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- (54) **Title:** HIGH-ALLOY SPHEROIDAL GRAPHITE CAST IRON HAVING AN AUSTENITIC STRUCTURE, USE OF SAID
CAST IRON FOR MANUFACTURING STRUCTURAL COMPONENTS AND STRUCTURAL COMPONENT MADE OF SAID
CAST IRON

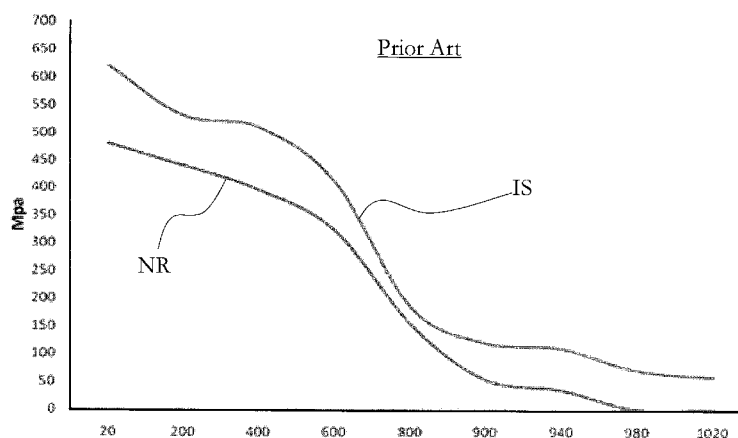


FIG.1

- (57) **Abstract:** The present invention relates to a high-alloy spheroidal graphite cast iron having an austenitic structure comprising the following ingredients in the following percentages by weight: Chrome (Cr) ranging from 1,6% to 2,0%, Molybdenum (Mo) ranging from 0,9% to 1,1%, Niobium (Nb) ranging from 0,3% to 0,5%, Nickel (Ni) ranging from 34% to 36%, Silicon (Si) ranging from 6,1% to 6,7%, Carbon (C) ranging from 1,6% to 2,0%, Tungsten (W) ranging from 0,5% to 0,7%, Manganese (Mn) ranging from 0,5% to 0,65%; the present invention relates also to a structural component intended to operate in the temperature range of exhaust gases ranging from 920°C to 1020°C and particularly for exhaust manifolds, turbines and/or turbo manifolds for automotive industry.



**HIGH-ALLOY SPHEROIDAL GRAPHITE CAST IRON HAVING AN
AUSTENITIC STRUCTURE, USE OF SAID CAST IRON FOR
MANUFACTURING STRUCTURAL COMPONENTS AND STRUCTURAL
COMPONENT MADE OF SAID CAST IRON**

DESCRIPTION

TECHNICAL FIELD

The present invention relates to the industry of construction ferroalloys, particularly to iron-carbon alloys such as cast irons and steels, and more in detail to a high-alloy spheroidal graphite cast iron having an austenitic structure with a chemical composition according to the preamble of claim 1.

5 PRIOR ART

In the current prior art a great number of iron-carbon alloys are known, each one characterized (shortly) by its own cost, workability and mechanical properties.

In particular, as regards mechanical properties, it is known that, other factors being equal, they considerably change as the temperature changes.

10 Therefore the choice of the ferroalloy with which to make a mechanical piece or a structural component is usually made even depending on the operating temperature taken by such structural component during its operational use.

On the other hand even the designing of a mechanical device is affected by such restrictions, since for example it is not possible to contemplate reaching specific
15 temperatures, otherwise the component will break.

In all these circumstances the choice of the material poses serious design problems since it is necessary to alternatively prefer reliability or cheapness, since usually it is not possible to have both of them.

A concrete example, in that sense, is the field of exhaust manifolds and turbines for
20 motor vehicles, as well as turbo manifolds (such technical field in English is often identified by the general term "automotive").

The recent technological developments have led the operating temperature reached by such pieces to increase till reaching values ranging about from 800°C to 1020°C.

The known alloys used for making these products, in the above operating temperature range, are usually two: high Nickel content cast iron or austenitic stainless Steels. The high Nickel content cast iron is available on the market under the name Ni-Resist cast iron and it has an austenitic structure; several compositions of this type of cast iron are known, one that is particularly useful for the application field to which reference is made is that described in the document titled as “Ni-resist type D5S –an improved material for turbocharger housings” published in 1980.

In order to understand the change in the mechanical properties of such cast iron and of the austenitic Steel as a function of temperature, reference is made to the annexed figure 1, wherein the abscissa represents Temperature in [°C], the ordinate represents the stress in [MegaPascal, Mpa] and the two graphs of the trend of the yield strength of cast iron EN-GJSA-XNiSiCr35-5-2 “Ni-Resist D5S” (indicated as NR) and of AISI 309S Steel (indicated as IS).

