Dec. 27, 1966 R. A. HUSEBY 3,294,599

METHOD AND APPARATUS FOR HEAT TREATING LOW CARBON STEEL

Filed July 30, 1963 2 Sheets-Sheet 1

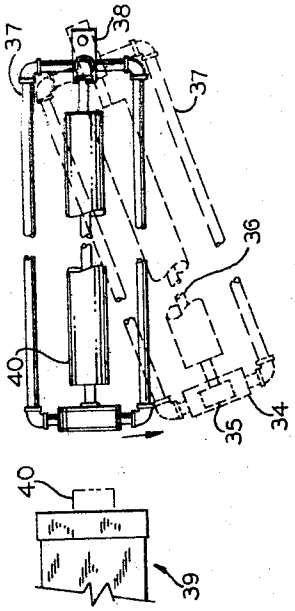

Fig. 2

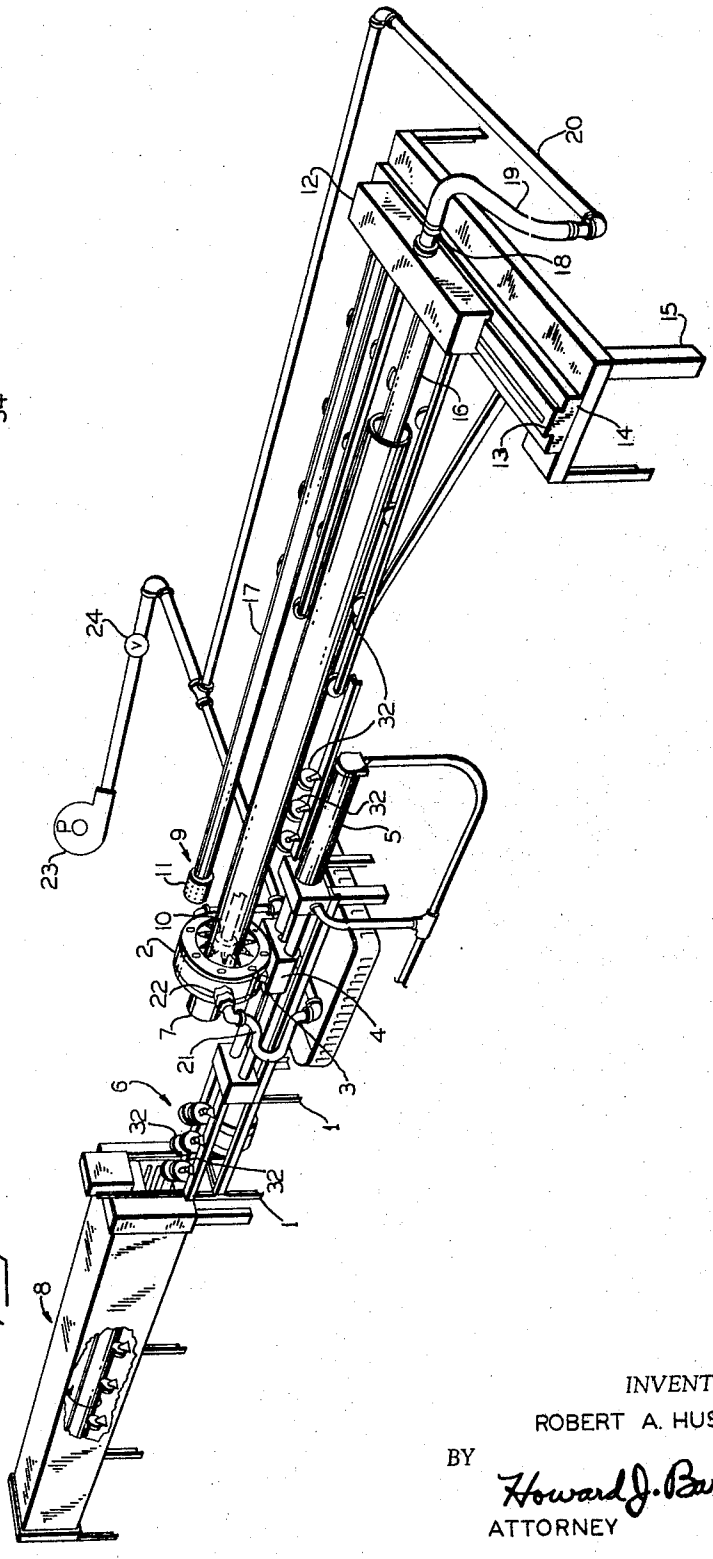

Fig. 1

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Fig. 3

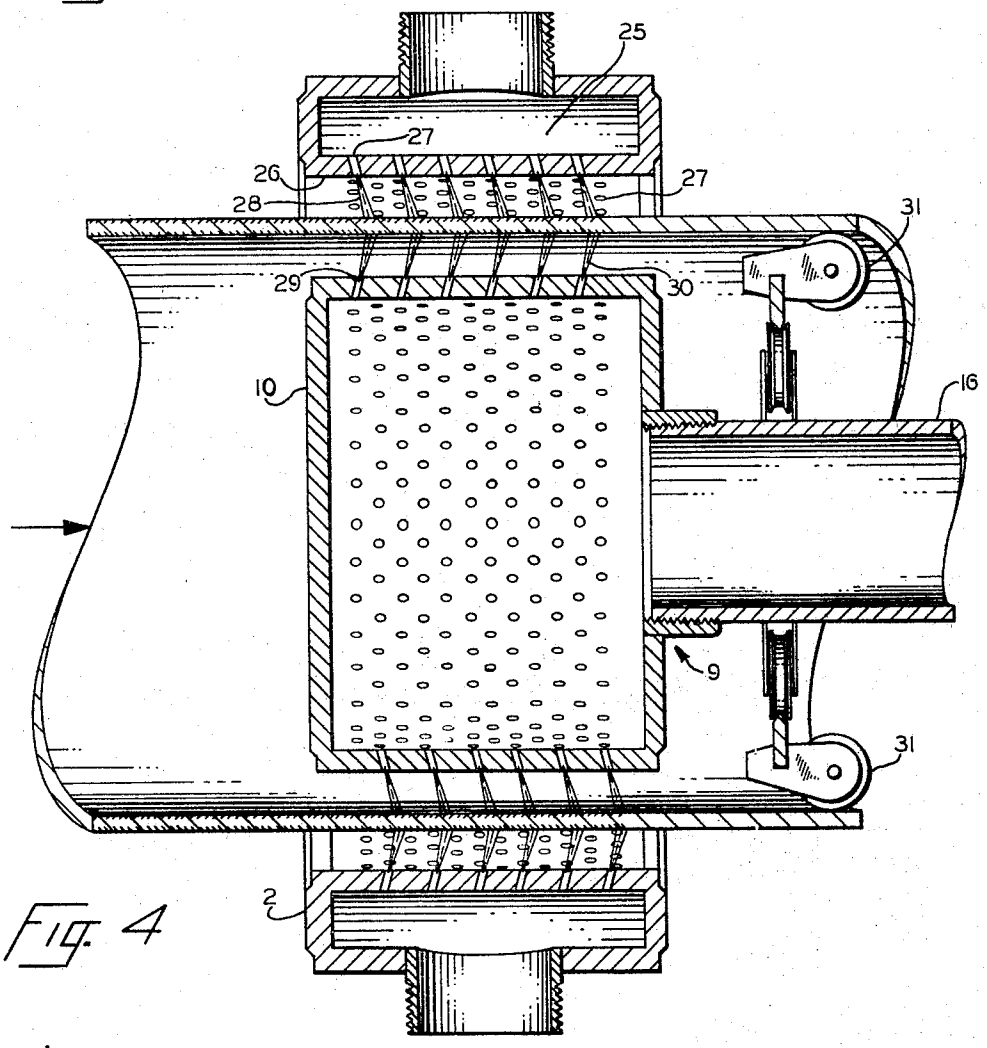
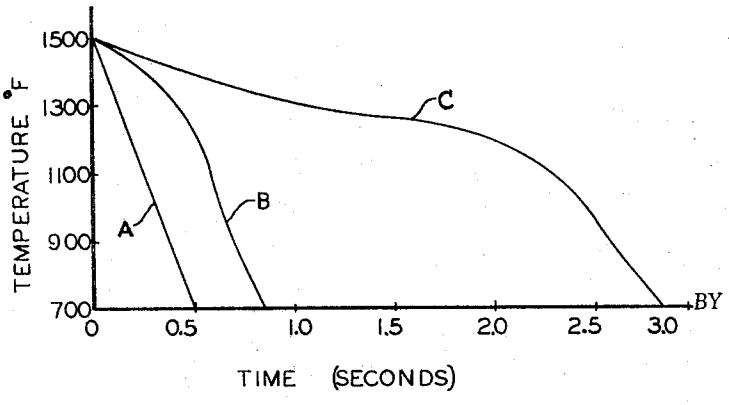



