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(54) Method of treating tool steel die materials

(57) In a method of hardening pilger dies to provide a hard case containing residual compressive stresses and tough body, the tool steel die is heated to the austenitizing temperature range, followed by selectively removing heat from the die at a predetermined faster rate in the direction of the desired case than the rate of heat removal from the balance of the die, and thereafter tempering the die.

The invention provides a fully hardened and tempered case on the working surface of the die and a tough body in the balance of the die, usually of lower hardness.

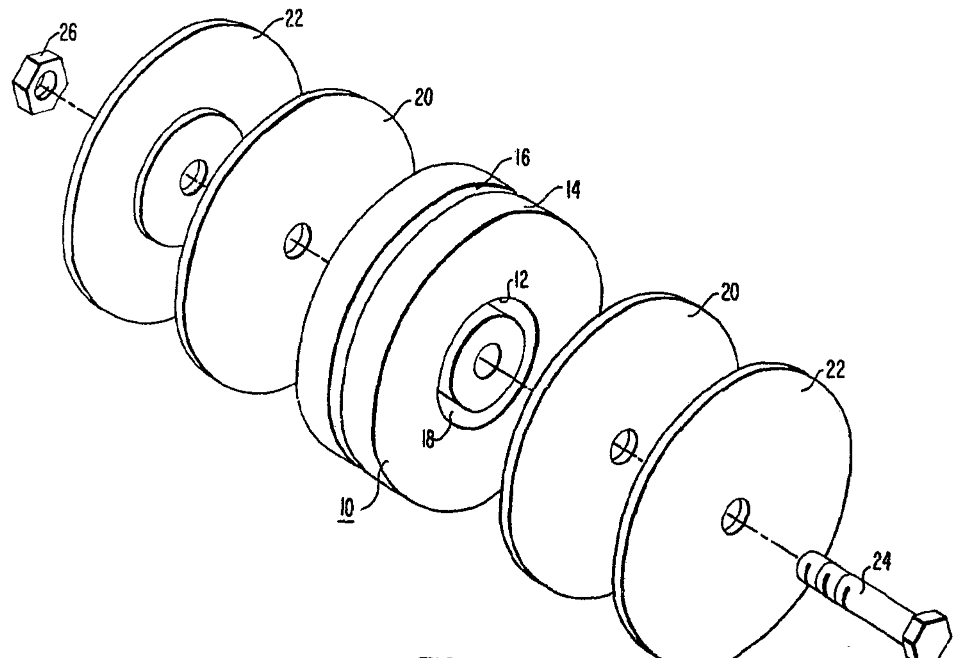

FIG. 1

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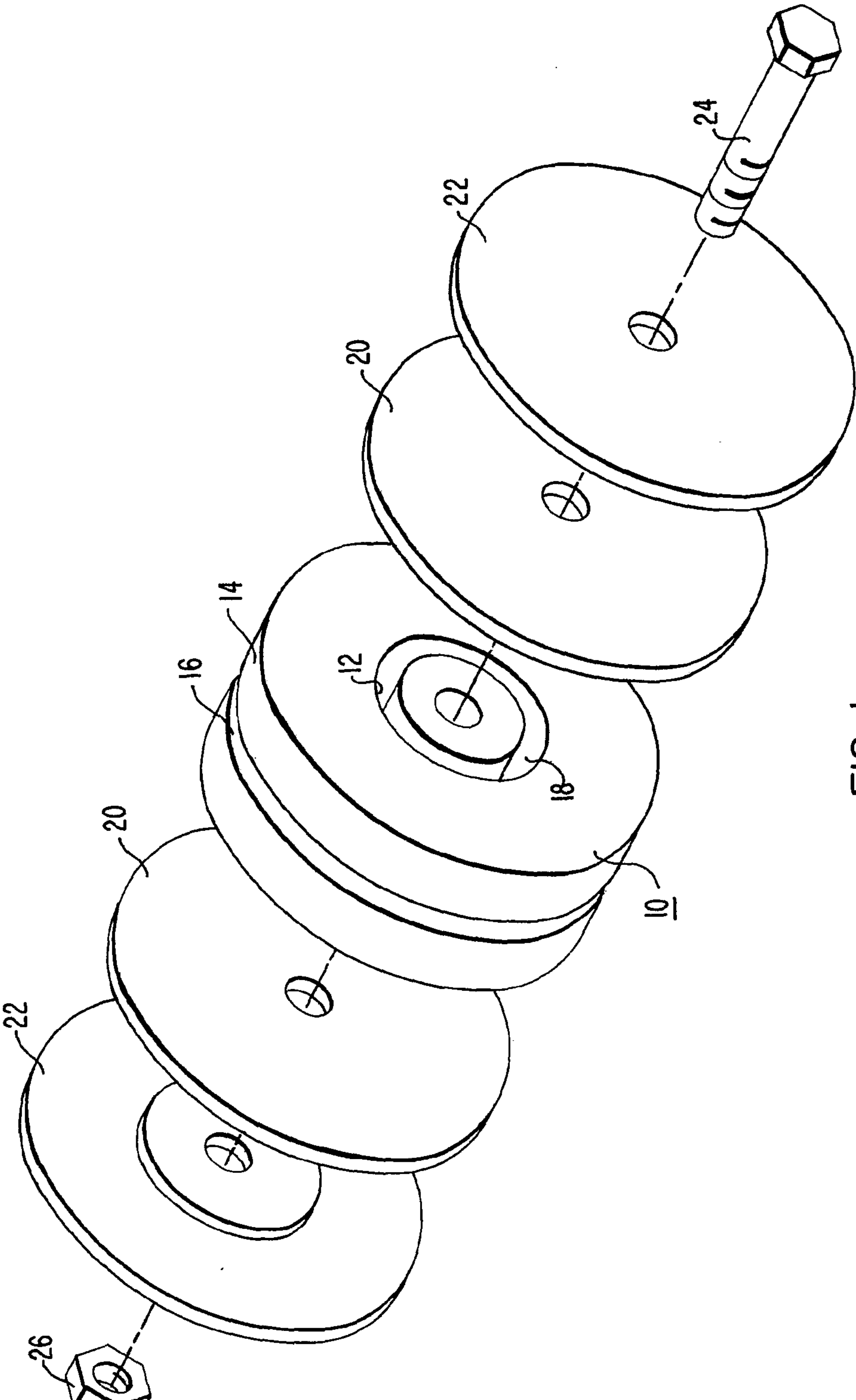

