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(54) **Prediction system for the graphitization index in specific areas of vermicular graphitic cast iron pieces**

(57) The method for predicting the degree of vermicularity (%) of pieces of vermicular graphite cast iron of the present invention specifically predicts the degree of

vermicularity in any specific area of any piece in a cluster of pieces that are simultaneously cast into a mold, in which the treatment of the metal has been carried out by the addition of Ce or Mg (with or without the addition of Ti).

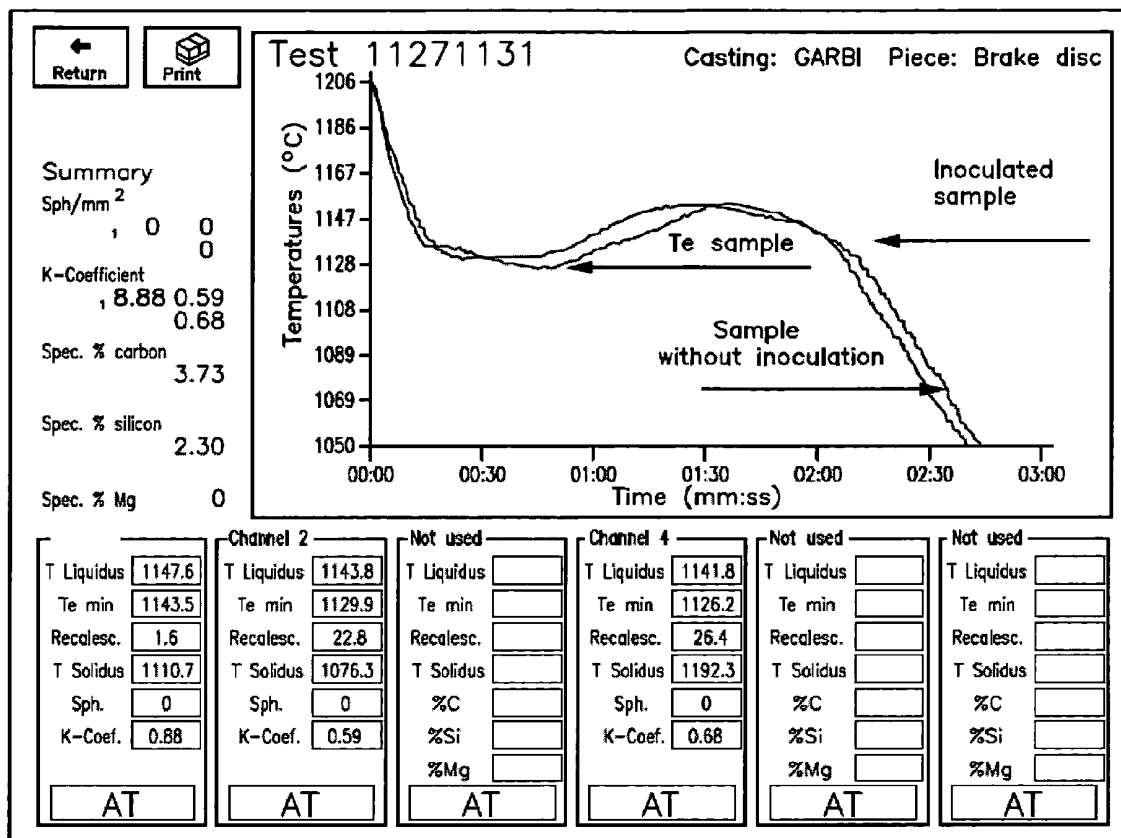


Fig. 1

DescriptionState of the Art

[0001] The characteristics of a cast iron do not depend only on its chemical composition, but also on its production process, both being factors which determine the shape in which the carbon present (combined, lamellar, spheroidal, compact, etc.) precipitates out during the solidification process.

