



(11)

EP 2 599 886 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:
13.08.2014 Bulletin 2014/33

(51) Int Cl.:
C22C 37/00 (2006.01) C22C 37/10 (2006.01)

(21) Application number: **11382369.4**

(22) Date of filing: **29.11.2011**

(54) **Gray cast iron with superfine graphite, high primary austenite fraction and optimized mechanical properties**

Grauguss mit superfeinem Graphit, einer hohen primären Austenitanteil und optimierten mechanischen Eigenschaften

Fonte grise avec graphite superfin, fraction élevée d'austénite primaire et propriétés mécaniques optimisées

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(43) Date of publication of application:
05.06.2013 Bulletin 2013/23

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Description

Field of the Invention

[0001] The present invention relates to a new material for use in the metallurgy industry, and more particularly, relates to a flake graphitic cast iron the composition of which allows obtaining a higher amount of primary austenite and a superfine graphite structure which allows achieving optimized mechanical properties (greater tensile strength and less hardness at equivalent carbon equality). Particularly, an intermediate structure between coral graphite and type D graphite" (called superfine graphite) conferring high strength and low hardness to relatively high equivalent carbons is achieved.

Background of the Invention

[0002] Gray cast iron or flake graphite cast iron continues to be a material with wide technological application in the sectors of automation, machine tool, renewable energies, etc.

[0003] Flake graphitic cast iron is a material with low manufacturing cost and with physical properties of great technological value (relatively high heat conductivity, great vibration absorbing capacity, low thermal shrinkage, etc.). However, the mechanical properties of many of these materials are limited if compared with those commonly obtained in other types of iron alloys (steels or nodular cast irons), which do not have the advantageous physical properties of flake cast irons.

[0004] The common microstructure of gray cast iron is made up of graphite sheets inside a ferritic/pearlitic core. The mechanical and physical properties depend on the length and distribution of the graphite sheets and on the resulting ferrite/pearlite ratio.

[0005] Table 1 shows the chemical compositions associated with the different types of flake graphitic cast iron according to the ASTM A48-94 standard. To better appreciate the properties and the ratio thereof with the equivalent carbon content, a column has been added for this parameter which is calculated as $CE = \%C + \%Si/3$.

Table 1.

Class	% Carbon	% Silicon	Equivalent Carbon (CE)	Tensile strength MPa	Hardness HB
20	3.40-3.60	2.30-2.50	4.30	152	156
25	-	-	-	179	174
30	3.10-3.30	2.10-2.30	3.88	214	210
35	-	-	-	252	212
40	2.95-3.15	1.70-2.00	3.67	293	235
50	2.70-3.00	1.70-2.00	3.47	362	262
60	2.50-2.85	1.90-2.10	3.34	431	302

[0006] Compositions and mechanical properties of several types of gray cast iron.

[0007] Tensile strength of the flake graphitic cast iron can be increased by reducing the CE of the alloy (especially the C content as shown in Table 1) or by adding alloy elements strengthening the core.

[0008] The reduction of CE is associated to an increase of hardness (see Table 1) and an increase of the alloy shrinkage phenomena due to the precipitation of a lower amount of graphite.

[0009] The objective of adding specific alloy elements such as Cu, Mo and Mn (W. Xu et al., Materials Science and Engineering A 390 (2005) 326-333), Nb and Ni (J. K. Jaxzarowski et al., Patent 20080206584, *All metal or with adjacent metals*), lanthanides (rare earth elements) (J. Van Eeghem et al., Patent 3997338, *Patent Genius*) or Cu, Mo and Cr (N. Katori and S. Ishii, Patent 11181988, *Patentstorm*), is to obtain structures with lower ferrite/pearlite ratio and to reduce the interlayer spacing between the ferrite and cementite sheets forming the pearlite phase, causing the latter to be more resistant.

[0010] The other aspect with a decisive influence on tensile strength is the graphite shape and distribution. Fine flake graphite with type D distribution is commonly obtained in hypo-eutectic cast irons subjected to relatively high cooling rate. It is also possible to obtain this graphitic structure in cast irons with a normal sulfur content (0.03-0.08 % by weight), high titanium content (0.5 - 1%) and high cooling rates (B. Lux, Mem. Sci. Rev. Mett. LXVI, 196, 347).

