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# (54) AUSTENITIC CAST IRON, PROCESS FOR MANUFACTURING THE SAME, AUSTENITIC CAST IRON CASTINGS, AND EXHAUST SYSTEM PARTS

AUSTENITISCHES GUSSEISEN, HERSTELLUNGSVERFAHREN DAFÜR, GEHÄUSE AUS AUSTENITISCHEM GUSSEISEN UND ABGASSYSTEMTEILE

FONTE AUSTÉNITIQUE, SON PROCÉDÉ DE FABRICATION, PIÈCES MOULÉES EN FONTE AUSTÉNITIQUE, ET PIÈCES DE SYSTÈME D’ÉCHAPPEMENT

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## Description

### TECHNICAL FIELD

**[0001]** The present invention relates to an austenitic cast iron, which is excellent in terms of heat resistance, and the like; to a cast product, which is comprised of that; to a production process for the same; and to a component part for exhaust system.

### BACKGROUND ART

**[0002]** It is often the case that members being formed as complicated configurations, and relatively large-size members are manufactured by means of casting; what is more cast products being made of relatively inexpensive cast irons (hereinafter referred to as "cast products" simply) are used frequently.

**[0003]** In cast iron, C in the alloy whose major component is made of iron-carbon exceeds the maximum solid solubility limit in $\gamma$ iron (e. g. , about 2% by mass), and the cast iron is accompanied by eutectoid solidification. Usually, in order to improve the characteristics, such as the mechanical properties, corrosion resistance and heat resistance, various alloying elements are added. Such a cast alloy is referred to as an alloy cast iron, and especially those cast irons with great alloying-element contents are referred to as high-alloy cast irons. These high-alloy cast irons are usually divided into ferritic cast ions and austenitic cast irons roughly depending on the difference between the crystalline structures of their crystallizing bases.

**[0004]** Among them, since the austenitic cast irons are comprised of austenite phase (or $\gamma$ phase) mainly, not to mention in high-temperature region, but in ordinary-temperature range as well, they are good in terms of heat resistance, oxidation resistance, corrosion resistance, and the like; and are moreover good in terms of ductility, toughness, and so forth. Accordingly, the austenitic cast irons are often used for members that are made use of in harsh environments such as high-temperature atmospheres. For example, speaking of the field of automobiles, turbocharger housings, exhaust manifolds, catalyst cases, and the like, are given. Any one of the members is a component part, and the like, which is exposed to high-temperature exhaust gases, and consequently which is required to exhibit long-term durability.

**[0005]** By the way, various types are available in the austenitic cast irons as well, and the following are representative ones: Niresist, nimol, nicrosilal, monel, minober, nomag, and the like. Moreover, in Japanese Industrial Standards (i.e., JIS), too, 9 types are prescribed for the flake graphitic cast iron (e.g., FCA), and 14 types are prescribed for the spheroidal graphitic cast iron (e. g. , FCDA).

**[0006]** In the conventional austenitic cast irons, an austenite phase has been made obtainable even in ordinary-temperature range by having them contain Ni, namely, an austenite stabilizing element, in a large amount (Ni: from 18 to 36%, for instance). This Ni is expensive considerably compared with Fe, namely, the parent material, and the other alloying elements, and consequently cast products comprising the conventional austenitic cast irons have been high costs considerably.

**[0007]** Surely, like Niresist (FCDA-NiMn137 as per JIS), an austenitic cast iron whose Ni content is less comparatively has also come to be known publicly. However, Niresist (FCDA-NiMn137 as per JIS) is poor in term of oxidation resistance. Moreover, when observing Niresist by X-ray analysis (or XRD), the austenite proportion becomes 100%. In actuality, however, it takes a lamellar structure (i.e., a structural construction in which a plurality of long and thin rod-shaped constructions are lined up so that a striped pattern is seen) in which lamellar carbides exist, in addition to the austenite structure, in the Fe base, as can be understood when looking at photographs in Fig. 5 (that is, the two photographs on the left side). Therefore, Niresist has such a structure that it is not possible to say any longer that the austenite phase makes a single phase.

**[0008]** Incidentally, when lamellar (or acicular) carbides exist in addition to the austenite structure, tensile stress occurs in austenite upon being heated, because those carbides whose thermal expansion coefficient is greater than that of the austenite expand more than the austenite does. Accordingly, in the case where Niresist (FCDA-NiMn137 as per JIS) is used for members, like automotive exhaust-system components part that are exposed to high temperatures and ordinary temperature repeatedly, there is such a fear that cracks might occur in the austenite structure because tensile stress occurs repeatedly in the austenite structure. Further, austenite phase has a great solute carbon content compared with that of ferrite phase. Accordingly, upon the transformation from ferrite to austenite, ambient graphite comes to be dissolved/solid solved therein as being accompanied by the austenitizing; then, it becomes likely to make voids in the graphite sections; and then the degradation of the resulting cast product's strength is facilitated. Furthermore, chilling, which results from super saturated C, is facilitated because of returning back to ferrite phase again at the time of cooling; consequently, the following are feared: the increase of chill phase being accompanied by cooling/heating cycle; embrittlement being accompanied therewith; and volumetric expansion.

Moreover, when being an unstable structural construction in which lamellar carbides, and the like, exist in addition to the austenite structure, the resulting austenitic cast irons have such a drawback as well that the workability worsens, because work-induced martensite that is very hard appears at the time of cutting work.

**[0009]** In addition, an austenitic cast iron whose Si content is increased while making the Ni content much less than that of aforementioned Niresist is disclosed in a patent literature mentioned below.

Patent Literature No. 1: Japanese Unexamined Patent Publication (KOKAI) Gazette No. 58-27, 951

**[0010]** Further, GB 801,698 A discloses improvements in or relating to spheroidal graphite cast irons.

**[0011]** DE 26 46 276 A1 discloses a cast iron alloy and a method for producing machine parts.

## DISCLOSURE OF THE INVENTION

### Assignment to be Solved by the Invention

**[0012]** Aforementioned Patent Literature No. 1 discloses that, in relation to oxidation resistance, namely, an index of heat resistance concerning austenitic cast iron, the more the Si content enlarges the less the oxidized weight increment per unit area becomes (see Fig. 6 of Patent Literature No. 1). However, according to studies by the present inventors, the Si content that becomes excessive results in declining the elongation of austenitic cast iron, and in worsening the machinability. Consequently, considering the reliability and the mass-producibility of heat-resistant members comprising austenitic cast irons, and the like, it is not practical to enhance the oxidation resistance to such a level that is sufficient in view of practical use by only adjusting the Si content.

**[0013]** The present invention is one which has been done in view of such circumstances. Specifically, it is an object to provide a low-cost austenitic cast iron that is an austenitic cast iron whose contained amount of Ni is less, and which is excellent not only in terms of thermal-fatigue strength, and the like, but also in terms of oxidation resistance. Moreover, in addition to that, it is another object to provide austenitic cast products comprising that austenitic cast iron, and a manufacturing process for the same, and furthermore exhaust-system component parts, namely, some of those austenitic cast products.

### Means for Solving the Assignment

**[0014]** The present invention relates to an austenitic cast iron according to claim 1, to a process according to claim 12 or 13, to an austenitic cast product according to claim 14 and to a component part according to claim 15. Further beneficial developments are set forth in the dependent claims.

**[0015]** The present inventors studied earnestly to solve this assignment; as a result of their repeated trial and error, they succeeded in obtaining an austenitic cast iron that exhibited favorable characteristics, even in the case of reducing the contained amount of nickel (Ni), by adjusting the contained amounts of carbon (C), silicon (Si), chromium (Cr), nickel (Ni), manganese (Mn) and copper (Cu). In particular, it was possible to obtain an austenitic cast iron that exhibited good oxidation resistance by adjusting the Cr content and/or the Cu content without ever increasing the Si content excessively, even while reducing the Ni content. The present inventors arrived at completing a variety of inventions, which will be described later, by developing these achievements.

### (Austenitic Cast Iron)

**[0016]**

(1) Specifically, an austenitic cast iron according to the present invention is characterized in that:

it comprises:

basic elements comprising carbon (C), silicon (Si), chromium (Cr), nickel (Ni), manganese (Mn) and copper (Cu); and

the balance comprising iron(Fe), inevitable impurities and/or a trace-amount modifier element, which is effective in improving characteristic, in a trace amount;

it is an austenitic cast ironbeing a cast iron that is structured by a base comprising an Fe alloy in which an austenite phase makes a major phase in ordinary-temperature region;

wherein said basic elements fall within compositional ranges that satisfy the following conditions when the entirety of said cast iron is taken as 100% by mass (hereinafter being simply expressed as "%"):

C: from 1 to 5%;
Si: from 3 to 5%;
Ni: from 7 to 15%;

Mn: from 0.1 to 8%;
Cu: 2.5% or less;
Cr: 0.5 to 4%; and
Cr + Cu: 0.5% or more.

(2) First of all, the Ni content becomes a considerably small amount relative to the entire cast iron in the austenitic cast iron according to the present invention. In view of the conventional technical common sense, it seems that no base is obtainable, base in which an austenite phase, which is stabilized in ordinary-temperature range, makes a major phase. However, in the present invention, an austenite phase was obtained successfully by setting, even though on the premise of that small-amount Ni content, the respective contained amounts of the other alloying elements, namely, C (especially, $C_s$, a solute carbon content), Si, Cr, Mn and Cu to appropriate ranges that satisfy the aforementioned respective conditions.

**[0017]** In particular, in the austenitic cast iron according to the present invention, the oxidation resistance, which is indexed by a later-described oxidizedweight decrement, and the like, is improved by means of containing Cr or Cu in an adequate amount even while suppressing the upper limit of the Si content.

It is believed herein that Cr forms a passive film, which comprises dense and fine chromium oxides, adjacent to the surface of the austenitic cast iron and has then improved its oxidation resistance. Moreover, Cr combines with carbon in the cast-iron base to precipitate carbides therein, and accordingly is capable of improving the high-temperature proof stress of the cast iron by means of precipitation strengthening of the base. However, Cr that becomes excessive is not preferable, because carbides increase so that the toughness and workability, which are indexed by means of the Charpy-impact value and so forth decline. Hence, in the austenitic cast iron according to the present invention, the Cr content is from 0.5 to 4%.

Further, when Cr is contained, such an effect is available that the structure is stabilized so that lamellar and/or acicular carbides are less likely to emerge, as can be also understood from the table of Gibbs free energies.

**[0018]** Moreover, Cu yields an effect of making the fcc structure more stable, because it has an fcc structure, namely, a crystalline structure that is similar to austenite at ordinary temperature, and because it has a dense structure that is much less likely to pass oxygen than is ferrite with a bcc structure. And, Cu does not at all enter oxidized film, and then Cu is enriched at the interface between the oxidized film and metal; accordingly Cu turns into an fcc structure possessing the lattice constant that differs from that of parent phase; consequently Cu demonstrates a barrier-layer effect that inhibits the interstitial action of oxygen atoms possessing such an energy state that they are likely to force into the parent base; and it is believed therefore to have its oxidation resistance improve.

Moreover, in addition to stabilizing an austenite structure by solving in the base in the same manner as Ni does, Cu is an effective element for refining crystalline particles in the base's structure and then having the high-temperature proof stress improve. Further, as a result of being studied earnestly by the present inventors, it was understood that Cu also yields an effect of decreasing hardness, and consequently it is possible to intend to improve the workability of austenitic cast product.

However, when Cu becomes excessive, the peritectic structure of Cu emerges to hinder graphite's spheroidizing; consequently, the strength and the like of cast iron decline, or the peritectic structure of Cu emerges so that elongation performance worsens at the time of high temperatures. Therefore, it is preferable to contain Cu within such a range that does not worsen ductility at the time of high temperatures. Hence, it is allowable to set the upper limit of Cu at 2.5%, for instance.

In the present invention, since to have oxidation resistance improve is one of the objectives, it is preferable to involve Cu and Cr, which improve oxidation resistance, in an amount of 0.5% or more by sum total. It is preferable that the lower limit of this Cu + Cr can be 1%, 1.5%, or further 2%.

And, it is suitable to set the Ni content to from 8 to 14% in obtaining an austenitic cast iron, which is provided with strength, heat resistance (including oxidation resistance), elongation, ductility, toughness, workability, and the like, in a well balanced manner like the present invention, at low cost.

(Austenitic Cast Product and Manufacturing Process for the Same)

**[0019]**

(1) It is possible to grasp the present invention not only as the above-described austenitic cast iron but also as an austenitic cast iron that comprises that austenitic cast iron. As some of the examples of an austenitic cast product according to the present invention, it is possible to give members, such as exhaust-system component parts, which are exposed in high-temperature environments.

(2) Further, it is possible to grasp the present invention as a manufacturing process for that austenitic cast product

as well.
Specifically, it is permissible that the present invention can even be a manufacturing process for austenitic cast iron that is characterized in that it comprises:

a molten-metal preparation step of preparing a molten metal with the aforementioned compositional range;
a pouring step of pouring the molten metal into a casting die; and
a solidification step of cooling the molten metal that has been poured into the casting die, and then solidifying the molten metal;
wherein a cast product comprising the above-described austenitic cast iron according to the present invention is obtainable.

(3) By the way, in expanding applications of the austenitic cast iron (or cast product) according to the present invention, it is also often the case to add various modifier elements at the time of casting. For example, it is often the case that an auxiliary agent is added in order to increase the number of graphite particles that crystallize in structures of the base, or in order to spheroidize their configurations.

**[0020]** Hence, it is permissible that the manufacturing process for austenitic cast iron according to the present invention can even be one being characterized in that it comprises:

a modifier-free-molten-metal preparation step of preparing a modifier-free molten metal comprising a molten metal with the compositional range as set forth in either one of claims 1 through 15;
an auxiliary-agent addition step of adding an auxiliary agent, which includes at least one member being selected from the group consisting of inoculant agents that make cores of graphite to be crystallized or precipitated, and spheroidizing agents that facilitates spheroidizing of the graphite, to the modifier-free molten metal directly or indirectly;
a pouring step of pouring a molten metal into a casting die, the molten metal being after the auxiliary-agent addition step or during the auxiliary-agent addition step; and
a solidification step of cooling the molten metal that has been poured into the casting die, and then solidifying the molten metal;
wherein a cast product comprising the aforesaid austenitic cast iron is obtainable, the austenitic cast iron in which substantially spheroidal graphite is crystallized or precipitated within the resulting base.

(Additional Constitution)

**[0021]** It is allowable that the austenitic cast iron (including the austenitic cast product) according to the present invention, or the manufacturing process for the same according to the present invention, can have contents as set forth below. Moreover, it is even allowable to further add one or two or more constitutions, which are selected arbitrarily from the constitutions that are listed below, to the aforementioned present invention.
Note that is should be notified that it is feasible to add the constitutions, which are selected from those set forth below, additionally to a plurality of inventions in a superimposed manner and arbitrarily. Moreover, it is feasible to combine any one of the constitutions, which are set forth below, with each other appropriately beyond the categories. For example, it is needless to say that, when being one of the constitutions that are directed to a composition of the austenitic cast iron, it can be relevant to the austenitic cast iron as well as the manufacturing process for the same. In addition, although it appears at first glance to be a constitution that is directed to a "process, " it can turn into a constitution that is directed to a "product" when comprehending it as a product-by-process.
**[0022]** Another austenitic cast iron according to the present invention is characterized in that it comprises:

basic elements comprising C, Si, Cr, Ni, Mn and Cu; and
the balance comprising Fe, inevitable impurities and/or a trace-amount modifier element, which is effective in improving characteristic, in a trace amount;
it is an austenitic cast iron being a cast iron that is structured by a base comprising an Fe alloy in which an austenite phase makes a major phase in ordinary-temperature region;
wherein: a carbon equivalent (hereinafter being simply expressed as "$C_{eq}$") according to one of the following expressions being given by the respective contained amounts of C and Si satisfies a first condition according to the following expressions; and simultaneously the contained amounts of Ni satisfies a second condition according to the following expressions; and the contained amount of Cu satisfies a third condition according to the following expressions; when the entirety of said cast iron is taken as 100% by mass (hereinafter being simply expressed to as "%"); and

a nickel equivalent (hereinafter being simply expressed as "$Ni_{eq}$") according to another one of the following expressions being given by the respective contained amounts of Ni, Mn and Cu and a solute carbon content ($C_s$), namely, a content of C being solved in Fe, and a chromium equivalent (hereinafter being simply expressed as "$Cr_{eq}$") according to still another one of the following expressions being given by the respective contained amounts of Cr and Si fall within compositional ranges that satisfy fourth and fifth conditions according to the following expressions when the entirety of said base is taken as 100%:

First Condition: $2 \leqq C_{eq} \leqq 5$;
Second Condition: $7 \leqq Ni \leqq 15$ (%);
Third Condition: $0 \leqq Cu \leqq 2.5$ (%);
Fourth Condition: $A_1 \cdot Cr_{eq} + B_1 \leqq Ni_{eq} \leqq 30$ where "$A_1$" = -0.8, and "$B_1$" = 21.6;
Fifth Condition: $C_{eq} \leqq 13.5$;
Carbon Equivalent: $C_{eq} = C + Si/3$;
Nickel Equivalent: $Ni_{eq} = Ni + 30 \cdot C_s + 0.5 \cdot Mn + Cu$; and
Chromium Equivalent: $Cr_{eq} = Cr + 1.5Si$

**[0023]** (2) In this austenitic cast iron according to the present invention, the Ni content is set to a considerably small amount relative to the entire cast iron, as specified in the second condition. Consequently, in view of the conventional technical common sense, it seems that no base with austenite phase, which is stabilized in ordinary-temperature range, is obtainable.
However, in the present invention, an austenite phase was obtained successfully by setting, even though on the premise of that small-amount Ni content, the respective contained amounts of the other alloying elements, namely, C (especially, $C_s$), Si, Cr, Mn and Cu, to proper ranges that satisfy the aforementioned respective conditions. Hereinafter, the respective conditions that prescribe the present invention will be explained.

**[0024]** First of all, the carbon equivalent ($C_{eq}$) is prescribed like the first condition, because the present invention is anyway a cast iron, which is accompanied by peritectic solidification.
Next, the Ni content is prescribed like the second condition, because the present invention is a cast iron whose Ni is reduced. Even when considering the second condition, relative to the composition of the entire cast iron, on the premise of the first condition, the austenitic cast iron according to the present invention is distinguishable from many other conventional austenitic cast irons.

**[0025]** Further, in the present invention, the Cu content is prescribed like the third condition in order to obtain an austenitic cast iron that is excellent in terms of elongation performance at the time of high temperatures. As a result of experiments done by the present inventors, it was found out that peritectic Cu exists in austenitic cast irons that include Cu abundantly in the analyzed compositions. It is speculated that the resultant peritectic Cu worsens the elongation performance of the austenitic cast irons at the time of high temperatures.

**[0026]** Moreover, in the present invention, attentions are focused on bases comprising Fe alloys, on the basis of those Ni content and $C_{eq}$. That is, such indexes as the nickel equivalent ($Ni_{eq}$) and chromium equivalent ($Cr_{eq}$) that are found from the basic elements were introduced, and then a composition of the entire base, which makes the core of the cast-iron structure, is determined by means of the fourth and fifth conditions.

**[0027]** As a result of experiments this time around, it was found out austenitic cast irons, which satisfy the aforementioned fourth and fifth conditions, do not have any lamellar structure that exists in austenite even when setting Cu to fall in the aforementioned range. And, it is speculated that they are materials that are strong against thermal fatigue, because no lamellar structure exists in austenite.

**[0028]** These fourth and fifth conditions are based on the Schaeffler's structural diagram. As it is evident by referring to many famous technical literatures that the Schaeffler' s structural diagram originally specifies the relationship between the composition and weld structure that are relevant to welded section, or the relationship between the composition and structure that are relevant to austenitic stainless cast steel or the like. That is, the Schaeffler's structural diagram is not necessarily used for cast-iron structure with great carbon content essentially. This issue is also understandable from the fact that the solute carbon content is used in the conversion of $Ni_{eq}$.

**[0029]** Considering such circumstances, although it seems that the aforementioned fourth and fifth conditions are equivalent to the Schaeffler' s structural diagram at first glance, it is possible to say that the fourth and fifth conditions are totally novel conditional formulas, which have been obtained from various sincere experiments done by the present inventors, in the field of cast iron that differs from such fields that the Schaeffler's structural diagram intends for essentially. Therefore, the austenitic cast iron whose basic elements satisfy the aforementioned first through fifth conditions is an epoch-making cast iron that is not on the extension of the conventional technical common sense.
Note that it is natural that the austenitic cast iron according to the present invention exhibits austenite cast iron's other excellent properties because of its structure and composition.

**[0030]** (3) In the austenitic cast iron according to the present invention, it is possible to identify its composition, on the

premise of the Ni content being specified in said second condition, by setting the respective alloying elements, which constitute the basic elements, individually, or combining themvariously, with a plurality of methods, that is, other than the methods being prescribed as described above or along with the methods being prescribed as described above.
For example, it is also permissible to set the lower limit of $C_{eq}$ at 2.1%, or further at 2.5%; and it is even permissible to set its upper limit at 4.5%, or further at 4.3%, and the like. Moreover, it is also permissible to set the lower limit of C at 2. 1%, or further at 2.5%; and it is even permissible to set its upper limit at 4.5%, or further at 4.3%. In addition, it is also permissible to set the lower limit of Si at 3%; and it is even permissible to set its upper limit at 5%, or further at 4.5%, and so forth.

**[0031]** Moreover, it is also permissible to set the lower limit of Cr at 0.5%, at 1%, or at 1.2%; and it is even permissible to set its upper limit at 4%, at 3%, or at 2%, and the like.
It is also permissible to set the lower limit of Cu at 0%, at 0.1%, at 0.2%, at 0.3%, at 0.5%, at 0.7%, or at 1%; and it is even permissible to set its upper limit at 2%, at 1.7%, at 1.5%, or at 1.3%, and the like. Note that, when the lower limit of Cu is referred to as 0% in the specification of the present application, it not only means $0\% \leqq Cu$ but also $0\% < Cu$.
It is also permissible to set the lower limit of Mn at 3%, at 4%, or at 5%; and it is even permissible to set its upper limit at 8%, or at 7%. Details on the actions and compositions of each of these elements will be described later.

**[0032]** Note that it is possible to use these upper limits and lower limits independently, or to combine them arbitrarily to use; and that it is possible to set up ranges in which the upper limits make lower limits, or moreover to set up ranges in which the lower limits make upper limits. Moreover, as far as it is possible to identify the compositions of the basic elements, it is possible to combine compositions for the respective alloying elements arbitrarily to use. These notes are common issues in the present specification.

**[0033]** On the basis of above, an example in which the austenitic cast iron according to the present invention is prescribed by a composition of the entire cast iron is specified as follows. Specifically, the present invention can be an austenitic cast iron that comprises: basic elements comprising C, Si, Cr, Ni, Mn and Cu; and the balance comprising Fe, inevitable impurities and/or a trace-amount modifier element, which is effective in improving characteristic, in a trace amount; and which is a cast iron that is structured by a base comprising an Fe alloy in which an austenite phase makes a major phase in ordinary-temperature region; and the present austenitic cast iron can be prescribed as an austenitic cast iron as well that is characterized in that:

> said basic elements are set so that not only a carbon equivalent (hereinafter being simply expressed as "$C_{eq}$") according to the following expression that is given by means of the respective contained amounts of C and Si, but also Ni, Cu and Si fall within compositional ranges that are specified as mentioned below when the entirety of said cast iron is taken as 100% by mass (hereinafter being simply expressed as "%"):
>
> $2 \leqq C_{eq} \leqq 5$ (%) ;
> $7 \leqq Ni \leqq 15$ (%);
> $0 \leqq Cu \leqq 2.5$ (%); and
> $3 \leqq Si \leqq 5$ (%)

**[0034]** Moreover, on the basis of above, another example in which the austenitic cast iron according to the present invention is prescribed by a composition of the entire cast iron is specified as follows. Specifically, the present invention can be an austenitic cast iron that comprises: basic elements comprising C, Si, Cr, Ni, Mn and Cu; and the balance comprising Fe, inevitable impurities and/or a trace-amount modifier element, which is effective in improving characteristic, in a trace amount; and which is a cast iron that is structured by a base comprising an Fe alloy in which an austenite phase makes a major phase in ordinary-temperature region; and the present austenitic cast iron can be prescribed as an austenitic cast iron as well that is characterized in that:

> said basic elements are set so that not only a carbon equivalent (hereinafter being simply expressed as "$C_{eq}$") according to the following expression that is given by means of the respective contained amounts of C and Si, but also Ni, Cu and Cr fall within compositional ranges that are specified as mentioned below when the entirety of said cast iron is taken as 100% by mass (hereinafter being simply expressed as "%"):
>
> $2 \leqq C_{eq} \leqq 5$ (%);
> $7 \leqq Ni \leqq 15$ (%) ;
> $0 \leqq Cu \leqq 2.5$ (%); and
> $0.5 \leqq Cr \leqq 4$ (%)

**[0035]** (4) By the way, it is not needed that the "austenite phase" being referred to in the present invention be an austenite single phase completely. That is, the clause, "austenite phase makes a major phase," purports to make the

following permissible: of course not only such a case as being comprised of an austenite single phase alone that exhibits 100% austenite by X-ray analysis, and which does not include any lamellar structure that is made of those like martensite and perlite in the austenite; in addition thereto but also such a case as including a martensite phase slightly.
If being notified daringly, it is allowable that an austenite single phase can be present more than 50% by volume, 60% by volume or more, 70% by volume or more, 80% by volume or more, 90% by volume or more, or further 95% by volume or more.
Whether the base's structure is an austenite phase or not is prescribed by means of the above-described fourth condition substantially. That is, it is possible to narrow down a metallic structure to be obtained to an austenite single phase by setting the intercept of a border line, which demarcates the lower limit of $Ni_{eq}$ in the aforementioned fourth condition, at 21.6. Note that it should be notified that the indexing of $B_x$, which designates the intercept of the border line that is indicated in the present invention, is an expediential one.

**[0036]** In the present invention, the upper limit of $Ni_{eq}$ relative to the entire base is not limited essentially as far as Ni is a small amount relative to the entire cast iron as specified in the second condition, because it is one of the objectives to obtain a cast iron that has a base being an austenite phase in ordinary-temperature region while reducing the content of Ni to be made use of.
However, the elements other than Ni also exhibit limitations in terms of their solute contents in Fe. Moreover, those elements that get greater is not preferable, not only because costs have risen though the reduction of the Ni content can be intended, but also because desirable cast-iron structures have become less likely to obtain. Hence, in the present invention, although the upper limit of $Ni_{eq}$ is set at 30%, it is preferable that the upper and lower limits of $Ni_{eq}$ can be either one of 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, or further 20%.
Since issues that are similar to above apply to $Cr_{eq}$ as well, the upper limit of $Cr_{eq}$ is set at 13.5% in the present invention while considering the generation circumstances of carbides that are believed to be the cause of fatigue-strength decline. However, it is preferable that the upper and lower limits of $Cr_{eq}$ can be either one of 12%, 11%, 10%, 9%, 8%, 7%, 6%, 5%, or 4%.
In particular, such a case as where $Cr_{eq}$ is from 5 to 8% and $Ni_{eq}$ is 18% or more, or where $Cr_{eq}$ is from 7 to 9% and $Ni_{eq}$ is 13% ormore, is preferable, because the precipitation of lamellar carbides (including acicular carbides) does not occur or it is suppressed.

**[0037]** The "trace-amount modifier element" being referred to in the present invention is a trace-amount element that is effective in improving characteristic. For example, it can be an element that contributes to metallic structure, such as spheroidizing graphite that crystallizes or precipitates or increasing the number of the particles, and making austenite phase finer or stabilizing it. Moreover, it is permissible that it can also be an element that contributes to mechanical characteristic, such as strength in room-temperature region or high-temperature region, high-temperature durability (i.e., creep strength, and the like), toughness, and elongation. In addition, it is permissible that it can even be an element that contributes to oxidation resistance, thermal expandability, thermal conductivity, workability, , and so forth. Furthermore, it is permissible that it can also be an element that contributes to castability, such as flowability at the time of casting, and suppressing cast defects like cracks, shrinkage or pores.
As the "inevitable impurities," the following are given: impurities being included in raw materials, impurities getting mingled or the like at the time of casting, and so on. They are elements that are difficult to remove because of being costly, or due to technical reasons, etc. For example, as for such inevitable impurities, phosphorous (P), and the like, are given.

**[0038]** In the present invention, the compositions of the trace-amount modifier element and inevitable impurities are not limited in particular, because the compositions of the basic elements are important. For example, even when being an austenitic cast iron in which no trace-amount modifier element is included, not to mention the inevitable impurities, it falls within the range of the present invention. Note that, even when being an element that can make a trace-amount modifier element, it is permissible to treat it also as an inevitable impurity depending on its contained amount, or an application of the resulting cast iron, and the like.

**[0039]** When designating as "from 'x' to 'y'" in the present specification, it includes the lower limit, "x, " and the upper limit, "y," unless otherwise notified. Moreover, the elemental symbols or indexes (e.g., $Ni_{eq}$, $Cr_{eq}$, $C_{eq}$, $C_s$, and the like), which are used in the conditional formulas or mathematical formulas in the present specification, index the contained amounts of those elements (% by mass) unless otherwise notified. In addition, the mark, "· ," which is set forth in those conditional formulas or mathematical formulas, means multiplication (or product).
Further, for the component compositions that are used in the present invention, the following are given: a compositional range relative to the entirety of a cast iron; and another compositional range relative to the entirety of a base, namely, a part that constitutes that cast iron. However, the compositional range relative to the entire base is a portion that is relevant to the $Ni_{eq}$ and $Cr_{eq}$ which affect the base's structure fundamentally. Therefore, compositions, which the present specification prescribes herein regarding portions other than the portion that is relevant to the $Ni_{eq}$ and $Cr_{eq}$, mean componential compositions relative to the entirety of cast irons unless otherwise notified.

BRIEF DESCRIPTION OF THE DRAWINGS

**[0040]**

Fig. 1 is an XRD diagram on various cast irons with different compositions.

Fig. 2 is a correlation diagram for showing $Cr_{eq}$-$Ni_{eq}$ regarding various cast irons with different compositions.

Fig. 3 is an XRD diagram on a cast iron (e.g., Test Specimen No. 2-2) that only had a distinct plate thickness to each other.

Fig. 4A is photomicrographs for showing metallic structures at respective positions in a surface and the inside of a cast-product sample (e.g., Test Sample No. 3-1).

Fig. 4B is photomicrographs for showing metallic structures at respective positions in a surface and the inside of a cast-product sample (e.g., Test Sample No. 3-2).

Fig. 5 is photomicrographs for showing metallic structures regarding respective cast irons, namely, a basic material (FCDA-NiMn137 as per JIS) and a Cu-added material made by adding Cu to that base material, together with the Schaeffler's structural diagram on which their positions are designated.

Fig. 6 is photomicrographs for showing metallic structures of cast-product samples (e.g., Test Sample Nos. 6-1 through 6-12).

Fig. 7 is a graph for illustrating a relationship between Cu addition amount and elongation in Fourth Test.

Fig. 8 is graph for illustrating a relationship between Cr addition amount and proof stress in Fourth Test.

Fig. 9 is an XRD diagram on cast irons with different compositions.

Fig. 10 is diagrams on correlations between the temperatures of various cast irons and the linear expansion coefficients, wherein the correlation diagram labeled (a) in the same drawing corresponds to Test Specimen No. 6-5; the correlation diagram labeled (b) in the same drawing corresponds to Test Specimen No. 4-3; the correlation diagram labeled (c) in the same drawing corresponds to Test Specimen No. R3; the correlation diagram labeled (d) in the same drawing corresponds to Test Specimen No. R4; and the correlation diagram labeled (e) in the same drawing corresponds to Test Specimen No. R6; respectively.

Fig. 11 is a bar graph for illustrating oxidized weight decrements of various test specimens.

Fig. 12 is diagrams for illustrating correlations between oxidized weight decrements and amounts of contained elements that are relevant to various test specimens, wherein labeled (a) in the same drawing is relevant to the contained amounts of Cr; and labeled (b) in the same drawing is relevant to the contained amounts of Ni.

Fig. 13 is diagrams for illustrating correlations between oxidized weight decrements and amounts of contained elements that are relevant to various test specimens, wherein labeled (a) in the same drawing is relevant to the contained amounts of Mn; and labeled (b) in the same drawing is relevant to the contained amounts of Cu.

Fig. 14 is a bar graph for illustrating Charpy-impact values of various test specimens.

Fig. 15 is a diagram for illustrating a correlation between Charpy-impact values and contained Cr amounts that are relevant to various test specimens.

Fig. 16 a bar graph and dispersion diagram for illustrating 0.2% proof stresses and fracture elongations of various test specimens at 800 °C.

Fig. 17 is diagrams for illustrating correlations between fracture elongations and amounts of contained elements that are relevant to various test specimens, wherein labeled (a) in the same drawing is relevant to the contained amounts of Cr; and labeled (b) in the same drawing is relevant to the contained amounts of Cu.

Fig. 18 is a bar graph for illustrating hardnesses of various test specimens.

Fig. 19 is a photograph for showing misrun defects which make an index for evaluating the various test specimens' molten-metal running properties.

Fig. 20 is a bar graph for relatively evaluating molten-metal running properties exhibited by various test specimens, and illustrates them with respect to that of Test Specimen No. 7-1 being taken as "1."

Fig. 21 is a bar graph for illustrating thermal-fatigue lives of various test specimens.

Fig. 22 is a bar graph for illustrating thermal-fatigue lives of various test specimens.

Fig. 23 is a graph for illustrating correlations between values of hardness rise and plate thicknesses of a test specimen when various elements were added in an amount of 1%.

Fig. 24 is photographs for explaining a method of quantifying shrinkage magnitudes in various test specimens.

Fig. 25 is a bar graph for relatively evaluating shrinkage magnitudes exhibited by various test specimens, and illustrates them with respect to that of Test Specimen No. R3 being taken as "1."

Fig. 26 is a graph for illustrating correlations between average linear expansion coefficients of various test specimens and widths of heating temperatures.

Fig. 27 is a bar graph for illustrating average linear expansion coefficients of various test specimens.

Fig. 28 is a bar graph for illustrating thermal conductivities of various test specimens.

Fig. 29 is a bar graph for illustrating oxidized weight decrements of various test specimens at respective heating temperatures.

Fig. 30 is a bar graph for illustrating proof stresses of various test specimens at respective temperatures.

Fig. 31 is a bar graph for illustrating tensile strengths of various test specimens at respective temperatures.

Fig. 32 is a bar graph for illustrating fracture elongations of various test specimens at respective temperatures.

Fig. 33 is a bar graph for illustrating thermal-fatigue lives of various test specimens under respective conditions.

## BEST MODE FOR CARRYING OUT THE INVENTION

**[0041]** The present invention will be explained in more detail while giving embodiment modes. Note that, although austenitic cast irons will be dealt with mainly in the present specification to explain the present invention, it should be notified that their contents can be applied appropriately not only to the austenitic cast product (including the component part for exhaust system) according to the present invention but also to the process for manufacturing the same. Moreover, whether any one of the embodiment modes is considered best or not depends on subject matters, their required performance, and the like.

### (Composition)

### (1) Basic Elements

**[0042]** An austenitic cast iron according to the present invention comprises basic elements, and Fe, namely, the balance. The basic elements comprise six types of elements, namely, C, Si, Cr, Ni, Mn and Cu. However, in a case where the austenitic cast iron does not include any Cu substantially, five elements, namely, C, Si, Cr, Ni and Mn, make the basic elements. Hereinafter, the actions or functions of each of these respective elements, and their suitable compositions will be explained.

### (i) C and Si

**[0043]** (a) C drops the molten temperature of Fe, and enhances the flowability of molten metal (including modifier-free molten metal). Consequently, it is an indispensable element for ferrous casting. Since C in Fe-C system alloys exceeds the maximum solid-solubility limit so that cast irons are accompanied by eutectic solidification, the lower limit of C can be 1, 1.7%, 1.8%, 1.9%, 2%, or 2.1% fundamentally; and its upper limit can be 5%, or further 4.3%. Note that C that exceeds the solid-solubility limit crystallizes as graphite.

When C is too little, no preferable castability can be obtained because the flowability of molten metal has declined. When C is too much, the resulting base's structure decreases, and thereby the resulting austenitic cast iron's mechanical characteristics, and the like, decline. Moreover, cast defects, such as shrinkage cavities, become likely to occur at the time of casting. Hence, it is more preferable that the lower limit of C can be 2%, or 2.5%, and that its upper limit can be 5%, or 3.5%.

**[0044]** (b) Note that the solute carbon content ($C_s$), which becomes necessary for calculating the $Ni_{eq}$ being referred to in the present invention can be found essentially by analyzing the composition of Fe base structure, or by subtracting a total amount of C, which crystallized or precipitated graphite and carbides,such as cementite ($Fe_3C$), have consumed, from the entire amount of blended C.

However, since this $C_s$ is a trace amount, it is difficult to analyze it accurately. Moreover, it has been understood empirically that $C_s$ falls in a virtually constant range. Hence, even when assuming that $C_s$ = 0.03% in calculating $Ni_{eq}$ to finding it, it is the actuality however that errors that occur in the resulting $Ni_{eq}$ are small to such an extent that they can be negligible substantially. Hence, in the present invention, $Ni_{eq}$ has come to be found on the assumption that $C_s$ = 0.03%.

