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(54) Title: THERMOMECHANICAL PROCESSING

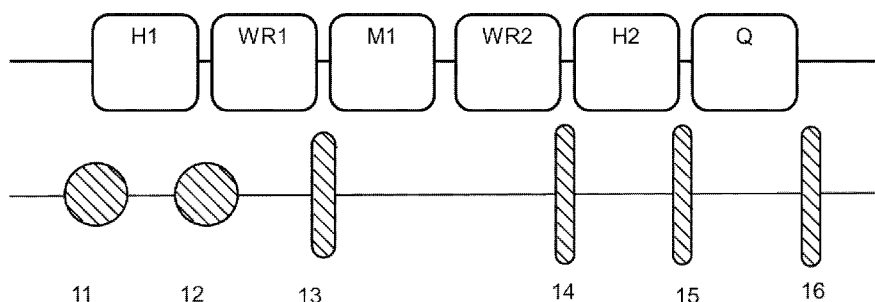


Fig. 1

(57) Abstract: A process of producing a shaped and elongated steel element, comprising the steps of warm rolling a steel wire rod or wire into a shaped and elongated steel element, followed by heating the shaped and elongated steel element at a temperature above the upper transformation temperature (Ac_3/A_{cm}) of the steel, and quenching the shaped and elongated steel element after heating.

Thermomechanical Processing

Technical Field

[0001] The invention relates to a process of producing a shaped and elongated steel element by thermomechanical processing (TMP), in particular to a flat shaped steel wire or flat blade made by TMP.

Background Art

[0002] Thermomechanical processing is now a vital part of the production route for many steel products. The shape as well as the microstructure of the steel can be modified by TMP for the benefit of the final product and application.

[0003] US5922149A discloses a TMP for making an elongated shaped wire. A shaped wire is produced either by cold shaping (e.g. rolling) or by hot shaping from steel. Afterwards, at least one quenching operation is carried out on the shaped wire.

[0004] US5542995A discloses a method of making flat steel strapping or strip from rods, bars or slit steel. A piece of steel is heated to an elevated temperature greater than A_{c3} / A_{cm} . Then the steel is hot rolled by at least seven stands in order to obtain the final designed strapping or strip shape. The hot rolled strapping or strip is quenched to form desired grain structure.

[0005] Hot rolling and cold rolling are the two common techniques in the production of steel products where steel needs to be moulded and reshaped. Steel rolling involves metal stock passing through a pair of rolls. Rolling produces flat steel sheets or strips of a specific thickness, and the process is classified according to the temperature at which the metal is rolled. If the temperature of the metal is above its recrystallization temperature, or the temperature at which the grain structure of the metal can be altered, then the process is termed as hot rolling. On the contrary, cold rolling is normally carried out at room temperature.

[0006] For hot rolling process, large deformation can be successively repeated, as the steel remains soft and ductile. The hardness of the steel cannot be

well controlled by hot rolling and it is a function of chemical composition and the rate of cooling after rolling. Even though the hardness of the steel can be controlled at a rather low level, it cannot be increased over different stands. The hardness of hot rolled products is generally lower than that of cold rolled ones and the required deformation energy of hot rolling is less than that of cold rolling as well. In addition, during hot rolling the grain growth, in particular for plain carbon steel, is accelerated as the temperature is above the austenitizing temperature (Ac_3) of steel (generally above 725°C ~ 825°C depending on the composition). In the meantime, when the temperature is above 700°C , the oxide at the outer surface of steel significantly grows. Both facts are detrimental to the properties, e.g. strength, of the steel. Also the experience of surface oxidation will result in material loss and poor final surface finish.

[0007] Cold rolling processes has an added effect of work hardening and strengthening the material thus further improving the material's mechanical properties. It also improves the surface finish and holds tighter tolerances allowing desirable qualities that cannot be obtained by hot rolling. However, room temperature steel is less malleable than hot steel, so cold rolling cannot reduce the thickness of a work piece as much as hot rolling in a single pass. In addition, the ductility of the cold rolled steel decreases due to strain hardening thus making it more brittle.