[0002] The shape of the graphite defines the mechanical behavior of cast iron. In graphite cast irons, most of what is produced is spheroidal graphite cast iron and lamellar graphite cast iron, in which the graphites precipitate out in spheroidal and lamellar shapes, respectively. The suitable material for manufacture is chosen depending on the features that the pieces must comply with and taking into account economic factors. Nevertheless, the properties of the material also depend on the perlite/ferrite ratio of the matrix structure.

[0003] The pieces made of vermicular graphite cast iron (VGI) cover an intermediate field between the properties offered by the pieces of the aforementioned types produced.

[0004] Thus, compared to cast iron lamellar, the vermicular graphite cast iron has greater ductility and tensile strength, whereas compared to spheroidal cast iron, vermicular graphite cast iron has greater thermal conductivity, a better response to vibration and thermal shocks, as well as a lower shrinkage tendency during cooling.

[0005] In accordance with the stipulations of the ISO 16112 standard, type III (compact), IV - V (intermediate) and VI (spheroidal) graphites, as they are classified in ISO 945, can coexist in VGI.

[0006] The percentage of vermicular graphite or degree of vermicularity in the metal produced, hereinafter referred to as CGMet(%), is established by the proportion of each of these groups of graphite. The determination of this percentage is what offers a clear idea about the mechanical properties of the material.

[0007] Taking into account that each of the factors influencing the degree of vermicularity is the cooling rate of the metal during its solidification process, hereinafter referred to as CGMod(%) when the factors influencing the cooling rate, i.e., the thermal modulus, are taken into account in the calculation of the percentage of vermicular graphite.

[0008] Different patents use the thermal analysis (TA) technique and the cooling curves of the molten metal to obtain information relating to the CGMet(%) and distribution of the precipitated graphites:

[0009] WO9206809 describes a method for knowing the amount of modifying agent that must be added to the liquid metal to obtain the desired structure. Patent uses two cooling curves recorded by means of thermocouples located in the thermal center and in the outer area in a metal sample obtained of the cast iron to be treated.

[0010] Patent EP0327237 describes a method in which a sample of cast iron treated with Mg is poured into a vessel containing a certain amount of Te and S or Se. If the active Mg in the cast iron is less than the amount that can be neutralized by the additions of S and Se, the presence of Te will force carbidic solidification. If there is a larger amount of active Mg than that with which the additions S and Se are neutralized, the solidification of the metal will be graphitic despite the presence of the Te.

[0011] EP0327237 furthermore indicates that by means of thermal testing in cups with different amounts of additions of S and Se, the Mg content necessary for the production of vermicular graphite cast iron can be controlled.

[0012] Patent WO9825133 describes a method for predicting the microstructure in which a graphite cast iron will solidify, by means of cooling curves, without referring to the different CGMod(%) that may occur in one and the same piece as a consequence of the different cooling rates occurring therein.

[0013] Patent Ru2337973C2 explains a system for obtaining spheroidal and vermicular cast iron, for single pieces or large-scale production by means of controlling the process depending on the amount of liquid metal to be used, the concentration of sulphur and oxygen and the time of the process.

[0014] Patent WO2007017350 relates to a process for obtaining cast iron with vermicular graphite with high operational security. For that purpose, a magnesium treatment alloy composed of magnesium and another metal (to the exclusion of silicon) is added according to the invention to an iron melt with a sulphur content of less than 0.05% by weight kept in a treatment vessel in an inert atmosphere, until the magnesium content of the iron melt amounts to 0.005-0.018 % by weight.

[0015] Patent US6544359 describes a system for obtaining objects of vermicular cast iron from a cast iron melt with a carbon content at the desired final level and a silicon content below the desired final value, by means of adding magnesium compounds, for the purpose of regulating the amount of oxygen in the material.

[0016] In any case, none of these processes is able to predict the behavior of the material in specific areas of the piece. The result is always given in a generic manner without taking into consideration the particular geometric or functional characteristics of the pieces produced.

[0017] The patents available, therefore, are not able to predict the behavior that the material produced has in very specific portions, and what factors such as the thickness or high mechanical stressing, can be starting points of fracturing.

