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(54) **A precipitation hardenable, austenitic hot work steel and a method of treating the same.**

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**Description**

## TECHNICAL FIELD

5 The present invention relates to a precipitation hardenable, austenitic hot work steel having a high hot yield strength, a good resistance to tempering as well as good hot ductility (toughness) at temperatures of about 700 °C. The invention also relates to a method of treating such a steel.

## BACKGROUND ART

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When copper, brass and steel are hot formed, e.g. subjected to extrusion and press-forging, the molding tools are subjected to very high temperatures as well as to a high mechanical load. The blanks to be formed generally are preheated to temperatures of above 700 °C, and thus, the working tool surface in contact with the work piece may reach temperatures of about 700 °C. In this way the life of the tools usually is very limited, which implies a serious technical and economic problem in this respect. The tool life ordinarily is limited by the development of any of the following damages, resulting in a rejection of the tool:

- \* hot wearing
- \* plastic deformation
- \* cracks/ruptures

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Thus, the possible damages to the tools constitute a material technology problem, which it is hard to solve and consequently, the properties of the tool material are of significant importance for the tool life.

Mainly the following properties of the tool material are crucial if the maximum resistance to the important damage causes is to be obtained:

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- \* hot yield strength (hot hardness)
- \* resistance to tempering-back
- \* hot ductility/toughness.

These properties must have maximum values at temperatures of about 700 °C. Particularly the hot yield strength and the resistance to tempering-back (the ability to resist a time-dependent softening at high temperatures) are of crucial importance.

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Presently for such tools to some extent conventional, martensitic hot work steels are used, e.g. type AISI H13 (about 0.40% C-1.0% Si-0.5% Mn-5% Cr- 1.3% Mo-0.9% V). These steel grades have a good ductility/toughness but unfortunately an insufficient hot strength and resistance to tempering at the temperatures of interest (about 700 °C). Consequently, their tool lives ordinarily are too short as regards primarily hot wearing and plastic deformation, respectively.

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Also, so called superalloys are used increasingly, which are highly alloyed metallic materials, usually precipitation hardened by means of intermetallic phases. Such materials may have a very high hot strength and resistance to tempering-back and have very satisfactory tool lives in many instances. However, the drawbacks of the superalloys are that they are very expensive to use due to their chemical composition and difficult to obtain (difficult to manufacture) in sufficiently large dimensions. Examples of superalloys, used in this connection, are e.g.: iron base alloy A 286 (about 0.04% C-15% Cr- 26% Ni- 1.3% Mo-2.0% Ti-0.2% Al) and nickel base alloy René 41 (about 0.10% C- 19% Cr-55% Ni-11% Co-10% Mo- 3% Ti-1.5% Al), respectively.

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Lately also ceramic materials are being used increasingly for smaller tools in this field. Ceramic materials can have an extremely good hot strength and resistance to tempering-back. However, the problem with the ceramic materials available so far is that they are too brittle and thus, they too easily cause tool breakdowns due to crack formation/ruptures. Also, they are very expensive and it is difficult to machine them, thus causing very high tool costs.

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GB-A-1 384 234 discloses a hot work tool steel made from an austenitic steel alloy hardened by carbide precipitation. The alloy comprises 0.62 %C, 19.1 %Mn, 4.33 %Cr, 1.8 %V, 0.81 %Mo, 0.95 Si and 0.11 %Ni.

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## BRIEF DISCLOSURE OF THE INVENTION

The object of the present invention is to suggest a steel material for tools, used to hot form copper, brass and steel, having the following combination of properties:

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- \* This steel has a very good combination of critical characteristics (a high hot yield strength, a good resistance to tempering and a good hot ductility/toughness). The hot yield strength and the resistance to tempering-back are superior to those which can be reached by conventional, martensitic hot work

steels. Rather they are in the same class as what can be reached with exclusive superalloys.

