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## (54) Powder metallurgy tool steel.

(57) A new composition for powder-metallurgy (PM) tool steel, characterized by the absence of Co, reduction of W content and increase in Mo and V contents id disclosed. The steel contains (wt%) , C from 1,50 to 1.85, Mn from 0,20 to 0.55, Si from 0.35 to 0.70, W from 1.50 to 3.00, Mo from 8.00 to 9.50, V from 5.50 to 6.50, and Cr from 3-00 to 5.00, the remainder being iron and minor impurities.
The powder used in the manufacturing process is obtained by atomization in a gas which may be nitrogen or argon, the ensuing particles being spherical in shape, 80% of them being smaller than 500 μm.
The manufacturing process comprises the following steps :
cooling during powder solidification at a rate between 1000 and 10000°C/s
hot isostatic pressing to obtain a semifinished piece
transformation of the semi into the desired product
heating of the product in a salt-bath at a temperature between 1160 and 1200°C for between 3 and 10 minutes
hardening in a salt-bath at a temperature between 450 and 600°C followed by cooling to room temperature
series of three successive temperings at temperatures between 530 and 560°C, between 540 and 570°C, and again between 530 and 560°C, each for between one and two hours.
The tool steel, obtained in this way, contains precipited carbides of the M2C-MC type measuring less than 3.5μm and a volume fraction between 13 and 18%.

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The present invention concerns PM. More precisely it concerns a composition designed specifically for Hot Isostatic Pressing (HIP) capable of furnishing finished products with very good service behaviour.

Metal cutting tools (hobs, cutters, millers, etc.) are subject to very difficult working conditions so they require very good hardness, wear resistance, cutting capacity, thermal shock resistance, toughness, etc,; some of these qualities are actually in contrast with one another and are not easily attained.

The main types of high-speed steels come under two headings

– tungsten steels, containing from 10 to 20% tungsten, from 5 to 15% cobalt, smaller quantities of chromium and vanadium, and from 0.7 to 1.5% carbon

– molybdenum steels, containing from 3 to 10% molybdenum, up to 8% tungsten, up to 12% cobalt, from 2 to 5% chromium, from 1 to 4% vanadium and from 0.8 to 1.5% carbon.

In tool steels the main functions of the alloy elements are to increase hardenability, form hard wear-resistant carbides, and maintain hardness during tempering or anyway during heating to high temperatures.

Solidification, cooling and more generally treatment conditions help produce the desired characteristics in the steel by exerting an influence on carbide type and size, morphology and extent of segregation, and microstructure.

The introduction of powder metallurgy has led to relatively easy mastery of segregation and microstructural phenomena, but never the less there remain numerous difficult-to-control aspects which have a bearing on finished-product quality.

Furthermore, modern ultra-high-speed machining practices require tools of extremely high quality, and there is a big loss of production every time work is stopped to change a tool.

Hence the search for improvements in tool quality continues unabated. So far progress has been achieved by employing larger quantities of costly alloy elements such as cobalt and tungsten.

The object of the present invention is to provide a better quality PM tool steel which ensures a considerably longer tool life.

Another object is to improve the productivity of the machines on which the ensuing tools are used.

A further object of the invention is to eliminate or at least limit the use of costly, strategic elements, thus lowering the price of the tools made from the steel concerned.

According to the present invention, a molten steel having the following composition (%wt): C from 1,50 to 1.85%, Mn from 0.20 to 0.55%, Si from 0,35 to 0.70%, W from 1.50 to 3.00%, Mo from 8.00 to 9.50%, V from 5.50 to 6.50%, Cr from 4.00 to 5,00%, the remainder being iron and impurities, is atomized in an inert gas (nitrogen or argon) to obtain a powder whose grain-size distribution includes at least 80% (by wt) of particles finer than 500 um.

During atomization the powder cooling rate is between 1000 and 10000°C/s. This results in a powder of excellent chemical uniformity, containing very fine carbide precipitates, which are useful during subsequent treatments, as will be explained below.

The powders thus obtained are subjected to Hot Isostatic Pressing to obtain semis such as round bars or more complex shapes which, in turn, can be worked to obtain the desired finished product. The latter is then heated in a salt-bath at a temperature between 1160 and 1200°C for 3 to 10 minutes, hardened in a salt-bath in the usual way at a temperature between 450 and 600°C and then cooled to ambient temperature. Finally the product is tempered three times in succession at temperatures between 530 and 560°C, then 540 and 570°C and again between 530 and 560°C; each of these treatment lasts for between one and two hours. The purpose of these thermal treatments is to solubilize and reprecipitate the carbides in the best possible way as regards composition, quantity and dimensions for the purpose of the invention. Since the carbides are already in very fine form in the atomized powders, they can be solubilized at relatively low temperatures in the 1160 to 1200°C range without there being any excessive grain growth. The carbides thus obtained are of the M2C-MC type; their maximum diameter is less than 3.5 um, typically being between 0.5 and 2.5 um, and they are present with a volume fraction between 13 and 18%.