As it can be clearly seen in the graph the IS Steel generally has a yield strength (the temperature being equal) higher than NR cast iron; however it has also a considerably higher cost, about twice that of NR cast iron.

In the temperature range from 940°C to 980°C NR cast iron has a sharp drop of the yield strength: at 940°C the yield strength of the cast iron is equal to about 35 Mpa (TAB.1) and exceeding this temperature the yield strength drops to zero, actually making the cast iron not more usable in the field of interest starting from 940°C.

On the contrary, IS Steel, at such temperature value has a quite high yield strength, equal to about 110 Mpa.

Since the temperature range is typically that of exhaust manifolds, turbines and turbo manifolds used in the “automotive” field, the problem described above is present.

In the temperature range from 900°C to 1020°C, the choice of the material with which to make the exhaust manifolds, turbines and turbo manifolds is quite complicated: on one hand, by selecting NR cast iron, cheap castings are obtained but they are easily subjected to damages, on the other hand, by selecting austenitic IS stainless Steel, reliable items are obtained but with a considerable high cost.

It has to be noted, incidentally, that for such products, the yield strength of austenitic IS stainless Steel has a value considerably higher than that required by the specifications of the several manufacturers, with the consequence that the use of austenitic stainless Steel appears to be unreasonable with respect to the real
5 mechanical requirements of exhaust manifolds, turbines and turbo manifolds but it is the only feasible way if one desires to avoid an early braking of such pieces.

Therefore in the current prior art there is the need of having available a material that is cheap to be made and to be worked and having good mechanical properties (e.g. a good yield strength) at the temperatures ranging from 900°C to 1020°C.

10 OBJECTS AND SUMMARY OF THE INVENTION

The present invention aims at overcoming the drawbacks of the prior art.

Particularly, the present invention aims at providing a material accomplishing the requirements set forth above.

A first object of the present invention is a high-alloy spheroidal graphite cast iron
15 having an austenitic structure comprising the following ingredients in the following percentages (by weight, on the total amount):

Chrome (Cr)	ranging from 1,6% to 2,0%
Molybdenum (Mo)	ranging from 0,9% to 1,1%
Niobium (Nb)	ranging from 0,3% to 0,5%
20 Nickel (Ni)	ranging from 34% to 36%
Silicon (Si)	ranging from 6,1% to 6,7%
Carbon (C)	ranging from 1,6% to 2,0%
Tungsten (W)	ranging from 0,5% to 0,7%
Manganese (Mn)	ranging from 0,5% to 0,65%.

25 Optionally, in an advantageous variant, the cast iron of the present invention comprises also Phosphorous and Copper in percentages that will be explained below.
A further object of the present invention is a component, particularly a structural component, made of said cast iron, in particular made by a casting process followed by one or more chip removal machining processes.

Still another object of the present invention is a turbo manifold for internal combustion engines (Otto or diesel engines) made of said cast iron.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below with reference to non-limiting examples, provided by way of example and not as a limitation in the annexed drawings. These drawings show different characteristics of the present invention, and particularly:

Figure 1 is the trend of the yield strength as a function of temperature of a known type of cast iron and a Steel, it being known too;

Figure 2 is the trend of the yield strength of the cast iron according to the present invention;

Figure 3 is the comparison between yield strengths as a function of temperature of known materials and of the cast iron according to the present invention;

Figure 4 is the graph of UTS (ultimate tensile strength) of the cast iron according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The high-alloy spheroidal graphite cast iron having an austenitic structure according to the present invention comprises the following ingredients in the following percentages by weight:

Chrome (Cr)	ranging from 1,6% to 2,0%
Molybdenum (Mo)	ranging from 0,9% to 1,1%
Niobium (Nb)	ranging from 0,3% to 0,5%
Nickel (Ni)	ranging from 34% to 36%
Silicon (Si)	ranging from 6,1% to 6,7%
Carbon (C)	ranging from 1,6% to 2,0%
Tungsten (W)	ranging from 0,5% to 0,7%
Manganese (Mn)	ranging from 0,5% to 0,65%.

The applicant surprisingly has found that the high-alloy spheroidal graphite cast iron having an austenitic structure comprising, among other things, the above ingredients with the mentioned percentages has optimal mechanical properties, which are

between those of NR cast iron described above and those of austenitic IS Stainless Steels mentioned above.

Advantageously, moreover, the cast iron according to the present invention has a cost intermediate between that of known NR cast iron and that of austenitic stainless steel, therefore having an interesting cost saving in comparison with austenitic Stainless Steel.

