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(54) **Manufacturing process of spheroidal castings**

(57) The present invention relates to a process for manufacturing spheroidal castings by using metal or permanent molds. The resulting mechanical properties of

the new parts are considered of great interest due to, among other reasons, the large number of graphite spheroids obtained in the parts.

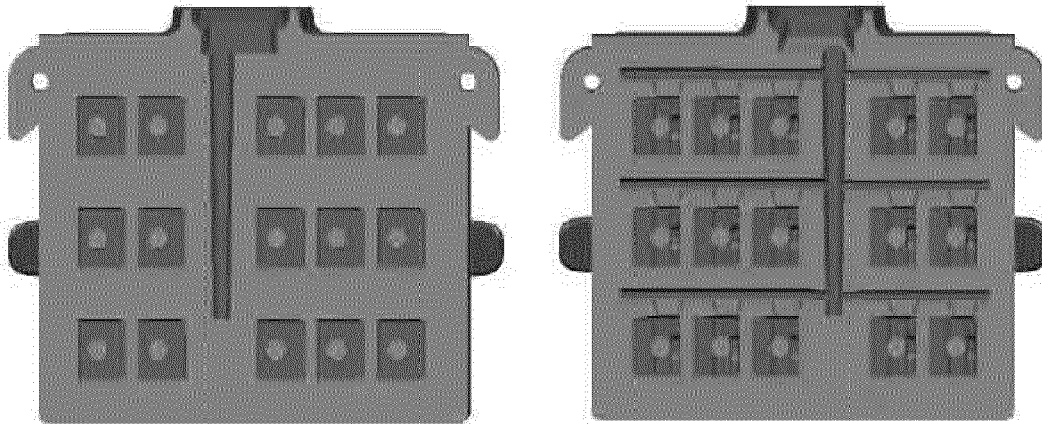


Fig. 1

Description

[0001] The present invention relates to a process for the manufacturing of spheroidal castings by using metal or permanent molds. The resulting mechanical properties of the new parts are considered of great interest due to, among other things, the large number of graphite spheroids obtained in the parts.

PRIOR STATE OF THE ART

[0002] The manufacturing of iron castings is mainly oriented to achieve economically competitive and metallic materials with suitable properties for the functionality of the components designed. In the latter case, part of current research efforts is directed towards obtaining graphite castings with optimized properties. The purpose of these "new cast materials" focuses on providing a more economical alternative to the use of steel or other special alloys for the manufacturing of high-performance parts.

[0003] Within the field of cast iron with precipitated graphite, spheroidal casting constitutes one of the materials that have been most widely used since its discovery in the 1950s. Compared to laminar or grey casting, the formation and subsequent growth of graphites in spheroidal form leads to significant increases in the break loads, the elastic limits, and, especially, in the elongations of the material. An adequate combination of these three mechanical properties entails the obtaining of materials with a wide range of technological applications.

[0004] Moreover, the massive formation of graphite spheroids inside the metal matrix has even more interesting consequences. Under these conditions, the diffusion of carbon atoms [M. Wessén, I. Svensson, Metall. Mat. Trans. A, A27, 1996, 2209-2220] towards the numerous spheroids available during the cooling period of austenite (γ -Fe) is favored. Consequently, suitable conditions are obtained for the formation and growth of ferrite (α -Fe) in the solid-solid transformation [J. Sertucha, R. Suárez, J. Izaya, L. A. Hurtado, J. Lagazpi, Int. J. Cast Met. Res., 2006, 19, 315-322]. This structural phase confers a high degree of ductility and impact resistance to the material, except in those cases wherein the contents of Si and/or P are high. [L. E. Björkegren, K. Hamberg, Proc. Keith Millis Symposium on Ductile Cast Iron, 2003; I. Riposan, M. Chisamera, S. Stan, Int J. Cast Met. Res, 20, 2007, 64-67]. On the other hand, the influence of cooling conditions on the structural characteristics and, consequently, the mechanical properties of cast iron with spheroidal graphite are well known [G. M. Goodrich, R. W. Lobenhofer, AFS Trans., 2007, 115, Working Paper No. 07-045, B. V. Kovacs, AFS Trans., 1981, 89, 79-96.]

[0005] The vast majority of current manufacturing processes use molds made with mixtures the primary component whereof is silica sand (SiO_2).

[0006] This refractory material is characterized by a comparatively low thermal conductivity, which greatly limits the cooling rate of the cast alloy inside this type of molds.

[0007] This type of technique has the following disadvantages:

- molding operations are more difficult, unmolding and the obtaining of parts is slow.
- presence of sand inclusions.
- low density of the spheroids per unit volume of material (less homogeneity in the properties of the material).
- due to the low solidification rate, greater additions of magnesium are required in the treatments in order to ensure a proper spheroidization index in the material.
- high risk of metal contraction.
- low yields in the molds (ratio between the metal in the parts and the metal cast in the mold).
- there is a possibility of deformation in the mold impressions due to the metalostatic pressure (lower dimensional precisions in the parts).
- need for subsequent finishing operations (burrs) in the parts.
- low thermal conductivity of the material and poor machinability.