Note that 0.03% is the solid-solubility limit of C to $\alpha$ (ferrite) phase in the Fe-C binary system phase diagram. Since it is presumed from viewing the phase diagram that the solute content to $\gamma$ (austenite) phase can be this solute content or more, the value of $C_s$ has come to be assumed to be 0.03% as the minimum value of the solute content.

**[0045]** (c) Si lowers the eutectic temperature of metastable system, facilitates the eutectic crystallization of $\gamma$ Fe-graphite, and then contributes to the crystallization of graphite. Moreover, Si forms passive films, which comprise silicon oxide in the vicinity of crystallizing graphite's surface, and thereby enhances the oxidation resistance of cast iron.

When Si is too little, no such effects can be obtained sufficiently; and Si being too much is not preferable because it causes the decline of elongation and the worsening of machinability. Hence, the lower limit of Si is 3%, or further 3.5%. It is preferable that the upper limit of Si can be 5%, or further 4.5%.

(d) By the way, Si has an action of shifting a eutectic carbon content of Fe-C system toward lower-concentration side, and then a carbon equivalent ($C_{eq}$ = C + Si/3) in which an Si content is taken account into a C content is used as an index. Hence, it is more preferable that the lower limit of $C_{eq}$ can be set at 2.1%, at 2.5%, or further at 3%. It is more preferable that its upper limit can be set at 5%, or at 4.3%, namely, the eutectic point in the Fe-C system phase diagram, or further at 3.5%.

(ii) Cr

**[0046]** Cr binds with carbon in cast-iron base to precipitate carbides therein, and then improves the high-temperature proof stress of cast iron by means of the precipitation strengthening of the resulting base. Moreover, it makes it possible to improve the oxidation resistance because it forms passive films, which comprise dense and fine chromium oxides in the vicinity of the resulting cast iron's surface.
Moreover, Cr being too much is not preferable because carbides increase so that the toughness and workability decline. Hence, it is preferable that the lower limit of Cr can be 0.5%, 0.7%, 1%, 1.2%, or further 1.5%. It is preferable that the upper limit of Cr can be 4%, 3%, 2.5%, or further 2%.

**[0047]** Incidentally, when the present inventors analyzed cast irons in which Cr was contained in an amount of from 9 to 15% relative to the entire cast irons, it was understood that many Cr-Mn system carbides crystallized or precipitated so that the resulting cast irons are chilled (or carbidize) as a whole.

(iii) Ni

**[0048]** Ni is an effective element in the austenitization of base's structure. When Ni is too little, it is hard to obtain stable austenite phase. On the other hand, when Ni becomes too much, making austenitic cast iron inexpensive by means of the reduction of Ni content, namely, one of the objectives of the present invention, cannot be intended.
Hence, it is preferable that the lower limit of Ni can be 12%, 11%, 10%, 9%, 8%, or further 7%. Moreover, it is preferable that the upper limit of Ni can be 15%, 14%, 13%, 12%, 11%, 10%, or further 9%.

(iv) Cu and Mn

**[0049]** (a) Cu and Mn are effective elements in the austenitization of base's structure, as well as Ni.
Note herein that the equation for calculating $Ni_{eq}$ according to the present invention can be turned into 0.5Mn + Cu = $Ni_{eq}$ -Ni - $30C_s$.
And, the upper limit of Ni according to the present invention is no higher than 15%. Moreover, regardless of the total contained amount of C, $C_s$ falls within a virtually constant range (e.g., from 0 to 0.8%). The $C_s$ content falls in such a range, because the solute amount of C in $\gamma$ Fe declines from 2.1%, namely, the maximum, to 0.8% approximately as being accompanied by temperature decline in the Fe-C binary system phase diagram.

**[0050]** Incidentally, although "0.5," namely, the coefficient of Mn, is one which is specified in the Schaeffler' s structural diagram, "1, " namely, the coefficient of Cu, is one which the present inventors had come to know totally newly as a result of their earnest studies through a variety of experiments, and the like. The background on this issue will be described in detail as follows.

**[0051]** Cast-iron test specimens were made ready, cast-iron test specimens which comprised the following, respectively: a basic material (Fe-3%C-2.3%Si-13%Ni-7%Mn equivalent to FCDA-NiMn137 as per JIS, that is, equivalent to later-described Test Specimen No. R2 in Table 1A) ; and a Cu-added material in which Cu was added in an amount of 6.5% to this basic material (equivalent to later-described Test Specimen No. 1-1 in Table 1A). The following are shown in Fig. 5 all together: structural photographs in which these were observed; and their positions, which were findable from their respective compositions, on the Schaeffler's structural diagram.
In the case of the basic material, $Ni_{eq}$ =18.2, and $Cr_{eq}$ = 4.1 can be derived from its own composition. When plotting these on the Schaeffler's structural diagram, it is expected that the basic material has a quasi-austenite structure of "A" + "M." This fact was also ascertained from the structural photograph of the basic material. That is, it was ascertained that the basic material's base comprised an austenite phase (or $\gamma$ phase), and lamellar carbides that were formed of 2 phases, namely, carbide layers, which were seemed to precipitate from that $\gamma$ phase during the process of cooling at the time of casting, and an $\alpha$ phase.
Note that, compared with such a martensite structure as can be observed in usual ferritic cast iron, like that of FCD4500 as per JIS, the thicknesses of the carbide layers in the basic material became greater and the intervals between the layers became wider, it is believed because of the fact that the basic material contained Mn that is more likely to generate carbides (that is, whose free energy is lower) than is Fe comparatively.

**[0052]** By the way, when analyzing the composition of the Cu-added material in which Cu was added to the basic material, the compositions of the major elements were as follows: 2.3% Si; 10.4% Ni; 6.5% Mn, and 7.2% Cu. When applying these compositions to the conventional Schaeffler's structural diagram, they make $Ni_{eq}$ (= Ni + 30· $C_s$ + 0.5 · Mn) = 14.7, and $Cr_{eq}$ (= Cr + 1.5Si) = 3.5. When plotting these on the Schaeffler' s structural diagram as they were, the resulting position falls in the martensite region (or "M" region).
However, no lamellar carbides like those in the basic material were seen in the actual structural photographs of the Cu-

added material. That is, it is believed that the base turned into an austenite single phase virtually by means of adding Cu. This is speculated because of the following: the lamellar carbides disappear by means of the Cu addition so that $\gamma$ phase has stabilized.

According to this result, the base of the Cu-added material should come to be positioned essentially in the austenite single phase region (i.e., "A" region), so to speak, on the Schaeffler's structural diagram. When $Cr_{eq}$ = 3.5, $Ni_{eq}$ being 22.5 or more enters the "A" region on the conventional Schaeffler' s structural diagram.

**[0053]** If so, in the case of the aforementioned Cu-added material, a discrepancy, namely, at least $\Delta Ni_{eq} = 22.5 - 14.7 = 7.8$, comes to arise between $Ni_{eq}$, which is found calculationally from the analyzed compositions, and $Ni_{eq}$, which is assumed from observing the actual structure. It is apparent that the cause of arising such a discrepancy results from the addition of Cu from the above-described background. Therefore, it is believed that the added Cu has facilitated the austenitization of the base of the Cu-added material and has then stabilized an austenite phase. To put it in other words, it is possible to say that Cu has acted in the direction of augmenting $Ni_{eq}$. And, an influential proportion to $Ni_{eq}$ by means of Cu becomes ($\Delta Ni_{eq}$/Analyzed Contained Cu Amount) = 7.8/7.2 = 1.08, and is about "1" approximately at a moderate estimate. And, think of the background, namely, the metallic structure changes from "A" + "M" to "A" by means of the addition of Cu, it is hardly think of the influential proportion to $Ni_{eq}$ by means of Cu that becomes far greater than "1." Hence, in the present invention, the coefficient of Cu is set at "1" in calculating $Ni_{eq}$.

**[0054]** (b) As described above, in addition to solving into base and then stabilizing austenite structure as well as Ni, Cu refines the crystalline grains in base's structure to improve the high-temperature proof stress. Moreover, it is an effective element in improving the oxidation resistance and corrosion resistance as well.

However, when Cu becomes excessive, the peritectic structure of Cu appears so that the spheroidizing of graphite is hampered to decline the strength and the like of cast iron. Moreover, Cu that becomes excessive is not preferable, because the peritectic structure of Cu appears and thereby the elongation performance at the time of high temperatures worsens. Hence, it is preferable that the lower limit of Cu can be 0%, 0.1%, 0.3%, 0.5%, 0.7%, 1%, or further 1.2%. The upper limit of Cu is 2.5%, preferably 2%, 1.8%, or further 1.8%. Note that, as described above, in a case where an austenitic cast iron according to the present invention comprises Cu as an essential element, the lower limit of Cu being 0% means that 0% < Cu. On the other hand, in another case where Cu is not an essential element, the lower limit of Cu being 0% means that 0% $\leqq$ Cu.

**[0055]** (c) In addition to being effective in the stabilization of austenite structure, Mn is also an effective element in the removal and the like of S that becomes the cause of flowability worsening and embrittlement.

When Mn is too little, these effects cannot be obtained sufficiently. When Mn becomes excessive, Mn carbides increase to cause the decline of the toughness and so forth of cast iron, or the decline of heat resistance. Moreover, that is not preferable, because gas defects, such as blow holes, become likely to occur. Hence, it is preferable that the lower limit of Mn can be 0.1%, 0.5%, 1%, 2%, 2.5%, 3%, 4%, or further 5%. It is preferable that The upper limit of Mn is 8%, preferably 7%, or further 6%.

(2) Trace-amount Modifier Element

**[0056]** (a) It is preferable tomake a trace-amount element be contained in order to improve a variety of characteristics, such as the metallic structure of austenitic cast iron (or cast product), the oxidation resistance, the corrosion resistance, the strength in ordinary-temperature region or high-temperature region, mechanical characteristics like strength or toughness, and electric characteristics. Austenitic cast irons that include such a modifier element also falls within the limitations of the present invention naturally as far as the basic elements fall within the above-described ranges.

**[0057]** The trace-amount modifier element can be the following: magnesium (Mg), rare-earth elements (R.E.), aluminum (Al), calcium (Ca), barium (Ba), bismuth (Bi), antimony (Sb), tin (Sn), titanium (Ti), zirconium (Zr), molybdenum (Mo), vanadium (V), tungsten (W), niobium (Nb), or nitrogen (N).

The content of each of these elements can be adjusted appropriately depending on characteristics that are required for austenitic cast irons. However, from the viewpoints of influences and so forth to costs and the compositions of the basic elements, the trace-amount modifier elements are 1% or less, preferably 0.8%, or further 0.6% or less in a total contained amount.

**[0058]** An added trace-amount modifier element might possibly disappear and the like during casting, because the melting point is lower than that of Fe. Accordingly, the content of each of the respective elements does not necessarily coincide with the total addition amount of that element. Consequently, as far as being effective in the improvement and so forth of cast structure, it is permissible that the contained amount of that trace-amount modifier element can be at the minimum level that is detectable.

**[0059]** (b) A representative trace-amount modifier element is each of the respective elements that are included in an inoculant agent, which facilitates the crystallization of graphite within Fe base, or a spheroidizing agent, which facilitates the spheroidizing of resultant crystallized graphite. An auxiliary agent, such as an inoculant agent or spheroidizing agent, is blended at the time of preparing a molten metal, or is added appropriately at the time of casting. However, its contained elements and the contained amounts of the respective elements are not fixed, but vary greatly. That is, it is the actual situation however that they are sought by trial and error in order to obtain desired cast structures (e.g., the configurations of crystallizing graphite or the number of their particles especially), and the like. Therefore, it is difficult to clearly identify the type of the trace-amount modifier elements and their contained amounts. And, adhering to the type of the trace-amount modifier elements and the contained amounts is against the true aim of the present invention.

**[0060]** However, Mg and R.E. (e.g., cerium (Ce) especially) have been known publicly as spheroidizing agents for crystallizing graphite. Hence, in the case of the austenitic cast iron according to the present invention as well, it is preferable to include Mg in an amount of from 0.01 to 0.1% and/or Ce in an amount of from 0.005 to 0.05%, Mg and Ce which serve as a trace-amount modifier elements respectively, relative to the entire cast iron being taken as 100%.

**[0061]** Here, since Mg is likely to disappear from inside high-temperature motel metals, it is preferable that the addition amount can be adjusted to such an extent that its lower limit becomes 0.02%, or further 0.03%, relative to the entire cast iron being taken as 100%. Although the upper limit of the contained Mg amount is not limited in particular as far as it does not affect the compositions of the basic elements, it can be, in actuality however, 0.07%, or further 0.06%, relative to the entire cast iron being taken as 100%.

**[0062]** Since Ce, namely, an R.E., is expensive, and moreover since the effect of spheroidizing is obtainable even when being included in a small amount, it is preferable that the upper limit of Ce can be 0.03%, or further 0.01%, relative to the entire cast iron being taken as 100%. Although the lower limit of Ce is not limited in particular as far as it falls in a range in which the effect of serving as a spheroidizing agent is obtainable, the lower limit thereof can be, in actuality however, 0.007%, or further 0.008%, relative to the entire cast iron being taken as 100%.

### (3) Inevitable Impurities

**[0063]** As inevitable impurities, phosphorous (P), and sulfur (S) are given, for instance. P is harmful to the spheroidizing of graphite, and moreover precipitates in crystal grain boundaries to decline oxidation resistance and room-temperature elongation. S is also harmful to the graphitic spheroidizing. Therefore, it is preferable that each of these inevitable impurities can be set at 0.02% or less, or further 0.01% or less.

### (Production Process)

**[0064]** (1) Since the present invention is a manufacturing process for austenitic cast iron, it is equipped with a molten-metal preparation step, a pouring step, and a solidification step that are like those as describe above. However, in the case of manufacturing members, such as automotive component parts for which high reliability is required, with cast products, it is required that the austenitic cast iron according to the present invention be a spheroidal graphite cast iron. Hence, it is desired to crystallize a large number of spheroidal graphite finely and minutely within base that comprises austenite phase, and accordingly the blend or addition of auxiliary agent, such as an inoculant agent or spheroidizing agent, is done.

**[0065]** For instance, these auxiliary agents have been blended beforehand from the stage of the molten-metal preparation step. However, in order to prevent the disappearance of those auxiliary agents, and such a fading phenomenon that the effects of the auxiliary agents reduce as being accompanied by the elapse of time, and in order to make the auxiliary agents function effectively, it is more suitable to first prepare such a molten metal, which comprises the basic elements, previously (i.e., a modifier-free-molten-metal preparation step), and then to be equipped with an auxiliary-agent addition step of blending an auxiliary agent with or adding it to that modifier-free molten metal directly or indirectly.

**[0066]** Here, the case of adding an auxiliary agent "directly" is such a case where it is added to the modifier-free molten metal before pouring it into a casting die, and the like. Moreover, the case of adding or the like an auxiliary agent "indirectly" is such a case where it is charged in a cavity of casting die in advance, and so forth. For example, when being the case of inoculating, it is permissible to do it by any one of the following: ladle inoculation, inoculating inside casting die, wire inoculation, and so on. It is the same in the case of spheroidizing treatment, too.

**[0067]** After all, since ordinary cast products are cast by injecting the molten metal (or modifier-free molten metal) into a ladle from a melting furnace or retaining furnace and then pouring that molten metal into a casting die, it is even permissible that the addition of an auxiliary agent can be carried out at any one of those stages. Moreover, it is permissible that the auxiliary agent can have any one of powdery shapes, granular shapes, wired shapes, and the like. Note that, although the auxiliary agent can be represented by inoculant agents and spheroidizing agents, it can be additive agents other than these.

**[0068]** (2) In view of the composition elementally, it is preferable that the inoculant agent can comprise one or more members of Si, Ca, Bi, Ba, Al, Sn, Cu, or R.E., for instance. To be concrete, the following inoculant agents are available: Si-Ca-Bi-Ba-Al-system ones, Si-Ca-Bi-Al-R.E.-system ones, Si-Ca-Al-Ba-system ones, Si-Sn-Cu-system ones, and the like. The addition amount or blended amount of inoculant agent is determined in consideration of the disappearance, the fading phenomenon, and so forth. Hence, it is preferable to set so that the total addition amount becomes from 0.05

to 1%, for instance, when the entire modifier-free molten metal is taken as 100%.

**[0069]** In view of the composition elementally, it is preferable that the graphite spheroidizing agent can comprise one or more members of Mg, and R.E., for instance. To be concrete, the following spheroidizing agents are available: Mg-R.E.-system ones, Mg simple substance, R.E. simple substances such as mish metal (or Mm), Ni-Mg-system ones, Fe-Si-Mg-system ones, and the like. The addition amount or blended amount of spheroidizing agent is also determined in consideration of the disappearance, the fading phenomenon, and so forth. For example, it is preferable to add a spheroidizing agent so that a residual Mg content (that is, a content of Mg that remains in a prepared cast iron) becomes from 0.01 to 0.1%, more preferably, from 0.03 to 0.08%, when the entire modifier-free molten metal is taken as 100%. Note that, as far as the configuration or number of particles of crystallizing graphite falls within the desirable range, it is optional that to what extent any one of the inoculant agents or spheroidizing agents is added.

(Austenitic Cast Product)

**[0070]** (1) Although the austenitic cast product according to the present invention is members with desirable configuration that comprise the above-described austenitic cast iron according to the present invention, it is needless to say that their configurations, wall thicknesses, and the like, do not matter at all.

**[0071]** Here, although it is also possible to think of that the thickness, configuration, size, casting designs and the like of cast product have influences on the structure, cast defects and so forth of austenitic cast iron, it had been ascertained that, in the case of the austenitic cast product according to the present invention, the base is a stable austenite phase. Moreover, even in a case where the thickness of cast product is so thin that the molten metal is quenched and then rapidly solidified partially, the present inventors had ascertained already that it is possible to obtain desired spheroidal graphite cast irons by adjusting the addition method of an auxiliary agent or the addition timing appropriately.

**[0072]** (2) The structure of austenitic cast iron is divided roughly into a base structure, and a eutectic structure. A base structure according to the present invention comprises an austenite phase of Fe. A eutectic structure according to the present invention is graphite.

Generally speaking, although cast irons are classified variously depending on the forms of crystallizing graphite, being spheroidal graphite cast irons is preferable because they are good in terms of every one of characteristics, such as mechanical characteristics, compared with those of the other cast irons. Hence, it is suitable that the austenitic cast iron according to the present invention can also comprise a spheroidal graphite cast iron.

**[0073]** The structure of spheroidal graphite cast iron is indexed by means of a spheroidized proportion of graphite and the number of graphite particles in general. First of all, actual austenitic cast products that are good in terms of characteristics exhibit such a spheroidized proportion of graphite, which crystallized or precipitated in the base, as 70% or more, 75% or more, 80% or more, or further 85% or more. Next, the greater the number of graphite particles that have crystallized or precipitate is, the more desirable it is. For example, in a section whose cast-product wall thickness is 5 mm or less, it is suitable that the number of graphite particles whose particle diameter is 10 $\mu$m or more can be 50 pieces/mm$^2$ or more, 75 pieces/mm$^2$ or more, or further 100 pieces/mm$^2$ or more. Note that it is preferable that spheroidal graphite can be dispersed within base very finely. Moreover, in a section whose cast-product thickness is 5 mm or less, it is suitable that the number of graphite particles whose particle diameter is 5 $\mu$m or more can be 150 pieces/mm$^2$ or more, 200 pieces/mm$^2$ or more, 250 pieces/mm$^2$ or more, or further 300 pieces/mm$^2$ or more. Note that it is preferable that spheroidal graphite can be dispersed within base very finely.

**[0074]** Note that the spheroidized proportion of graphite can be measured by means of "G5502 10.7.4" as per JIS or the spheroidized-graphite-proportion judgment testing method as per old JIS "5502" (or the NIK method). Moreover, the number of graphite particles can be measured by means of counting the number of graphite particles per unit area.

**[0075]** (3) Not only the austenitic cast iron according to the present invention is excellent in terms of strength, toughness, workability and the like in ordinary-temperature region, but also it is excellent in terms of heat resistance such as highly resistant to oxidation and high-temperature proof stress. Hence, the austenitic cast product according to the present invention that comprises this cast iron is suitable for exhaust-system component parts for automobile, and so forth. To be more concrete, the housings of turbocharger, exhaust manifolds, catalyst cases, and so on. This is because not only these component parts are always exposed in high-temperature environments that result from high-temperature exhaust gases, but also they are exposed to the sulfur oxides, nitrogen oxides etc. in the exhaust gases.

**[0076]** The austenitic cast product according to the present invention is not limited to members that are made use of in such high-temperature region. It is natural that it is utilizable in such members as well that are made use of in ordinary-temperature region or warm region. In particular, since the austenitic cast product according to the present invention can be manufactured at lower cost than conventional ones, the range of its utilization can also be expanded. Moreover, the field of utilization is not limited to the field of automobiles and the field of engines, and the austenitic cast product according to the present invention can be utilized for various kinds of members, too.

(EXAMPLES)

**[0077]** The present invention will be explained more concretely while giving examples.

(First Test)

(1) Manufacturing Method of Test Specimens

**[0078]** Raw materials, which included at least one or more members of C, Si, Cr, Ni, Mn and Cu (i.e., basic elements) and the balance of Fe, were blended and mixed variously, and they were air melted with a high-frequency furnace, thereby obtaining 47-kg molten metals (i.e., a molten-metal preparation step). Eachofthesemoltenmetals was poured into a casting die (e.g., sand die) that had been made ready in advance (i.e., a pouring step). On this occasion, they were tapped at about 1,550 °C, and were poured at about 1,450 °C. Moreover, the after-pouring molten metals were solidified by natural cooling (that is, in a state of as cast), thereby obtaining test specimens with said configuration (or cast products) (i.e., a solidification step).

**[0079]** Note that the addition of an auxiliary agent, such as an inoculant agent and spheroidizing agents, was also carried out when casting the respective test specimens. The addition of the inoculant agent was carried out by adding "CALBALLOY" (containing Si-Ca-Al-Ba) produced by OSAKA SPECIAL ALLOY Co., Ltd. in an amount of 0.2% by mass with respect to the modifier-free molten metals being taken as 100%. The addition of the spheroidizing agents was carried out by adding the following to the modifier-free molten metals: an Mg simple substance in an amount of 4% by mass; R.E. (e.g., misch metal) in an amount of 1.8%; and an Sb simple substance in an amount of 0.005% by mass; with respect to the modifier-free molten metals being taken as 100%. Note that the amount of Mg was great because the disappearance and the like were considered.

**[0080]** The casting die being used herein was a sand die whose size was 50 mm in width × 180 mm in overall length, and from which a stepped plate-shaped cast product was obtainable, stepped plate-shaped cast product whose height (or thickness) changed in five stages in the following order: (i) 50 mm (50 mm in length) ---> (ii) 25 mm (45 mm in length) ---> (iii) 12 mm (40 mm in length) ---> (iv) 5 mm (25 mm in length) ---> 3 mm (20 mm in length).

**[0081]** Moreover, for the measurements of proof stress and tensile strength, type-"B" "Y"-shaped blocks as per JIS were prepared by means of mold casting, and then $\phi 6$ round rod test specimens were prepared from the rectangular vertical cross-sectional part of the resulting "Y"-shaped blocks.

(2) Measurement of Test Specimens

**[0082]** Five types of test samples (e.g., Nos. 1-1 through 1-5) having different blended compositions were manufactured by means of the aforementioned manufacturing process. Samples, which were collected from a section of the respective test specimens with 5-mm thickness, were subjected to the following analyses.

**[0083]** (i) The respective samples were analyzed compositionally by mean of an X-ray micro analyzer (or EPMA), thereby obtaining the analyzed compositions of the entire cast irons and the analyzed compositions of the Fe bases. The thus obtained compositions of the basic elements are shown in Table 1A.

Note that the designation, "-" in Table 1A, specifies either one of being unblended, being unanalyzed or unmeasured, or being unable to analyze or unable to measure. This applies similarly to other tables in the present specification, namely, to Tables 1B through 4B.

**[0084]** (ii) Moreover, Fig. 1 illustrates an analyzed diagram (or XRD) in which the respective samples were analyzed by X-ray diffraction. For reference, XRDs on representative cast irons, which have been said to be austenitic cast irons (e.g., Reference Examples: R1 and R2), are also illustrated on Fig. 1 all together. Further, austenite proportions, which were found based on those XRDs, are also shown in Table 1 all together.

**[0085]** (iii) Furthermore, the $Ni_{eq}$ and $Cr_{eq}$ that are referred to in the present invention were calculated from the Fe-base composition of each of the samples, and were then shown in Table 1A. Each of those $Ni_{eq}$ and $Cr_{eq}$ were plotted on the correlation diagram that is illustrated in Fig. 2. Test Specimen Nos. 1-1 through 1-5 are designated with ● marks. The representative conventional cast irons (e.g., R3: D-5S, and R4: D-2) were designated with ○ marks. Here, the $Ni_{eq}$ was found while assuming that $C_s = 0.03\%$, because it is difficult to analyze the $C_s$ directly.

Note that, in order to discuss whether the obtained cast irons are an austenitic cast iron or not based on the $Ni_{eq}$-$Cr_{eq}$ correlation diagram illustrated in Fig. 2, that is, in order to discuss how much percentages an austenite proportion account for in the Fe bases, strictly speaking, it is necessary to analyze the compositions of the Fe bases from which carbides and graphite are removed. Hence, regarding Test Specimen Nos. 1-1 through 1-5, the $Ni_{eq}$ and $Cr_{eq}$ that went with this way of thinking were calculated, and are then shown in Table 1A.

**[0086]** However, even when being those which are said to be an austenitic cast iron in general, very few of them comprise a 100%-austenite single-phase base as described above. And, excepting C most of which crystallizes or

precipitates as graphite, there is a correlation between the analyzed compositions of the Fe bases and the analyzed compositions of the entire cast irons as far as they fall within the compositional ranges that are prescribed in the present invention, and there is no such a great discrepancy between both of them.
Hence, regarding Reference Example Nos. R1 through R6 in Table 1A and test specimens other than Nos. 1-1 through 1-5 therein, the $Ni_{eq}$ and $Cr_{eq}$, which were calculated using the analyzed compositions of the entire cast irons that served as the substitutes for the analyzed compositions of the Fe bases, are given, for reference for the sake of convenience.

**[0087]** (iv) In the measurements of proof stress and tensile strength, tests were carried out at 150 °C and 800 °C in conformity to "G0567" as per JIS. The resultant measured data on the proof stress and tensile stress are shown in Table 1A and Table 1B all together.

(3) Evaluation

**[0088]** (i) From Table 1A and Fig. 1, it is understood that, in any one of the cases of Test Specimen Nos. 1-1 through 1-5 in which the Ni contents were reduced, austenite phases (or $\gamma$ phases) appeared in the same manner in R1 and R2, namely, conventional austenitic cast irons.
In particular, in the cases of Test Specimen Nos. 1-1 through 1-3, it is understood that the bases' structure turned into an austenite single phase virtually when the contained Ni amounts were at around 10% at the highest.

**[0089]** (ii) Moreover, it was understood from the analyzed compositions of the Fe bases in Table 1A that Si solves into Fe in an amount of up to 5.1% at least, Cu solves thereinto in an amount of up to 7.2% at least, and Mn solves thereinto in an amount of up to 14.5% at least. Moreover, with reference to the Fe-Ni binary system phase diagram, it is possible to say that Ni falling within the range according to the present invention completely solves into Fe.

(Second Test)

(1) Manufacturing Method of Test Specimens

**[0090]** Raw materials, which included at least one or more members of C, Si, Cr, Ni, Mn and Cu (i.e., basic elements) and the balance of Fe, were blended and mixed variously, and they were air melted with a high-frequency furnace, thereby obtaining 47-kg stock molten metals (i.e., a modifier-free-molten-metalpreparationstep). Each of these modifier-free molten metals was poured into a casting die (e.g., sand die) that had been made ready in advance (i.e., a pouring step). In the present test, an inoculant agent and spheroidizing agents that comprised a variety of compositions had been charged into the casting die in advance (i.e., an auxiliary-agent addition step). The other steps were the same as those in the case of First Test.

(2) Measurement of Test Specimens

**[0091]** Thirteen types of Test Specimen Nos. 2-1 through 2-13 having different blended compositions were manufactured by means of the aforementioned manufacturing process. Samples, which were collected from a section of the respective test specimens with 12-mm thickness, were subjected to the following analyses.

**[0092]** (i) In the same manner as in the case of First Test, the analyzed composition and austenite proportion of each of the samples were found. These results are shown in Table 2A and Table 2B.

**[0093]** (ii) Regarding each of the samples, a structural observation was carried out by means of the optical-microscope photograph, thereby examining the crystallized form of eutectic graphite. The spheroidized graphite proportion was found by means of the judgment testing method according to "G5502 (or the NIK method)" as per old JIS.
The number of graphite' s particles was found by counting those whose particle diameters were 10 $\mu$m or more in a 4.8-$mm^2$ area.
Further, a hardness (Hv at 20 kgf) making an index of cast product's strength, and the like, was measured as well. These results are shown in Table 2B all together.

**[0094]** (iii) Furthermore, in the same manner as First Test, the $Ni_{eq}$ and $Cr_{eq}$ were calculated from the analyzed composition of each of the entire samples, and were then shown in Table 2B. Each of these $Ni_{eq}$ and $Cr_{eq}$ was plotted with "+" marks on the structural diagram in Fig. 2 in a superimposed manner. The $C_s$ was treated in the same manner as in the case of First Test.

**[0095]** (iv) In the same manner as in the case of First Test, the heat-resistant strength of each of the samples was found, and was then shown in Table 2B all together.

(3) Evaluation

**[0096]** (i) As can be understood when examining Table 2B carefully, it is understood that it is possible to obtain bases having austenite phases virtually even when the Ni contents are less.

**[0097]** By the way, according to researches by the present inventors, it was ascertained that bases' structure does not affect the thickness of test specimens. To put it differently, it is possible to say that the cast iron according to the present invention is not affected by the solidifying rate, and the like, and thereby stable austenite phases are formed. An XRD that evidences this issue is illustrated in Fig. 3. The XRD in Fig. 3 was obtained by subjecting the 5-mm-thickness section and 12-mm-thickness section of Test Specimen No. 2-2 to X-ray diffraction.

**[0098]** (ii) However, as can be understood when examining Table 2B carefully, those being austenitic cast irons do not necessarily turn into spheroidal graphite cast irons. And, there were such cases that the spheroidized proportions, and the number of spheroidal-graphite particles were low.

Therefore, in order not only to turn the cast iron's base structure into an austenite phase but also to obtain a eutectic structure in which spheroidal graphite is crystallized adequately, it becomes necessary not only to set the compositions of the basic elements in a molten metal or modifier-free molten metal within the ranges according to the present invention but also to take individual measures in compliance with cast products' configuration, molten metals' composition, and the like. For example, it is desired to select the types of auxiliary agent, the addition amounts, and so forth, appropriately in compliance with cast products' configuration, molten metals' composition, and so on. Hence, examples in which the present inventors optimized the eutectic structures individually will be specified in later-described Third Test.

**[0099]** (iii) As can be understood from Table 2B, it is also appreciated that any one of the test specimens being directed to the present invention had strength (or hardness) and heat-resistance strength that were equivalent to or more than those of conventional austenitic cast irons (e.g., Reference Examples R3 and R4). In particular, the test specimens being directed to the present invention exhibited larger proof stresses at 800 °C, which matter in view of practical perspective, than did the conventional austenitic cast irons. As a result of this, it was possible to ascertain that the austenitic cast iron being directed to the present invention has high heat resistance that is equivalent to or more than those of conventional ones.

(Third Test)

(1) Manufacturing Method of Test Specimens

**[0100]** Although the compositions of the basic elements, and the types and addition amounts of the auxiliary agents were changed, the others were set in the same manner as those of Second Test and then two types of test specimens, namely, Test Specimen No. 3-1 and Test Specimen No. 3-2, were manufactured.

An inoculant agent being added in Test Specimen No. 3-1 was "TOYOBARON BIL," namely, 74.18Si-1.23Ca-0.55Ba-0.72Bi-0.51A1-Fe, produced by TOYO DENKA Co., Ltd. This one was added in a proportion of 0.2% by mass with respect to the modifier-free molten metal.

Moreover, used spheroidizing agents were the following: an Mg simple substance in an amount of 4% by mass; R.E. (e.g., misch metal) in an amount of 1.8% by mass; and an Sb simple substance in an amount of 0.005% by mass; and those were added in the respective proportions with respect to the modifier-free molten metals. Note that the amount of Mg was great because the disappearance and the like were considered.

**[0101]** An implant agent being used in Test Specimen No. 3-2 was said "TOYOBARON BIL." This one was added in a proportion of 0.4% by mass with respect to the modifier-free molten metal. As for spheroidizing agents, the following were added to the modifier-free molten metal: Mg in an amount of 4% by mass; R.E. (e.g., misch metal) in an amount of 1.8%; and Sb in an amount of 0.0005% by mass. Here, the added Sb amount differed from that in Test Specimen No. 3-1.

(2) Measurement of Test Specimens

**[0102]** (i) In the same manner as in the case of Second Test, the analyzed composition and austenite proportion of each of the samples were found. These results are shown in Table 3A and Table 3B.

**[0103]** (ii) Samples were collected from each section of the respective aforementioned test specimens whose thickness was 25 mm, 12 mm, 5 mm and 3 mm, and then they were measured for the spheroidized proportion of graphite, the number of graphite particles, and the hardness (Hv at 20 kgf) in the same manner as Second Test.

**[0104]** (iii) The optical-microscope photographs of the respective samples are shown in Fig. 4A and Fig. 4B. #1 through #5 in the diagrams indicate that the structural photographs show the samples' sections that were prepared by dividing the samples into five sections evenly from the sand die's upper-face side to the lower-face side. For example, #1 specifies the structure in the vicinity of the uppermost face, and #5 specifies the structure in the vicinity of the lowermost face. Note that the structural photographs were taken after etching the samples' faces with 3% nital.

**[0105]** (iv) In the same manner as in the case of First Test, the heat-resistant strength of each of the samples was found, and was then shown in Table 3B all together.

(3) Evaluation

**[0106]** (i) First of all, from the austenite proportions in Table 3B, it is understood that the bases' structure turned into an austenite phase in any one of the test specimens.

**[0107]** (ii) Next, as can be seen from Fig. 4A and Fig. 4B, it is understood that graphite crystallized spheroidally and virtually uniformly.

In particular, in the case of Test Specimen No. 3-2, the spheroidized proportion exceeded 70% even when it is a 3-mm-thickness sample in which the molten metal was likely to be solidified rapidly. Moreover, even when having any one of the thicknesses, the number of graphite particles exceeded 200 pieces/mm$^2$, and furthermore the hardness could also be maintained within a range of from 200 Hv to 300 Hv approximately regardless of the locations. From these, it is possible to say that the austenitic cast iron (or cast product) according to the present invention excels in terms of mechanical characteristics, and moreover excels in terms of post-casting mechanical workabilities as well due to the moderate hardness.

**[0108]** (iii) Of course, it is needless to say that any one of these test specimens had strength (or hardness) and heat-resistance strength that were equivalent to or more than those of conventional austenitic cast irons (e.g., Reference Examples R3 and R4), as can be understood from Table 3B, in the same manner as in the case of the above-described test specimens, though the Ni contents are small.

Therefore, when using a cast iron like Test Specimen No. 3-2, it is appreciated that cast products with stable characteristics are obtainable, cast products which are not affected very much by configurations, not to mention in terms of the heat resistance, but in terms of the other characteristics as well.

(Fourth Test)

(1) Manufacturing Method of Test Specimens

**[0109]** Although the compositions of the basic elements, and the types and addition amounts of the auxiliary agents were changed, the others were set in the same manner as those of Second Test and then twelve types of test specimens (i.e., Test Specimen Nos. 4-1 through 4-12) were manufactured.

Note that the addition of the auxiliary agents, such as an inoculants agent and spheroidizing agents, was also carried out. The added inoculant agent was "TOYOBARON BIL," namely, 74.18Si-1.23Ca-0.55Ba-0.72Bi-0.51Al-Fe, produced by TOYO DENKA Co., Ltd. This one was added in a proportion of 0.4% by mass with respect to the modifier-free molten metals. The addition of the spheroidizing agents was carried out by adding the following to the modifier-free molten metals: an Mg simple substance in an amount of 4% by mass; R.E. (e.g., misch metal) in an amount of 1.8% by mass; and an Sb simple substance in an amount of 0.0005% by mass; with respect to the modifier-free molten metal being taken as 100%. Note that the amount of Mg was great because the disappearance and the like were considered.

**[0110]** Moreover, for the measurements of proof stress, tensile strength, elongation, reduction of area and Young's modulus, type-"A" "Y"-shaped blocks as per JIS were prepared by means of mold casting, and then $\phi$ 6 round-bar test specimens were prepared from the rectangular vertical cross-sectional section of the resulting "Y"-shaped blocks.

(2) Measurement of Test Specimens

**[0111]** Twelve types of Test Specimen Nos. 4-1 through 4-12, which were manufactured by means of the aforementioned manufacturing process but which had different blended compositions, were subjected to the following analyses.

