

PATENT SPECIFICATION

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(54) CONTROLLED COOLING OF HOT-ROLLED STEEL PRODUCTS

(71) We, CENTRE DE RECHERCHES METALLURGIQUES—CENTRUM VOOR RESEARCH IN DE METALLURGIE, a Belgian Body Corporate, of 47 rue Montoyer, Brussels, Belgium, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of treating a hot-rolled steel product, which may for example be reinforcing rod, wire rod, or bar of circular or non-circular cross-section (all these products being referred to as "rods" below), or sections (which term is used below to include sheet bar and strip).

The main qualities required by users of a rolled steel product, among others, are as high as possible a limit of elasticity for the grade of steel used, as well as satisfactory fatigue strength, ductility, weldability, or drawability, depending on the circumstances and the use for which the product is intended.

To this end, we have already suggested suitably cooling a rolled product while emerging from the finishing stand of the hot rolling mill, by means of a fluid, so as to produce martensitic and/or bainitic quenching of the surface layer of all or part of the product. Such a method comprises three steps.

The first step takes place as soon as possible after the product has emerged from the last finishing stand, and during this step the product is subjected to rapid cooling sufficiently effective to ensure that the cooling speed down to a certain depth below the surface is higher than the critical martensitic quenching speed. At the end of the first step, the product has a central austenitic zone surrounded by a zone consisting of a mixture of austenite and martensite (the proportion of martensite increasing from the centre towards the periphery) and possibly bainite.

The cooling fluid used for carrying out this step is generally water with or without conventional additives or an aqueous solution of one or more mineral salts, etc.; the fluid could also be a mist obtained for example by suspending water in a gas, or it could be a gaseous fluid such as steam. From a practical point of view, desired rapid cooling of the rolled product is obtained by choosing the cooling apparatus and by suitably adjusting the length and the flow rate characteristics of the cooling zone.

During the second step, the product is subjected to cooling in the air. The heat-transfer coefficient of this medium is very low and the thermal gradient in the cross-section of the product is very high, and thus the quenched surface zone is heated by conduction of heat from the core. Martensite formed during the first step thus undergoes tempering (referred to as self-tempering), which results in satisfactory ductility while maintaining a high limit of elasticity. During the second step, the non-transformed austenite in the surface layer is transformed into bainite while the core remains austenitic in nature.

The third step takes place while the product rests in a cooling area and consists in quasi-isothermal transformation of the remaining austenite. The structure obtained from such a transformation can consist of ferrite-pearlite or ferrite-pearlite-bainite (or even bainite) depending on the product treated and the operating conditions of the method.

The object of the present invention is to provide a particularly interesting method of treating a product by martensitic and/or bainitic surface quenching followed by self-tempering which produces a particular composite structure in the product. This method consists in determining an important datum in order to choose the conditions for carrying out the treatment.

The method is based on the observation of

the temperature variations at an intermediate point which, at the end of the martensitic and/or bainitic quenching, is located immediately below the quenched surface layer. The cooling law of such a point during treatment can be stated as follows:

(i) rapid cooling from the temperature at the end of the rolling operation, the duration of this rapid cooling being equal to that of the quenching operation;

(ii) slow cooling, corresponding to cooling the product in still air, down to ambient temperature.

In the temperature/time curve reproducing the cooling course at the intermediate point under consideration, there will be a slope variation corresponding to a change of cooling.

It should be noted that, during the slow cooling step described above, the skin temperature increases, whereas that of the central part continually decreases after emergence from the rolling mill. While each evolves in its own way, the temperature at the skin and the temperature at the core on the same cross-section converge towards a point called the equalization temperature, from where the two curves continue substantially parallel to one another.

We have already suggested choosing as a point of convergence of these two curves a temperature in the range 600 to 730°C. We have found unexpectedly that there is a direct relationship between the equalization temperature as defined above and the mechanical properties of the product subjected to surface quenching and self-tempering, independently of the grade of the steel, even in the presence of alloying elements (e.g. Nb). In practice, cooling can be carried out so as to attain the chosen equalization temperature by consequently adjusting in particular the time spent by the product in the quenching apparatus.

We have also discovered a role played by the temperature at which there is a change in the slope of the temperature/time curve representing cooling at an intermediate point as defined above. Thermal analysis tests have shown that the microstructure obtained in a steel of a given composition substantially depends on this particular temperature. As this temperature decreases, acicular structures will increasingly appear in the zone located below the quenched layer; i.e. the microstructure in this zone passes from ferrite-pearlite to ferrite-pearlite-bainite and finally to bainite.

The method according to the present invention takes these observations into account and results in a treatment which ensures products having better defined properties.

The present invention provides a method of treating a hot-rolled steel product in order to provide the treated product with desired

mechanical properties, in which the product, emerging from the finishing stand of a hot rolling mill, is subjected to cooling by means of a fluid in such a manner that martensitic and/or bainitic quenching of the surface layer of all or part of the product is obtained, the non-quenched portion of the product remaining at a temperature sufficient to cause, during further air-cooling, tempering of the martensitic and/or bainitic surface layer to be obtained, whereby a variation in the slope of the course of cooling of an intermediate point located immediately beneath the quenched layer takes place owing to the change from fluid-cooling to air-cooling, the temperature at which the slope variation is to take place in order to give the zone located immediately beneath the quenched layer a microstructure chosen from the range of structures extending from ferrite-pearlite to bainite, depending on the said desired mechanical properties, is determined, and the fluid-cooling and air-cooling conditions are regulated so that the slope variation takes place at the temperature determined.