[0008] For all these reasons, it is necessary to develop new methodologies for obtaining castings that improve the disadvantages outlined above.

DESCRIPTION OF THE INVENTION

[0009] The present invention relates to a new process for the manufacturing of spheroidal cast iron parts, which solves all the disadvantages mentioned above, when molds made up of mixtures containing silica sand (SiO_2) as the primary constituent are used. This is done by using metal or "permanent" molds. The use of this new type of mold has the following advantages:

- Improved surface finish and minimal mold-metal interaction. Easier process for the surface cleaning of the parts.

- Ease of molding operations (it is only necessary to open and close the shells, in addition to the proper maintenance thereof).
- Speed in the unmolding and obtaining of the parts.
- Absence of sand inclusions (the most common defect in castings that use sand molds).
- 5 - High density of spheroids per unit volume of material (greater homogeneity in the properties of the material).
- Due to the increased solidification rate, it is necessary to add lower amounts of magnesium in the treatments in order to ensure a correct spheroidization index in the material.
- Low risk of metal contraction (minimization of shrink holes and microshrink holes).
- High yields in the molds (ratio between the metal in the parts and the metal cast in the mold).
- 10 - There is no possibility of deformations in the mold impressions caused by the metalostatic pressure (greater dimensional precision in the parts).
- If the molds are well-adjusted, subsequent finishing operations (burrs) on the parts are hardly necessary.
- Such a significant increase in the number of spheroids per unit volume results in an increase in the thermal conductivity of the material and improved machinability.

15 **[0010]** This new technique can be used for the manufacturing of castings for the automotive industry, hydraulic components, metal molds for the glass industry, centrifuged tubes, etc. The use of metal molds greatly accelerates the solidification rate and subsequent cooling of the material, causing major changes in the structures obtained in the as-cast state.

20 **[0011]** Therefore, a first aspect of the present invention is a process for manufacturing spheroidal castings, which comprises the following steps:

- a) fusion of the metal loads at a temperature of between 1400 and 1600°C.
More preferably, between 1430 and 1450°C.
- 25 b) adjustment of the metal loads to achieve the required composition;
- c) spheroidization treatment at temperatures below 1148°C, and
- d) casting process in metal or "permanent" molds.

30 **[0012]** According to a preferred embodiment, the metal loads are selected from the group formed by high carbon ingots, foundry chip briquettes, pig iron, scrap metal, steel from the automotive sector, returns or any combination thereof. Preferably, the metal loads are selected from high-carbon ingots, returns, foundry chip briquettes, steel from the automotive industry or any combination thereof.

[0013] According to another preferred embodiment, the composition of the metal loads is:

- 35 - between 25 and 90% of high-carbon ingots
- between 0 and 30% of steel from the automotive sector
- between 0 and 50% of foundry chip briquettes
- between 1 and 50% of returns

40 **[0014]** Always keeping in mind that the sum of all components must be 100%. Preferably, the composition of the metal loads is:

- between 30 and 80% of high-carbon ingots
- between 0 and 25% of steel from the automotive sector
- 45 - between 0% and 35% of foundry chip briquettes
- between 1 and 35% of returns

[0015] Always keeping in mind that the sum of all components must be 100%.

[0016] Even more preferably, the composition of the loads is:

- 50 - 75% of high-carbon ingots
- 20% of steel from the automotive sector
- 0% of foundry chip briquettes
- 5% of returns.

55 or

- 33.33% of high-carbon ingots

- 0% of steel from the automotive sector
- 33.33% of foundry chip briquettes
- 33.33% of returns

5 **[0017]** Always keeping in mind that the sum of all components must be 100%.

[0018] According to a preferred embodiment, after the adjustment of the metal loads the following composition is obtained:

- C: from 3.95 to 4.05% by weight.
- 10 - Si: from 1.00 to 2.60% by weight.
- Mn: from 0.40 to 0.80% by weight.
- S: from 0.00 to 0.20% by weight.
- Others:

15 **[0019]** More preferably, after the adjustment of the metal loads the following composition is obtained:

- C: from 3.60 to 4.05% by weight.
- Si: from 1.90 to 2.60% by weight.
- Mn: from 0.50 to 0.80% by weight.
- 20 - S: from 0.00 to 0.10% by weight.
- Others:

[0020] Always keeping in mind that the sum of all components must be 100%.

[0021] All these weight percentages are with respect to the total weight of the melt.

25 **[0022]** According to another preferred embodiment, the process of fusion of the metal loads is performed in rotary kilns. On the other hand, the melting and stay times of said metal load is 60 to 80 minutes (hours), preferably 70 minutes.