The cast iron according to the present invention essentially has all the best properties for overcoming the drawbacks mentioned above and for serving the function as a material for making turbo manifolds for internal combustion engines.

It has to be noted from now on that the cast iron according to the present invention has, in a temperature range from about 780°C to 840°C, a yield strength still higher than that of IS Steel, making it even preferable than the latter for specific applications in such temperature range.

Silicon is a graphitizing element and it moves the eutectic transformation to the left increasing the eutectic temperature; these two combined actions (the graphitizing action and movement of the eutectic curve) reduces the solidification range for a given carbon value.

Moreover, Silicon is an Alphagene element and in the value range of the invention (from 6,1 to 6,7%) it moves the solidification of the alloy in the stable system (graphite and ferrite).

Moreover it reduces the stability of eutectic and pearlitic carbide.

The carbon content of the eutectoid is reduced by the Silicon of about 0,1% for each 1% increase of Silicon ($T_{stable} = 1154^{\circ}\text{C} + 4^{\circ}\text{C}\cdot\text{Si} - 2^{\circ}\text{C}\cdot\text{Mn} - 30^{\circ}\text{C}\cdot\text{P}$; $T_{metastable} = 1147^{\circ}\text{C} - 10^{\circ}\text{C}\cdot\text{Si} - 30^{\circ}\text{C}\cdot\text{P} + 30^{\circ}\text{C}\cdot\text{Cr}$).

Therefore, in plain words, it is possible to say that therefore the fact of adding Silicon in the shown percentages gives a high dimensional stability at high temperatures and a better acid corrosion resistance; in the percentages shown above it improves also hot scaling (oxidation loss).

It has to be noted here also that, in principle, the provision of Silicon with values higher than 6% by weight would be inadvisable in an austenitic cast iron, on the basis of the available scientific literature.

This derives from the fact that Silicon notoriously is an alphagene element, which promotes the formation of stable ferrite, opposing the formation of austenite, therefore in a cast iron with austenitic matrix as the one of the present invention it would be contrasting.

The applicant has surprisingly noted that the contemporaneous presence of Tungsten does not affect the formation of the austenitic matrix, since it combines with the graphite segregated by the Silicon and resulting in the formation of further very stable Tungsten carbides.

As regards Nickel, it has to be noted that it has a Gammagene effect and it reduces the critical points and the critical cooling speed, as well as it refines the perlite grain.

Nickel, in the shown percentages, guarantees the stability of the cast iron matrix from ambient temperature to 1020°C and it does not generate carbides.

As regards Chrome, it is an Alphagene element and it is a high carbide forming element and it forms very thermally stable carbides.

The percentages of Chrome shown in the formulation of the cast iron according to the present invention guarantees the graphitization of the eutectic cementite and of perlite to slow down during a normal slow cooling.

With Chrome exceeding 1% carbides are formed.

A general improvement of mechanical properties can be obtained by adding from 1,6% to 2% about of Chrome according to the present invention, due to the strong stabilizing effect of perlite, exerted by Chrome, and to the removal of free perlite formed after the slow cooling.

This effect of the Chrome results in an increase in hardness and wear resistance of cast iron.

The cast iron according to the present invention therefore shows an excellent stability at high temperature and a better corrosion resistance preventing scales from being formed helping the formation of the austenitic matrix.

5 Molybdenum, in the percentages shown above, is the most effective element for improving the resistance of the cast iron according to the present invention and for improving its toughness.

In the percentage of about 1% (from 0.9% to 1.1%) it advantageously has the effect of stabilizing the perlite and of improving the structural uniformity, which, consequently, increases the resistance and the hardness.

10 Molybdenum forms intercrystalline carbides and it easily segregates together with chromes in eutectic phosphides.

Moreover molybdenum added in percentages from 0,9% to 1,1% improves the heat resistance and it provides a good wear resistance.

15 As regards on the contrary Niobium the fact of adding it in percentage from 0,3% to 0,5% into the formulation of the cast iron according to the present invention mainly aims at improving the mechanical properties thereof reducing the size of eutectic cells.

In addition it reduces the tendency of carbide formation due to the reduction of undercooling and the increase in the number of eutectic cells and it opposes
20 advantageously the precipitations of Chrome carbides that cause ductility to be reduced.

Tungsten, in the percentages shown above, provides the cast iron according to the present invention with an optimal corrosion resistance and most of mineral acids affect it only weakly.

25 Tungsten considerably increases the hardness and the high melting temperature makes it a choice very suitable for structural applications subjected to high temperatures, such as those the present invention relates to, such as for instance turbo manifolds, exhaust manifolds for turbines in the "automotive" field or the like. Its high elastic modulus is exploited at low temperatures.