- \* This steel has a low content of expensive alloy elements and thus, the alloy cost will be much lower than for superalloys. The cost is instead comparable with that of conventional, martensitic hot work steels, which in this respect are considered to be "cheap" tool materials.
- 5 \* This steel can be processed (melted, forged/milled and heat-treated etc.) successfully, using processes/methods designed for conventional tool steel materials - also with sufficiently large dimensions.

Steel materials having the above-mentioned characteristics are according to the invention precipitation hardenable, austenitic alloys with the following composition ranges (percent by weight):

10 0.35-0.60 C

max. 1 Si

9-17 Mn

2-8 Cr

max. 2 Ni

15 1-4 Mo, which completely or partially can be replaced by the double amount of W (percent by weight)

1.2-1.8 V

0.001-0.020 B

The remainder essentially Fe and impurities.

The invention is defined in claims 1 and 10. Preferred embodiments are shown in claims 2 - 9.

20 The technical features of the steel can be briefly described in the following way:

- subsequent to a solution heat treatment in the temperature range of 1100-1200 °C and cooling to ambient temperature the matrix consists of austenite and a hardness of about 25 HRC is obtained.
- through an ageing treatment in the temperature range of 650-750 °C the hardness can be increased through a precipitation hardening to not more than about 45 HRC. The matrix is after the ageing process and the cooling to ambient temperature still austenitic.
- 25 - The strong precipitation hardening effect, which can be as high as about 20 HRC, measured as a hardness increase, is obtained through an intragranular precipitation of the very finely dispersed and heat resistant MC-material (vanadium carbide), during the ageing process.
- This steel has in its precipitation hardened condition a pronounced high temperature strength and resistance to tempering-back, combined with a comparably good ductility/toughness.
- 30

The unique combination of alloy elements in well-balanced amounts gives the steel material its optimal features. The importance of each one of the abovementioned alloy elements will now be briefly described, without any particular preference.

Carbon and vanadium in combination constitute the main ingredient of the precipitation hardening phase vanadium carbide (MC). The effect of the precipitation hardening is dependent on the amount of carbon and vanadium present in solution after the solution heat treatment. At least about 0.35, preferably at least 0.4% carbon is needed in order to obtain an efficient hardening effect. However, it is not possible to dissolve more than about 0.6% carbon, when this type of steel is solution heat treated. Surplus carbon remains in the form of not dissolved vanadium carbides, which impairs the ductility/toughness of the steel in a not desirable way. This means, that the steel according to the invention is to contain 0.35 - 0.60% carbon, with an optimal carbon content in the range 0.4-0.5% carbon.

Silicon is not a necessary alloy element according to the invention, but it can be used in amounts, which are normal, when deoxidization is used in steel making. However, silicon stimulates the carbon activity in austenite, which means that silicon counteracts the necessary solution of vanadium carbide during the solution heat treatment. Therefore the silicon content is limited according to the invention to a maximum of 1%.

Manganese is a strongly austenite stabilizing element and is used according to the invention in order to make the steel austenitic at all temperatures. We have found that at least about 9% Mn, preferably at least 10% Mn is necessary in order to obtain this. Also, manganese lowers the carbon activity in the austenite and consequently improves at the same time the solution of vanadium carbide during the solution heat treatment. However, a high manganese content leads to certain metallurgical complications in the steel making and thus, a too high content means unnecessary problems and costs. Thus, the manganese content is limited to not more than 17%, preferably not more than 15%, with an optimal manganese content in the range 10.5-13%.

Chromium and manganese have similar effects on the austenite stabilization and the carbon activity. Also, chromium improves in a desirable way the oxidation resistance of the steel. Thus, at least 2% chromium, preferably at least 3% chromium ought to be added to the steel. However, when a chromium content more than about 10% is used, chromium starts forming chromium carbides to a not desirable

degree during the ageing treatment, which has a detrimental effect on the precipitation hardening from vanadium carbides. Consequently, the steel according to the invention suitably must not contain more than 8% chromium, preferably not more than 7% chromium, with an optimal chromium content in the range 4-6% chromium.

