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The present invention relates to a spheroidal graphite cast iron alloy.

In the state of the art, gear rims are known which for example are used for transmitting a drive torque to a milling machine. These rims are in spheroidal graphite cast iron or in steel.

In the state of the art, spheroidal graphite cast iron gear rims are calculated either according to the AGMA 6014 (6114 respectively) standard or according to the ISO 6336 standard.

According to the ISO 6336 standard, the maximum admissible stresses are given according to the curves of part 5 of this same standard, curves of σ_{Hlim} (pressure stress) and σ_{Flim} (root flexural stress of the gear tooth), versus hardnesses. The higher the hardness, the higher are the maximum admissible stresses and therefore the larger is the power which may be transmitted by the gear rim.

In present curves from ISO 6336, the hardness range extends up to 300HB, the produced grades are according to the EN 1563 standard – spheroidal graphite cast iron grades – in which grades with a tempered ferritic, pearlitic and martensitic matrix are only taken into consideration.

For calculations according to the AGMA 6014 (6114 respectively), references are made to the material standards ASTM A536 and ISO 1083. The curves giving admissible stresses versus hardness are given up to about 340HB. But for high hardnesses, there are no corresponding grades in the standards.

The present cast iron grades give the possibility of obtaining at best hardnesses of 320HB on gear rims. For very large powers, they reach their limit of use and presently the only solution is to change the material by passing to cast steel. The 320HB hardnesses of present cast irons are obtained by quenching followed by tempering.

There also exist grades according to EN 1564 – spheroidal graphite cast iron grades obtained by staged quenching, so-called ADI cast irons – for which the values of σ_{Hlim} and σ_{Flim} are also defined depending on hardness intervals. Staged quenching is achieved in a bath of salts. In order to produce gear rims, it will be necessary to be equipped with pans of large dimensions.

The object of the invention is to give the possibility of manufacturing a cast iron part, for which transmissible power is significant. In particular, the object of the invention is to give the possibility of manufacturing a cast iron part, such as a gear rim, notably of large size, in spheroidal graphite cast iron. The goal is to develop an alloy grade which attains these criteria in particular with simple and economical heat treatment means.

For this purpose, the object of the invention is an alloy as indicated in claim 1.

According to particular embodiments, the alloy includes one or more of the features indicated in claim 2 to 5.

The object of the invention is also a part manufactured in an alloy as described above, the part being defined in claim 6 to 9.

The invention also relates to methods for manufacturing a part, defined in claims 10 to 13.

The invention will be better understood upon reading the description which follows, only given as an example.

The object of the invention is a spheroidal graphite cast iron alloy. It gives the possibility of obtaining high hardnesses and therefore high admissible stresses, notably on large size parts.

The part for example is a cogwheel or a gear rim or a gear wheel or a gear crown. The part is preferably a part of a large dimension, i.e. having the largest dimension of the part of at least 2,000mm. Preferably, the part has an outer diameter of at least 2,000mm, or of at least 3,000mm, or of at least 6,000mm. The axial thickness, generally the width of the teeth, the largest of the part is for example of at least 150mm, or of at least 250mm, or of at least 550mm. A gear rim according to the invention has a rim thickness of at least 80mm or of at least 120mm or of at least 150mm and a modulus of at least 10 or of at least 16 or of at least 22 or of at least 25.

Preferably, the high hardness is obtained with a tempering heat treatment. The hardness depends on the composition of the alloy and optionally on various heat treatments which the part undergoes during its elaboration, whether this be during cooling after casting or during subsequent ovenings.

All the indications are subsequently given in % by weight of the total weight.

A first aspect of the invention is the chemical composition of the alloy.

The alloy is cast iron with spheroidal graphite.

Its basic composition is iron, addition elements and inevitable impurities. The addition elements are carbon (C), silicon (Si), and magnesium (Mg). The element which forms the remainder of the alloy is therefore iron (Fe).

Generally, the alloy comprises, in addition to the basic composition, nickel (Ni) between 4.1% and 7%, copper (Cu) between 0.5% and 3% and molybdenum (Mo) between 0.15% and 0.8%.

Further, the alloy comprises manganese (Mn) up to 1% or up to 0.8%.

Further, the alloy comprises chromium (Cr) up to 0.4%.

Further, the alloy comprises carbon (C) between 2.5% and 4% and silicon (Si) between 1.5% and 4.4%.

The nickel (Ni) content of the alloy may be at least 4.2%, 4.3%, 4.4%, 4.5%, or 4.8% and at most 7%, 6.5%, 6%, or 5.8%.

The molybdenum (Mo) content may be comprised between at least 0.15%, 0.25%, or 0.3% and at most 0.8%, or 0.5%.

The copper (Cu) content may be comprised between at least 0.5%, 1%, or 1.5%, or at most 3%, 2.5%, or 2.2%.

It is to be noted that the low limits and high limits of the above contents are independent one from another. The Nickel content can therefore be for example comprised between 4.4% and 7%.

The carbon (C) content may be comprised between 3% and 3.6%.

The silicon (Si) content may be comprised between 1.8% and 2.4%.

The chromium (Cr) content may be less than 0.2%.

The manganese (Mn) content may be greater than 0.2%.

The alloy according to the invention can consist of the above elements, whereby manganese (Mn), and/or chromium (Cr) and/or phosphorus (P) and/or sulfur are/is optional element/s or present in traces.

According to the example, the alloy comprises in addition to iron (Fe) and inevitable impurities, the following elements, within the limits shown:

	C	Si	Ni	Mo	Cu	Mn	Cr	Mg	P	S
Min.	2.5	1.5	3.5	0.15	0.5			0.02		
Max.	4	4.4	7	1	3	1	0.4	0.1	0.04	0.015

As an example, the hardness that can be obtained with the alloy according to the invention is indicated in the following table, as a function of the chemical composition, other than the basic composition.