Disclosure of Invention

[0008] It is an object of the invention to provide a new TMP which can avoid the disadvantages of the prior art.

[0009] It is also an object of the invention to provide a TMP which can produce a shaped and elongated steel element having an acceptable ductility and hardness.

[0010] It is a further object of the invention to provide a TMP which can produce a shaped and elongated steel element within required tolerances by less reduction steps.

- [0011] It is still an object of the invention to develop a TMP by means of which a shaped steel wire can be produced with a high productivity ensuring constant and good quality.
- [0012] It is still another object of the invention to develop an economical TMP having low cost and small space requirement.
- [0013] According to the present invention, there is provided a process of producing a shaped and elongated steel element. It comprises the steps of warm rolling a steel wire rod or wire into a shaped and elongated steel element, followed by heating the shaped and elongated steel element at a temperature above the upper transformation temperature (A_{c3}/A_{cM}) of the steel; and quenching the shaped and elongated steel element after heating. Herein, warm rolling refers to a process that passes metal heated at elevated temperatures which are below the lower transformation temperature (A_{c1}) between two rolls to flatten and lengthen the metal. The upper transformation temperature (A_{c3}/A_{cM}) or the austenitization temperature refers to the temperature in Fe-C phase diagram where the formation of austenite starts. This temperature depends on steel grade and carbon content in steel. The process according to the invention combines warm rolling, further austenitizing heating and quenching in a single continuous line rendering the production more economical and energy efficient. Compared with hot rolling, according to the present invention, the duration of a steel rod or wire maintained at a temperature above A_{c3}/A_{cM} is limited or shortened by warm rolling followed by austenitizing heating. This on the one hand can limit the thickness of oxide layer at the surface, and on the other hand can control grain growth at relatively low temperature. In comparison with steels treated by conventional hot rolling, the grain size of the steel element is limited and much smaller according to the process of the present invention. Because smaller grains are less susceptible to quench cracks than coarser grains, the fatigue life of the steel element produced according to the process of the present invention increases. Moreover, in warm or hot rolling, the steel element will lose heat during contact with the rolling mill itself (rollers),

rolling emulsion and guiding rollers. There is a big risk that this will cause fluctuations in the steel temperature along the wire, because the losses will change over time (e.g. temporary more emulsion splashes on the wire). By having an additional austenitizing operation after rolling, temperature fluctuation is avoided resulting in a more homogeneous steel product. In addition and importantly, the dimension or precision of the shaped and elongated steel element is well controlled by warm rolling. The tolerance, e.g. $\pm 20 \mu\text{m}$ and preferably $\pm 10 \mu\text{m}$, of the shaped and elongated steel elements is acceptable with limited reduction steps.

[0014] According to the present invention, the wire rod or wire may be steel has carbon content ranging from 0.1 to 1.0 wt%. Preferably, the wire rod or wire may also be a plain carbon steel preferably having a carbon content ranging from 0.45 to 0.70 wt%. The wire may be a half product has a circular cross-section with a diameter of 2 to 15 mm. For instance, the wire has a diameter of 3 to 4 mm, 5 to 6 mm or about 7, 8, 9, or 10 mm. The shaped and elongated steel element may be a flat shaped steel wire having a near rectangular cross-section. The width of the flat shaped steel wire may be ranging from 2.3 to 20 mm and the thickness may be ranging from 0.5 to 5 mm. As an example, the width of the flat shaped steel wire is ranging from 5 to 15 mm and the thickness is ranging from 0.5 to 3.5 mm. As another example, the width of the flat shaped steel wire is ranging from 10 to 15 mm, e.g. 12, 13, 14 and 15mm, and the thickness is ranging from 2.5 to 4 mm, e.g. 2.8, 3.0 and 3.5 mm. As yet another example, the width by thickness of the flat shaped steel wire with near rectangular cross-section is 6x0.8 mm, 7x0.9 mm or 7x1.0 mm. The relatively thin or small dimension flat shaped steel wire is hardly to be produced precisely by hot rolling. The heat of the heated wire will be quickly dissipated when the wire exits from the austenitizing furnace or when the wire gets contact with the rollers due to the small dimension and thus small capacity of the wire. Heat loss is more likely to occur for the steel wire having a small cross-sectional area than for steel wire having a large cross-sectional area. According to the present invention, warm rolling makes it possible to produce thin or small dimension flat shaped wire.