**[0112]** (i) In the same manner as in the case of First Test, the analyzed composition and austenite proportion of each of the samples were found. These results are shown in Table 4A and Table 4B.

**[0113]** (ii) Samples were collected from each section of the respective aforementioned test specimens whose thickness was 25 mm, 12 mm, 5 mm and 3 mm, and then they were measured for the spheroidized proportion of graphite, the number of graphite particles, and the hardness (Hv at 20 kgf) in the same manner as Second Test.

**[0114]** (iii) Samples were collected from a section of the respective aforementioned test specimens whose thickness was 25 mm, and the optical-microscope photographs of the respective samples are shown in Fig. 6, respectively. Note that the structural photographs were taken after etching the samples' face with 3% nital.

**[0115]** (iv) Further, in the same manner as First Test, the $Ni_{eq}$ and $Cr_{eq}$ were calculated from the analyzed composition of each of the entire samples, and were then shown in Table 4B. Each of these $Ni_{eq}$ and $Cr_{eq}$ was plotted with "■" marks on the structural diagram in Fig. 2 in a superimposed manner. The $C_s$ was treated in the same manner as in the case of First Test.

**[0116]** (v) In the measurements of proof stress, tensile strength, elongation, reduction of area and Young' s modulus, tests were carried out at 800 °C in conformity to "G0567" as per JIS, and then those results are shown in Table 4B all together. Moreover, the measured data on conventional cast irons are shown as Reference Example Nos. R3 through

R6 in Table 4B all together.

**[0117]** (iv) The thermal-fatigue strength and thermal-fatigue life were measured using ϕ 5-mm round-bar test specimens that were collected from mold-casted type-"A" "Y"-shaped blocks as per JIS, and using ϕ 8-mm round-bar test specimens that were collected from mold-casted type-"B" "Y"-shaped blocks as per JIS. In this test, while changing the temperature of the test specimens with 100% constrained rate repetitively between 800 °C and 150 °C, the test specimens were examined for the following: the number of cycles at which stress lowered by 10%; the number of cycles at which stress lowered by 25%; and the number of cycles at which they fractured apart. These results are illustrated in Fig. 21 (e.g., the results on the ϕ 5-mm round-bar test specimens) and Fig. 22 (e.g., ϕ 8-mm round-bar test specimens), respectively. The "Stress Decline by 10%" and "Stress Decline by 25%" mean the number of cycles when peak stress on the tensile side decreased by 10% from peak stress at the time of the number of cycle = 2, and the number of cycles when it decreased by 25% therefrom, respectively.

(3) Evaluation

**[0118]** (i) First of all, in any one of the test specimens, it is understood from the results of the X-ray analysis that the austenite proportion became 100% as shown in Table 4A, and it is understood from Fig. 6 that no lamellar structures were seen in the Fe bases. Note however that there were even some test specimens in which structures that resembled lamellar structures seemed like to exist. However, no striped patterns were seen in those structures; when they were viewed in an enlarged manner with a microscope, no long and thin rod-shaped structural substances existed like those in lamellar structures but only structural substances that were cut here and there existed. And, the structural substances that are cut here and there do not become the cause of the occurrence of cracks in austenite when they expand at the time of high temperatures. Moreover, concerning any one of the test specimens being labeled Test Specimen Nos. 4-1 through 4-12 as well, a magnet did not react to their 25-mm-thickness and 12-mm-thickness sections, and accordingly it was ascertained that they were free from magnetism. That is, being free from magnetism means that ferrite, namely, a magnetic substance, does not exist, and consequently it is possible to speculate that they comprised an austenite single phase. Note that, regarding the 3-mm-thickness and 5-mm-thickness sections, there were some test specimens to which the magnet reacted. However, since it is not possible to think of that there are cases where ferrite exists and where no ferrite exists depending on thicknesses in an identical test specimen, it is speculated that magnetism is exhibited with regard to the sections with thinner thickness, not because ferrite exists, but because carbides increase at the time of casting when the thickness gets thinner. Moreover, it is apparent from Table 4B and Fig. 2 that a mathematical formula, namely, $Ni_{eq} \geqq Al \cdot Cr_{eq} + B1$, was satisfied in any one of the cases of Test Specimen Nos. 4-1 through 4-12 in which no lamellar structures were seen in their Fe bases (that is, Test Specimen No. 4-9 existed on a straight line with the least intercept, and this line is expressed by $Ni_{eq} = Al \cdot Creq + 22.9$).

**[0119]** On the contrary, it was ascertained that Niresist (FCDA-NiMn137 as per JIS) exhibited magnetism because the magnet reacted with respect to all of the 25-mm, 12-mm, 5-mm and 3-mm sections of the test specimens that were used in First Test. That is, since it exhibits magnetism, the existence of ferrite, namely, a magnetic substance, is speculated. Moreover, as a result of calculation using "$Ni_{eq}$" and "$Cr_{eq}$" of Test Specimen No. R2 being set forth in Table 1A, it was ascertained to be $Ni_{eq} < Al \cdot Cr_{eq} + B1$ (that is, Test Specimen No. R2 exists on a straight line, namely, $Ni_{eq} = Al \cdot Cr_{eq} + 21.5$).

Therefore, it is understood that, when defining "$Ni_{eq}$" and "$Cr_{eq}$" like the present specification and then considering the adaptability of the fourth and fifth conditions based on them, it is possible to accurately demarcate whether a base's structure is an austenitic cast iron (or cast product), which is made of austenite single phase, or not.

**[0120]** (ii) Next, as can be understood from Table 4A, Table 4B and Fig. 7, it is appreciated that Test Specimen Nos. 4-3, 4-4, 4-7, 4-8, 4-11 and 4-12 whose Cu addition amounts were less comparatively had structural constructions and high-temperature strengths that were hardly inferior to those of conventional austenitic cast irons (e.g., Reference Example Nos. R3 and R4). Moreover, even when observing those test specimens with an optical microscope, no Cu peritectic structure was seen.

**[0121]** On the contrary, it is understood that, in Test Specimen Nos. 4-1, 4-2, 4-5, 4-6, 4-9 and 4-10 whose Cu addition amounts were great comparatively, the elongation and reduction of area worsened at the time of high temperature. When observing those test specimens with an optical microscope, Cu peritectic structures were seen. Consequently, the cause of worsening the elongation and reduction of area at the time of high temperature is speculated tobe the resulting Cu peritectic structures.

Hence, it is understood that, when considering the adaptability of Cu like the present specification, it is possible to accurately demarcate whether it is an austenitic cast iron (or cast product) that is good in terms of elongation and reduction of area or not.

**[0122]** (iii) Further, as can be seen from Fig. 8, it is understood that the more the Cr addition amount increased the higher the proof stress (MPa) became.

**[0123]** (iv) Therefore, it is appreciated that cast products, which are stable, not to mention, in the heat resistance but in the other characteristics as well, are obtainable by using cast irons like Test Specimen Nos. 4-3, 4-4, 4-7, 4-8, 4-11 and 4-12. Further, since the cast iron according to Test Specimen No. 4-3 not only comprised Ni in a lesser content but also was good in terms of the proof stress, it is possible to say that it was the best one among the aforementioned test specimens.

(v) Furthermore, as can be seen from Fig. 21 and Fig. 22, Test Specimen Nos. 4-3, 4-7, 4-8, 4-11 and 4-12, namely, the present austenitic cast irons, had a thermal-fatigue life that was extended far greater than those of Test Specimen Nos. R5 and R6 and ferritic cast irons. Moreover, even when their thermal-fatigue lives were compared with those of general austenitic cast irons, the former was equivalent to or more than the latter.

In addition, it was ascertained from Fig. 21 and Fig. 22 that increasing the Cr content even in the austenitic cast irons results in extending the thermal-fatigue life in any one of them. Likewise, it was ascertained from Fig. 21 that the increasing Cu content results in extending the thermal-fatigue life in any one of them even when their Cr contents are identical with each other.

(Fifth Test)

(1) Manufacturing Method of Test Specimens

**[0124]** Although the compositions of the basic elements, and the types and addition amounts of the auxiliary agents were changed, the others were set in the same manner as those of Fourth Test and then twelve types of Test Specimen Nos. 5-1 through 5-12 were manufactured.

Note that the addition of the auxiliary agents, such as an inoculant agent and a spheroidizing agent, was also carried out. The added inoculant agent was "TOYOBARON BIL," namely, 74.18Si-1.23Ca-0.55Ba-0.72Bi-0.51Al-Fe, produced by TOYO DENKA Co., Ltd. This one was added in a proportion of 0.4% by mass with respect to the modifier-free molten metals. For the spheroidizing agent, a spheroidizing agent that had the following in the following contained amounts was made use of: 4%-by-mass Mg simple substance; and 1.8%-by-mass R.E. (e.g., misch metal); and the addition was carried out by adding it to the modifier-free molten metals so that the Mg residual amount became from 0.04 to 0.05% by mass with respect to the 100% modifier-free molten metals and the Sb-simple-substance residual amount became 0.0005% by mass with respect to them.

(2) Measurement of Test Specimens

**[0125]** Twelve types of Test Specimen Nos. 5-1 through 5-12, which were manufactured by means of the aforementioned manufacturing process but which had different blended compositions, were subjected to the following analyses.

**[0126]** (i) In the same manner as in the case of First Test, the analyzed composition and austenite proportion of each of the samples were found. These results are shown in Table 5A and Table 5B. Note that the analyzed compositions in the present specification are based on wet analysis.

Fig. 9 illustrates an analyzed diagram (or XRD) in which samples that were collected from the 25-mm-thickness section of some of the test specimens were subjected to an X-ray diffraction analysis. Moreover, Fig. 10 illustrates correlations between linear expansion coefficients and temperatures that were measured for the other some of the test specimens.

**[0127]** (ii) Samples were collected from each section of the respective aforementioned test specimens whose thickness was 25 mm, 12 mm, 5 mm and 3 mm, and then they were measured for the spheroidized proportion of graphite, the number of graphite particles, and the hardness (Hv at 20 kgf) in the same manner as Second Test. However, the subject of the spheroidized proportion of graphite, and that of the number of graphite particles were those whose graphite particle diameters were 5 μm or more.

(iii) Using test specimens in which Cr, Mn, Ni and Cu were added in an amount of 1% by mass, respectively, and which had a thickness of 25 mm, 12 mm, 5 mm and 3 mm, respectively, correlations between the values of hardness rise and the plate thicknesses of those test specimens were examined when each of the respective elements was added independently. These results are illustrated in Fig. 23. Note that the composition of a test specimen, which made the basis for comparison (i.e., the datum for hardness), was Fe-3%C-4%Si.

**[0128]** (iv) Further, in the same manner as First Test, the $Ni_{eq}$ and $Cr_{eq}$ were calculated from the analyzed composition of each of the entire samples, and were then shown in Table 4B. Each of these $Ni_{eq}$ and $Cr_{eq}$ was plotted with "♦" marks on the structural diagram in Fig. 2 in a superimposed manner. The $C_s$ was treated in the same manner as in the case of First Test.

**[0129]** (v) The oxidation resistance was evaluated by measuring the oxidized weight reduction or oxidized weight increment based on "Z 2282" as per JIS. To be concrete, a variety of test specimens with $\phi$ 20 × 20 mm, which were collected from type-"B" and type-"D" "Y"-shaped blocks as per JIS that were prepared by means of mold casting, were first retained in an air atmosphere at 800°C for 100 hours. Iron balls whose shot spherical diameter was 0.4 mm were then projected to the test specimens that were after this heat treatment, and the projection was carried out until oxide layers on their surfaces disappeared. Here, the oxidized weight increment or oxidized weight decrement was each of the test specimens' mass increment or mass decrement per unit area. The oxidized weight increment was obtained by deducting amass of each of the test specimens before the heat treatment from another mass of the test specimen immediately after the aforementioned heat treatment (or before being shot). The oxidized weight decrement was obtained by deducting a mass of each of the test specimens after being shot from another mass of the test specimen immediately after the aforementioned heat treatment (or before being shot).

**[0130]** The thus foundoxidizedweight increments and oxidized weight decrements are shown in Table 5B. Moreover, Fig. 11 illustrates the oxidized weight reductions of the respective test specimens with a bar graph. Note that, in Fig. 11, the oxidized weight reductions of some of the test specimens that are shown in Tables 4A and 4B are also illustrated all together in addition to the oxidized weight reductions of the test specimens that are shown in Tables 5A and 5B.

**[0131]** Moreover, Figs. 12 (a) and (b), and Figs. 13 (a) and (b) illustrate results of examining correlations between the contained amounts (or addition amounts) of Ni, Mn, Cr and Cu (i.e., the basic elements that are directed to the austenitic cast iron according to the present invention) and oxidized reductions on the basis of Fe-3%C-4%Si-"a"%Ni-"b"%Mn-"c"%Cr-"d"%Cu (% by mass).

**[0132]** (vi) The toughness was evaluated by carrying out a test based on "Z 2242" as per JIS and then measuring the Charpy-impact values of the respective test specimens. To be concrete, the Charpy-impact values of the respective test specimens were measured under room temperature using V-notched test specimens with 10 × 10 × 50 mm that were collected from type-"B" and type-"D" "Y"-shaped blocks as per JIS.

The thus found Charpy-impact values are shown in Table 5B. Moreover, Fig. 14 illustrates the Charpy-impact values of the respective test specimens with a bar graph. Note that, in Fig. 14, the Charpy-impact values of some of the test specimens that are shown in Tables 4A and 4B are also illustrated all together in addition to the Charpy-impact values of the test specimens that are shown in Tables 5A and 5B.

In addition, Fig. 15 illustrates correlations between the Charpy-impact values of the respective test specimens, which are shown in Fig. 14, and the contained amounts of Cr in the respective test specimens.

**[0133]** (vii) In the measurements of proof stress, tensile strength, elongation, reduction of area and Young's modulus, tests were carried out at 800 °C in conformity to "G0567" as per JIS, and then those results are shown in Table 5B all together. Moreover, the measured data on conventional cast irons are shown as reference examples (e.g., Nos. R3 through R6) in Table 5B all together.

Note that ϕ 6-mm round-bar test specimens, which were collected from type-"A" "Y"-shaped blocks as per JIS that were prepared by means of mold casting, were used for the measurements of proof stress, tensile strength, elongation, reduction of area and Young' s modulus.

**[0134]** Fig. 16 illustrates the 0.2% proof stress and fracture elongation of each of the test specimens with a bar graph. In this case as well, those of some of the test specimens that are shown in Tables 4A and 4B are also illustrated all together in addition to those of the test specimens that are shown in Tables 5A and 5B. Moreover, Fig. 17 illustrates correlations between the respective test specimens' rupture elongation and their contained Cr amount or contained Cu amount.

**[0135]** Note that, other than Cr, the test specimens that are plotted in Fig. 17 (b) had compositions as follows. One with Cu = 0% had Ni = 14.5% and Mn = 5.5%; another one with Cu = 1.5% had Ni = 13% and Mn = 5.5%; still another one with Cu = 3% had Ni = 11.5% and Mn = 5.5%; and the other one with Cu = 4.5% had Ni = 10.0% and Mn = 5.5%. Further, Fig. 18 illustrates the hardness (Hv at 20 kgf) of each of the above-described test specimens with 5-mm plate thickness with a bar graph.

**[0136]** (viii) When each of the test specimens was cast, amolten-metal running property was also investigated. To be concrete, an area of molten-metal running portion was found for a plate-configured test specimen that is illustrated in Fig. 19, area of molten-metal running portion which was determined by subtracting an area of defective molten-metal running portion from a total area of the test specimen that was obtained when a molten metal ran completely. Based on the resulting molten-metal running property, the molten-metal running properties of the respective test specimens were evaluated relatively.

Fig. 20 illustrates results of the relative evaluation on the molten-metal running properties with a bar graph. In the relative evaluation, the area of the molten-metal running portion being exhibited by Test Specimen Nos. 5-1, 5-9 and 4-3, that is, the test specimens that were considered showing the most satisfactory molten-metal running property, was taken as "1," and then the molten-metal running portions of the other test specimens were evaluated relatively to that of the formers.

**[0137]** (ix) When each of the test specimens was cast, shrinkages were investigated as well. To be concrete, as shown in Fig. 24, an inner shrunk portion or outer shrunk portion, which occurred in a test specimen, was filled up with shot balls with ϕ 0.5 mm, and then a total weight of the filled shot balls was measured to evaluate a shrinkage magnitude. Fig. 25 illustrates results of evaluating the shrinkage magnitudes of the respective test specimens relatively while taking the shrinkage magnitude of Test Specimen No. R3 as "1. "

**[0138]** (x) First of all, correlations between heating-temperature ranges and linear expansion coefficients were surveyed. The measurement of linear expansion coefficient was carried out while changing the temperature of a test specimen at an incremental temperature rate of 3 °C /min. within a specific range. This measurement was carried out in a nitrogen atmosphere with 0.05 MPa. A configuration of the used test specimens was a squared-column shape with 3 mm × 3 mm square and 15 mm in length. The test specimens had been annealed in advance by heating them to 950 °C or more in air. This measurement was carried out twice for each of the test specimens, respectively, and then their averages were found. The resulting outcomes are illustrated in Fig. 26. Note that, in Fig. 26, the designation, "E-06," means $10^{-6}$ (i.e., parts per million).

**[0139]** Next, the heating-temperature width was limited to from 150 to 800 °C, and then an average linear expansion coefficient of each of the test specimens was found. The resulting outcomes are illustrated in Fig. 27.

**[0140]** (xi) The respective test specimens' thermal conductivity was measured at room temperature. The resulting outcomes are illustrated in Fig. 27.

(3) Evaluation

**[0141]** (i) First of all, in any one of the test specimens, it is understood from the results of the X-ray analysis that the austenite proportion became 100% as shown in Table 5A. Moreover, this issue can also be ascertained by comparing the graphic forms of Test Specimen No. R3, which has been known generally as an austenitic cast iron, or those of Test Specimen No. R6, which has been known as a ferritic cast iron, with those of Test Specimen No. 5-5, and the like, in the XRD diagram that is shown in Fig. 9 and the correlation diagram between temperatures and linear expansion coefficients that is shown in Fig. 10. That is, it is seen from Fig. 9 that the XRD diagrams of Test Specimen No. 5-1, No. 5-5 and No. 5-9 showed the same form as that of another Test Specimen No. R3 comprising an austenitic phase, and that they showed different forms from that of Test Specimen No. R6 comprising a ferrite phase.

**[0142]** Moreover, the following canbe seen from Fig. 10: Test Specimen No. 5-5's correlation diagram between temperatures and linear expansion coefficients showed a gentle form, which was similar to those of other Test Specimen No. 4-3, No. R3 and No. R4 that comprised an austenite phase, up to around 910 °C at least; and the linear expansion coefficient did not change abruptly unlike the linear expansion coefficient of Test Specimen No. R6 comprising a ferrite phase that did so contrarily in a specific temperature zone (e.g., at around 750 °C). It was ascertained from these facts as well that the cast irons according to Test Specimen Nos. 5-1 through 5-12 are austenitic cast irons that virtually comprise an austenite single phase, respectively.

**[0143]** On the other hand, as can be seen from Fig. 2, such Test Specimen Nos. 5-1 through 5-12 are positioned essentially in the mixture phase of austenite phase (A) and martensite phase (M) on the Schaeffler's structural diagram tentatively. However, regardless of the compositions with such positioning, the austenitic cast iron according to the present invention turned into an austenite single phase virtually by adjusting an overall compositional range adequately.

**[0144]** Moreover, it is possible to speculate that the test specimens turn into an austenite single phase even when the Ni equivalents are less in a range where the Cr equivalents falls in a range of from 7 to 9, because of the following facts: NiMn137 is not an austenite single phase at ordinary temperature; and all of the test specimens (e.g., the test specimens that are present below the dotted line in Fig. 2) turned into an austenite phase, respectively, and such test specimens were speculated to be less likely to turn into an austenite single phase than is NiMn137 on the Schaeffler' s structural diagram.

**[0145]** It is speculated that Cu and Ni are equivalent with respect to an Ni equivalent in the Schaeffler's structural diagram; consequently, it is possible to speculate that Test Specimen No. 5-12 keeps being an austenite single phase even when the Cu content is increased from "0" to "1.5" and the Ni content is reduced from "8.5" to "7," for instance, because there is not any change in the Ni equivalent. When doing thusly, it is possible to furthermore reduce the Ni content.

**[0146]** Moreover, Mn and Ni make a relationship, namely, 0.5:1, with respect to an Ni equivalent in the Schaeffler's structural diagram; consequently, it is possible to speculate that Test Specimen No. 5-12 keeps being an austenite single phase even when the Mn content is reduced from "7.5" to "0.1" and the Ni content is increased from "8.5" to "12.2," for instance, because there is not any change in the Ni equivalent. Note that, not increasing the amount of the Ni content alone, it is permissible to increase both of the Ni content and Cu content. In this way, when the Mn content, namely, a factor of raising hardness, can be decreased, it is possible to lower the hardness of austenitic cast iron.

**[0147]** (ii) Next, it is appreciated from Fig. 11 that Test Specimen Nos. 5-1 through 5-12 were good in terms of the oxidation resistance because the oxidized weight reduction was 100 mg/cm$^2$ or less in any one of them. In particular, as can be seen from Fig. 12 and Fig. 13, the oxidized weight reduction is affected greatly by the contained elements' types and their contained amounts, and their influential powers become the following order: Cr > Ni > Cu > Mn. In austenitic cast irons like the present invention in which the Ni contents are made less considerably than those of conventional ones, it was ascertained that having them contain Cr or Cu (Cr especially) is effective in the improvement of their oxidation resistance.

**[0148]** (iii) On the other hand, it is seen from Fig. 14 and Fig. 15 that the toughness of the austenitic cast irons declined as the contained amounts of Cr increased. However, it was ascertained that those whose contained amount of Cr was 2.5% by mass approximately had toughness that is equivalent to or more than those of conventional austenitic cast iron (i.e., Test Specimen No. R5) and ferritic cast iron (i.e., Test Specimen No. R6). Further, it is also seen from Fig. 15 that there was such a tendency that the less the contained amount of Mn was the higher the toughness (or Charpy-impact value) of the austenitic cast irons became.

From Fig. 12 and Fig. 15, it is possible to say that it is more preferable that the contained amount of Cr can be from 0.5 to 2% by mass, or further from 0.5 to 1.5% by mass approximately, in order to secure the oxidation resistance and toughness that can be equivalent to or more than those of conventional austenitic cast irons (e.g., Test Specimen Nos. R3 and R4).

**[0149]** (iv) It is seen from Fig. 16 that any one of the cast irons according to Test Specimen Nos. 5-1 through 5-12 had high-temperature strength (e.g., 0.2% proof stress and fracture elongation at 800 °C) that was the same or more than those of conventional austenitic cast irons (e.g., Test Specimen Nos. R3 through R5) and ferritic cast iron (e.g., Test Specimen No. R6).

Moreover, it is seen from Fig. 17 (a) that, though the austenitic cast irons' fracture elongation at high temperature was improved by means of increasing the contained amount of Cr, it became a virtually saturated state when that contained amount was 2.5% by mass approximately. On the other hand, it is seen from Fig. 17 (b) that the austenitic cast irons' fracture elongation at high temperature was decreased sharply by means of increasing the contained amount of Cu. Hence, it is possible to say that it is preferable that the upper limit of the contained amount of Cr can be 3% by mass or less, or further 2.5% by mass, approximately; and it is preferable that the upper limit of the contained amount of Cu can be 2% by mass approximately.

**[0150]** (v) From Fig. 18, it seems that Test Specimen Nos. 5-1 through 5-12 (that is, their sections with 5-mm plate thickness) also exhibited favorable workability in cutting, and the like, because the hardness of any one of them was 250 Hv approximately.

Note that, as can be seen from Fig. 23, the hardness of test specimen is affected by the additive elements and plate thicknesses. That is, it becomes such a tendency that the hardness of test specimen rises when adding Cr or Mn. On the contrary, it becomes such an opposite tendency that the hardness of test specimen declines when adding Ni or Cu. From these facts, it is appreciated that an austenitic cast iron with desired hardness is obtainable by means of the selection of these additive elements and the adjustment of their addition amounts.

However, the resulting hardness is affected by the thickness of test specimen (or cast product) as well. Although the influence of the additive elements is great at sections with smaller plate thicknesses, it was appreciated that the greater those plate thicknesses become the smaller the influence of any one of the additive elements becomes and then the hardness shows such a tendency that it converges to that of a test specimen comprising a datum composition.

**[0151]** (vi) From the relative evaluation on molten-metal running that is illustrated in Fig. 20, any one of Test Specimen Nos. 5-1 through 5-12 was superior to a conventional austenitic cast iron (e.g., Test Specimen No. R5) in terms of the molten-metal running property. In particular, it was also ascertained that the austenitic cast irons, which are directed to the present invention, were superior to another conventional austenitic cast iron (e.g., Test Specimen No. R3) in terms of the molten-metal running property, because their molten-metal running properties were very favorable, that is, they were about 1 in all of them, excepting Test Specimen No. 5-11, regardless of being evaluated relatively.

**[0152]** (vii) From the relative evaluation on shrinkage magnitude that is illustrated in Fig. 25, it was seen that, in any one of the test specimens, the shrinkage magnitude was less than that in a representative austenitic cast iron (e.g., Test Specimen No. R3). To be concrete, it was from 70 to 85% approximately in the test specimens that exhibited the greater shrinkage magnitudes; and it was from 35 to 50% approximately in the test specimens that exhibited the lesser shrinkage magnitudes; and accordingly the shrinkage magnitudes could be approximated to the shrinkage magnitude of a ferritic cast iron (e.g., Test Specimen No. R5).

**[0153]** (viii) It was seen from Fig. 26 that, regardless of heating-temperature zones, the average linear expansion coefficients of the austenitic cast irons according to Test Specimen No. 4-3 and No. 5-5 were virtually equal to the average linear expansion coefficient of an existing austenitic cast iron (e.g., Test Specimen No. R4).

**[0154]** Moreover, according to Fig. 27, not only the average linear expansion coefficients of Test Specimen Nos. 5-1 through 5-12 as well as those of Test Specimen Nos. 4-3, 4-4, 4-11 and 4-12 were surely higher than those of existing ferritic cast irons (e.g. , Test Specimen Nos. R5 and R6), but also they were a little bit higher than those of existing austenitic cast irons (e.g., Test Specimen Nos. R3 and R4) roughly.

**[0155]** (ix) According to Fig. 28, although the thermal conductivities of Test Specimen Nos. 5-1 through 5-12 as well as those of Test Specimen Nos. 4-3, 4-4, 4-11 and 4-12 were lower than the thermal conductivities of existing ferritic cast irons (e.g., Test Specimen Nos. R5 and R6), they were virtually equal to the thermal conductivity of an existing austenitic cast iron (e.g., Test Specimen No. R3).

**[0156]** (x) It is possible to say that Test Specimen Nos. 5-5 and 5-6 were excellent materials, because they exhibited moderate hardness and were good in terms of the oxidation resistance despite their contents of Ni that were less.

(Sixth Test)

(1) Manufacturing Method of Test Specimens

**[0157]** Although the compositions of the basic elements, and the types and addition amounts of the auxiliary agents were changed, the others were set in the same manner as those of Second Test and then six types of Test Specimen Nos. 6-1 through 6-6 were manufactured. Note that the addition of the auxiliary agents, such as an ioculant agent and a spheroidizing agent, was also carried out when casting the respective test specimens.

**[0158]** The added inoculants agent was "TOYOBARON BIL," namely, 74.18Si-1.23Ca-0.55Ba-0.72Bi-0.51Al-Fe, produced by TOYO DENKA Co., Ltd. This one was added in a proportion of 0.4% by mass with respect to the modifier-free molten metals.
For the spheroidizing agent, a spheroidizing agent, which had an Mg simple substance and R.E. (e.g., misch metal) in a contained amount of 4% by mass and 1.8% by mass respectively, was made use of; and the addition was carried out to the stock molten metals so that a residual amount of Mg became from 0.04 to 0.06% by mass and a residual amount of Sb simple substance became 0.0005% by mass with respect to the 100% stock molten metals.

(2) Measurement of Test Specimens

**[0159]** Six types of Test Specimen Nos. 6-1 through 6-6, which were manufactured by means of the aforementioned manufacturing process but which had different blended compositions, were subjected to the following analyses.

**[0160]** (i) In the same manner as in the case of First Test, the following were found, respectively: the analyzed composition of each of the samples; $C_{eq}$, $Ni_{eq}$ and $Cr_{eq}$ based on that analyzed composition; and the austenite proportion. These results are shown in Table 6A. Note that, although the analysis on the major elements of the respective test specimens was carried out based on wet analysis, a gas analysis was also carried out with respect to the respective test specimens in conjunction with the former analysis. In this gas-analysis method, gases that were gasified by means of high-frequency combustion, were quantified by infrared absorption spectrophotometry using an analyzing apparatus that was produced by LECO Corporation, and thereby O was quantified by infrared absorption spectrophotometry and N was quantified by thermal conductivity method.

**[0161]** (ii) Samples were collected from each section of the respective aforementioned test specimens whose thickness was 25 mm, 12 mm, 5 mm and 3 mm, and then they were measured for the spheroidized proportion of graphite, the number of graphite particles, and the hardness (Hv at 20 kgf) in the same manner as Second Test. However, the subject of the spheroidized proportion of graphite, and that of the number of graphite particles were those whose graphite particle diameters were 5 μm or more. These results are shown in Table 6B.

**[0162]** (iii) The oxidation resistance of each of the test specimens was evaluated by measuring the oxidized weight reduction or oxidized weight increment based on "Z 2282" as per JIS. To be concrete, a variety of test specimens with 20 × 30 × 5 mm, which were collected from type-"B" and type-"D" "Y"-shaped blocks as per JIS that were prepared by means of mold casting, were first retained in each of 750-°C, 800-°C and 850-°C air atmospheres for 100 hours. Iron balls whose shot spherical diameter was 0.4 mm were then projected to the test specimens that were after this heat treatment, and the projection was carried out until oxide layers on their surfaces disappeared. Here, the oxidized weight increment or oxidized weight decrement was each of the test specimens' mass increment or mass decrement per unit area. The oxidized weight increment was obtained by deducting a mass of each of the test specimens before the heat treatment from another mass of the test specimen immediately after the aforementioned heat treatment (or before being shot). The oxidized weight decrement was a value that was obtained by dividing a deducted value, which was obtained by deducting a mass of each of the test specimens after being shot from another mass of the test specimen immediately after the aforementioned heat treatment (or before being shot), with a surface area of the test specimen. The thus found oxidized weight increments and oxidized weight decrements are shown in Table 6B.

**[0163]** Furthermore, regarding the cases as well where the temperature in air atmosphere in which the respective test specimens were heated and then retained were set at 750 °C and 850 °C instead of 800 °C, The oxidized weight reduction and oxidized weight increment were measured for each of the test specimens. Not only the results are shown in Table 6C but also the oxidized weight reductions of the respective test specimens are illustrated with a bar graph in Fig. 29. Note that the oxidized weight reductions of the Test Specimen Nos. R3, R4, R5 and R7 that comprised conventional cast irons are also shown all together inTable 6A, Table 6B and Fig. 29 for comparison, in addition to those of present Test Specimen Nos. 6-1 through 6-6. Incidentally, the oxidized weight reductions that are given in Table 6A, Table 6B and Fig. 29 are averaged values of their twice-measured values, and the oxidized weight increments are averaged values of their thrice-measured values.

**[0164]** (vi) The measurements of proof stress (e.g., 0.2% proof stress), tensile strength and elongation were carried out onto the respective test specimens whose temperature was 800 °C in conformity to "G0567" as per JIS. For these measurements, ϕ 6-mm round-bar test specimens, which were collected from type-"B" "Y"-shaped blocks as per JIS that were prepared by means of mold casting, were used. Those results are shown in Table 6B all together.

**[0165]** Furthermore, regarding the cases as well where the temperature of each of the test specimens was set at room temperature (or R. T.), 750 °C and 850 °C in addition to 800 °C, the proof stress, tensile strength and elongation were measured similarly for each of the test specimens. Not only the results are shown in Table 6C but also the proof stresses, tensile strengths and elongations of the respective test specimens are illustrated with a bar graph in Figs. 30 through 32, respectively. In these cases as well, the proof stresses, tensile strengths and elongations of the Test Specimen Nos. R3, R4, R5 and R7 that comprised conventional cast irons are also shown all together for comparison, in addition to those of present Test Specimens Nos. 6-1 through 6-6. Incidentally, the proof stresses, tensile strengths and elongations that are given in Table 6A, Table 6B and Figs. 30 through 32 are averaged values of their thrice-measured values.

**[0166]** (v) A thermal-fatigue life of each of the test specimens was measured. The measurement of this thermal-fatigue life was carried out in the following manner. Test specimens, namely, $\phi$ 8-mm round bars, which were collected from type-"B" "Y"-shaped blocks as per JIS and which comprised various compositions, were made ready.

**[0167]** While setting a constrained ratio to each of the test specimens at 100%, those test specimens' temperature was fluctuated between 800 °C and 200 °C repeatedly to examine the following respectively: the number of cycles at which stresses that acted on the test specimens lowered by 10%; the number of cycles at which they lowered by 25%; the number of cycles at which they lowered by 50%; and the number of cycles at which the test specimens fractured apart. Furthermore, in addition to the case where a constrained ratio to each of the test specimens was set at 100%, regarding the cases as well where the constrained ratio was set at 50% and 30%, each of the following was found similarly: the number of cycles at which stresses that acted on the test specimens lowered by 10%, 25% and 50%; and the number of cycles at which the test specimens fractured apart.

**[0168]** Note that this thermal fatigue test was carried out with a coffin-type thermal fatigue testing machine, and that the constrained ratio $\eta$ means a proportion of a constrained magnitude "B" with respect to a free expansion magnitude "A" (i.e., $\eta$ = "B"/"A" $\times$ 100 (%)). Moreover, "10%-stress decline, 25%-stress decline, or "50%-stress decline" means the following: the number of cycles when a peak stress on the tensile side decreased by 10% therefrom; the number of cycles when a peak stress on the tensile side decreased by 25% therefrom; and the number of cycles when a peak stress on the tensile side decreased by 50% therefrom, respectively; on the basis of a peak stress when the number of cycles = 2.

**[0169]** In addition to the aforementioned thermal-fatigue test, each of the test specimens' temperature was fluctuated between 150 °C and 800 °C repeatedly while setting the constrained ratio of those test specimens at 100%, thereby examining the number of cycles at which stresses that acted on the test specimens lowered by 10%, the number of cycles at which they lowered by 25%, and the number of cycles at which the test specimens fractured apart, respectively.

**[0170]** Not only these results are shown in Table 6C collectively but also the thermal-fatigue lives of the test specimens are illustrated with a bar graph in Fig. 33. Note that, regarding Test Specimen Nos. R3, R4, R5 and R7 as well that comprised conventional cast irons, each of their thermal-fatigue lives is shown all together for comparison, in addition to those of present Test Specimen Nos. 6-1 through 6-6.

**[0171]** (vi) A linear expansion coefficient of each of the test specimens was found. This linear expansion coefficient was found by measuring a change of each of the test specimens in the length when the test specimens' temperature was changed from 40 °C and up to 900 °C at a temperature-increment rate of 3 °C/min in the presence of nitrogen atmosphere (e.g., 0.05 MPa). A configuration of the test specimens that were used for this measurement was adapted into a squared-column shape with 3 mm $\times$ 3 mm squared section and 15 mm in length. The respective test specimens had been annealed in advance by heating them to 950°C or more in air. These results are given in Table 6C.

**[0172]** Note that, in Table 6C, being set forth as "' Averaged' Linear Expansion Coefficient" means average thermal expansion coefficients from 40 and up to 900 °C, and that these averaged linear expansion coefficients are values that were obtained by further averaging their twice-measured values (averaged linear expansion coefficients) being found for the respective test specimens.

(3) Evaluation

**[0173]** (i) First of all, in any one of the Test Specimen Nos. 6-1 through 6-6 in Table 6A, the austenite proportion was 100% virtually according to the results of the X-ray analysis. This issue can also be understood from the fact that those linear expansion coefficients of Test Specimen Nos. 6-1 through 6-6 were equivalent to that of Test Specimen No. R3 that has been known generally as an austenitic cast iron.

**[0174]** (ii) Next, as can be understood from Table 6B, the spheroidized proportions in the respective test specimens were high regardless of their plate thicknesses, and the number of graphite particles became sufficient even in test specimens with larger plate thicknesses. That is, it is understood that graphite crystallized as spherical shapes virtually evenly in any one of Test Specimen Nos. 6-1 through 6-6 regardless of the plate thickness. Therefore, when having the same compositions as those of these test specimens, cast products can be obtained, cast products which comprise metallic structures in which graphite is crystallized as spherical shapes virtually evenly not only in their surfaces but also in their insides.

**[0175]** Further, in the test specimen with any one of the plate thicknesses, it is possible to say that the austenitic cast irons (or cast products) according to the present example was good not only in terms of mechanical characteristics but also in terms of machinability, because the hardness was stabilized as from 200 Hv to 300 Hv approximately.

**[0176]** (iii) As can be appreciated from Table 6B, Table 6C and Fig. 29, the oxidized weight reduction was 30 mg/cm$^2$ or less approximately when the heating temperature was 750 °C; and it was as small as 50 mg/cm$^2$ or less approximately when the heating temperature was 800 °C; in any one of Test Specimen Nos. 6-1 through 6-6. It is understood that the austenitic cast irons according to the present example were good in terms of the oxidation resistance, because any one of the oxidized weight reductions was 100 mg/cm$^2$ or less approximately even in the case where the heating temperature was 850 °C.