Fig. 4

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# METHOD AND APPARATUS FOR HEAT TREATING LOW CARBON STEEL

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This invention is directed to a method and apparatus for heat treating of low carbon steel, and more particularly, to a method for continuous internal and external quenching of a heated, low carbon steel tubular member, which is moved horizontally through a continuous stream of quenching media to produce a quenched pipe of uniform martensitic steel, and superior physical properties.

The apparatus of the invention provides a high quenching rate because of the complete elimination of the vapor phase of the quenching media at either surface of the member being quenched. One important advantage is that steels which were previously considered not quenchable in the commercial sense are now successfully quenched by the method of the invention to provide relatively lightweight tubular members having excellent hardness and tensile strength, without sacrificing ductility.

In the past, various devices have been designed for quenching tubular members. Some of these devices incorporated both inside and outside quenching heads with the tubular member moving in a vertical direction. Because of practical limitations, such devices were used only for surface hardening of items such as casing pipe. The inner quench head is supported from above in these devices, and it is necessary to first dispose the inner quench head completely within the pipe before commencing either the heating or the quenching operation. As a result, the vertical quenching as disclosed in the prior art has been limited to surface hardening.

Horizontal quenching apparatus for tubular members has been proposed, but none of the prior devices disclose simultaneous external and internal quenching of a tubular member. Prior horizontal quenching devices are designed for "pass-through" quenching, in which successive workpieces travel through the quenching zone. Such devices did not have internal quench heads, and the workpiece was not quenched at its internal surface.

The past practice of quencing pipe has required the use of steels containing upwards of .30% carbon and some alloy, such as 1.6% manganese. Such apparatus included only an external quench head, and it was thought necessary to include some alloy to obtain the desired hardness and strength by quenching, because quenching time was in the order of 8 seconds for quenching of both inside and outside surfaces of a pipe having about ½" wall thickness. This long quench time eliminated low carbon steels from consideration because the alloy requirement previously needed made them non-competitive.

This invention is primarily directed to a method and apparatus for rapid quenching of a low carbon steel workpiece. This method produces high tensile strength steel from a workpiece containing less than .25% carbon by weight. The invention has commercial significance because a low cost, readily formable low carbon steel workpiece is first fabricated, and then subsequently quenched to obtain physical properties comparable to high cost, high alloy steels, which are difficult to form and which are too costly for use in petroleum pipe lines.

The quenching is accomplished in a substantially continuous manner, which provides complete and uniform quenching throughout the stock thickness of the workpiece. The method is particularly well adapted to the quenching of carbon steels containing from .15% to .25% carbon by weight which are commonly known as the carburizing grades. It has also been utilized for successful quench hardening of low carbon steel of about .08% C in ¼" thickness. It is possible to quench harden steels having even a lower carbon content, provided they are less than ¼" in stock thickness.



In the method of the invention, continuous streams of the liquid quench media under high pressure are directed at the heated steel surface. The use of a continuous stream completely eliminates the vapor blanket around the workpiece, which has been a problem in prior art quenching methods utilizing low carbon steel.