FIG. 1

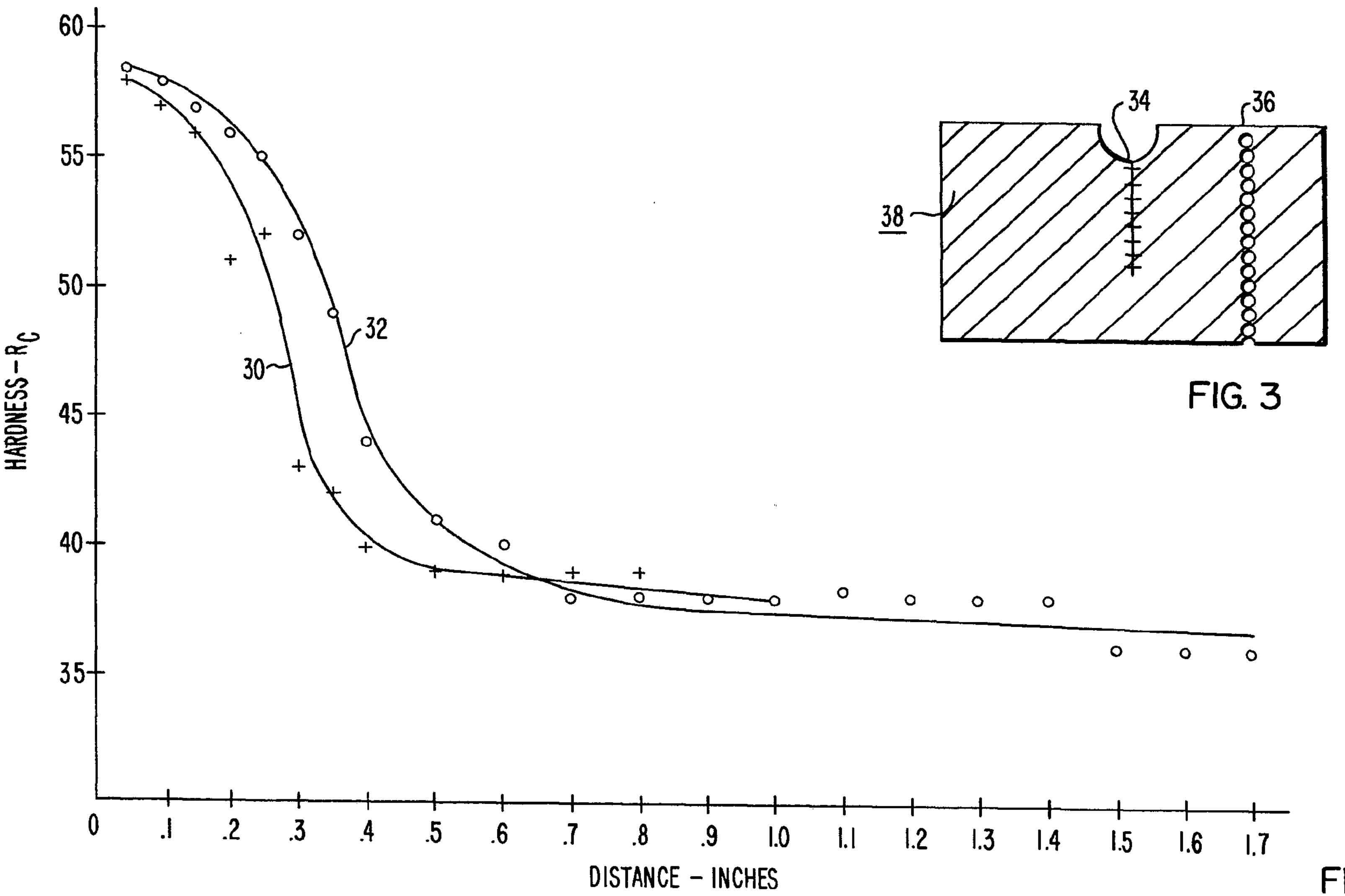

FIG. 3

FIG. 2

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SPECIFICATION

Method of treating die materials

This invention relates to tool steels and in particular to a method of treating die steels to obtain improved useful life when these tool steels are used for example in a pilger machine.

Pilger machines employ opposed dies with the tapered groove on the periphery of the dies in the working area. The reciprocation of the opposed dies over the tube being worked which is supported by a mandrel results in the cold reduction of the work tube.

One of the criteria for satisfactory die performance is the number of feet of tubing produced over the die life. Typically the die will be used until the groove surface deteriorates to a point that defects are produced on the tube surface. The groove and periphery of the die will then be remachined, for example by grinding, to remove the defect and the die returned to service. Dies are regrooved and reused as many times as possible within the limits of the die and machine dimensions. The regrinds may total as many as six or more. The reason for this becomes apparent when one considers the use of a pilger machine for the production of for example Zircaloy tubing for a nuclear reactor.

One of the major considerations in the production of Zircaloy-4 tubing for nuclear reactor fuel cladding is the hydriding behavior of the final product. The formation of hydrides in the tube material is a natural consequence of the in-service corrosion of the Zircaloy-4 by the hot coolant water. Some of the hydrogen produced by the corrosion reaction tends to diffuse into the tube material and for platelets of zirconium hydride. The presence of these hydrides adversely affects the mechanical properties of the tube especially if they are oriented in a radial direction in the tube wall.

A principal method of minimizing the formation of these radially oriented hydrides is to adjust the crystalloagraphic texture of the tube such that the hydride platelets prefer to form circumferentially. This is done primarily by suitable control of the tube manufacturing process and in particular the final cold pilger mill reduction. The approach to minimizing radial hydriding in Zircaloy-4 tubing is to maximize the amount of wall reduction versus the diameter reduction during cold working. That is produce the tubing with a high ratio of percent wall reduction to percent diameter reduction. This results in a texture in this hexagonal close pack material such that the basal poles are oriented primarily in a radial direction. The development of such a texture produces a material which is highly resistant to the formation of radial hydrides during subsequent hydriding test and in nuclear reactor service.

According to the present invention a method of hardening piler dies to provide a hard case containing residual compressive stresses and a tough body comprises a method of hardening pilger dies to provide a hard case containing residual compressive stresses and tough body, which comprises heating the die to the austenitizing temperature range, selectively removing heat from the die at a predetermined faster rate in the direction of the desired case thar the rate of heat removal from the balance of the die, and thereafter tempering the die.

