



(22) Date de dépôt/Filing Date: 2009/11/17
(41) Mise à la disp. pub./Open to Public Insp.: 2010/05/20
(30) Priorité/Priority: 2008/11/20 (AT A 1815/2008)

(51) Cl.Int./Int.Cl. *C22C 38/24* (2006.01),
C22C 38/12 (2006.01)
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(54) Titre : ALLIAGE D'ACIER POUR FORMAGE A CHAUD
(54) Title: HOT-FORMING STEEL ALLOY

(57) **Abrégé/Abstract:**

A hot-forming steel alloy comprising, in addition to iron and impurity elements, carbon, silicon, manganese, chromium, molybdenum, vanadium and nitrogen within the concentration ranges set forth in the claims. This abstract is neither intended to define the invention disclosed in this specification nor intended to limit the scope of the invention in any way.



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ABSTRACT OF THE DISCLOSURE

A hot-forming steel alloy comprising, in addition to iron and impurity elements, carbon, silicon, manganese, chromium, molybdenum, vanadium and nitrogen within the concentration ranges set forth in the claims. This abstract is neither intended to define the invention disclosed in this specification nor intended to limit the scope of the invention in any way.

HOT-FORMING STEEL ALLOY

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a hot-forming steel alloy with high toughness and at the same time a great hardening depth and/or improved martensitic through-hardening capability with a thermal quenching and tempering of products such as, for example, die-casting dies or extrusion dies and the like.

2. Discussion of Background Information

[0003] A thermal quenching and tempering of a part, e.g., of hot-forming steel, to adjust a high material hardness at operating temperatures of the part up to about 550°C and more, essentially means heating the material to a temperature at which it has a cubic face-centered atomic structure or an austenitic structure, followed by a forced cooling to obtain a martensitic structure and a subsequent tempering treatment, optionally multiple times, at temperatures of generally more than about 500°C. During the tempering, on the one hand the stresses in the material formed during the cooling and structural transformation are reduced at least in part, and on the other hand the material hardness is increased or a so-called secondary increase in hardness is achieved due to carbide precipitates.

[0004] A transformation of an austenitic structure into a martensitic structure, as one skilled in the art is aware, calls for a minimum cooling rate of the material, because this transformation takes place as a diffusionless flip-over process of the atomic structure due to a markedly high subcooling. Lower cooling rates lead to the formation of a bainite or pearlite structure.

[0005] The properties of a material depend on the chemical composition thereof and on the microstructure thereof adjusted by a thermal treatment and produce therefrom a specific property profile of a part.

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[0006] In other words: the chemical composition of a material and the intensity of the cooling or the heat dissipation from the surface during the hardening of the part determine the microstructure in the region of the surface and, due to the rewarming from the interior of the part, the microstructural development depending on the distance from the part surface. The respective local fine structure determines the material properties of the thermally quenched and tempered material locally present.

[0007] For reasons of increasingly economic production of the products, hot-forming materials for die cast molds and the like are subject to increasing stresses through shortened press sequence times and increased casting pressures. Furthermore, complex geometries of the mold cavities are provided to an increasing extent, so that much higher total stresses of the material are present overall. These total stresses can cause tool failure due to stress cracks, fire cracks, coarse fracture, corrosion and erosion, so that materials with a high hardness and strength as well as high toughness and ductility at the same time are required. However, these required properties depend on the chemical composition of the alloy and the tempered properties of the same resulting therefrom.

[0008] Cr-Mo-V steels have long been used for hot-forming tools, wherein the steel types X38 CrMoV 51 and X38 CrMoV 53 according to DIN steel iron list material no. 1.2343 and material no. 1.2367, as also given in the list, are "highly resistant to tempering" and suitable for "tools with large dimensions."

[0009] Material no. 1.2343 is used for "highly stressed tools, dies and presses."

[0010] The above materials have a high hardening depth and a deep-reaching tempering quality to required hardness values between 50 and 55 HRC. However, their toughness properties are low, which can be a disadvantage for the wearing qualities of die casting molds.