Tungsten in percentages from about 0.5% to 0.7% provides a good creep resistance.

Surprisingly (even if Tungsten is generally known and not recommended in this field due to its tendency to generate an excessive hardness and a low workability of the material) the applicant has noted that it, inserted in the cast iron according to the present invention, increases the presence of stable intergranular carbides that even more provides dimensional stability and stiffness at high temperatures.

The undesired effect related to the presence of Tungsten in the cast iron according to the present invention and related to the excessive surface hardness has been brilliantly overcome by the applicant by inserting in the formulation according to the present invention Silicon in the shown percentages, which, by having a graphitizing function, helps in segregating the free graphite increasing workability characteristics.

Finally, as regards Manganese, in the percentages from 0,5% to 0,65% it advantageously acts as a strong austenite stabilizer; it has to be noted incidentally that Manganese in higher amounts combines with carbon in the form of Mn_3C , isomorphous carbide, similar to cementite, and therefore it has to be avoided.

Manganese in this formulation, is also the gammagene element stabilizing pearlite and refining the pearlitic matrix.

Optionally, moreover, the high-alloy spheroidal graphite cast iron having an austenitic structure according to the present invention further comprises the following ingredients in the following percentages by weight:

Phosphorus (P) $\leq 0,1\%$

Copper (Cu) $\leq 0,1\%$

The advantages deriving from the cast iron of the present invention can be immediately found also from the analysis of the annexed figure 2, wherein the abscissa represents Temperature in $^{\circ}C$, the ordinate represents the mechanical stress in [MegaPascal, Mpa] and wherein the yield strength of the cast iron according to the present invention is shown.

As it can be immediately seen the trend of the yield strength of the cast iron 1 according to the present invention, in the temperature range from 850°C to 980°C is considerably higher than that of the known NR cast iron.

Such comparison between the yield strength 1 of the cast iron according to the present invention, NR cast iron and IS Steel described above is shown in the graph of figure 3, that goes back to graphs of figures 1 and 2 and it sums them together in a single overview.

The test has been carried out on a specimen of the cast iron according to the present invention having the following ingredients in the following exact percentages by weight:

Niobium (Nb)	equal to 0,4%
Carbon (C)	equal to 1,7%
Chrome (Cr)	equal to 2,0%
Molybdenum (Mo)	equal to 1,0%
Nickel (Ni)	equal to 36%
Silicon (Si)	equal to 6,4%
Tungsten (W)	equal to 0,6%
Manganese (Mn)	equal to 0,55%

It has to be noted that these values are even the best one as regards the composition of the cast iron of the present invention, since they have the best balance between manufacturing costs and mechanical properties, especially as regards the temperature range and the applications in the automotive field to which reference is made not as a limitation.

The values that have been found, in addition to being visible in the graph of figure 3, are even put in Tab.1 below.

Temperatures [°C]	Yield Strenght [Mpa]		
	Invention	AISI 309S	EN-GJSA-XNiSiCr35-5-2
20	493	621	480
200	461	531	
400	458	510	
600	348	414	325
800	203	186	155
900	82		54
940	78	110	35
980	63		
1020	45	59	

Tab.1

Incidentally it has to be noted that, in the range temperature from 780°C to 1020°C and denoted as INT (a) of figure 3, the yield strength 1 of the cast iron according to the present invention is always higher than that of known NR cast iron.

It has to be noted even that in the range temperature from 780°C to 840°C, denoted by INT(b) in figure 3, the yield strength of the cast iron according to the present invention is even higher than that of the more expensive IS Steel, thus actually making the cast iron according to the present invention not only cheaper than Steel, but also more resistant as regards specific applications.

Finally in the temperature range above 980°C, denoted by INT(c) in figure 3, the cast iron according to the present invention has a yield strength lower than that of IS Steel, but still sufficient for making turbo manifolds and exhaust manifolds in the automotive field.

In this INT(c) range the NR cast iron is completely useless, since its yield strength is equal to about zero, while Steel has, in addition to a considerably higher cost, even mechanical properties exceeding the performances required by a normal turbo

manifold.

Therefore in this way it is possible to say that the cast iron according to the present invention is a privileged choice for making such mechanical components.

In addition, even further analyses on the cast iron according to the present invention
5 have confirmed this condition of things, and they have shown that it has also a good behavior as regards UTS (ultimate tensile strength) as a function of temperature, such as shown in the annexed figure 4 wherein the abscissa represents the temperature at which the specimen is subjected, measured in [C°], the ordinate represents the axial force to which the cylindrical specimen is subjected in
10 MegaPascal [Mpa].

