－ United States Patent [15] 3,658,602
Pomey [45] Apr. 25, 1972

[54] METHOD FOR QUENCHING STEEL RAILS IN A FLUIDIZED POWDER MEDIUM

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[22] Filed: May 15, 1969
[21] Appl. No.: 825,043

[30] Foreign Application Priority Data

Dec. 30, 1968 France 182073

[52] U.S. Cl. 148/14, 148/16, 148/27, 263/2, 263/6, 263/52
[51] Int. Cl. C21d 1/56, C21d 9/04
[58] Field of Search 148/13, 13.1, 14, 16, 16.7, 148/22, 27; 263/2, 6, 52; 266/2

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[57] ABSTRACT

Process for quenching steel and rails, in a fluidized powder medium. The fluidized medium is formed by mixing a powder of chromium, iron, nickel, molybdenum or tungsten, or alloys of these metals, with a pure steam or a gas comprising essentially steam.

13 Claims, No Drawings

METHOD FOR QUENCHING STEEL RAILS IN A FLUIDIZED POWDER MEDIUM

The present invention, due to the collaboration of Mr Jacques POMEY, Consulting Engineer of the Company USINOR, relates to the quenching of rails, and more particularly relates to a method for quenching in a fluidized powder medium.

It is known to quench pieces of steel in a powder medium fluidized by a gas. It is also known to bring this medium to a given temperature for achieving the hardening in stages. As solid powder material, it is known to employ refractory oxides such as corundum, silica, zirconium, silicates of alumina and silico-aluminates. As gaseous fluidizing agent, air is always employed when quenching steels for reasons of convenience. It is known that these media have a high apparent heat conductivity, which ensures good temperature homogeneity, and that the coefficient of heat transfer at the solid steel part/fluidized powder medium interface is relatively high.

Efforts have been made to act on all the parameters of the medium so as to improve this transfer coefficient. For example, powder media as varied as glass, bronze or copper are known, and it has been observed that the optimum values of the heat transfer coefficient where of the same order of magnitude for all these materials, whereas aluminum or lead gave lower values. In practice, only alumina in the corundum variety fluidized by air is employed as quenching medium. It is known that the cooling power of this quenching medium is between that of oil and that of blown air.

The problem therefore remained of finding the fluidized powder medium having a better transfer coefficient at the interface between the solid steel and powder medium so as to permit higher cooling rates which are desired for quenching steels having less carbon or above all having less alloy elements than those which would be necessary for quench hardening in the corundum-air medium.

Another feature of powder media is that they have insulating properties in the state of rest, and above all in the non-settled state after stopping the fluidization, namely : low apparent heat conductivity, low transfer coefficient at the interface between the solid steel part and the powder medium at rest. Consequently, the powder media are characterized by a very large difference between these two thermic properties between the fluidized state and the state of rest. Consequently, if the shape of the parts to be hardened is complicated, or if there are extensive regions on the surface where the tangent plane is but little inclined to the horizontal, the powder product can become calmly deposited therein and considerably reduce the heat exchanges. Consequently, these power media usually tend to result in irregularities in the cooling which result in detrimental distorsions and inequalities of hardening.

On the other hand, it has been shown in French Pat. No: 1,458,157 relating to the heat treatment of railway track rails, that it is possible to benefit from this property in the case of quenching rails, provided that the rail is disposed horizontally and in an inverted manner so that the rail head is lowermost and the rail flange constitutes a horizontal plane on which is deposited a heap of powder material at rest. Under these conditions, it is attempted to balance the discharge of the heat from the head and the flange so as to reduce the distorsions. With a fluidized powder medium of corundum and air it was found that the desired result was exceeded, since the head cooled quicker than the flange as opposed to what happens under the usual cooling conditions. The problem in this case is therefore to find a medium having intermediate properties so that there is at each instant of cooling equality between the mean temperature of the flange and that of the head of the rail so that the rail can be quenched without distorsion and that, after treatment, it be sufficiently straight not to require a straightening operation.

Thus, in the present state of knowledge and in comparison with the corundum-air medium, no fluidized powder medium for quenching track rails was heretofore known which ensured both a higher cooling rate and less quenching deformation of railway track rails. The problem is difficult since these two properties are usually contradictory. Indeed, accelerating the cooling increases the temperature inequality in the rail and consequently the deformations.