[0011] The sulfur modifies the length and the distribution of the graphite sheets in flake graphitic cast iron, enhancing precipitation according to type A distribution (K. M. Muzumdar and J. F. Wallace, AFS Transactions, 81 (1973) 412-423). The reduction of the S content below 0.02 % by weight, causes the precipitation of graphite sheets according to the type D distribution due to the subcooling increase (M. Chisamera, et al., AFS Transactions, 07-023 (05)). As the S content

increases, S (sulfides)-based compounds which act as the origins for graphite precipitation are formed, type A distribution being favored (B. Francis, Metallurgical Transactions A, 10a, 1979) (I. Riposan, et al., Proceedings of the AFS Cast Iron Inoculation Conference, 2005).

[0012] Coral graphite is a type of very branched graphite different from type D distribution and from vermicular (or compact) graphite. Coral graphite is obtained from Fe-C-Si alloys with very low alloying, especially with very reduced S content (less than 0.001 % by weight) and with high cooling rates (B. Lux, Giesserei Forschung, 19, 1967, 141) are obtained. This type of chemical compositions does not have practical industrial applications due to the economic increase involved in producing an alloy of these characteristics.

[0013] The addition of titanium increases the subcooling, favoring graphite precipitation according to a type D distribution (Y. S. Lerner, AFS Transactions 104 (1996) 1011-1016), (R.I. Morozova, et al., Khimichskoe i Neftyanoe Mashinostroenie, No. 1 (1972) 16-17) (AND. S. Lerner, Journal of Materials Engineering and Performance, 12 (2) (2003) 141-146) (X. Lin, et al., Modern Cast Iron, 2001-04) (B. Shen, et al, Modern Cast Iron, 2006-06), note also the article by Sissener, J., Combined Influence of Vanadium and Titanium on Cast Iron with Lamet kr Graphite, FTJ, 1979.

[0014] According to some authors, there is a critical level of 0.04 % by weight of Ti, below which the tensile strength reduces and above which this strength increases (M. C. McGrath, et al, AFS Transactions 09-86). The conclusion of another study indicates that the Ti content must not exceed 0.075% (Y. S. Lerner, AFS Transactions 104 (1996) 1011-1016). In other published works, an increase of the tensile strength is obtained with Ti contents up to 0.36% (R.I. Morozova, et al., Khimichskoe i Neftyanoe Mashinostroenie, No. 1 (1972) 16-17) (X. Lin, et al., Modern Cast Iron, 2001-04). In all the cases, the S content is that common for the flake graphitic cast irons (0.065-0.110%). In practice, the Ti content in manufacturing parts from flake graphitic cast iron is limited to 0.030%, because the formation of complex compounds reduce the service life of the tools used for performing the machining operation (D. Zeng, et al., Tsinghua Science and Technology, 2008, Vol. 13, No. 2, 127-131).

[0015] Today, flake cast iron covers a range of strengths which may vary from 150 to 450 MPa. It is important to point out from Table 1 that in order to obtain a tensile strength greater than 300 MPa, the equivalent carbon content must be very low (less than 3.67%), but on the other hand, this composition is associated to a relatively low hardness (greater than 235 HBW) and a high cavity and microcavity forming capacity.

[0016] It is also known that the typical tensile strength of flake graphitic cast iron with a 4% equivalent carbon content (CE) varies from 230 to 300 MPa (ASM Specialty Handbook, Cast Irons, J.R. Davis Editor, ASM International, Materials Park, Ohio (1996)), 260 MPa being the average tensile value and 215 HBW being hardness value. The amount of primary austenite in the cast irons with this composition varies from 10 to 25%, whereas the rest is made up of the eutectic phase.

[0017] From the above mentioned, it can be seen that there is a real need of new compositions for flake cast iron with improved mechanical properties in response to the existing requirements for manufacturing economically competitive parts with a performance similar to those obtained by means of adding specific chemical alloy elements.