The characteristics imparted to the tools by that treatment are usually in line with the highest values encountered in the best known tool steels used, even as regards properties that are antithetic or difficult to combine, such as hardness and toughness. It is precisely this general line-up at high values which renders the quality of these tool far superior to any yet known.

Three steels, CSM1, CSM2 and CSM3, have been prepared as per the present invention. Their compositions and those of three comparable steels already on the market, RIF1, RIF2 and RIF3, are compared in Table 1.

RIF1 and RIF2 represent the best tungsten and molybdenum ingot steels respectively, while RIF3 is the most widely used powder steel.

TABLE 1

| Steel | C | Mn | Si | W | Mo | V | Cr | Co |
|---|---|---|---|---|---|---|---|---|
| | Percent composition (by weight) | | | | | | | |
| CSM1 | 1.65 | 0.38 | 0.43 | 1.72 | 8.20 | 6.14 | 4.8 | - |
| CSM2 | 1.71 | 0.35 | 0,60 | 2.35 | 9.20 | 5.80 | 4.51 | - |
| CSM3 | 1.83 | 0.45 | 0.52 | 2.76 | 8.69 | 5.56 | 4.22 | - |
| RIF1 | 1.53 | nd | nd | 12.34 | - | 4.89 | 4.34 | 5.01 |
| RIF2 | 1.12 | nd | nd | 1.60 | 9.72 | 1.15 | 3.70 | 7.87 |
| RIF3 | 1.33 | nd | nd | 6.36 | 4.96 | 3.07 | 4.21 | 8.33 |

The characteristics of the precipitates, in terms of carbide type, diameter and volume fraction, are given in Table 2.

TABLE 2

| Steel | Volume Fraction (%) | Diameter (um) | Carbide type |
|---|---|---|---|
| CSM1 | 13.6 | 0.9-2.0 | M2C-MC |
| CSM2 | 16.8 | 1.3-2.3 | M2C-MC |
| CSM3 | 17.3 | 0.8-1.7 | M2C-MC |
| RIF1 | 14.3 | 14-16 | M6C-MC |
| RIF2 | 6.0 | 12-17 | M6C-(MC) |
| RIF3 | 13.0 | 4-7 | M6C-(MC,M2C) |

Table 3 reports hardness and wear resistance, Table 4 cutting capacity (Taylor Test), and Table 5 toughness and thermal shock resistance (HF=Heat-cracking Factor).

TABLE 3

| Steel | Hardness | | Wear |
|---|---|---|---|
| | at ambient temp.(RCH) | at 550°C (BH) | (Marcelin Test) |
| CSM1 | 67 | 682 | 7.4 |
| CSM2 | 69 | 710 | 5.9 |
| CSM3 | 66 | 685 | 7.7 |
| RIF1 | 67 | 642 | 5.1 |
| RIF2 | 68 | 722 | 17.7 |
| RIF3 | 66 | 680 | 21.3 |

The above hardnesses are Rockwell (RCH) at ambient temperature and Brinnell (BH) at 550°C. The Marcelin Wear Resistance Test is a technological test well known to esperts.

In the following table the cutting speeds V20, V40 and V60 in the Taylor Test indicate the cutting speeds in metres/minute to which the tool deteriorates in 20, 40 and 60 minutes, respectively.

TABLE 4

| Steel | Cutting Capacity | | (Taylor Test) |
|---|---|---|---|
| | V20 | V40 | V60 |
| CSM1 | 48.9 | 47.3 | 45.8 |
| CSM2 | 47.6 | 45.8 | 45.1 |
| CSM3 | 46.4 | 46.8 | 45.6 |
| RIF1 | 49.8 | 47.4 | 46.1 |
| RIF2 | 46.2 | 44.3 | 42.8 |
| RIF3 | 45.9 | 44.3 | 43.3 |

TABLE 5

Dynamic bending rupture strength and thermal shock resistance

| | Rupture strength (MPA) | | HF |
|---|---|---|---|
| | Longitudinal | Transversal | |
| CSM1 | 390 | 300 | 11.5 |
| CSM2 | 410 | 305 | 12.1 |
| CSM3 | 400 | 295 | 11.2 |
| RIF1 | 132 | 65 | 66.1 |
| RIF2 | 160 | 85 | 26.9 |
| RIF3 | 420 | 305 | 10.1 |

The rupture strengths, in MPA, given in the above Table are for test specimens cut longitudinally and transversally from the original bar.

The heat-cracking factor (HF) indicates the ability of the material to support rapid thermal cycles, as well as the rate at wich thermal fatigue cracks develop and propagate in said material. This factor is measured in the laboratory by means of a test designed by the proprietor of this invention, the method being as follows:

A test disc of the material concerned is made to rotate and heated by induction so that part of its surface on the maximum circumference is heated to about 800°C. At the same time, half of said circumference is cooled by water sprays so that during every revolution of the test specimen its surface is subjected to a thermal cycle between the heating temperature indicated and about 100°C.