Therefore from the above it is easy to understand how the use of the cast iron according to the present invention for making structural components intended to be used at high temperature is optimal as regards several perspectives: both the cost one and mechanical property one.

15 In this way therefore it is possible to envisage to advantageously make exhaust manifolds, turbines and turbo manifolds of Otto or diesel engines with peak temperatures of the exhaust gases ranging from 950°C to 1020 °C by the cast iron according to the present invention: mechanical stresses to which they are subjected are widely withstandable by the material in question, and the manufacturing cost is
20 low with respect to austenitic Stainless Steel.

Obviously a person skilled in the art can provide to add further ingredients with respect to those shown above, possibly in order to improve other mechanical properties or in order to suit the behavior to particular operating conditions of the structural components, without departing from the protecting scope of the present
25 invention.

Still, the person skilled in the art can provide to slightly change the percentage ranges described above and claimed below, obtaining a cast iron equal to the one just described and therefore without departing from the scope of the present invention.

CLAIMS

1. High-alloy spheroidal graphite cast iron having an austenitic structure

characterized in that

5 it comprises the following ingredients in the following percentages by weight:

	Chrome (Cr)	ranging from 1,6% to 2,0%
	Molybdenum (Mo)	ranging from 0,9% to 1,1%
	Niobium (Nb)	ranging from 0,3% to 0,5%
10	Nickel (Ni)	ranging from 34% to 36%
	Silicon (Si)	ranging from 6,1% to 6,7%
	Carbon (C)	ranging from 1,6% to 2,0%
	Tungsten (W)	ranging from 0,5% to 0,7%
	Manganese (Mn)	ranging from 0,5% to 0,65%.

15 2. Cast iron according to the preceding claim, comprising the following ingredients in the following percentages by weight:

	Niobium (Nb)	equal to 0.4%
	Carbon (C)	equal to 1.7%
	Chrome (Cr)	equal to 2,0%
20	Molybdenum (Mo)	equal to 1,0%
	Nickel (Ni)	equal to 36%
	Silicon (Si)	equal to 6.4%
	Tungsten (W)	equal to 0.6%
	Manganese (Mn)	equal to 0.55%

25 3. Cast iron according to one of the preceding claims, further comprising the following ingredients in the following percentages by weight:

	Phosphorus (P)	$\leq 0,1\%$
	Copper (Cu)	$\leq 0,1\%$.

4. Use of a cast iron according to any of the preceding claims for manufacturing a structural component made at least in part by a casting process.

5. Structural component characterized in that it comprises at least a
5 portion made of a cast iron according to one or more of the preceding claims.

6. Exhaust manifold, turbine or turbo manifold for an internal combustion engine characterized in that at least in part it is made of a cast iron according to one or more of the preceding claims.