Summary of the Invention

[0018] In a first aspect of the invention, there is provided a Flake gray cast iron with a higher amount of primary austenite and a superfine flake graphite, high tensile strength and relatively low hardness values, which is obtained by following a gray cast iron standard manufacturing process, and which has a strength greater than and a hardness similar to the flake graphitic cast iron with a same equivalent carbon content.

[0019] It has been found that the above object is accomplished by means of the superfine graphite gray cast iron of the present invention comprising the following composition:

from 3.2 to 3.6% by weight of C;
from 1.8 to 2.2% by weight of Si,
from 0.1 to 0.8% by weight of Mn,
up to 0.02% by weight of S,
up to 0.1 % by weight of P,
from 0.15 to 0.60% by weight of Ti

the rest of the composition is iron and traces of other elements commonly present in this type of cast irons.

[0020] The gray cast iron thus obtained with the composition of the present invention has a ratio between the primary austenite with respect to the eutectic phases of 0.3 to 0.5, with graphite separations giving rise to a superfine morphology, having a tensile strength greater than 300 MPa and a hardness less than 200 HBW.

[0021] In a preferred embodiment of the present invention, the following composition is used: 3.4 % by weight of C; 2.05 % by weight of Si; 0.53% by weight Mn; 0.008 % by weight of S; 0.017 % by weight P and from 0.19 to 0.40% by weight of Ti.

[0022] An additional object of the invention is to thus provide a cast iron containing superfine graphite which is a form

of intermediate graphite between type D and coral graphite, with a high ratio of primary austenite with respect to the eutectic phases and subjected to cooling rates up to 1°C/s.

[0023] Another object of the invention is to provide a cast iron containing superfine graphite with a hardness/tensile strength ratio less than that corresponding to the flake graphitic cast irons with similar chemical compositions (except S and Ti contents).

[0024] And yet another object of the invention is to provide a flake graphitic cast iron having low manufacturing cost but with high strengths and comparable to those obtained in economically more expensive cast irons of high alloy.

[0025] More particularly, the present invention allows obtaining a family of economically competitive flake graphitic cast irons with improved mechanical properties. These materials can be manufactured by following a common methodology (without special production requirements) and need minor addition of a specific element (Ti).

Brief Description of the Drawings

[0026] To complement the description that is being made and for the purpose of aiding to better understand the features of the invention according to several preferred practical embodiments thereof, a set of drawings is attached as an integral part of said description in which the following has been depicted with an illustrative and non-limiting character:

Figure 1 shows an optical metallography of a flake graphitic cast iron prepared according to the present invention.

Figure 2 shows a metallography obtained by means of scanning electron microscopy of a flake graphitic cast iron with superfine graphite prepared according to the present invention.

Detailed Description of the Preferred Embodiments of the Invention

[0027] As has been mentioned, the present invention allows obtaining a family of economically competitive flake graphitic cast irons with improved mechanical properties. These materials can be manufactured by following a common methodology (without special production requirements) and need minor addition of only a specific element which is titanium (Ti).

[0028] Particularly the materials of the present invention allow reaching tensile strength values greater than 300 MPa, elastic limits greater than 250 MPa and hardnesses less than 200 HBW, following a manufacturing methodology similar to that commonly used, i.e., a molten alloy is prepared but the chemical composition thereof is that specified below:

from 3.2 to 3.6% by weight of C;
from 1.8 to 2.2% by weight of Si,
from 0.1 to 0.8% by weight of Mn,
up to 0.02% by weight of S,
up to 0.1% by weight of P
from 0.15 to 0.60% by weight of Ti
the rest of the composition is iron and traces of other elements.

[0029] The alloy is then inoculated in casting vein with an inoculant material, adding between 0.05 and 0.25% by weight with respect to the amount of alloy cast in a sand mold.

[0030] The grain size of the inoculant product is preferred to be from 0.1-0.5 mm and its chemical composition, the following:

- Si = 60-75%;
- Al = 0.02-3.90%;
- Ca = 0.3-4.5%;
- Bi = <2.5%;
- Ba = <2.5%;
- Zr = <2.5%;
- Sr = <2.5%;
- Rare earth elements = <4.5%

the rest of the chemical composition Fe and other minor residual elements.

