3,174,884 METHOD OF SURFACE HARDENING STEEL ROLLS AND APPARATUS FOR CARRYING OUT THE SAME

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The invention relates to a method of surface-hardening forged or cast steel rolls, particularly cold rolls. A well known technique for raising the temperature of the surfaces which are to be hardened and one which is used particularly for the hardening of rolls is that of inductive or conductive heating. Especially in the case of cold rolls the introduction of inductive hardening has eliminated difficulties which had been encountered before. Inductive hardening did away with the necessity of raising the temperature of the entire roll to hardening temperature and of then quenching the same for forming the desired hard surface skin. It permitted the surface of the roll to be heated to a given depth and to be quenched without affecting the core of the roll. Consequently a tough core could be formed with a hard skin. In the course of extended practical experience this method has been developed to give very satisfactory results.

Nevertheless the method has one decisive drawback. As known, particularly in large rolls having diameters exceeding 250 mm., the technique of progressive hardening is employed. This consists in advancing an inductor across the roll surface and in quenching the surface by spraying it immediately behind the inductor. Despite the adoption of various techniques, such as a slow speed of advance or the provision of two inductors in tandem as well as the choice of low frequencies for energising the inductor coil, it was impossible to obtain satisfactory hardened layers of greater depth. When this is the aim, there is considerable risk of the outermost skin being damaged and of hair cracks appearing after a time. It was therefore necessary to compromise by foregoing the advantage of greater depth of the hardened zone in favour of obtaining an unexceptionable surface skin.

The object envisaged by the invention is a method which permits production of rolls having the phenomenon to be raised to hardening temperature, said zone being quenched immediately afterwards as the inductor moved on.

According to the invention the surface of the workpiece is adjacent cooled to prevent its temperature from rising to beyond the critical Acr point. During inductive heating cooling is performed in the region which is actually under the influence of the inductors. In conductive heating the entire surface of the workpiece through which the current passes must be cooled. Although the surface is thus cooled the use of a high power density nevertheless permits a temperature peak above the Acr temperature to be generated inside the workpiece at a not inconsiderable distance from the surface without much difficulty. This means that a temperature peak is generated inside the work without overheating the external surface and without injuring the outermost skin of the workpiece.

When the desired temperature peak in the workpiece interior has been reached cooling is stopped and the temperatures are allowed to equalize. A high temperature wave is thus allowed to travel from the interior to outside through the entire zone that is to be hardened and when this has occurred quenching takes place for the purpose of hardening this zone.

By the application of the method proposed by the invention the hardening effect can be arranged to penetrate far deeper into the work than was hitherto possible. Moreover an external surface which has not sustained damage can thus be created because at no time is the outside surface overtreated. The greater penetrating effect of this hardening process has the further result that the hardened zones are better supported and are unlikely to yield when later they are exposed to considerable loads. The invention therefore eliminates a deficiency of surface-hardened workpieces which are later exposed to high loads. Conductive heating has the special advantage of being highly efficient with a high power factor.

The desired temperature equalization between the temperature peak inside the workpiece and the cooled external layer can take place if there is an interval of delay between the termination of cooling and the beginning of quenching. However, the process can be assisted by supplementary inductive heating. This is especially useful if the workpieces consist of sensitive steels.

In such steels the temperature peak must not significantly exceed the actual hardening temperature. In order to prevent the overall temperature from dropping below the critical Acr point when the temperatures equalise, supplementary heating is useful. Supplementary heating can ensure that the temperature distribution curve between the external skin and the point where the temperature peak had been created is completely horizontal, whereas temperature equalisation without additional heating results in a temperature curve which slightly rises towards the points where the temperature peak had been established.

It is best to work with currents having frequencies between 50 and 600 c./s., since the intention to penetrate as far as possible into the workpiece interior when heating and hardening militates against the use of higher frequency currents.

The proposed method is ideal for deep hardening without affecting the structure of even deeper zones and of the core. The temperature at which the external skin should be maintained by cooling will generally depend upon the workpiece dimensions, the electrical power applied, the duration of heating and other factors.

Consequently, cooling will be so arranged that the permeability of the cooled zone remains low. Temperatures between 600 and 780° C. should be best.

