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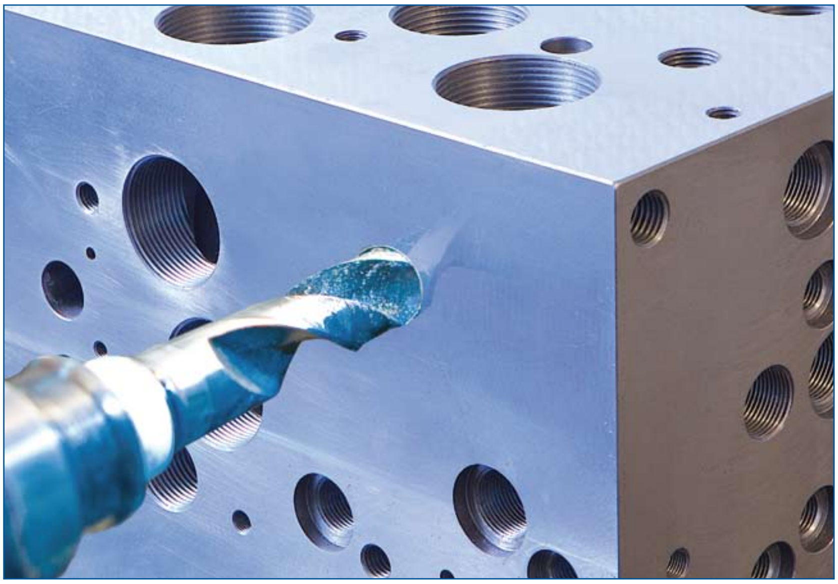
GOPAG® C 500 F

Cast material for mechanical engineering with higher strength and breaking elongation and highly homogeneous hardness distribution

1 Introduction

Meeting the demands that designers and manufacturing engineers make of a component is a special challenge for the caster. Increased strength and breaking elongation enable the designer to ensure a light component with high functionality. However, as a rule, these material properties suffer from poorer or more complicated machinability and often increase manufacturing costs substantially.



Due to cost constraints, the automobile industry has been implementing solutions that mark a turn toward modified materials for a long time now. For example, spheroidal graphite cast iron with a higher silicon content came into use in Sweden some twenty years ago, and the Swedish standard SS 140725, which lists the materials 450-15 and 500-10, was published in 1998. The highly siliconized material 500-10 was also included in the international standard ISO 1083 under the designation ISO1083/JS/500-10. German automobile manufacturers adapted components to the new material. The individual manufacturers took different paths in doing so and some patented new materials. The basis of the material with a higher silicon content has also been included in the new draft prEN 1563:2010 for spheroidal graphite cast iron as standardized material GJS 500-14. Strength and breaking elongation are improved without expensive alloying elements. The advantages of the material GOPAG® C 500 F in a hydraulic block were described from the user's point of view in an article published in the June 2010 issue of the journal fluid. The user was able to integrate the input material from Gontermann-Peipers optimally in the existing process chain. The advantages due to significantly faster drilling, lower tool wear and high process reliability led the company Power Hydraulik to also use this new material GOPAG® C 500 F for hydraulic blocks with a nominal pressure of up to 420 bar.

The fundamental principles behind spheroidal graphite cast iron with a higher silicon content and its use in industrial applications up until now are presented in the following chapters.

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2 Increasing the strength of cast iron through increased use of solid solution strengthening

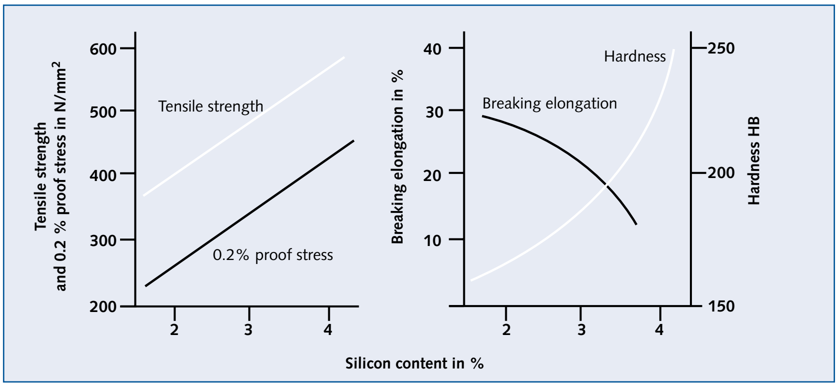
2.1. Solid solution strengthening through higher silicon concentrations

Solid solution strengthening changes the mechanical properties of crystalline solids by adding intersital or substitutional atoms; intersital or substitutional solid solutions form. Crystalline solids with a long-range atomic order have a regular crystalline structure. If solute atoms are added to the crystalline structure, the lattice is distorted. Solute atoms with a similar atomic radius replace solvent atoms in their lattice positions; substantially smaller atoms occupy an intersital site. The distortion of the lattice inhibits sliding movements in the crystal. These processes at the atomic level result in an increase in strength and a reduction in plasticity. In cast iron materials, the iron-carbon-silicon alloys, the silicon is added to the body-cantered cubic lattice of the α-solid solution (ferrite) at substitutional positions; silicon atoms replace iron atoms in the lattice. The carbon occupies intersital sites in the α-solid solutions.