- [0015] The more rolling stands the steel wire passes, the more the thickness is reduced. The number of rolling stands applied depends on the desired thickness reduction. In the present invention, the shaped and elongated steel element may be rolled to final dimension through two thickness reducing warm rolling stands, i.e. a first warm rolling stand and a second warm rolling stand. Two warm rolling stands are used to flatten or reduce the thickness of the wire from a diameter about 4 mm to a flat shape having a width by thickness at about 7x0.9 mm. More rolling stands may also be applied depending on the desired reduction. Compared with cold rolling for a similar reduction, the application of warm rolling significantly simplifies the process and reduces the cost.
- [0016] According to the present invention, the tension of shaped steel element may be measured and controlled before a first thickness reducing warm rolling stand and in-between the two thickness reducing warm rolling stands. Moreover, the shaped and elongated steel element is rolled by a rectangle forming or an edge rolling stand between the first and the second thickness reducing warm rolling stands. It is important to minimize the tension and/or keep it constant in the steel wire moving between stands. Tension can result in a substantial narrowing or breaking of the steel wire. A precision speed regulation system can be used to control the speed at which the rollers are driven to minimize tension. More specifically, it is important to keep the tension constant.
- [0017] According to the present invention, the wire rod or wire is first warmed up to, e.g. 400°C to 700°C and preferably 600°C to 700°C before rolling. Any suitable heating method may be used to warm up the wire rod or wire, such as in a resistance furnace, oven, infrared radiant (IR) heater, gas burner, fluidized bed or via any conductive heating. As another example, a mid-frequency induction heating furnace may also be used to warm up the wire. Hereby, mid-frequency means a frequency ranging from 10 to 200 kHz. Preferably, a unit that adjusts the temperature of the steel to compensate for heat loss that may occur during the rolling step is used during warm rolling. After warming rolling, the shaped and elongated steel element is austenitized by further heat treatment. The heat treatment may

be carried out in a resistance furnace, an IR furnace or a high frequency induction heating furnace. Preferably, the furnace is flushed with inert or reducing gas, such as nitrogen, to keep the steel in a protected atmosphere to avoid oxidation. Hereby, high frequency means a frequency ranging from 250 kHz to 2 MHz. It has been found that the frequency of induction heating determines the skin depth of the object. In the present invention, the skin depth is preferably adapted according to the wire thickness/diameter to obtain an efficient heating.

[0018] According to the present invention, a quenching carries out after the austenitization of the shaped and elongated steel element. Quenching is cooling down very fast from high temperature to low temperature. According to the invention, the quenching starts above austenitization temperature. The quenching step may occur down to between the temperature (M_s) at which martensite formation starts and the temperature (M_f) at which martensite formation is finished. Preferably, the quenching is down to a temperature below M_f , e.g. 100°C during a period less than 30 seconds and preferably less than 6 seconds, and more preferably less than 3 seconds to form martensitic structure. The quenching can be done in an oil bath, a salt bath, a polymer bath or in a water bath. Then the quenched shaped and elongated steel element is tempered at a temperature ranging from 320°C to 600°C during a period ranging from 1 to 200 seconds, preferably 1 to 20 seconds to relief stress and to have necessary ductility. Tempering can be done in a salt bath, in a bath of a suitable metal alloy with low melting point, in a suitable furnace or oven, or can be reached by means of induction or a combination of a furnace and induction. Then the shaped and elongated steel element is cooled down to room temperature.

[0019] Alternatively, the quenching can be down to a temperature above the temperature (M_s) which martensite formation starts during a period less than 60 seconds and preferably less than 30 seconds to form perlitic structure. The quenching may be down to a temperature slightly above M_s . For instance, the starting temperature of martensitic transformation M_s of

the steel is around 280 °C depending on the composition of the steel and the quenching is down to a temperature around 300°C within 30 seconds.