[0023] According to another preferred embodiment, in the step of adjusting the carbon and silicon contents, they are added depending on the content in the molten metal (metal loads) obtained in step a) in order to optimize the next step c) of spheroidization, such that the molten metal loads are transferred to at least 1 induction furnace (1000 Hz), preferably 3 induction furnaces. On the other hand, the temperature of the base metal is maintained within a range between 1400 and 1500°C, preferably between 1400 and 1450°C.

[0024] In another preferred embodiment, the spheroidization treatment comprises the following steps:

- a. addition of FeSiMg in a proportion of 0.7 to 1.0% by weight with respect to the metal loads to be treated to the treatment ladle.
- 35 b. addition of an inoculant on the FeSiMg in a proportion of 0.15 to 0.20% by weight with respect to the metal loads to be treated.
- c. addition of steel clippings so that these amply cover the FeSiMg and the inoculant previously entered into a reaction chamber;
- 40 d. filling of the metal loads from step b) to a 20 to 30% by volume of the ladle, guiding the fall of the metal towards the end opposite to a reaction chamber;
- e. completing the filling of the ladle with the metal loads, and
- f. slagging the metal treated.

45 **[0025]** According to a preferred embodiment, the FeSiMg alloy comprises the following composition:

- Si: from 30 to 60% by weight;
- Mg: from 1 to 30% by weight;
- Ca: from 0.1 to 4% by weight;
- 50 - Al: from 0.1 to 3% by weight;
- Rare earths: from 0 to 3% by weight, and
- Fe: from 30 to 60% by weight;

[0026] Even more preferably, the FeSiMg alloy comprises the following composition:

- 55 - Si: from 40 to 48% by weight;
- Mg: from 4 to 10% by weight;
- Ca: from 0.5 to 1.5% by weight;

- Al: from 0.3 to 1.2% by weight;
- Rare earths: from 0 to 1.3% by weight, and
- Fe: from 35 to 50% by weight;

5 **[0027]** According to another preferred embodiment, the inoculant comprises the following composition:

- Si: from 50 to 90% by weight;
- Ca: from 0.1 to 5.5% by weight;
- Al: from 0.1 to 5% by weight;
- 10 - Ba: from 0 to 15% by weight;
- Bi: from 0 to 5% by weight;
- Rare earths: from 0 to 4.5% by weight;
- Fe: from 15 to 35% by weight;

15 **[0028]** In an even more preferred embodiment, the inoculant comprises the following composition:

- Si: from 68 to 78% by weight;
- Ca: from 0.3 to 1.9% by weight;
- Al: from 0.3 to 1.5% by weight;
- 20 - Ba: from 0 to 9.5% by weight;
- Bi: from 0 to 1.2% by weight;
- Rare earths: from 0 to 1% by weight;
- Fe: from 20 to 30% by weight;

25 **[0029]** According to another preferred embodiment, stamped steel clippings are added until they cover the FeSiMg.

[0030] In another preferred embodiment, following the spheroidization step, a casting step is performed in metal or "permanent" molds. Said step comprises the following sub-steps:

- a. transfer of the metal from the spheroidization step to a casting ladle equipped with an outlet siphon;
- 30 b. slagging of the treated metal from the previous step;
- c. filling of the metal or permanent molds or through the siphon, ensuring that the ladle cup is full during the entire process of filling the molds;
- d. vein addition (addition at the mold or shell inlet) of an inoculant to the casting metal in a weight percentage of 0.15% with respect to the metal treated in the ladle, the composition whereof is:

- 35 - C: 3.70 to 3.85% by weight;
- Si: 2.55 to 2.67% by weight;
- Mn: 0.6 to 0.7% by weight;
- P: 0.035 to 0.07% by weight;
- 40 - S: 0.010 to 0.014% by weight;
- Mg: 0.023 to 0.036% by weight, and
- Cu: 0.01 to 0.02% by weight.

- e. unmolding of the metal parts obtained, and
- 45 f. shot-blasting of the parts obtained in the previous step.

[0031] In the present invention, spheroidization is understood to mean a method for relieving the residual stresses in a high-carbon steel, consisting of heating for a long time at the lowest transformation temperature thereof, followed by slow cooling until it reaches room temperature.

50 **[0032]** Throughout the description and the claims, the word "comprise" and the variants thereof are not intended to exclude other technical characteristics, additives, components or steps. For persons skilled in the art, other objects, advantages and characteristics of the invention will become apparent partly through the description and partly through the practice of the invention. The following examples and drawings are provided by way of illustration and are not intended to limit the scope of the present invention.

55 DESCRIPTION OF THE FIGURES

[0033]

Figure 1.- Figure 1 shows the configuration of the half-molds designed to manufacture jaws for the railway sector.

Figure 2.- Heat treatment applied to the jaws in order to eliminate carbides.

[0034] The evolution of the temperature in one of the parts during application of the treatment.

EXAMPLES

[0035] In the embodiment example, the implications arising from the use of silica sand or metal molds for the production of nodular castings with high requirements (wind energy sector) are comparatively studied. On the other hand, the advantages and disadvantages of using permanent molds in a production process are determined.