**[0177]** However, it is understood that the Cr content or the Ni content affects greatly the suppression of the oxidized weight reduction, that is, the improvement of the oxidation resistance, when comparing Test Specimen No. 6-1 with Test Specimen No. 6-5 or comparing Test Specimen No. 6-5 with Test Specimen No. 6-6, for instance. In particular, in Test Specimen No. 6-3 in which both of the Cr content and Ni content were great, it was ascertained that the suppression of the oxidized weight reduction was so remarkable as being at the same level as that in Test Specimen No. R7.

**[0178]** (iv) As can be appreciated from Table 6B, Table 6C and Figs. 30 through 32, the proof stress, tensile strength and fracture elongation were equivalent to or more than those of Test Specimen No. R3 or Test Specimen No. R4, namely, those of conventional austenitic cast irons, in any one of Test Specimen Nos. 6-1 through 6-6. Especially, in Test Specimen No. 6-2 that did not include any Cu, the proof stress and tensile strength hardly lowered, and the elongation improved remarkably to exhibit high ductility.

In particular, in Test Specimen No. 6-6, the oxidation resistance improved considerably because it contained Cr. Besides, it demonstrated such a good characteristic that the hardness was low comparatively because the contained amount of Cr was 1.5% in Test Specimen No. 6-6 and was less than 2.5% in Test Specimen No. 6-3.

**[0179]** (v) As can be appreciated from Table 6C and Figs. 33, any one of the thermal-fatigue lives of Test Specimen Nos. 6-1 through 6-6 were equivalent to or more than those of Test Specimen No. R3 or Test Specimen No. R4, namely, those of general austenitic cast irons. However, when viewing the thermal-fatigue life as a whole, the greater the Ni content was and the less the Cr content was the longer the test specimens' thermal-fatigue life became. Moreover, the test specimens that contained an appropriate amount of Cu had a longer thermal-fatigue life rather than those that did not.

(TABLE 1A)

| Test Specimen No. | Entire Cast Iron | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Blended (or Target) Composition (% by mass) | | | | | | Analyzed Composition (% by mass) | | | | | | $C_{eq}$ |
| | C | Si | Cr | Ni | Mn | Cu (Mo) | C | Si | Cr | Ni | Mn | Cu | |
| 1-1 | 3 | 2.3 | 0 | 13 | 6.5 | 6.5 | 3.28 | 2.11 | 0.034 | 13.6 | 6.51 | 6.49 | 4.0 |
| 1-2 | 3 | 4 | 0 | 13 | 6.5 | 6.5 | 2.88 | 4.38 | 0.009 | 13.53 | 6.79 | 6.4 | 4.3 |
| 1-3 | 3 | 4 | 2 | 13 | 6.5 | 6.5 | 3.09 | 4.31 | 1.98 | 13.75 | 6.71 | 6.43 | 4.5 |
| 1-4 | 3 | 4 | 2 | 9 | 6.5 | 13 | 2.89 | 4.17 | 2.07 | 9.71 | 6.76 | 11.91 | 4.3 |
| 1-5 | 3 | 4 | 2 | 6 | 13 | 13 | 3.15 | 4.42 | 2.10 | 6.30 | 13.35 | 10.61 | 4.6 |
| R1 | 3 | 2.25 | 2 | 15 | - | 6.5 | 3.1 | 2.0 | 3.5 | 16.04 | 1.10 | 6.77 | 3.7 |
| R2 | 3 | 2.25 | - | 13 | 7 | - | 3.0 | 2.4 | 0.5 | 13.52 | 7.35 | 0.022 | 3.8 |
| R3 | 2.0 | 5.0 | 2 | 35 | 0.6 | - | 2.0 | 4.7 | 2.0 | 35.03 | 0.56 | - | 3.5 |
| R4 | 2.8 | 2.8 | 2 | 20.5 | 0.8 | - | 2.3 | 2.8 | 2.0 | 21.22 | 1.21 | - | 3.3 |
| R5 | 3.8 | 2.6 | - | - | 0.8 or less | - | 3.5 | 2.7 | - | - | 0.44 | - | 4.4 |
| R6 | 3.1 | 4.2 | - | - | 0.6 or less | Mo 0.5 | 2.8 | 4.4 | - | - | 0.40 | - | 4.2 |

**(continued)]** (TABLE 1A (continued))

| | Fe Base | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | Analyzed Composition (% by mass) | | | | | | $Ni_{eq}$ | $Cr_{eq}$ | A.P. (%) *1 | |
| | $C_s$ | Si | Cr | Ni | Mn | Cu | | | | |
| 1-1 | Not Analyzable | 2.3 | 0.1 | 10.4 | 6.5 | 7.2 | 21.9 | 3.6 | 100 | |
| 1-2 | Not Analyzable | 4.6 | 0 | 9.4 | 5.8 | 7.1 | 20.4 | 6.9 | 100 | |
| 1-3 | Not Analyzable | 4.5 | 1.5 | 10.1 | 5.6 | 6.7 | 20.6 | 8.3 | 100 | |
| 1-4 | Not Analyzable | 5.1 | 1.6 | 7.5 | 7 | 6.6 | 18.6 | 9.3 | 50 | |
| 1-5 | Not Analyzable | 4.5 | 1.6 | 4.2 | 14.5 | 5.3 | 17.8 | 8.4 | 30 | |
| R1 | Unanalyzed | | | | | | 24.4 | 6.4 | 100 | *2 |
| R2 | Unanalyzed | | | | | | 18.2 | 4.1 | 100 | JIS: FCDA-NiMn137 |
| R3 | Unanalyzed | | | | | | 36.3 | 8.9 | 100 | JIS: FCDA-NiSiCr3522 (or ASTM: D-5S) |
| R4 | Unanalyzed | | | | | | 22.8 | 6.1 | 100 | JIS: FCDA-NiCr202 (or ASTM: D-2) |
| R5 | Unanalyzed | | | | | | 1.2 | 4.1 | 0 | JIS: FCDA 450 |
| R6 | Unanalyzed | | | | | | 1.2 | 6.7 | 0 | HiSiMo FCD |

(Note) *1: "A. P." stands for Austenite Proportion.

*2: JIS: FCA-NiCuCr1562 (one in which graphite was spheroidized by means of spheroidizing treatment)

(TABLE 1B)

| Test Specimen No. | Heat-resistance Strength (MPa) | | | | Remarks |
|---|---|---|---|---|---|
| | 150 °C | | 800 °C | | |
| | Proof Stress | Tensile Strength | Proof Stress | Tensile Strength | |
| 1-1 | Unmeasured | | | | |
| 1-2 | Unmeasured | | | | |
| 1-3 | Unmeasured | | | | |
| 1-4 | Unmeasured | | | | |
| 1-5 | Unmeasured | | | | |
| R1 | Unmeasured | | | | JIS: FCA-NiCuCr1562 (one in which graphite was spheroidized by means of spheroidizing treatment) |
| R2 | Unmeasured | | | | JIS: FCDA-NiMn137 |
| R3 | 181 | 419 | 73 | 116 | JIS: FCDA-NiSiMn3522 (or ASTM: D-5S) |
| R4 | 219 | 446 | 87 | 134 | JIS: FCDA-NiCr202 (or ASTM: D-2) |
| R5 | 403 | 503 | 27 | 48 | JIS: FCD 450 |
| R6 | 459 | 610 | 28 | 43 | HiSiMo FCD (or TS: FCDA4) |

(TABLE 2A)

| Test Specimen No. | Blended Composition of Basic Elements (% by mass) | | | | | | Analyzed Composition of Entire Cast Iron (% by mass) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Cr | Ni | Mn | Cu | C | Si | Cr | Ni | Mn | Cu | Mg | Ce | S | P |
| 2-1 | 3.0 | 4.0 | 1.5 | 10.0 | 5.5 | 6.0 | 2.95 | 3.90 | 1.41 | 10.10 | 5.52 | 6.18 | 0.04 | 0.01 | 0.005 | 0.03 |
| 2-2 | 3.0 | 4.0 | 1.5 | 10.0 | 5.5 | 6.5 | 3.04 | 3.75 | 1.41 | 9.90 | 5.47 | 7.39 | 0.04 | 0.01 | 0.007 | 0.03 |
| 2-3 | 3.0 | 4.0 | 1.5 | 6.0 | 14.5 | 6.0 | 3.01 | 4.04 | 1.52 | 6.26 | 14.50 | 6.09 | 0.03 | 0.01 | 0.001 | 0.04 |
| 2-4 | 3.0 | 4.0 | 1.5 | 10.0 | 5.5 | 5.5 | 3.05 | 3.95 | 1.54 | 10.00 | 5.42 | 5.53 | 0.04 | 0.01 | 0.008 | 0.03 |
| 2-5 | 3.0 | 4.0 | 1.5 | 7.5 | 14.5 | 6.0 | 3.06 | 4.19 | 1.48 | 7.75 | 14.5 | 6.05 | 0.04 | 0.01 | 0.002 | 0.04 |
| 2-6 | 3.0 | 4.0 | 1.5 | 7.5 | 7.5 | 6.0 | 3.04 | 3.81 | 1.51 | 7.42 | 7.52 | 6.03 | 0.03 | 0.01 | 0.006 | 0.03 |
| 2-7 | 3.0 | 4.0 | 1.5 | 7.5 | 10.0 | 6.0 | 3.04 | 3.98 | 1.50 | 7.64 | 10.10 | 5.93 | 0.03 | 0.01 | 0.005 | 0.03 |
| 2-8 | 3.0 | 4.0 | 1.5 | 6.0 | 10.0 | 6.0 | 3.02 | 4.00 | 1.52 | 6.06 | 10.20 | 5.91 | 0.03 | 0.01 | 0.004 | 0.03 |
| 2-9 | 3.0 | 4.0 | 1.5 | 5.0 | 14.5 | 8.0 | 3.04 | 3.97 | 1.48 | 5.22 | 14.90 | 8.48 | 0.04 | 0.01 | 0.001 | 0.03 |
| 2-10 | 3.0 | 4.0 | 1.5 | 7.5 | 7.5 | 8.0 | 2.95 | 3.85 | 1.47 | 7.56 | 7.67 | 7.91 | 0.03 | 0.01 | 0.005 | 0.03 |
| 2-11 | 3.0 | 4.0 | 1.5 | 7.5 | 5.5 | 8.0 | 3.00 | 2.96 | 1.52 | 7.66 | 5.74 | 8.28 | 0.01 | - | 0.005 | 0.03 |
| 2-12 | 3.0 | 4.0 | 1.5 | 6.0 | 10.0 | 8.0 | 3.04 | 3.94 | 1.49 | 6.10 | 9.84 | 7.61 | 0.03 | 0.01 | 0.003 | 0.03 |
| 2-13 | 3.0 | 4.0 | 1.5 | 6.0 | 7.5 | 8.0 | 3.01 | 3.87 | 1.51 | 6.31 | 7.73 | 7.86 | 0.03 | 0.01 | 0.003 | 0.03 |

(TABLE 2B)

| T. S. No. | Equivalent (%) | | | Cast Structure | | | | Heat-resistant Strength (MPa) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{eq}$ | $Ni_{eq}$ | $Cr_{eq}$ | Austenite Proportion (%) | Spheroidized Proportion (%) | Number of Particles (Pieces/mm$^2$) | Hardness Hv (20 kgf) | 150 °C | | 800 °C | |
| | | | | | (12-mm Section) (10-μm Minimum Graphite Particle Dia.) | | (12-mm Section) | Proof Stress | Tensile Strength | Proof Stress | Tensile Strength |
| 2-1 | 4.25 | 19.9 | 7.3 | 100 | 80 | 226 | 217 | 240 | 412 | 91 | 93 |
| 2-2 | 4.29 | 20.9 | 7.0 | 100 | 75 | 108 | 231 | 244 | 374 | 87 | 88 |
| 2-3 | 4.36 | 20.5 | 7.6 | 100 | 74 | 51 | 459 | - | - | - | - |
| 2-4 | 4.37 | 19.1 | 7.5 | 100 | 71 | 244 | 209 | 239 | 417 | 95 | 97 |
| 2-5 | 4.46 | 22.0 | 7.8 | 100 | 66 | 71 | 487 | - | - | - | - |
| 2-6 | 4.31 | 18.1 | 7.2 | 100 | 50 | 183 | 269 | 241 | 301 | 84 | 87 |
| 2-7 | 4.37 | 19.5 | 7.5 | - | 48 | 180 | 266 | - | - | - | - |
| 2-8 | 4.35 | 18.0 | 7.5 | 100 | 41 | 174 | 332 | 260 | 320 | 93 | 113 |
| 2-9 | 4.36 | 22.1 | 7.4 | - | Chilled | No Graphite | 538 | - | - | - | - |
| 2-10 | 4.23 | 20.2 | 7.2 | - | Chilled | No Graphite | 467 | - | - | - | - |
| 2-11 | 3.99 | 19.7 | 6.0 | - | Chilled | No Graphite | 363 | - | - | - | - |
| 2-12 | 4.35 | 19.5 | 7.4 | - | Chilled | No Graphite | 546 | - | - | - | - |
| 2-13 | 4.30 | 18.9 | 7.3 | - | Chilled | No Graphite | 490 | - | - | - | - |

(TABLE 3A)

| T. S. No. | Blended Composition of Basic Elements (% by mass) | | | | | | Analyzed Composition (% by mass) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Cr | Ni | Mn | Cu | C | Si | Cr | Ni | Mn | Cu | Mg | Ce | Ba | Al | Ca | S | P |
| 3-1 | 3 | 4 | 1.5 | 10 | 5.6 | 6.7 | 2.95 | 4.24 | 1.45 | 9.77 | 5.37 | 6.48 | 0.03 | 0.01 | 0.0011 | 0.01 | 0.01 | 0.004 | 0 |
| 3-2 | 3 | 4 | 1.5 | 10 | 5.5 | 5.5 | 3.11 | 3.67 | 1.5 | 10.4 | 5.65 | 5.67 | 0.03 | 0.01 | 0.002 | 0.002 | 0 | 0.007 | 0.04 |

(TABLE 3B)

| T. S. No. | Equivalent (%) | | | Austenite Proportion (%) | Spheroidized Proportion (10-$\mu$m Mini. Graphite Particle Dia.) | | | | Number of Particles (10-$\mu$m Mini. Graphite Particle Dia.) | | | | Hardness Hv (20 kgf) | | | | Heat-resistant Strength (MPa) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Thickness of Test Specimen at Collected Sections (mm) | | | | | | | | | | | | 150 °C | | 800 °C | |
| | $C_{eq}$ | $Ni_{eq}$ | $Cr_{eq}$ | | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | P. S. *1 | T.S. *2 | P. S. *1 | T. S. *2 |
| 3-1 | 4.33 | 20.0 | 7.8 | 100 | 72.8 | 64.5 | 57 | 60 | 99.2 | 74.9 | 63.5 | 283 | 213 | 221 | 221 | 346 | 239 | 380 | 86 | 87 |
| 3-2 | 4.33 | 19.9 | 7.0 | 100 | 85 | 83 | 74 | 71 | 233 | 241 | 387 | 282 | 218 | 213 | 227 | 303 | 246 | 405 | 96 | 98 |

(Note) *1: "P. S." stands for Proof Stress.
*2: "T. S." stands for Tensile Stress.

(TABLE 4A)

| T. S. No. | Blended Composition of Basic Elements (% by mass) | | | | | | Analyzed Composition of Entire Cast Product (% by mass) | | | | | | | | | | Equivalent (%) | | | A. P. (%) *1 | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Cr | Mn | Ni | Cu (Mo) | C | Si | Cr | Ni | Mn | Cu (Mo) | P | Mg | Ce | S | $C_{eq}$ | $Ni_{eq}$ | $Cr_{eq}$ | | |
| 4-1 | 3.0 | 4.0 | 1.5 | 5.5 | 10.0 | 4.5 | 2.95 | 3.88 | 1.58 | 10.07 | 5.79 | 4.54 | 0.018 | 0.038 | 0.015 | 0.006 | 4.2 | 18.4 | 7.4 | 100 | |
| 4-2 | 3.0 | 4.0 | 1.5 | 5.5 | 11.5 | 3.0 | 3.01 | 3.91 | 1.62 | 11.76 | 5.8 | 3.09 | 0.021 | 0.039 | 0.016 | 0.005 | 4.3 | 18.7 | 7.5 | 100 | |
| 4-3 | 3.0 | 4.0 | 1.5 | 5.5 | 13.0 | 1.5 | 2.96 | 3.87 | 1.64 | 12.94 | 5.98 | 1.56 | 0.022 | 0.034 | 0.015 | 0.004 | 4.3 | 18.4 | 7.4 | 100 | |
| 4-4 | 3.0 | 4.0 | 1.5 | 5.5 | 14.5 | 0.0 | 3.04 | 3.95 | 1.62 | 14.11 | 6.02 | 0.01 | 0.021 | 0.039 | 0.017 | 0.005 | 4.4 | 18.0 | 7.5 | 100 | |
| 4-5 | 3.0 | 4.0 | 0.5 | 5.5 | 10.0 | 4.5 | 3.01 | 3.95 | 0.56 | 9.85 | 5.85 | 4.63 | 0.021 | 0.043 | 0.017 | 0.005 | 4.3 | 18.3 | 6.5 | 100 | |
| 4-6 | 3.0 | 4.0 | 0.5 | 5.5 | 11.5 | 3.0 | 2.97 | 4 | 0.55 | 11.61 | 5.5 | 3.12 | 0.019 | 0.041 | 0.017 | 0.006 | 4.3 | 18.4 | 6.6 | 100 | |
| 4-7 | 3.0 | 4.0 | 0.5 | 5.5 | 13.0 | 1.5 | 2.93 | 3.9 | 0.55 | 13.11 | 5.95 | 1.57 | 0.023 | 0.041 | 0.018 | 0.005 | 4.2 | 18.6 | 6.4 | 100 | |
| 4-8 | 3.0 | 4.0 | 0.5 | 5.5 | 14.5 | 0.0 | 2.99 | 4.08 | 0.55 | 14.58 | 6.03 | 0 | 0.022 | 0.042 | 0.019 | 0.006 | 4.4 | 18.5 | 6.7 | 100 | |
| 4-9 | 3.0 | 4.0 | 0.0 | 5.5 | 10.0 | 4.5 | 2.92 | 3.89 | 0.01 | 10.17 | 5.4 | 4.56 | 0.024 | 0.049 | 0.02 | 0.005 | 4.2 | 18.3 | 5.8 | 100 | |
| 4-10 | 3.0 | 4.0 | 0.0 | 5.5 | 11.5 | 3.0 | 2.92 | 3.85 | 0.01 | 11.76 | 5.73 | 3.1 | 0.024 | 0.04 | 0.018 | 0.004 | 4.2 | 18.6 | 5.8 | 100 | |
| 4-11 | 3.0 | 4.0 | 0.0 | 5.5 | 13.0 | 1.5 | 2.96 | 3.85 | 0.01 | 13.23 | 5.84 | 1.54 | 0.024 | 0.039 | 0.018 | 0.005 | 4.2 | 18.6 | 5.8 | 100 | |
| 4-12 | 3.0 | 4.0 | 0.0 | 5.5 | 14.5 | 0.0 | 2.99 | 3.88 | 0.01 | 14.58 | 5.98 | 0 | 0.022 | 0.04 | 0.0019 | 0.006 | 4.3 | 18.5 | 5.8 | 100 | |
| R3 | 2.0 | 5.0 | 2.0 | 0.6 | 35.0 | - | 2.0 | 4.7 | 2.0 | 35.0 | 0.6 | - | 0.017 | 0.066 | - | 0.010 | 3.5 | 36.3 | 8.9 | 100 | JIS: FCDA-NiSiCr3522 (or ASTM: D-5S) |
| R4 | 2.8 | 2.8 | 2.0 | 0.8 | 20.5 | - | 2.3 | 2.8 | 2.0 | 21.2 | 1.2 | - | 0.022 | 0.052 | - | 0.018 | 3.3 | 22.8 | 6.1 | 100 | JIS: FCDA-NiCr202 (or ASTM: D-2) |
| R5 | 3.8 | 2.8 | - | 0.8 or less | - | - | 3.5 | 2.7 | - | - | 0.4 | - | 0.040 | 0.028 | - | 0.010 | 4.4 | 1.2 | 4.1 | 0 | JIS: FCD450 |
| R6 | 3.1 | 4.2 | - | 0.6 or less | - | Mo 0.5 | 2.8 | 4.4 | - | - | 0.4 | Mo 0.47 | 0.038 | 0.036 | - | 0.009 | 4.2 | 1.2 | 6.7 | 0 | HiSiMo FCD (or TSFCDA4) |

(Note) *1: "A. P." stands for Austenite Proportion.

(TABLE 4B)

| T. S. No. | Cast Structure | | | | | | | | | | | | Heat-resistant Strength (800 °C) | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spheroidized Proportion (%) (Graphite's Min. Particle Dia.: 10 $\mu$m) | | | | Number of Particles (pieces/mm$^2$) (Graphite's Min. Particle Dia.: 10 $\mu$m) | | | | Hardness Hv (20 kgf) | | | | Proof Stress | Tensile Stress | Elongation | Reduction of Area | Young's Modulus | |
| | Thickness of Test Specimen at Collected Section (mm) | | | | | | | | | | | | | | | | | |
| | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | MPa | MPa | % | % | GPa | |
| 4-1 | 84 | 78 | 79 | 63 | 158 | 315 | 328 | 177 | 221 | 219 | 244 | 274 | 97 | 100 | 2 | 0 | 84 | |
| 4-2 | 89 | 87 | 90 | 82 | 228 | 320 | 462 | 257 | 203 | 206 | 230 | 257 | 87 | 120 | 3 | 1 | 75 | |
| 4-3 | 82 | 90 | 88 | 79 | 104 | 265 | 457 | 360 | 192 | 192 | 211 | 239 | 75 | 121 | 19 | 17 | 82 | |
| 4-4 | 80 | 87 | 86 | 83 | 205 | 294 | 372 | 385 | 188 | 190 | 214 | 248 | 78 | 126 | 31 | 29 | 77 | |
| 4-5 | 73 | 71 | 63 | 59 | 150 | 417 | 180 | 112 | 201 | 194 | 205 | 215 | - | 79 | 0 | 0 | 78 | |
| 4-6 | 88 | 85 | 87 | 87 | 124 | 240 | 416 | 553 | 189 | 181 | 192 | 207 | 79 | 82 | 2 | 1 | 71 | |
| 4-7 | 81 | 88 | 83 | 82 | 197 | 256 | 276 | 245 | 179 | 167 | 177 | 198 | 71 | 110 | 13 | 13 | 83 | |
| 4-8 | 79 | 82 | 90 | 86 | 191 | 204 | 481 | 417 | 180 | 167 | 180 | 205 | 73 | 114 | 29 | 29 | 81 | |
| 4-9 | 86 | 77 | 74 | 63 | 142 | 256 | 152 | 152 | 189 | 190 | 201 | 209 | - | 57 | 0 | 0 | 74 | |
| 4-10 | 69 | 86 | 85 | 80 | 146 | 273 | 298 | 241 | 185 | 178 | 185 | 200 | 73 | 75 | 1 | 0 | 71 | |
| 4-11 | 77 | 83 | 81 | 85 | 274 | 286 | 322 | 409 | 178 | 163 | 170 | 193 | 68 | 105 | 12 | 9 | 78 | |
| 4-12 | 77 | 85 | 78 | 82 | 226 | 221 | 243 | 320 | 165 | 163 | 172 | 191 | 71 | 111 | 29 | 26 | 80 | |
| R3 | Unmeasured | | | | | | | | | | | | 73 | 116 | 31 | 32 | 101 | JIS: FCDA-NiSiCr3552 (or ASTM: D-5S) |
| R4 | Unmeasured | | | | | | | | | | | | 87 | 134 | 25 | 23 | 90 | JIS: FCDA-NiCr202 (or ASTM: D2) |
| R5 | Unmeasured | | | | | | | | | | | | 27 | 48 | 35 | 35 | 41 | JIS: FCD450 |
| R6 | Unmeasured | | | | | | | | | | | | 28 | 43 | 72 | 68 | 65 | HiSiMo FCD (or TSFCDA4) |

(TABLE 5A)

| T. S. No. | Blended Composition of Basic Elements (% by mass) | | | | | | Analyzed Composition of Entire Cast Product (% by mass) | | | | | | | | | | Equivalent (%) | | | A. P. (%) *1 | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Cr | Mn | Ni | Cu (Mo) | C | Si | Cr | Ni | Mn | Cu | P | Mg | Ce | S | $C_{eq}$ | $Ni_{eq}$ | $Cr_{eq}$ | | |
| 5-1 | 3.0 | 4.0 | 1.5 | 5.5 | 10.0 | 1.5 | 2.94 | 4.01 | 1.58 | 10.3 | 5.57 | 1.47 | 0.025 | 0.038 | 0.022 | 0.005 | 4.3 | 15.5 | 7.6 | 100 | |
| 5-2 | 3.0 | 4.0 | 1.5 | 5.5 | 11.5 | 1.5 | 3.04 | 3.96 | 1.57 | 11.7 | 5.66 | 1.44 | 0.021 | 0.047 | 0.023 | 0.005 | 4.4 | 16.9 | 7.5 | 100 | |
| 5-3 | 3.0 | 4.0 | 1.5 | 7.5 | 10.0 | 1.5 | 2.98 | 3.95 | 1.55 | 10.2 | 7.57 | 1.45 | 0.03 | 0.040 | 0.023 | 0.005 | 4.3 | 16.3 | 7.5 | 100 | |
| 5-4 | 3.0 | 4.0 | 1.5 | 7.5 | 11.5 | 1.5 | 3.01 | 3.95 | 1.56 | 11.8 | 7.52 | 1.45 | 0.028 | 0.048 | 0.024 | 0.006 | 4.3 | 17.9 | 7.5 | 100 | |
| 5-5 | 3.0 | 4.0 | 2.5 | 5.5 | 10.0 | 1.5 | 3.01 | 3.94 | 2.66 | 10.3 | 5.62 | 1.48 | 0.024 | 0.042 | 0.021 | 0.005 | 4.3 | 15.5 | 8.6 | 100 | |
| 5-6 | 3.0 | 4.0 | 2.5 | 5.5 | 11.5 | 1.5 | 2.95 | 4.04 | 2.63 | 11.8 | 5.57 | 1.47 | 0.025 | 0.050 | 0.022 | 0.005 | 4.3 | 17.0 | 8.7 | 100 | |
| 5-7 | 3.0 | 4.0 | 2.5 | 7.5 | 10.0 | 1.5 | 3.03 | 3.97 | 2.65 | 10.0 | 7.49 | 1.46 | 0.026 | 0.041 | 0.020 | 0.005 | 4.4 | 16.1 | 8.6 | 100 | |
| 5-8 | 3.0 | 4.0 | 2.5 | 7.5 | 11.5 | 1.5 | 3.03 | 3.99 | 2.61 | 11.1 | 7.46 | 1.42 | 0.025 | 0.046 | 0.022 | 0.004 | 4.4 | 17.2 | 8.6 | 100 | |
| 5-9 | 3.0 | 4.0 | 1.5 | 5.5 | 10.0 | 0.0 | 2.91 | 3.93 | 1.59 | 9.9 | 5.63 | 0.036 | 0.023 | 0.042 | 0.021 | 0.005 | 4.2 | 13.7 | 7.5 | 100 | |
| 5-10 | 3.0 | 4.0 | 1.5 | 5.5 | 11.5 | 0.0 | 2.92 | 3.92 | 1.58 | 11.4 | 5.58 | 0.017 | 0.024 | 0.043 | 0.021 | 0.005 | 4.2 | 15.1 | 7.5 | 100 | |
| 5-11 | 3.0 | 4.0 | 1.5 | 7.5 | 8.5 | 1.5 | 3.00 | 3.92 | 1.58 | 8.4 | 7.47 | 1.43 | 0.022 | 0.046 | 0.022 | 0.005 | 4.3 | 14.5 | 7.5 | 100 | |
| 5-12 | 3.0 | 4.0 | 1.5 | 7.5 | 8.5 | 0.0 | 3.01 | 3.94 | 1.6 | 8.4 | 7.63 | 0.036 | 0.029 | 0.044 | 0.022 | 0.005 | 4.3 | 13.2 | 7.5 | 100 | |
| R3 | 2.0 | 5.0 | 2.0 | 0.6 | 35.0 | - | 2.0 | 4.7 | 2.0 | 35.0 | 0.6 | - | 0.017 | 0.066 | - | 0.010 | 3.5 | 36.3 | 8.9 | 100 | JIS: FCDA-NiSiCr3522 (or ASTM: D-SS) |
| R4 | 2.8 | 2.8 | 2.0 | 0.8 | 20.5 | - | 2.3 | 2.8 | 2.0 | 21.2 | 1.2 | - | 0.022 | 0.052 | - | 0.018 | 3.3 | 22.8 | 6.1 | 100 | JIS: FCDA-NiCr202 (or ASTM: D-2) |
| R5 | 3.8 | 2.8 | - | 0.8 or less | - | - | 3.5 | 2.7 | - | - | 0.4 | - | 0.040 | 0.028 | - | 0.010 | 4.4 | 1.2 | 4.1 | 0 | JIS: FCD450 |
| R6 | 3.1 | 4.2 | - | 0.6 or less | - | Mo 0.5 | 2.8 | 4.4 | - | - | 0.4 | Mo 0.47 | 0.038 | 0.036 | - | 0.009 | 4.2 | 1.2 | 6.7 | 0 | HiSiMo FCD |

(Note) *1: "A. P." stands for Austenite Proportion.

(TABLE 5B)

| T. S. No. | Cast Structure | | | | | | | | | | | | Heat-resistant Strength (800 °C) | | | | | 0.R. Test *1 (800 °C × 100 hr.) | | Charpy Impact Value at R. T. with V-notch | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spheroidized Proportion (%) (Graphite's Min. Particle Dia.: 5 $\mu$m) | | | | Number of Particles (pieces/mm$^2$) (Graphite's Min. Particle Dia.: 5 $\mu$m) | | | | Hardness Hv (20 kgf) | | | | Proof Stress | Tensile Stress | Elongation | Reduction of Area | Young's Modulus | O. W. I. *2 | O. W. R. *3 | | |
| | Thickness of Test Specimen at Collected Sections (mm) | | | | | | | | | | | | | | | | | | | | |
| | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | MPa | MPa | % | % | GPa | mg/cm$^2$ | mg/cm$^2$ | J/cm$^2$ | |
| 5-1 | 81 | 78 | 84 | 85 | 200 | 273 | 508 | 664 | 191 | 207 | 230 | 275 | 73 | 122 | 16 | 14 | 67 | 40 | 69 | 10.2 | |
| 5-2 | 84 | 81 | 85 | 80 | 176 | 279 | 735 | 1026 | 188 | 196 | 221 | 250 | 72 | 117 | 16 | 16 | 66 | 38 | 58 | 9.9 | |
| 5-3 | 78 | 86 | 89 | 86 | 157 | 269 | 430 | 636 | 211 | 221 | 253 | 339 | 78 | 132 | 16 | 16 | 65 | 41 | 62 | 4.8 | |
| 5-4 | 79 | 83 | 88 | 86 | 269 | 329 | 635 | 997 | 198 | 212 | 239 | 280 | 77 | 128 | 15 | 14 | 68 | 38 | 56 | 6.5 | |
| 5-5 | 81 | 80 | 86 | 87 | 236 | 265 | 399 | 494 | 219 | 228 | 269 | 335 | 76 | 136 | 18 | 16 | 73 | 39 | 49 | 4.4 | |
| 5-6 | 77 | 84 | 89 | 85 | 168 | 265 | 424 | 623 | 220 | 222 | 247 | 302 | 75 | 133 | 19 | 17 | 76 | 35 | 46 | 4.6 | |
| 5-7 | 77 | 80 | 85 | 87 | 153 | 193 | 300 | 230 | 239 | 255 | 310 | 433 | 79 | 145 | 15 | 13 | 67 | 36 | 48 | 2.8 | |
| 5-8 | 75 | 76 | 81 | 82 | 146 | 245 | 343 | 366 | 226 | 233 | 269 | 343 | 77 | 140 | 18 | 16 | 65 | 33 | 41 | 3 | |
| 5-9 | 74 | 81 | 84 | 77 | 165 | 275 | 481 | 253 | 201 | 221 | 256 | 356 | 77 | 131 | 29 | 26 | 63 | 48 | 76 | 7.7 | |
| 5-10 | 76 | 76 | 85 | 81 | 216 | 260 | 489 | 670 | 192 | 203 | 227 | 302 | 75 | 128 | 29 | 27 | 67 | 41 | 65 | 9.5 | |
| 5-11 | 77 | 78 | 83 | 84 | 201 | 360 | 441 | 396 | 219 | 233 | 275 | 403 | 76 | 130 | 16 | 14 | 63 | 42 | 81 | 5.3 | |
| 5-12 | 74 | 79 | 86 | 87 | 172 | 266 | 199 | 145 | 228 | 267 | 424 | 548 | 79 | 144 | 26 | 23 | 68 | 50 | 94 | 3.8 | |
| R3 | 87 | 90 | 75 | 66 | 177 | 454 | 859 | 1181 | 159 | 158 | 157 | 164 | 73 | 116 | 31 | 32 | 101 | 13 | 22 | 11.5 | JIS: FCDA-NiSiCr3552 (or ASTM: D-5S) |
| R4 | Unmeasured | | | | | | | | | | | | 87 | 134 | 25 | 23 | 90 | 45 | 66 | 24 | JIS: FCDA-NiCr202 (or ASTM: D2) |
| R5 | Unmeasured | | | | | | | | | | | | 27 | 48 | 35 | 35 | 91 | 2 | 83 | 2.9 | JIS: FCD450 |

(continued)

| T. S. No. | Cast Structure | | | | | | | | | | | | Heat-resistant Strength (800 °C) | | | | | 0.R. Test *1 (800 °C × 100 hr.) | | Charpy Impact Value at R. T. with V-notch | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spheroidized Proportion (%) (Graphite's Min. Particle Dia.: 5 μ m) | | | | Number of Particles (pieces/mm$^2$) (Graphite's Min. Particle Dia.: 5 μ m) | | | | Hardness Hv (20 kgf) | | | | Proof Stress | Tensile Stress | Elongation | Reduction of Area | Young's Modulus | O. W. I. *2 | O. W. R. *3 | | |
| | Thickness of Test Specimen at Collected Sections (mm) | | | | | | | | | | | | | | | | | | | | |
| | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | MPa | MPa | % | % | GPa | mg/cm$^2$ | mg/cm$^2$ | J/cm$^2$ | |
| R6 | 80 | 81 | 85 | 85 | 154 | 266 | 434 | 603 | 237 | 231 | 242 | 297 | 28 | 43 | 72 | 68 | 65 | 5 | 37 | 1.2 | HiSiMo FCD (or TSFCDA4) |

(Note) *1: "O. R. Test" stands for Oxidation Resistance Test.
*2: "O. W. I." stands for Oxidized Weight Increment.
*2: "O. W. R" stands for Oxidized Weight Reduction.