[0031] The molten alloy is cast in the following step using any conventional means. The ways of casting are essentially with an automatic casting system or using semiautomatic or manual ladles and pouring the alloy into the mold.

[0032] The mold used is made of sand (chemical molding or green sand moulding). Any flow mark capable of manufacturing (horizontal or vertical) sand molds can be used.

[0033] An advantage of the present invention is that the number of chemical alloying elements is reduced because only Ti is used as strengthening agent for strengthening the metal core.

[0034] Another advantage of the present invention is that alloys with high equivalent carbon contents is worked with, which show lower shrinkage capacity in the solidification process (minimizing shrinkage defects) and their behaviour during the part machining operations is clearly more favorable due to the presence of a higher amount of precipitated graphite.

[0035] The materials of the present invention are oriented to the manufacturing of parts from flake graphitic cast iron which are mainly intended for the sectors of automation (disc brake, casings, steering wheels, engine blocks), machine-tool (bed plates) and/or in the manufacturing of pulleys, valve bodies, etc. Currently, a considerable number of parts are manufactured using flake cast irons containing high contents of the alloy elements Cu, Mo, V, Sn, Sb, etc. The present invention offers a group of alloys with improved mechanical properties forming a cheaper and simpler alternative for the conventional materials.

[0036] The invention will be better understood from the following examples having only illustrative and non-limiting character of the invention.

Example 1: not according to the invention

[0037] A cast iron load which consisted of 15 kg ingot and 85 kg low S content returns was prepared. Said load was introduced in a medium frequency induction furnace (250 Hz, 100 Kw) with a 100 kg capacity. The objective composition was 3.4% C and 2.1% Si. After having been melted and the temperature being increased to 1500°C, the metal was transferred to a 50 kg ladle in order to cast the alloy prepared in two molds. Each of these molds configures a standard Type II wedge (according to EN-1563 standard).

[0038] Before casting, an amount of 0.2% by weight of inoculant with the following composition (68.1% Si; 1.65% Ca; 0.89% Al; 0.45% Bi; 0.38% Ba; 0.37% RE) was deposited at the bottom of the molds.

[0039] After ending the casting, the remaining alloy contained in the ladle was returned to the furnace. In this step, the carbon content was adjusted and 75 g FeTi (65% Ti) were added. The temperature of the resulting alloy was elevated and the latter was transferred again from the furnace to the casting ladle in order to cast a second pair of molds. The method was repeated two more times with addition of 200 g FeTi each time. Finally, 5 kg ingot and 35 kg returns from the spheroidal graphitic cast iron were added for the purpose of reducing the Ti content to half.

[0040] Cylindrical test pieces of 10 mm were prepared from each of the wedges manufactured for the purpose of conducting tensile tests (tensile strength, elastic limit and elongation). Metallographic analyses and analyses by scanning electron microscopy on the rupture of the tested test pieces were also performed.

[0041] The chemical composition of the alloy in each ladle as well as the statistical average of mechanical properties (tensile strength - UTS in MPa, elastic limit in MPa and elongation in %) are presented in Table 2. The equivalent carbon content (CE) was calculated using the following equation $CE = \%C + 0.31 \times \%Si - 0.027 \times \%Mn$.

Table 2

Ladle	CE	C	Si	Mn	P	S	Cu	Ti	UTS	YS	EI	HB
1	4.05	3.43	2.06	0.53	0.018	0.007	0.11	0.017	168	134	0.7	150
2	4.02	3.40	2.05	0.53	0.016	0.008	0.11	0.073	199	159	0.5	160
3	3.98	3.37	2.02	0.53	0.016	0.008	0.12	0.190	334	297	0.4	185
4	3.96	3.34	2.03	0.50	0.017	0.008	0.11	0.400	345	282	0.7	200
5	4.08	3.46	2.04	0.52	0.017	0.008	0.10	0.200	327	275	0.7	185

[0042] It was observed that, in the presence of a very low sulfur content (<0.01% by weight) and high Ti content (0.2-0.4% by weight), the tensile strength increases from 170 to 327-345 MPa, with a slight increase of hardness.

[0043] The morphology of the graphite obtained is presented in Figures 1 and 2. It is observed that the graphite is extremely thin with type D and coral type flake distributions.