This invention provides an effective and reliable means for quenching a low alloy steel tubular member to obtain a martensitic steel having superior physical properties, including high tensile strength, substantially improved hardness and substantial improvement in notched bar impact strength.

The quenched martensite steel of this invention also exhibits good ductility. The explanation is believed to be in the crystallographic structure. The quenching process of the invention produces a martensite having less than .25% carbon. It is believed that martensites having higher than .25% carbon contain a high percentage of a crystallographic structure which is not ductile, because it cannot deform readily.

The means for obtaining the improved quenched tubular member is the quenching fixture which includes means for moving a heated tubular member horizontally relative to a pair of complementary, high-velocity spray quench heads. The outer quench head directs the solid streams of quenching media against the outer surface of the tubular member, and the inner quench head simultaneously directs continuous streams of quenching media against the same portion of the tubular member on the inside surface thereof. The quenching proceeds continuously and progressively along the length of the tubular member, and the tubular member is simultaneously rotated to prevent sagging while it is in the heated condition.

Experience has indicated that the portion of the tubular member being quenched must enter the quench head region at a temperature not less than the temperature at which transformation to the desired homogeneous crystalline structure takes place, in order to provide a uniform crystalline structure after quenching. Also, the quenching action must be adequate to lower the temperature of the tubular member from the transformation temperature to a temperature at which the permanent retention of the desired uniform crystalline structure is obtained in a predetermined minimum time, depending on carbon and alloy content of the steel being quenched.

The apparatus of the invention can be adapted in various ways to quench an unlimited number of tubular members in succession. This can be accomplished by providing apparatus including a pair of inner quench heads, each being adapted to co-operate with an outer quench head. The outer quench head and one of the inner quench heads are disposed in line with a heating furnace. When the tubular member has been uniformly heated to a temperature above the transformation temperature previously mentioned, the tubular member is moved out of the furnace, and is conveyed through the quench head assembly. After quenching has been completed, the outer quench head is indexed toward the furnace away from the first inner quench head, and the quenched tubular member surrounding it. The inner quench head and tubular member then move laterally away from the outer quench head to provide clearance so that the quenched tubular member can be removed from the first inner quench head assembly. At this point, the second inner quench head is lined up with the outer quench head, which indexes back to a position surrounding the second inner quench head. The cycle

is then repeated, employing the combination of the second inner quench head and the outer quench head.

The drawings and the following detailed description of the invention illustrate the best mode presently contemplated for carrying out the invention.

In the drawings:

FIGURE 1 is a side elevational perspective view of the apparatus of the invention;

FIG. 2 is a top plan view showing an alternative loading and unloading plan incorporating a single inner and outer quench head;

FIG. 3 is an enlarged detailed sectional view showing the inner and outer quench heads in relation to the tubular member being quenched; and

FIG. 4 is a graph comparing the difference in quench time between two immersion quenching methods and the method of the invention.

As shown in the drawings, the quenching apparatus comprises a frame **1** which supports an annular external quench head **2**. As can be seen in FIGURE 1, the base **3** of the quench head **2** is slidably supported on a carriage **4** which is supported by the frame **1**. The carriage **4** is connected to a hydraulic drive assembly **5** which moves the external quench head **2** from a rearward unloading position to a forward quench position.

The external quench head **2** is disposed in axial alignment with conveyor track **6**, which is also mounted on the frame **1**, and which receives a heated tubular member **7** from a furnace **8**, which is also disposed in axial alignment with the external quench head **2**.

An internal quench head assembly **9**, which includes a pair of internal quench heads **10** and **11**, is disposed on a laterally slidable carriage **12**, which is keyed to a V-shaped rail **13** on a track **14** of a frame **15**. The quench heads **10** and **11** are disposed on a pair of parallel booms **16** and **17** respectively. The booms **16** and **17** are tubular and provide conduits for the quenching media to travel from the carriage **12** to the respective internal quench head. The back of the carriage **12** is connected at nozzle **18** to a high pressure, flexible conduit **19**. The conduit **19** is, in turn, connected to a pipe system **20**.