Various test specimens of the same material are tested for 500, 1000, 2000 and 4000 revolutions. They are then ground and examined under the microscope to measure the number, length and penetration of the cracks formed during the test.

For each series of cycles a factor C is determined by the formula:

$$Cn = r \times Lm \times Pmax$$

where Cn is the factor C after n cycles; r corresponds to the measured crack density, assessed as the number of cracks per millimetre of length of the circumference of the test piece; Lm is the average length of the cracks, being the sum of the lengths of the cracks divided by their number and Pmax is the maximum depth of penetration of the cracks measured along the radius of the test piece.

The Heat-cracking Factor is then determined by the following formula:

$$HF = (D1 + D2 + D3 + D4):4$$

where D1 is $C_{500}$:500; D2, D3 and D4 are ($C_{1000}$-$C_{500}$):(1000-500), ($C_{2000}$-$C_{1000}$):(2000-1000) and ($C_{4000}$-$C_{2000}$):(4000-2000).As is evident from the preceding Tables, the steel according to the invention is in line - characteristic by characteristic - with the best products on the market, and it is the only one which maintains all its properties consistently high compared therewith. Precisely because of this singular feature of possessing excellent values simultaneously for all relevent characteristics, the steel as per this invention is found to be of an exceptionally high quality in practical applications that is not encountered in any other steel for the same applications.

Envelope-cutting hobs produced according to the present invention and tested over long periods on high-speed gear-making operations have increased line productivity by 400 to 500%. In particular, hobs with CSM1, CSM2 and CSM3 compositions have repeatedly resulted in the production of up to 12000 very hard quenched and tempered steel gears without requiring sharpening, while the average for RIF3 powder steel hobs is 4000 pieces, which is in itself better than the performance of conventional ingot steel hobs. Hence productivity is improved not only through an increase in the number of pieces produced with the same tool, but even more so through avoidance of tool-change stoppages, which are extremely costly in modern high-speed machining operations.

## Claims

**1)** Powder-metallurgy tool steel characterized by the following composition (%wt): C from 1,50 to 1.85, Mn from 0,20 to 0.55, Si from 0.35 to 0.70, W from 1.50 to 3.00, Mo from 8.00 to 9.50, V from 5.50 to 6.50, and Cr from 3-00 to 5.00, the remainder being iron and minor impurities.

**2)** Steel as per Claim 1 characterized by the fact that the powder is obtained by atomization in a gas which may be nitrogen or argon, the ensuing particles being spherical in shape, 80% of them being smaller than 500 um.

**3)** Steel as per Claim 2, characterized by the fact that after submission to the following cycle:

– cooling during powder solidification at a rate between 1000 and 10000°C/s

– hot isostatic pressing to obtain a semifinished piece

– transformation of the semi into the desired product

– heating of the product in a salt-bath at a temperature betwe en 1160 and 1200°C for between 3 and 10 minutes

– hardening in a salt-bath at a temperature between 450 and 600°C followed by cooling to room temperature

– series of three successive temperings at temperatures between 530 and 560°C, between 540 and 570°C, and again between 530 and 560°C, each for between one and two hours

it contains precipited carbides of the M2C-MC type measuring less than 3.5 um and a volume fraction between 13 and 18°%.

**4)** Steel as per Claim 3 characterized by the fact that the maximum dimension of said carbides is between 0.5 and 2.5 um.

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# EUROPEAN SEARCH REPORT

Application Number

EP 91 83 0235

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl.5) |
|---|---|---|---|
| A | EP-A-0 076 326 (FURUKAWA ELECTRIC CO., LTD) * Claims 1-5; page 8, lines 2-8 * --- | 1-3 | C 22 C 33/02 |
| A | US-A-4 880 461 (UCHIDA) * Claims 1-4 * --- | 1 | |
| A | US-A-4 276 087 (HASWELL et al.) * Clams 1-6 * & LU-A-82 061 --- | 1-3 | |
| A | US-A-4 249 945 (HASWELL et al.) * Claims 1-3 * & LU-A-81 268 --- | 1 | |
| A | US-A-3 117 863 (ROBERTS et al.) * Claims 1-12 * --- | 1-3 | |
| A | STAHL UND EISEN, vol. 110, no. 1, 15th January 1990, pages 93-103; S. WILMES: "Pulvermetallurgische Werkzeugstähle - Herstellung, Eigenschaften und Anwendung" * Complete article * ----- | 1-4 | |
| | | | **TECHNICAL FIELDS SEARCHED (Int. Cl.5)** |
| | | | C 22 C 33/02 |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 25-10-1991 | LIPPENS M.H. |

CATEGORY OF CITED DOCUMENTS

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