[0044] In view of this description and the set of drawings, the person skilled in the art would understand that the embodiments of the invention which have been described can be combined in multiple ways within the object of the invention.

Claims

1. Flake graphite cast iron **characterized in that** it comprises the following composition:

from 3.2 to 3.6% by weight of C;
 from 1.8 to 2.2% by weight of Si,
 from 0.1 to 0.8% by weight of Mn,
 up to 0.02% by weight of S,
 up to 0.1 % by weight of P
 from 0.15 to 0.60% by weight of Ti
 the rest of the composition being iron and traces of other elements.

2. Flake graphite cast iron of claim 1, **characterized in that** it comprises a ratio of primary austenite with respect to the eutectic phases of 0.3 to 0.5.
3. Flake graphite cast iron of claim 1 or 2, **characterized in that** it has graphite separations giving rise to a superfine morphology.
4. Flake graphite cast iron of any of claims 1 to 3, **characterized in that** it has a tensile strength greater than 300 MPa.
5. Flake graphite cast iron of any of claims 1 to 4, **characterized in that** it has a hardness less than 200 HBW.
6. Composition of any of claims 1 to 5, **characterized in that** it comprises:
 - 3.4% by weight of C,
 - 2.05% by weight of Si,
 - 0.53% by weight Mn;
 - 0.008% by weight of S;
 - 0.017% by weight of P and
 - from 0.19 to 0.4% by weight of Ti.

Patentansprüche

1. Gusseisen mit Lamellengraphit, **dadurch gekennzeichnet, dass** es die folgende Zusammensetzung aufweist:
 - von 3,2 bis 3,6 Gewichtsprozent C,
 - von 1,8 bis 2,2 Gewichtsprozent Si,
 - von 0,1 bis 0,8 Gewichtsprozent Mn,
 - bis zu 0,02 Gewichtsprozent S,
 - bis zu 0,1 Gewichtsprozent P
 - von 0,15 bis 0,60 Gewichtsprozent Ti
 - wobei der Rest der Zusammensetzung Eisen und Spuren von anderen Elementen ist.
2. Gusseisen mit Lamellengraphit nach Anspruch 1, **dadurch gekennzeichnet, dass** es ein Verhältnis von Primäraustenit zu den eutektischen Phasen von 0,3 bis 0,5 hat..
3. Gusseisen mit Lamellengraphit nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** es Graphitausscheidungen hat, welche eine superfine Morphologie erzeugen.
4. Gusseisen mit Lamellengraphit nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** es eine Zugfestigkeit von mehr als 300 MPa hat.
5. Gusseisen mit Lamellengraphit nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, dass** es eine Härte von weniger als 200 HBW hat.
6. Zusammensetzung nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** sie folgendes aufweist:
 - 3,4 Gewichtsprozent C,
 - 2,05 Gewichtsprozent Si,
 - 0,53 Gewichtsprozent Mn;
 - 0,008 Gewichtsprozent S;

0,017 Gewichtsprozent P; und
von 0, 19 bis 0,4 Gewichtsprozent Ti.

5 **Revendications**

1. Fonte grise de graphite en paillettes, **caractérisée en ce qu'elle** comprend la composition suivante :

10 de 3,2 à 3,6 % en poids de C ;
 de 1,8 à 2,2 % en poids de Si,
 de 0,1 à 0,8 % en poids de Mn,
 jusqu'à 0,02 % en poids de S,
 jusqu'à 0,1 % en poids de P,
15 de 0,15 à 0,60 % en poids de Ti,
 le restant de la composition étant constitué de fer et de traces d'autres éléments.

2. Fonte grise de graphite en paillettes selon la revendication 1, **caractérisée en ce qu'elle** comprend un rapport d'austénite primaire par rapport aux phases eutectiques de 0,3 à 0,5.

20 3. Fonte grise de graphite en paillettes selon la revendication 1 ou 2, **caractérisée en ce qu'elle** a des séparations en graphite donnant naissance à une morphologie superfine.

4. Fonte grise de graphite en paillettes selon l'une quelconque des revendications 1 à 3, **caractérisée en ce qu'elle** a une résistance à la traction supérieure à 300 MPa.