Long and costly research has enabled this problem to be solved. The invention provides a method of quenching steel railway track rails in a fluidized powder medium comprising placing the rail in a horizontal inverted position and quenching the rail in a fluidized medium consisting essentially of a powder of a substance selected from the group consisting of chromium, iron, nickel, molybdenum, tungsten and alloys of these metals, and a gas mainly consisting of steam.

Further features and advantages of the invention will be apparent from the ensuing description.

As an introduction to a description of the features and advantages of the process and fluidized medium according to the invention, there will first be made a comparative study of two quenching processes, namely a process employing a known fluidized corundum-air medium and a process employing a fluidized metallic chromium powder-steam medium according to the invention, the corundum powder having a grain size in the neighborhood of 0.1 mm diameter and the metallic chromium powder 0.08 – 0.18 mm diameter. The fluidized powder media are maintained at the temperature of 175° C. The flows are maintained around the optimum value of fluidization.

The experimental apparatus for containing the fluidized powder medium is cylindrical and has for effective dimensions : diameter 600 mm, height of the powder bed : 400 mm.

The steel specimens are round bars having a diameter of 60 mm and a length of 300 mm. The specimens are of eutectoid carbon steel : C = 0.85%, Mn = 0.3%, Si = 0.3%. Two thermoelectric couples are placed in such manner that the hot weld is halfway from the end sections, one on the axis and the other near the surface. The specimens are quenched in a position with the axis vertical or horizontal. In the latter case, the surface couple is near the point having a vertical tangent plane.

Each steel specimen is austenitized at 900° C, the period for bringing to the temperature in the muffle furnace being 45 minutes, and the period during which the temperature is maintained 30 minutes (total time 75 minutes). The specimen is thereafter quenched in the fluidized powder medium at 175° C and the temperatures are recorded as a function of time.

The cooling times are counted from the furnace removal temperature (900° C) or from the moment when the couple indicates 800° C. The cooling times are counted for the various indicated core or heat temperatures (650°, 600°, 500°, C). The times measured from 800° C onward are more accurate.

The symbol *t*, which designates these times in minutes, has added thereto the index 1 or 2 depending on whether the hardening is carried out respectively in the corundum-air medium or chromium-steam medium. The relative differences and gains have been calculated as a percentage. The results are given in the Tables I, II, III and IV respectively which relate to specimens having a horizontal axis and a core couple, a horizontal axis and a surface couple, a vertical axis and a core couple and a vertical axis and a surface couple.

TABLE I

	Co-rundum/ air t_1	chromium-steam t_2	t_1-t_2	$\frac{t_1-t_2}{t_1}100$
900° to				
650°C	4.4	3	1.4	32
600°C	5	3.6	1.4	28
500°C	6.5	4.8	1.7	26
400°C	7.4	6.1	1.3	17½
800° to				

650°C	3.2	2.1	1.1	34
600°C	3.8	2.7	1.1	30½
500°C	5.3	3.9	1.4	26
400°C	6.2	5.2	1	16

TABLE II

	Co-rundum/air t_1	chromium steam t_2	t_1-t_2	$100\frac{t_1-t_2}{t_1}$
900° to				
650°C	1.7	1.4	0.3	17½
600°C	2.8	2.2	0.6	21
500°C	5.1	3.8	1.3	25
400°C	6.1	4.4	1.7	27
800° to				
650°C	1.2	0.6	0.6	50
600°C	2.3	1.4	0.9	39½
500°C	4.6	3	1.6	35
400°C	5.6	3.8	1.8	32

TABLE III

	Co-rundum/air t_1	Chromium/steam t_2	t_1-t_2	$100\frac{t_1-t_2}{t_1}$
900° to				
650°C	3.8	2.8	1	26
600°C	4.4	3	1.4	32
500°C	5.2	3.7	1.5	29
400°C	7.0	4.8	2.2	31
800° to				
650°C	3.3	2	1.3	39
600°C	3.9	2.2	1.7	44
500°C	4.7	2.9	1.8	38
400°C	6.5	4	2.5	39

TABLE IV

	Co- Chromium/ rundum/air t_1	Chromium/steam t_2	t_1-t_2	$100\frac{t_1-t_2}{t_1}$
900° to				
650°C	2	1.5	0.5	25
600°C	3.4	2.3	1.1	32
500°C	5.1	3.4	1.7	33
400°C	6.9	4.4	2.5	36
800° to				
650°C	1.5	0.9	0.6	40
600°C	2.9	1.7	1.2	52
500°C	4.6	2.8	1.8	39
400°C	6.4	3.3	3.1	40.5

As all the heatings were carried out in a muffle furnace and with a rather long heating time, the surface oxidation state is rather pronounced so that the transfer coefficients are lowered and the relative differences between the different cooling media are reduced. However, the benefit remains very distinct and reveals the advantage of the chromium/steam medium.