[0011] With a material no. 1.2343, a considerable increase in the material toughness after a quenching and tempering treatment can be achieved by a reduction of the provided silicon content from 0.90 to 1.20% by weight to a concentration of about 0.2% by weight, but high cooling rates during hardening are necessary for this, which often cannot be achieved.

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[0012] It would be advantageous to have available a hot-forming steel alloy of the type mentioned at the outset which forms a largely complete martensitic microstructure during a forced cooling from the austenite range even at low cooling rates, after which a high hardness and improved toughness of the material are achieved through a targeted tempering treatment.

SUMMARY OF THE INVENTION

[0013] The present invention provides hot-forming steel alloy. The alloy comprises, in the following elements in % by weight, based on the total weight of the alloy:

| | |
|-----------------|----------------------------------|
| Carbon (C) | from about 0.35 to about 0.42 |
| Silicon (Si) | from about 0.15 to about 0.29 |
| Manganese (Mn) | from about 0.40 to about 0.70 |
| Chromium (Cr) | from about 4.70 to about 5.45 |
| Molybdenum (Mo) | from about 1.50 to about 1.95 |
| Vanadium (V) | from about 0.40 to about 0.75 |
| Nitrogen (N) | from about 0.011 to about 0.016, |

remainder iron and impurity elements.

[0014] In one aspect of the alloy of the present invention, the maximum concentrations of one or more impurity elements present therein may be as follows:

| | |
|----------------|---------------------------|
| Phosphorus (P) | not more than about 0.005 |
| Sulfur (S) | not more than about 0.003 |
| Nickel (Ni) | not more than about 0.10 |
| Tungsten (W) | not more than about 0.10 |
| Copper (Cu) | not more than about 0.10 |
| Cobalt (Co) | not more than about 0.10 |
| Titanium (Ti) | not more than about 0.008 |
| Niobium (Nb) | not more than about 0.03 |

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| | |
|----------------|-----------------------------|
| Oxygen (O) | not more than about 0.003 |
| Boron (B) | not more than about 0.001 |
| Arsenic (As) | not more than about 0.01 |
| Tin (Sn) | not more than about 0.0025 |
| Antimony (Sb) | not more than about 0.01 |
| Zinc (Zn) | not more than about 0.001 |
| Calcium (Ca) | not more than about 0.0002 |
| Magnesium (Mg) | not more than about 0.0002. |

[0015] In yet another aspect of the alloy of the present invention, the alloy may comprise from about 0.37 % to about 0.40 % by weight of C and/or

from about 0.16 % to about 0.28 % by weight, e.g., from about 0.18 % to about 0.25 % by weight of Si and/or

from about 0.45 % to about 0.60 % by weight, e.g., from about 0.50 % to about 0.58 % by weight of Mn and/or from about 4.80 % to about 5.20 % by weight, e.g., from about 4.90 % to about 5.10 % by weight of Cr and/or

from about 1.55 % to about 1.90 % by weight, e.g., from about 1.65 % to about 1.80 % by weight of Mo and/or

from about 0.45 % to about 0.70 % by weight, e.g., from about 0.52 % to about 0.60 % by weight of V and/or

from about 0.012 % to about 0.015 % by weight of N.

[0016] In a further aspect, the alloy of the present invention may comprise, in % by weight:

| | |
|----------------|-------------------------------|
| Carbon (C) | from about 0.37 to about 0.40 |
| Silicon (Si) | from about 0.16 to about 0.28 |
| Manganese (Mn) | from about 0.45 to about 0.60 |
| Chromium (Cr) | from about 4.80 to about 5.20 |

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Molybdenum (Mo) from about 1.55 to about 1.90
 Vanadium (V) from about 0.45 to about 0.70
 Nitrogen (N) from about 0.012 to about 0.015.

[0017] In a still further aspect, the alloy may comprise, in % by weight:

Carbon (C) from about 0.37 to about 0.40
 Silicon (Si) from about 0.18 to about 0.25
 Manganese (Mn) from about 0.50 to about 0.58
 Chromium (Cr) from about 4.90 to about 5.10
 Molybdenum (Mo) from about 1.65 to about 1.80
 Vanadium (V) from about 0.52 to about 0.60
 Nitrogen (N) from about 0.012 to about 0.015.