(TABLE 6A)

| T. S. No. | Blended Composition of Basic Elements (%) | | | | | | Analyzed Composition of Entire Cast Product (% by mass) | | | | | | | | | | | | | | Equivalent (%) | | | A. P. *1 (%) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | ppm | | | | | | | | |
| | | | | | | | | | | | | | | | | | n=1 | n=2 | n=1 | n=2 | | | | | |
| | C | Si | Cr | Mn | Ni | Cu (Mo) | C | Si | Cr | Ni | Mn | Cu | P | Mg | Ce | S | O | | N | | $C_{eq}$ | $Ni_{eq}$ | $Cr_{eq}$ | | |
| 6-1 | 3.0 | 4.0 | 2.5 | 5.5 | 10.0 | 1.5 | 3.03 | 3.90 | 2.50 | 10.00 | 5.40 | 1.50 | 0.03 | 0.05 | 0.02 | 0.01 | 8 | 5 | 66 | 65 | 4.3 | 15.1 | 8.4 | 100 | |
| 6-2 | 3.0 | 4.0 | 2.5 | 5.5 | 10.0 | 0.0 | 2.95 | 4.00 | 2.50 | 10.00 | 5.40 | 0.02 | 0.03 | 0.05 | 0.03 | 0.01 | 2 | 5 | 81 | 80 | 4.3 | 13.6 | 8.5 | 100 | |
| 6-3 | 3.0 | 4.0 | 2.5 | 5.5 | 13.0 | 1.5 | 2.97 | 3.90 | 2.50 | 13.00 | 5.40 | 1.40 | 0.03 | 0.05 | 0.03 | 0.01 | 2 | 2 | 79 | 79 | 4.3 | 18.0 | 8.4 | 100 | |
| 6-4 | 3.0 | 4.0 | 2.5 | 5.5 | 8.0 | 1.5 | 2.94 | 4.00 | 2.60 | 8.10 | 5.50 | 1.50 | 0.03 | 0.06 | 0.04 | 0.01 | 3 | 4 | 98 | 98 | 4.3 | 13.3 | 8.6 | 100 | |
| 6-5 | 3.0 | 4.0 | 1.5 | 5.5 | 10.0 | 1.5 | 2.99 | 4.00 | 1.50 | 9.90 | 5.50 | 1.50 | 0.03 | 0.05 | 0.03 | 0.01 | 4 | 2 | 60 | 59 | 4.3 | 15.1 | 7.5 | 100 | |
| 6-6 | 3.0 | 4.0 | 1.5 | 5.5 | 13.0 | 1.5 | 3.00 | 4.00 | 1.50 | 13.10 | 5.40 | 1.50 | 0.04 | 0.06 | 0.03 | 0.03 | 4 | 3 | 52 | 52 | 4.3 | 18.2 | 7.5 | 100 | |
| R3 | 2.0 | 5.0 | 2.0 | 0.6 | 35.0 | - | 2.0 | 4.7 | 2.0 | 35.0 | 0.6 | - | 0.017 | 0.066 | - | 0.010 | - | - | - | - | 3.5 | 36.3 | 8.9 | 100 | JIS: FCDA-NiSiC r3552 (or ASTM: D-5S) |
| R4 | 2.8 | 2.8 | 2.0 | 0.8 | 20.5 | - | 2.3 | 2.8 | 2.0 | 21.2 | 1.2 | - | 0.022 | 0.052 | - | 0.018 | - | - | - | - | 3.3 | 22.8 | 6.1 | 100 | JIS: FCDA-NiCr 02 (or ASTM: D-2S) |
| R5 | 3.8 | 2.8 | - | 0.8 or less | - | - | 3.5 | 2.7 | - | - | 0.4 | - | 0.040 | 0.028 | - | 0.010 | - | - | - | - | 4.4 | 1.2 | 4.1 | 0 | JIS: FCD450 |
| R6 | 3.1 | 4.2 | - | 0.6 or less | - | Mo 0.5 | 2.8 | 4.4 | - | - | 0.4 | Mo 0.47 | 0.038 | 0.036 | - | 0.009 | - | - | - | - | 4.2 | 1.2 | 6.7 | 0 | HiSiMo FCD (or TSFCDA4) |
| (Note) *1: "A. P." stands for Austenite Proportion. | | | | | | | | | | | | | | | | | | | | | | | | | |

(TABLE 6B)

| T. S. No. | Cast Structure | | | | | | | | | | | | Oxidation Resistance (800 °C × 100 hr.) | | Heat-resistant Strength (800 °C) | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spheroidized Proportion (%) (Graphite's Min. Particle Dia.: 5 μ m) | | | | Number of Particles (pieces/mm²) (Graphite's Min. Particle Dia.: 5 μ m) | | | | Hardness Hv (20 kgf) | | | | Oxidized Weight Increment | Oxidized Weight Decrement | Proof Stress | Tensile Strength | Elongation | |
| | Thickness of Test Specimen at Collected Pars (mm) | | | | | | | | | | | | | | | | | |
| | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | 25 | 12 | 5 | 3 | (mg/cm²) | (mg/cm²) | (MPa) | (MPa) | (%) | |
| 6-1 | 84 | 84 | 86 | 87 | 135 | 212 | 375 | 464 | 226 | 238 | 253 | 303 | 27 | 39 | 73 | 129 | 16 | |
| 6-2 | 70 | 75 | 83 | 84 | 109 | 157 | 184 | 191 | 235 | 267 | 270 | 387 | 77 | 46 | 77 | 140 | 25 | |
| 6-3 | 81 | 82 | 83 | 81 | 160 | 209 | 329 | 695 | 205 | 220 | 232 | 252 | 20 | 32 | 74 | 128 | 18 | |
| 6-4 | 81 | 82 | 85 | 83 | 110 | 179 | 164 | 65 | 250 | 280 | 350 | 523 | 23 | 49 | 77 | 132 | 20 | |
| 6-5 | 78 | 81 | 85 | 86 | 212 | 225 | 404 | 762 | 205 | 223 | 231 | 252 | 29 | 55 | 70 | 117 | 18 | |
| 6-6 | 84 | 85 | 88 | 88 | 167 | 293 | 455 | 950 | 184 | 205 | 208 | 224 | 22 | 44 | 70 | 115 | 17 | |
| R3 | 87 | 90 | 75 | 66 | 177 | 454 | 859 | 1181 | 159 | 158 | 157 | 164 | 13 | 22 | 73 | 116 | 31 | JIS: FCDA-NiSiCr3552 (or ASTM: D-5S) |
| R4 | Unmeasured | | | | | | | | | | | | 45 | 66 | 87 | 134 | 25 | JIS: FCDA-NiCr202 (or ASTM: D2) |
| R5 | Unmeasured | | | | | | | | | | | | 2 | 83 | 27 | 48 | 35 | JIS: FCD450 |
| R6 | 80 | 81 | 85 | 85 | 154 | 266 | 434 | 603 | 237 | 231 | 242 | 297 | 5 | 37 | 28 | 43 | 72 | HiSiMo FCD (or TSFCDA4) |

(TABLE 6C)

| Test Specimen No. | Oxidation Resistance Test (in air for 100 hours) | | | | | | Tensile Test | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oxidized Weight Increment (mg/cm$^2$) | | | Oxidized Weight Decrement (mg/cm$^2$) | | | 0.2% Proof Stress (MPa) | | | | Tensile Strength (MPa) | | | | Elongation (%) | | | |
| | 750 ℃ | 800 ℃ | 850 ℃ | 750 ℃ | 800 ℃ | 850 ℃ | R.T. | 750 ℃ | 800 ℃ | 850 ℃ | R.T. | 750 ℃ | 800 ℃ | 850 ℃ | R. T. | 750 ℃ | 800 ℃ | 850 ℃ |
| 6-1 | 28 | 27 | 24 | 22 | 39 | 82 | 316 | 100 | 73 | 55 | 477 | 174 | 129 | 96 | 7 | 12 | 16 | 17 |
| 6-2 | 32 | 77 | 25 | 27 | 46 | 104 | 326 | 100 | 77 | 59 | 460 | 179 | 140 | 104 | 4 | 26 | 25 | 31 |
| 6-3 | 16 | 20 | 26 | 20 | 32 | 40 | 292 | 100 | 74 | 55 | 454 | 171 | 128 | 96 | 10 | 16 | 18 | 17 |
| 6-4 | 15 | 23 | 24 | 25 | 49 | 102 | 334 | 106 | 77 | 54 | 479 | 177 | 132 | 98 | 4 | 11 | 20 | 18 |
| 6-5 | 21 | 29 | 25 | 33 | 55 | 123 | 286 | 96 | 70 | 53 | 475 | 156 | 117 | 89 | 13 | 15 | 18 | 16 |
| 6-6 | 18 | 22 | 30 | 29 | 44 | 87 | 265 | 93 | 70 | 52 | 463 | 152 | 115 | 86 | 17 | 19 | 17 | 19 |
| R3 | 8 | 6 | 6 | 12 | 14 | 12 | 257 | - | 73 | - | 463 | - | 116 | - | 26 | - | 31 | - |
| R4 | 17 | 27 | 45 | 35 | 54 | 90 | 223 | 94 | 72 | 60 | 415 | 147 | 113 | 92 | 12 | 25 | 29 | 23 |
| R5 | 17 | 27 | 45 | 104 | 171 | 309 | 416 | - | 27 | - | 546 | - | 48 | - | 7 | - | 35 | - |
| R6 | 6 | 5 | 1 | 13 | 14 | 39 | 578 | - | 28 | - | 656 | - | 43 | - | 6 | - | 72 | - |

**(continued)]** (TABLE 6C (continued))

| Test Specimen No. | Thermal-fatigue Test | | | | | | | | | | | | | | | Linear Expansio Coeffici (×10$^{-6}$/K) (40-900 ℃) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 200 ℃ <---> 800 ℃ | | | | | | | | | | | | 150 ℃ <---> 800 ℃ | | | |
| | 100% Constrained Ratio | | | | 50% Constrained Ratio | | | | 30% Constrained Ratio | | | | 100% Constrained Ratio | | | |
| | Stress Decline by 10% | Stress Decline by 25% | Stress Decline by 50% | Frac-tured Apart | Stress Decline by 10% | Stress Decline by 25% | Stress Decline by 50% | Frac-tured Apart | Stress Decline by 10% | Stress Decline by 25% | Stress Decline by 50% | Frac-tured Apart | Stress Decline by 10% | Stress Decline by 25% | Frac-tured Apart | |
| 6-1 | 77 | - | - | 77 | 259 | - | - | 259 | 802 | 830 | 863 | 933 | - | - | - | 21 |
| 6-2 | - | - | - | 58 | 245 | 257 | 274 | 318 | - | - | - | - | - | - | - | - |
| 6-3 | 55 | 57 | 59 | 64 | - | - | - | 367 | - | - | - | - | - | - | - | - |
| 6-4 | - | - | - | 31 | - | - | - | 221 | - | - | - | - | - | - | - | - |
| 6-5 | - | - | - | 80 | 364 | 371 | - | 372 | 1118 | 1146 | 1163 | 1211 | - | - | - | 20 |
| 6-6 | - | - | - | 99 | 251 | 255 | - | 256 | 1042 | 1059 | 1076 | 1087 | 108 | 110 | 116 | 20 |
| R3 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 117 | 17 |
| R4 | 188 | 191 | 193 | 193 | 398 | 441 | 508 | 565 | 1346 | 1373 | 1402 | 1508 | 105 | - | 107 | 19 |
| R5 | - | - | - | - | - | - | - | - | - | - | - | - | 38 | 48 | 58 | 16 |
| R6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 76 | 16 |

## Claims

1. An austenitic cast iron in which an austenite phase makes a major phase in ordinary-temperature region, being **characterized in that**:

   it comprises as basic elements
   C: from 1 to 5% by mass;
   Si: from 3 to 5% by mass;
   Ni: from 7 to 15% by mass;
   Mn: from 0.1 to 8% by mass;
   Cu: 2.5% by mass or less; and
   Cr: 0.5 to 4% by mass ;
   and optionally trace-amount modifier elements selected from the group consisting of Mg, rare-earth elements, Al, Ca, Ba, Bi, Sb, Sn, Ti, Zr, Mo, V, W, Nb, and N, wherein the trace-amount modifier elements are 1% by mass or less;
   the balance comprising iron (Fe) and inevitable impurities.

2. The austenitic cast iron as set forth in claim 1, wherein said Ni is from 8 to 12%.

3. The austenitic cast iron as set forth in claim 1, wherein said Mn is from 5 to 8%.

4. The austenitic cast iron as set forth in claim 1, wherein said Cr is from 1 to 2%.

5. The austenitic cast iron as set forth in either one of claims 1 through 4, wherein said Cu is 0.1% or more.

6. The austenitic cast iron as set forth in claim 5, wherein said Cu is 0.5% or more.

7. The austenitic cast iron as set forth in either claim 6, wherein said Cu is from 1 to 2%.

8. The austenitic cast iron as set forth in claim 1, wherein:

   a value, $Cr_{eq}$ (i.e., $Cr_{eq} = Cr + 1.5 \bullet Si$), is further from 5 to 8%; and
   another value, $Ni_{eq}$ (i.e., $Ni_{eq} = Ni + 30 \bullet C_s + 0.5 \bullet Mn + Cu$ where $C_s$: solute carbon content) is further 18% or more;
   or wherein:

      said $Cr_{eq}$ value is from 7 to 9%; and
      said $Ni_{eq}$ value is 13% or more.

9. The austenitic cast iron as set forth in claim 1, wherein said basic elements further fall within compositional ranges that satisfy the following conditions:

   C: from 2.5 to 3.5%;
   Si: from 3.5 to 5%;
   Ni: from 9 to 14%;
   Mn: from 1 to 6%;
   Cr: from 1 to 2%; and
   Cu: from 1 to 2%.

10. The austenitic cast iron as set forth in claim 1, wherein said basic elements further fall within compositional ranges that satisfy the following conditions:

    C: from 2.5 to 3.5%;
    Si: from 3.5 to 4.5%;
    Ni: from 12 to 14%;
    Mn: from 5 to 6%;

Cr: from 1 to 2%; and
Cu: from 1 to 2%.

**11.** The austenitic cast iron as set forth in either one of claims 1 through 10,
wherein a spheroidized proportion of said graphite that is crystallized or precipitated in said base is 70% or more; and/or
wherein said graphite that is crystallized or precipitated has particles in a quantity of 100 pieces/mm$^2$ or more, particles whose particle diameter is 5 $\mu$m or more and which are present in a section of cast product whose wall thickness is 5 mm or less; and/or
wherein said base comprises an austenite single phase.

**12.** A manufacturing process for austenitic cast product, the manufacturing process being **characterized in that** it comprises:

a molten-metal preparation step of preparing a molten metal with the compositional range as set forth in either one of claims 1 through 10;
a pouring step of pouring the molten metal into a casting die; and
a solidification step of cooling the molten metal that has been poured into the casting die, and then solidifying the molten metal;
wherein a cast product comprising the austenitic cast iron as set forth in claim 11 is obtainable.

**13.** A manufacturing process for austenitic cast product, the manufacturing process being **characterized in that** it comprises:

a modifier-free-molten-metal preparation step of preparing a modifier-free molten metal comprising a molten metal with the compositional range as set forth in either one of claims 1 through 10;
an auxiliary-agent addition step of adding an auxiliary agent, which includes at least one member being selected from the group consisting of inoculants that nucleate the graphite, and spheroidizing agents that facilitates spheroidizing of the graphite, to the modifier-free molten metal directly or indirectly;
a pouring step of pouring a molten metal into a casting die, the molten metal being after the auxiliary-agent addition step or during the auxiliary-agent addition step; and
a solidification step of cooling the molten metal that has been poured into the casting die, and then solidifying the molten metal;
wherein a cast product comprising the austenitic cast iron as set forth in claim 11 is obtainable, the austenitic cast iron in which substantially spheroidal graphite is crystallized or precipitated within the resulting base.

**14.** An austenitic cast product being **characterized in that** the austenitic cast product is obtainable by means of the manufacturing process as set forth in either of claim 12 or 13.

**15.** A component part for exhaust system being **characterized in that** the exhaust-system component part is obtainable by means of the manufacturing process as set forth in either of claim 12 or 13.

## Patentansprüche

**1.** Austenitisches Gusseisen, bei welchem eine austenitische Phase eine Hauptphase im gewöhnlichen Temperaturbereich ausmacht, **dadurch gekennzeichnet, dass**:

es als Grundelemente umfasst
C: von 1 bis 5 Masse-%;
Si: von 3 bis 5 Masse-%;
Ni: von 7 bis 15 Masse-%;
Mn: von 0,1 bis 8 Masse-%;
Cu: 2,5 Masse-% oder weniger; und
Cr: 0,5 bis 4 Masse-%;
und optional Spuren von Modifikationselementen ausgewählt aus der Gruppe bestehend aus Mg, Seltenerdelementen, Al, Ca, Ba, Bi, Sb, Sn, Ti, Zr, Mo, V, W, Nb und N, wobei die Spuren von Modifikationselementen 1 Masse-% oder weniger betragen;

wobei der Rest Eisen (Fe) und unvermeidbare Verunreinigungen umfasst.

**2.** Austenitisches Gusseisen nach Anspruch 1,
wobei das Ni von 8 bis 12% beträgt.

**3.** Austenitisches Gusseisen nach Anspruch 1,
wobei das Mn von 5 bis 8% beträgt.

**4.** Austenitisches Gusseisen nach Anspruch 1,
wobei das Cr von 1 bis 2% beträgt.

**5.** Austenitisches Gusseisen nach einem der Ansprüche 1 bis 4, wobei das Cu 0,1% oder mehr beträgt.

**6.** Austenitisches Gusseisen nach Anspruch 5, wobei das Cu 0,5% oder mehr beträgt.

**7.** Austenitisches Gusseisen nach Anspruch 6, wobei das Cu von 1 bis 2% beträgt.

**8.** Austenitisches Gusseisen nach Anspruch 1, wobei:

ein Wert $Cr_{eq}$ (d.h., $Cr_{eq} = Cr + 1{,}5 \cdot Si$) ferner von 5 bis 8% beträgt; und
ein weiterer Wert $Ni_{eq}$ (d.h., $Ni_{eq} = Ni + 30 \cdot C_s + 0{,}5 \cdot Mn + Cu$, wobei $C_s$: Gehalt an gelöstem Kohlenstoff) ferner 18% oder mehr beträgt;
oder wobei:

der $Cr_{eq}$-Wert von 7 bis 9% beträgt; und
der $Ni_{eq}$-Wert 13% oder mehr beträgt.

**9.** Austenitisches Gusseisen nach Anspruch 1, wobei
die Grundelemente ferner innerhalb von Zusammensetzungsbereichen fallen, die die folgenden Bedingungen erfüllen :

C: von 2,5 bis 3,5%;
Si: von 3,5 bis 5%;
Ni: von 9 bis 14%;
Mn: von 1 bis 6%;
Cr: von 1 bis 2%; und
Cu: von 1 bis 2%.

**10.** Austenitisches Gusseisen nach Anspruch 1, wobei
die Grundelemente ferner innerhalb von Zusammensetzungsbereichen fallen, die die folgenden Bedingungen erfüllen :

C: von 2,5 bis 3,5%;
Si: von 3,5 bis 4,5%;
Ni: von 12 bis 14%;
Mn: von 5 bis 6%;
Cr: von 1 bis 2%; und
Cu: von 1 bis 2%.

**11.** Austenitisches Gusseisen nach einem der Ansprüche 1 mit 10,
wobei ein kugelförmiger Anteil des Graphits, der kristallisiert oder präzipitiert ist, in der Basis 70% oder mehr beträgt; und/oder
wobei der Graphit, der kristallisiert oder präzipitiert ist, Teilchen in einer Menge von 100 Stück/mm$^2$ oder mehr aufweist, Teilchen, deren Teilchendurchmesser 5 $\mu$m oder mehr beträgt und welche in einem Abschnitt des Gussprodukts vorhanden sind, dessen Wandstärke 5 mm oder weniger beträgt; und/oder
wobei die Basis eine Austeniteinphase umfasst.

**12.** Herstellungsverfahren für ein austenitisches Gussprodukt, wobei das Herstellungsverfahren **dadurch gekennzeich-**

**net ist, dass** es umfasst:

einen geschmolzenes Metall Anfertigungsschritt des Anfertigens eines geschmolzenen Metalls mit dem Zusammensetzungsbereich nach einem der Ansprüche 1 mit 10;
einen Gießschritt des Gießens des geschmolzenen Metalls in eine Gussform; und
einen Verfestigungsschritt des Abkühlens des geschmolzenen Metalls, das in die Gussform gegossen wurde, und dann Verfestigen des geschmolzenen Metalls;
wobei das Gussprodukt, das das austenitische Gusseisen nach Anspruch 11 umfasst, erhältlich ist.

**13.** Herstellungsverfahren für eine austenitisches Gussprodukt, wobei das Herstellungsverfahren **dadurch gekennzeichnet ist, dass** es umfasst:

einen modifikatorfreies geschmolzenes Metall Anfertigungsschritt des Anfertigens eines modifikatorfreien geschmolzenen Metalls, das ein geschmolzenes Metall mit dem Zusammensetzungsbereich nach einem der Ansprüche 1 mit 10 umfasst;
einem Hilfsmittelzugabeschritt des Zugebens eines Hilfsmittels, welches zumindest ein Mitglied ausgewählt aus der Gruppe bestehend aus Impfmitteln, die eine Keimbildung des Graphits hervorrufen, und Kugelglühmitteln, die das Kugelglühen des Graphits vereinfachen, beinhaltet, direkt oder indirekt zu dem modifikatorfreien geschmolzenen Metall;
einen Gießschritt des Gießens eines geschmolzenen Metalls in eine Gussform, wobei das geschmolzene Metall sich nach dem Hilfsmittelzugabeschritt oder während des Hilfsmittelzugabeschritts befindet; und
einen Verfestigungsschritt des Kühlens des geschmolzenen Metalls, das in die Gussform gegossen wurde, und dann Verfestigen des geschmolzenen Metalls;
wobei ein Gussprodukt, das das austenitische Gusseisen nach Anspruch 11 umfasst, erhältlich ist, das austenitische Gusseisen, bei welchem im Wesentlichen kugelförmiges Graphit innerhalb der resultierenden Basis kristallisiert oder präzipitiert ist.

**14.** Austenitisches Gussprodukt, **dadurch gekennzeichnet, dass** das austenitische Gussprodukt mittels des Herstellungsverfahrens nach einem der Ansprüche 12 oder 13 erhältlich ist.

**15.** Komponententeil für ein Abgassystem, **dadurch gekennzeichnet, dass** das Abgassystemkomponententeil mittels des Herstellungsverfahrens nach einem der Ansprüche 12 oder 13 erhältlich ist.

## Revendications

**1.** Fonte austénitique dans laquelle une phase austénitique forme une phase majeure dans une zone de température ordinaire, est **caractérisée en ce qu'**elle :

comprend comme éléments de base
C : de 1 à 5% en masse ;
Si : de 3 à 5% en masse ;
Ni : de 7 à 15% en masse ;
Mn : de 0,1 à 8% en masse ;
Cu : 2,5% en masse ou moins ; et
Cr : 0,5 à 4% en masse ;
et facultativement des éléments modificateurs à l'état de traces choisis dans le groupe constitué de Mg, éléments de terres rares, Al, Ca, Ba, Bi, Sb, Sn, Ti, Zr, Mo, V, W, Nb et N, où les éléments modificateurs à l'état de traces sont de 1% en masse ou moins ;
le reste comprenant du fer (Fe) et des impuretés inévitables.

**2.** Fonte austénitique telle que définie dans la revendication 1,
dans laquelle ledit Ni est de 8 à 12%.

**3.** Fonte austénitique telle que définie dans la revendication 1,
dans laquelle ledit Mn est de 5 à 8%.

**4.** Fonte austénitique telle que définie dans la revendication 1, dans laquelle ledit Cr est de 1 à 2%.

**5.** Fonte austénitique telle que définie dans l'une quelconque des revendications 1 à 4, dans laquelle ledit Cu est de 0,1% ou plus.

**6.** Fonte austénitique telle que définie dans la revendication 5, dans laquelle ledit Cu est de 0,5% ou plus.

**7.** Fonte austénitique telle que définie dans la revendication 6, dans laquelle ledit Cu est de 1 à 2%.

**8.** Fonte austénitique telle que définie dans la revendication 1, dans laquelle :

une valeur, $Cr_{eq}$ (c.-à-d., $Cr_{eq} = Cr + 1,5.Si$), est en outre de 5 à 8% ; et
une autre valeur, $Ni_{eq}$ (c.-à-d., $Ni_{eq} = Ni + 30.Cs + 0,5.Mn + Cu$ où Cs : teneur en carbone en solution) est en outre de 18% ou plus ;
ou où :

ladite valeur $Cr_{eq}$ est de 7 à 9% ; et
ladite valeur $Ni_{eq}$ est de 13% ou plus.

**9.** Fonte austénitique telle que définie dans la revendication 1, dans laquelle
lesdits éléments de base se trouvent en outre dans des plages de composition qui satisfont les conditions suivantes :

C : de 2,5 à 3,5% ;
Si : de 3,5 à 5% ;
Ni : de 9 à 14% ;
Mn : de 1 à 6% ;
Cr : de 1 à 2% ; et
Cu : de 1 à 2%.

**10.** Fonte austénitique telle que définie dans la revendication 1, dans laquelle
lesdits éléments de base se trouvent en outre dans des plages de composition qui satisfont les conditions suivantes :

C : de 2,5 à 3,5% ;
Si : de 3,5 à 4,5% ;
Ni : de 12 à 14% ;
Mn : de 5 à 6% ;
Cr : de 1 à 2% ; et
Cu : de 1 à 2%.

**11.** Fonte austénitique telle que définie dans l'une quelconque des revendications 1 à 10,
dans laquelle une proportion sphéroïdale dudit graphite qui est cristallisé ou précipité dans ladite base est 70% ou plus ; et/ou
dans laquelle ledit graphite qui est cristallisé ou précipité comprend des particules en une quantité de 100 pièces/$mm^2$ ou plus, des particules dont le diamètre de particule est de 5 $\mu$m ou plus et qui sont présentes dans une section de produit de fonderie dont l'épaisseur de paroi est de 5 mm ou moins ; et/ou
dans laquelle ladite base comprend une seule phase austénitique.

**12.** Processus de fabrication pour produit de fonderie austénitique, le processus de fabrication étant **caractérisé en ce qu'**il comprend :

une étape de préparation de métal fondu qui consiste à préparer un métal fondu avec la plage de composition telle que définie dans l'une quelconque des revendications 1 à 10 ;
une étape de coulée qui consiste à faire couler le métal fondu dans une matrice de coulée ; et
une étape de solidification qui consiste à refroidir le métal fondu qu'on a fait couler dans la matrice de coulée, puis à solidifier le métal fondu ;
où un produit de fonderie comprenant la fonte austénitique telle que définie dans la revendication 11 peut être obtenu.

**13.** Processus de fabrication pour produit de fonderie austénitique, le processus de fabrication étant **caractérisé en ce qu'**il comprend :

une étape de préparation de métal fondu sans modificateur qui consiste à préparer un métal fondu sans modificateur comprenant un métal fondu avec la plage de composition telle que définie dans l'une quelconque des revendications 1 à 10 ;
une étape d'ajout d'agent auxiliaire qui consiste à ajouter un agent auxiliaire, qui comporte au moins un élément qui est choisi dans le groupe constitué d'inoculants qui forment des noyaux de graphite, et des agents de sphéroïdisation qui facilitent la sphéroïdisation du graphite, au métal fondu sans modificateur directement ou indirectement ;
une étape de coulée qui consiste à faire couler un métal fondu dans une matrice de coulée, le métal fondu étant obtenu après l'étape d'ajout d'agent auxiliaire ou pendant l'étape d'ajout d'agent auxiliaire ; et
une étape de solidification qui consiste à refroidir le métal fondu qu'on a fait couler dans la matrice de coulée, et puis à solidifier le métal fondu ;
où un produit de fonderie comprenant la fonte austénitique telle que définie dans la revendication 11 peut être obtenu, la fonte austénitique dans laquelle un graphite essentiellement sphéroïdal est cristallisé ou précipité à l'intérieur de la base résultante.

**14.** Produit de fonderie austénitique qui est **caractérisé en ce que** le produit de fonderie austénitique peut être obtenu au moyen du processus de fabrication tel que défini dans l'une quelconque des revendications 12 ou 13.

**15.** Partie constitutive pour un système d'échappement qui est **caractérisée en ce que** la partie constitutive de système d'échappement peut être obtenue au moyen du processus de fabrication tel que défini dans l'une quelconque des revendications 12 ou 13.

# Fig.1

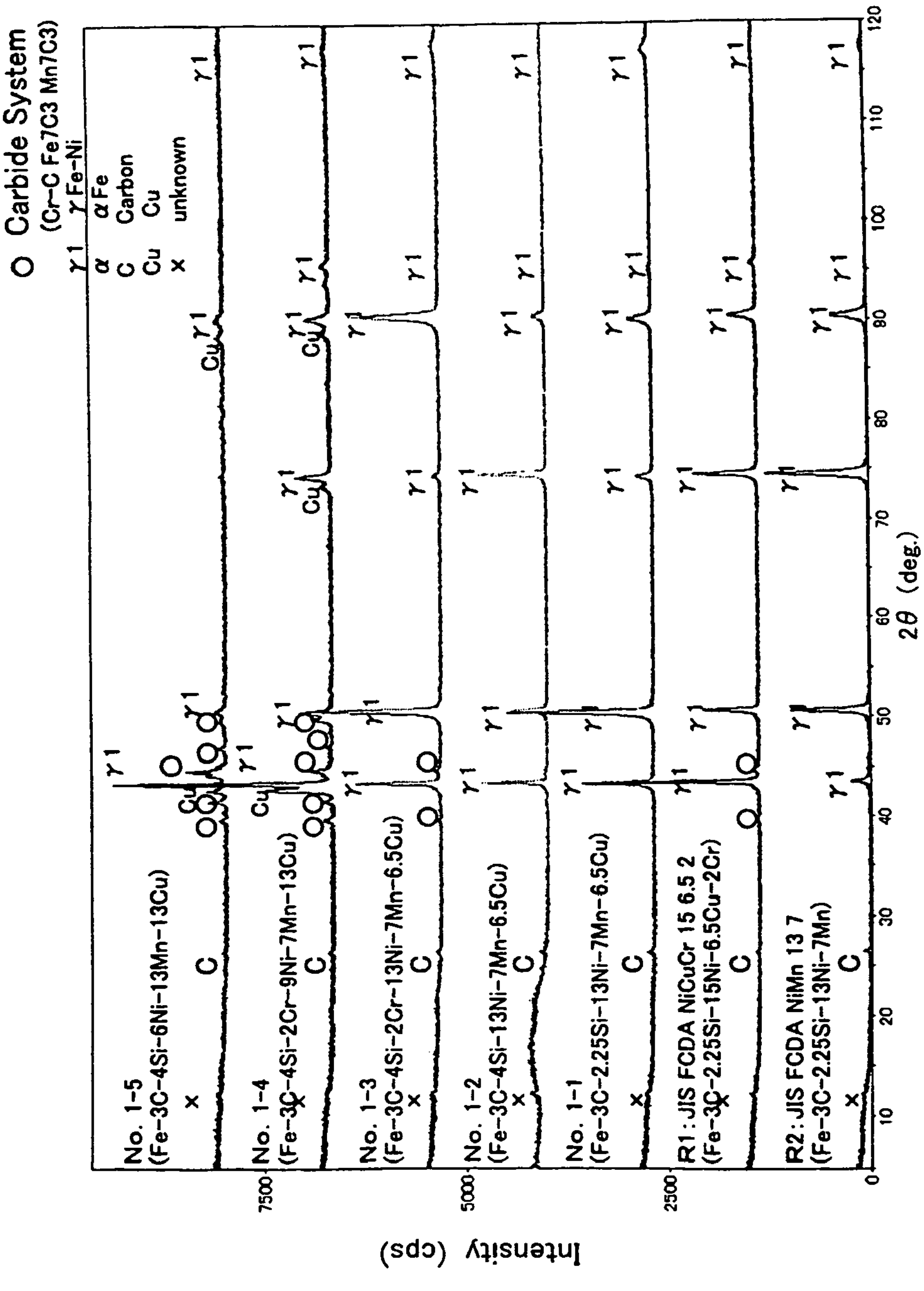

○ Carbide System
(Cr–C Fe7C3 Mn7C3)
γ1 γ Fe-Ni
α αFe
C Carbon
Cu Cu
× unknown
No. 1-5
(Fe-3C-4Si-6Ni-13Mn-13Cu)
No. 1-4
(Fe-3C-4Si-2Cr-9Ni-7Mn-13Cu)
No. 1-3
(Fe-3C-4Si-2Cr-13Ni-7Mn-6.5Cu)
No. 1-2
(Fe-3C-4Si-13Ni-7Mn-6.5Cu)
No. 1-1
(Fe-3C-2.25Si-13Ni-7Mn-6.5Cu)
R1: JIS FCDA NiCuCr 15 6.5 2
(Fe-3C-2.25Si-15Ni-6.5Cu-2Cr)
R2: JIS FCDA NiMn 13 7
(Fe-3C-2.25Si-13Ni-7Mn)
γ1
C
Cu
×
Intensity (cps)
0
2500
5000
7500
0
10
20
30
40
50
60
70
80
90
100
110
120
2θ (deg.)

Fig.2

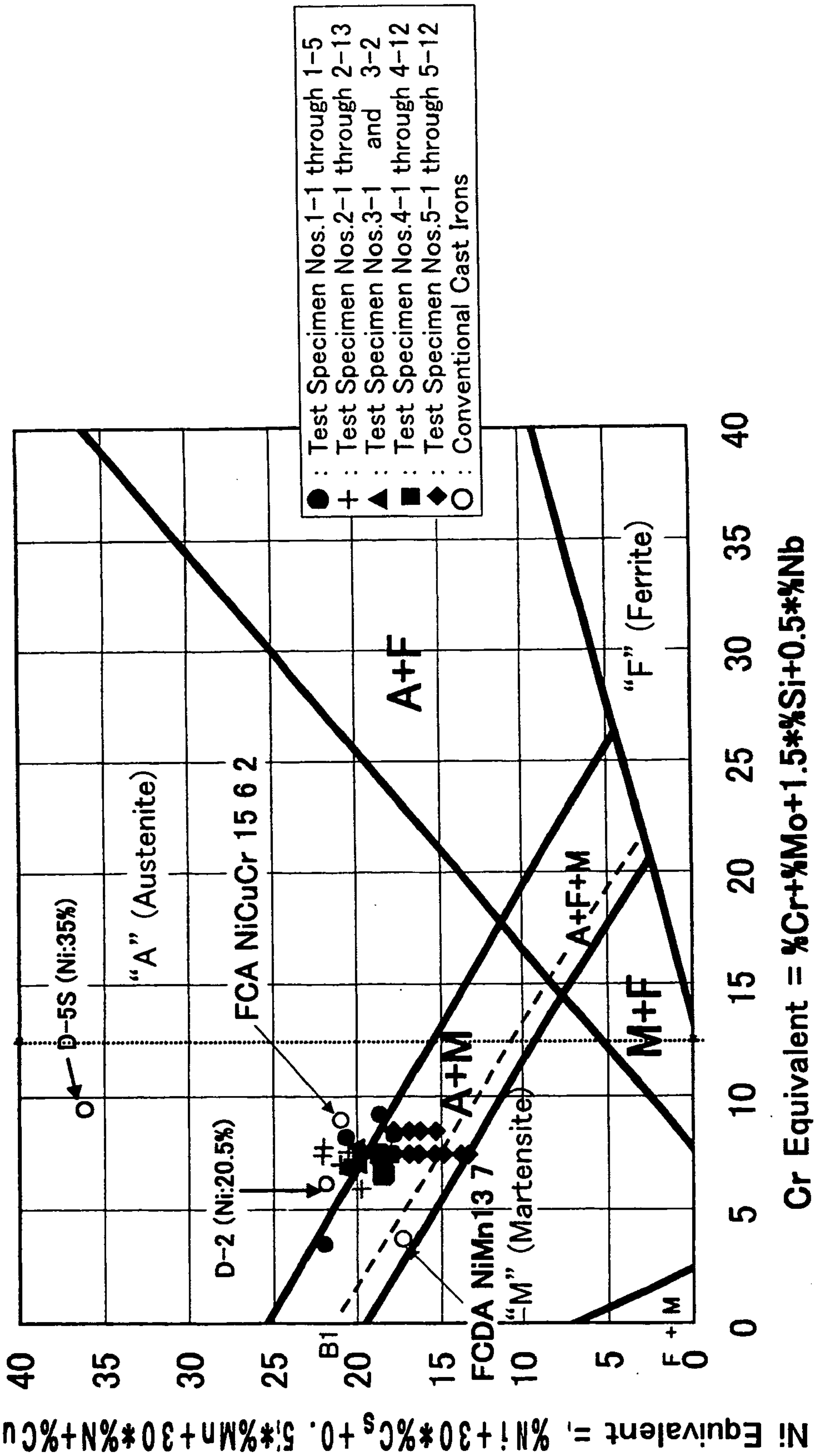

●: Test Specimen Nos.1-1 through 1-5
+: Test Specimen Nos.2-1 through 2-13
▲: Test Specimen Nos.3-1 and 3-2
■: Test Specimen Nos.4-1 through 4-12
◆: Test Specimen Nos.5-1 through 5-12
○: Conventional Cast Irons
"A" (Austenite)
A+F
"F" (Ferrite)
A+F+M
M+F
A+M
"M" (Martensite)
F+M
D-5S (Ni:35%)
D-2 (Ni:20.5%)
FCA NiCuCr 15 6 2
FCDA NiMn13 7
B1
Cr Equivalent = %Cr+%Mo+1.5*%Si+0.5*%Nb
Ni Equivalent =, %Ni+30*%C_s+0.5*%Mn+30*%N+%Cu
0
5
10
15
20
25
30
35
40