[0020] All the steps are carried out in one single continuous line. Hereby, “single continuous line” means one processing step is directly followed by another processing step without interruption till completing all the steps. The processes according to the present invention significantly save space and energy and simplify the requirement for the equipment.

[0021] The final product is a shaped and elongated steel element, in particular a flat shaped steel wire or flat blade having a near rectangular cross-section. This flat shaped steel wire or flat blade can be applied as a wiper for window screen of autos, spring wire or a reinforcing element.

Brief Description of Figures in the Drawings

[0022] Figure 1 is a schematic representation of the TMP for making a shaped and elongated steel element according to the first embodiment of present invention.

[0023] Figure 2 shows a temperature profile of the steel element according to a first embodiment of the present invention.

[0024] Figure 3 shows a temperature profile of the steel element according to a second embodiment of the present invention.

Mode(s) for Carrying Out the Invention

Embodiment 1

[0025] Starting material is a round steel wire having a diameter of 3.5 mm. It may have various composition, e.g. 0.45 to 0.75 wt% carbon content and the remaining is iron.

[0026] Figure 1 is a schematic representation of the TMP for making a shaped and elongated steel element. The essential or characteristic processing steps which the steel wires go through according to the invention are indicated by blocks of first heating (H1), first warm rolling (WR1), measure of tension of steel wires (M1), second warming rolling (WR2), second heating or austenitizing (H2), and quenching (Q). These steps will be further discussed below. In figure 1, the cross section of the steel wire

after each step is schematically illustrated. The temperature profile of the steel wire during the thermomechanical process is schematically shown in figure 2.

- [0027] The first step of the processing is a pay-off step, wherein a starting material, i.e. a round steel wire with a diameter of 3.5 mm, is dispensed and begins going through the steps of the process. Pay-off can be accomplished utilizing a rotating carousel pay-off reel. Preferably, a dual station having two carousel reels is utilized so that a second coil can be loaded while a first coil is being paid out.
- [0028] The next step for the coiled round steel wire is a straightening step wherein the steel wire is at least partially straightened and the coil set is at least partially removed. The straightening step can be performed utilizing a conventional straightener. Then the steel wire is cleaned and the scaling on the wire is removed prior to further processing. The steel wire may be drawn by drawing dies to reduce the diameter and may further increase the tensile strength.
- [0029] Referring to figure 1, the next step is a first heat treatment on the steel wire represented by block H1. The drawn steel wire (11) is heated up to a desired temperature, e.g. 600°C to 700°C in a mid-frequency induction furnace. This is indicated by stage A in the temperature profile of the steel wire as shown in figure 2. The position, in particular the tension, of the drawn steel wire is preferably measured before passing through the mid-frequency induction heating furnace.
- [0030] The next step is rolling the warmed steel wire (12) preferably including a first warm rolling (WR1), and a second warm rolling (WR2) as shown in figure 1. The warmed round steel wire (12) is first driven and passed through a first rolling stand (WR1). The steel wire (12) is shaped into a flat shape and in the meantime the thickness of the steel wire (12) is reduced. Due to the significant temperature difference between the steel wire and roller, heat transfer occurs from the warm steel wire to the cold rolling stand when the warm steel wire contacts the rollers. The heat loss of the steel wire causes a slight temperature drop thereof. This temperature drop is reflected by a first stepwise temperature drop in stage B of figure 2. A

unit to adjust the temperature of the steel is preferably used. Then the steel wire (13) goes through a tension measure and control unit to minimize the tension in the steel wire moving between stands. A rectangle forming stand may be applied that has flat top and bottom rollers have a flat roll pass design to produce rectangular cross-section steel. Alternatively, a non-driven edge rolling may be applied to control the width and edge variation of the flat shaped steel wire. Afterward, a second warm rolling (WR2) is applied for further thickness reduction. The heat loss of the steel wire during the second warm rolling is indicated by a second stepwise temperature drop in the stage B of figure 2. The steel wire (14) after these rolling steps as an example has a flat shape and a near rectangular cross-section with a width of 6 to 10 mm and a thickness of 0.8 to 1.5 mm. The tolerance of the thickness of the flat shaped steel wire is about $\pm 20 \mu\text{m}$.