	Ni	Mo	Cu	C	Si	Mn
HB 320	4.3-5.6	0.3-0.45	1.5-2	3.3-3.45	1.8-2	0.3-0.6
HB 330	4.6-5.9	0.3-0.45	1.5-2	3.3-3.45	1.8-2	0.3-0.6
HB 340	4.7-6	0.3-0.45	1.5-2	3.3-3.45	1.8-2	0.3-0.6
HB 350	4.8-6.1	0.35-0.5	1.5-2	3.3-3.45	1.8-2	0.3-0.6
HB 360	4.9-6.2	0.35-0.5	1.5-2	3.3-3.45	1.8-2	0.3-0.6

A second aspect of the invention is the method for manufacturing a part in an alloy according to the invention.

First of all, the part is cast into a mold.

Once the part is cast, it undergoes cooling, notably slow cooling, in its mold, notably until ambient temperature (<50°C). The part is then subject to a heat treatment. The term of « slow » means less than 100°C/h, 80°C/h or 50°C/h. The slow cooling takes preferably place over the whole cooling period.

The heat treatment consists of tempering. It is a bulk heat treatment, it gives the possibility of obtaining the desired hardness and indicated above over the whole thickness of the part. The hardness therefore does not extend over only a few millimeters at the surface.

The part is then machined, notably by turning and in the case of a gear rim, the teeth are cut.

The HB hardness of the alloy according to the invention and notably of the spheroidal graphite cast iron is comprised between 320HB and 400HB. The part in this alloy thus gives the possibility of transmitting very great powers.

The obtained metallographic structure of the alloy consists of 90% of nodules of type VI or V (according to EN ISO 945-1) and of a bainitic matrix which may include residual austenite (up to 10%), carbides (up to 5%), tempered martensite (up to 5%) and pearlite (up to 20%).

The obtained characteristics on a cast sample, side by side, are the following:

Sample	Thickness (mm)	Mechanical properties				
		Ultimate tensile strength (MPa)	Min. 0.2 yield strength (MPa)	Min. elongation (%)	Ultimate foot fatigue strength σ_{Flim} (N/mm²)	Ultimate flank fatigue strength σ_{Hlim} (N/mm²)
Sample 1 (Type HB 320)	≥80	850	570	1	256-330	730-840
Sample 2 (Type HB 330)	≥80	860	580	1	259-306	745-855
Sample 3 (Type HB 340)	≥80	880	600	1	263-310	760-870
Sample 4 (Type HB 350)	≥80	890	610	1	267-314	775-885
Sample 5 (Type HB 360)	≥80	910	630	1	271-318	790-900

The ultimate fatigue strengths are given for a calculation according to ISO 6336.

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Patentkrav

1. Kuglegrafit-støbejernslegering, som i vægt% består af følgende bestanddele:

- carbon (C) mellem 2,5% og 4%,
- silicium (Si) mellem 1,5% og 4,4%,
- magnesium (Mg) mellem 0,02% og 0,1%,
- nikkel (Ni) mellem 4,1% og 7%,
- kobber (Cu) mellem 0,5% og 3%,
- molybdæn (Mo) mellem 0,15 og 0,8%,
- mangan (Mn) ≤ 1%,
- krom (Cr) ≤ 0,4%,
- fosfor (P) ≤ 0,04%,
- svovl (S) ≤ 0,015%,

hvor resten er jern (Fe) og uundgåelige urenheder.

2. Legering ifølge krav 1, hvor indholdet af mangan (Mn) er ≤ 0,8%.

3. Legering ifølge et hvilket som helst af de foregående krav, hvor indholdet af nikkel (Ni) er mindst 4,2%, 4,3%, 4,4%, 4,5% eller 4,8% og højst 7%, 6,5%, 6% eller 5,8%.

4. Legering ifølge et hvilket som helst af de foregående krav, hvor indholdet af kobber (Cu) er mindst 0,5%, 1 % eller 1,5% og højst 3%, 2,5% eller 2,2%.

5. Legering ifølge et hvilket som helst af de foregående krav, hvor indholdet af molybdæn (Mo) er mindst 0,15%, 0,25% eller 0,3% og højst 0,8% eller 0,5%.

6. Stykke, fremstillet i en legering, **kendetegnet ved, at** legeringen er en legering ifølge et hvilket som helst af de foregående krav, og i særdeleshed er stykket et tandhjul eller især en tandkrans.

7. Stykke ifølge krav 6, **kendetegnet ved, at** stykket er et stykke af store dimensioner, dvs. den største dimension af stykket er mindst 2000mm.

8. Stykke ifølge et hvilket som helst af kravene 6 eller 7, **kendetegnet ved, at** hårdheden HB af kuglegrafitstøbejernet ligger mellem 320HB og 400HB.

9. Stykke ifølge krav 8, **kendetegnet ved, at** hårdheden strækker sig over hele stykkets tykkelse.

10. Fremgangsmåde til fremstilling af et stykke ifølge et hvilket som helst af kravene 6 til 9, **kendetegnet ved** de følgende trin:
- støbe et råt støbejernstykke i en form,
- afkøle det rå støbejernstykke, især i form, for at opnå stykket.

11. Fremgangsmåde ifølge krav 10, hvor det rå støbejernstykke varmebandles, især med en anløbning.

12. Fremgangsmåde ifølge et af kravene 10 eller 11, hvor trinnet med afkøling af stykket er et trin med langsom afkøling, især mindre end 100°C/h, 80°C/h eller 50°C/h.

13. Fremgangsmåde ifølge et hvilket som helst af kravene 10 til 12, hvor afkølingen udføres til den omgivende temperatur.