MEAN
113: CALCULATE STANDARD DEVIATION
114: CALCULATE PROBABILITY FOR SPECIMEN TO CONTAIN PARTICLES EXCEEDING A PREDETERMINED SIZE
115: RELATE CALCULATED PROBABILITY TO AN ALLOWABLE MAX PROBABILITY

Fig. 1

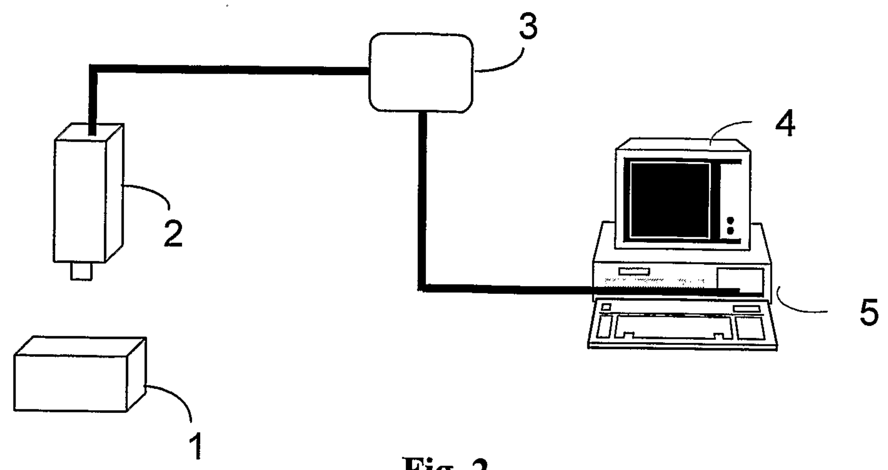

Fig. 2

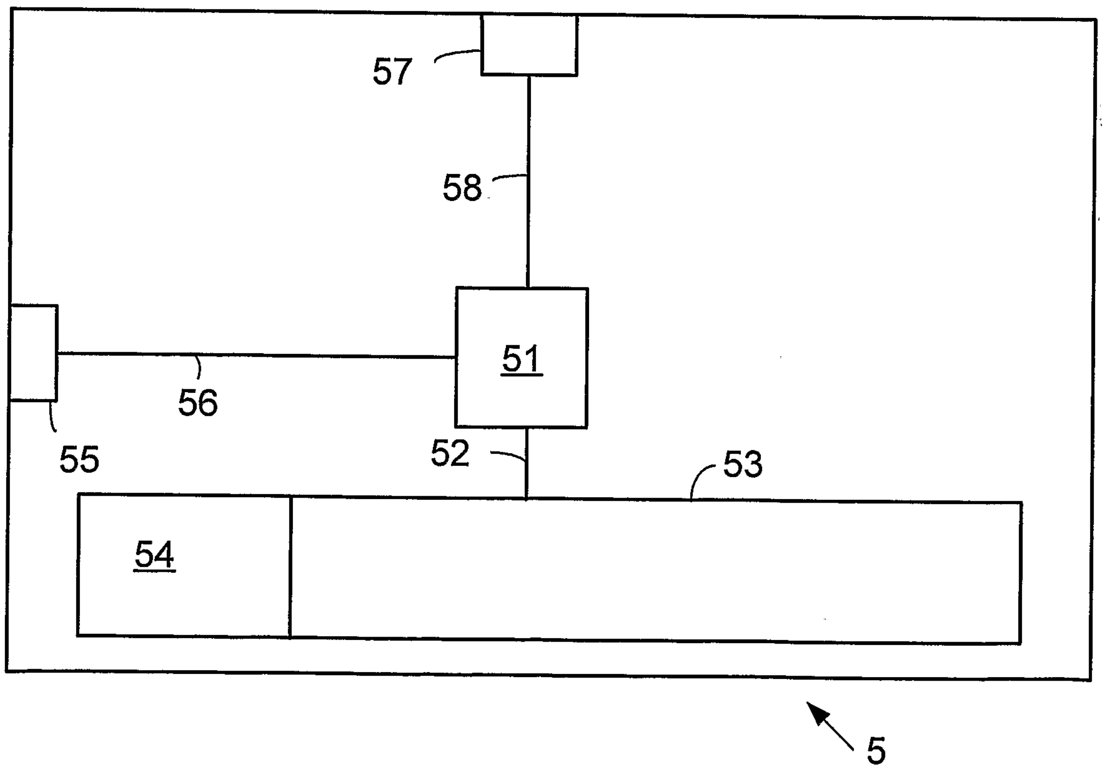

Fig. 3

Fig. 4

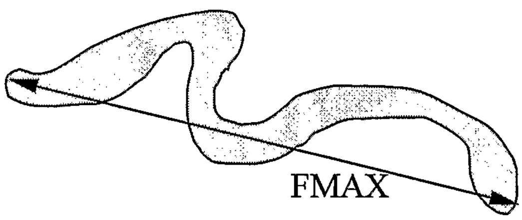

Fig. 5

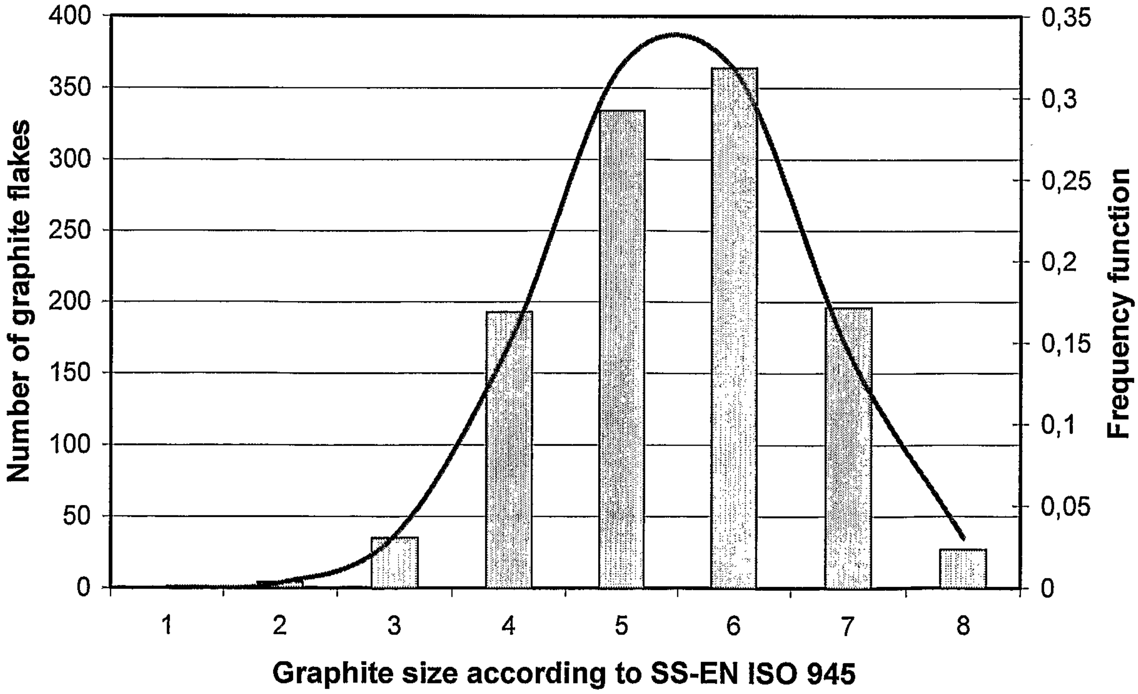

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 2004/001116

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G06T 7/00, G06M 11/00, G01N 15/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G06T, G06M, G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Bildanalys av gjutjärn, Roya Khomand, Uppsala Master´s thesis in Computer science Examensarbete MN3, 2002-10-26, ISSN 1100-1836, p 1-62, http://www.csd.uu.se, see the whole document --	1-6
A	"Statistics", Alexander M. Mood, in AcessScience@McGraw-Hill, http://www. accessscience.com, D01 10.1036/1097-8542.652400, last modified: July 15, 2002. See the whole document --	1-6
A	US 3887764 A (JOHN MICHAEL GIBBONS ET AL), 3 June 1975 (03.06.1975), abstract --	1-6

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 October 2004	19 -10- 2004
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Mats Raidla/Els Telephone No. +46 8 782 25 00

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4829374 A (SEIICHI MIYAMOTO ET AL), 9 May 1989 (09.05.1989), abstract -- --------	1-6

US	3887764	A	03/06/1975	DE	2222340	A	16/11/1972
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				JP	63127148	A	31/05/1988