2.2. Solid solution strengthening in cast iron

Solid solution strengthening in spheroidal graphite cast iron by silicon is a known fact. **Fig. 1** shows the influence of silicon content on the mechanical properties of ferritic spheroidal graphite cast iron /1/. Tensile strength, 0.2% proof stress and Brinell hardness increase as silicon content increases. Breaking elongation, on the other hand, decreases. As silicon content increases, the transition temperature shifts to higher temperatures /2/.

Fig. 1: Dependency of tensile strength, 0.2% proof stress, breaking elongation and hardness on silicon content in ferritic spheroidal graphite cast iron /1/



In spheroidal graphite cast iron as a Fe-Si-C material, solid solution strengthening already takes effect as a property forming mechanism with a silicon content of approx. 2.6%.

In ferritic spheroidal graphite cast iron according to EN 1563, breaking elongations of 15 to 22% are attained with samples taken from separately cast test specimens with tensile strengths of 350 to 400 N/mm². In connection with the material grade EN-GJS-500-7C with a minimum of 500 N/mm² and 7% breaking elongation, an interesting thought originated some 15 years ago: This type of cast iron has a metallic basic matrix consisting of a specific proportion of ferrite and perlite. It is not always possible to adjust this mixed structure of the metallic base material stably in production. The result is a relatively high variation in Brinell hardness that can lead to difficulties in machining. Development projects originated with the objective of producing the material grade EN-GJS-500-7C with a purely ferritic basic matrix through higher silicon concentrations to attain lower variations in Brinell hardness. Higher silicon concentrations inhibit perlite formation during eutectoid transformation, and stronger solid solution strengthening occurs.

For a long time, further solid solution strengthening through higher silicon concentrations was thought to be unusable because of the simultaneous tendency towards brittleness. However, more recent investigations /3 to 7/ indicate that very interesting combinations of mechanical properties can be attained with higher silicon concentrations. The results of this research and development work are described below.

2.3. Research and development work in the recent past (sand casting)

In connection with the production of large castings with wall thicknesses of 60 to 200 mm, the intention was to achieve a reduction in weight using a high-strength grade of spheroidal graphite cast iron /4/. Researchers investigated the influence of alloying elements (Cu, Mn, Ni, Mo, Si, Nb), inoculants and inoculation treatment and cooling conditions. The specimen were removed from a wedge shaped test block measuring 100 to 600 x 1000 x 500 mm. The results were checked in a press frame for an internal high-pressure forming machine with wall thicknesses of 60 to 200 mm in samples from cast-on test specimen. A spheroidal graphite cast iron with the following chemical composition led to success: 3.10% C, 3.75% Si, 0.22% Mn, 0.016% P, 0.005% S and 0.044% Mg. This resulted in a spheroidal graphite cast iron with a purely ferritic basic matrix without heat treatment.

The following mechanical properties were attained: With cast-on samples 517 - 521 N/mm² tensile strength, 413 - 417 N/mm², 0.2% proof stress, 14.0 - 14.5% breaking elongation, 20% breaking contraction, and 171.6 - 173.3 kN/mm² elastic modulus. In samples from the test block 485 - 505 N/mm² tensile strength, 393 - 395 N/mm² proof stress, 10 - 16% breaking elongation, 8.5 - 15% breaking contraction depending on the location in the test block. The tensile strength, proof stress, breaking elongation and breaking contraction within the temperature range of -80 °C to + 300 °C are reported **(Fig. 2).**

In machining of motor vehicle components consisting of the ferrtic-perlitic material grade EN-GJS-500-7 with a silicon content of 2.25%, difficulties were observed during turning, milling and drilling because of the relatively large Brinell hardness range (170 to 230 HB). However this was caused by fluctuations in perlite content because of varying rates of cooling in the castings during eutectoid transformation. Research and development of spheroidal graphite cast iron and higher silicon concentrations of (3.66 to 3.85%) led to success /3, 5/. This resulted in a material grade of spheroidal graphite cast iron with a purely ferritic metallic base material with the following mechanical properties: Tensile strength at least 500 N/mm², 0.2% proof stress at least 360 N/mm², breaking elongation at least 10% and a hardness range of 185 to 215 HB. The more homogenous distribution of hardness in the castings (plus/minus 20 HB) made it possible to reduce cutting tool wear and increase cutting speed. In addition, the noise level during machining also decreased. The cost reduction was stated to be 10%. The optimum chemical composition was stated to be as follows: 3.3% C, 3.75% Si, max. 0.3% Mn, max. 0.05% P, max. 0.03% S and 0.02 to 0.08% Mg. The following material parameters were stated as a recommendation for a new grade of spheroidal graphite cast iron: Minimum tensile strength 500 N/mm², min. 0.2% proof stress 360 N/mm², min. breaking elongation A5 10%, Brinell hardness 185 to 215. The new grade of silicon-rich spheroidal graphite cast iron GJS-500-10 with a ferritic matrix was standardized in Swedish standard SS14 07 25 „Spheroidal graphite cast iron - SS cast iron 0725“. 1998-03-18.

R. Larker /6/ dealt with solid solution strengthened ferritic spheroidal graphite cast iron for the use of such castings in hydraulically actuated equipment. With these cast components, it is necessary to attain very high manufacturing accuracy during machining. Values for tensile strength, 0.2% proof stress and breaking elongation are stated as a function of the silicon concentration within the range of 2.25 to 4.2% Si with the known tendencies that strength and hardness increase and ductility (breaking elongation), on the other hand, decreases as silicon content increases. A silicon content of 3.7% is preferred for development of a material grade with a ferritic base material. Because of the much lower variations in Brinell hardness over the casting cross-section **(Fig. 3),** – ± 2.6 through the use of material grade GJS-500-10 in comparison with ± 10 when using material grade GJS-500-7 – machinability improved by 20 to 30%. Experts caution against the formation of chunky graphite. This undesirable form of graphite substantially impairs the favourable mechanical properties in the material grade GJS-500-10.