[0031] The next step is austenitizing the flat shaped steel wire by a second heat treatment as represented by block H2 in figure 2. Any commercially available furnace may be used as austenitizing furnace, preferably a high frequency induction generator is applied. The flat shaped steel wire is heated up to a temperature that is greater than point Ac3 of the steel, e.g. above 900°C. This is shown by stage C in the temperature profile of the steel wire in figure 2. By passing the austenitizing furnace, the temperature of the steel wire (15) is harmonized and maintained at a temperature that is greater than point Ac3 of the steel, e.g. about 950°C (stage D in figure 2).

[0032] In this embodiment, a quenching (block Q in figure 1) is performed for metallurgical transformation to a martensite. This is represented by stage E in figure 2. The flat shaped steel wire (15) is rapidly quenched from a temperature greater than point Ac3 of the steel down to a temperature below the temperature (M_f in figure 2) at which martensite formation finishes e.g. from a temperature of around 950°C down to a temperature of around 100°C during a period, e.g. less than 6 seconds. Quenching can be done in an oil bath, a salt bath or in a polymer bath.

- [0033] A tempering is preferably desired after quenching. The quenched flat shaped steel wire (16) is tempered in a temperature range e.g. between 320 to 600°C, and preferably between 350 to 500°C. Then the flat shaped steel wire is cooled down to room temperature.
- [0034] Finally, the flat shaped steel wire is cut and diverted to allow continuous process. The final product is taken up.
- [0035] In addition, an extrusion step may be applied and the wire is preferably coated with polymers. For instance, the steel wire is coated with polyvinyl chloride (PVC) and preferably coated with polyethylene terephthalate (PET).
- [0036] All the above steps are carried out in one single continuous wire line designed to work at a speed between 100 m/min to 200 m/min, e.g. at around 120 m/min, 150 m/min and 180 m/min.

Embodiment 2

- [0037] According to the second embodiment of the present invention, a perlitic structure is formed after quenching differing from the martensitic structure as to the first embodiment. The temperature profile of the steel wire according to the second embodiment is illustrated in figure 3.
- [0038] A similar treatment to the first embodiment except the quenching is carried out on the steel wire. According to the second embodiment, in the quenching step as referred by block Q in figure 1, the flat shaped steel wire from austenitizing furnace (stage D in figure 3) is quickly cooled down (stage EI in figure 3) to a temperature slightly above the temperature of M_s . For example, the flat shaped steel wire is fast cooled down from about 950°C to about 580°C (such as in about 30 seconds) and hold at about 580°C for a while, e.g. for 10 seconds to 3 minutes. The steel wire is then further cooled down in water as shown by stage EII in figure 3. As an example, it takes about 20 minutes to cool down the steel wire from 580°C to 100°C.
- Alternatively, water air patenting may be applied. The steel wire is gradually or slowly cooled from the austenitizing temperature such as about 950°C down to room temperature.

[0039] The flat shaped steel wire treated by the quenching step according to the second embodiment has a perlitic structure.

[0040] The invention illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. It should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the inventions embodied herein may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention.

Claims

1. A process of producing a shaped and elongated steel element, comprising the steps of:
warm rolling a steel wire rod or wire into a shaped and elongated steel element;
followed by heating the shaped and elongated steel element at a temperature above the upper transformation temperature (Ac_3/A_{cm}) of the steel; and
quenching the shaped and elongated steel element after heating.
2. A process of producing a shaped and elongated steel element according to claim 1, wherein the tolerance of the thickness of the shaped and elongated steel elements is $\pm 20 \mu\text{m}$.
3. A process of producing a shaped and elongated steel element according to claim 1 or 2, wherein the wire rod or wire is a steel having a carbon content ranging from 0.1 to 1.0 wt%.
4. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the wire rod or wire is a plain carbon steel.
5. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the steel wire rod or wire has a circular cross-section with a diameter of 2 to 15 mm.
6. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the shaped and elongated steel element is a flat shaped steel wire having a dimension of a width ranging from 2.3 to 20 mm and a thickness ranging from 0.5 to 5 mm.
7. A process of producing a shaped and elongated steel element according to claim 6, wherein the shaped and elongated steel element is rolled to said dimension through a first and a second thickness reducing warm rolling stand.