Nickel is like manganese a strongly austenite stabilizing element and consequently, it can partly replace manganese in the steel. However, like silicon nickel stimulates the carbon activity of the austenite in a way which impairs the solution treatment. Therefore, nickel is not a desirable alloy element in this respect and the nickel content is limited according to the invention to not more than 2%, preferably not more than 0.5%. Suitably the steel ought to contain nickel only in amounts, which are normal for unavoidable accessory elements.

Molybdenum improves the resistance to tempering-back of the steel by delaying the coarsening of the vanadium carbides during an over-ageing. Also, molybdenum results in substantial increases in the hot yield strength, partly due to a solution hardening contribution. Consequently, molybdenum ought to be used in an amount not less than 1%. The effect of molybdenum increases, when the amount increases up to about 4%, where a saturation tendency appears. Therefore, molybdenum should be used in an amount of between 1 and 4%, with an optimal content in the range 2-3%.

Since tungsten and molybdenum are very similar, even if the atomic weight of tungsten is twice as large as that of molybdenum, it is reasonable to expect, that similar effects can be obtained with a tungsten addition, in an amount which is twice as large, expressed in weight-percentage. Consequently, it may be possible to replace, fully or partially, molybdenum with tungsten in an amount, which is twice as large, expressed in weight-percentage. However, for production-technical, scrap handling-technical and consequently also economical reasons, molybdenum should not be replaced by tungsten at all in the steel, and therefore, the preferred composition of the steel contains tungsten only at impurity levels.

Vanadium is the main ingredient in the precipitation hardened phase vanadium carbide (MC). Consequently, this substance is a key element according to the invention and when the present carbon contents are used, at least about 1.2% vanadium is required in order to obtain a reasonably efficient hardening effect. However, too high a vanadium content impairs the necessary solution of the vanadium carbide during the solution treatment, and therefore, the steel should not contain more than 1.8% vanadium. The optimal vanadium content is found in the range 1.3-1.7%.

As has been mentioned above a good hot ductility/toughness is of primary importance for tool applications of interest. The weak link of the microstructure as regards the ductility/toughness of a precipitation hardened, austenitic steel of this type is the strength (cohesion) of the austenite grain boundaries. The grain boundaries are usually weaker than the interior of the grains and consequently, the ruptures tend to follow the grain boundaries, resulting in a low ductility/toughness. This situation primarily depends on the precipitation of unfavorable grain boundary carbides (e.g.  $M_{23}C_6$ , in which M is Cr, Mo, Mn and Fe) during the ageing, in combination with the desirable finely dispersed intragranular vanadium carbide. These grain boundary carbides make the grain boundaries brittle by lowering their cohesion.

In this connection boron is of crucial importance as a microalloy ingredient. When boron is added, it will end up mainly in the austenite grain boundaries thanks to its very low solubility in the steel. In this way boron dramatically alters the conditions in the grain boundaries and then also the conditions for a precipitation of grain boundary carbides. In this type of steel boron additions apparently lower the amount of obtained grain boundary carbides as well as their capacity to make the steel brittle in a way, which is very important to the hot ductility/toughness (a doubling of the coefficient of cross-sectional contraction in a tensile testing machine at 700 °C). Very small boron additions (a few thousandths of a percent) are sufficient to "fill" the grain boundaries of the steel and then principally result in a sufficient effect. Therefore, the steel according to the invention shall contain at least 0.001% boron, but in order to obtain the desired effect without doubt the amount of boron ought to be at least 0.003%. However, too high amounts of boron may result in easily fusible boride phases, which is disadvantageous as regards the processing (forging/milling) of the steel. Thus, the amount of boron ought to be not more than 0.020%, preferably not more than 0.015%.

#### EXPERIMENTS - PREFERRED COMPOSITION

A few 50 kg laboratory charges were made, steels No. 1-5 in Table 1. Preliminary laboratory tests indicated, that the best combination of features was obtained with steels No. 2, 4 and 5. Starting from these results a 6 ton production charge was made, having the nominal composition (remainder iron and impurities in normal amounts):

| C    | Si  | Mn   | Cr  | Mo  | V   | B     |
|------|-----|------|-----|-----|-----|-------|
| 0.45 | 0.5 | 12.0 | 5.0 | 2.5 | 1.5 | 0.009 |

The true composition is shown in Table 1, steel No. 6.