The material grade GJS-500-10 was included in international standardization with the designation ISO 1083/JS/500-10 (2004).

Fig. 2: Influence of the test temperature on material characteristics in the tensile test /4/

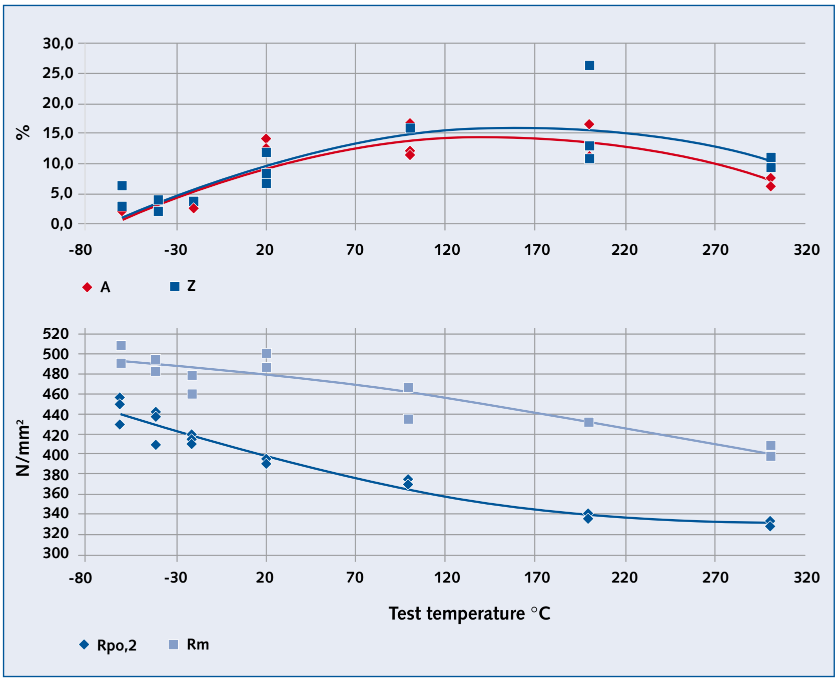


Fig. 3: Swivel housing: Distribution of the Brinell hardness over the cross-section of the casting when GJS-500-7 or GJS-500-10 is used /6/

J. Kikkert /7/ dealt, proceeding from material grade GJS-500-10, with the development of the material grades GJS-450-18, GJS-500-14 and GJS-600-10 using higher silicon concentrations of 3.5 to 5.4% Si in the spheroidal graphite cast iron. **Fig. 4** conveys an impression of the influence of the silicon content on the tensile strength and 0.2% proof stress. Solid solution strengthening has an effect until the silicon content reaches 4.5%. The breaking elongation **(Fig. 5)** decreases only slightly until silicon content reaches 4.5%, but drops sharply at higher silicon concentrations. **Fig. 6** shows the fatigue strength for a swivel bearing made of different grades of spheroidal graphite cast iron, whereby the silicon-rich material grade GJS-600-10 performs well. This leads to the conclusion that the solid solution strengthening caused by silicon can be used up to tensile strengths exceeding 600 N/mm². The representation of Brinell hardness and 0.2% proof stress **(Fig. 7)** clearly reveals that the fluctuations in Brinell hardness are significantly lower with the ferritic material grades GJS-500-14 and GJS-600-10 than with the traditional material grades GJS-500-7 and GJS-600-3. J. Kikkert /7/ therefore proposes that the material grades GJS-450-18, GJS-500-14 and GJS-600-10 be included in European standardization **(Table 02 - p. 6)** and speaks in this connection of the second generation of spheroidal graphite cast iron.

Table 01: Mechanical properties of material grade GOPAG® C 500 F for various continuous casting dimensions

Mechanical properties		
Dimension t (mm)	$60 < t \leq 120$	$120 < t \leq 400$
Tensile strength R_m (N/mm²)	490	470
Proof stress $R_{p0,2}$ (N/mm²)	370	360
Elongation A (%)	12	10

Fig. 4: Dependence of tensile strength and proof stress on silicon content in spheroidal graphite cast iron /7/

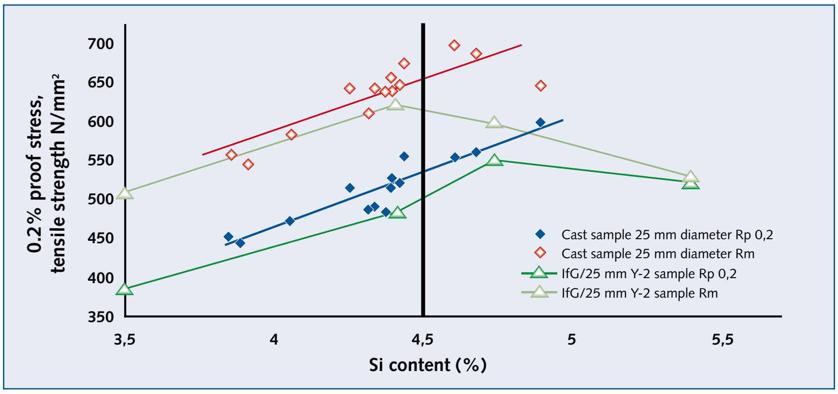


Fig. 5: Dependence of breaking elongation on silicon content in spheroidal graphite cast iron /7/