8. A process of producing a shaped and elongated steel element according to claim 7, wherein the tension of the shaped and elongated steel element is controlled before the first thickness reducing warm rolling stand and in-between the first and the second thickness reducing warm rolling stands.
9. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the wire rod or wire is warmed up to a temperature ranging from 400°C to 700°C in one of a resistance furnace, oven, infrared radiant (IR) heater, a mid-frequency induction heating furnace, gas burner, fluidized bed, or via any conductive heating before the warm rolling.
10. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the heating is carried out in one of a resistance furnace, an IR furnace or a high frequency induction heating furnace.
11. A process of producing a shaped and elongated steel element according to any one of claims 7 to 10, wherein the shaped and elongated steel element is rolled by a rectangle forming or an edge rolling stand between the first and the second thickness reducing warm rolling stands.
12. A process of producing a shaped and elongated steel element according to any one of preceding claims, wherein the quenching is down to a temperature below a temperature (M_f) at which martensite formation finishes, during a period less than 30 seconds to form a martensitic structure.
13. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the shaped and elongated steel element after quenching is tempered at a temperature ranging from 320°C to 600°C during a period ranging from 1 to 200 seconds.

14. A process of producing a shaped and elongated steel element according to any one of claims 1 to 11, wherein the quenching is down to a temperature above the temperature (M_s) at which martensite formation starts during a period less than 60 seconds to form perlitic structure.
15. A process of producing a shaped and elongated steel element according to any one of the preceding claims, wherein the shaped and elongated steel element is applied as a wiper for window screen of autos, spring wire or a reinforcing element.