Table 1

The chemical composition (percent by weight) of the produced steels, the remainder mainly being iron

**Steel**

| No. | C   | Si   | Mn   | P    | S    | Cr   | Ni  | Mo   | V    | Cu  | N    | B    |
|-----|-----|------|------|------|------|------|-----|------|------|-----|------|------|
| 1   | .44 | .46  | 9.6  | .007 | .007 | 5.54 | 6.0 | 2.55 | 1.49 | .03 | .022 | .008 |
| 2   | .45 | .51  | 11.1 | .008 | .006 | 5.68 | .04 | 2.55 | 1.35 | .03 | .022 | .008 |
| 3   | .45 | 1.00 | 15.8 | .010 | .007 | 11.3 | .07 | 2.03 | 1.65 | .02 | .025 | .009 |
| 4   | .44 | .049 | 12.5 | .008 | .006 | 5.59 | .04 | 2.50 | 1.51 | .02 | n.a. | .009 |
| 5   | .44 | .45  | 12.3 | .008 | .006 | 5.46 | .04 | 2.60 | 1.75 | .02 | n.a. | .009 |
| 6   | .45 | .52  | 11.8 | .017 | .008 | 5.14 | .17 | 2.45 | 1.50 | -   | .047 | .008 |

Castings made of steel No. 6 were forged and milled under conditions similar to production conditions, the results being excellent, to various rod dimensions of between 30 mm  $\varnothing$  and 150 mm  $\varnothing$ . This shows clearly that this steel can be made using conventional steel production methods within a dimensional area, which is suitable for the intended use.

Laboratory tests (microstructure examinations, strength tests, hot drawing tests and impact strength tests respectively) on forged rods gave the following typical results:

**Solution treated condition, 1150°C-1h-water**

Hardness: 240 HB

Microstructure: Austenite with a certain amount of not dissolved carbides of MC-type.

**Aged condition, 700°C-12h-air**

Hardness: 45 HRC

Microstructure: The same as above plus a minor grain boundary carbide precipitation and a very finely dispersed precipitation of intragranular vanadium carbide (MC).

Impact strength : 12 joule at ambient temperature

(Charpy V): 25 joule at 700 °C

High temperature strength at 700 °C:

| R <sub>p0.2</sub> (MPa) | R <sub>m</sub> (MPa) | A <sub>5</sub> (%) | Z (%) |
|-------------------------|----------------------|--------------------|-------|
| 660                     | 740                  | 8                  | 37    |

As a comparison it should be mentioned that the martensitic hot work steel AISI H13 and the superalloys A286 and René 41, respectively, are able to give roughly the following hot yield strength values (R<sub>p0.2</sub>) at 700 °C: 150 MPa, 550 MPa and 850 MPa, respectively.

Thus, the obtained results show that the steel according to the invention has a very attractive combination of high temperature strength, resistance to tempering-back and hot ductility (toughness).

Two field tests were conducted, in which the steel was tested as a tool material for mandrels (60mm  $\varnothing$  x 200 mm) for hot extrusion of tube bends made of brass. Such mandrels involve a difficult material-technical problem, since they are subjected to a large mechanical load as well as to high temperatures, due to extended contact times with the hot brass materials, which are extruded. The life of the mandrels, which is quite limited, since they sooner or later will be deformed plasticly (be bent), is in this respect a critical production factor during the hot extrusion. Thus, the application is very typical of what the steel is designed to be used for. In one of the tests a comparatively easily extruded brass alloy (CuZn40Pb2) was used and in the other test a more difficultly extruded alloy (CuZn36Pb2As). Normally the martensitic hot work steel AISI H13 is used for the mandrels referred to. In addition to the new steel material according to the invention an additional martensitic hot work steel AISI H19 was tested, which has a more elevated high temperature strength than H13 and for this reason often is used in applications of the present type, as well as the two superalloys A 286 and René 41.