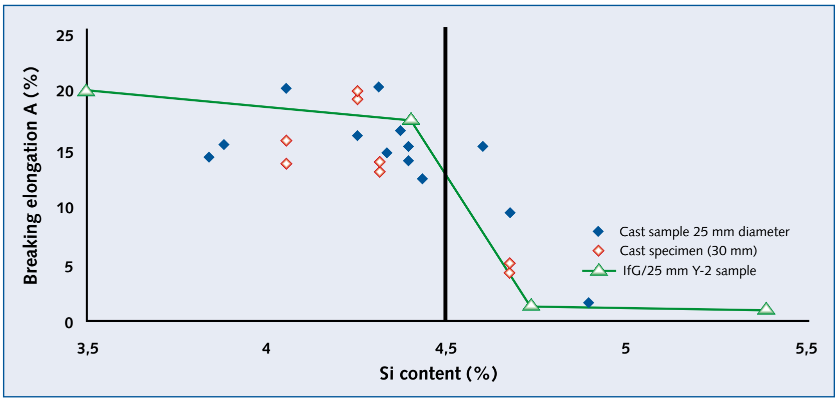


Fig. 6: Fatigue strength for a swivel bearing for the material grade GJS-600-10 compared with other material grades /7/

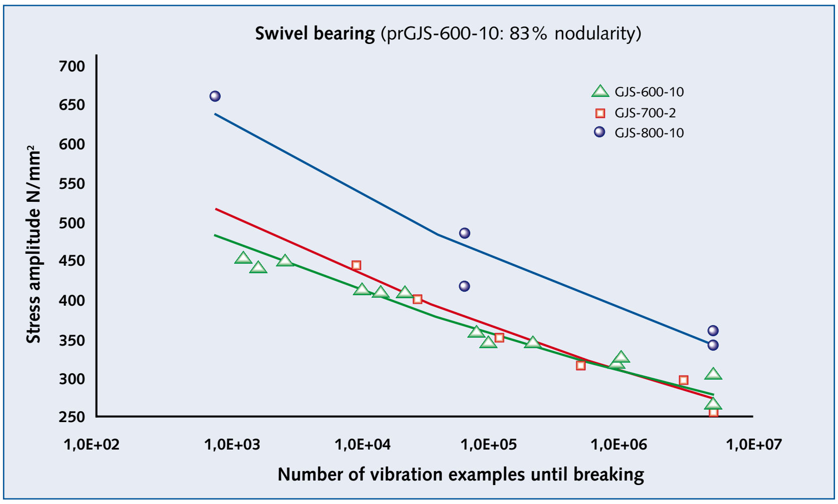
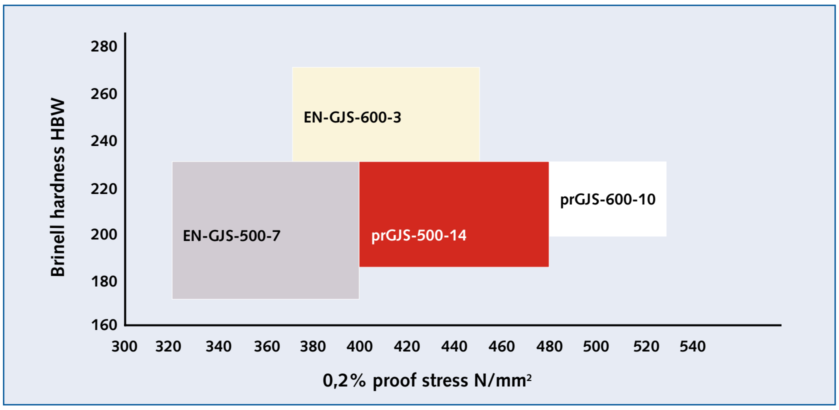


Fig. 7: Dependence of the Brinell hardness on the 0.2% proof stress for the material grades GJS-500-7 and GJS-600-3 or GJS-500-14 and GJS-600-10



3 Research and development at Gontermann-Peipers (continuous casting)

All of the previously described findings were determined in the production of castings using the sand casting process. In continuous casting of spheroidal graphite cast iron, the conditions during solidification and further cooling are different from those in the sand casting process. Continuous castings made of cast iron are produced using the horizontal continuous casting method. The procedure, the peculiarities of this method, and the attainable mechanical properties, in conjunction with a proposal for European standardization (EN), have been described in works /8, 9/. Gontermann-Peipers supplies continuous cast sections of specific lengths either unfinished or semi-finiched. Gontermann-Peipers also offers semi-finishing on all sides to nearly finished dimensions according to customer wishes. This prevents customers having to perform additional operations.

