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(71) Applicant: **AB VOLVO**
Torslanda
S-405 08 Göteborg(SE)

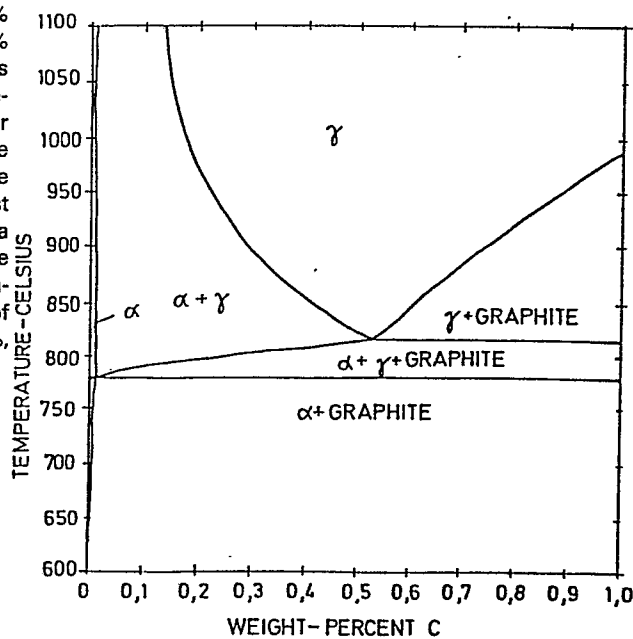
(72) Inventor: **Stenfors, Sven-Eric**
Viborgska Vägen 17
S-122 37 Enskede(SE)

(74) Representative: **Ekelöf, Carl Herman et al,**
H ALBIHNS PATENTBYRA AB Box 7664
S-103 94 Stockholm(SE)

(54) **A method for manufacturing austempered spheroidal graphite iron.**

(57) A method for producing austempered spheroidal graphite iron having a microstructure comprising bainite, ferrite and austenite. A nodular-iron casting containing 2-3.5% Si, 0-2% Mn, 0-5% Ni 0-0.3% Sn, 0-0.03% Cr, 0-3% Mo, 0-1.5% Cu, and 3.3-3.8% C and at most 0.08% P and 0-0.15% S is partially austenitized by heat treatment at a temperature beneath the temperature at which austenite and graphite or austenite are in equilibrium, but within the temperature range in which ferrite, austenite and graphite are in equilibrium. The temperature of the casting is then rapidly lowered by at least 100 K min⁻¹, and is held at a constant temperature within a range of 235 and 425°C, wherewith part of the austenite formed is converted to bainite to provide a casting that includes a bainite structure with a residual austenite content of 5-40%, preferably 15-20%, and a ferrite content of 10-15%, preferably 20-40%.

IRON ALLOY 2,7% SILICON; 0,2% MANGANESE



A method for manufacturing austempered spheroidal graphite iron.

The present invention relates to a method for manufacturing a novel material of the spheroidal graphite iron kind possessing good mechanical strength and working properties.

Obviously, it is highly beneficial to be able to cast products which exhibit good properties, since cast products require far less machining work during manufacture than do forged products or products produced by machine cutting operations. Consequently, there has been developed a cast iron in which the carbon present is precipitated out as graphite nodules upon solidification, through the action of nodulizing additives, such as magnesium. This material is known as spheroidal graphite iron or nodular iron and has far better strength properties than products made of grey iron with graphite precipitated in flake form. Cast iron can also be produced with the carbon bound as cementite, which provides a hard, brittle and extremely difficultly worked product.