[0036] The fusion process of the materials was carried out in rotary kilns with a capacity of 5500 kg. The metal loads used were composed of 75% of high-carbon ingots, 20% of steel from the automotive sector and 5% of returns. Following the fusion of these loads, the resulting metal is transferred to three induction furnaces (1000 Hz) with a capacity of 1800 kg, in order to adjust the Carbon and Silicon contents (chemical composition by weight graphite: C $\geq$ 98%; FeSi: %Si = 74.6, %Al = 0.8, %Fe = 24.6) and raise the temperature of the base metal to 1400-1450°C. Table 1 shows the chemical composition ranges used in the preparation of the base metal.

Table 1. Chemical compositions of the base metal

Element (%)						
C	Si	Mn	P	S	Cu	Cr
3.95-4.05	2.40-2.50	0.60-0.70	0.035-0.07	0.010-0.017	0.01-0.02	0.01-0.03

[0037] The spheroidization treatments of the base metal were made by transferring 70-75 kg from the electric furnaces to a ladle with a maximum capacity of 90 kg and equipped with a siphon outlet for the metal. Prior to carrying out this operation, the following were introduced, in this order, into the reaction chamber pertaining to this treatment ladle: 0.8% of the alloy FeSiMg621 (2-10 mm granulometry and chemical composition by weight: %Si = 44.1, %Mg = 6.8; %Ca = 2.2, %Al = 0.6, %RE = 1.2% and %Fe = 45.1), 0.15% of a commercial inoculant (0.5 to 3 mm granulometry and chemical composition by weight: %Si = 64.3; %Ca = 1.3, %Al = 0.9, %Ba = 9.3 and %Fe = 24.2) and stamped steel clippings as opacifying material. The discharge of metal from the electric furnace is performed such that the metal falls on the side opposite to that occupied by the reaction chamber at the bottom of the treatment ladle. The weight of the metal transferred was controlled with the aid of a dynamometer placed on the spoon.

[0038] After the treatment reaction with magnesium is completed, the slag was conveniently removed from the metal and the latter was quickly transferred to a ladle with a capacity of about 80 kg and equipped with an outlet siphon. The purpose of this device is to prevent the introduction of the slag formed inside the molds during the casting. The metal contained in the casting ladle was occasionally slagged off with this same aim. The casting of the molds was performed manually through the siphon, ensuring that the casting cup was kept full throughout the entire process of filling the molds. A post-inoculation of the casting metal was performed, by vein adding 0.15% of a commercial inoculant (0.2-0.7 mm granulometry and chemical composition by weight: %Si = 73.5; %Ca = 1.7, %Al = 1.0, %Bi = 0.9% and %Fe = 22.9).

Table 2. Chemical compositions of the metal treated with Mg

Element (%)						
C	Si	Mn	P	S	Cu	Cr
3.95-4.05	2.40-2.50	0.60-0.70	0.035-0.07	0.010-0.017	0.01-0.02	0.01-0.03

[0039] The silica sand molds were manufactured using a high-pressure vertical molding line (12 kp/cm²) and mixtures composed of: 80.8% of re-used silica sand, 9.3% of activated sodium bentonite, 4.5% of carbonaceous material, 3.6% of water and 1.8% of new silica sand. The mixtures were sent to the molding machine with a compactibility of 38-41 %.

[0040] The permanent molds were manufactured by machining a crude foundry product, cast into a mold previously prepared for this purpose. The material used to prepare this crude product is flake graphite cast iron of the EN-GJL-200 grade.

[0041] After the machining and subsequent adjustment operations, the molds were coated internally with a layer of refractory paint and mounted on a carousel with a capacity for 12 molds, all equipped with an internal water refrigeration system. At each turn of the carousel, a system of acetylene-fed burners was used to provide a layer of coal dust on the refractory paint that covers the internal face of the metal molds. The addition of this carbonaceous layer may be regulated

in each case. The temperature of the molds was controlled manually.

[0042] The parts used to conduct this study are: a component of the brakes used in wind furnaces and a clamping jaw for railway tracks. The weight of the brake caliper is 7.2 kg, showing sections between 5 and 43 mm. In the case of the jaw, the weight is 0.35 kg and sections vary between 5 and 12 mm. Thus, it is possible to evaluate the effect of different cooling rates in the same component. Figure 1 shows the configuration of the half-molds designed to manufacture jaws for use in the railway sector.

[0043] The parts manufactured in both the permanent molds and in those manufactured with the silica sand mixtures correspond to the brake caliper. The jaw was manufactured using only metal molds. After the manufacturing thereof, the parts were unmolded and, subsequently, shot blasted.

[0044] The materials of these parts were subjected to metallographic study in order to determine the spheroidization index (SI), the nodular density (N) and the composition of the metal matrix in different sections. The values of these parameters were obtained by analyzing 5 different observation fields in each sample and comparing them to standard patterns [15, 16]. On the other hand, the mechanical properties were determined on test-tubes machined directly on the parts. The dimensions of these test-tubes were dependent on the area of the part wherefrom they were obtained.