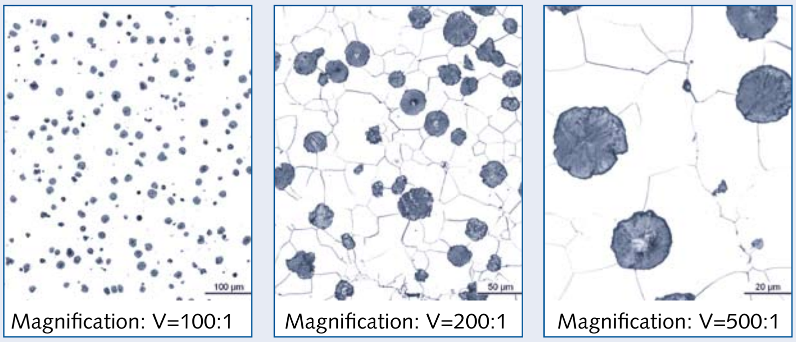
In connection with the advancement of continuous casting of spheroidal graphite cast iron with solid solution strengthening, Gontermann-Peipers (GP) presented the material grade GOPAG® C 500 F (GP-protected brand name) with a ferritic matrix in the casting state, in comparison with GJS-500-7C. **(Fig. 8). Fig. 8a** shows the microstructure of GOPAG® C 500 F with a ferritic matrix and **Fig. 8b** the microstructure of GJS-500-7C with a matrix of ferrite and approx. 30% perlite. The formation of perlite and thus the extremely hard cementite contained in it is largely inhibited by the higher silicon content. This material grade GOPAG® C 500 F complies with the specifications in European standards for spheroidal graphite cast iron, which is designated GJS-500-14C. The following non-binding reference values are stated for the chemical composition of this material grade: 2.80 to 3.80% C, 3.30 to 3.90% Si, 0.025 to 0.075% Mg, max. 0.1% Cu. In conformity with the cast iron standards DIN EN 1561 and DIN EN 1563, these details regarding the chemical analysis are non-binding manufacturer's reference values.

The samples used to determine the mechanical properties are removed directly from the strand **(Fig. 9),** marked with the letter „C" /8/. The stress-strain curves for the material grade GOPAG® C 500 F in comparison with a forged steel typically used in the hydraulics sector **(Fig.10)** clearly show the plastic range with the breaking elongation after the 0.2% proof stress. The mechanical properties attained for the new material grade are shown in **Table 01 - page 4** for various continuous casting shapes.

For the new material grade GOPAG® C 500 F, it is readily apparent that the mechanical properties can be produced within stringent tolerances on a production scale, whereby the narrow tolerance range for the breaking elongation particularly stands out.

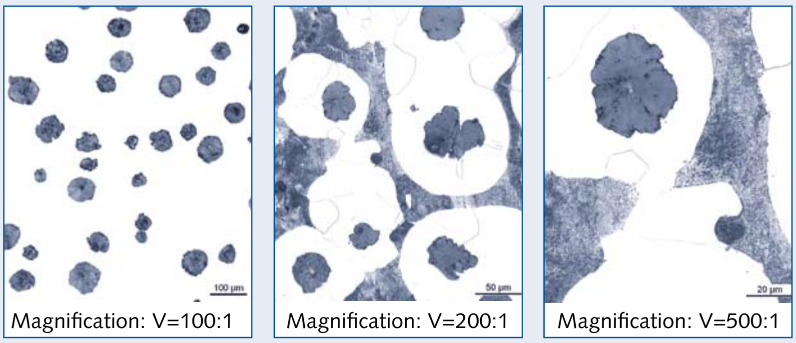
Fig. 8: Structure of continuous cast iron: a) GOPAG® C 500 F
b) Microstructure GJS-500-7C 8a

8a



Werkstoff: GOPAG® C 500 F
Gefüge: 100% ferrite
visual assessment

8b



Material: EN-GJS-500-7C
Structure: approx. 30% perlite, rest ferrite
visual assessment

Fig. 9: Sampling for the determination of the mechanical properties of continuous cast iron

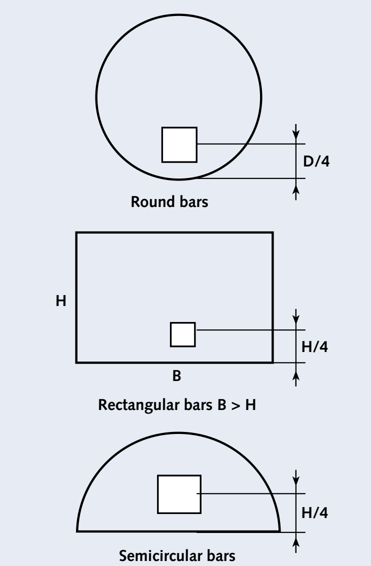
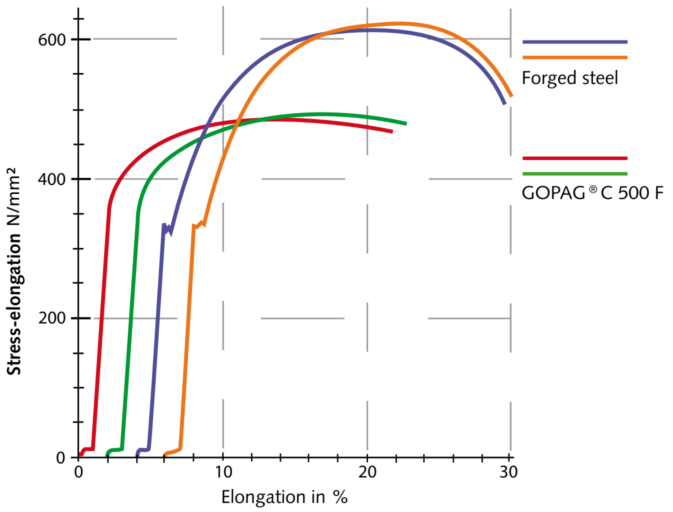