The following results were obtained:

| With CuZn40Pb2, blank temperature about 700°C |                |                                |
|-----------------------------------------------|----------------|--------------------------------|
| Mandrel material                              | Hardness (HRC) | Mandrel life (number of shots) |
| AISI H13                                      | 47             | 650                            |
| AISI H19                                      | 48             | 1050                           |
| A 286                                         | 35             | 425                            |
| The steel acc. to the invention               | 44             | 2900                           |

| With CuZn36Pb2As, blank temperature about 775°C |                |                                |
|-------------------------------------------------|----------------|--------------------------------|
| Mandrel material                                | Hardness (HRC) | Mandrel life (number of shots) |
| AISI H 13                                       | 47             | 200                            |
| René 41                                         | 41.5           | 200                            |
| The steel acc. to the invention                 | 44             | 1700                           |

The results show that the steel according to the present invention results in very satisfactory performances in these preliminary field tests within a typical area of application. It is true that additional field tests are required, before more general conclusions can be drawn, but the results show, that the steel has a potential, which enables it to strongly surpass martensitic hot work steels and also to directly compete with established superalloys.

## Claims

1. A precipitation hardenable, austenitic hot work steel having a high hot yield strength, a good resistance to tempering, and a good hot ductility (toughness) at temperatures of about 700 °C, **characterized** in that it has the following composition, expressed in percent by weight:

0.35 - 0.60 C

max. 1 Si

9 - 17 Mn

2 - 8 Cr

max. 2 Ni

1 - 4 Mo, which fully or partly can be replaced by double the amount of W (% by weight)

1.2 - 1.8 V

0.001 - 0.020 B

the remainder iron and impurities in normal amounts.

2. A steel according to claim 1, **characterized** in that it contains 0.4 - 0.5 C.
3. A steel according to claim 1, **characterized** in that it contains 10 - 15 Mn.

4. A steel according to claim 3, **characterized** in that it contains 10.5 - 13 Mn.
5. A steel according to claim 1, **characterized** in that it contains 3- 7 Cr, preferably 4 - 6 Cr.
- 5 6. A steel according to claim 1, **characterized** in that it contains 2 - 3 Mo.
7. A steel according to claim 1, **characterized** in that it contains 1.3 - 1.7 V.
8. A steel according to claim 1, **characterized** in that it contains 0.003 - 0.015 B.
- 10 9. A steel according to any of claims 1-8, **characterized** in that it has the following chemical composition:  
0.42 - 0.48 C  
0.1 - 0.8 Si  
11.6 - 12.4 Mn  
15 4.5 - 5.5 Cr  
max 0.5 Ni  
2.2 - 2.8 Mo  
1.2 - 1.6 V  
0.003 - 0.015 B  
20 the remainder iron and impurities.
10. A method of treating a steel having the following chemical composition, expressed in percent by weight:  
0.35 - 0.60 C  
25 max. 1 Si  
9 - 17 Mn  
2 - 8 Cr  
max. 2 Ni  
1 - 4 Mo, which fully or partly can be replaced by double the W-amount (% by weight)  
30 1.2 - 1.8 V  
0.001 - 0.020 B  
the remainder iron and impurities in normal amounts, and manufacturing tools of this steel, **characterized** in that the steel is forged and/or hot-milled to rods or blocks, the boron contents of the steel preferably existing in the austenite grain boundaries, in which the presence of boron counteracts the precipitation of grain boundary carbides not favorable to the ductility, in that the forged and/or hot-milled steel is solution treated in the temperature range 1100 - 1200 °C and is cooled to ambient temperature, the steel retaining an austenitic matrix and obtaining a hardness of max. 30 HRC, in that of this solution treated steel, tools are made to at least a nearly finished condition through cutting shaping, and in that said tools are age-treated in the temperature range 650 - 750 °C, a very finely dispersed and temperature-resistant, intragranular precipitation of vanadium carbide (MC) in the still austenitic matrix being obtained and a hardness increase to more than 40 HRC due to the precipitation hardening.