The relative percentage gains $100\ t_1-t_2/t_1$ in changing from the corundum-air medium to the chromium-steam medium are given in the Table V.

TABLE V

The values of $100\ t_1 - t_2/t_1$ are calculated from 800° C onwards.

Orientation of the cylinder	Horizontal		Vertical	
Position of the couple	heart	surface	heart	surface
Reference to preceding tables	I	II	III	IV
Optimum value	34	50	44	52
mean value	26.5	39	40	45.4

It can be seen, therefore, that the benefit is considerable. With steels having the analysis C = 0.85% and Mn = 1.85%, changing from the corundum-air medium to the chromium-steam medium suffices to pass from a 70 percent pearlitic structure to a perfectly quenched structure, which is a lower bainitic or martensitic structure (as desired, depending on the duration of immersion before the final cooling at room temperature).

By way of example, round steel bars having the same dimensions as before but in two grades of alloy steels designated A and B, were austenitized at 900° C for a period of 75 minutes of full heating, quenched vertically in the fluidized chromium-steam powder medium at 170° C, maintained immersed for 4 minutes and then cooled in calm air. After cutting the median cross section with the grindstone, the hardnesses Te along a diameter were measured. These were expressed in Rockwell indices (Rc cone). The results are given in Table VI.

TABLE VI

ROCKWELL HARDNESS AFTER QUENCHING

Analysis of the steel	A	B
% C	1.05	1.05
% Mn	1.80	0.35
% Cr	–	1.30
% W	–	–
% Si	0.3	0.35
Rc hardness surface	55–51	55–53
Rc hardness in the heart	57	55½

It can be seen that hardness variations along the radius are very small and are those which can be normally obtained owing to accidental variations of a cast steel in ingot form and rolled into a bar.

The same steels A and B, when austenitized under the same conditions and then immersed in a corundum-air medium at 170° C, do not harden. The Rc hardness remains between 28 and 36 in the heart, 30 and 40 on the surface.

Tests were also carried out on self-hardening steel so as not have the recalescence in the concerned range of temperatures. Specimens of the same size, with a couple in the heart and quenched in the vertical position, were tested. The austenitizations were effected at 900° C and, during the quenching, the temperature was recorded and the times required for reaching either 700° C or 500° C were noted. Air quenching, oil quenching, in both cases at room temperature and quenching in the chromium powder-steam medium at 140° C were compared. The results are given in Table VII.

TABLE VII

Medium Nature	Temperature °C	from 900° to 700°C time (minutes)	from 900° to 500°C time (minutes)
Air	28	340	1,060
Chromium steam	140	60	120
Oil	28	50	100

It can be seen that the cooling rate of the quenching medium consisting of chromium powder fluidized with steam at the temperature of 140° C is very near that of a bath of oil at room temperature. This is a remarkable result.

Further, the invention not only improves the cooling capacity of the medium and, consequently, its steel quenching properties, but also avoids the unequal heat and the quenching deformations in the case of railway track rails treated in accordance with the teaching of U.S. Pat. No. 1,458,157 relating to the heat treatment of rails.

If a rail is cooled in accordance with the usual natural air cooling conditions, it is well known that the flange of the rail, whose surface area is substantially double that of the head for a mass of a given magnitude, cools much quicker. Between the head and the flange, this unequal heat results in differences in the simultaneousness in both the heat shrinkages of the cooling and the extensions of the transformation. As the different parts are rigidly interconnected stresses are set up which are more or less released by flow at high temperatures but which cause, at low temperatures when the metal is rigid, permanent deformations. It is well known that, as it issues from the mill, the rail which cools naturally in the air on a grid deforms in the shape of a sword. To specify the direction of the curve, it is assumed that, during the cooling, the rail is held fast in such manner that it is maintained rectilinear. The heat stresses are released at high temperatures by flowing in the regions in extension whereas at the end of the cooling the steel becomes rigid so that the direction of the residual stresses is determined by the last moments of the cooling. As it is the head of the rail which cools last, it tends to shrink and, as it is not free to do so, it becomes the center of tensile stresses. If, after cooling, the holding means are removed, the head contracts and elastically deforms the rail until the stresses are balanced internally. The rolling face of the head becomes concave and the bearing face of the flange convex.