Fig.3

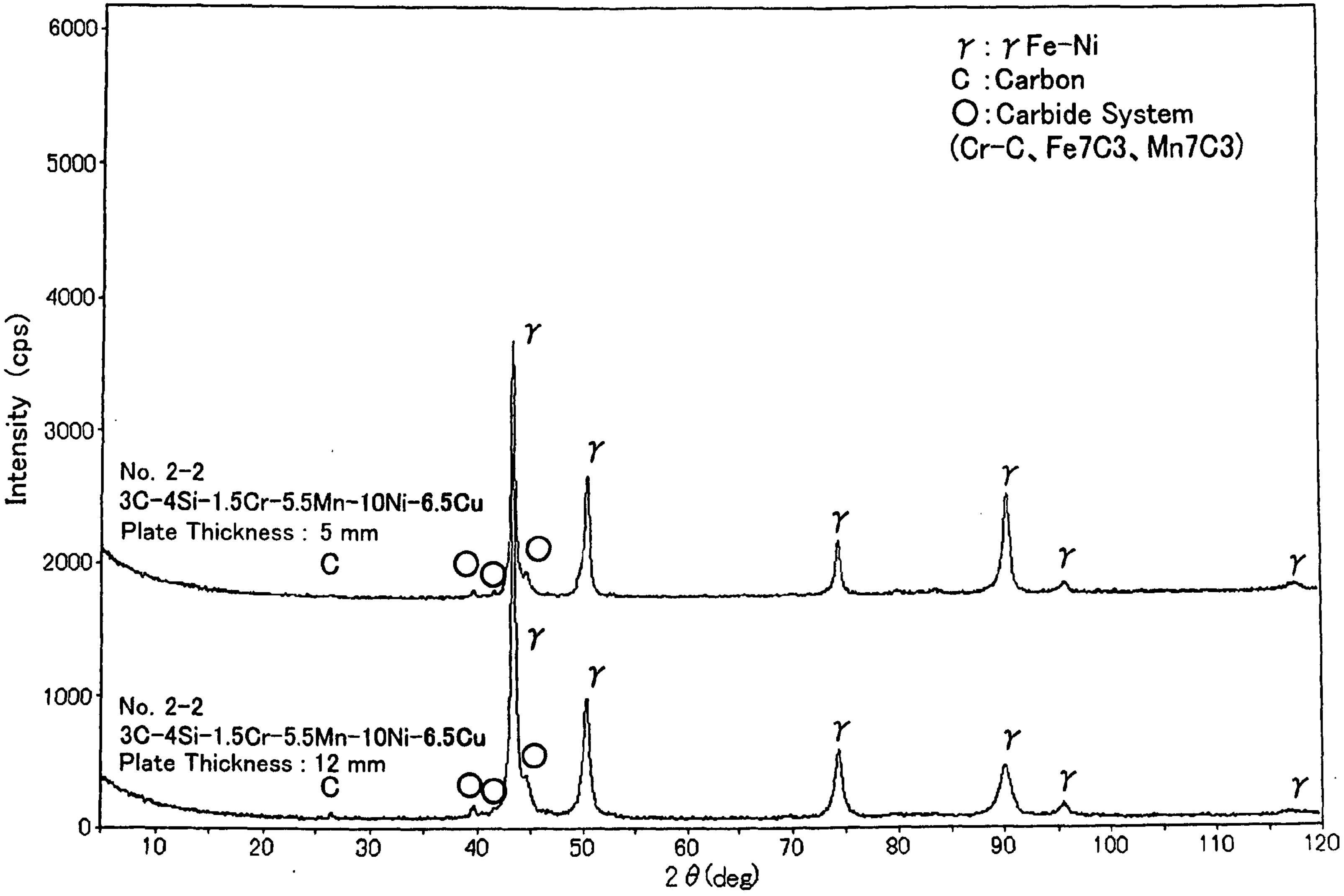
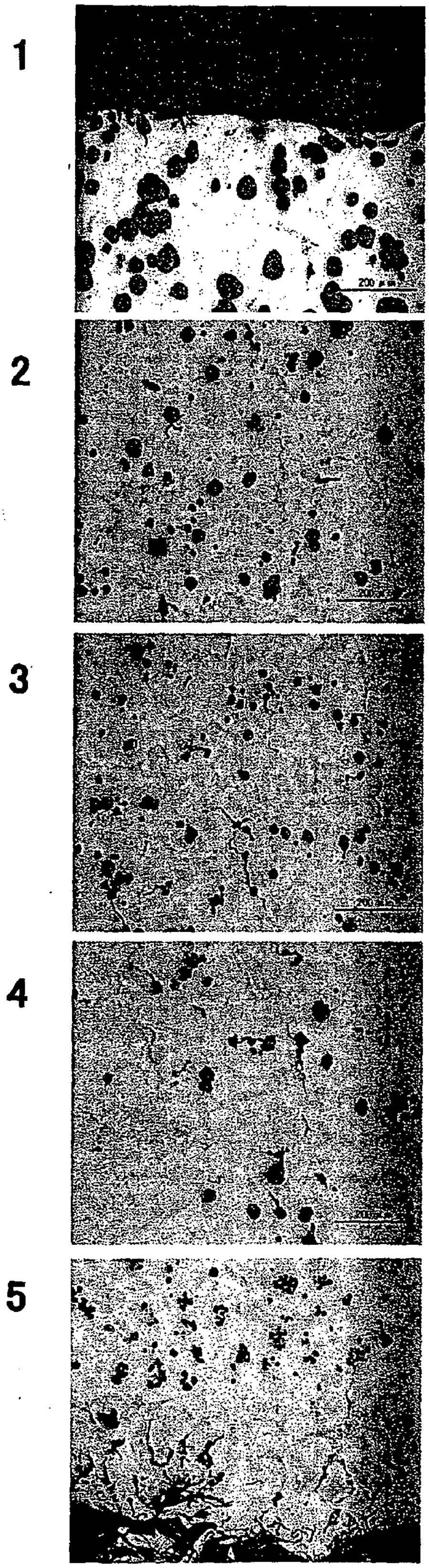
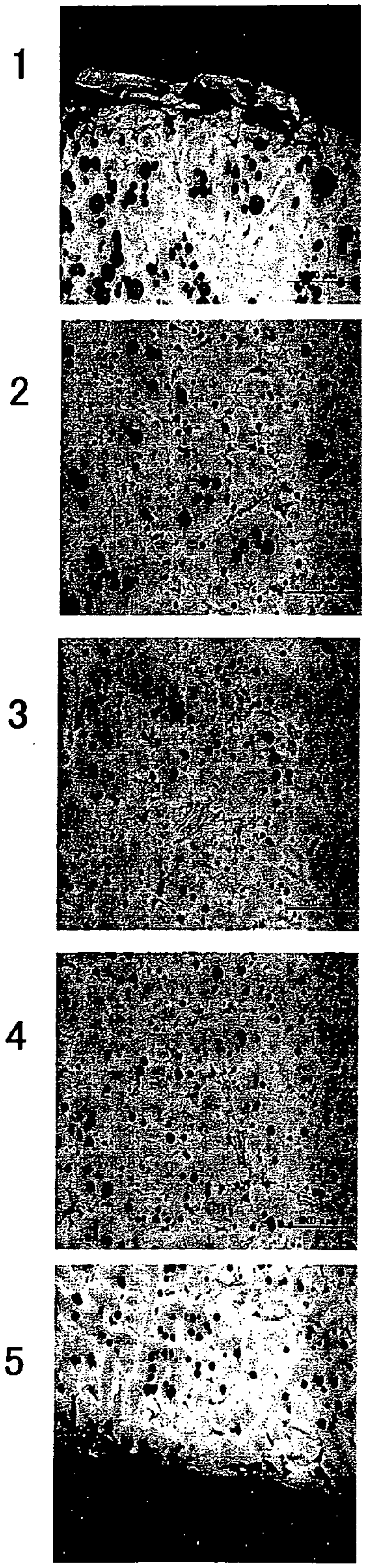

γ : γ Fe-Ni
C : Carbon
○ : Carbide System
(Cr-C、Fe7C3、Mn7C3)
No. 2-2
3C-4Si-1.5Cr-5.5Mn-10Ni-6.5Cu
Plate Thickness : 5 mm
No. 2-2
3C-4Si-1.5Cr-5.5Mn-10Ni-6.5Cu
Plate Thickness : 12 mm
C
○
γ
Intensity (cps)
0
1000
2000
3000
4000
5000
6000
10
20
30
40
50
60
70
80
90
100
110
120
2θ(deg)

Fig.4A



No. 3-1
(at 25-mm Location)

Fig.4B



No.3-2
(at 25-mm Location)

Fig.5

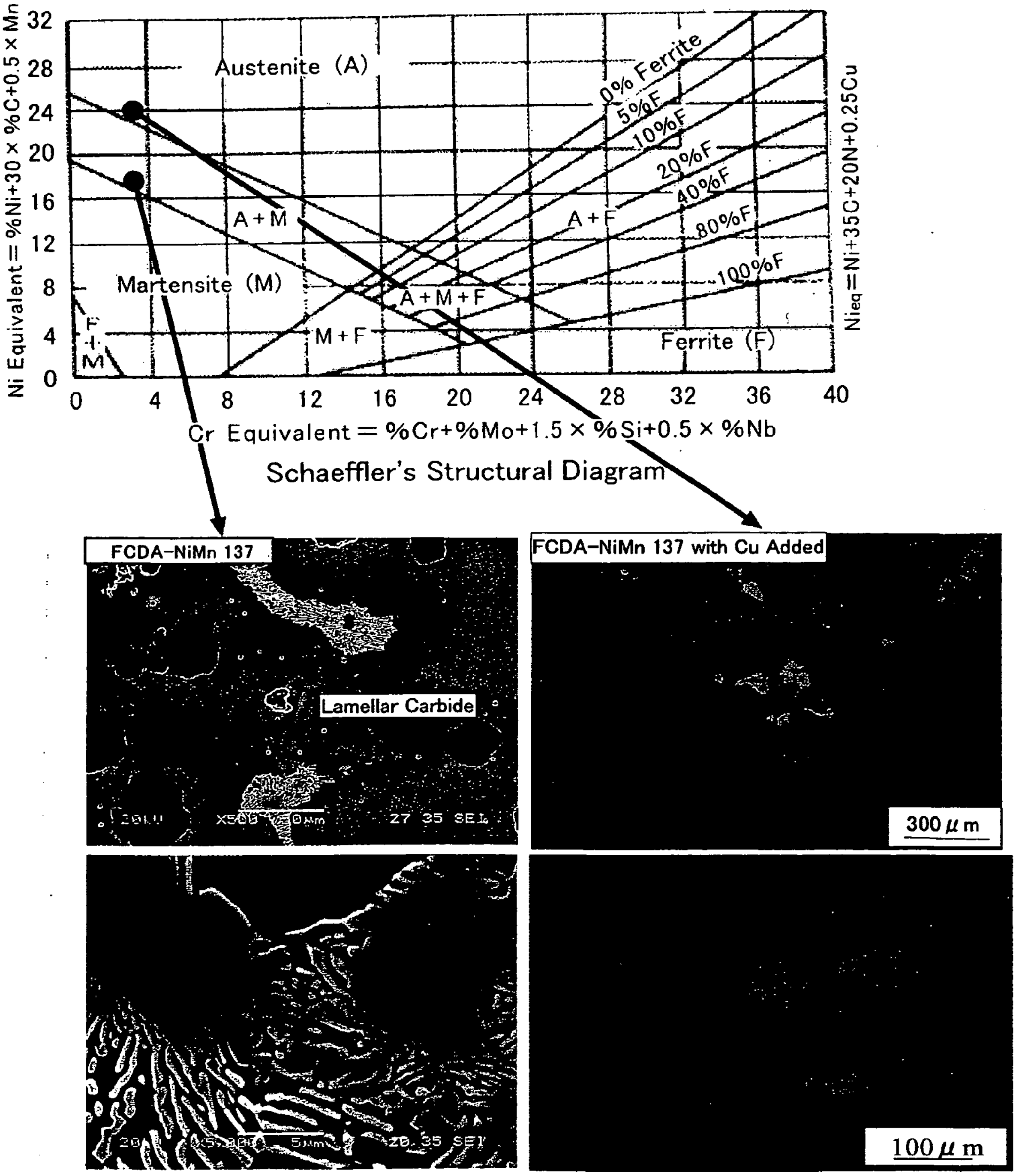
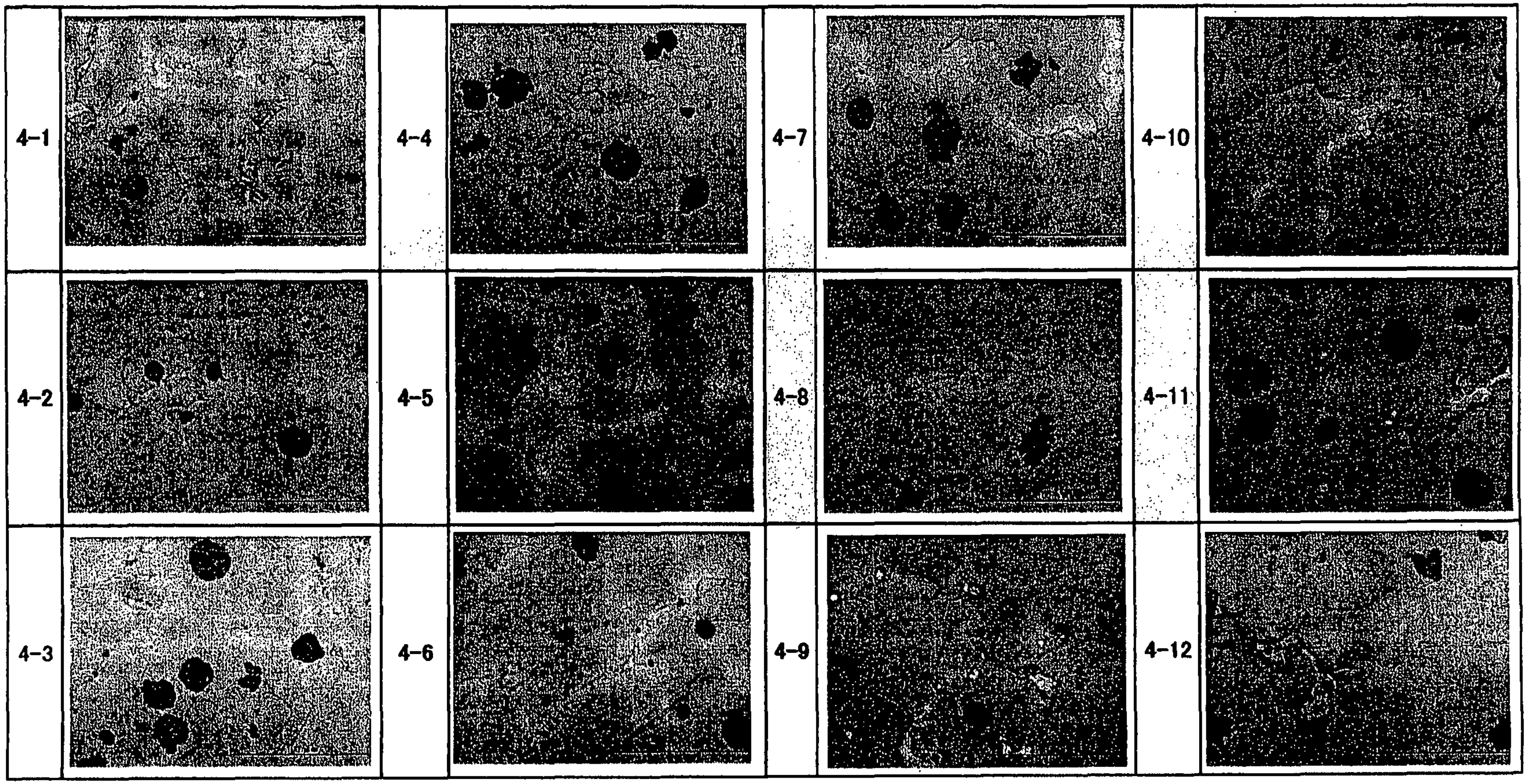

Ni Equivalent = %Ni+30 × %C+0.5 × Mn
32
28
24
20
16
12
8
4
0
Austenite (A)
0% Ferrite
5%F
10%F
20%F
40%F
80%F
100%F
A + M
A + F
Martensite (M)
A + M + F
F + M
M + F
Ferrite (F)
Nieq = Ni+35C+20N+0.25Cu
0
4
8
12
16
20
24
28
32
36
40
Cr Equivalent = %Cr+%Mo+1.5 × %Si+0.5 × %Nb
Schaeffler's Structural Diagram
FCDA-NiMn 137
Lamellar Carbide
FCDA-NiMn 137 with Cu Added
300µm
100µm

Fig.6



# Fig.7

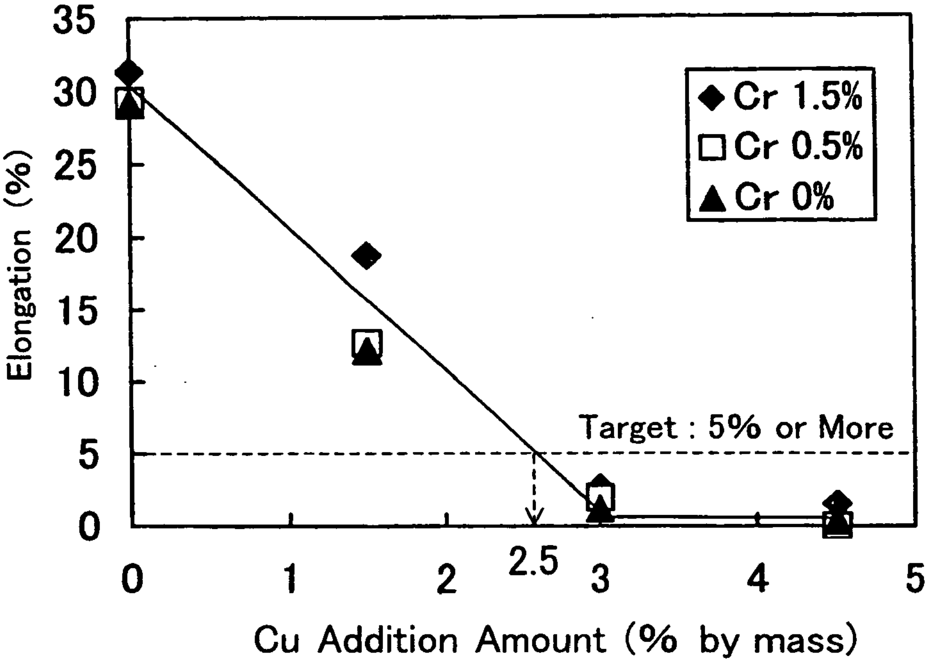
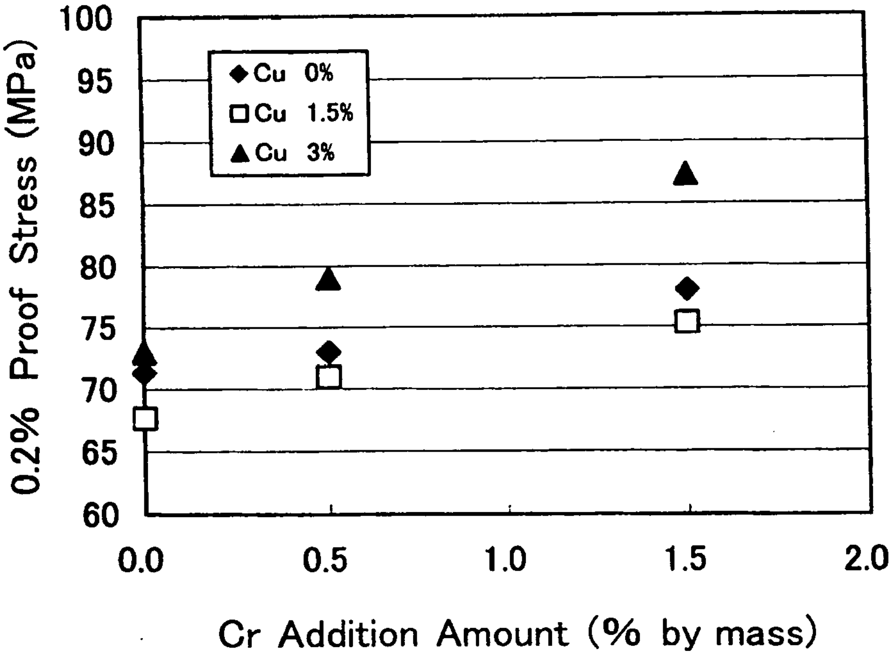
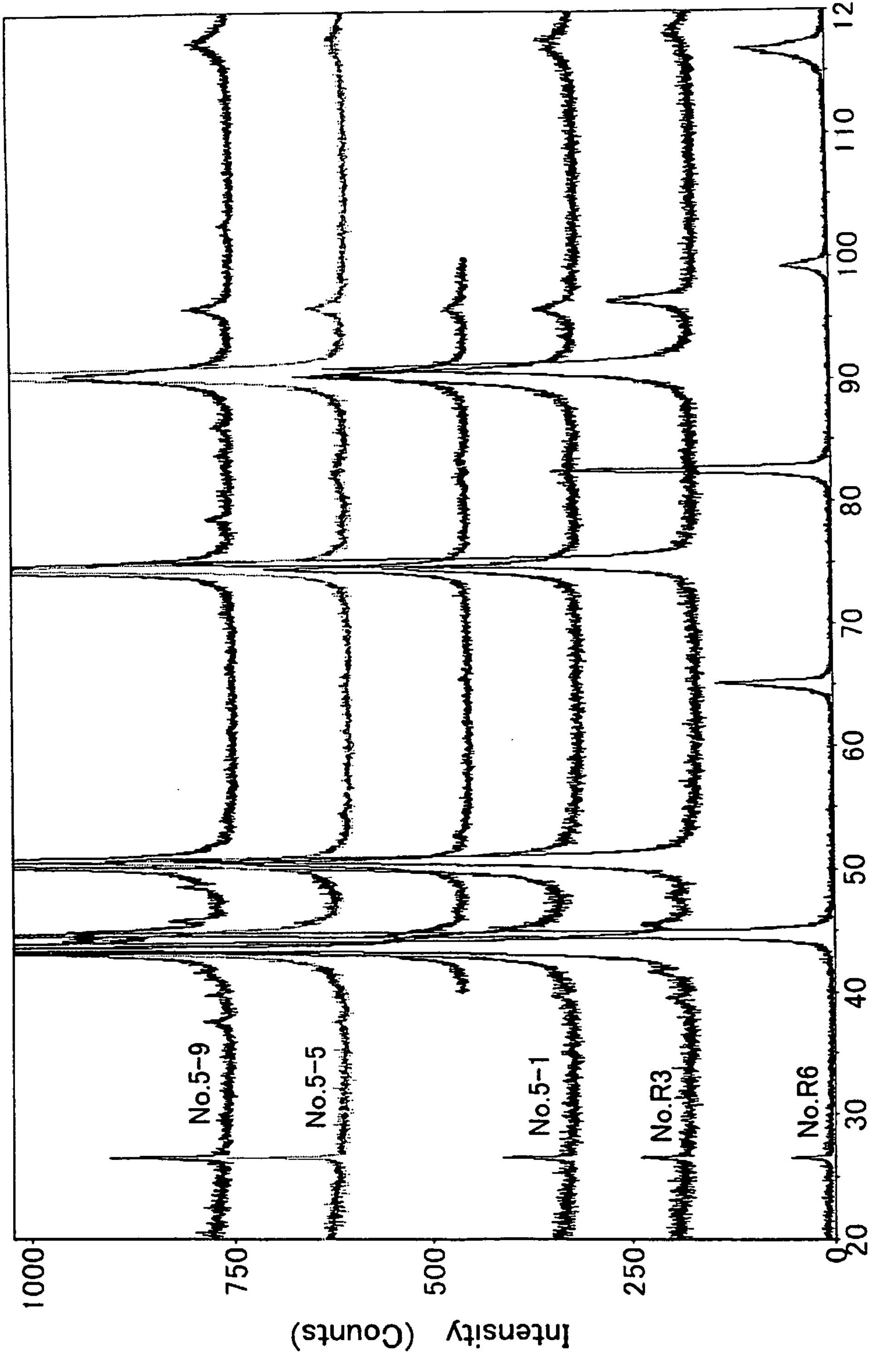

Elongation (%)
35
30
25
20
15
10
5
0
◆ Cr 1.5%
□ Cr 0.5%
▲ Cr 0%
Target : 5% or More
0
1
2
2.5
3
4
5
Cu Addition Amount (% by mass)

Fig.8



100
95
90
85
80
75
70
65
60
0.2% Proof Stress (MPa)
◆ Cu 0%
□ Cu 1.5%
▲ Cu 3%
0.0
0.5
1.0
1.5
2.0
Cr Addition Amount (% by mass)

Fig.9


Intensity (Counts)
1000
750
500
250
0
20
30
40
50
60
70
80
90
100
110
120
2θ (deg.)
No.5-9
No.5-5
No.5-1
No.R3
No.R6

## Fig.10

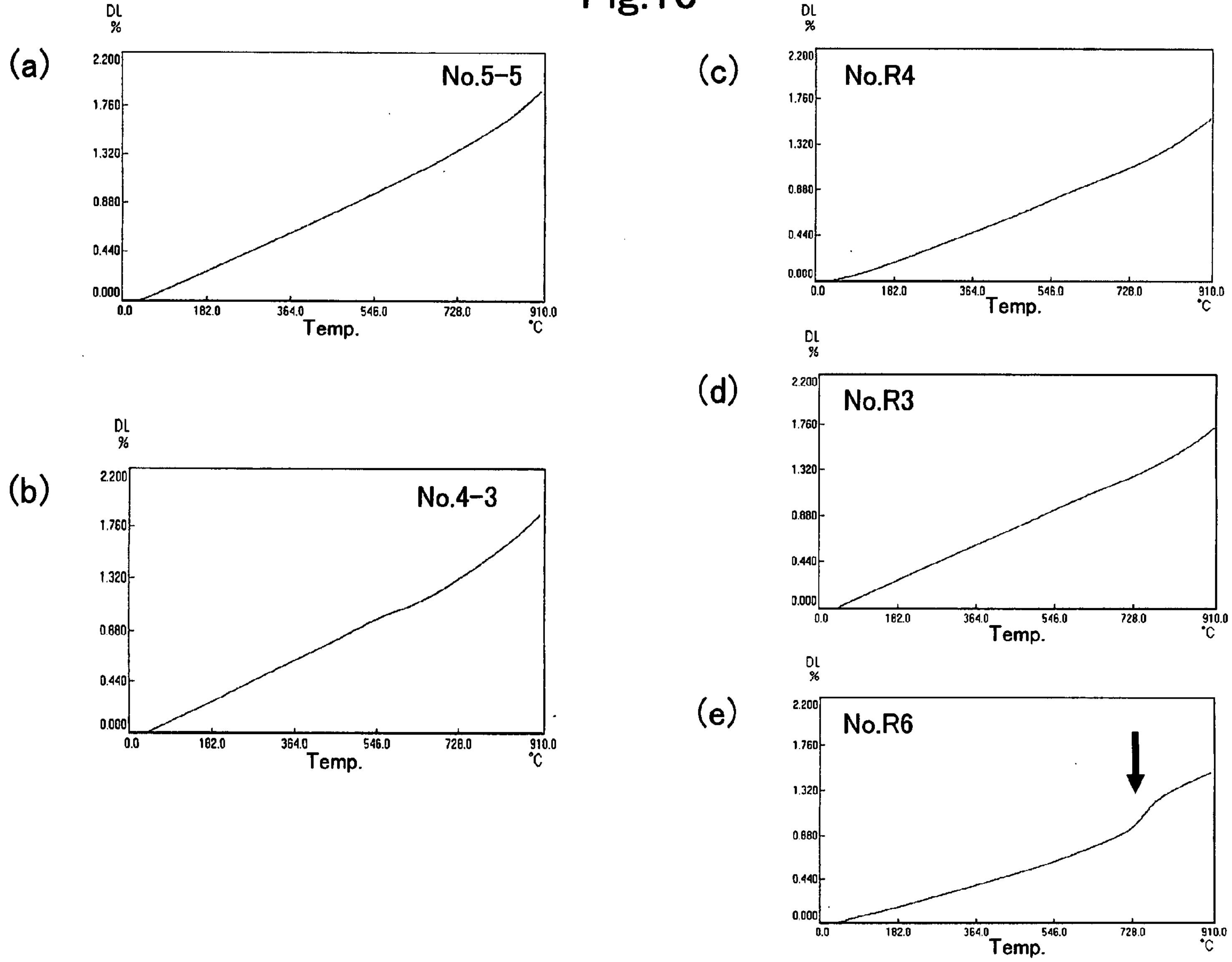

(a)
No.5-5
DL
%
2.200
1.760
1.320
0.880
0.440
0.000
0.0
182.0
364.0
546.0
728.0
910.0
°C
Temp.
(b)
No.4-3
DL
%
2.200
1.760
1.320
0.880
0.440
0.000
0.0
182.0
364.0
546.0
728.0
910.0
°C
Temp.
(c)
No.R4
DL
%
2.200
1.760
1.320
0.880
0.440
0.000
0.0
182.0
364.0
546.0
728.0
910.0
°C
Temp.
(d)
No.R3
DL
%
2.200
1.760
1.320
0.880
0.440
0.000
0.0
182.0
364.0
546.0
728.0
910.0
°C
Temp.
(e)
No.R6
DL
%
2.200
1.760
1.320
0.880
0.440
0.000
0.0
182.0
364.0
546.0
728.0
910.0
°C
Temp.

Fig.11

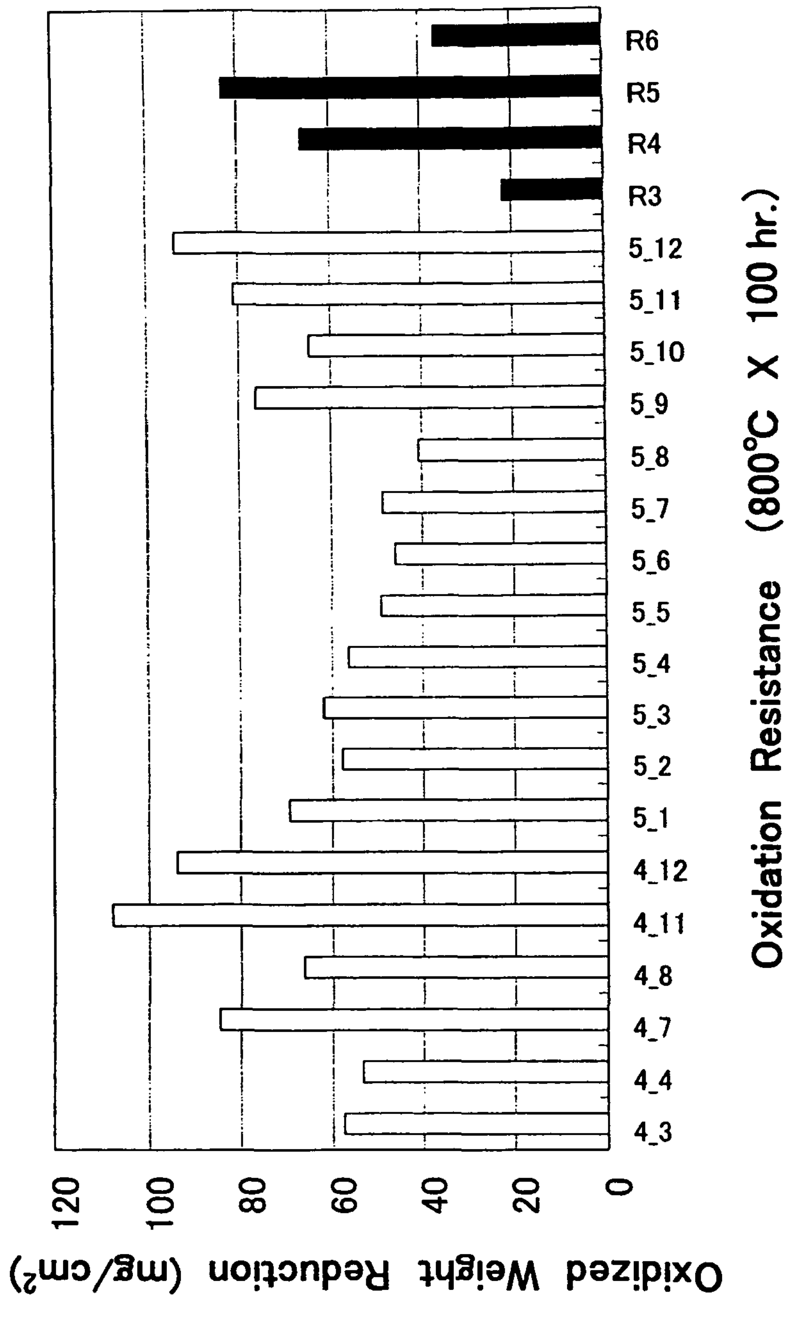
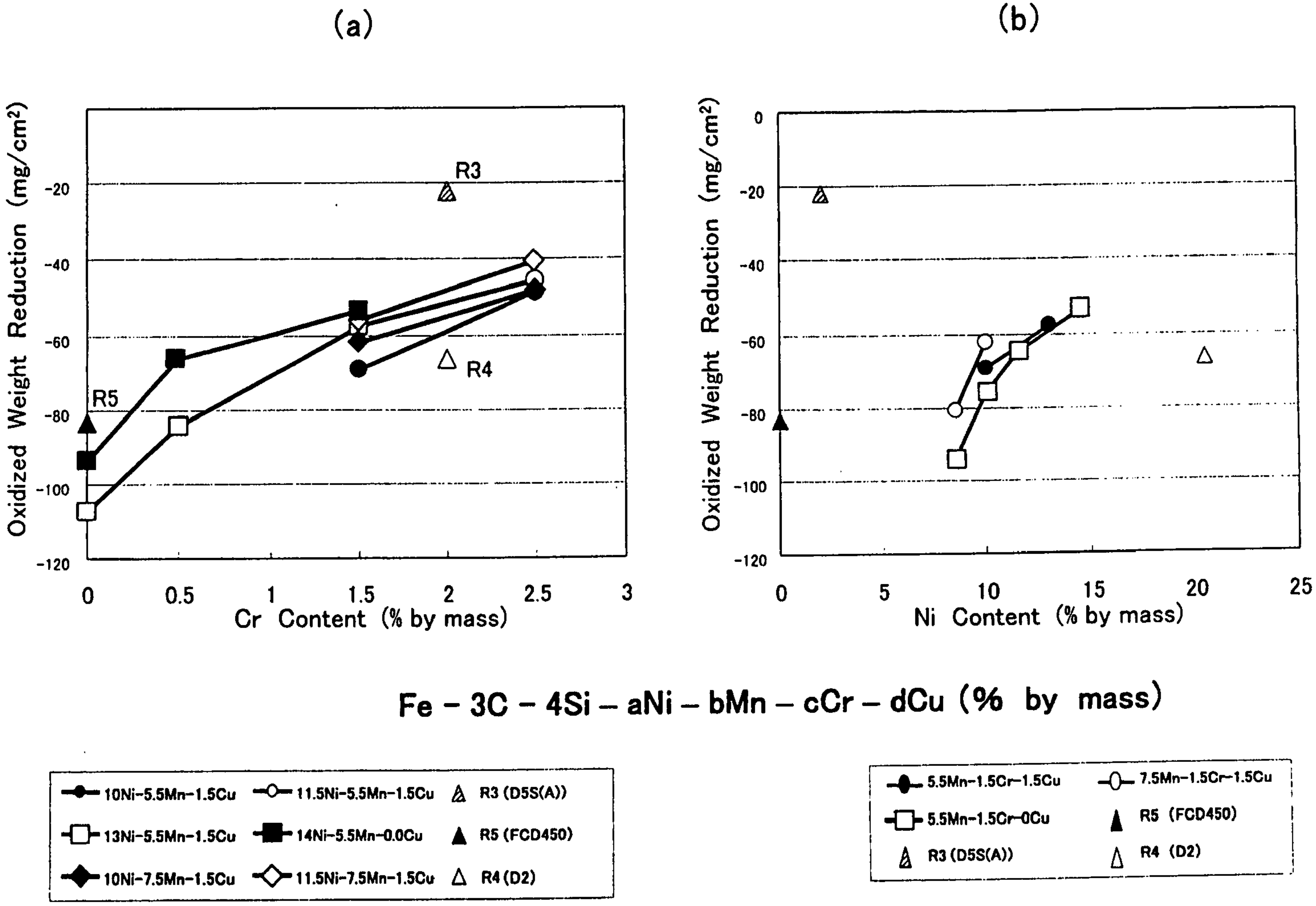

Oxidized Weight Reduction (mg/cm²)
0
20
40
60
80
100
120
4_3
4_4
4_7
4_8
4_11
4_12
5_1
5_2
5_3
5_4
5_5
5_6
5_7
5_8
5_9
5_10
5_11
5_12
R3
R4
R5
R6
Oxidation Resistance (800°C X 100 hr.)