#### Patentansprüche

- 45 1. Aushärtbarer, austenitischer Warmarbeitsstahl, der eine hohe Warmstreckfestigkeit, eine gute Beständigkeit gegen Anlassen und eine gute Warmdehnbarkeit (Zähigkeit) bei Temperaturen von etwa 700 °C aufweist, dadurch gekennzeichnet, daß er die folgende Zusammensetzung, ausgedrückt in Gew.-%, aufweist:  
50 0,35 - 0,60 C  
max. 1 Si  
9 - 17 Mn  
2 - 8 Cr  
max. 2 Ni  
55 1 - 4 Mo, das ganz oder teilweise gegen die doppelte Menge an W (Gew.-%) ausgetauscht sein kann  
1,2 - 1,8 V  
0,001 - 0,020 B  
der Rest Eisen und Verunreinigungen in normalen Mengen.

2. Stahl gemäß Anspruch 1, dadurch gekennzeichnet, daß er 0,4 - 0,5 C enthält.
3. Stahl gemäß Anspruch 1, dadurch gekennzeichnet, daß er 10 - 15 Mn enthält.
- 5 4. Stahl gemäß Anspruch 3, dadurch gekennzeichnet, daß er 10,5 - 13 Mn enthält.
5. Stahl gemäß Anspruch 1, dadurch gekennzeichnet, daß er 3 - 7 Cr, vorzugsweise 4 - 6 Cr, enthält.
6. Stahl gemäß Anspruch 1, dadurch gekennzeichnet, daß er 2 - 3 Mo enthält.
- 10 7. Stahl gemäß Anspruch 1, dadurch gekennzeichnet, daß er 1,3 - 1,7 V enthält.
8. Stahl gemäß Anspruch 1, dadurch gekennzeichnet, daß er 0,003 - 0,015 B enthält.
- 15 9. Stahl gemäß einem der Ansprüche 1 - 8, dadurch gekennzeichnet, daß er die folgende chemische Zusammensetzung aufweist:  
0,42 - 0,48 C  
0,1 - 0,8 Si  
11,6 - 12,4 Mn  
20 4,5 - 5,5 Cr  
max. 0,5 Ni  
2,2 - 2,8 Mo  
1,2 - 1,6 V  
0,003 - 0,015 B  
25 der Rest Eisen und Verunreinigungen.
10. Verfahren zur Behandlung eines Stahls, der die folgende chemische Zusammensetzung, ausgedrückt in Gew.-%, aufweist:  
0,35 - 0,60 C  
30 max. 1 Si  
9 - 17 Mn  
2 - 8 Cr  
max. 2 Ni  
1 - 4 Mo, das ganz oder teilweise gegen die doppelte W-Menge (Gew.-%) ausgetauscht sein kann  
35 1,2 - 1,8 V  
0,001 - 0,020 B  
der Rest Eisen und Verunreinigungen in normalen Mengen, und zur Herstellung von Werkzeugen aus diesem Stahl, dadurch gekennzeichnet, daß der Stahl zu Stäben oder Blöcken geschmiedet und/oder warm gewalzt wird, wobei der Borgehalt des Stahls vorzugsweise in den Austenit-Korngrenzen vor-  
40 kommt, in denen die Gegenwart von Bor der Ausscheidung von für die Dehnbarkeit ungünstigen Korngrenzen-Carbiden entgegenwirkt, daß der geschmiedete und/oder warm gewalzte Stahl im Temperaturbereich 1100 - 1200 °C lösungsbehandelt und auf Umgebungstemperatur abgegekühlt wird, wobei der Stahl eine austenitische Matrix behält und eine Härte von max. 30 HRC erhält, daß aus diesem lösungsbehandelten Stahl durch Schneidformung Werkzeuge in einem mindestens nahezu fertigen  
45 Zustand hergestellt werden und daß die Werkzeuge im Temperaturbereich 650 - 750 °C vergütungsbehandelt werden, wobei eine sehr fein dispergierte und temperaturbeständige, intragranulare Ausscheidung von Vanadiumcarbid (MC) in der noch immer austenitischen Matrix erhalten wird und eine Härte wegen der Aushärtung auf mehr als 40 HRC zunimmt.