Pipe system **20** also connects to a pair of high pressure flexible conduits **21** which connect to nozzles **22** on the external quench head **2**. The pipe system **20** is connected to a high pressure turbine pump **23** which contains the quench media under extremely high pressure no less than 30 p.s.i. The optimum pressure presently employed with existing equipment is about 100 p.s.i. The high pressures are provided by a turbine pump **23** capable of delivering sufficient quenching media at a rate to provide adequate quenching action. The flow of quenching media is turned on and off by operation of valve **24**, shown in FIGURE 1.

The detailed construction of the external quench head **2** and the internal quench head **10** can be seen in FIG. 3 of the drawings. The external quench head **2** is ring shaped, and includes an annular chamber **25**. The external quench head **2** completely surrounds the tubular member **7** being quenched, and the tubular member **7** travels through the middle opening of the quench head during quenching. The inside surface **26** of the external quench head **2** is perforated with small openings **27** through which jets **28** of quench media are projected against the outer surface of tubular member **7**. Each jet **28** is directed at a slight angle away from the unquenched portion of the tubular member **7** to prevent premature cooling of the unquenched portion of the tubular member. Premature quenching would otherwise be caused by splashing action of the quench media before the tubular member enters the quench head. Disposing the jets at an angle away from the unquenched portion of member **7** avoids uneven advance quenching. The direction of jets **28** is determined by the cant of the openings **27**, as seen in FIG. 3. It has been determined through experience that the diameter of the openings **27** should be in the range from 1/16" to 4/16" for best quenching performance, and to obtain full quenching action to a depth of about 3/8" in the workpiece.

A steel workpiece up to 3/8" thick which contains .15% C and .45% Mn can be fully quenched to optimum hardness by the method of the invention. A workpiece greater than 3/8" thickness appears to require a small additional amount of Mn up to about 1% to obtain maximum quench hardening throughout the stock thickness. In any case, the practical limitation of stock thickness which can be quenched to advantage is substantially increased by the method of the invention.

The internal quench head **10** is cylindrical in shape and has openings **29** uniformly distributed on its outer surface which opposes the inner surface of the tubular member **7** during quenching, so that the inside surface of member **7** can be quenched simultaneously with the outer surface thereof. As can be seen, the openings **29** in the internal quench head **10** are also slanted to direct jets **30** at a small angle away from the unquenched portion of member **7**, and openings **29** also range in diameter from 1/16" to 4/16".

The internal quench head **10** is disposed on the end of boom **16**, which is a long, tubular conduit. The boom **16** supports the quench head **10**, and supplies the quenching media under pressure to the quench head **10**. A plurality of support rollers **31** are attached to the boom **16** near the quench head **10** to provide support for the quench head **10** before and during the quenching operation when the high velocity quenching jets **30** tend to drive the quench head **10** off-center.

As seen in FIGURE 1, the conveyor track **6** includes a plurality of conveyor rollers **32** which impart a spiral rotary motion to the tubular member **7** to prevent it from sagging as it is being conveyed through the quenching heads, and as it comes from the heating furnace **8**. Similar conveyor rollers **32** are disposed in the furnace **8** to rotate the tubular member **7** to prevent sagging of the tubular member while it is in the furnace.

The internal quench head **11** is similar to the quench head **10** described above, and also is adapted to co-operate with the external quench head **2** to quench a tubular member **7**. As best seen in FIGURE 1, the quench head **11** is supported on boom **17**, which is attached to the transverse slideable carriage **12**. Lateral movement of the carriage **12** disposes either quench head **10** or **11** in alignment with furnace **8** to receive a tubular member **7** for quenching.

In the sequence of operations, the heated tubular member **7** emerges from the furnace **8** and passes through the external quench head **2** and over the internal quench head **10**. As the tubular member **7** enters the quench region, it must be at a temperature not less than the temperature at which transformation to the desired homogeneous crystallographic structure takes place. As the tubular member moves through the quenching region, the high velocity jets **28** and **30** impinge on the hot surface to progressively instantaneously cool the portion of the tubular member so exposed to a temperature below the desired transformation temperature to produce the uniform crystallographic structure and retain it permanently. The tubular member **7** is rotated while in the heated condition to prevent sagging and thereby avoid permanent deformation from its desired dimensions.