An alloy is employed which may be air hardening, oil hardening or water hardening depending upon its ultimate particular use and which through heat treatment has the ability to form a hardened case. Particular success in cold pilger mills has been obtained with an oil hardening composition such as the steel known as 52100. A closely allied steel is that produced by Bofers and is identified as SR1855. Typically these compositions comprise about 1% carbon, up to about $1\frac{1}{2}$% silicon, up to about 1% manganese, about $1\frac{1}{4}$% chromium and the balance iron with the usual incidental impurities.

The technique for directionally hardening these materials involves a refinement in the heat treatment to produce a fully hardened and tempered case on the working surface of the die and a tough body in the balance of the die. This tough body is usually of lower hardness.

In this respect the periphery and the groove comprise one of the working surfaces of the pilger die and is heat treated to provide a compressive residual stress due to the lack of complete hardening of the core or body portion of the die. The compressive residual stresses resist groove surface deterioration in service and the high case hardness provides the needed strength in service. At the same time the balance of the die is placed in a state of tensile stress. This is accomplished by applying an insulation to the bore of the die and to all of the exposed surfaces except the periphery and groove of the die where the hardened case is desired. By thus applying the insulation and heat treating the material in accordance with the steel manufactures recommendations, the hardened periphery and groove is obtained which will have high strength and compressive residual stresses while the body of the steel will be provided with a toughness and will essentially be placed in a state of tensile stress as opposed to the surface compressive stress of the directionally hardened die.

In order that the invention can be more clearly understood, a convenient embodiment thereof will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of one manner of directionally hardening a pilger die;

Figure 2 illustrates a plot of the hardness traverse of a typical pilger die employing the teachings of this invention; and

Figure 3 illustrates a section through the die and is marked to show the hardness traverses.

In practicing the method of the present invention, a die steel is selected which will provide the suitable hardened case and a tough body and which can be machined to provide the requisite die configuration on the outer periphery as well as being adaptable to the actual machinery itself. In the production of Zircaloy-4 fuel clad tubing, it has been found that an oil hardening grade of steel is eminently suited although it is possible to use air hardening as well as water hardening steels. In particular, two compositions which have been successfully employed have the following composition, SR1855 contains 1.0% carbon, 1.5% silicon, 0.8% manganese, 1.0% chromium, and the balance iron with incidental impurities. Another composition which is also useful is that material known as 52100 which contains 1.0% carbon, 0.3% silicon, 0.4% manganese, about 1.45% chromium, and the balance iron with incidental impurities. These materials, in the properly annealed condition, can be machined in order to produce the requisite groove characteristics of a pilger die and can be bored so that the die may be placed within a pilgering machine. It is only after the die is in its final configuration, that is, the die is provided with the bore so that it may be attached to the cold pilger machine and is provided with a groove periphery that will actually work the Zircaloy-4 fuel clad tubing after finishing machining following the teachings of this invention, that the material is in condition for the application of the method of the present invention.

In this respect, the die shown generally at 10 in Figure 1, is provided with a bore 12 and a periphery 14 into which a predetermined shaped groove 16 has been previously fabricated by any suitable method. The pilger die 10 is thereafter provided with a heat insulating material which is utilized to plug the bore 12, said plug being identified with the numeral 18. Adjacent to the side wall of the die 10 a similar heat insulating material usually in sheet form and identified with the numeral 20 is provided so that the same may be held in close proximity and preferably touching the side wall of the die 10. A steel end plate 22 is provided adjacent the heat insulating material sheet opposite to the face of the side wall of the die body 10 and the entire assembly is thereafter locked in place by means of bolt 24 and a corresponding nut 26 which is disposed to extend from the steel end plate 22 on one side of the die through to the steel end plate on the other side of the die. As thus assembled the pilger die is ready for heat treatment.

The refractory heat insulating material as described previously may be a material such as that marketed by the Carborundum Corporation under the name "FiberFrax" (R.T.M.) or a material made by Hitco and marketed under the name "Refrasil". Both products have been used successfully. The material, whichever is used, must be heat insulating and thus refractory in nature so that the heat which could be extracted through the side walls and the bore where the refractory heat insulating material is placed is removed at a substantially slower rate than the direction where there is no refractory heat insulating material, namely, the periphery and the groove of the die.