[0018] Therefore, an important step forward is provided in the invention described below as it offers information about the resulting CGMod(%) in specific portions of a piece as a result of studying data obtained from the thermal analysis

(TA) of the treated metal and the thermal modulus of the areas of the controlled piece.

[0019] Furthermore, none of the previously described processes offers the possibility of obtaining a melt of the piece in which a specific area thereof has the desired percentage of vermicular graphite, as will be possible by means of the use of the present invention.

[0020] The invention furthermore includes the opportunity to enter the necessary calculations in a metallurgical quality management program, the result thus being obtained in a simple and automated manner.

General Description of the Invention

[0021] The present document describes a system for the control, in real time, of the percentage of vermicular graphite with which specific areas of pieces made of vermicular graphite cast iron will solidify.

[0022] An important step forward is provided with this invention as the system can be applied to those specific areas of the pieces which, due to greater mechanical requirements or smaller thicknesses, are more exposed to being critical.

[0023] To that end, when providing the prediction, the system herein described takes into consideration the effect of at least two factors: the metallurgical quality and the cooling rate with which pieces solidify.

[0024] The control of the metallurgical quality is carried out by means of thermal analysis and the subsequent treatment of the cooling curves recorded on an inoculated sample, a sample without inoculation and a sample with the addition of tellurium.

[0025] The cooling rate is included in the calculations by means of the parameter: inverse modulo. Its calculation is possible by means of applying reverse engineering. This parameter includes in its calculation all those factors influencing the rate at which the pieces cool.

Prediction of the percentage of vermicular graphite in the metal (CGMet)

[0026] Any agent which is added to the metal when it is in its liquid state and its purpose is to force the precipitation of the carbon in any of the previously mentioned shapes according to the ISO 945 standard is called a modifying agent. Ce, Mg and Ti have traditionally been used as modifying agents. The first two are added for the purpose of forcing the precipitation of the graphite in any of types III to IV, whereas the third agent is added to control the modifying effect of the aforementioned agents.

[0027] A neutralizing agent is that agent which is combined with the modifying agents added, preventing their modifying action.

[0028] The study of the cooling curves and of the thermal parameters recorded on samples of standard thermal analysis offers reliable information about the shape in which the graphites precipitate out and, accordingly, about the future in mechanical behavior of the material.

[0029] The prediction of CGMet(%), the datum referring to the state in which the treated metal will solidify, is done by means of the study of the thermal analysis cooling curves recorded on inoculated samples, samples without inoculation and samples with the addition of tellurium (Figure 1). The equation is generically expressed as follows:

$$CGMet(\%) = f(\text{Thermal parameters recorded in the TA samples})$$

[0030] The value given indicates the proportion of graphites in one mm² of sample and of types III, IV and V according to ISO 945 standard, compared to the total number of graphite particles formed for the inoculated sample for thermal analysis.

Prediction of the percentage of vermicular graphite in specific areas of a piece (CGMod)

[0031] The proposed method uses the thermal modulus (Mt) concept for predicting the CGMod(%) in specific portions of a piece. This parameter, associated with the cooling rate, is obtained by means of classic methodology as the ratio between the volume of metal and the surfaces thereof that are able to remove heat.

[0032] In isolated systems in which there are no factors influencing the cooling and solidification process other than the actual geometry of the piece, it is possible to establish a direct relationship between the CGMet(%) of the material and the Mt of the pieces (Figure 2).

[0033] The equation is written as follows:

$$CGMod(\%)' = f(Mt, CGMet(\%))$$

where M_t is the thermal modulus (cm) of the studied area and $CGMet(\%)$ is the prediction of the percentage of vermicular graphite in the metal.

[0034] However, the actual cooling conditions of a piece do not correspond with those described for an isolated system, so it is necessary to define a new concept, such as that the inverse modulo (M_i). This concept is associated with the cooling rate of the piece, external influence factors, such as coolants, molding variables, location of the piece in the mold, proximity of other pieces, etc., being included therein.