[0018] The present invention also provides a part which comprises the alloy of the present invention as set forth above (including the various aspects thereof). The part may, for example, be a die-casting die or an extruder, or a part of a die-casting die or an extruder.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The present invention is further described in the detailed description which follows, in reference to the drawings by way of non-limiting examples of exemplary embodiments of the present invention, and wherein:

Fig. 1 is a graph showing impact strength values of tested materials after a thermal quenching and tempering as a function of the cooling parameters in the hardening treatment.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0020] The particulars shown herein are by way of example and for purposes of illustrative discussion of the embodiments of the present invention only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the present invention. In this

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regard, no attempt is made to show structural details of the present invention in more detail than is necessary for the fundamental understanding of the present invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the present invention may be embodied in practice.

[0021] As set forth above, the present invention provides a hot-working steel alloy which comprises the alloying elements in the following concentrations in % by weight, based on the total weight of the alloy:

| | |
|-----------------|----------------------------------|
| Carbon (C) | from about 0.35 to about 0.42 |
| Silicon (Si) | from about 0.15 to about 0.29 |
| Manganese (Mn) | from about 0.40 to about 0.70 |
| Chromium (Cr) | from about 4.70 to about 5.45 |
| Molybdenum (Mo) | from about 1.50 to about 1.95 |
| Vanadium (V) | from about 0.40 to about 0.75 |
| Nitrogen (N) | from about 0.011 to about 0.016, |

remainder iron (Fe) and impurity elements.

[0022] On of the advantages of the alloy according to the present invention may be seen essentially in that the elements overall, in particular the elements silicon, molybdenum, vanadium and nitrogen, are coordinated with one another in terms of transformation kinetics so that a desired strength and hardness with a high toughness of the material can be achieved with a thermal quenching and tempering with a reduced cooling rate during hardening.

[0023] It is thus possible either to achieve greater penetration depths of a martensitic hardness microstructure that is favorable for the mechanical properties of the part with a given cooling rate or advantageously to use a lower cooling rate during a hardening and to thus minimize the hardening strains in a die-casting die, which often is provided with an engraving or with a negative mold of the cast part. This is particularly important because a so-called vacuum hardening of molded parts is being used to an increasing extent, wherein a heating in vacuum also takes place for reasons of avoiding oxidations

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and decarburization of the processed surface of the workpiece or the mold during an austenitization, after which a forced cooling is carried out with a nitrogen gas flow. For this type of hardening of a part, an alloy with the chemical composition according to the present invention has proven to be particularly useful.

[0024] A further significant increase in the toughness properties of the tempered and quenched material can be achieved when the hot-working steel alloy has the following concentrations of one or all of the following impurity elements in % by weight, based on the total weight of the alloy:

| | |
|----------------|-------------------------------|
| Phosphorus (P) | not higher than about 0.005 |
| Sulfur (S) | not higher than about 0.003 |
| Nickel (Ni) | not higher than about 0.10 |
| Tungsten (W) | not higher than about 0.10 |
| Copper (Cu) | not higher than about 0.10 |
| Cobalt (Co) | not higher than about 0.10 |
| Titanium (Ti) | not higher than about 0.008 |
| Niobium (Nb) | not higher than about 0.03 |
| Oxygen (O) | not higher than about 0.003 |
| Boron (B) | not higher than about 0.001 |
| Arsenic (As) | not higher than about 0.01 |
| Tin (Sn) | not higher than about 0.0025 |
| Antimony (Sb) | not higher than about 0.01 |
| Zinc (Zn) | not higher than about 0.001 |
| Calcium (Ca) | not higher than about 0.0002 |
| Magnesium (Mg) | not higher than about 0.0002. |

[0025] The above elements can form either precipitates or compounds which are enriched in particular at the grain boundaries and result in a leap-like reduction of the

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toughness properties of the material once a concentration limit is reached or they cause grain boundary coatings, which likewise have an unfavorable effect.