Preferably, the temperature at which the slope variation is produced in the course of cooling the said zone is obtained by regulating the time spent the product in the cooling apparatus; in particular, the time spent is increased in order to decrease the temperature at the beginning of the transformation at the non-quenched zones, and thus to start the formation of, and then to increase, the amount of bainite in the said zone.

In practice, the method will normally be carried out in an installation whose main elements (finishing stand of the rolling mill and still-air cooling zone) are fixed sites, this determining the available length for the quenching zone. It is only rarely that one can adapt the installation to possible requirements of the method. Generally speaking, the speed and temperature of the rolled product at the outlet of the last stand of the rolling mill are also given data of the process.

On the other hand, the method is applied to one product at a time only and one knows the dimensions of this product, the composition of the steel of which the product is made, and thus the CCT (Continuous Cooling Transformation) diagram peculiar to this product.

Knowledge of this diagram puts one in a position of being able to determine a certain number of conditions in which the method of treating the product are to be applied, more specifically the temperatures at the beginning of allotropic transformation and the maximum time available to effect surface quenching, particularly down to the desired depth, by aiming at a predetermined value of the equalization temperature and another predetermined value for the slope variation in the cooling course in the zone located im-

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mediately beneath the martensitic and/or
intic quenched layer.

5 In order to define the characteristics of the
cooling apparatus, e.g. the length of the
cooling zones and the fluid flow rates to be
applied in them, it is possible to establish
curves giving the temperature gradients at
different points in the cross-section of the
rolled product subjected to the treatment;
10 one can then determine the amount of heat
to be extracted.

From these known data of the treatment
installation and of the product to be treated,
by averaging the evaluation of cooling
15 requirements to be applied, it is then possible
to define the characteristics of the cooling
apparatus and the fluid flow rates applied by
this apparatus.

20 WHAT WE CLAIM IS:—

1. A method of treating a hot-rolled
steel product in order to provide the treated
product with desired mechanical properties,
in which the product, emerging from the
25 finishing stand of a hot-rolling mill, is sub-
jected to cooling by means of a fluid in such a
manner that martensitic and/or bainitic
quenching of the surface layer of all or part of
the product is obtained, the non-quenched
30 portion of the product remaining at a tem-
perature sufficient to cause, during further

air-cooling, tempering of the martensitic and/
or bainitic surface layer to be obtained,
whereby a variation in the slope of the course
of cooling of an intermediate point located 35
immediately beneath the quenched layer
takes place owing to the change from fluid-
cooling to air-cooling, the temperature at
which the slope variation is to take place in
order to give the zone located immediately 40
beneath the quenched layer a microstructure
chosen from the range of structures extending
from ferrite-pearlite to bainite, depending on
the said desired mechanical properties, is
determined, and the fluid-cooling and air- 45
cooling conditions are regulated so that the
slope variation takes place at the tem-
perature determined.

2. A method as claimed in claim 1; in
which the said temperature is adjusted by 50
adjusting the duration of fluid-cooling.

3. A method as claimed in claim 2, in
which the temperature at the beginning of
transformation in the non-quenched portion 55
is decreased by increasing the duration of
fluid-cooling.

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cooling zones and the fluid flow rates to be
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curves giving the temperature gradients at
different points in the cross-section of the
10 rolled product subjected to the treatment;
one can then determine the amount of heat
to be extracted.

15 From these known data of the treatment
installation and of the product to be treated,
by averaging the evaluation of cooling
requirements to be applied, it is then possible
to define the characteristics of the cooling
apparatus and the fluid flow rates applied by
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1. A method of treating a hot-rolled
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finishing stand of a hot-rolling mill, is sub-
jected to cooling by means of a fluid in such a
manner that martensitic and/or bainitic
quenching of the surface layer of all or part of
the product is obtained, the non-quenched
30 portion of the product remaining at a tem-
perature sufficient to cause, during further

air-cooling, tempering of the martensitic and/
or bainitic surface layer to be obtained,
whereby a variation in the slope of the course
of cooling of an intermediate point located 35
immediately beneath the quenched layer
takes place owing to the change from fluid-
cooling to air-cooling, the temperature at
which the slope variation is to take place in
order to give the zone located immediately 40
beneath the quenched layer a microstructure
chosen from the range of structures extending
from ferrite-pearlite to bainite, depending on
the said desired mechanical properties, is
determined, and the fluid-cooling and air- 45
cooling conditions are regulated so that the
slope variation takes place at the tem-
perature determined.

2. A method as claimed in claim 1, in
which the said temperature is adjusted by 50
adjusting the duration of fluid-cooling.

3. A method as claimed in claim 2, in
which the temperature at the beginning of
transformation in the non-quenched portion
is decreased by increasing the duration of 55
fluid-cooling.

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