Spheroidal graphite iron thus possesses good qualities, which can be further improved by hardening. Consequently, attention has been directed towards the possibility of hardening spheroidal graphite iron in a manner to obtain a phase having a bainite structure. Bainite comprises a mixture of ferrite and cementite. Austempering to a bainite structure is effected by subjecting a casting having a ferritic and perlitic basic structure to an austenitic process (austenitization). The material is then cooled rapidly to a point above the martensite point (M_s), whereafter the austenite is converted isothermally to bainite. There is normally obtained an austenite residue of from 10-50%, which is considered to have a favourable effect on the mechanical properties. Spheroidal graphite

iron which has been austempered is used, for example, in the gears of vehicle engines, and experiments are being made with the use of austempered spheroidal graphite iron in the crank shafts of petrol driven engines, where it has previously been necessary to forge the crank shafts. A bainite structure can also be obtained, of course, by regulating the cooling process during a casting operation in a manner which enables a bainite structure to be obtained.

It is normally difficult to machine or otherwise work solidified spheroidal graphite iron, which incorporates a bainite structure. Such machining is necessary when manufacturing components with narrow measurement tolerances, such as gears and rotating engine components, since hardening always results in changes in dimensions. Obviously, there is a need for a spheroidal graphite iron which can be more readily worked subsequent to being austempered with the remaining desirable properties unchanged, and which can be used as a substitute material for forged engine components for example.

Thus, austempering is effected by austenitization, to obtain smoother carbon distribution and an adapted carbon content in the basic material, i.e. material between and at a given distance from the precipitated nodular graphite. The cast austenitized component is then rapidly cooled to a temperature above the martensite conversion M_s . The component is then maintained at this temperature for a period of time sufficient to permit total and partial isothermal conversion of the basic mass to bainite in a suitable medium. The formation of bainite can be controlled by suitable determination of the carbon content and the soaking temperature. Subsequent to completing isothermal bainite formation process, the spheroidal graphite iron casting is allowed to cool in air, wherewith a part of the

residual austenite will convert to martensite. The basic material then consists of bainite, residual austenite, and with short soaking times martensite. Austenitization is preferably effected in a salt bath or furnaces, and the isothermic conversion normally in a salt bath, and at lower temperatures in an oil bath.

The conversion to bainite is effected in two stages, in which there is first precipitated ferrite as Widmanstätten ferrite at not too low temperatures, whereafter cementite and ferrite is precipitated therebetween. The formation of ferrite causes the carbon content of the residual austenite to increase. Silicon has a delaying effect on the bainite conversion, which first results in a constant residual austenite content, which is then converted to bainite at longer isothermic conversion times. The time taken to obtain a bainite structure can be reduced by lowering the silicon content, although a certain amount of silicon is required to obtain solidification to grey iron.

According to GB-A-2 133 805 a ferrite-bainite cast iron with spheroidal graphite is produced by austenizing at a temperature such that the material comprises a mixture of ferrite and austenite after the austenitization process. According to this patent a spheroidal graphite iron is produced by smelting an iron alloy containing 3.0-3.6% carbon, 3.5-5.0 % silicon, 0.7-5.0% nickel, 0-0.3% molybdenum, 0.2-0.4% manganese, less than 0.015% sulphur and 0.06% phosphorus, the resultant molten bath being allowed to cool in the presence of a nodulizing agent. The solidified cast iron is then heated to a temperature of 855-900°C for 1-3 hours, whereafter the bath is cooled with an effect of at least 152°C min⁻¹ to 205-400°C and is held at this temperature for 0.5-4 hours, whereafter it is cooled to room temperature. It is evident from the patent specification that a ferrite-bainite structure

was not obtained when the silicon content was below 4% or the nickel content below 0.7%, or when the isothermic treatment exceeded or fell short of the stipulated time interval.