RESULTS AND DISCUSSION

[0045] The structural characterizations were carried out in a narrow section and in a massive section, pertaining to three brake calipers manufactured in silica sand molds, three jaws and three brake calipers manufactured using metal molds, all of them as-cast. The results obtained from these studies are included in Table 3.

Table 3. Results of the metallographic characterizations (as-casting parts), where SI represents the nodularity and N represents the no. of nodules per mm²

Brake calipers (metal mold)								
Section (mm)	SI (%)	N (mm ⁻²)	Nuclear structure (%)			Peripheral structure (%)		
			Ferrite	Perlite	Carbides	Ferrite	Perlite	Carbides
41	>90	750-1100	85-100	15-0	0	90-100	10-0	0
8-9	>90	950-1400	90-100	10-0	0	100	0	0
Brake calipers (silica sand mold)								
Section (mm)	SI (%)	N (mm ⁻²)	Nuclear structure (%)			Peripheral structure (%)		
			Ferrite	Perlite	Carbides	Ferrite	Perlite	Carbides
41	>90	180-220	30-35	70-65	0	15-25	85-75	0
8-9	>90	340-480	10-20	90-80	0	2-10	98-90	0
Jaws (metal mold)								
Section (mm)	SI (%)	N (mm ⁻²)	Nuclear structure (%)			Peripheral structure (%)		
			Ferrite	Perlite	Carbides	Ferrite	Perlite	Carbides
11	>90	950-1400	35-40	65-60	0	20-30	80-68	Trazas-2
6	>90	1300-1500	15-25	85-75	0-Trazas	10-15	85-75	5-10

[0046] The comparative analysis of the data in Table 3 clearly shows the strong increase in the number of graphite spheroids when cooling of the material takes place inside the metal molds. This can be verified when comparing the brake calipers manufactured using silica sand molds to those obtained from the permanent molds. In the case of the clamping jaw, it is a smaller part and has narrower sections. However, for a similar cooling section, significant increases in the N parameter are not obtained as compared to the brake calipers. This reveals the strong influence of the solidification rate on the values of the N parameter obtained.

[0047] Another aspect to consider is the content of ferrite observed in each case. The calipers manufactured in the metal mold are largely or completely ferritic; however, those coming from the sand molds do not exceed 30-35% of this phase in any of the sections inspected (the content of manganese in the metal casting is 0.60 to 0.70%). This behavior must be primarily attributed to the presence of a greater number of graphite nodules per unit volume in the materials cooled in the metal mold. Thus, the distance between spheroids decreases considerably and the efficient diffusion of

Carbon atoms from austenite is favored during the cooling thereof in the solid state, even though the latter is probably faster than in the parts manufactured inside the sand molds. It is necessary to consider that, when using permanent molds, the unmolding usually occurs 50-60 seconds after completing filling of the mold. In the case of manufactures with sand molds, this time may exceed 10 min.

[0048] When comparing the matrix structures in similar sections of the brake calipers and the jaws, both manufactured with metal molds, it is observed that the rate of cooling of austenite does exert an influence on the formation of ferrite during the eutectoid transformation. Even with higher values of the N parameter, the jaws show lower contents of this phase than the calipers (Table 3). This may be related to the size of the parts and the influence of this parameter on the cooling rate of the material when said parts are unmolded and remain in contact with air.

[0049] Another structural phase detected, which reveals the behavior described above, is iron carbides. This type of compounds are formed only in the clamping jaws, i.e. in the narrower sections with more critical cooling kinetics. It is logical to verify that the highest concentration of carbides was observed in the peripheral areas pertaining to the narrower sections in this part. The more rapid cooling that occurred in these areas in contact with the metal mold favors the appearance of carbide phases. In these cases, effective control of the temperature of the molds and ensuring effective inoculation in the metal casting becomes even more relevant.

[0050] The point is to add very active graphite nucleation elements (Ca, Si, Ba, Bi, etc.), which may counteract the effect exerted by the high solidification rate on the formation of carbides. In the process methodology used in this work two inoculations were performed: in the treatment with FeSiMg and a post-inoculation in the casting vein. However, it has not been possible to prevent the formation of carbides in the most critical sections of the jaws. The utility of the carbides formed in the peripheral areas as an effective measure to prevent wear in parts with specific applications has been suggested. In any case, proper inoculation of the metal casting also contributes to minimize the formation of contraction defects and increases the number of nodules, especially in the narrower sections, as has been demonstrated in the present work. Although we have not detected the presence of contraction defects, the literature includes publications dealing with the appearance of shrink holes and/or microshrink holes in parts manufactured in metal molds.