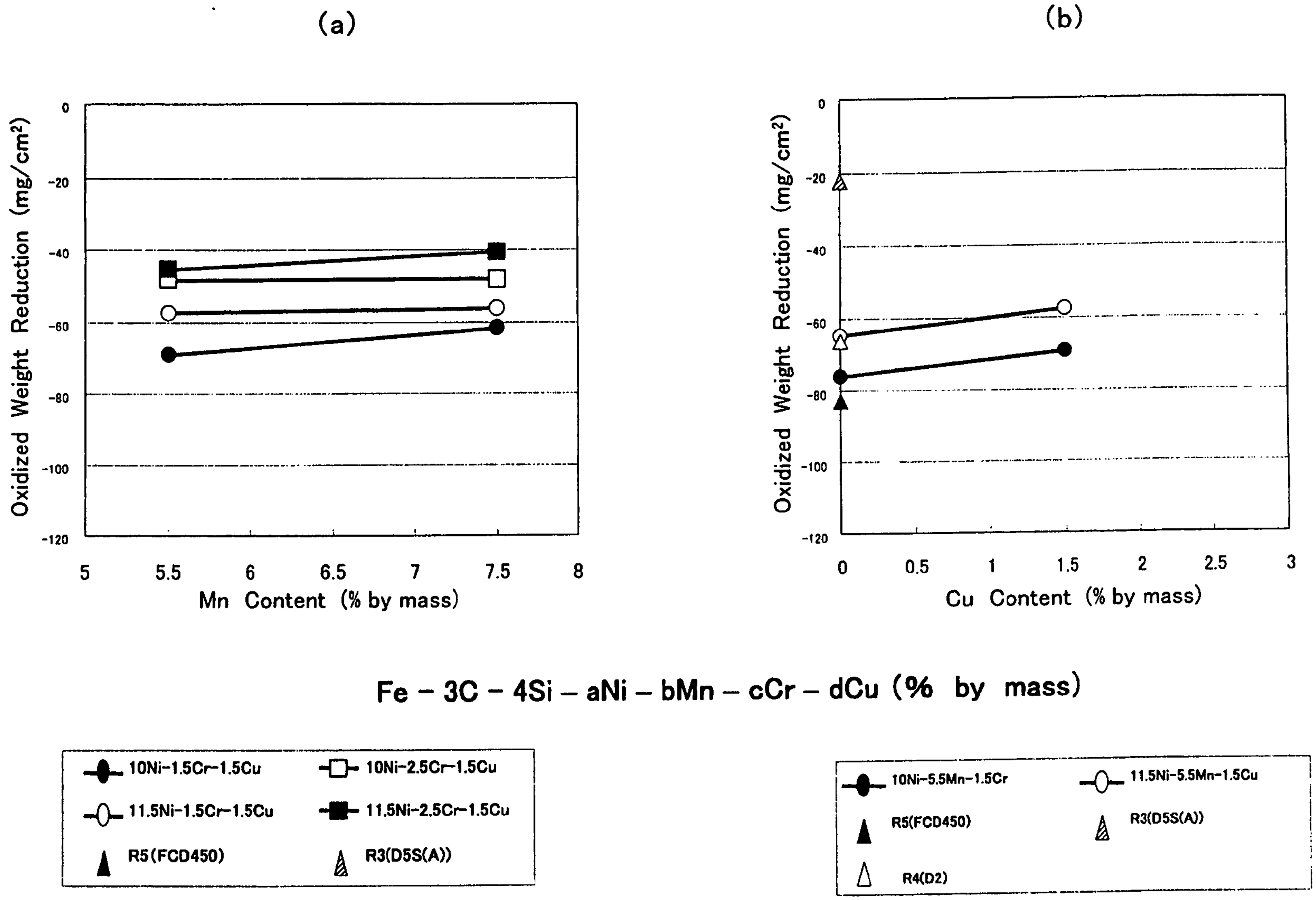
Fig.12



(a) (b)

Fe - 3C - 4Si - aNi - bMn - cCr - dCu (% by mass)

# Fig.13



Fe – 3C – 4Si – aNi – bMn – cCr – dCu (% by mass)

Fig.14

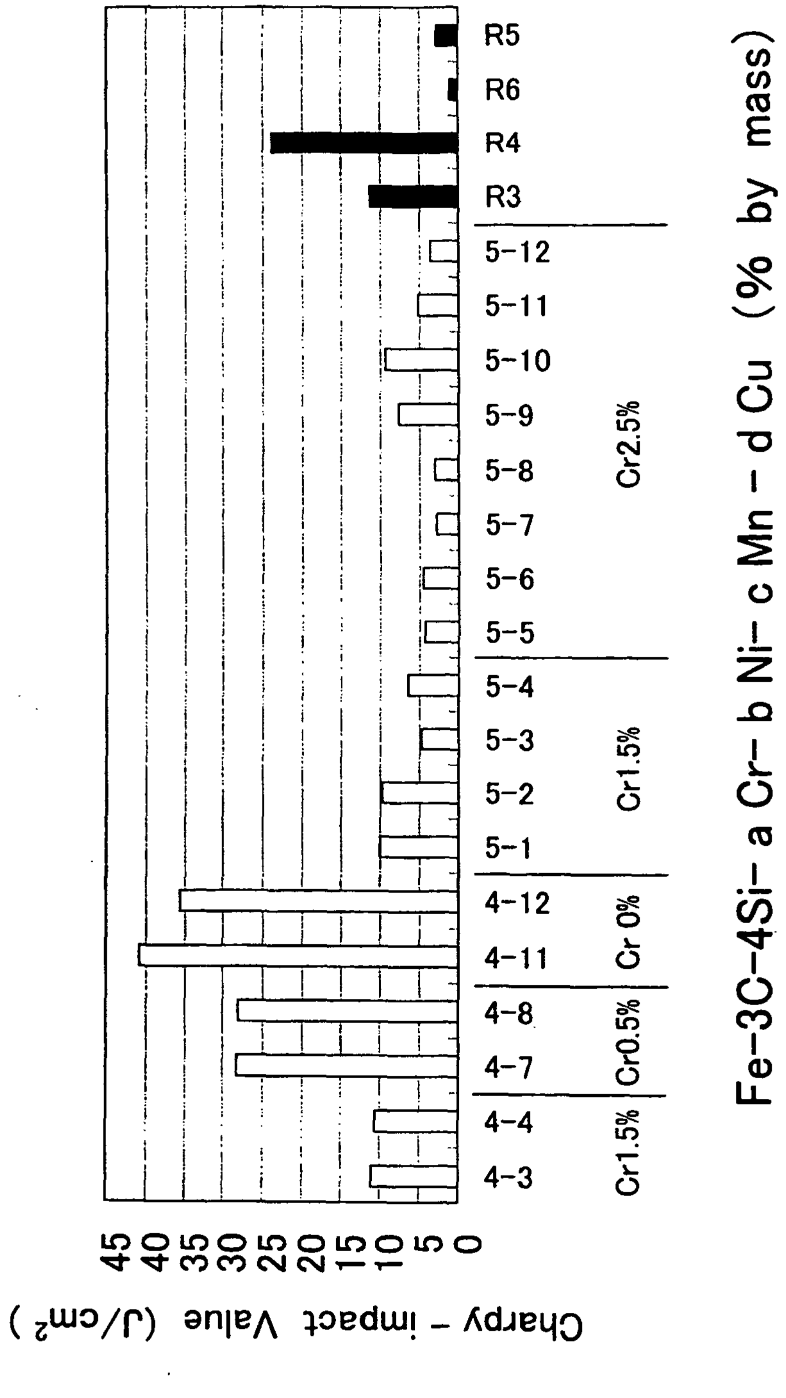

Charpy - impact Value (J/cm²)
0
5
10
15
20
25
30
35
40
45
4-3
4-4
Cr1.5%
4-7
4-8
Cr0.5%
4-11
4-12
Cr 0%
5-1
5-2
5-3
5-4
Cr1.5%
5-5
5-6
5-7
5-8
5-9
5-10
5-11
5-12
Cr2.5%
R3
R4
R6
R5
Fe-3C-4Si- a Cr- b Ni- c Mn - d Cu (% by mass)

Fig.15

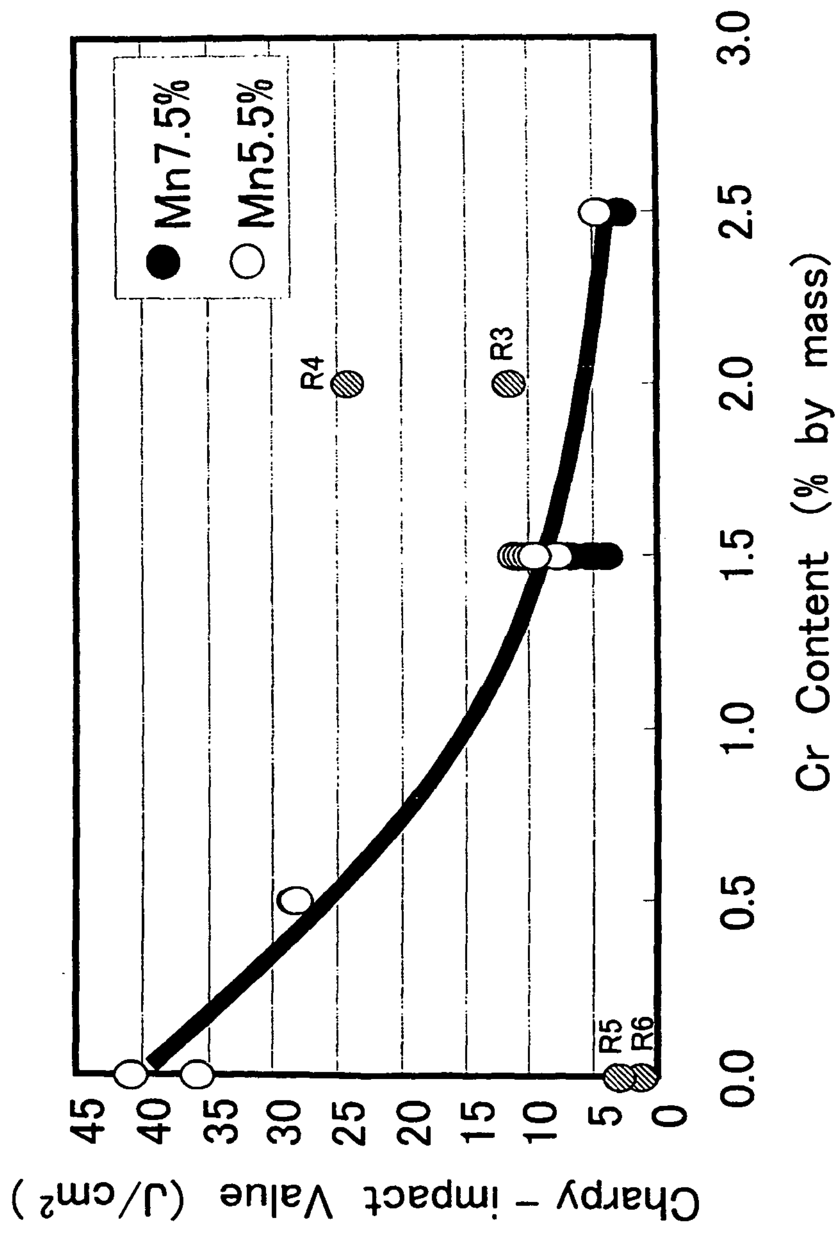

Charpy - impact Value (J/cm²)
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Cr Content (% by mass)
● Mn7.5%
○ Mn5.5%
R3
R4
R5
R6

Fig.16

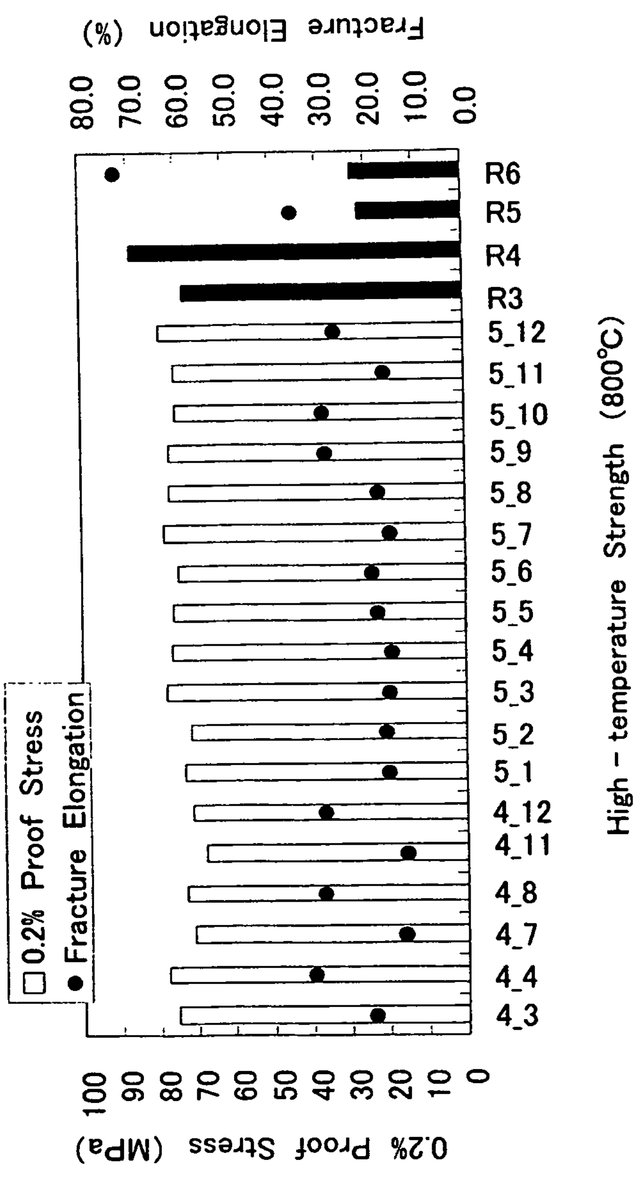
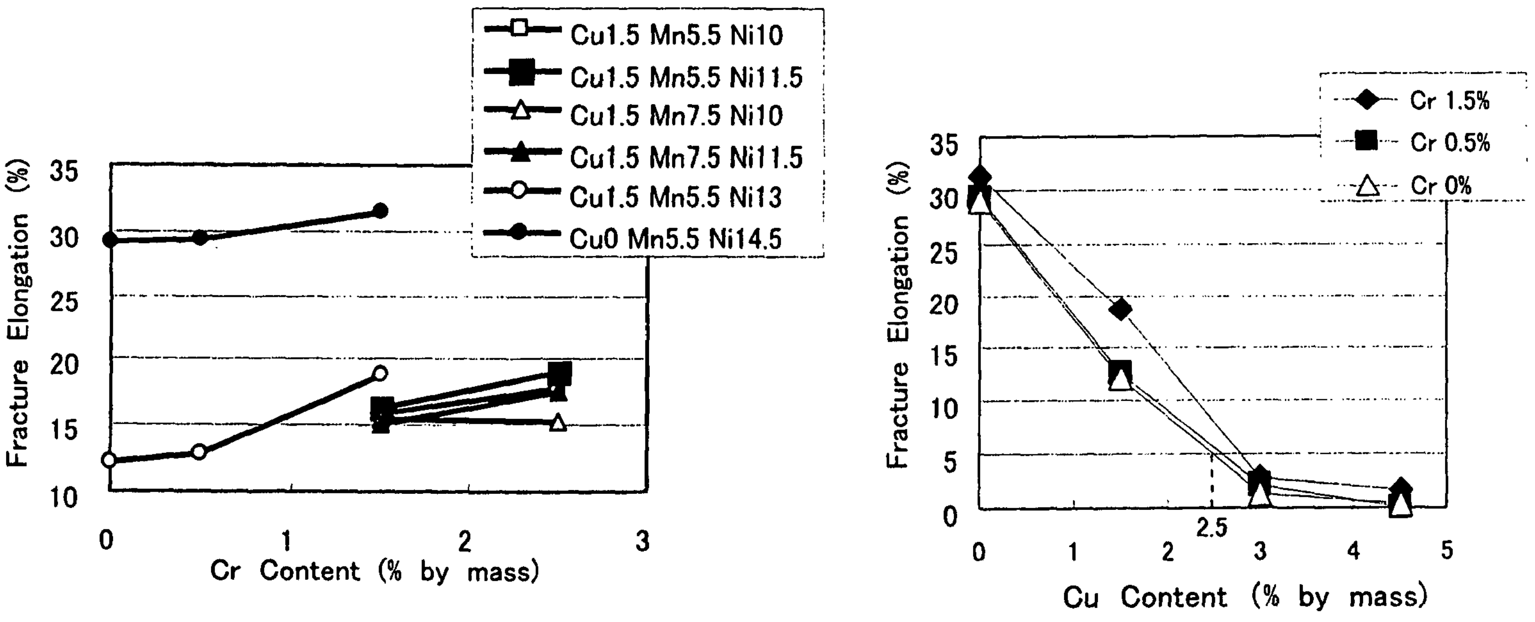

□ 0.2% Proof Stress
● Fracture Elongation
Fracture Elongation (%)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.2% Proof Stress (MPa)
100
90
80
70
60
50
40
30
20
10
0
R6
R5
R4
R3
5_12
5_11
5_10
5_9
5_8
5_7
5_6
5_5
5_4
5_3
5_2
5_1
4_12
4_11
4_8
4_7
4_4
4_3
High - temperature Strength (800°C)

Fig.17



(a)

(b)

Fe-3C-4Si-aCr-bNi-cMn-dCu (% by mass)

Fig.18

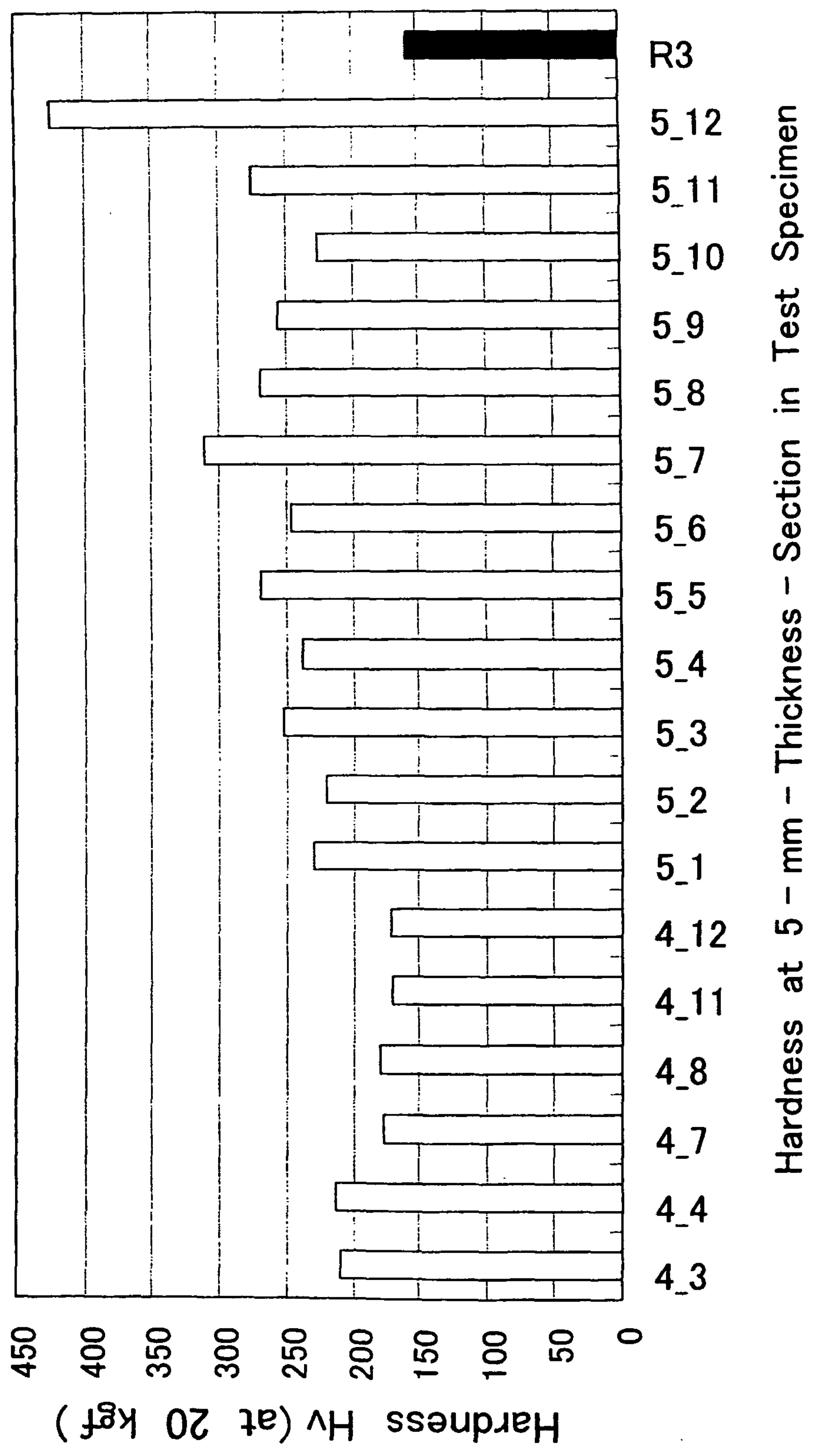
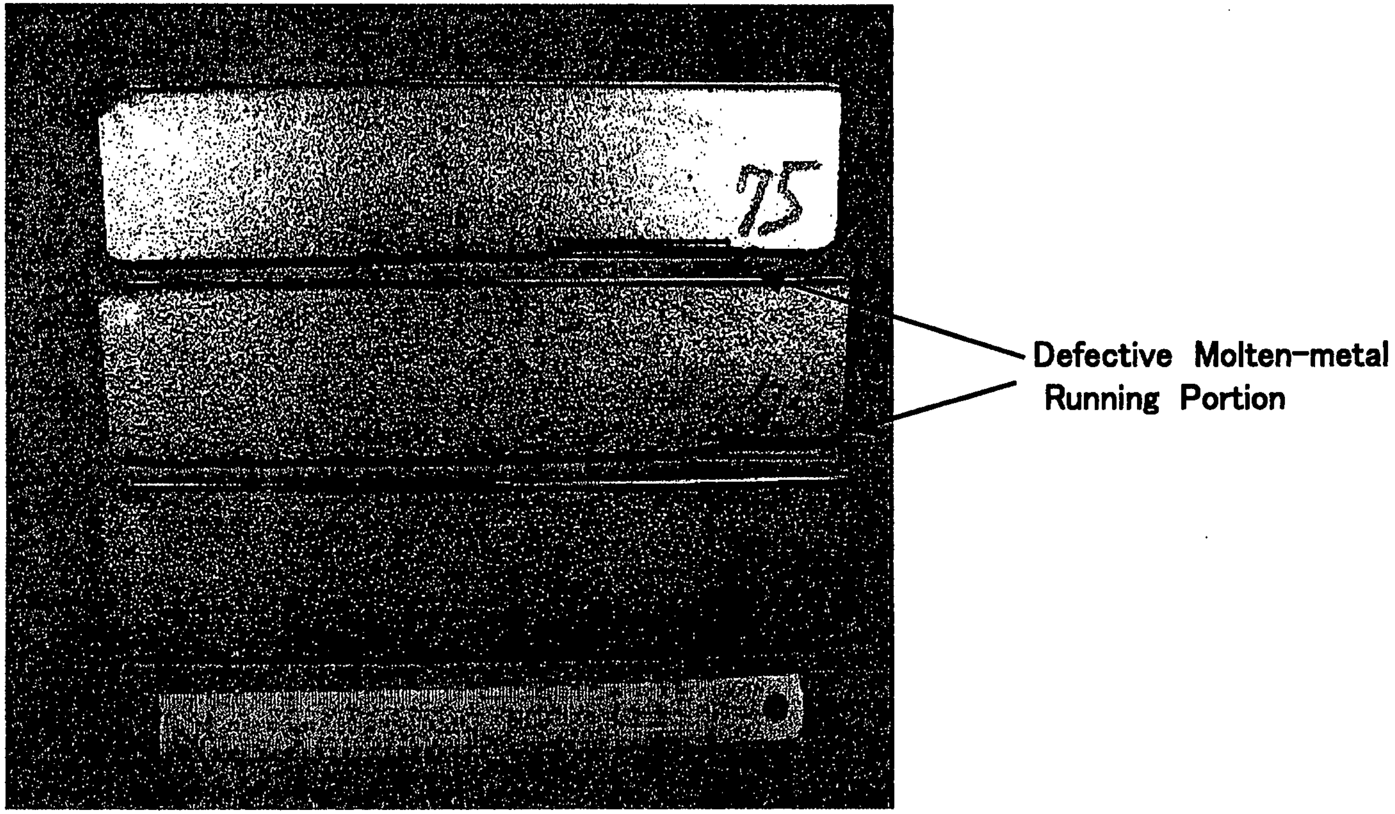
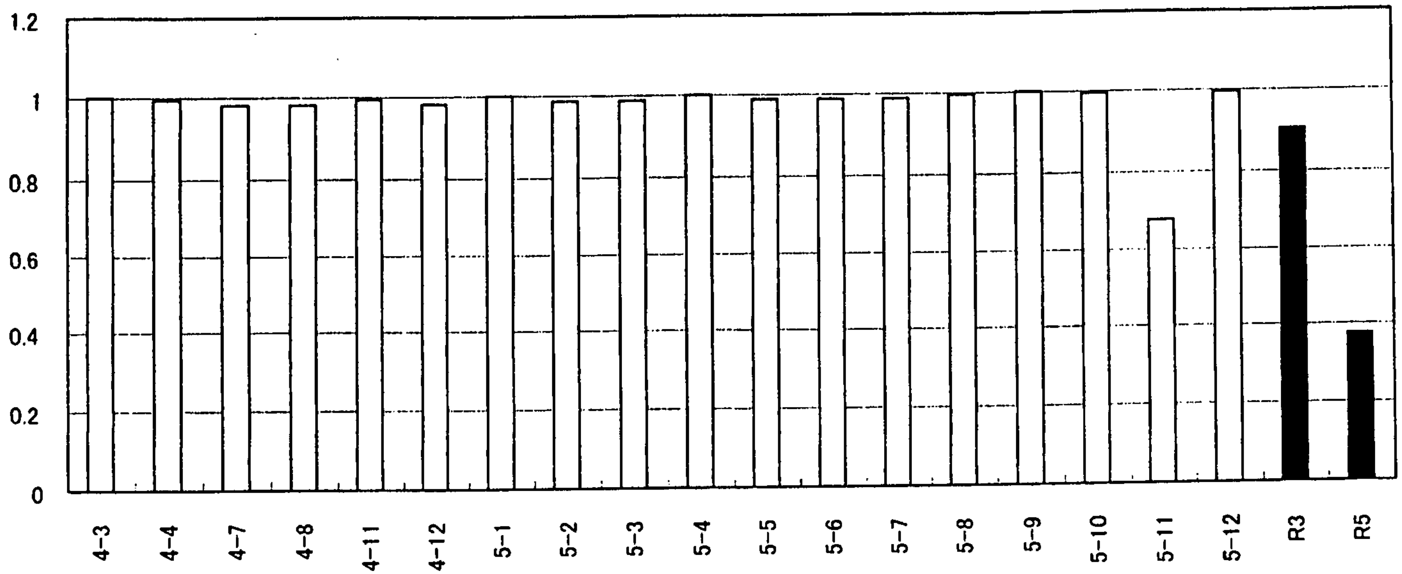

Hardness Hv (at 20 kgf)
450
400
350
300
250
200
150
100
50
0
Hardness at 5 - mm - Thickness - Section in Test Specimen
4_3
4_4
4_7
4_8
4_11
4_12
5_1
5_2
5_3
5_4
5_5
5_6
5_7
5_8
5_9
5_10
5_11
5_12
R3

Fig.19



Test Specimens for Evaluating Molten-metal Running

Fig.20



Molten-metal Running Evaluation

(In Case of Taking Evaluation on Test Specimen Nos. 4-3, 5-1 & 5-9 as "1")

Fig.21

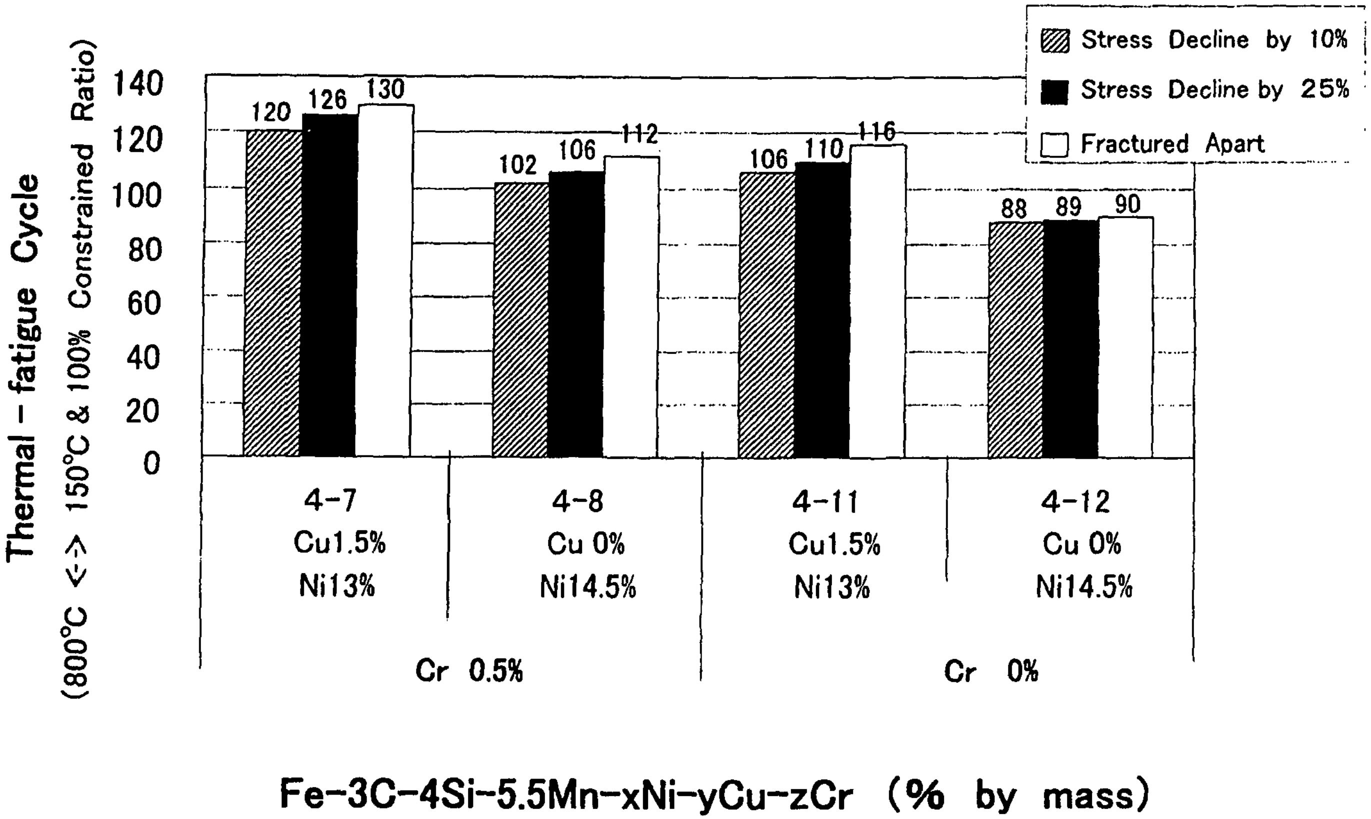
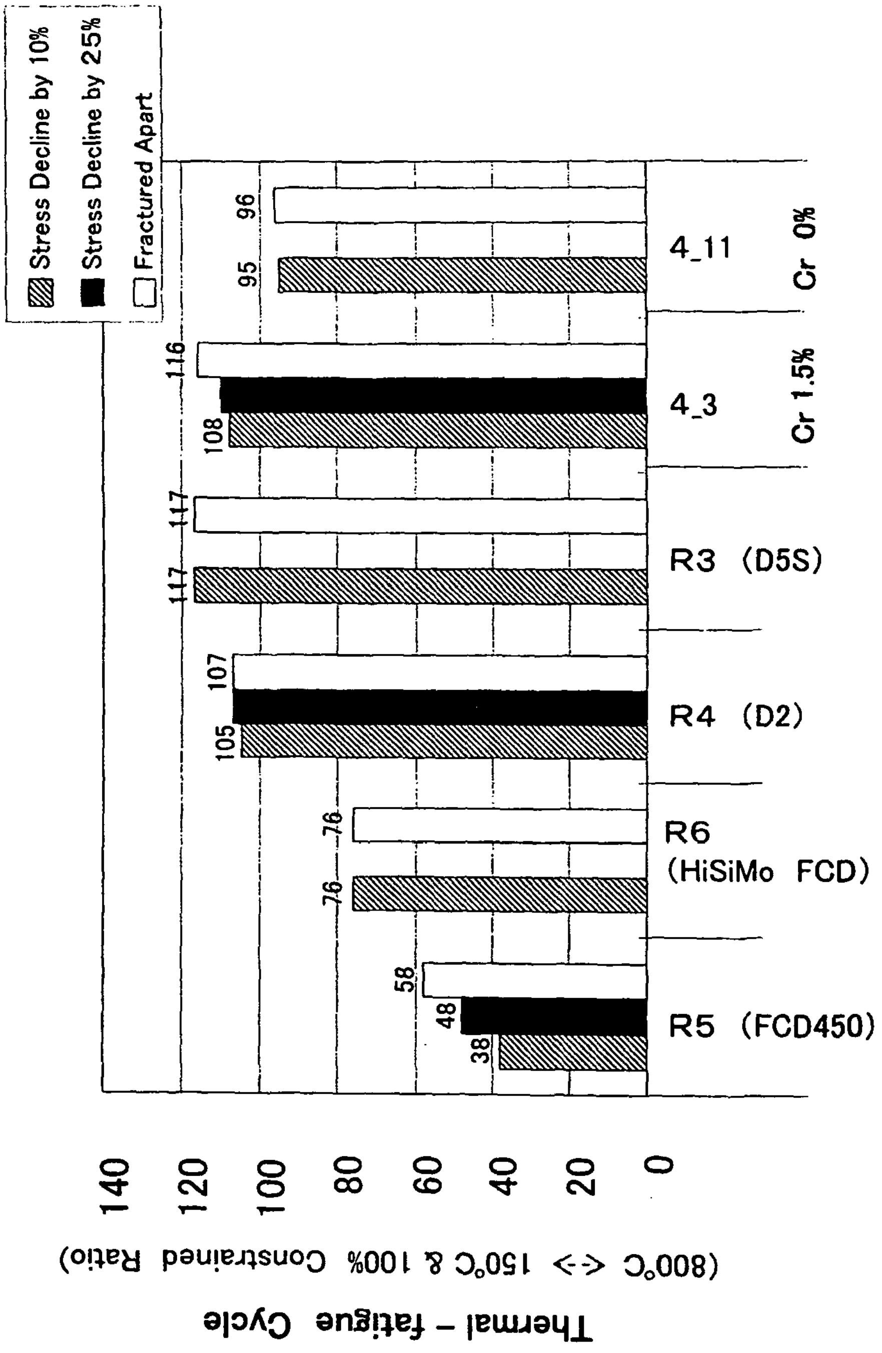

▨ Stress Decline by 10%
■ Stress Decline by 25%
☐ Fractured Apart
Thermal - fatigue Cycle
(800°C <-> 150°C & 100% Constrained Ratio)
140
120
100
80
60
40
20
0
120
126
130
102
106
112
106
110
116
88
89
90
4-7
Cu1.5%
Ni13%
4-8
Cu 0%
Ni14.5%
4-11
Cu1.5%
Ni13%
4-12
Cu 0%
Ni14.5%
Cr 0.5%
Cr 0%
Fe-3C-4Si-5.5Mn-xNi-yCu-zCr (% by mass)

Fig.22


▨ Stress Decline by 10%
■ Stress Decline by 25%
□ Fractured Apart
95
96
108
116
117
117
105
107
76
76
38
48
58
4_11
Cr 0%
4_3
Cr 1.5%
R3 (D5S)
R4 (D2)
R6
(HiSiMo FCD)
R5 (FCD450)
140
120
100
80
60
40
20
0
Thermal - fatigue Cycle
(800°C <-> 150°C & 100% Constrained Ratio)

## Fig.23

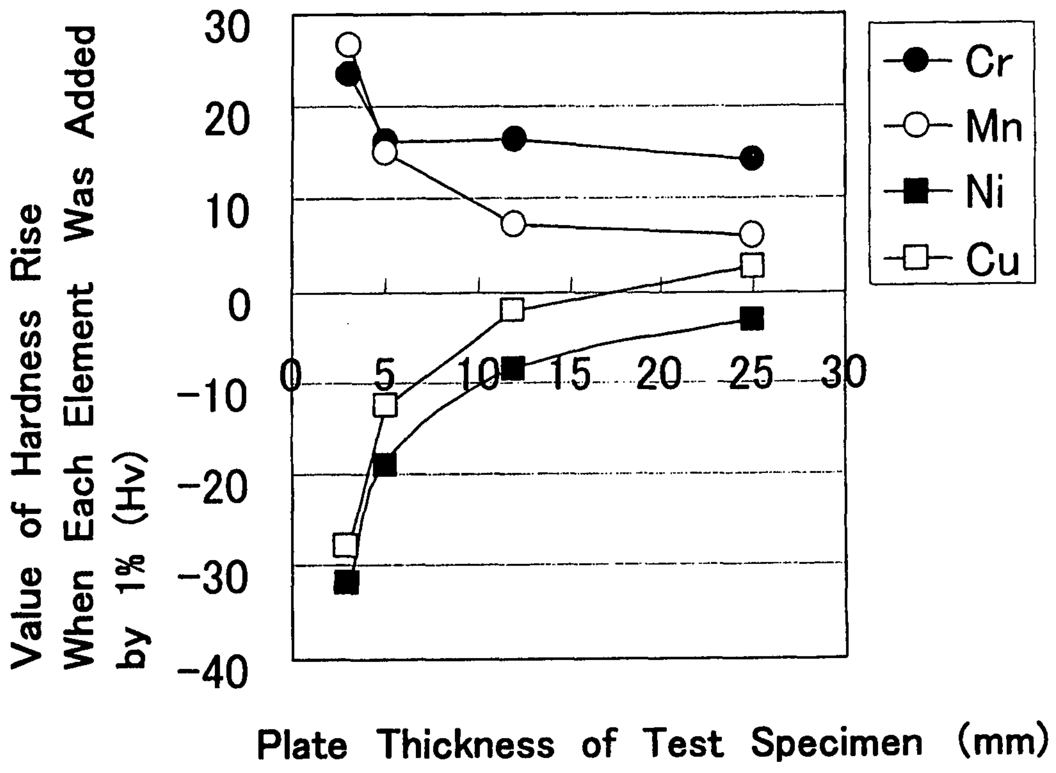
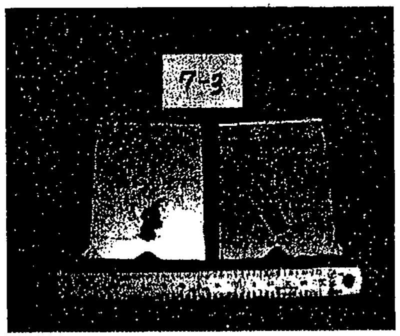
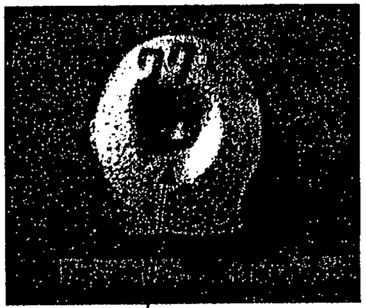