After the tubular member **7** has completely emerged from the furnace **8**, and has been completely quenched, the outer quench head **2** is moved axially towards the furnace **8** to provide clearance so that the internal quench head assembly **9** can be moved laterally, thereby disposing the internal quench head **11** in line with the external quench head **2**. The external quench head **2** is then moved axially into the same transverse plane of alignment with the internal quench head **11** to co-operate therewith in quenching the next successive tubular member **7** emerging from the furnace **8**. Simultaneously,

the previously quenched tubular member **7** is removed from the internal quench head **10**, and is moved on for further processing, thereby making the quench head **10** available for another cycle.

The system described above is preferred because it provides a continuous flow of workpieces from the heating furnace through the quenching machine, and away. Other embodiments of the invention are considered feasible, also. For example, FIG. 2 illustrates a single internal quench head assembly **33** which includes a swinging external quench head **34** and an internal quench head **35** mounted on one end of a swinging boom **36**. The boom **36** is pivotally mounted on a pivotal support means **38**, at the end opposite the internal quench head **35**.

The swinging external quench head **34** is supported in fixed relationship to the internal quench head **35** by a pair of booms **37**, which also extend from the pivotal support means **38**. The external quench head **34** follows the movement of the internal quench head **35**, because they are both pivoted to the same pivot means **38**.

In operation, the internal and external quench heads **35** and **34** are first disposed in alignment with furnace **39**. A tubular workpiece **40** is moved from the furnace **39** through the quench region of the quench heads **34** and **35**. After the workpiece **40** has been completely quench, the pivotal support means **38** pivots the quench heads **34** and **35**, the booms **36**, **37**, and the workpiece **40** away from the furnace **39**.

The quenched workpiece **40** is then unloaded, and the pivoted support means **38** is actuated to return the quench heads **34** and **35** into alignment with the furnace **39** to receive another workpiece **40** for quenching. This apparatus also preferably includes rollers for rotating the tubular member during quenching.

In another arrangement, the external quench head is fixed in position in relation to the furnace, and the internal quenching head assembly moves relative to the fixed external head. The internal quench head assembly includes a supporting boom for the quench head, and additional support means can be provided for the quench head and the supporting boom. The quench head is adapted to move into axial alignment with the furnace so that the internal quench head is lined up with the external quench head, and both the internal and external quench heads are lined up directly opposite the furnace to quench the workpiece as it emerges from the furnace.

In this last arrangement, the internal quenching head assembly is retracted from the quenched workpiece after the quenching operation is completed, and the workpiece is then withdrawn from the side of the quenching fixture. The quenching head assembly returns to the starting position to repeat the quenching cycle.

In any of the above described systems, it is important that the quenching be continuous and progress uniformly along the heated workpiece. In all the proposed systems, the heating furnace is preferably disposed close to the quench heads to assure minimum temperature loss from the workpiece during the time it moves from the furnace to the instant the first quenching jet hits the heated surface. The workpiece must not be permitted to cool below the pre-quench temperature for the particular material being quenched.

Another important requirement of the invention is that the individual quenching jets must be subjected to a pressure of at least 30 lbs. p.s.i. to attain the velocity necessary to form continuous, rod-like, jet streams which eliminate the vapor blanket which otherwise tends to form around the workpiece upon first contact of the quenching media with the workpiece. In actual operation, a pressure in the approximate range of 90–100 p.s.i. is preferred to positively eliminate the vapor phase at the surface of the workpiece, and to obtain good quenching action. If this vapor blanket is not eliminated, the quenching action will not take place in the required minimum time. The distance between the openings in the quench heads and the surfaces to be quenched should not exceed three inches for optimum jet stream effect under the above pressures.