It is obvious that if instead of cooling in calm air, the rail is quenched, the heat inequality in the mass is increased, which increases the deformations. In order to both ensure the quenching and eliminate the spatial heat inequality in the course of cooling, the following tests, which reveal the originality of the invention, were carried out.

Samples of 30 cm in length from 50 kg/meter, Thomas steel railway track rails of the S.N.C.F. (French Railways) Vignole type were taken. Arranged on each sample was a thermoelectric couple with hot welding to the heart of the head of the rail and another to the heart of the flange. These samples were austenitized at 900° C during the same time and quenched in different media. Apart from one exception, the rails were immersed horizontally in the inverted position, the rolling surface being lowermost and the flange uppermost and forming a horizontal plane. The sole exception corresponded to the immersion of a vertical rail. The cooling curves were recorded. On the latter are shown: the time at the end of which the mean temperature between the two couples reaches 500° C, the difference of temperature between the two couples and which one is the hotter. The results are shown in Table VIII.

TABLE VIII

Orientation of the rail	Quenching medium type	temperature	(x) time in min.	(xx) absolute difference (in °C)	(xxx) hottest side
Horizontal	calm-air	25°C	14	**75**	head
"	corundum-air	25°C	5	**170**	flange
"	corundum-air	175°C	6.5	**110**	"
"	chromium-steam	175°C	5.5	**6**	"
"	chromium-steam	140°C	5	**7**	"
Vertical	"	175°C	2.5	**155**	head

(x) time at the end of which the mean temperature of the two temperatures of the two couples is 500°C.
(xx) difference between the two couples at the end of the same time.
(xxx) at the end of the same time.

The following conclusions can be drawn from the foregoing :

1. On an average, the steam fluidized chromium powder medium cools quicker than the corundum-air medium at the same temperature of 175° C.

2. On an average, the chromium-steam medium at 140° C cools as quickly as the corundum-air medium at room temperature.

3. The head of the rail which has, for a mass of the same order as that of the flange, a surface which is roughly half and cools more slowly than the flange in the natural cooling in free air(the same is true on the grids at the outlet of the mill)and held vertically in the chromium powder medium fluidized with steam at 175° C. The difference is greater in the latter medium since it cools quicker and respects better the dissymmetry due to the profile.

4. When the horizontal rail is inverted and quenched in the powder medium, the direction of the temperature difference is reversed. This is due to the heat of the powder at rest deposited on the upper horizontal face of the flange.

5. Still with the same position of the rail, the temperature differential is smaller for the chromium-steam medium than for the corundum-air medium, irrespective of the temperature of these two media.

6. Again with the same position, the temperature differential is smaller for the corundum-air medium at 175° C than for the corundum-air medium at room temperature.

7. For the same position, and for the chromium-steam medium, the temperature differential remains very small, whether the medium be at 175° C or 140° C.

8. In conclusion, with the rail in the inverted horizontal position, the chromium-steam medium at 140° C eliminates the temperature differences while it ensures a very rapid cooling. No known medium has this remarkable property.

The foregoing tests concerned railway track rails of current manufacture whose analysis is C = 0.45%, Mn = 1.05%, so that in these media the steel is not hardened. The thermal anomaly or recalescence due to the pearlitic transformation is seen on the cooling curves. It will be understood that it completely disappears with steels which are more carburized and more alloyed, such as those shown in Table VI.

It may be added that each time that there is a heat or temperature inequality, there is a deformation of the rail and that only immersion in the new fluidized chromium-steam powder medium with a horizontal inverted orientation, results, after a complete cooling at room temperature, in a rectilinear rail devoid of deformation, if initially, at the moment of immersion of the rail, the temperature was homogeneous.

In conclusion, the fluidized chromium-steam powder medium has this double apparently paradoxical and contradictory property of resulting in a more rapid cooling of the immersed parts and avoiding deformations in the case of correctly oriented rails.

In other words, it has the double property of possessing a distinctly increased quenching power and eliminating hardening deformations of the rails. Finally, qualitatively, it possesses the double property of having sufficient quenching power for the contemplated steel compositions (which would not harden in the corundum-air medium) and completely eliminating the quenching deformations.

Other tests, which are not mentioned here since the results are analogous to those of the fluidized chromium-steam powder medium, have shown that the chromium can be replaced by one of the following metals : iron, nickel, molybdenum, tungsten, or by alloys of the latter mixed together or with other elements in any proportion, and in particular stainless steels containing chromium, chromium-nickel or chromium-aluminum; iron alloys such as ferro-chromium, ferro-silicon, ferro-molybdenum, ferro-tungsten, ferro-nickel, iron-aluminum; the nickel-chromium and nickel-copper alloys.