[0026] Through a chemical composition of the material according to the invention adjusted within relatively narrow limits according to a preferred embodiment of the same, the hot-forming steel alloy may contain one or more of the alloying elements in the following concentrations in % by weight, based on the total weight of the alloy:

| | |
|-----------------|---|
| Carbon (C) | from about 0.37 to about 0.40 |
| Silicon (Si) | from about 0.16 to about 0.28, preferably from about 0.18 to about 0.25 |
| Manganese (Mn) | from about 0.45 to about 0.60, preferably from about 0.50 to about 0.58 |
| Chromium (Cr) | from about 4.80 to about 5.20, preferably from about 4.90 to about 5.10 |
| Molybdenum (Mo) | from about 1.55 to about 1.90, preferably from about 1.65 to about 1.80 |
| Vanadium (V) | from about 0.45 to about 0.70, preferably from about 0.52 to about 0.60 |
| Nitrogen (N) | from about 0.012 to about 0.015, |

remainder iron (Fe) and impurity elements.

[0027] By means of this alloy according to the invention, which makes particular demands on a smelting technology, it is possible to achieve high toughness values of the material even with low cooling rates in the thermal quenching and tempering process with high material hardnesses.

[0028] The invention is described in more detail below based on test results.

[0029] The test results are illustrated in Fig. 1.

[0030] Alloys with a chemical composition according to the invention and according to DIN material no. 1.2343 with standard-conforming and with reduced Si contents and

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according to DIN material no. 1.2367, as given in Table 1, were examined after a thermal quenching and tempering treatment to a material hardness of 44 HRC with different cooling parameters λ during hardening. The value that characterizes the parameter λ is calculated as follows:

Cooling parameter [λ] corresponds to the time [in sec.] for a cooling from 800°C to 500°C divided by 100.

[0031] The alloying elements of the materials listed in Table 1 are indicated below, wherein the remainder represents the content of iron and accompanying elements and impurity elements.

TABLE 1

Alloy composition in % by weight

| Material No. | C | Si | Mn | P | S | N | Cr | Mo | Ni | V |
|--------------|------|------|------|-------|-------|-------|------|------|------|------|
| 1.2343 | 0.39 | 1.11 | 0.41 | 0.021 | 0.023 | - | 5.28 | 1.26 | 0.21 | 0.38 |
| 1.2343 So | 0.38 | 0.21 | 0.39 | 0.022 | 0.019 | - | 5.34 | 1.30 | 0.16 | 0.40 |
| 1.2367 | 0.38 | 0.40 | 0.47 | 0.029 | 0.021 | - | 5.00 | 2.98 | 0.20 | 0.61 |
| W 350 | 0.39 | 0.19 | 0.51 | 0.004 | 0.001 | 0.013 | 4.91 | 1.69 | 0.06 | 0.53 |

[0032] Fig. 1 shows that with a cooling parameter up to approx. $\lambda = 12$ the material no. 1.2343 with Si contents reduced to approx. 0.20% by weight in a thermally quenched and tempered state to a material hardness of 44 HRC has the highest toughness measured according to Charpy V. However, with increasing cooling parameter λ the toughness values subsequently drop sharply to a low level.

[0033] The materials no. 1.2343 with standard-conforming Si contents and no. 1.2367 have a lower toughness with a quenched and tempered hardness of 44 HRC, but have a remarkable through-hardening capability, which is documented by only slightly reduced toughness values as a function of the cooling parameter.

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[0034] Although at high cooling rates or in the range of the cooling parameter λ up to 13, a test alloy W 350 according to the invention shows slightly lower toughness values at room temperature in the state quenched and tempered to 44 HRC compared to the So material no. 1.2343 (Si \approx 0.2% by weight), the toughness of the material remains essentially unchanged at superior high values even with reduced cooling rates or higher cooling parameters.

[0035] It is noted that the foregoing examples have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the present invention. While the present invention has been described with reference to an exemplary embodiment, it is understood that the words which have been used herein are words of description and illustration, rather than words of limitation. Changes may be made, within the purview of the appended claims, as presently stated and as amended, without departing from the scope and spirit of the present invention in its aspects. Although the present invention has been described herein with reference to particular means, materials and embodiments, the present invention is not intended to be limited to the particulars disclosed herein; rather, the present invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A hot-forming steel alloy, wherein the alloy comprises, in addition to iron and impurity elements, the following elements in % by weight, based on a total weight of the alloy:

| | |
|-----------------|----------------------------------|
| Carbon (C) | from about 0.35 to about 0.42 |
| Silicon (Si) | from about 0.15 to about 0.29 |
| Manganese (Mn) | from about 0.40 to about 0.70 |
| Chromium (Cr) | from about 4.70 to about 5.45 |
| Molybdenum (Mo) | from about 1.50 to about 1.95 |
| Vanadium (V) | from about 0.40 to about 0.75 |
| Nitrogen (N) | from about 0.011 to about 0.016. |