25 5. Fonte grise de graphite en paillettes selon l'une quelconque des revendications 1 à 4, **caractérisée en ce qu'elle** a une dureté inférieure à 200 HBW.

30 6. Composition selon l'une quelconque des revendications 1 à 5, **caractérisée en ce qu'elle** comprend :

 3,4 % en poids de C,
 2,05 % en poids de Si,
 0,53 % en poids de Mn ;
 0,008 % en poids de S ;
35 0,017 % en poids de P et
 de 0,19 à 0,4 % en poids de Ti.

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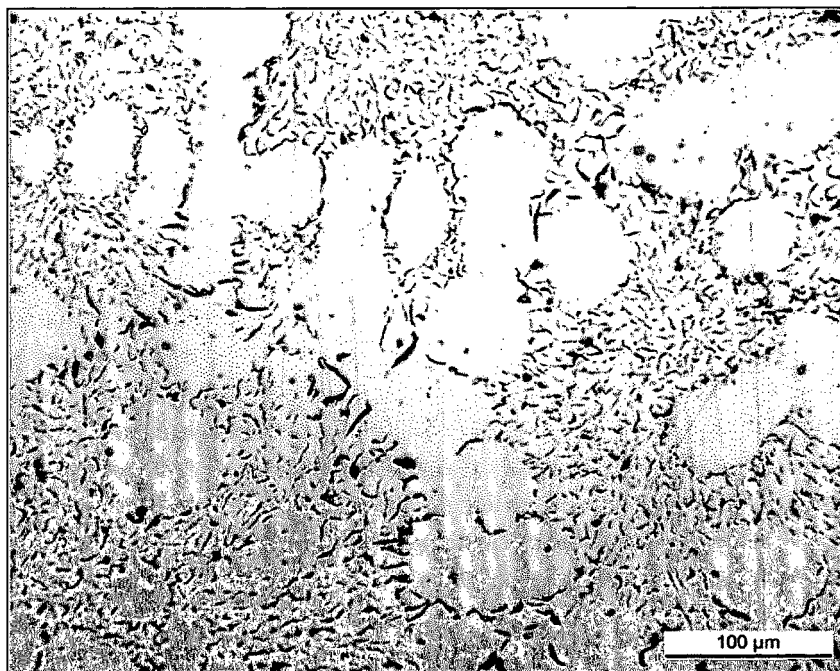


FIG. 1

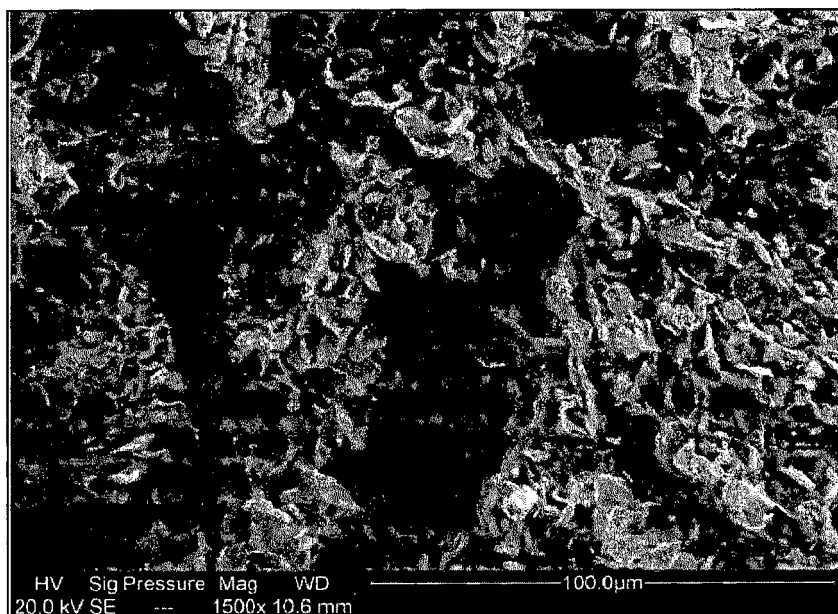


FIG. 2

REFERENCES CITED IN THE DESCRIPTION

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