[0051] In order to eliminate the presence of carbides in the jaws, three other parts were selected and subjected to a standardized heat treatment. The temperature evolution in one of these parts during the application of this treatment is shown in Figure 2. The treated parts were metallographically inspected in order to confirm the total decomposition of the carbides and the presence of completely ferritic matrix structures in all the sections previously analyzed, which are specified in Table 3

[0052] With regards to the surface finish of the parts, after the unmolding and subsequent cooling to room temperature, those manufactured using permanent molds show a surface covered only by a thin dark layer of iron oxides. This layer can be easily removed with a short period of shot blasting. Comparatively speaking, the surface quality of the parts manufactured with metal molds is greater than that obtained with the sand molds. On the other hand, the dimensional precision obtained using metal molds is also greater and more repetitive.

[0053] The surface defects that may be observed in certain parts and most often are: slag and wrinkles or folds. In the first case, given the speed of the solidification period, it is very important to ensure the cleanliness of the metal casting and the effectiveness of the filling systems in preventing the entry of slag into the cavities that form the parts. With regard to surface wrinkles in spheroidal cast iron pieces, it was observed that they are favored when using longer casting times and/or, primarily, the temperatures of the metal molds are higher.

[0054] All the parts selected in this study were inspected by X-ray fluoroscopy in order to determine the presence of internal defects caused by contraction of the metal during the solidification stage. The metal molds prepared to manufacture both the brake caliper and the clamping jaw do not include any type of power system (Figure 1).

[0055] It is therefore necessary to evaluate the presence of shrink holes and/or microshrink holes in the manufactured parts for information on the behavior of the expansion-contraction balance of the metal in the interior of the metal molds. In no case was the presence of contraction defects detected in the selected parts manufactured in metal molds. The absence of this type of porosity must be related to the cooling kinetics applied when using this type of molds. By contrast, the brake calipers manufactured in sand molds do show microshrink holes with a variable size, mainly in the section changes close to the more massive sections of the part.

[0056] Table 4 shows the values of the maximum load at breakage (B), the elastic limit (EL) and the elongation (E) obtained from the traction assays performed to determine the mechanical properties of the selected parts. In the case of the clamping jaws, the mechanical assays were conducted only on the three parts subjected to the ferritization heat treatment described in Figure 2. In the brake calipers, all the materials were assayed in the as-cast state. The traction test-tubes were machined from two areas in each part. In the brake calipers, these areas correspond to the space designed for the hydraulic system (pot) and the central body (center). In the jaws, the test-tubes were obtained from the support wedge and the support area of the part.

Table 4. Mechanical properties obtained on the part

As-cast brake calipers (metal mold)				
Area	Test-tube diameter (mm)	B (MPa)	EL (MPa)	E (%)
Pot	10	503-532	380-399	12-18
Center	10	505-520	376-402	13-20
As-cast brake calipers (silica sand mold)				
Area	Test-tube diameter (mm)	B (MPa)	EL (MPa)	E (%)
Pot	10	605-710	367-418	9-11
Center	10	618-706	378-411	6-9
Heat-treated jaws (metal mold)				
Area	Test-tube diameter (mm)	B (MPa)	EL (MPa)	E (%)
Wedge	5	435-466	294-313	18-20
Support	5	425-469	286-329	16-17

[0057] When comparing the mechanical properties of the brake calipers manufactured with metal and sand molds, the results obtained are consistent with the structural characteristics shown in Table 3. An increase in the solidification rate of the part inside the metal mold led to a strong increase in parameter N and a significant increase in the ferrite content.

[0058] These characteristics lead to materials that comfortably exceed 500 MPa of breakage load, with surprisingly high elastic limits (approximately 400 MPa) and elongations that may reach 20%. When transferring the part to molds manufactured with silica sand, materials are obtained with a greater load, a similar elastic limit and elongations that are clearly less than 12%.

[0059] In the case of the clamping jaw, the heat treatment applied transformed the structure, completely ferritizing it. Consequently, breakage loads are obtained that may exceed 450 MPa, elastic limits of about 300 MPa and elongations of up to 20%. Within this context, it must be borne in mind that they are results obtained directly on parts with a maximum section of 12 mm. Therefore, these results are of great interest, and they have a direct application in the design and subsequent manufacturing stages of nodular casting parts.

CONCLUSIONS

[0060] The results obtained in the present work have shown that the use of metal molds is suitable for the manufacturing of spheroidal cast iron parts with significant functional requirements. The main structural implications resulting from the use of this type of molds are the significant increase in the number of graphite nodules per unit volume of material and a no less considerable increase in the ferrite content in the metal matrix obtained at room temperature.

[0061] Both structural characteristics make it possible to manufacture parts with interesting mechanical properties, especially the large elongations obtained in alloys with breakage loads greater than 510 MPa.

[0062] Therefore, the characteristics of the production process using metal molds and the results presented in this study should be taken into account when defining the most appropriate and cost-effective methodology for the production of spheroidal iron castings. Below we summarize the main advantages and disadvantages encountered in this type of process as compared to the manufacturing using sand molds:

Claims

1. Process for manufacturing spheroidal cast iron parts, which comprises the following steps:

- fusion of the metal loads to a range of temperatures between 1400 and 1600°C;
- adjustment of the carbon and silicon contents of the metal loads melted in step (a);
- spheroidization treatment of the metal loads obtained in step (b) at temperatures below 1148°C, and
- casting process of the metal loads obtained in step (c) in metal molds.