30
20
10
0
−10
−20
−30
−40
0
5
10
15
20
25
30
Value of Hardness Rise When Each Element Was Added by 1% (Hv)
Plate Thickness of Test Specimen (mm)
Cr
Mn
Ni
Cu

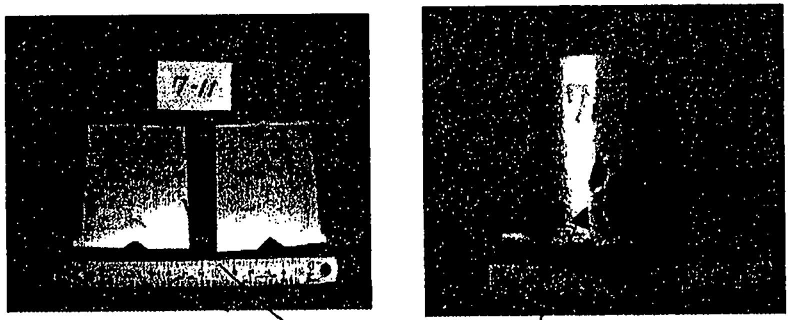
Fig.24



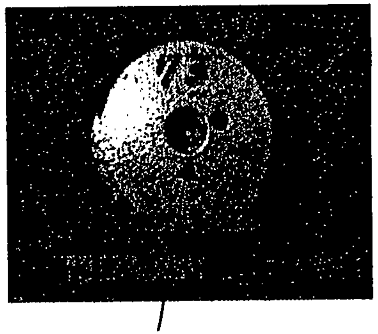
Evaluation on
Inner Shrinkage Magnitude
Filling Up with Shot Balls



Evaluation on
Outer Shrinkage Magnitude
Filling Up with Shot Balls



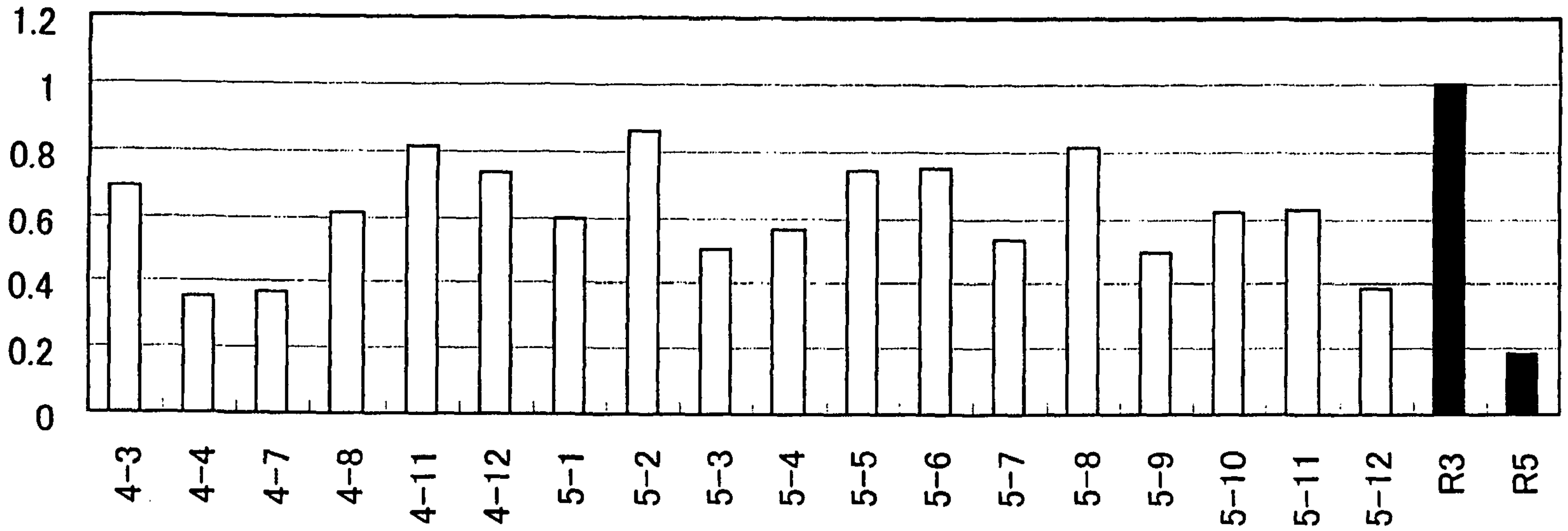
No Shrinkage Cavities at Cut Central Part,
but Evaluating Such Location, Which Was Continuous from
Outside to Inside, as Inner Shrinkage Magnitude Temporarily



Assume Test Specimen with
Least Shot-ball Quantity to
Exhibit Outer Shrinkage
Magnitude Being 0

Method of Quantifying Shrinkage Magnitude

Fig.25



Relative Evaluation on Shrinkage Magnitude

(In Case Where Shrinkage Magnitude of Test Specimen No. R3 Was Taken as "1")

Fig.26

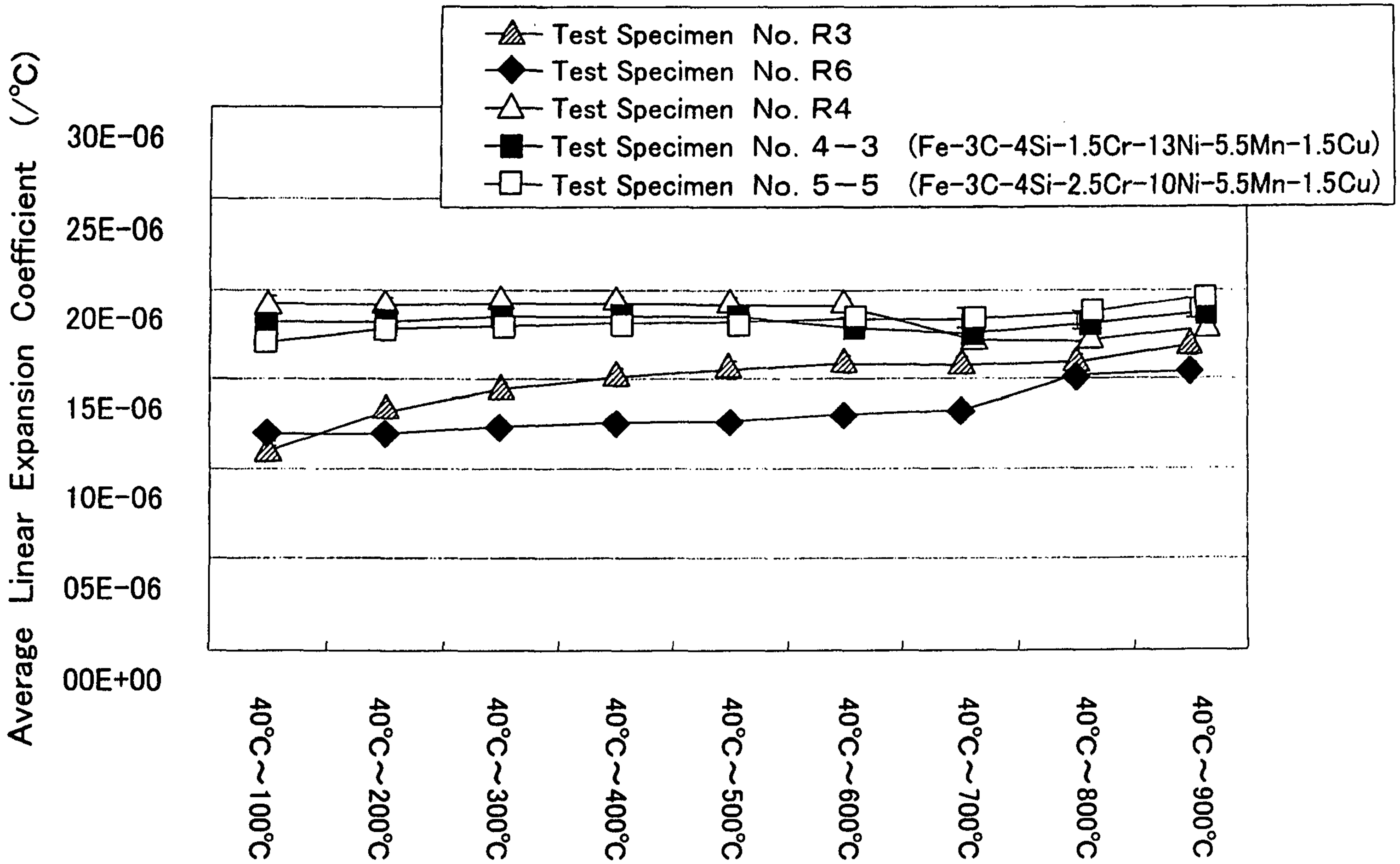

Test Specimen No. R3
Test Specimen No. R6
Test Specimen No. R4
Test Specimen No. 4−3 (Fe-3C-4Si-1.5Cr-13Ni-5.5Mn-1.5Cu)
Test Specimen No. 5−5 (Fe-3C-4Si-2.5Cr-10Ni-5.5Mn-1.5Cu)
Average Linear Expansion Coefficient (/°C)
30E−06
25E−06
20E−06
15E−06
10E−06
05E−06
00E+00
40°C∼100°C
40°C∼200°C
40°C∼300°C
40°C∼400°C
40°C∼500°C
40°C∼600°C
40°C∼700°C
40°C∼800°C
40°C∼900°C

Fig.27

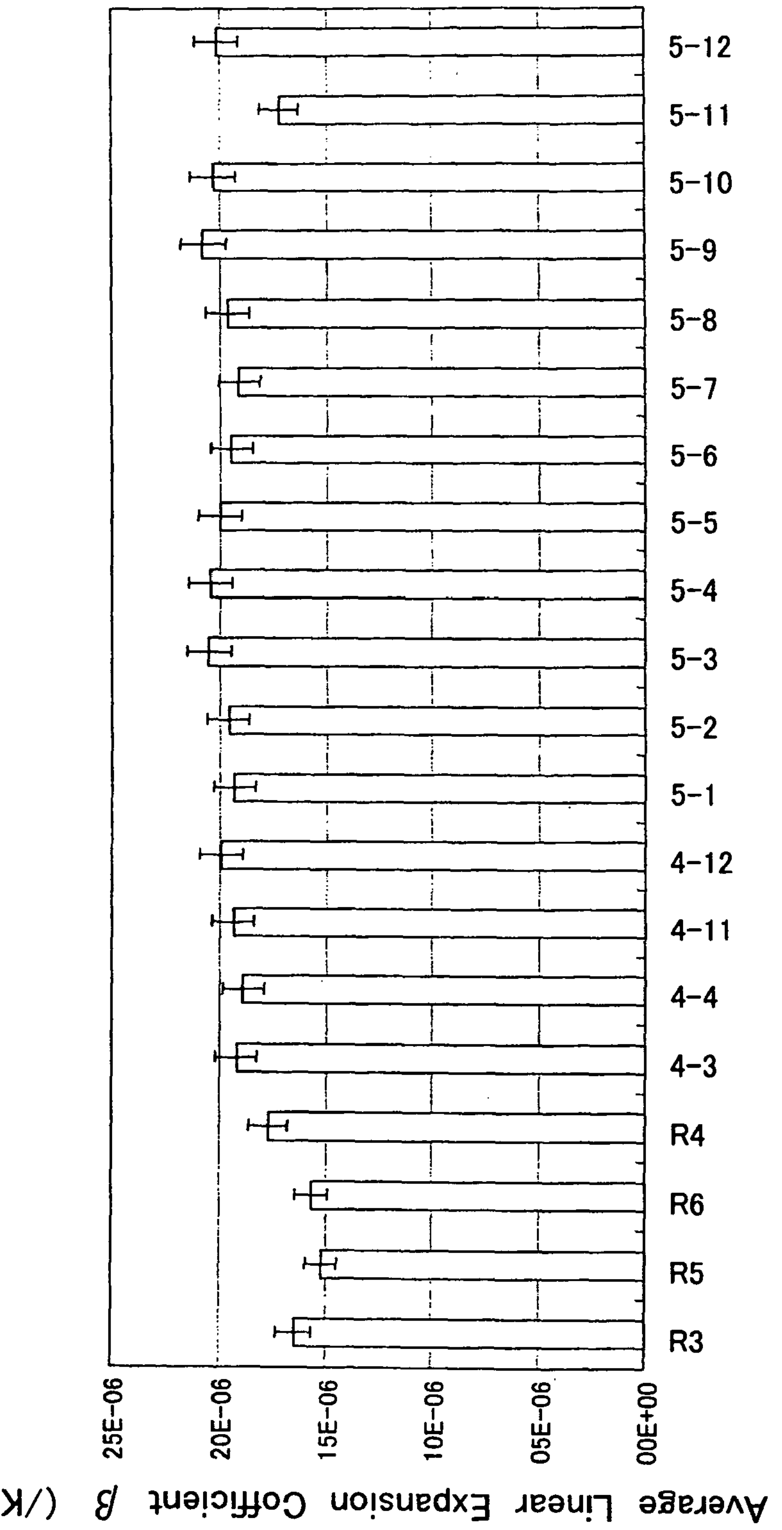
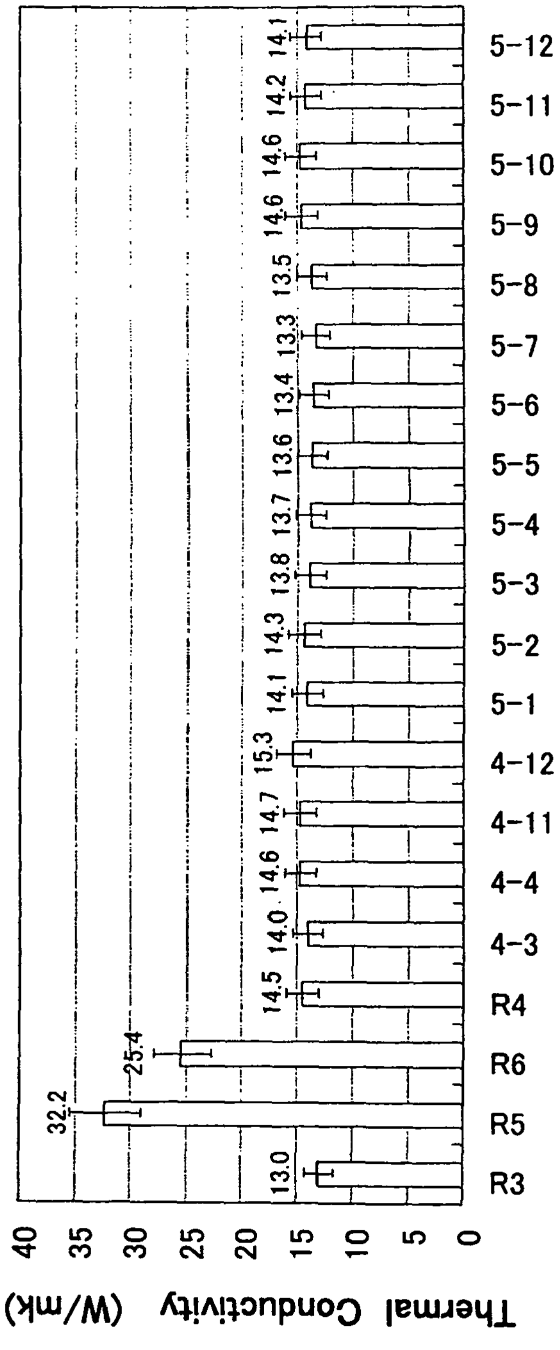

5-12
5-11
5-10
5-9
5-8
5-7
5-6
5-5
5-4
5-3
5-2
5-1
4-12
4-11
4-4
4-3
R4
R6
R5
R3
25E-06
20E-06
15E-06
10E-06
05E-06
00E+00
Average Linear Expansion Coefficient β (/K)

Fig.28


Thermal Conductivity (W/mk)
0
5
10
15
20
25
30
35
40
R3
R5
R6
R4
4-3
4-4
4-11
4-12
5-1
5-2
5-3
5-4
5-5
5-6
5-7
5-8
5-9
5-10
5-11
5-12
13.0
32.2
25.4
14.5
14.0
14.6
14.7
15.3
14.1
14.3
13.8
13.7
13.6
13.4
13.3
13.5
14.6
14.6
14.2
14.1

# Fig.29

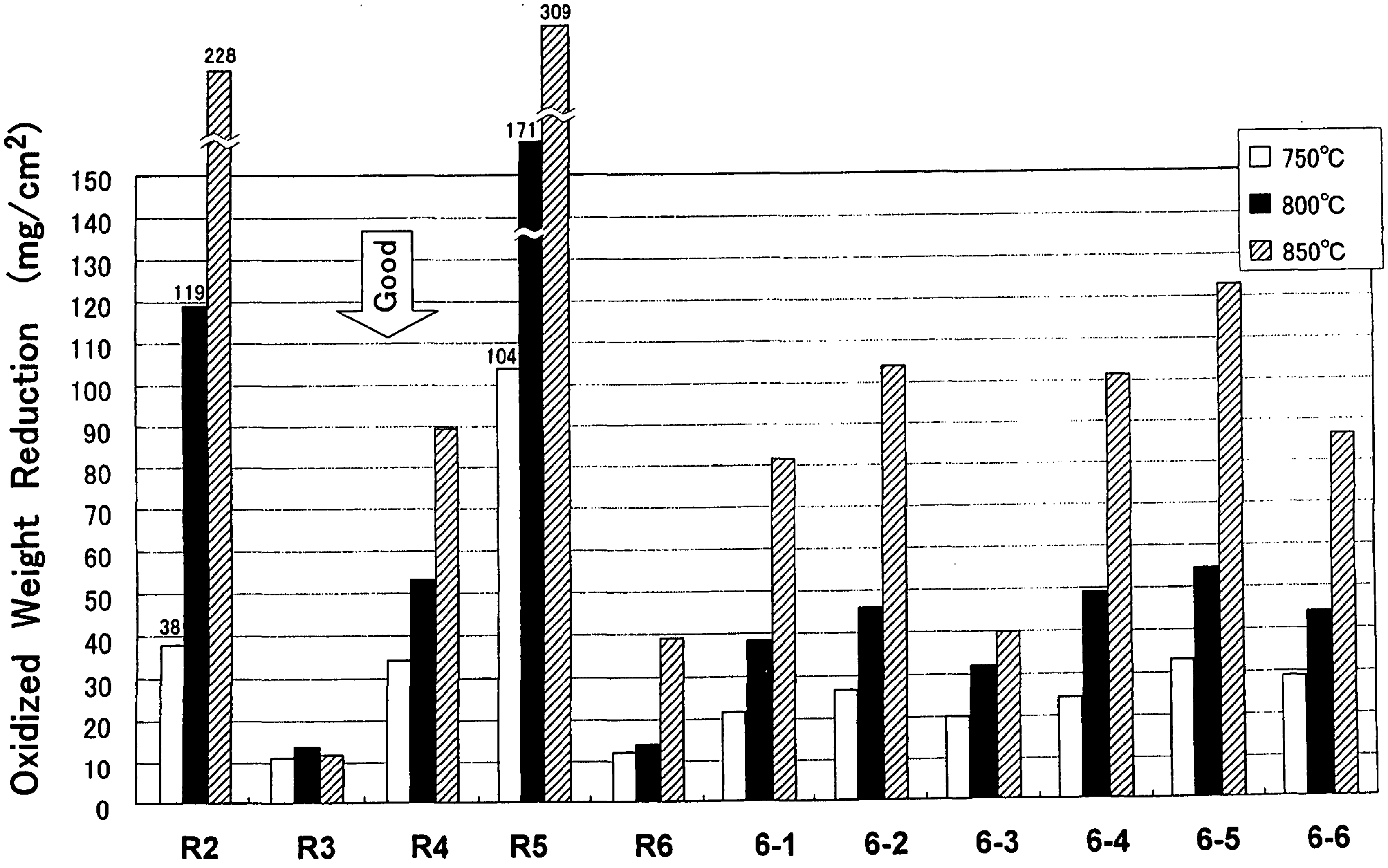
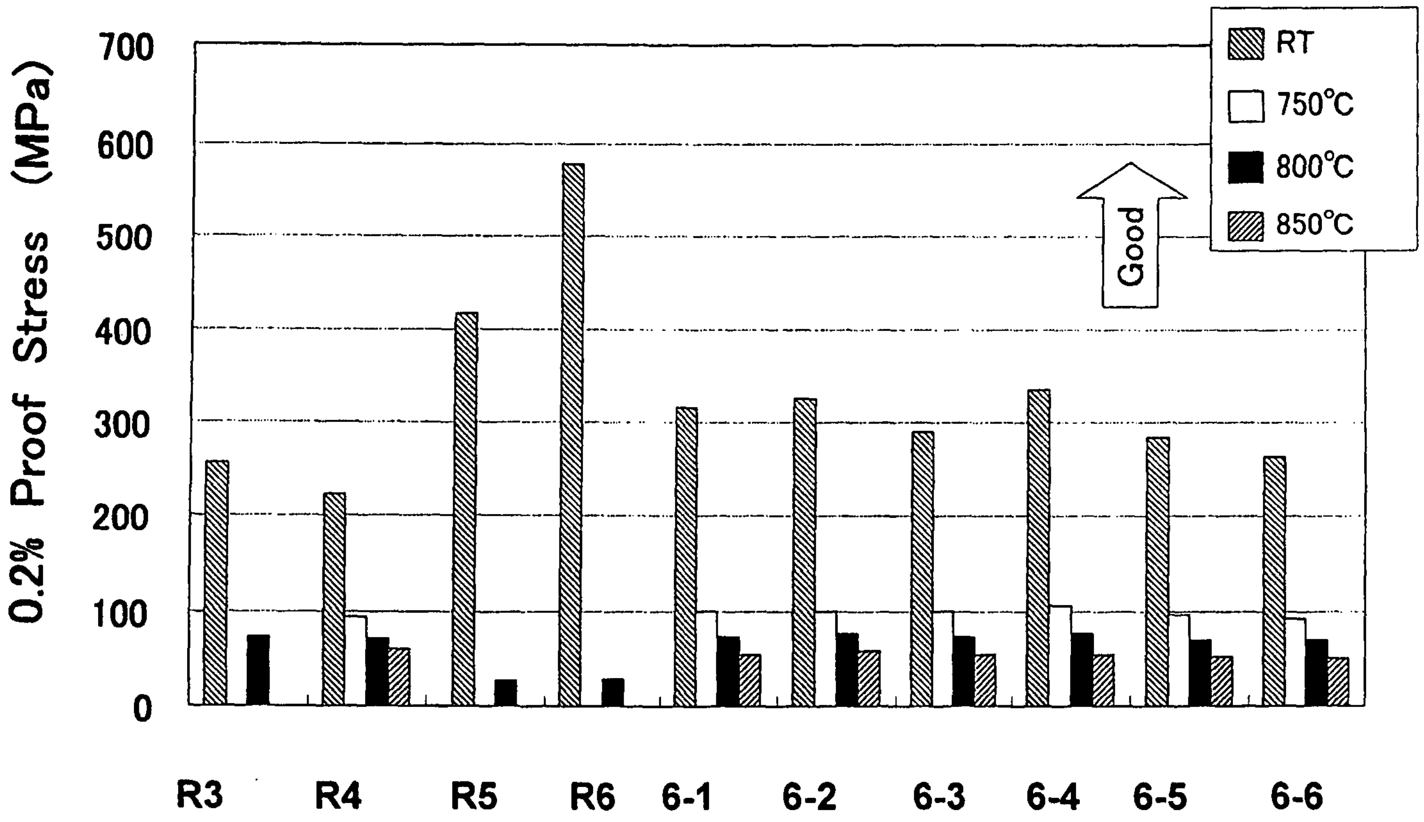

Oxidized Weight Reduction (mg/cm²)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
R2
R3
R4
R5
R6
6-1
6-2
6-3
6-4
6-5
6-6
38
119
228
104
171
309
Good
□ 750°C
■ 800°C
▨ 850°C

Fig.30


0.2% Proof Stress (MPa)
700
600
500
400
300
200
100
0
R3
R4
R5
R6
6-1
6-2
6-3
6-4
6-5
6-6
Good
▨ RT
☐ 750°C
■ 800°C
▨ 850°C

# Fig.31

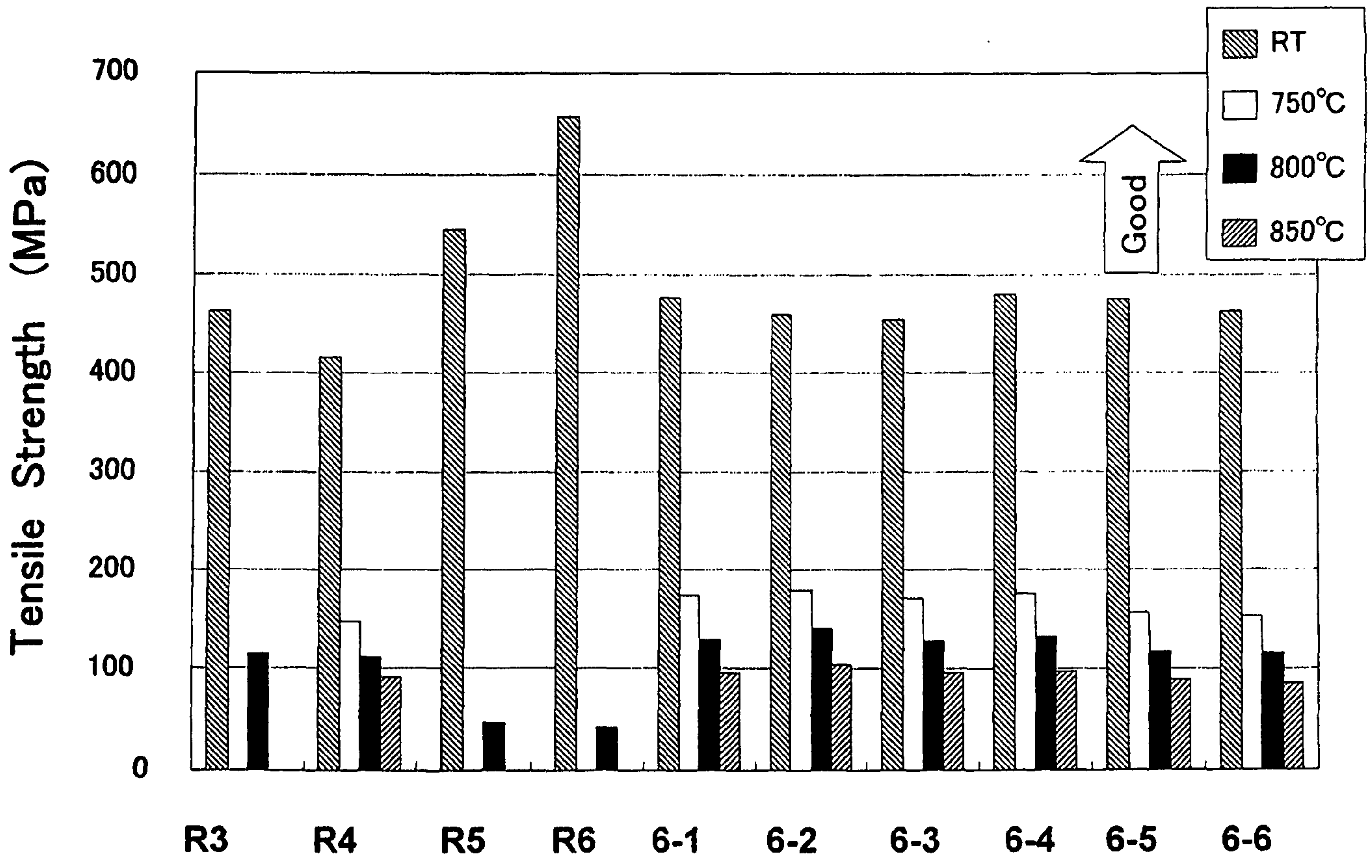

Tensile Strength (MPa)
700
600
500
400
300
200
100
0
R3
R4
R5
R6
6-1
6-2
6-3
6-4
6-5
6-6
Good
▧ RT
☐ 750°C
■ 800°C
▨ 850°C

Fig.32

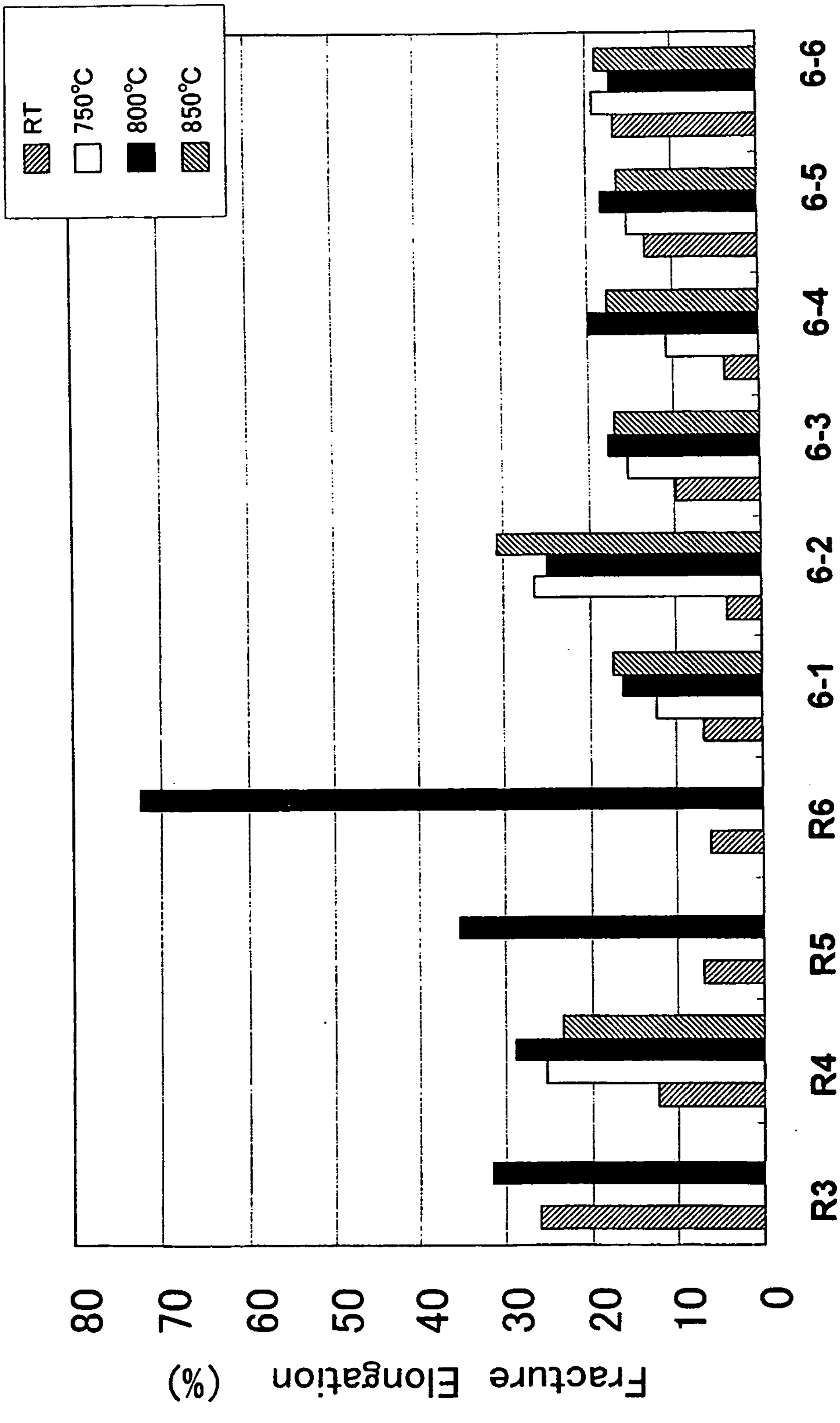
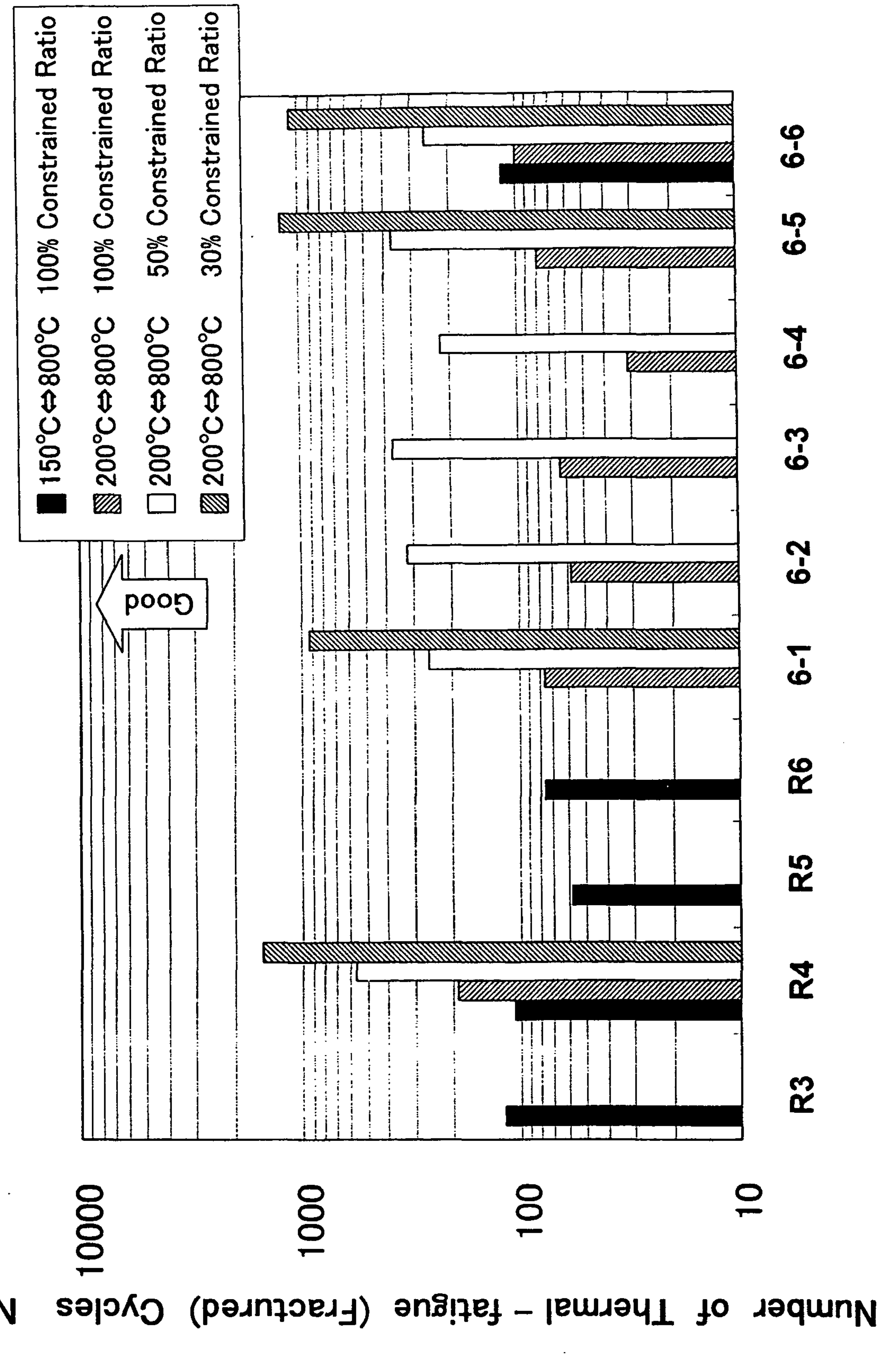

Fracture Elongation (%)
0
10
20
30
40
50
60
70
80
R3
R4
R5
R6
6-1
6-2
6-3
6-4
6-5
6-6
RT
750°C
800°C
850°C

Fig.33


■ 150°C⇔800°C 100% Constrained Ratio
▨ 200°C⇔800°C 100% Constrained Ratio
□ 200°C⇔800°C 50% Constrained Ratio
▧ 200°C⇔800°C 30% Constrained Ratio
Good
10000
1000
100
10
Number of Thermal - fatigue (Fractured) Cycles Nf
R3
R4
R5
R6
6-1
6-2
6-3
6-4
6-5
6-6

## REFERENCES CITED IN THE DESCRIPTION

### Patent documents cited in the description

- JP 58027951 A **[0009]**
- GB 801698 A **[0010]**
- DE 2646276 A1 **[0011]**