Specific quench data comparing the quench time under conventional quenching action and the quench time under applicant's system is illustrated graphically in FIG. 4 of the drawings. In FIG. 4, line A shows the practical quenching parameters obtained by applicant's system for a ¼" carbon steel workpiece containing .15% C and .45% Mn by weight. The temperature ranges are indicated along the vertical axis of the graph. Quench head pressure of 100 p.s.i. was used in the tests, and the temperature of the quenching media (water) was maintained below 125° F. As can be seen from the graph, the method of the invention requires only .5 second for complete quenching action. Line B of the graph indicates a substantial increase in time required for quenching a similar workpiece having the same composition as A by means of a caustic brine quench.

The graph shows that it takes about .8 second to accomplish the caustic brine quench, which, in addition, is not commercially desirable because of the difficulties inherent in using a caustic material. Line C represents the time-temperature relationship for the same workpiece when an agitated water quench is used. The time required for this quenching method is almost six times as long, and the uniformity of the quenching action obtained by applicant's method is not present. Furthermore, the agitated water quench does not produce uniform strength, hardness and ductility required for commercial pipe.

The graph shows that the acceptable minimum prequench temperature for the steel depicted by line A is 1550° F., and the maximum post-quench temperature is near 700° F. for a ¼" thick steel plate. The actual thickness of the member being quenched will cause some variation in the above figures.

Line A on the graph shows a maximum allowable time of .5 second for satisfactory quenching of a ¼" thick, low carbon steel containing .15% C and .45% Mn by weight. It can be seen from the graph that the agitated water quench shown by line C takes 2.9 seconds to go through the same temperature range. This time period is too long to obtain consistent and acceptable quench hardened properties for this particular steel composition. It should be understood that the quenching time under applicant's method can be decreased even further by supplying a greater quantity of quench media to the workpiece within the maximum allowable time period. The length of the quench heads can be increased to provide additional amounts of quench media to the tubular member **7**.

In the example given for line A, the quench media was water, at a temperature of 70° F., supplied to the openings **27** and **29** in the inner and outer quench heads under a gage pressure of 50 p.s.i. The diameter of each of the openings **27** and **29** was ⅛ inch, and the indiivdual openings **27** and **29** were spaced at ½ inch intervals, with the rows staggered. The openings **27** and **29** were of constant bore through ½ inch stock and were disposed at an angle of 20° from a line perpendicular to the longitudinal central axis of the quench head assembly, with all openings **27** and **29** disposed in longitudinal radial planes disposed about the longitudinal axis. It is important that the inlet portions of the openings **27** and **29** which first receive the quench media be rounded and smooth to avoid uneven quench flow and consequent uneven quenching of the tubular member **7**.

Uniform and simultaneous application of the quenching media to the inner and outer surfaces of the tubular member **7** is important to the success of the quenching system of the invention.

The length of the quench heads **2** and **10** is determined by the desired speed of travel of the tubular member **7**

through the quench region. The length of the quench heads must be sufficient to provide ample quenching to cool the tubular member **7** from the minimum prequench temperature to the below the maximum postquench temperature.

In the example, it was found that for a travel speed of 40 feet per minute, a quench head 6 inches long can be used with quench media under 50 p.s.i. pressure at 70° F. In this example, a ¼" thick carbon steel tubular member **7** was successfully quenched from 1500° F. to 700° F. in .5 second, thus providing a cooling rate of about 1600° F. per second.

As mentioned above, it is most important that the quenching media be concentrated under substantial pressure into the jets **28** and **30** which impinge uniformly and simultaneously on the opposite surfaces of the workpiece. The jets **28** and **30** must have sufficient velocity and pressure to eliminate the insulating vapor blanket of quench media which would otherwise form around the heated workpiece when the quenching action is initiated. To eliminate the vapor phase, it has been found that the maximum diameter of quench openings **27** and **29** for water under 100 p.s.i. pressure is limited to about ¼ inch diameter through ½ inch stock. The diameter of the jets **28** and **30** should be relatively constant. It is important that the jets **28** and **30** be maintained as continuous, pressurized columns of quenching media, that each jet should contact the tubular member **7** before any breakup thereof occurs.