Fig. 10: Stress-elongation curve for GOPAG ® C 500 F compared with a forged steel typically used in the hydraulics sector



Machine type:	UPD350KN	Transducer:	ZWICK ASM WS11-2000-ROD450
Manufacturer:	MFL/ZWICK	Software:	testXpert II

Fig. 11

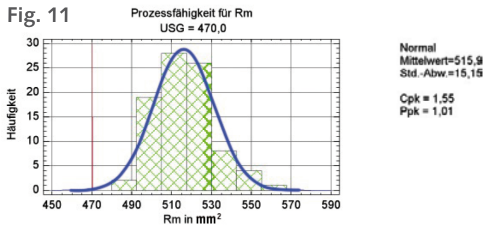


Fig. 12

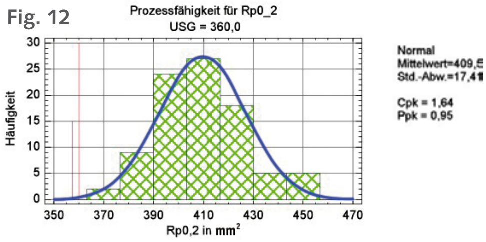


Fig. 13

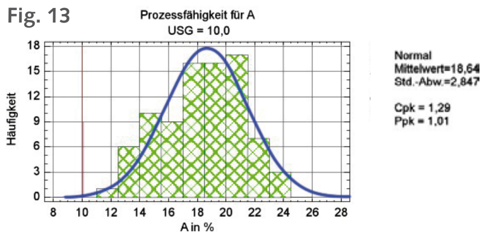


Fig. 14

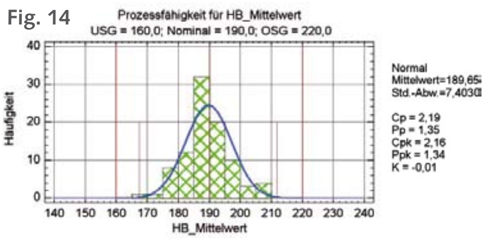


Fig. 15

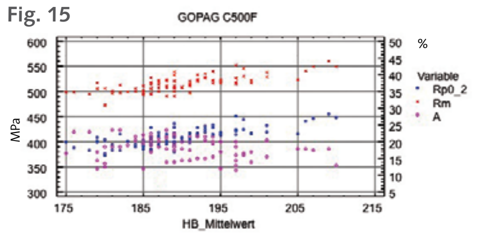


Table 02: Mechanical properties, excerpt of prEN 1563:2009

prEN 1563:2009 – Mechanical properties measured on test pieces machined from cast sample for solid solution strengthened ferritic grades

Material designation		Relevant wall thickness	0,2% proof stress	Tensile strength	Elongation
Symbol	Number	t mm	Rp0,2 N/mm² min.	Rm N/mm² min.	A % min.
EN-GJS-450-18	5.3107	$t \leq 30$	350	450	18
		$30 \leq t \leq 60$	340	430	14
		$60 < t \leq 200$	a	a	a
EN-GJS-500-14	5.3109	$t \leq 30$	400 (360)[1]	500 (500)[1]	14 (10)[1]
		$30 \leq t \leq 60$	390 (360)[1]	480 (490)[1]	12 (9)[1]
		$60 < t \leq 200$	a (350)[1]	a (470)[1]	a (7)[1]
EN-GJS-600-10	5.3110	$t \leq 30$	450	600	10
		$30 \leq t \leq 60$	430	580	8
		$60 < t \leq 200$	a	a	a

a To be agreed between the manufacturer and the purchaser
1) ISO 1083/JS500-10/U

Fig. 11, 12, 13 and 14 show the outstanding process capability for GOPAG ® C 500 F measured in terms of tensile strength, 0.2% proof stress, breaking elongation and Brinell hardness.

The characteristic values for the 0.2% proof stress, tensile strength and breaking elongation as a function of Brinell hardness for GOPAG ® C 500 F are illustrated in **Fig. 15.**

The hardness distribution across the strand cross-section is shown in **Fig.16.** The hardness range is substantially larger with the material GJS-500-7 with 185 to 220 HBW 5/750 than with the material GJS-500-14C (GOPAG® C 500 F) with 172 to 188 HBW 5/750. The difference in hardness relative to the previous 500 material is 35 HBW in the first case and 16 HBW in the second case with the new material.

Fig. 11: Representation of the process capability for the tensile strength Rm in N/mm² for GOPAG® C 500 F

Fig. 12: Representation of the process capability for the 0.2% proof stress Rp 0.2 in N/mm² for GOPAG® C 500 F

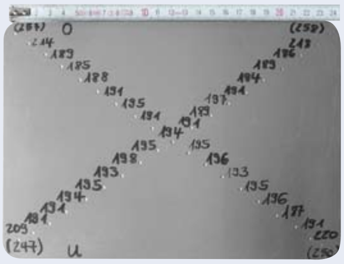
Fig. 13: Representation of the process capability for the breaking elongation A in % for GOPAG® C 500 F

Fig. 14: Representation of the process capability for the Brinell hardness HBW for GOPAG® C 500 F