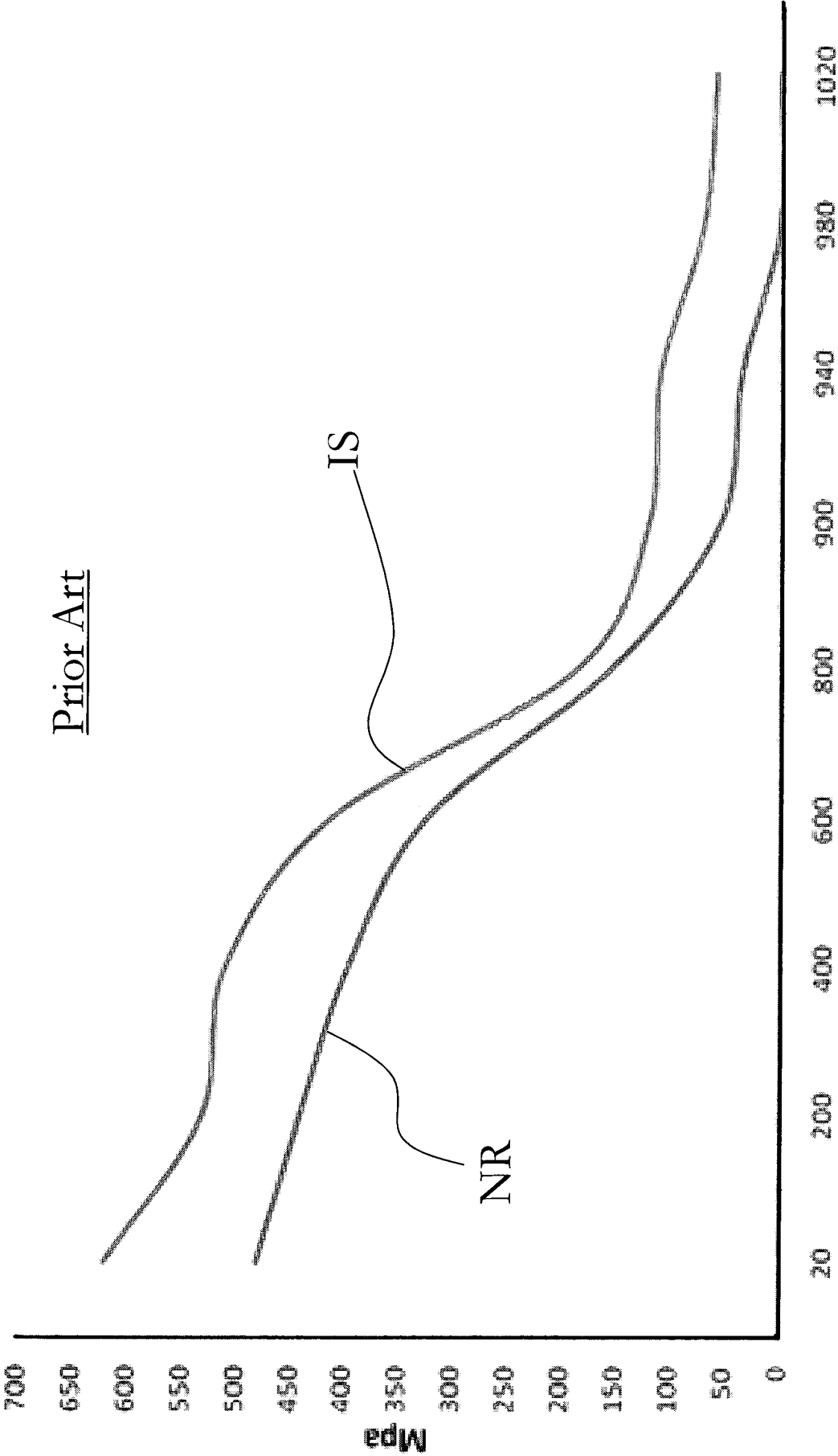


FIG.1