It has also been found that the use of a mixture of compressed air and water is particularly satisfactory as a coolant. The effect of this known type of coolant and quenching medium can be easily controlled by varying the proportion of compressed air and water as well as
pressure and quantity. It is therefore possible to provide a highly differentiated cooling effect.

Nevertheless, water or air can be individually used. During conductive heating it is advisable to cool the edges of the cylindrical part of the roll with air, gas, a liquid, or mixtures thereof. The method according to the invention is applicable to inductive heating by the progressive hardening method or by overall surface-hardening, that is to say to processes which are known and conventional in the technology of surface-hardening.

If the progressive hardening process is used the invention proposes to provide an inductor with a cooling sprayer arranged to act directly upon the zones on the workpiece which are under the influence of the inductor.

At an adjustable distance behind this combined inductor and sprayer a quenching sprayer. In a particularly simple arrangement the coolant may be sprayed on to the workpiece through the coil of the inductor itself.

An arrangement of this kind is schematically illustrated in FIG. 1. The roll 1 is being surface-hardened according to the method proposed by the invention. To this end an inductor coil 3 comprising several turns surrounds the roll. The coolant which keeps the outer skin cold despite the application of a high electrical power density is sprayed between the turns of the coil of the inductor 3 on the surface 1 of the roll which is exposed to the induction effect of the coil. This is indicated by arrows 4. The roll moves through the inductor as indicated by arrow 5. In the portion 6 of the roll which leaves the inductor the described equalisation of temperature levels between the peak generated inside the roll and the surface takes place, and when this portion of the roll reaches the quenching sprayer 7, the entire zone between the former temperature peak and the surface will have reached hardened temperature, i.e., a temperature about the critical Ac temperature. Quenching then proceeds in conventional manner.

FIG. 2 illustrates an alternative in which the work 1 is taken through the coil in translatory motion in direction of arrow 5 besides being simultaneously rotated about its axis as indicated by arrow 8. It is therefore possible in a manner known as such to provide one or more loops of the heating conductor, in the illustrated example those marked 9, with magnetically permeable laminations 10. Coolant spraying nozzles 11 are located between these loops 9. It will be understood that when axially advancing and simultaneously rotating the roll the same effect can be achieved as that described by reference to FIG. 1. The quenching sprayer 7 is indicated at 7.

In the arrangement according to FIG. 2 the equalisation of temperatures can be assisted by the provision of a further inductor in the intervening zone.

In FIG. 3 the entire cylindrical part 1 of roll 2 is embraced by the coils of an inductor 12. The coolant is sprayed on to the surface through the gaps between adjacent turns in the direction indicated by arrow 13. When the process of heating and simultaneous cooling has lasted long enough to generate a temperature peak inside the roll, power is cut off and the temperatures are allowed to equalise during a waiting period at the end of which the roll is quenched. For accelerating the equalisation of temperatures power can be supplied to the coil during this period of waiting whilst the cooling spray is shut off. It may be advisable to rotate the roll to ensure that the coolant and quenching medium will have a uniformly even effect. The coolant and quenching medium may be sprayed consecutively between the turns of the coil of the inductor 12. FIG. 4 shows an arrangement in which a heating loop 14 is arranged to extend axially along the length of the cylindrical part 1 of the roll. This loop is provided in conventional manner with magnetically permeable sheet metal laminations 15. The roll 2 rotates whilst advancing, and it will be readily understood that the entire surface of the roll will thus be heated. Immediately behind the inductor is a sprayer 16 through which a coolant and a quenching medium can be supplied in succession. Alternatively the quenching sprayer may take the form of a box 17 which surrounds the entire induction device.

For a cold roll between 400 and 500 mm diameter a power intensity of say 0.1 kw./sq. cm. surface will be needed. The temperature of the outer skin is maintained at 750° C., whereas the temperature peak in the interior may be 850° C.

After temperature equalisation with the simultaneous supply of further heat a temperature of 850° C. may be established substantially throughout the zone from the former peak to the external surface. The temperature peak is generated at a depth of 15 mm. by using a frequency of 500 c/s. A depth of the hardened zone of 20 mm. can thus be established with ease.

Unless the procedure proposed by the invention is employed, a depth of only 10 to 12 mm. can be achieved in otherwise similar circumstances.