2. The process according to claim 1, wherein the metal loads are selected from the group formed by high-carbon ingots, foundry chip briquettes, pig iron, scrap, steel from the automotive sector, returns or any combination thereof;

preferably, the metal loads are selected from the group formed by high-carbon ingots, returns, foundry chip briquettes, steel or any combination thereof.

3. The method according to any of claims 1 or 2, wherein the metal load has the following composition up to 100%:

- between 25 and 90% of high-carbon ingots, preferably between 30 and 80%, and
- between 1 and 50% of returns, preferably between 1 and 35%.

4. The method according to claim 3, wherein the metal load further comprises:

- a percentage equal to or less than 30% of steel from the automotive sector, preferably a percentage equal to or less than 25%;
- a percentage equal to or less than 50% of foundry chip briquettes, preferably a percentage equal to or less than 35%;

5. The method according to claim 1, wherein the metal load has the following composition:

- 75% of high-carbon ingots;
- 20% of steel from the automotive industry, and
- 5% of returns.

6. The method according to claim 1, wherein the metal load has the following composition:

- 33.33% of high-carbon ingots;
- 33.33% of foundry chip briquettes, and
- 33.33% of returns.

7. The method according to any of claims 1 to 6, where the process of melting the metal loads is performed in rotary kilns, at a load fusion temperature between 1430 and 1450°C.

8. The method according to any of claims 1 to 7, where the fusing and stay times of said metal load is 60 to 80 minutes, preferably 70 minutes.

9. The method according to any of claims 1 to 8, where, in the step of adjusting the carbon and silicon content, the molten metal loads from step a) are transferred to at least 1 induction furnace, preferably 3 consecutive induction furnaces, and are maintained within a temperature range between 1400 and 1500°C, preferably at a temperature range between 1400 and 1450°C.

10. The method according to any of claims 1 to 9, where, in step c), the spheroidization treatment comprises the following sub-steps:

- a. addition of FeSiMg in a proportion of 0.7 to 1.0% by weight with respect to the total weight of the metal loads to a treatment ladle;
- b. addition of an inoculant on FeSiMg in a proportion of 0.15 to 0.20% with respect to the total weight of the metal loads;
- c. addition of steel clippings to the mixture obtained in sub-step b);
- d. filling to 20 to 30% by volume of the ladle of the metal loads obtained in step b);
- e. addition of the molten metal loads from step b) until the ladle is filled, and
- f. slagging off of the treated metal obtained in sub-step e).

11. The method according to claim 10, wherein the alloy FeSiMg comprises the following composition up to 100%:

- Si: from 30 to 60% by weight, preferably from 40 to 48% by weight;
- Mg: from 1 to 30% by weight, preferably from 4 to 10% by weight;
- Ca: from 0.1 to 4% by weight, preferably from 0.5 to 1.5% by weight;
- Al: from 0.1 to 3% by weight, preferably from 0.3 to 1.2% by weight, and
- FE: from 30 to 60% by weight, preferably from 35 to 50% by weight.

12. The method according to claim 11, wherein the alloy FeSiMg further comprises a percentage equal to or less than 3% by weight of rare earths, preferably a percentage equal to or less than 1.3% by weight of rare earths.

13. The method according to any of claims 10 to 12, where the inoculant comprises the following composition up to 100%:

- Si: from 50 to 90% by weight, preferably from 68 to 78% by weight;
- Ca: from 0.1 to 5.5% by weight, preferably from 0.3 to 1.9% by weight;
- Al: from 0.1 to 5% by weight, preferably from 0.3 to 1.5% by weight; and
- Fe: from 15 to 35% by weight, preferably from 20 to 30% by weight.

14. The method according to claim 13, wherein the inoculant further comprises a percentage equal to or less than 15% by weight of Ba, a percentage equal to or less than 5% by weight of Bi and a percentage equal to or less than 4.5% by weight of rare earths; preferably the inoculant comprises a percentage equal to or less than 9.5% by weight of Ba, a percentage equal to or less than 1.2% by weight of Bi and a percentage equal to or less than 1% by weight of rare earths.

15. The method according to any one of claims 1 to 14, where step d), of casting in metal molds, comprises the following sub-steps:

- a. transfer of the metal from the spheroidization step to a casting ladle equipped with an outlet siphon;
- b. slagging off of the treated metal from the previous stage;
- c. filling of the metal or permanent molds through a siphon;
- d. vein addition of an inoculant to the metal casting, in a weight percentage of 0.15% with respect to the metal treated in the ladle, the composition whereof is:

- C: 3.70 to 3.85% by weight;
- Si: 2.55 to 2.67% by weight;
- Mn: 0.6 to 0.7% by weight;
- P: 0.035 to 0.07% by weight;
- S: 0.010 to 0.014% by weight;
- Mg: 0.023 to 0.036% by weight, and
- Cu: 0.01 to 0.02% by weight.