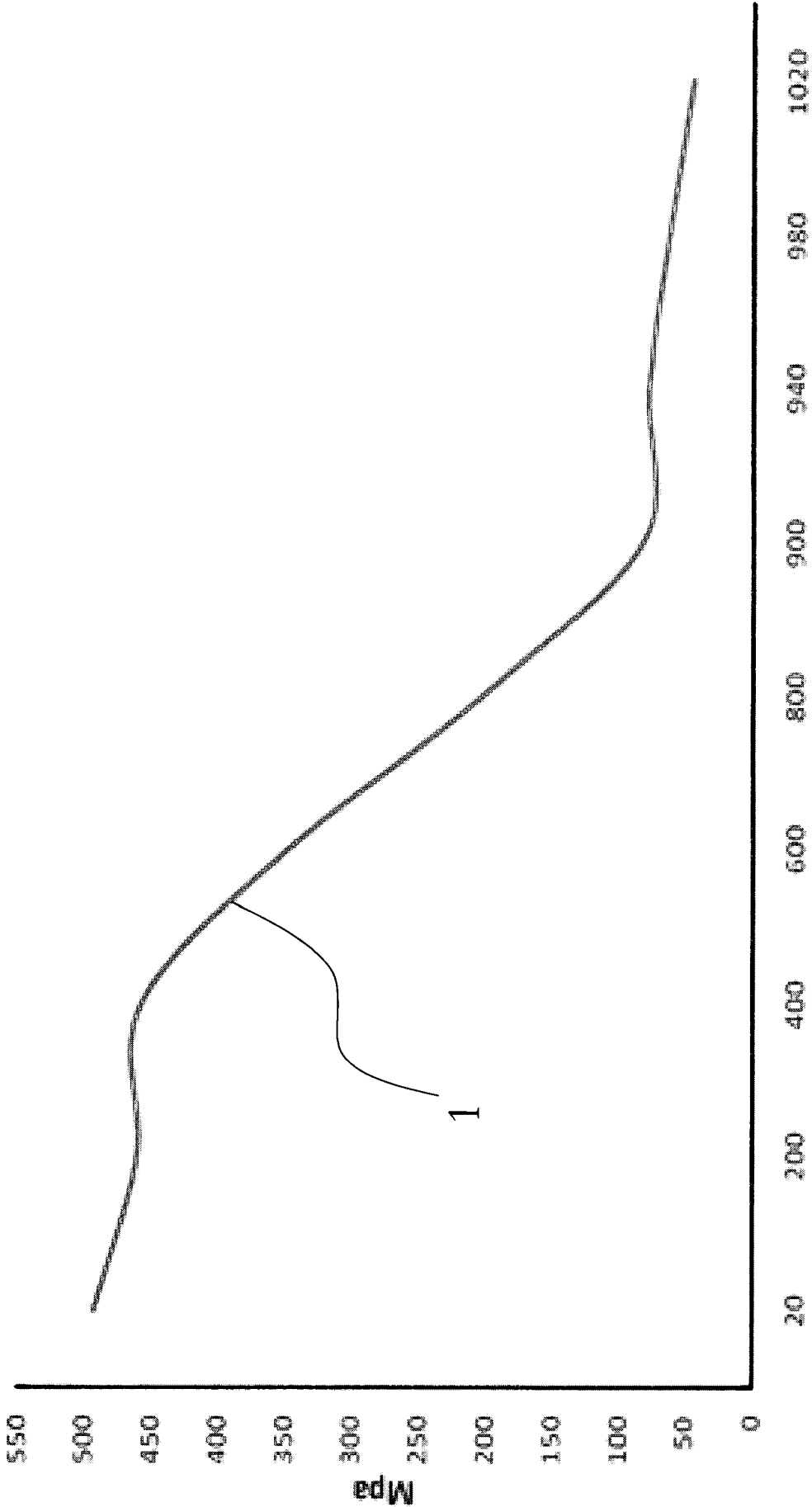


FIG.2

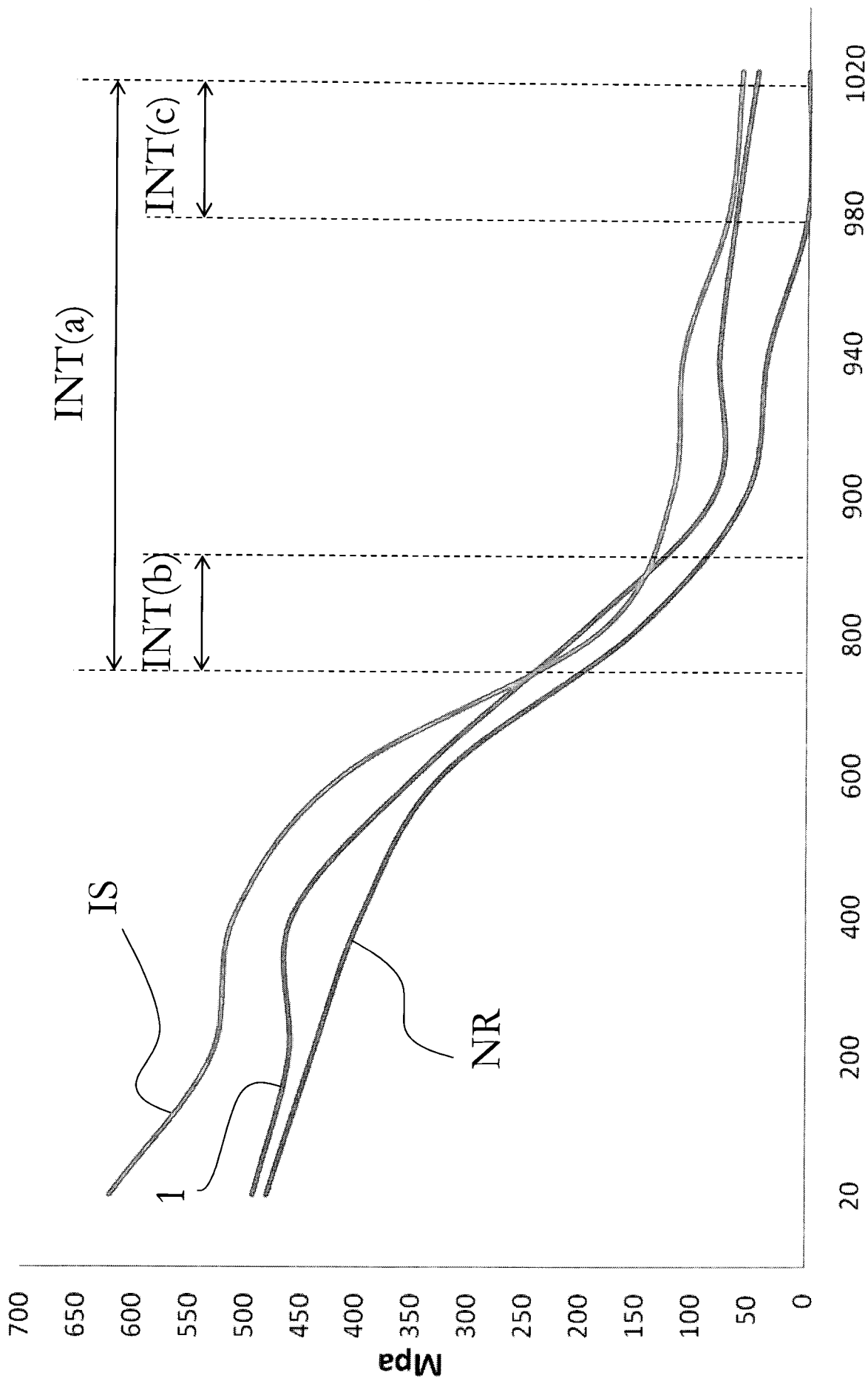