It has now been found possible, in accordance with the invention, to obtain an austempered spheroidal graphite iron having a microstructure of bainite, ferrite, and residual austenite although with negligible martensite content, and possessing extremely good working properties and extremely good strength properties, which enable austempered spheroidal graphite iron to be utilized economically as a material for the manufacture of machine and engine components, such as gears and crank shafts, with respect to both mechanical strength and economic manufacturability. In accordance with the invention there is austenitized a cast product manufactured from an iron alloy containing 2-3.5% silicon, 0.2% manganese, 0-5% nickel, 0-0.3% tin, 0-0.3% chromium, 0-3% molybdenum, 0-1.5% copper, 3.3-3.8% carbon, and at most 0.08% phosphorus and 0.015% sulphur, partly by heat treating the casting at a temperature beneath the level at which austenite and graphite, or just austenite are in equilibrium, but within the temperature range in which ferrite, austenite and graphite are in equilibrium, and then rapidly lowering the temperature of the casting by at least 100 Kmin^{-1} , and thereafter holding the casting at a constant temperature for 0.5 to 4 hours, this temperature being between 235 and 425°C , wherewith part of the austenite formed is converted to bainite, to provide a casting containing a bainite structure with a residual austenite content of 5-40% and a ferrite content of 10-50%.

Figure 1 is an iron-carbon diagram of an alloy containing 2.7% silicon and 0.2% manganese. As is normal practice, the sign α represents ferrite and the sign γ austenite. It

will be seen from the diagram that an area is formed in which ferrite, austenite and graphite are in equilibrium within an area corresponding to the line A, in the iron-carbon diagram. The magnitude and precise location of this three-phase area varies with the composition of the iron, and silicon and the manganese content are therewith of particular significance. The existence of this area is well known to those skilled in this art, although the realization of its significance when austempering spheroidal graphite iron, to obtain a bainite structure, is an important contribution to the art. It is possible with knowledge of Gibbs free energies to calculate thermodynamically the location of the three-phase area for a given composition.

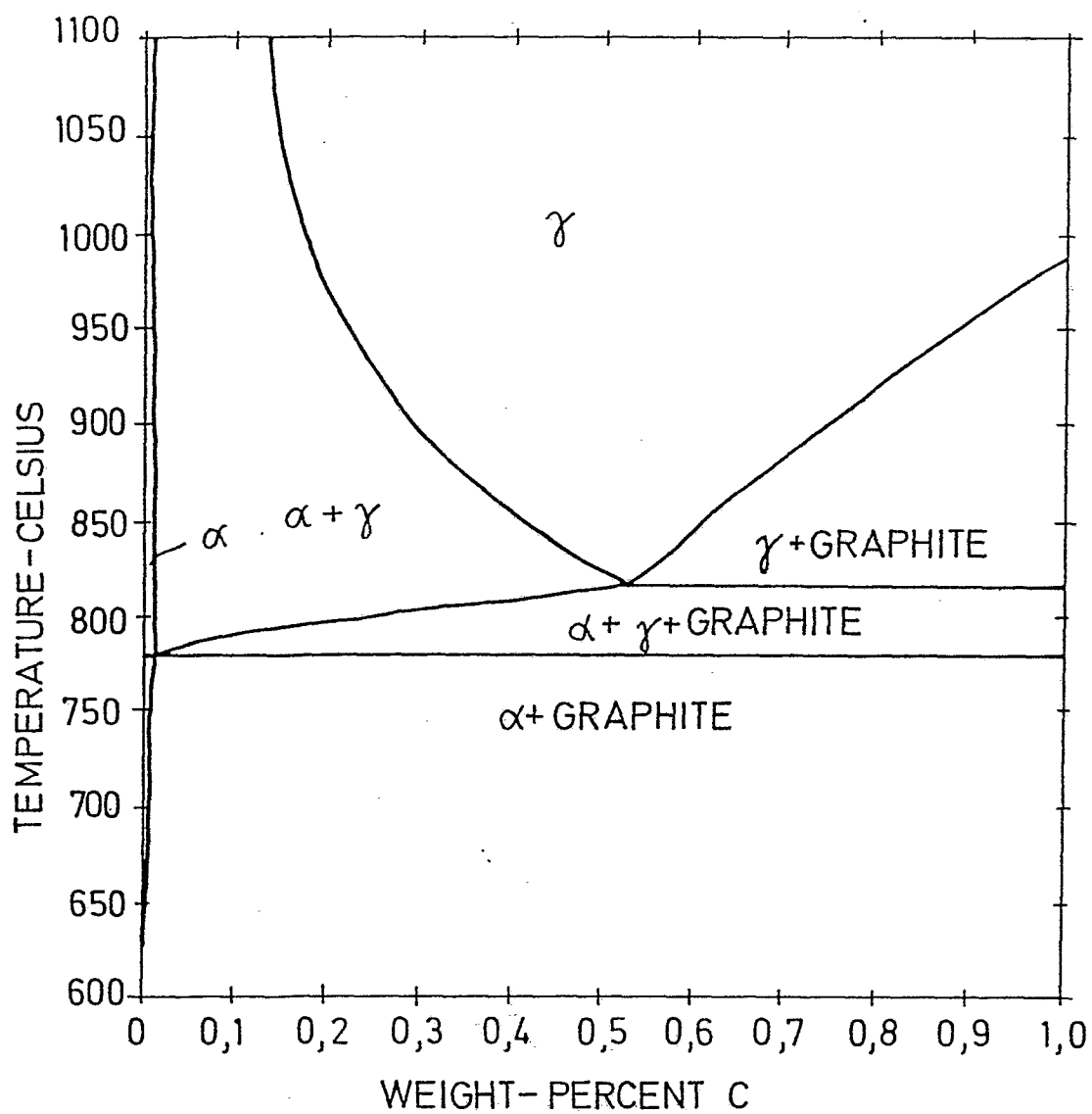
A higher silicon content results in a broader three-phase area, and hence the silicon content suitably lies within 2.7-4.5% by weight, preferably within 3.0-3.6%. The higher silicon contents, however, render the material more difficult to machine or cut, due to solution annealing of the ferrite present. The manganese content increases the three-phase area and, in accordance with the invention, is preferably held between 0 and 2%. Subsequent to austenitization, the temperature of the casting is lowered at a rate corresponding to at least 100 K min^{-1} , and is thereafter held at a constant temperature of between 285 and 425°C for sufficient length of time for part of the austenite formed to convert to bainite, therewith providing a casting which incorporates a bainite structure with a residual austenite content of 5-40%, preferably 15-20%, and a ferrite content of 10-50%, preferably 20-40%.