It is advisable for surface hardening to begin the treatment by first heating to about 750° C. with a relatively low power density in the absence of cooling. As soon as this temperature has penetrated far enough, the equipment is operated at a high power density with the simultaneous application of the coolant. If the progressive method of hardening is used, the described procedure can be performed by providing a further preliminary inductor operating with a low power density ahead of the main inductor.

For applying the proposed method to a conductive heating process the invention further proposes to apply the current supply contacts in the form of rollers or slippers to the ends of the roll and to locate them in a common axial plane through a roll generator. A linear zone of the roll surface can thus be raised to elevated temperature. Since the roll also rotates about its own axis the heating effect will affect the entire cylindrical surface. Rotation of the roll being continued until an even surface temperature distribution at the desired level has been achieved.

FIG. 5 illustrates two different forms of such an arrangement.

Roll 1 revolves as indicated by arrow 2. Contact rollers 3 or possibly slippers supply current to the end of the cylindrical part of the roll. This disposition is employed if it is desired to create a hardened zone as indicated by the dotted line at 4, i.e., a zone which ends slightly short of the ends 5 of the cylindrical part of the roll.

The problem is indicated at 7.

In either case it is advisable to place the current supply conductors 8 and 9 as closely as possible to the roll surface. The current will then be concentrated near the roll surface.

The slippers or contact rollers are conveniently water-cooled to remove the heat generated by contact resistance and the heat generated in the contact bodies themselves and in their supply leads.

What I claim is:

1. A method of surface-hardening rolls, particularly cold rolls, of forged or cast steel that can be hardened by heating and quenching, in which a hardened zone penetrating to greater depth than usual is generated by applying a high electrical power density and thereby heating the roll above the critical point while at the same time cooling the surface of the roll to a temperature below the said critical point thereby to establish a temperature peak above the critical point inside the work, then discontinuing said cooling and equalising the temperatures be-
between the said peak and the said surface and causing the temperature of the whole of the zone which is to be hardened to attain at least the critical temperature, and then quenching the roll.

2. A method of surface-hardening rolls of forged or cast steel that can be hardened by heating and quenching which comprises heating the roll around its periphery by the application of a high electrical power density and thereby generating a temperature peak above the $A_0$ point in the work under the surface while at the same time within the same axial extent of the roll in which heating is thus taking place cooling the surface to temperature in the region of the $A_0$ point and then discontinuing the cooling and allowing the temperature between the said peak and the surface to equalise and the temperature of the whole of the zone which is to be hardened to rise to a temperature at least up to the $A_0$ point and then quenching the said zone.

3. The method according to claim 1, in which the equalisation of temperature is assisted by supplementary heating, after discontinuing said surface cooling and before commencing said quenching.

4. The method according to claim 1, in which the said heating is effected by the application of low frequency currents between 50 and 600 c/s.

5. The method according to claim 1, in which the temperature of the cooled outer skin is maintained in the region between 600 and 780° C. while undersurface heating takes place.

6. The method according to claim 1 in which a compressed air and water mixture is used in at least one of the said cooling and quenching steps.

7. The method according to claim 1, in which heating is performed electro-inductively and the roll is progressively heated by relative axial movement between the roll and the inductor means.

8. The method according to claim 1, in which the heating is performed electro-inductively and simultaneous heating and cooling take place on the overall peripheral surface of the roll.

9. The method according to claim 1 in which the roll is primarily heated to about 750° by the application of relatively low specific power without being simultaneously cooled and is then heated by the application of high specific power while being simultaneously cooled.

10. The method according to claim 1, in which the heating is effected electro-conductively.

11. The method according to claim 10 in which the edges of the cylindrical portion of the roll are cooled and prevented from reaching the hardening temperature.

12. A method of surface-hardening rolls, particularly cold rolls, of forged or cast steel which can be hardened by heating and quenching, in which a hardened zone penetrating to a greater depth than twelve millimetres is generated by heating the roll in the region under its surface at a high electrical power density produced by currents of a frequency of from fifty to six hundred cycles per second while at the same time applying a cooling medium to the surface and thereby cooling said surface to a temperature below a critical temperature and from 600° C. to 780° C. whereby a temperature peak above the said critical temperature is generated inside the work which is at least 100° C. greater than that to which the surface is cooled; discontinuing the surface cooling and equalising the temperatures between the said peak and the said surface and causing the temperature of the whole of the zone which is to be hardened to attain at least the critical temperature and then quenching the roll.

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