FIG.3

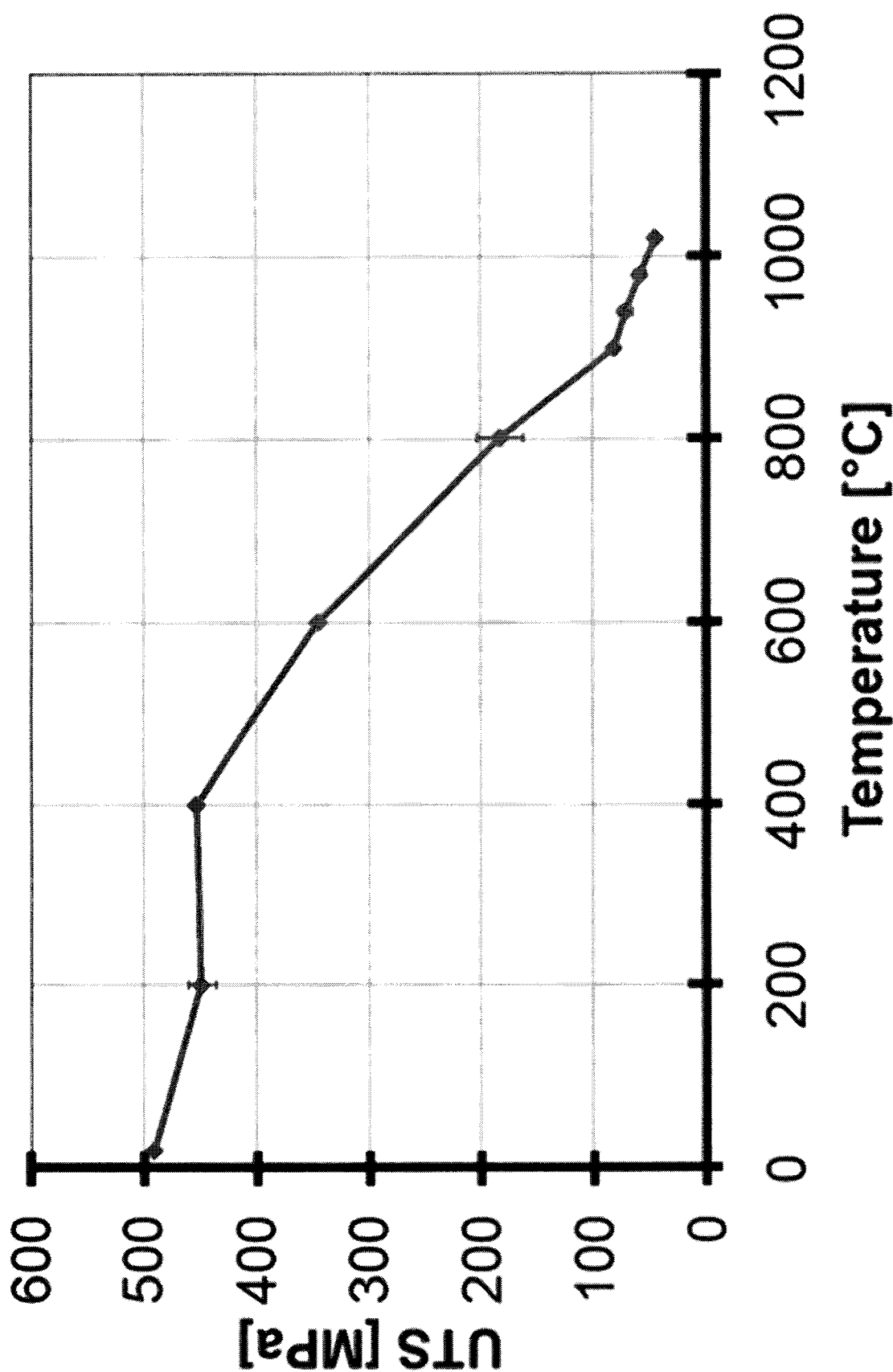


FIG.4