CLAIMS

1. A method for producing an austempered spheroidal graphite iron having a microstructure comprising bainite, ferrite and austenite, characterized in that a spheroidal graphite iron casting containing 2-3.5% Si, 0-2%Mn, 0-5% Ni, 0-0.3% Sn, 0-0.3% Cr, 0-3% Mo, 0-1.5% Cu and 3.3-3.8% C and at most 0.08% P and 0.015% S is partially austenitized by heat treatment at a temperature beneath the temperature at which austenite and graphite or austenite are in equilibrium, but within the temperature range in which ferrite, austenite and graphite are in equilibrium, whereafter the temperature of the casting is rapidly lowered by at least 100 K min^{-1} , and is then held at a constant temperature for 0.5 to 4.0 hours, this temperature being 235 to 425°C , wherewith part of the austenite formed is converted to bainite to provide a casting that includes a bainite structure with a residual austenite content of 5-40% and a ferrite content of 10-50%,
2. A method according to Claim 1, characterized in that the residual austenite content is caused to lie between 15 and 20%.
3. A method according to Claim 1, characterized in that subsequent to austenitization there remains a ferrite content of 20-40%.

1/1

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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	EP-A1-O 018 445 (MÜHLBERGER, HORST DR.) ---	1-3	C 21 D 5/00
X	PATENT ABSTRACTS OF JAPAN, Vol. 8, No. 150(C-233) /15877, 12th July 1984 & JP-A-59 56518 (HONDA GIKEN KOGYO K.K.) 02-04-1984 *Abstract*		
P	EP-A2-O 144 907 (NISSAN MOTOR COMPANY, LIMITED) ---		
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			C 21 D
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
STOCKHOLM		19-08-1986	DAHL B.
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			