2. The alloy of claim 1, wherein the alloy comprises, in % by weight:

| | |
|-----------------|----------------------------------|
| Carbon (C) | from about 0.37 to about 0.40 |
| Silicon (Si) | from about 0.16 to about 0.28 |
| Manganese (Mn) | from about 0.45 to about 0.60 |
| Chromium (Cr) | from about 4.80 to about 5.20 |
| Molybdenum (Mo) | from about 1.55 to about 1.90 |
| Vanadium (V) | from about 0.45 to about 0.70 |
| Nitrogen (N) | from about 0.012 to about 0.015. |

3. The alloy of claim 1, wherein the alloy comprises, in % by weight:

| | |
|-----------------|----------------------------------|
| Carbon (C) | from about 0.37 to about 0.40 |
| Silicon (Si) | from about 0.18 to about 0.25 |
| Manganese (Mn) | from about 0.50 to about 0.58 |
| Chromium (Cr) | from about 4.90 to about 5.10 |
| Molybdenum (Mo) | from about 1.65 to about 1.80 |
| Vanadium (V) | from about 0.52 to about 0.60 |
| Nitrogen (N) | from about 0.012 to about 0.015. |

4. The alloy of claim 1, 2 or 3, wherein maximum concentrations of one or more impurity elements in % by weight, based on a total weight of the alloy, are:

| | |
|----------------|-----------------------------|
| Phosphorus (P) | not more than about 0.005 |
| Sulfur (S) | not more than about 0.003 |
| Nickel (Ni) | not more than about 0.10 |
| Tungsten (W) | not more than about 0.10 |
| Copper (Cu) | not more than about 0.10 |
| Cobalt (Co) | not more than about 0.10 |
| Titanium (Ti) | not more than about 0.008 |
| Niobium (Nb) | not more than about 0.03 |
| Oxygen (O) | not more than about 0.003 |
| Boron (B) | not more than about 0.001 |
| Arsenic (As) | not more than about 0.01 |
| Tin (Sn) | not more than about 0.0025 |
| Antimony (Sb) | not more than about 0.01 |
| Zinc (Zn) | not more than about 0.001 |
| Calcium (Ca) | not more than about 0.0002 |
| Magnesium (Mg) | not more than about 0.0002. |

5. The alloy of any one of claims 1 to 4, wherein the alloy comprises from about 0.37 % to about 0.40 % by weight of C.

6. The alloy of any one of claims 1 to 5, wherein the alloy comprises from about 0.16 % to about 0.28 % by weight of Si.

7. The alloy of claim 6, wherein the alloy comprises from about 0.18 % to about 0.25 % by weight of Si.

8. The alloy of any one of claims 1 to 7, wherein the alloy comprises from about 0.45 % to about 0.60 % by weight of Mn.

9. The alloy of claim 8, wherein the alloy comprises from about 0.50 % to about 0.58 % by weight of Mn.
10. The alloy of any one of claims 1 to 9, wherein the alloy comprises from about 4.80 % to about 5.20 % by weight of Cr.
11. The alloy of claim 10, wherein the alloy comprises from about 4.90 % to about 5.10 % by weight of Cr.
12. The alloy of any one of claims 1 to 11, wherein the alloy comprises from about 1.55 % to about 1.90 % by weight of Mo.
13. The alloy of claim 12, wherein the alloy comprises from about 1.65 % to about 1.80 % by weight of Mo.
14. The alloy of any one of claims 1 to 13, wherein the alloy comprises from about 0.45 % to about 0.70 % by weight of V.
15. The alloy of claim 14, wherein the alloy comprises from about 0.52 % to about 0.60 % by weight of V.
16. The alloy of any one of claims 1 to 15, wherein the alloy comprises from about 0.012 % to about 0.015 % by weight of N.
17. A part which comprises an alloy as defined in any one of claims 1 to 16.
18. The part of claim 17, wherein the part is a die-casting die, an extruder, or a portion thereof.