[0035] The calculation of M_i is carried out from the actual $CGMod(\%)$ measured by means of metallographic inspections and the $CGMet(\%)$ value according to the following methodology:

- 1.- The thermal modulus (M_t) is calculated by means of the classic methodology.
- 2.- A general percentage of vermicular graphite of the metal, $CGMet(\%)$, is obtained depending on the data obtained by thermal analysis and the previous M_t .
- 3.- The actual $CGMod(\%)$ value is determined by means of metallographic analysis.
- 4.- The inverse modulo is calculated according to the $CGMet(\%)$ and $CGMod(\%)$ values obtained in the previous steps.

[0036] The metallographic analysis carried out in step 3 above is based on an image analysis program which, for each area of a piece intended to be studied, obtains five micrographs magnified 100 times. The existing graphite particles are sub-divided into groups according to the shape factor to which they belong. The final value obtained for the percentage of vermicular graphite by means of metallographic inspection is given as the average value obtained from the 5 measurements taken.

[0037] This value of the inverse modulo (M_i) is calculated for various qualities, i.e. for different vermicular graphite density values, so the value which is finally obtained is a mean value of those obtained in all the tests. It can generally be stated that there is little difference among the values obtained.

[0038] Finally, M_t is replaced in the preceding equation with M_i , and the definitive expression for the calculation of the percentage of vermicular graphite of the sample is as follows:

$$CGMod(\%) = f(M_i, CGMet(\%))$$

[0039] Therefore, the huge advancement of the described system is based on the possibility of obtaining actual information about the degree of vermicularity in specific portions of the pieces. The control of those areas intended for greater wear, mechanical requirements, etc., can thus be assured, more useful and accurate information than that which is offered by the other available methods thus being obtained.

[0040] Furthermore, the possibility that lamellar graphites are formed, which is very important since their appearance, even though minor or in isolated cells, causes a drastic reduction of the mechanical properties of fracture load or elongation in the material, is very reliably predicted by means of the proposed system.

[0041] The importance of preventing the formation of lamellar graphites can be found in the fact that the designers of pieces determine the minimum thicknesses thereof based on the mechanical properties inherent to the material in which they will be manufactured. When pieces are made of vermicular graphite cast iron, the formation of lamellar graphites causes a reduction in the tensile strength of the material, whereby risking a fracture of the piece while it is functioning.

[0042] The method has demonstrated its effectiveness for the control of the processes in which the spheroidization treatments have been carried out by means of additions of Ce or Mg (with or without the addition of Ti).

Description of the Drawings

[0043]

Figure 1 shows a recording of the cooling curves and solidification in an inoculated sample, sample without inoculation and sample with the addition of tellurium.

Figure 2 shows the influence of the thermal modulus (M_t , in cm) on the percentage of vermicular graphite (%).

Figure 3 shows a brake disc for a wind generator controlled in practical case 1.

Figure 4 shows selected control areas in the turbo manifold used in practical case 2

Detailed Description of Particular Embodiments

[0044] Two examples of applying the method for predicting the percentage of vermicular graphite in specific areas of

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pieces made of vermicular graphite cast iron (CGMod(%)) are described below.

Case 1. Manufacture of brake discs for wind generators of VGI and ferrite matrix.

5 **[0045]** Figure 3 shows an image of the brake disc in which the areas to be controlled are indicated.

[0046] The steps that must be followed for applying the predictive method are:

(1) Definition of the areas to be controlled.

10 Area 1: Area where it is fixed with the shaft.
Area 2: Area of the brake track.

(2) Determination of the thermal modulus (Mt) of the areas defined in step 1 according to the classic methodology.

15 Area 1: Mt = 2.20 cm.

Area 2: Mt = 1.35 cm.

(3) Determination of the inverse modulo (Mi) of the areas defined in step 1 according to the previously described methodology.