As thus assembled the unit may be heated to the austenitizing temperature held for a suitable period of time to bring the die section to temperature and thereafter the die is quenched. More specifically one heat treatment found to be effective has been to heat the die to a temperature within the range of 830°C and 950°C with the preferred range being about 870°C ± 7°C. At this temperature or temperature ranges the die is usually held for a period of one hour and thereafter the die with its assembled insulation is thereafter quenched usually in oil to a temperature of about 50°C to 70°C. At this particular juncture, a check of the die periphery should show a Rockwell$_c$ hardness of about 61R$_c$ and the bore should have a hardness of about 45 Rockwell$_c$.

Following quenching the material is usually subjected to a tempering treatment and usually consists of a double tempering treatment at a temperature of between 275°C and about 350°C depending upon the toughness and hardness required in the bore and the periphery respectively. Since the oil quenching of the material from the austenitizing temperature may result in the retention of some of the austenitic phase, it is desirable to double temper the die where such retained austenite is evident within the microstructure.

In order to more clearly demonstrate the effect of the method of the heat treatment of the present invention, reference may be had to Figure 2 which is a diagram of the hardness versus the distance from an actual die peripheral surface that was treated in accordance with the precepts of the present invention. The curve 30 represents the distance from the surface commencing at the base of the groove 34 as graphically illustrated in section from the die section 38 of Figure 3 whereas curve 32 plots the hardness versus the distance from the periphery of the tread as measured along the line 36 as shown in Figure 3. Thus it will be clear that by utilizing the method of the present invention a hard case and a tough body is provided to the die 38 which is employed in a pilger mill.

By referring to the following there is set forth a comparison of the average first groove lives of pilger dies produced by various heat treatment practices including the practice of the subject invention. A convenient measure is to express the life as the number of feet of Zircaloy-4 fuel clad tubing produced in the last of three pilger reductions. The last reduction is the most costly pilger reduction and thus benefits the most by an increase in the die life. During a given one year period, the first groove die life in which a single slack quench was employed resulted in the production of an average of 25,276 feet of tubing. By changing the heat treatment to a multiple slack quench in an attempt to achieve a hardened case by common quenching practice, resulted in three months production for the first groove life of about 20,045 feet of tubing. On the other hand the average first groove life of the dies which were treated in accordance with the present invention revealed an average of 41,530 feet of tubing being produced for the first groove life.

From the foregoing it is apparent that considerable savings are possible since the method of the present invention achieves a lengthy campaign of pilgering between die changes and thus reduces the die cost per foot of tubing pilger. Moreovr there is a reduced frequency of die changes required per foot of pilger tube and more importantly there is improved productivity throughout. In one type of die alone, the savings is conservatively estimated to be in the neighborhood of about $50,000 per year. It is thus seen that as a result of the heat treatment thus employed there is a tempered martinsite case of a high hardness usually between $Rockwell_c$ 55 and $Rockwell_c$ 53 with the balance of the die body comprising bainite or tempered bainite of a hardness of about between 38 $Rockwell_c$ and 45 $Rockwell_c$. This then will provide the tough body and will assure that while the surface of the steel is in a compressive stress situation the body of the steel is in a state of tensile stress.

CLAIMS

1. A method of hardening pilger dies to provide a hard case containing residual compressive stresses and tough body, which comprises heating the die to the austenitizing temperature range, selectively removing heat from the die at a predetermined faster rate in the direction of the desired case than the rate of heat removal from the balance of the die, and thereafter tempering the die.

2. A method according to claim 1, in which the case includes the tapered groove and the periphery of the die and the balance of the exposed surfaces of the die being provided with an insulating coating at least during the austenitizing treatment.

3. A method according to claim 1 in which the case has a thickness of between $\frac{1}{2}$ inch and 1 inch measured from the periphery of the die with a corresponding hardness of between about R_c 53 and R_c 63.

4. A method according to claim 3, in which the outer periphery is hardened to a value of between 61 R_c and 63 R_c and the balance of the die is hardened to a value between about 35 R_c and 45 R_c.

5. A method of hardening pilger dies as claimed in claim 1 to provide a hard case containing residual compressives stresses and tough body, said method being substantially as described herein with particular reference to the accompanying drawings.

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