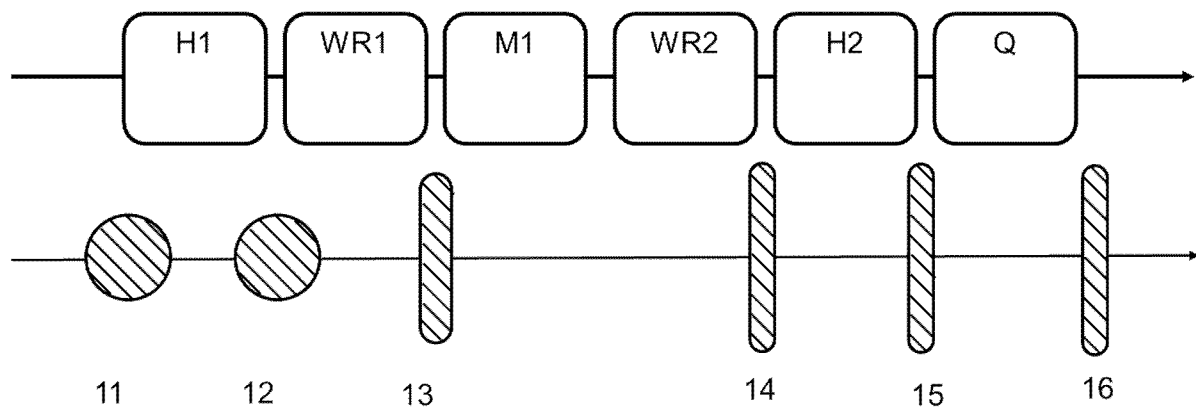


Fig. 1

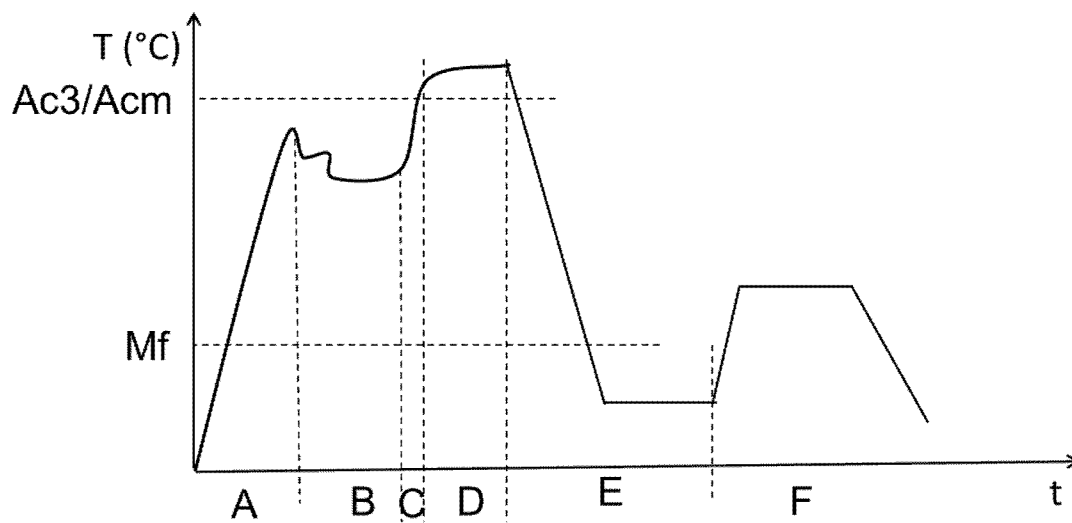


Fig. 2

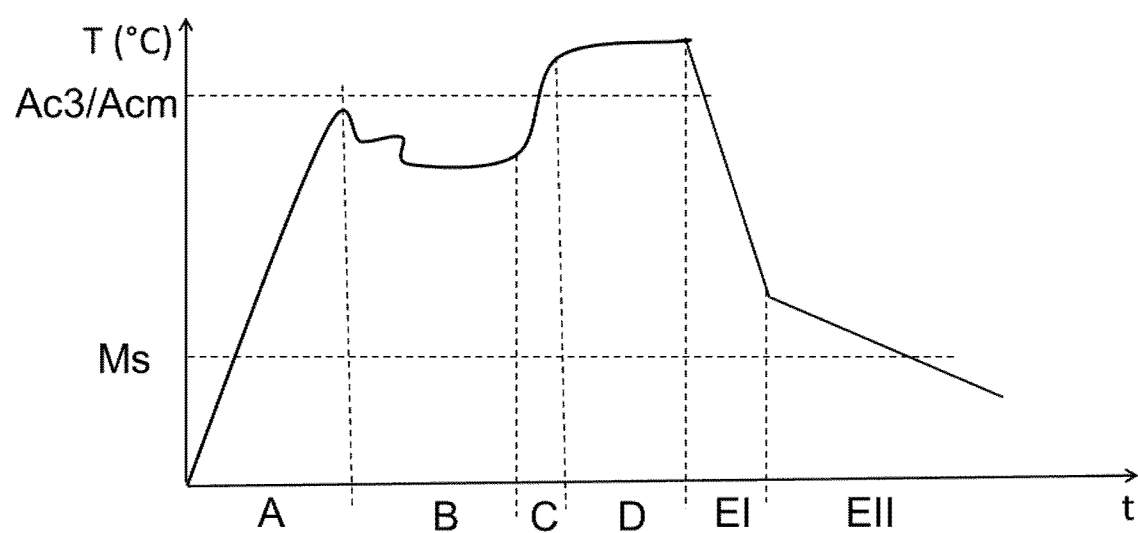


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER

INV. C21D8/06 C21D9/00 C21D9/52 C21D1/18
ADD.

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)
C21D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 104 511 477 A (BEKAERT SA NV) 15 April 2015 (2015-04-15) the whole document -----	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

26 August 2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CN 104511477	A	15-04-2015	NONE