- e. unmolding of the metal parts obtained, and
- f. shot-blasting of the parts obtained in the previous step.

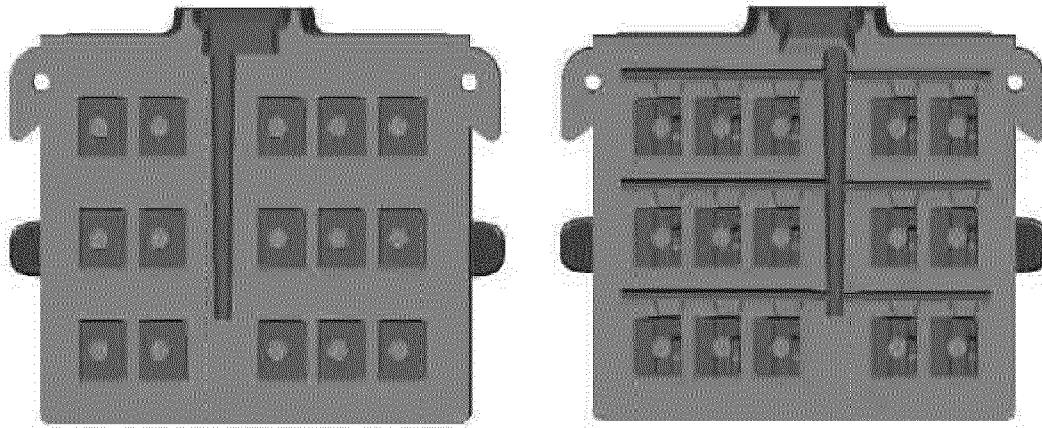


Fig. 1

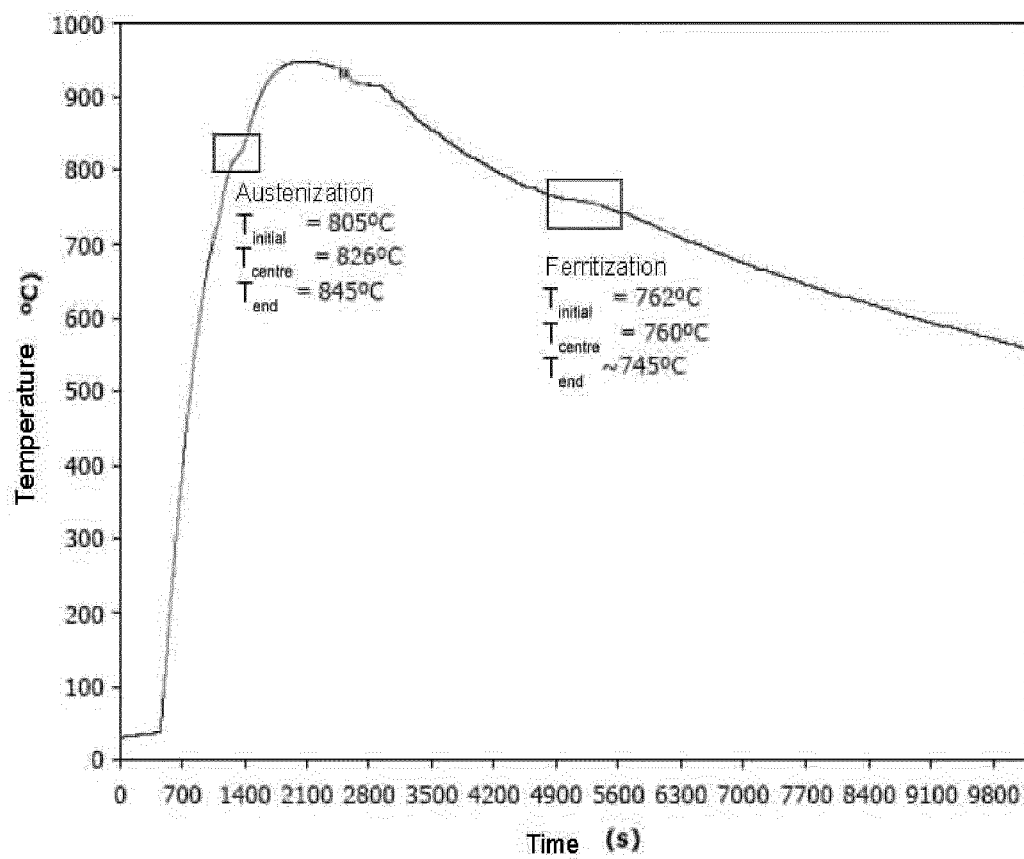


Fig. 2



EUROPEAN SEARCH REPORT

Application Number
EP 11 19 5727

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search The Hague		Date of completion of the search 17 April 2012	Examiner Gimeno-Fabra, Lluís
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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17-04-2012

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