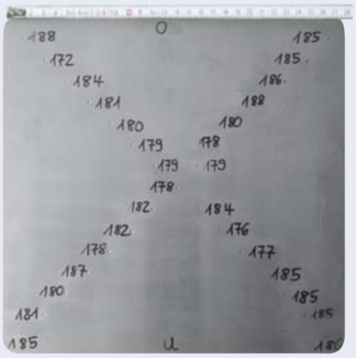
Fig. 15: 0.2% proof stress, tensile strength and breaking elongation as a function of Brinell hardness for GOPAG ® C 500 F

Fig. 16: Hardness distribution over the cross-section

a) GJS-500-7



b) GOPAG® C 500 F



Thus it is apparent that solid solution strengthening with higher silicon concentrations leads to a predominantly ferritic microstructure with high strength and high breaking elongation in both sand casting and continuous casting. The material grade GJS-500-14C can be produced without perlite components with a higher breaking elongation and has an outstanding yield strength/tensile strength ratio of approx. 0.8.

A significant amount of continuously cast spheroidal graphite cast iron material is used for hydraulic control blocks **(Fig. 17).** The company Power-Hydraulik GmbH /11/ has already had very positive experiences with the aforementioned material over a long period of time. The material GJS-500-7C was no longer suitable for higher internal hydrostatic pressures in the range of 350 to 420 bar. In 2009, Gontermann-Peipers introduced the new continuous cast iron with the designation GOPAG® C 500 F. Thus now forged steel can be replaced even at higher internal hydrostatic pressures.

External inspection of such hydraulic control blocks reveals only a row of holes. On the inside, they contain an extensive system of intertwined channels **(Fig. 18).** This channel system is produced by drilling. Approx. one third of the original weight of the hydraulic control blocks is removed by drilling. Cylindrical grinding or circular milling, reaming, honing and thread cutting are used as additional processing technologies. This extensive drilling requires a material with outstanding machinability. This was intensely tested on various materials in cooperation with Weidemann Hydraulics. Gontermann-Peipers' new material grade GJS-500-14C (GOPAG® C 500 F) stands out because of its outstanding machinability /11//12/. This refers to all important machining parameters, spindle speeds, feeds, cutting forces and the favourable chip breakage behaviour.

Fig. 17: Hydraulic control block made of spheroidal graphite cast iron

It was possible to achieve significant improvements in processing times, tool life and machine maintenance as well as the surface roughness of the finish qualities obtainable through cutting (drilling) and other precision machining methods.

The homogenous metallic matrix of the microstructure in the entire hydraulic block and the lubrication effect of the graphite contained in the material substantially improve machinability **(Fig. 19).**

Fig. 18: Internal channels in a hydraulic block control block Weidemann Hydaulik

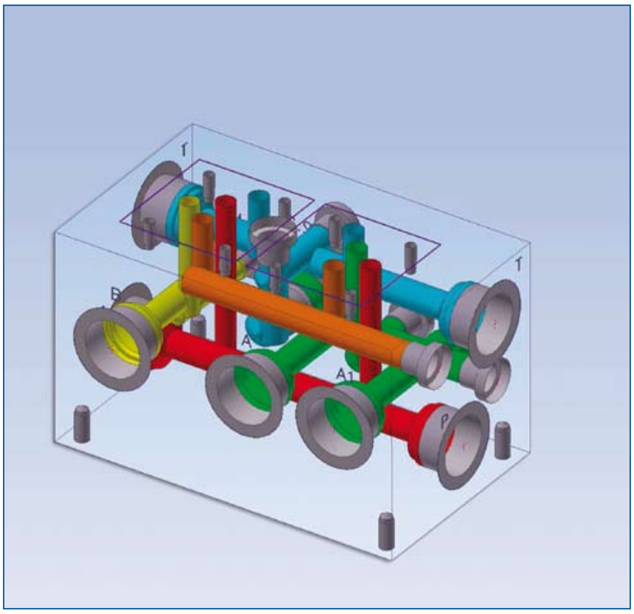
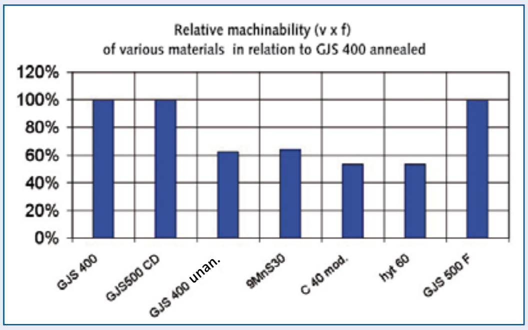
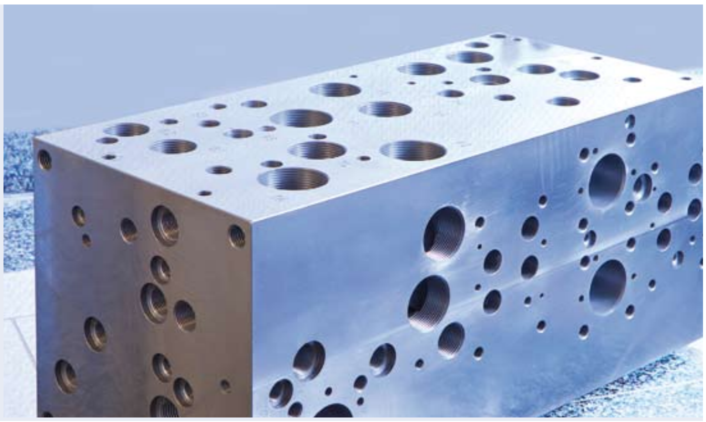