## 50 Revendications

1. Acier austénitique pour travail à chaud durcissable par précipitation présentant une limite d'élasticité à chaud élevée, une bonne résistance au revenu, et une ductilité (résilience) à chaud satisfaisante à des températures de 700 °C environ, caractérisé en ce que la composition de l'acier est la suivante,  
55 exprimée en pourcentage en poids :  
C : 0,35 à 0,60  
Si : 1 au maximum  
Mn : 9 à 17



- Cr : 2 à 8  
 Ni : 2 au maximum  
 Mo : 1 à 4, pouvant être remplacé en partie ou en totalité par le double de la quantité en W (% en poids)  
 5 V : 1,2 à 1,8  
 B : 0,001 à 0,020  
 la quantité complémentaire consistant en du fer et des impuretés en quantités normales.
2. Acier selon la revendication 1, caractérisé en ce qu'il renferme de 0,4 à 0,5 % de C.
- 10 3. Acier selon la revendication 1, caractérisé en ce qu'il renferme de 10 à 15 % de Mn.
4. Acier selon la revendication 3, caractérisé en ce qu'il renferme de 10,5 à 13 % de Mn.
- 15 5. Acier selon la revendication 1, caractérisé en ce qu'il renferme de 3 à 7 % de Cr, de préférence de 4 à 6 %.
6. Acier selon la revendication 1, caractérisé en ce qu'il renferme de 2 à 3 % de Mo.
- 20 7. Acier selon la revendication 1, caractérisé en ce qu'il renferme de 1,3 à 1,7 % de V.
8. Acier selon la revendication 1, caractérisé en ce qu'il renferme de 0,003 à 0,015 de B.
9. Acier selon l'une quelconque des revendications 1 à 8, caractérisé en ce qu'il a la composition chimique suivante :  
 25 C : 0,42 à 0,48  
 Si : 0,1 à 0,8  
 Mn : 11,6 à 12,4  
 Cr : 4,5 à 5,5  
 30 Ni : 0,5 au maximum  
 Mo : 2,2 à 2,8  
 V : 1,2 à 1,6  
 B : 0,003 à 0,015  
 la quantité complémentaire consistant en du fer et des impuretés.
- 35 10. Procédé de traitement d'un acier ayant la composition chimique suivante, exprimée en pourcentage en poids :  
 C : 0,35 à 0,60  
 Si : 1 au maximum  
 40 Mn : 9 à 17  
 Cr : 2 à 8  
 Ni : 2 au maximum  
 Mo : 1 à 4, pouvant être remplacé en partie ou en totalité par le double de la quantité en W (% en poids)  
 45 V : 1,2 à 1,8  
 B : 0,001 à 0,020  
 la quantité complémentaire consistant en du fer et des impuretés en quantités normales, et procédé de fabrication d'outils en cet acier, caractérisé en ce que l'acier est forgé et/ou laminé à chaud en des barres ou blocs, la teneur en bore de l'acier se trouvant, de préférence, à la périphérie des grains d'austénite, où la présence de bore contrecarre la précipitation des carbures à la périphérie des grains non favorables à la ductilité, en ce que l'acier forgé et/ou laminé à chaud est traité par solution dans la plage de températures de 1100 °C à 1200 °C et est refroidi à température ambiante, l'acier demeurant une matrice austénitique et obtenant une dureté de 30 HRC au maximum, en ce qu'à partir de cet acier traité par solution sont fabriqués des outils jusqu'à une condition d'achèvement presque complet par façonnage par découpe, et en ce que lesdits outils subissent un traitement de vieillissement dans la plage de températures de 650 °C à 750 °C, une précipitation intragranulaire de carbure de vanadium (MC), très finement dispersée et résistante à haute température, étant obtenue dans la matrice encore austénitique ainsi qu'une augmentation de dureté jusqu'à plus de 40 HRC en raison du durcissement

par précipitation.

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