A significant result of the invention is the creation of a new high strength, low carbon steel tubular member which is lightweight. A forty foot section of 30 inch diameter pipe made under the invention weighs about 35% less than a conventional pipe of the same length having equivalent strength.

Although the specific description set forth herein illustrates quenching of a tubular member, applicant has applied the method of the invention equally well to other configurations of workpieces, such as channel shaped members. In all cases, it is important that the rapid quenching rate between 800 and 1600° F. per second be maintained in order to completely quench a low carbon steel workpiece containing between .08 and .25% carbon by weight, and substantially no alloy. It is again important that the streams of quenching water impinge the workpiece surface as continuous streams with no break up into droplets. In this way, complete quenching action is assured. Quenching water pressures are generally from 30–100 p.s.i. A greater water pressure may be used, although it is not necessary, since the quenching speed does not appear to increase further when an excess of 100 p.s.i. water pressure is used, due to the limits of the conductivity of the steel itself.

The increase in tensile strength obtained for a low carbon steel quenched by the method of the invention is substantial. A steel having a carbon content between .08–25% by weight and substantially no alloy, and having an original tensile strength of between 40,000 p.s.i. and 60,000 p.s.i. may be quenched by the method of the invention to obtain an increased tensile strength in the range between 155,000 and 250,000 p.s.i. The quenched steel can, of course, be further heated for tempering purposes in the conventional manner to reduce the tensile strength and improve ductility to a desired value. The tempering process is normally done in a tempering furnace having a temperature between 400°–1100° F.

It has been observed that increasing the carbon content of the steel towards .25% decreases the initial temperature required to obtain a homogeneous austenite towards the lower limit of the upper transformation temperature range of 1500°–1850° F. The cooling rate required also decreases as the carbon content increases. The lower temperature also decreases towards the lower limit of the lower transformation temperature range as the carbon content increases towards .25% by weight.

The converse also is true. As the carbon content of the steel decreases, the initial temperature required to obtain a homogeneous austenite prior to the cooling increases towards the upper limit of the range between 1500 and 1850° F., the cooling rate must be increased, and the lower transformation temperature required increases towards 825° F.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

I claim:

**1.** A method of quenching a steel workpiece having a non-uniform crystallographic structure and containing up to .25% by weight of carbon, and up to about 1% manganese by weight and the balance Fe, the steps comprising, heating said workpiece to a temperature above 1550° F., and simultaneously subjecting both the opposite surfaces of said workpiece to a plurality of pressurized, rod-like, continuous streams of a quenching fluid in sufficient quantity to lower the temperature throughout said workpiece from 1550° F. to a temperature below 70° F. in less than .5 second whereby a steel workpiece having a uniform martensitic crystallographic structure throughout the thickness thereof is obtained.

**2.** A method of quenching a tubular steel workpiece having a non-uniform crystallographic structure and containing up to 0.25% by weight of carbon and up to about 1% by weight of manganese and the balance iron, comprising the steps of heating said workpiece to a temperature above 1550° F., and simultaneously subjecting both the internal and external surfaces of said workpiece to a plurality of pressurized, rod-like, continuous streams of a quenching fluid in sufficient quantity to lower the temperature throughout said workpiece from 1550° F. to a temperature below 700° F. in less than 0.5 second whereby a steel workpiece having a uniform martensitic crystallographic structure throughout the thickness thereof is obtained.

**3.** The method of claim **1** in which the quenching fluid is water having a pressure in the range of 30 to 100 p.s.i.

**4.** The method of claim **2** in which the quenching fluid is water supplied through a plurality of 1/16" to 4/16" diameter nozzle openings and said openings are disposed at a distance less than 3 inches from the respective internal and external surfaces of said workpiece.

**5.** The method of claim **2** in which the steel contains from 0.12 to 0.18% by weight of carbon and from 0.40 to 0.60% by weight of manganese.

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# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,294,599 December 27, 1966

Robert A. Huseby

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, line 26, for "quench," read -- quenched, --; column 8, line 26, for "70° F." read -- 700° F. --.

Signed and sealed this 7th day of November 1967.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents