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# (54) STEEL FOR EXTRUSION TOOLS

(57) The present invention relates to a steel for extrusion tools characterized for lower cost and tempering resistance higher than that of conventional steel H13, whose chemical composition, in percentage by mass, comprises the following: Carbon between 0.40 and 0.60, Silicon below 1.0, Phosphorus below 0.030; Chromium between 2.5 and 4.5; Molybdenum between 0.5 and 0.7, considering that molybdenum can be replaced by tungsten in a ratio = 2W/1Mo; Vanadium between 0.10 and 1.0; Manganese below 1.0; the remainder consisting essentially of Fe and inevitable deleterious substances. As an option to provide high hardness after nitriding, the Al content of the steel of the present invention can bye ≤ 1.0; for high toughness purposes, however, this Al content should be kept below 0.10.

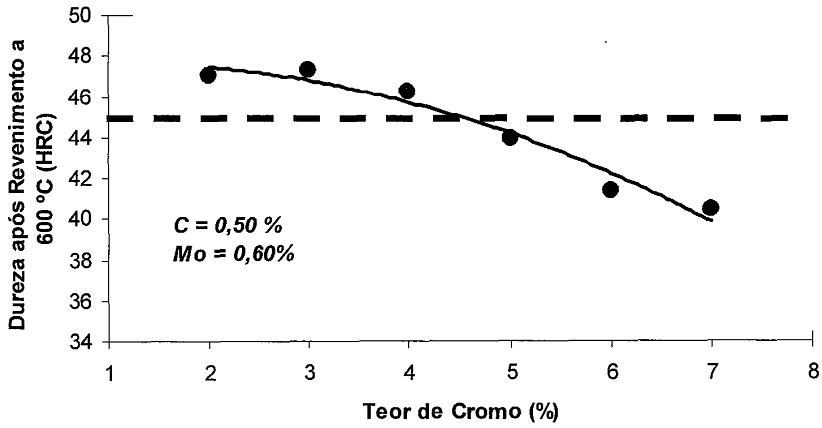

FIG. 1C

LEGEND: Hardness after tempering at 600°C (HRC)
Chrome content (%)

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## Description

**[0001]** The present invention relates to a steel intended for use in various hot form tools and dies, particularly for extrusion of aluminum alloys or other non-ferrous metals. Although initially designed for extrusion processes, the material can also be employed in other hot forming processes, in which the metal to be formed withstands temperatures above 600 °C, although the said steel can be employed in processes at lower temperatures or even at ambient temperature. The composition of the steel in question allows it to be classified as hot work tool steel, whose primary characteristic the lower content of high-cost alloying elements, such as molybdenum and vanadium, but with tempering resistance (or resistance to loss of hardness) greater than that of conventional steels of prior art concept. An additional alternative to the steel of the present invention is provided to increase hardness after nitriding, and may result in performance levels even greater than those of conventional steels, at the same time that the cost is kept low due to a simpler chemical composition. Such an effect is possible by carefully designing the alloy, and setting the optimum ranges of the elements: carbon, chromium, molybdenum and aluminum.

**[0002]** The term hot work tools is applied to a large number of hot-forming operations, employed in industries and focused on the production of parts for mechanical applications, especially automotive parts. The most popular hot-forming processes are forging of steel, and the extrusion or casting of non-ferrous alloys. Other applications performed at high temperature, typically above 500/600°C, can also be classified as hot work. In these applications, molds, dies, punches, inserts and other forming devices are classified by the generic term: hot work tools. These tools are usually made of steels, which require special properties to withstand high temperatures and the mechanical efforts of the processes in which those tools are employed.

**[0003]** Among their key properties of hot work steels, the following stand out: resistance after high temperature tempering, the resistance to the loss of hardness called tempering resistance, the toughness, the hardenability and physical properties such as thermal conductivity and specific heat.

**[0004]** The extrusion dies used for non-ferrous alloys, especially aluminum alloys are main hot work target for applying the steel of the present invention. These typical dies comprise an important segment of the tool steel market both in Brazil and abroad. In this application, the steels are very standardized, based on steels such as ABNT H13 (see Table 1), with quality requirements not as strict as those of other applications, e.g., pressure die casting, but with emphasis on lower production costs.

**[0005]** The increased cost of metal alloys, especially Mo and V, significantly impaired this segment, making it eager for low-cost alternatives. Low-alloy steels have been employed, such as DIN 1.2714 (chemical composition given in Table 1). However, their low wear resistance due to reduced hot strength and lower postnitriding hardness prevents them from being applied.

**[0006]** Recent developments, such as US 2009/0191086, were focused on the reduction of alloying elements, by means of reduced Cr, Mo and V content. However, negative effects are produced by reducing the Cr content. First, the alloys' composition is not sufficient to achieve high hardness after tempering (at least 45 HRC after tempering at 600°C). Second, a reduced Cr content can also generate lower hardness after nitriding, which is not suitable for extrusion applications, considering the apparent gain produced by nitridation in these applications (virtually all extrusion dies are currently nitrified).

**Table 1:** Typical chemical composition of steels of prior art concept. The sum Mo + V + Co is shown because these elements have the highest cost, and are closely related to the final cost of the tool steel. Content in percentage by mass and Fe balance. For all extrusion applications the W content is low, usually < 0.1 %.

| Designation | C | Si | Mn | Ni | P | Cr | Mo | V | Al |
|---|---|---|---|---|---|---|---|---|---|
| H13 | 0.38 | 1.0 | 0.3 | 0.3 | 0.025 | 5.0 | 1.2 | 1.0 | <0.05 |
| DIN 1.2714 | 0.56 | 0.3 | 0.7 | 1.7 | 0.025 | 1.1 | 0.5 | 0.1 | <0.05 |
| US 2009/0191086 | 0.38 | 0.5 | 1.3 | 0.3 | 0.009 | 2.4 | 0.6 | 0.5 | <0.05 or 0.53 |

**[0007]** A third problem of invention US 2009/0191086 relates to the hardness of the die core, which may be lower due to decreased hardenability as a result of reduced Cr and Mo contents. To avoid this, the alloys of invention US 2009/0191086 have higher Mn content, which lead to higher hardenability, potential segregation problems (banding) and excessive austenite retention. Both effects may impair the final hardness and toughness and, thus, the tool life. A final aspect can also be mentioned, with regard to the high Mn content: Scrap from this steel can hardly be incorporated into the production of conventional, low-Mn-content hot work steels.

**[0008]** Given all these drawbacks, invention US 2009/0191086 is considered by the authors as a cost-reducing solution, but with inferior properties. In the text of the patent, the authors quantify the expected efficiency loss, of about 20 to 30% lower than that of steel H13. Considering the machining and heat treatment costs associated with dies, this efficiency loss can be considered quite significant, thus requiring a reduction of the cost of the material by more than 30% to compensate the substitution. For example, considering that only 60% of the final die cost is associated with the tool steel used, a 30% lower life can only be viable if the cost of the new material is half the cost of the conventional material. From 2005 to 2008, when the cost of raw materials peaked, this could be true (though still difficult to occur, because the cost difference required is too high). However, for the current scenario, such cost reduction can hardly be achieved for steel H13, considering only the reduction of the Mo and Cr contents. Thus, reduction in cost associated with efficiency loss of the alloy of patent US 2009/0191086 can be currently considered impractical for such application.