20 Area 1: Mi = 2.24 cm.

25 Area 2: Mi = 1.32 cm.

(4) TA test on an inoculated sample, sample without inoculation and sample with the addition of tellurium
The CGMet(%) is generically calculated for the treated and inoculated metal from the results obtained in this test.

30 Area 1 and 2: CGMet(%) = 59

(5) Calculation of CGMod(%) for each selected area from the results obtained in steps 3 and 4.

35 Area 1. CGMod1(%) = 88

Area 2. CGMod2(%) = 73

Case 2. Manufacture of turbo manifolds for automobiles of VGI and SiMo quality.

[0047] Figure 4 shows an image of the turbo manifold in which the areas to be controlled are indicated.

40 **[0048]** The steps which must be followed for applying the predictive method are:

(1) Definition of the areas to be controlled.

45 Area 1: Area of the turbine.
Area 2: Manifold mouths.

(2) Determination of the thermal modulus (Mt) of the areas defined in step 1 according to the classic methodology.

50 Area 1: Mt = 0.53 cm.

Area 2: Mt = 0.40 cm.

(3) Determination of the inverse modulo (Mi) of the areas defined in step 1 according to the previously described methodology.

55 Area 1: Mi = 0.55 cm.

Area 2: Mi = 0.43 cm.

(4) TA test on an inoculated sample, sample without inoculation and sample with the addition of tellurium.

The CGMet(%) is generically calculated for the treated and inoculated metal from the results obtained in this test.

Area 1 and 2: CGMet(%) = 93

(5) Calculation of CGMod(%) for each selected area from the results obtained in steps 3 and 4.

Area 1. CGMod1(%) = 76

Area 2. CGMod2(%) = 65

Claims

1. A method for predicting the degree of vermicularity (%) of pieces of vermicular graphite cast iron, **characterized in that** it specifically predicts the degree of vermicularity in any specific area of any piece in a cluster of pieces that are simultaneously cast into a mold, in which the treatment of the metal has been carried out by the addition of Ce or Mg (with or without the addition of Ti).
2. The method for predicting the degree of vermicularity of pieces of vermicular graphite cast iron according to claim 1, as a function of the solidification conditions of the cluster and as a function of the specific inverse modulo of the area of the piece in question; the inverse modulo being determined from conventional predictions of the degree of vermicularity by thermal analysis and actual measurements of the degree of vermicularity in already melted pieces.
3. The method for predicting the degree of vermicularity of pieces of vermicular graphite cast iron according to claims 1 and 2, **characterized in that** it comprises a) determining the thermal modulus of each area of the piece by means of conventional methodology, b) predicting the degree of vermicularity in each area of the piece by means of conventional thermal analysis tools based on the thermal modulus of each area, c) determining the actual number of the degree of vermicularity by means of direct metallographic analysis of each area, d) calculating an inverse modulo according to the metallurgical quality, e) predicting the degree of vermicularity in each area of the piece by means of conventional thermal analysis tools based on the inverse modulo of each area.