Within the scope of the invention, the steam can be replaced by a gaseous mixture rich with steam. By way of example, this can be a mixture of a large amount of steam with a small amount of hydrogen and carbonic gas, possibly also nitrogen and traces of carbon mon-oxide. Thus, if there is added to the steam a small amount of methane, for example in the form of a natural gas or a coke works gas and if the methane is converted hot according to the desired reaction (from left to right):

$$CH_4+2H_2O \rightleftharpoons CO_2+4H_2$$

to which is added the gas-water equilibrium:

$$CO_2+H_2 \overset{(2)}{\rightleftharpoons} CO+H_2O$$

in the presence of a great excess of steam, the preceding reaction has an evolution in the direction (2) so that there are only traces of carbon mon-oxide, as is known. A heat exchanger provided between the steam before its introduction in the reactor and the gas issuing from the reactor improves the thermal balance, as is known. The conversion can be effected in a fluidized catalyst powder medium of nickel and with heating by means of tubes embedded in this medium in the known manner. Of course, no separation of the constituents of the reaction is effected so that the device is very simple and robust. A small addition of methane or coke works gas is sufficient to obtain cheaply a gaseous mixture which is rich with steam and has distinctly improved cooling properties.

It is obvious that for the operation of the quenching process, the temperature of the medium is higher than the boiling temperature of the water under the considered pressure. It is therefore higher than 100° C.

With this reservation, the temperature is defined by the conditions required for the metallurgical treatment. This can be, for example, a temperature but slightly higher than the Ms temperature of the beginning of the martensitic transformation of the considered steel if it is desired to effect a martensitic hardening in stages with the minimum of deformations and residual stresses. This can be a slightly lower temperature if the critical quenching rate so requires. If it is intended to effect an isothermic bainitic transformation, this can be, for example, the temperature corresponding to the maximum rate of bainitic transformation, of the order of 420° C, which temperature is slightly variable with the steel compositions. A temperature between 420° C and 500° C can be employed if it is desired to obtain less hardening than in the preceding case.

A higher temperature is of no interest owing to the lower rate of cooling and higher heating costs.

In conclusion, it may be said that the temperature must be chosen between 100° and 500° C by conventional metallurgical considerations.

Having now described my invention what I claim as new and desire to secure by Letters Patent is:

1. Process for quenching steel heated railway track rail issuing from a mill comprising placing the rail in a horizontal inverted position with the rail head being lowermost and quenching the rail in a fluidized medium consisting essentially of a powder of a substance selected from the group consisting of chromium, iron, nickel, and alloys of said metals, and a gas consisting essentially of steam, the temperature of the fluidized medium being 100°–500° C.

2. Process as claimed in claim 1, wherein said alloys are stainless steels containing as alloys a substance selected from the group consisting of chromium, chromium-nickel and chromium-aluminum.

3. Process as claimed in claim 1, wherein said alloys are ferro-alloys.

4. Process as claimed in claim 3, wherein said ferro-alloys are selected from the group consisting of ferro-chromium, ferro-silicon, ferro-nickel, iron-aluminum.

5. Process as claimed in claim 1, wherein said alloys are selected from the group consisting of nickel-chromium and nickel-copper alloys.

6. Process as claimed in claim 1, wherein said gas is pure steam.

7. Process as claimed in claim 1, wherein said gas consists of steam and small percentages of hydrogen and carbonic gas.

8. Process as claimed in claim 1, wherein said gas consists of steam and small percentages of hydrogen, carbonic gas, nitrogen and CO.

9. Process as claimed in claim 1, wherein said gas is obtained after conversion of methane by excess steam.

10. Process as claimed in claim 1, wherein said gas is obtained after conversion of natural gas by excess steam.

11. Process as claimed in claim 1, wherein said gas is obtained after conversion of coke works gas by excess steam.

12. Process according to claim 1 comprising placing the rail in a horizontal inverted position and quenching the rail in a fluidized medium consisting of a metallic powder of chromium and a fluidizing gas consisting essentially of steam.

13. Process according to claim 1 comprising placing the rail in a horizontal inverted position and quenching the rail in a fluidized medium consisting of a metallic powder of a ferro-chromium alloy and a fluidizing gas consisting essentially of steam.

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