Fig. 19: Block cylinder for a 2500 t sheet bending machine made of GOPAG® C 500 F chilled cast iron

Fig. 20: Relative machinability of various materials
Gontermann-Peipers drilling tests





In machining of the hydraulic blocks made of GOPAG® C 500 F in comparison with those made of forged steel /10//14/, the following advantages are emphasized: In general, forged steel is offered raw with a poorly machinable forging skin. Gontermann-Peipers' blanks, by contrast, are delivered rough machined upon request and only a final cut must be removed in order to attain the final dimensions. In the process, a surface roughness of Rz = 0.4 micrometers is attained. In comparison with forged steel, burr formation at the edges of the intertwining holes inside the hydraulic block is significantly lower in those made of GOPAG® C 500 F, which minimized costly manual labour for deburring. At Aachen University, fracture mechanics parameters KJi of 98 to 101 MPa x m 0.5 were ascertained, compared with 84 to 93 MPa x m 0.5 for the forged steel used up until now.

Today, fracture mechanics is a common method of calculation when dimensioning components that are subjected to high stresses. The highly siliconized material also evidenced a significantly better value than 11SMnPbB30+C in a burst test. This was done by screwing sealing plugs onto hydraulic control blocks made of both materials, which were then provided with an M 16 connector with a test connection (ETG88). With GOPAG® C 500 F, a pressure of 4971 bar was reached after 9036 ms before the component failed. With the alloyed steel, the component failed at a pressure of 4261 bar after 9164 ms. These comparisons clearly show the potential and possibilities of the material.

4 Summary

With the development of GOPAG® C 500 F with a ferritic matrix, Gontermann-Peipers have succeeded in marketing a very high quality continuous cast material.

The improvement in the properties of spheroidal graphite cast iron through solid solution strengthening with a higher silicon concentration evidenced in sand casting also leads to analogously positive results in continuous casting of spheroidal graphite cast iron. The stronger solid solution strengthening results in a ferritic matrix. In comparison with GJS-500-7 with the same tensile strength, the breaking elongation is doubled and the hardness range across the casting cross-section is cut in half with GOPAG ® C 500 F.

Machinability is improved substantially in comparison with the material GJS-500-7C. This leads to high cost savings when extensive cutting operations on hydraulic control blocks are involved.

With the development of the material grade GOPAG® C 500 F by Gontermann-Peipers, it has become possible to use continuous cast iron for hydraulic control blocks with pressure stages of 350 to 420 bar. Thus continuous castings made of GOPAG® C 500 F cast iron can be substituted for the forged steel used up until now for these high pressure stages. This material will become more important in the future due to the trend of alloying prices.

Literature

/1/ BCIRA-Broadsheet 211-2 (1982), vgl. Hasse, S.: Duktiles Gusseisen, Verlag Schiele & Schön, Berlin 1996, S. 49

/2/ Ductile Iron, QIT 1990, vgl. Hasse, S.: Duktiles Gusseisen, Verlag Schiele & Schön, Berlin 1996, S. 51

/3/ Björkegrenn, L.E., Hamberg, B., Johannesson, B.: Mechanische Eigenschaften und Bearbeitbarkeiten von mit Silizium verfestigten ferritischen Gusseisen mit Kugelgraphit Giesserei-Praxis (1999) Nr. 1, S. 11 – 17

/4/ VDG-Fachbericht 083 (2001), Innovative Gießerei, Fertigungstechnologie für endabmessungsnah gegossene Maschinebaukomponenten aus Grauguss (GG) und Gusseisen mit Kugelgraphit (GGG), Teilprojekt „Hochfeste GGG-Gussteile mit ausreichender Duktilität"

/5 / Björkegren, L.E., Hamberg, K.: Silicon Alloyed Ductile Iron with Excellent Ductility and Machinability. Proc. 2003 Keith Millis Symposium on Ductile Cast Iron, Hilton Head, SC, Oct. 2003, pp. 70 – 90

/6/ Larker, R.: Solution Strengthened Ferritic Ductile Iron ISO 1083/JS/500-10 Provides Superior Consistent Properties in Hydraulic Rotators. Proc. 2008 Keith Millis Symposium on Ductile Cast Iron, Oct. 2008, Las Vegas Nevada, AFS/DIS, ISBN 978-0-87433-6, pp. 169 – 177

/7/ Kikkert, J. Mischkristallverfestigtes ferritisches Gusseisen mit Kugelgraphit. Vortrag Deutscher Gießereitag 2009, 14. und 15. Mai 2009 in Berlin

/8/ Herfurth, K.: Gusseisen-Strangguss für eine innovative Teilefertigung konstruieren+giessen 30 (2005) Nr. 3, S. 2 – 17

/9/ Herfurth, K.: Gusseisen-Strangguss, Qualitätsbewertung konstruieren+giessen 33 (2008) Nr. 2, S. 11 – 20

/10/ Vollrath, K.: Hervorragende Bearbeitbarkeit und abgestimmte Logistikkette – bei Hochdruck-Hydraulikblöcken bietet Guss entscheidende Vorteile O+P (2010) H. 4

/11/ Vollrath, K.: Bei Hochdruck-Hydraulik-Blöcken bietet Guss entscheidende Vorteile Fluid (2010) H.6

/12/ Gorski, R., Dörfer, F. : Guss ist nicht gleich Guss , Konstruktion & Engineering Nov. 2009