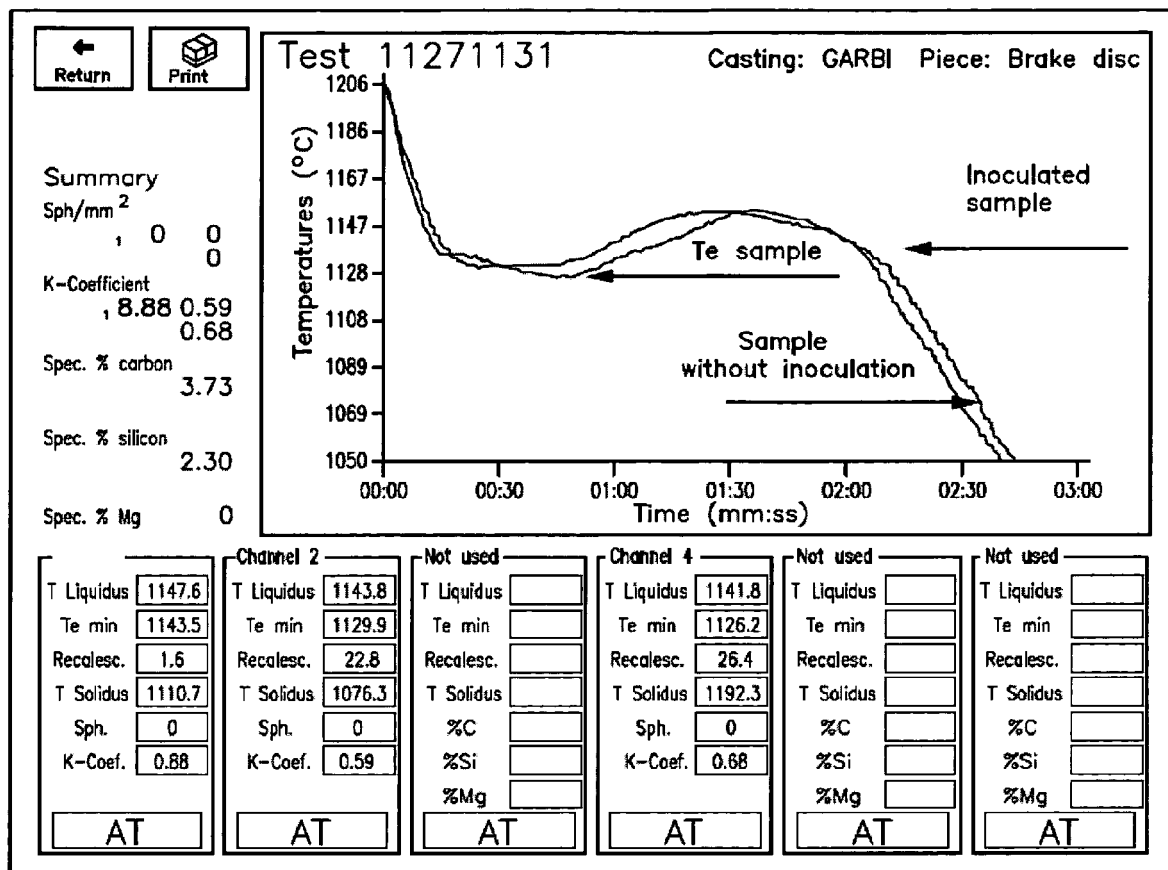


Fig. 1

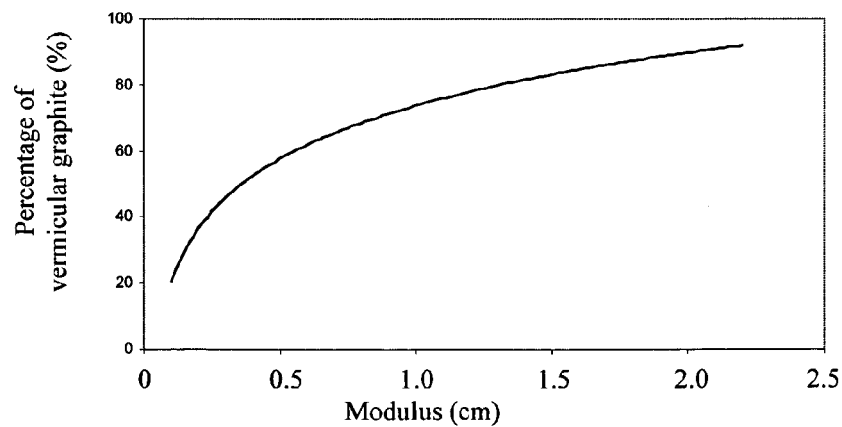


Fig. 2

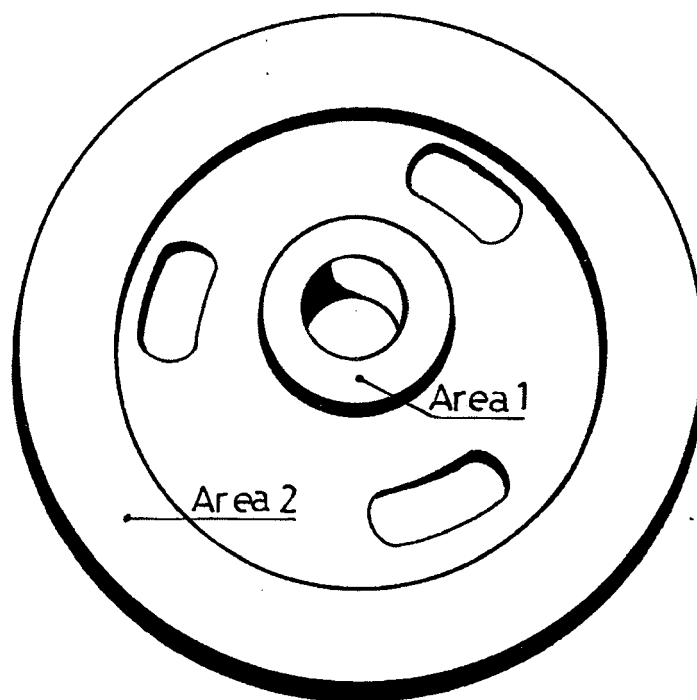
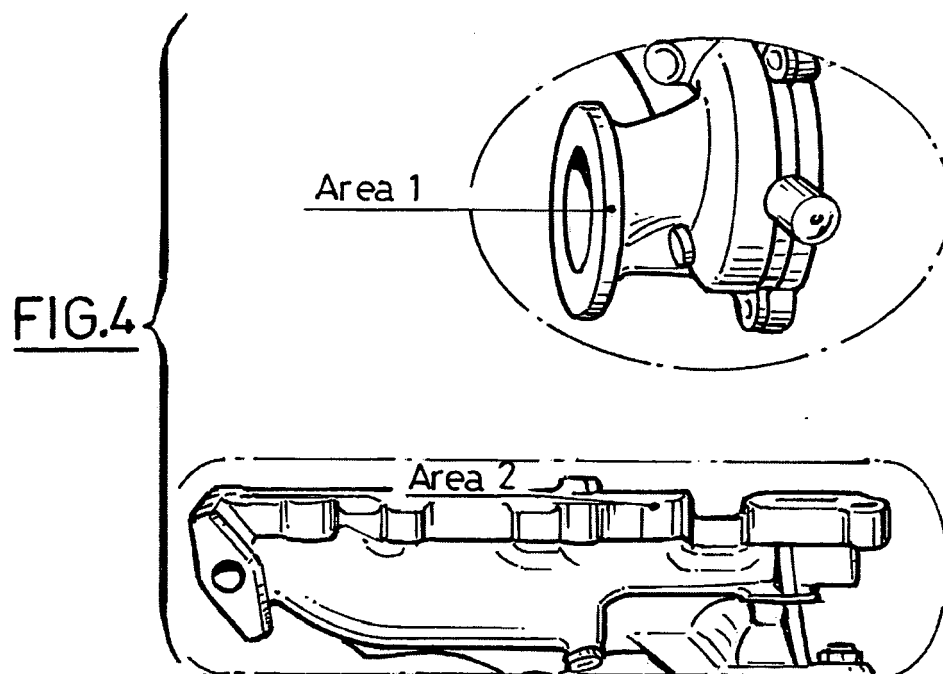


FIG. 3





EUROPEAN SEARCH REPORT

Application Number
EP 09 38 0173

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 6 354 356 B1 (HIRAOKA HIDETAKA [JP] ET AL) 12 March 2002 (2002-03-12) * claim 1; figures 1,5,6 * -----	1-3	INV. C21C1/10 C21C5/46 B22D2/00 G01N33/20
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 2 March 2010	Examiner Juhart, Matjaz
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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