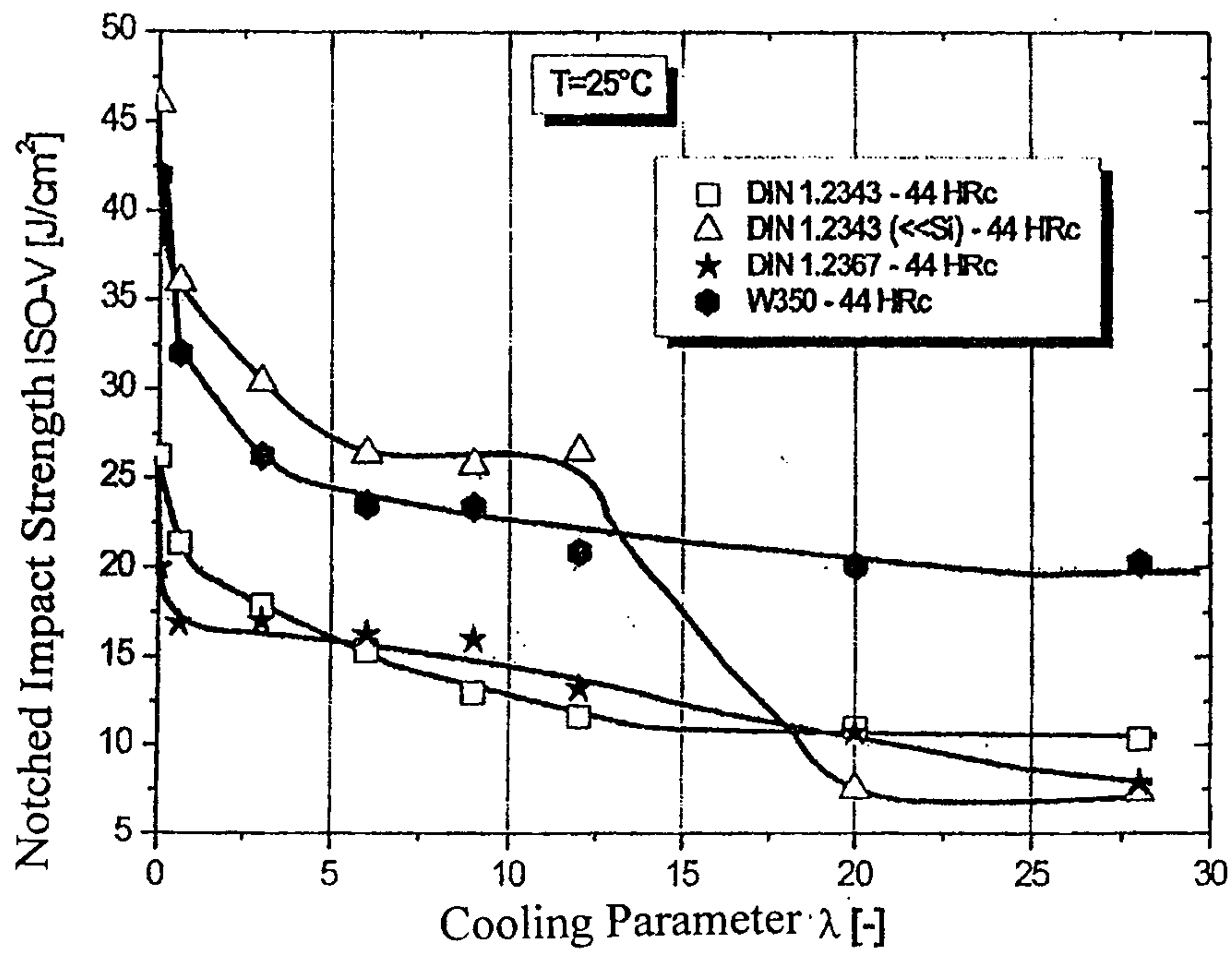


Fig. 1