**[0009]** Given this scenario, it is evident the need for a tool steel which effectively has a positive effect on tool life by means of an equivalent performance, but at a cost lower than that of steel H13. This is only possible if the steel in question has tempering resistance and hardness after tempering at 600°C (typical heat treatment condition) equivalent to those of steel H13, but with lower content of alloying elements and suitable hardness after nitriding. In addition, the material used must have high hardenability, but free of problems associated with high Mn content, thus allowing it to be applied to tools larger than extrusion dies.

**[0010]** Therefore, the steel of the present invention will fulfill all these needs.

**[0011]** To achieve the cost reduction/zero quality loss goal, the effect of the key elements related to hot strength, Cr and Mo, was studied separately. Apart from significant findings, this study also showed that the variation of the content of these elements is not sufficient to promote the hot strength required. Thus, the C content could be increased up to levels that did not impact toughness, especially whit the accompaniment of low P and Si contents. Finally, the Al effect was used to compensate for the reduction of Cr, hence, a potential lower hardness after nitriding. This work also focused on this issue because the nitrified layer is critical to providing wear resistance to various hot forming tools, especially extrusion and hot forging tools.

**[0012]** Therefore, in order to satisfy the above conditions, the steel of the present invention has a composition of alloying elements, which, in percentage by mass consists of:

- 0.40 to 0.60 C, preferably 0.45 to 0.55 C, typically 0.50 C
- 2.5 to 4.5 Cr, preferably 3.0 to 4.2 Cr, typically 3.8 Cr
- 0.30 to 0.90 Mo, preferably 0.50 to 0.70 Mo, typically 0.60 Mo.

**[0013]** Given its chemical similarity to W, Mo can be replaced with W, 2W:1 Mo ratio by mass.

- 0.1 to 1.0 V, preferably 0.3 to 0.8 V, typically 0.4 V; V can be partially or fully replaced with Nb, following a 1 Nb:0.5 V ratio by mass.
- up to 1.0 Si, preferably up to 0.50 Si, typically 0.30 Si Max 1.0 Mn, preferably max 0.80 Mn, typically max 0.50 Mn.

**[0014]** As described below, Al can be added simultaneously to the alloys of the present invention to provide gains in terms of hardness after nitriding, but also negative effects in terms of toughness and complexity of the steel-making process. Thus, the Al content must be dosed as follows, in percentage by mass:

- Max 1.0 Al, preferably max 0.80 Al, typically max 0.60 Al. For compositions in which the effects of Al are not targeted, this element should be treated as residual impurity, limited to 0.10, typically < 0.05.

**[0015]** The compositions should be characterized by balance by Fe (iron) and metallic or non-metallic deleterious substances inevitable to the steelmaking process, in which said non-metallic deleterious substances include but are not limited to the following elements, in percentage by mass:

- Max 0.030 P, preferably max 0.015 P, typically max 0.010 P.
- Max 0.10 S, preferably max 0.030 S, typically max 0.008 S.
- Max 1.5 Ni or Co, preferably up to 1.0 Ni or Co, typically below 0.5 Ni and Co.

**[0016]** Next, we describe the ratios of the specification of the composition of the new material. The percentages listed refer to percent by mass.

**[0017]** C: Carbon is primarily responsible for martensite hardening under low temperature conditions. However, together with the alloying elements, carbon also plays a role in the secondary hardening, important for the hardening at high temperature. In these cases, the C content is more important for hardness at temperatures below 600 °C, when hardness still depends on the martensite hardness or formation of cementite or Cr carbides. Furthermore, carbon is an important hardenability-promoting element, and causes no increase in cost. It is also considered important to increase hardness to 45 HRC and up, carbon contents of at least 0.40% are recommended, preferably above 0.45%. On the other hand, very high C contents, cause excessive precipitation of grain-shaped carbides at the time of quenching (especially when Mo and V contents are high), as well as lead to increased hardness and volume of secondary carbides. Thus, toughness is generally impaired., the C content should be limited to a maximum value of 0.60%, preferably below 0.55%. This limitation also plays a role in the reduction of the amount of retained austenite, preventing problems associated with dimensional instability and embrittlement.

**[0018]** Cr: The chromium content should be higher than 2.5%, preferably greater than 3.0%, because this element favors hardenability, which is important for application in large tools. However, the Cr content should be limited. The present invention has incorporated the concept of reducing the Cr content to improve tempering resistance. The mechanisms of this effect are not fully understood but they may be related to the formation of secondary Cr carbides, $M_7C_3$-type, which dissolve Mo and V are the first carbides to be formed. Therefore, the lower the Cr content, the lower the amount of $M_7C_3$ carbides and, thus, the greater the amount of Mo and V available for the formation of fine carbides $M_2C$ and MC, which are also important for secondary hardening. The end result is a significantly higher tempering resistance in steels with lower Cr content, thus enabling the reduction of the Mo content when compared to steels of prior art concept.

**[0019]** Mo and W: low concentrations of Mo have been employed in the present invention not only for the purpose of cost reduction, but also to promote the highest secondary hardness and tempering resistance equivalent or even greater than that of steel H13 in association with Cr and C contents. To do so, the alloy of the present invention must contain at least 0.30%, preferably above 0.50%. On the other hand, an extremely high Mo content might harm toughness due to deposition of proeutectic carbides during the quenching phase and can increase significantly the alloy cost, in an opposite direction to the cost-reduction goal of the present invention. Hence, the Mo content should be limited to 0.90%, preferably below 0.70%. Tungsten and molybdenum produce similar effects in the tool steel of the present invention, forming $M_2C$ or $M_6C$ secondary carbides. Thus, they can be jointly specified through the tungsten equivalent relationship ($W_{eq}$) given by the sum W + 2Mo, which normalizes the differences in atomic weight between the two elements.

**[0020]** V: Vanadium is primarily important for the formation of MC secondary carbides. Because they are very thin, these carbides block the movement of dislocation lines, increasing mechanical strength. V also improves grain growth, allowing high austenitizing temperatures (above 1000°C). For such effects, V must be above 0.1%, preferably above 0.3%. However, excessively high V grades may generate primary, difficult-to-solubilize carbides, thus reducing toughness, and also promote significant increase of costs. Hence, the V content should be lower than 1.0%, preferably below 0.6%.

**[0021]** Si: silicon produces a strong effect on secondary hardening and toughness. When a low Si concentration is used, toughness improves due to a better distribution of secondary carbides. Therefore, the Si content of the material of the present invention must be lower than 1.0%, typically below 0.5%.

**[0022]** Mn: high Mn contents may be considered undesirable for promoting intense micro-segregation generating banding at different degrees of hardness, and for increasing the retained austenite content; therefore Mn is considered a deleterious element in the present invention. Thus, the Mn content should be limited to 1.0%, preferably below 0.8%, typically below 0.50%.

**[0023]** Al: to promote greater hardness of the nitrified layer, the alloys' Al content can be high. However, the Al content, under these conditions, should be limited to 1.0% because they lead to decreased toughness. Thus, Al contents between 0.40% and 0.60% may be of interest for this purpose. However, for applications in which the hardness of the nitrified layer is slightly lower than that of steel H13, but high toughness is required, the Al content of the alloy of the present invention can be < 0.1 %, typically below 0.05%.

**[0024]** Residual Elements: Other elements such as Ni and Co should be considered as deleterious substances associated with the steelmaking deoxidation processes or inherent to the manufacturing processes. Hence, the Ni and Co content should be limited to 1.5%, preferably below 1.0%. In terms of formation of inclusions, the sulfur content should be controlled, because such inclusions may lead to cracking during operation; therefore the S content should remain below 0.050%, preferably below 0.020%. Also, for high toughness purposes, embrittling elements such as P should be avoided, being desirable $P < 0.030\%$, preferably $P < 0.015\%$, typically $P < 0.010\%$. Indeed, a low Cr content also helps to reduce the P content in electric arc furnace steelmaking processes, thus leading to conclusions that are not contradictory to the cost reduction philosophy desired.

**[0025]** The alloy, as described above, can be produced as rolled or forged products through conventional or special processes such as powder metallurgy, spray forming or continuous casting, such as wire rods, bars, wires, sheets and strips.

**[0026]** The experiments carried out are described below, and reference is made to the following attached figures:

- Figure 1A shows the effect of the Mo content on hardness after tempering at 600 °C, while Figures 1B and 1C show the effect of the Cr content at 0.60% Mo on usual C contents (Figure 1 B) and higher C contents (Figure 1C); the horizontal dashed line of Figures 1A, 1B and 1C indicates the Minimum Hardness desirable for the application.
- Likewise Figure 1, Figures 2A, 2B and 2C show the effect of molybdenum (Fig. 2A) and chromium (Fig. 2B and Fig.

2C) on tempering resistance. The higher the hardness at high temperatures the greater the alloy's tempering resistance. In all cases, the alloys were first annealed at 600°C.

- Figures 3A and 3B show the CCT curve of the compositions of the present invention, considering two Cr contents. Quantitative hardenability results can be obtained from the number of formed phases (pearlite and bainite) and, most importantly, from the final hardness obtained per rate. The compositions are summarized in Table 1, base 3, considering Cr contents of 3% and 4% for comparison purposes. Figure 3A illustrates the CCT curve for a 0.50% C, 3.00% Cr composition, and Figure 3B shows the CCT curve for a 0.50% C, 4.00% Cr composition.
- Figure 4 shows the CCT curve of H13 steel of the prior art concept, whose data can be compared to the results of the steel of the present invention. The same data concerning number of phases and hardness shown in Figure 3 can be assessed for different cooling rates.
- In Figures 5A and 5B, the alloys with the final composition of the present invention, PI 1 to PI 3, are compared in terms of hardness after tempering (Fig. 5A) and loss in hardness vs. time (Fig. 5B) at 600°C (referred to in the tempering resistance text).
- Figure 6 compares the results of impact toughness tests conducted for two types of transverse test specimens: unnotched (7 mm x 10 mm section, as per NADCA) or Charpy V, with 10 mm x 10 mm section and V notch. All materials treated to hardness 45 HRC according to the parameters of Figure 5a.
- Figure 7 shows the hardness profile of the nitrified layer of alloys PI 1, PI 2 and PI 3 vs. steel H13. A plasma nitriding process was conducted for steel H13. Prior to nitriding, all sample alloys were quenched and tempered such to reach 45 HRC.

EXAMPLE 1: Effect of Molybdenum, Chromium and Carbon

**[0027]** For this work, samples of approximately 200 g were collected in an experimental VIM furnace with varied composition for the same heat. Therefore, three heats were produced by varying the Cr, Mo and C contents, as shown in Table 1 below (details: Annex 1). Steel H11 served as a base for these alloys since it already has half of V content. The materials were always characterized after special annealing (austenitizing at 1010°C, oil solubilization and over-annealing at 810°C). In this process we used annealing at 1020 °C and tempering between 400 and 650°C. Steel H13, of typical industrial composition, was used as a base.

**[0028]** Hardness after tempering at 600°C is shown in Figure 1, highlighting the effects of reduced Mo and Cr contents, and also the effect of higher C content. With regard to the Mo content, a lower Mo concentration results in lower hardness after tempering. However, if the Cr content drops, post-tempering hardness rises. A possibility is that a lower Cr content reduces the amount of $M_7C_3$ which, in turn, dissolves Mo. Thus, a higher content of free Mo should be present in alloys of lower Cr content, which explains a more intense response to tempering.

**[0029]** Despite this important Cr effect, just reducing its content is not sufficient to promote the required hardness (about 45 HRC). Possibly, the required hardness can be obtained by tempering at lower temperatures. However, this practice is sometimes not feasible for hot work because the ideal tempering temperature should be 50 to 80°C above the working temperature to provide proper tempering resistance. Thus, for hot work involving extruded and cast aluminum, the typical tempering temperature should be 600 °C.

**Table 1:** Chemical compositions adopted for samples from the same heat with variation of a single element. The asterisks used in the Cr and Mo fields of the table below indicate that several compositions using this base were produced for the same heat, increasing the content of this element, but keeping the base composition of the heat.

| | Base 1 | Base 2 | Base 3 | H13 |
|---|---|---|---|---|
| Variation of ... | Mo | Cr | C | - |
| C | 0.36 | 0.36 | 0.48 | 0.37 |
| Si | 0.32 | 0.32 | 0.32 | 0.92 |
| Mn | 0.26 | 0.28 | 0.27 | 0.31 |
| P | 0.007 | 0.006 | 0.006 | 0.022 |
| S | 0.001 | 0.002 | 0.001 | 0.001 |
| Co | 0.02 | 0.02 | 0.02 | 0.02 |
| Cr | 5.00 | ** | *** | 4.82 |
| Mo | * | 0.65 | 0.6 | 1.17 |
| Ni | 0.15 | 0.06 | 0.06 | 0.11 |

(continued)

| | Base 1 | Base 2 | Base 3 | H13 |
|---|---|---|---|---|
| V | 0.4 | 0.41 | 0.41 | 0.79 |
| W | 0.01 | 0.01 | 0.01 | 0.09 |
| Cu | 0.02 | 0.03 | 0.03 | 0.03 |
| Al | 0.013 | <0.005 | <0.005 | 0.02 |
| * Mo variation: 0.05; 0.30; 0.60; 0.90; 1.22; 1.51<br>** Cr variation, considering 0.36%C: 2.0; 3.0; 4.0; 5.1; 6.2; 7.1,<br>*** Cr variation, considering 0.48%C: 2.0; 3.0; 4.0; 5.1; 6.1; 7.0; | | | | |

**[0030]** Therefore, to increase hardness after tempering at 600 °C, we increased the C content. As shown in Figure 1, the result was effective and hardness even higher than those from H13 were obtained. In this case, the C effect is related to increased formation of secondary carbides and, when associated with a lower Cr content, it provides the hardness required to start the work, even in alloys of lower Mo content (half of steel H13). In alloys of higher C content, a similar Cr effect can be observed.

**[0031]** Besides hardness after tempering, loss of hardness is also a key factor to promote adequate response by the alloys in question to the high temperatures they are subjected to. The results shown in Figure 2 demonstrate the important Mo effect in this regard (Fig. 2a), and also that the reduction of the Cr content is also an interesting option to reduce the loss of hardness, which means re-plotting the curves to higher hardness levels (see Fig. 2b). In alloys with higher C content (Fig. 2c), this effect is even stronger. Thus, the low Cr/ high C combination seems interesting.

**[0032]** On the other hand, the Cr content cannot be too low, such that hardenability is not reduced. This effect was studied in the curves of Figure 3 and compared to steel H13 in Figure 4. Quantitatively, hardness reached after 0.3 and 0.1°C/s corresponds to steel H13 with 635 HV and 521 HV (Figure 4), whereas the 3% Cr alloy corresponds to 595 HV and 464 HV under the same conditions (Figure 3a). The scenario changes for the 4% Cr alloy, which reaches hardness ≥ H13, i.e., 696 HV and 523 HV for rates of 0.3 and 0.1 °C/s (Figure 3b). Therefore, Cr contents close to 4% Cr seem to be more interesting. Extremely below this value, i.e., 3%Cr or less, the volume of bainite and the hardness after tempering may prevent the application. Thus, a 3.8% Cr content was selected for all other tests, production of pilot-scale billets and evaluation of mechanical properties.

EXAMPLE 2: Effect of Al content

**[0033]** After defining an alloy target, four heats (50 kg cast billets, 140 mm average section) were produced and forged as plates (Table 2) with dimensions of 65mm x 165mm. The materials were then annealed following the same process described in Example 1 and their properties were evaluated as discussed below.

**[0034]** The results confirmed the initial results shown in Figures 1 and 2, as shown in Figure 5. Thus, the new alloys can reach similar results in terms of hardness at 600°C (Figure 5a), or even better, in terms of tempering resistance, if compared to steel H13 (Figure 5b).

**Table 2:** experimental 50 kg billets produced for the alloys of the present invention (PI) and steel H 13.

| | PI1 | PI2 | PI3 | H13 |
|---|---|---|---|---|
| C | 0.50 | 0.49 | 0.51 | 0.38 |
| Si | 0.32 | 0.31 | 0.32 | 0.99 |
| Mn | 0.35 | 0.35 | 0.35 | 0.35 |
| P | 0.011 | 0.011 | 0.011 | 0.023 |
| s | 0.003 | 0.003 | 0.004 | 0.004 |
| Co | 0.01 | 0.01 | 0.01 | 0.02 |
| Cr | 3.76 | 3.78 | 3.81 | 5.25 |
| Mo | 0.62 | 0.64 | 0.61 | 1.32 |
| Ni | 0.14 | 0.13 | 0.13 | 0.13 |

(continued)

| | PI1 | PI2 | PI3 | H13 |
|---|---|---|---|---|
| V | 0.40 | 0.39 | 0.40 | 0.85 |
| W | 0.01 | 0.01 | 0.01 | 0.02 |
| Cu | 0.05 | 0.05 | 0.05 | 0.05 |
| Al | 0.037 | 0.51 | 1.02 | 0.031 |

**[0035]** Another important point can be compared in Figure 6, in terms of toughness. The toughness of the alloy of the present invention, when bearing low Al contents, is equivalent to that of steel H13. This demonstrates that the low Si and P contents of alloy P11 compensate for the loss of toughness likely to occur as the C content increases in relation to steel H13. Figure 6 also shows that toughness is inversely proportional to the Al content.

**[0036]** Al contents are responsible for a significant increase of hardness after nitriding, as shown in Figure 7. Thus, for applications in which high hardness of the nitrified layer is considered more relevant than toughness (e.g., extrusion of solid shapes), alloy PI 2 becomes interesting for having toughness > 200J and extremely high hardness of the nitrified layer (almost 1400 HV). Alloy PI 3 does not show gains in terms of the nitrified layer, but toughness is far lower.

**[0037]** On the other hand, in applications highly susceptible to cracking, such as pipe extrusion dies, toughness can be considered a key property. For these cases, alloy PII seems more appropriate, also showing hardness after nitriding similar to that of steel H13, reaching more than 1000 HV on surface, which is the typical specification for extrusion tools. Furthermore, as previously shown in Figure 5, alloy PI 1 also presents improved hot strength properties.

**[0038]** Therefore, considering the properties required for hot work applications, the alloys of the present invention show results equivalent to or better than those of steel H13. Such results are quite relevant for non-ferrous alloy extrusion dies, e.g., Al alloys, or hot forging dies. Alloy PI 1 has improved tempering resistance, but hardness after nitriding and toughness equivalent to steel H13, while alloy PI 2 has lower toughness, but tempering resistance and hardness after nitriding significantly higher than steel H13. The alloy should be selected on the basis of the most critical properties required for the application. However, in all cases, significant cost reductions can be obtained due to the low Mo and V content of the alloys of the present invention.

## Claims

1. STEEL FOR EXTRUSION TOOLS, **characterized by** a composition of alloying elements consisting essentially of, in percent by mass: C between 0.40 and 0.60, Si below 1.0, P below 0.030, Cr between 2.5 and 4.5, Mo between 0.5 and 0.7, V between 0.10 and 1.0, Mn below 1.0, Al up to 1.0, being the remaining composed of Fe and inevitable deleterious substances.

2. STEEL FOR EXTRUSION TOOLS, **characterized by** a composition of alloying elements consisting essentially of, in percent by mass, C between 0.40 and 0.60, Si below 0.50, P below 0.030, Cr between 3.0 and 4.2, Mo between 0.55 and 0.65, V between 0.30 and 0.8, Mn below 0.8, Al up to 0.80, being the remaining composed of Fe and inevitable deleterious substances.

3. STEEL FOR EXTRUSION TOOLS, **characterized by** a composition of alloying elements consisting essentially of, in percent by mass, C between 0.45 and 0.55, Si below 0.5, P below 0.030, Cr between 3.5 and 4.2, Mo between 0.55 and 0.65, V between 0.30 and 0.50, Mn below 0.50, Al up to 0.60, being the remaining composed of Fe and inevitable deleterious substances.

4. STEEL FOR EXTRUSION TOOLS, according to any claims from 1 to 3, **characterized by** an Al content limited to 0.10, in percent by mass.

5. STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 3, **characterized by** Aluminum content ≤ 0.05, in percent by mass.

6. STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 5, **characterized by** Cobalt and Nickel content < 1.0, in percent by mass.

7. STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 6, **characterized by** Phosphorus and Sulfur

content < 0.030, in percent by mass.

**8.** STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 7, **characterized by** Phosphorus content < 0.010, in percent by mass.

**9.** STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 8, **characterized by** the existence of Mo replaced with W, in a ratio in which 1 Mo = 2W.

**10.** STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 9, **characterized by** the existence of V replaced with Nb or Ti in a ratio in which 1V = 2Nbor1Ti.

**11.** STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to10, characterized for being used after quenching and tempering for hardness between 30 and 60 HRC, followed by nitriding heat treatment, to obtain surface hardness between 800 and 1500 HV to a maximum thickness of 0.50mm.

**12.** STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 11, **characterized by** being applied in molds, dies and general usage tools, for forming solid and liquid materials, at room temperature or at temperatures up to 1300°C.

**13.** STEEL FOR EXTRUSION TOOLS, according to any of claims from 1 to 11, **characterized by** being applied to tools for forming metals at temperatures between 300 and 1300°C, in applications of forging, extrusion or casting of ferrous or non-ferrous alloys.

**14.** STEEL FOR EXTRUSION TOOL, according to any of claims from 1 to 11, **characterized by** being applied to non-ferrous alloy hot extrusion tools, particularly aluminum alloys, and to solid shape or pipe extrusion dies.

**15.** STEEL FOR EXTRUSION TOOL, according to any of claims from 1 to 14, **characterized by** being produced for processes involving casting of billets and hot and cold forming, or even used with the gross structure of melting.

**16.** STEEL FOR EXTRUSION TOOL, according to any of claims from 1 to 14, **characterized by** being produced for processes involving fragmentation of liquid metal, such as powder metallurgy, powder injection or the process of forming by spray.

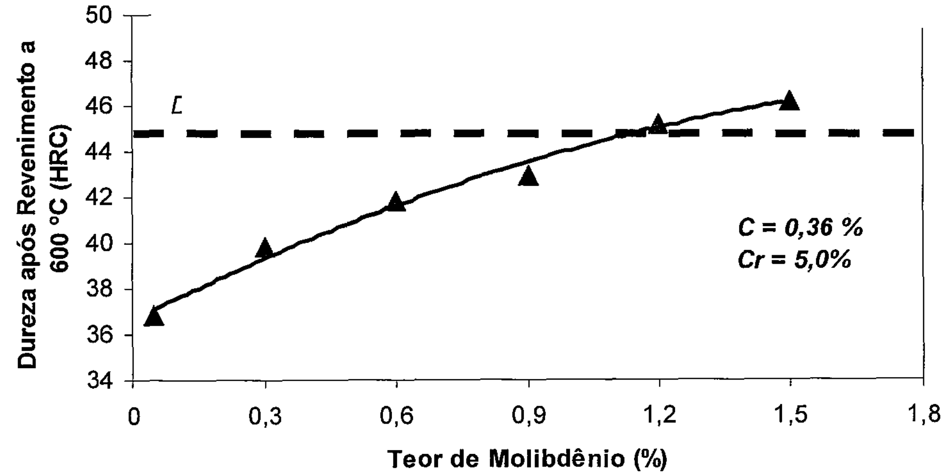

FIG. 1A

LEGEND: Hardness after tempering at 600°C (HRC)
Molybdenum content (%)

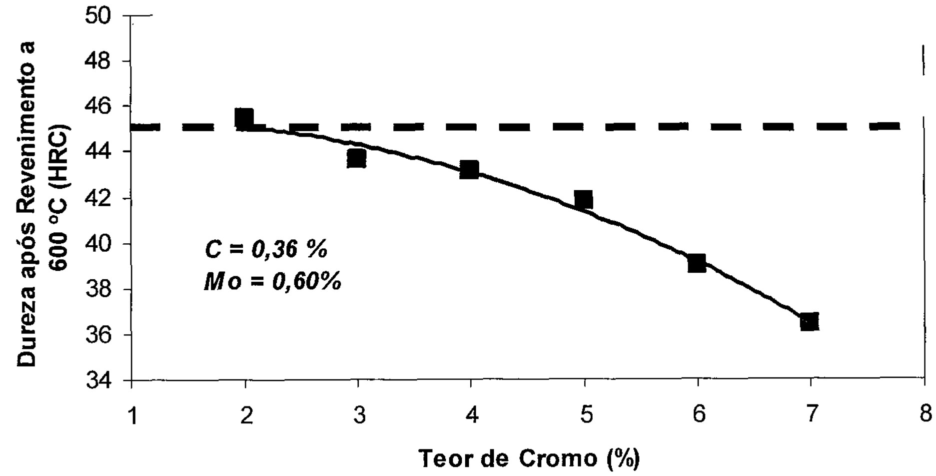

FIG. 1B

LEGEND: Hardness after tempering at 600°C (HRC)
Chrome content (%)

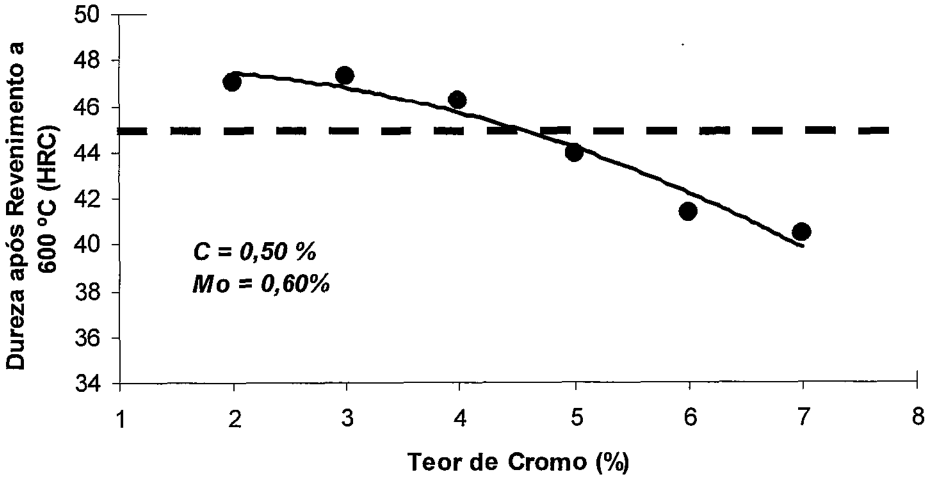

FIG. 1C

LEGEND: Hardness after tempering at 600°C (HRC)
Chrome content (%)

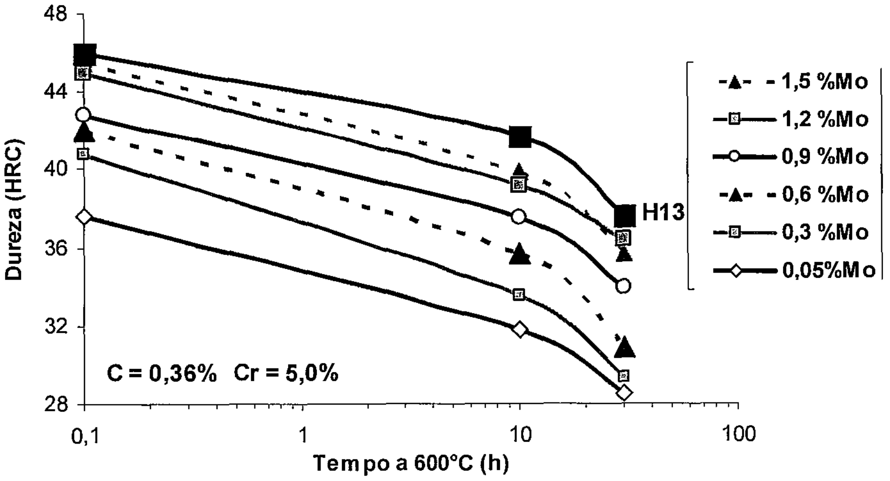

FIG. 2A

LEGEND: Hardness (HRC)
Time at 600°C (h)

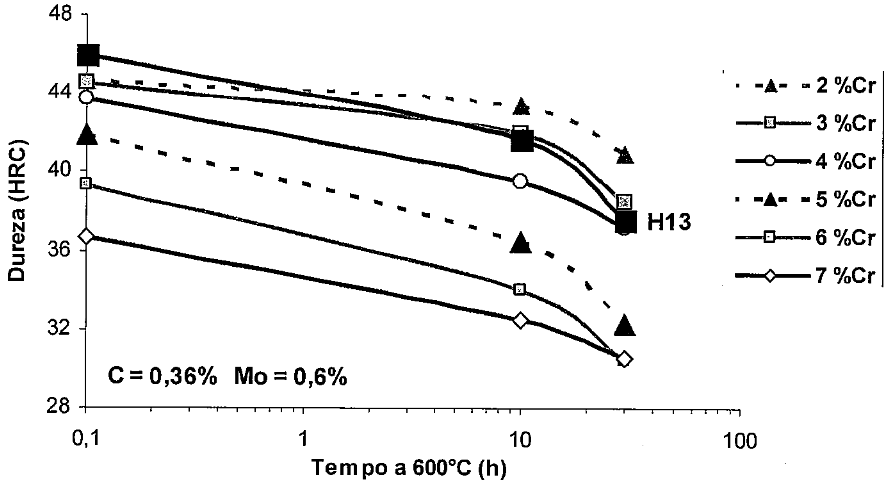

FIG. 2B

LEGEND: Hardness (HRC)
Time at 600°C (h)

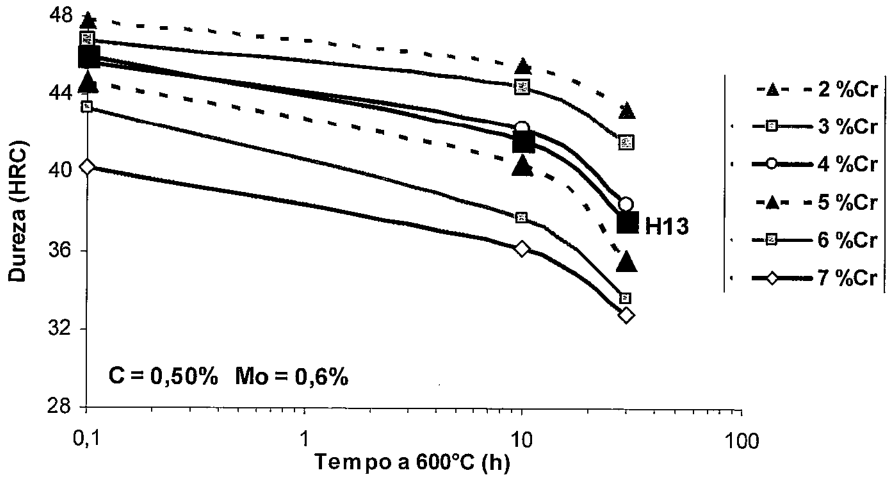

FIG. 2C

LEGEND: Hardness (HRC)
Time at 600°C (h)

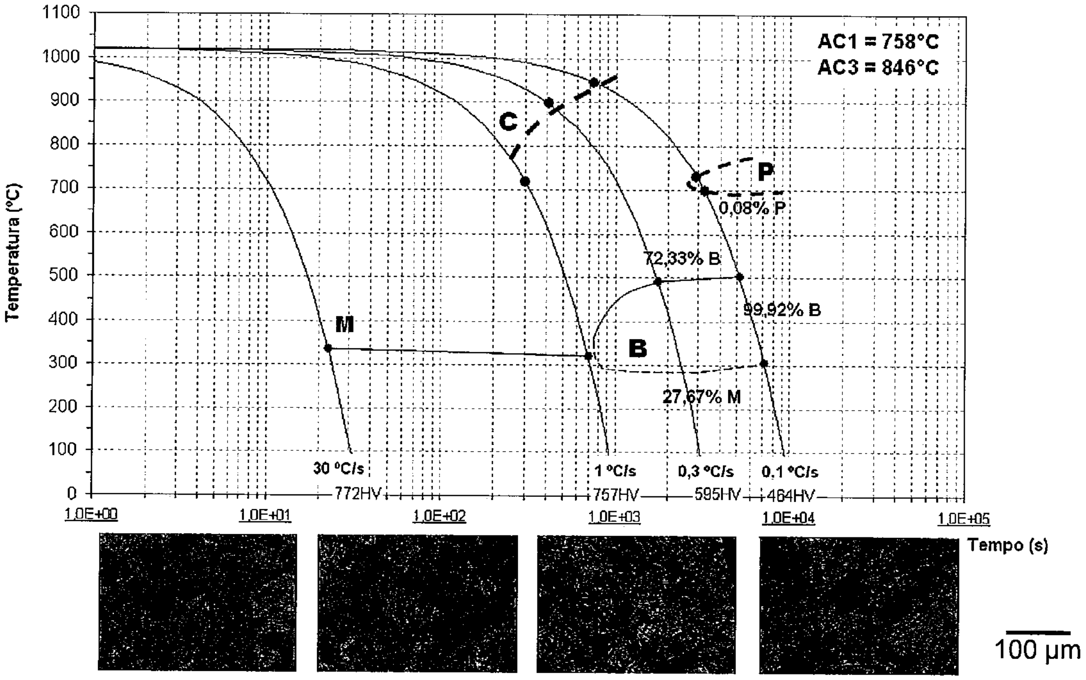

FIG. 3A

LEGEND: Temperature (°C)
Time (s)

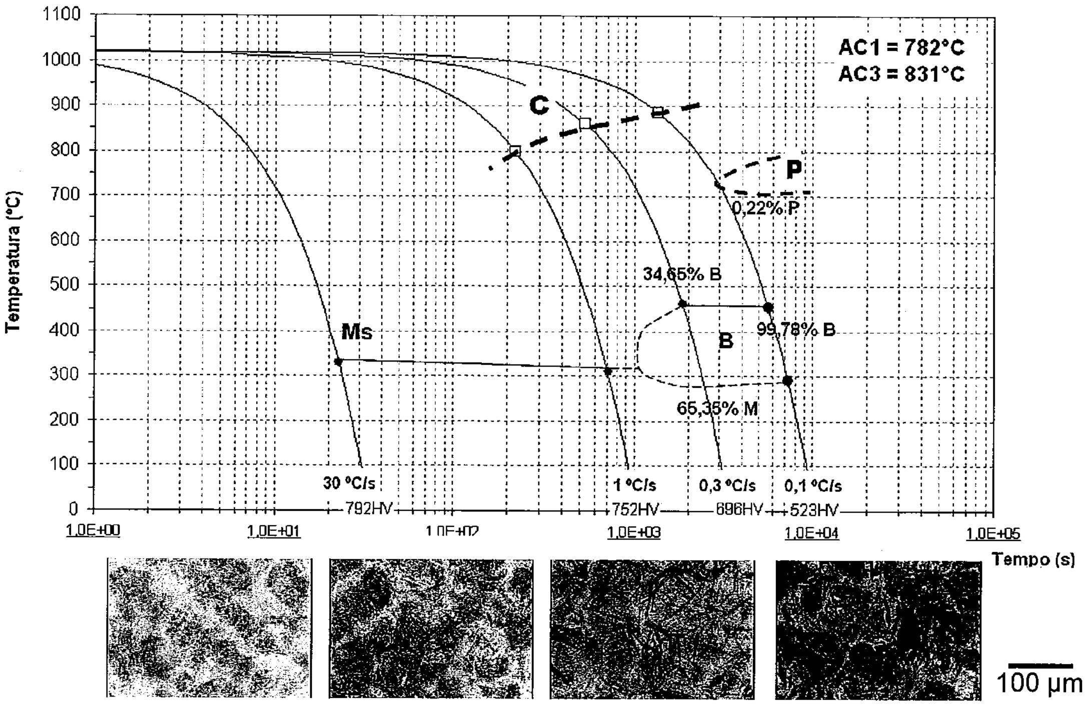

FIG. 3B

LEGEND: Temperature (°C)
Time (s)

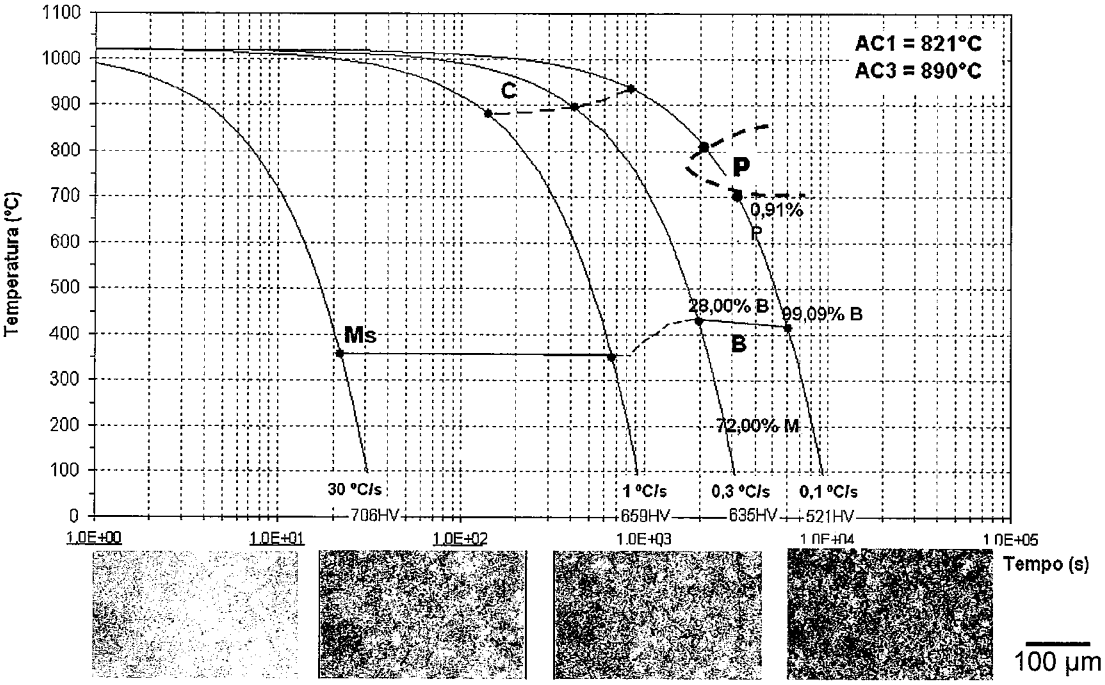

FIG. 4

LEGEND: Temperature (°C)
Time (s)

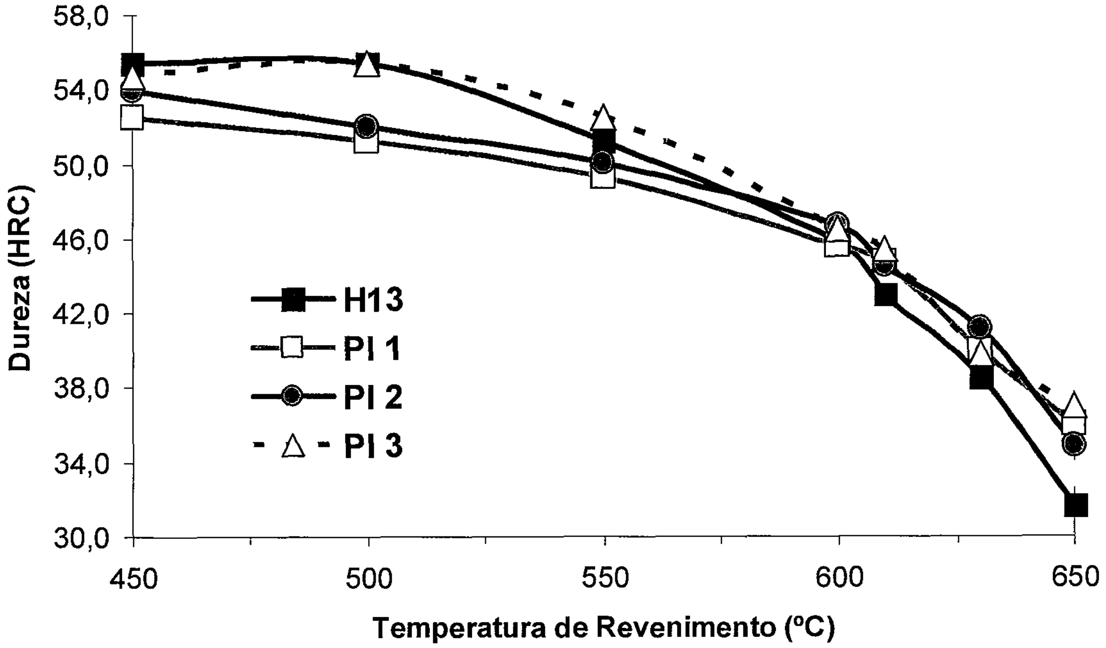

FIG. 5A

LEGEND: Hardness (HRC)
Tempering Temperature (°C)

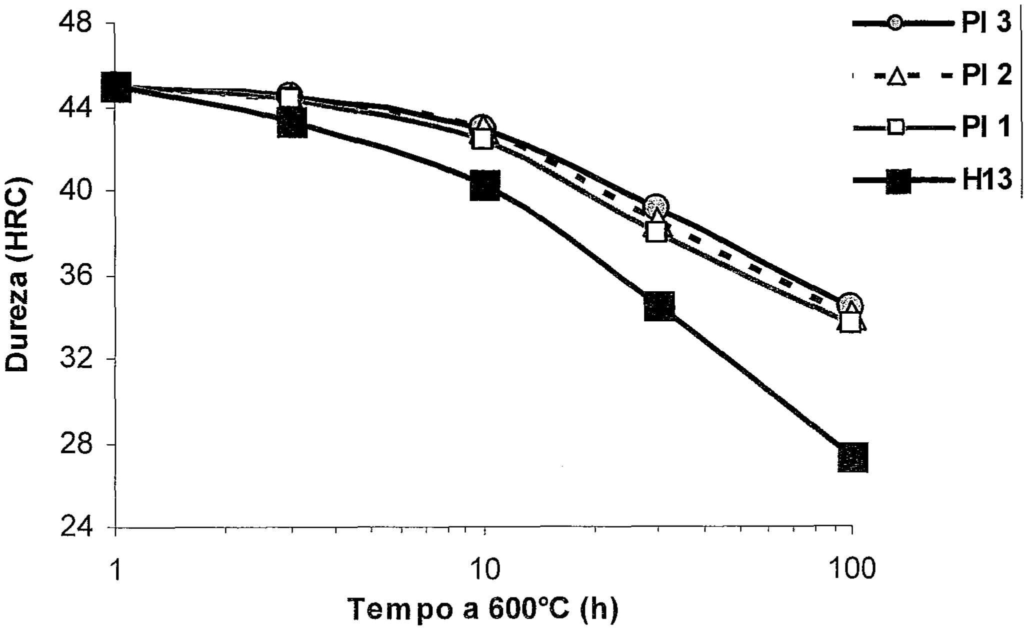

FIG. 5B

LEGEND: Hardness (HRC)
Time at 600°C (h)

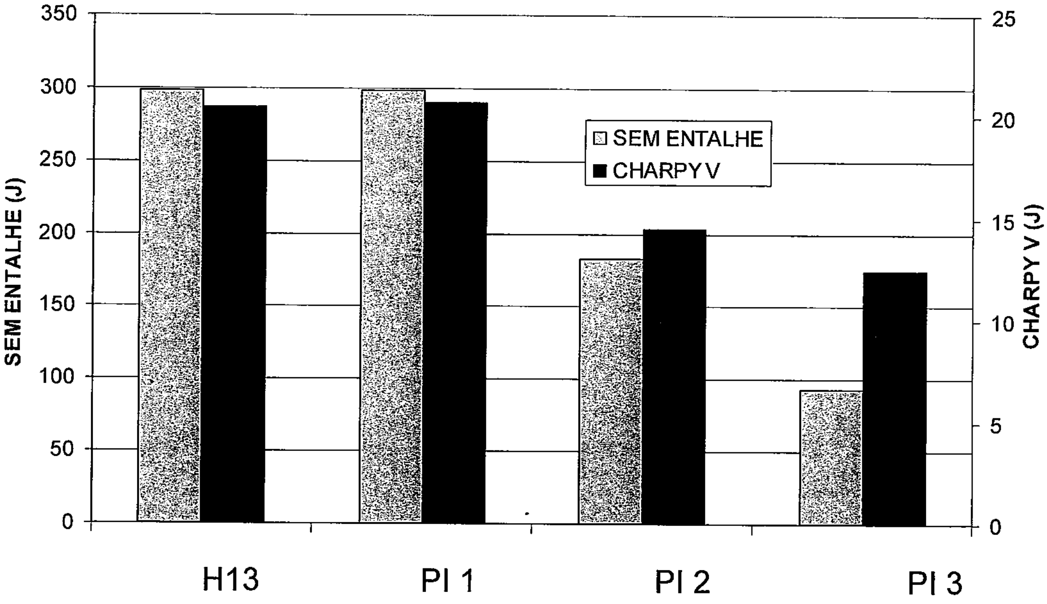

FIG. 6

LEGEND: UNNOTCHED (J)
UNNOTCHED

CHARPY V

CHARPY V (J)

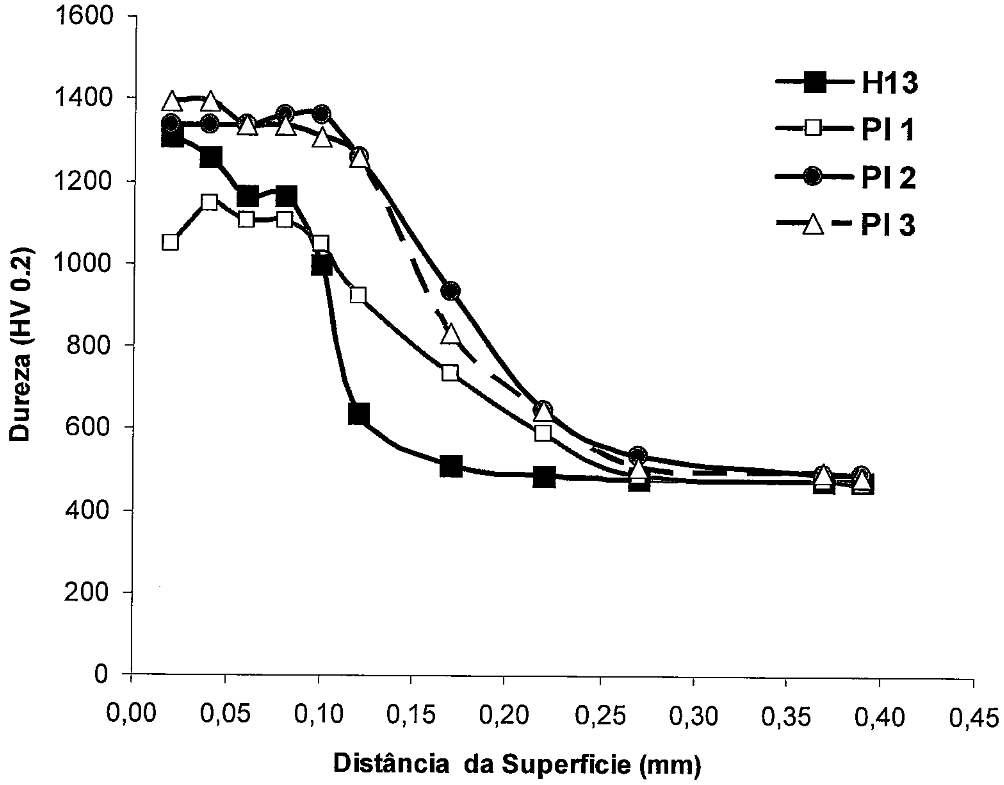

FIG. 7

LEGEND: Hardness (HV 02)
Distance from Surface (mm)

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/BR2011/000059

A. CLASSIFICATION OF SUBJECT MATTER

**C22C38/00 (20060101), C22C38/22 (20060101)**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**C22C**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

**BR-SINPI**

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**Epodoc, Espacenet, Google Scholar, ISI web of knowledge**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

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|---|---|
| Date of the actual completion of the international search<br>**11 April 2011** | Date of mailing of the international search report<br>040511 |
| Name and mailing address of the ISA/**BR**<br>INSTITUTO NACIONAL DA PROPRIEDADE INDUSTRIAL<br>Rua Mayrink Veiga nº 9, 18º andar<br>cep: 20090-050, Centro - Rio de Janeiro/RJ<br>Facsimile No. +55 21 2139-3663 | Authorized officer<br>**Frederico de Carvalho Nunes**<br>Telephone No. +55 21 2139-3493/3742 |

Form PCT/ISA/210 (second sheet) (July 2009)

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Information on patent family members

International application No.
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