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INTERNALLY HARDENED STRUCTURE

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Fig. 1.

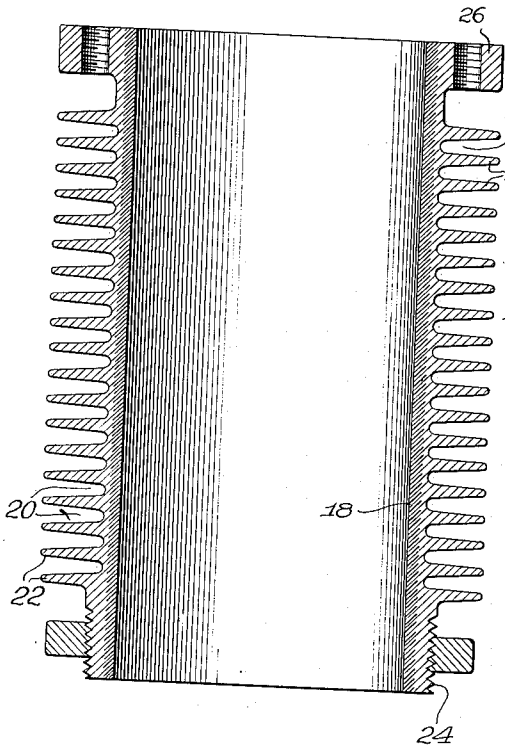


Fig. 2.

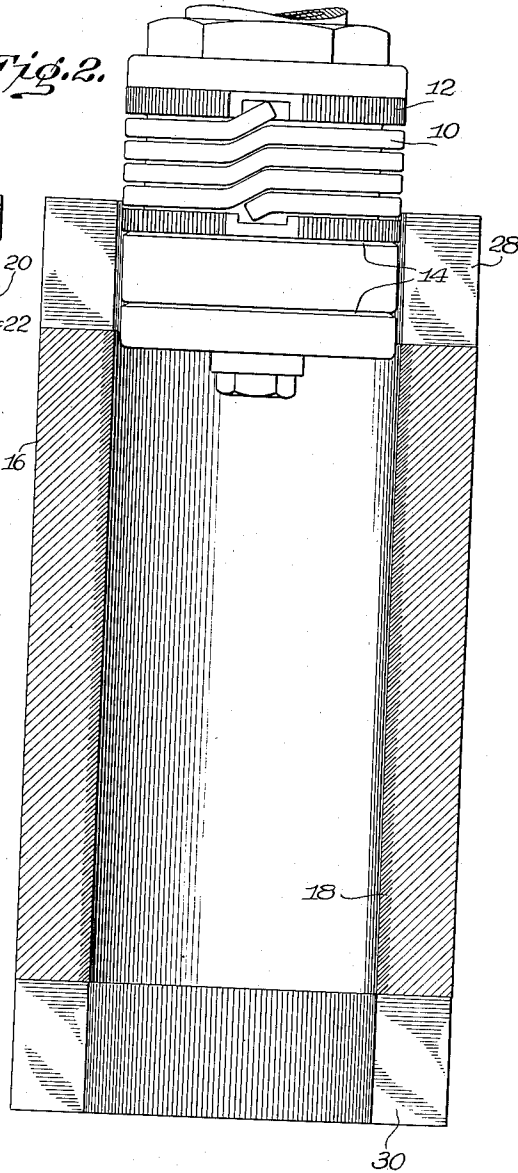
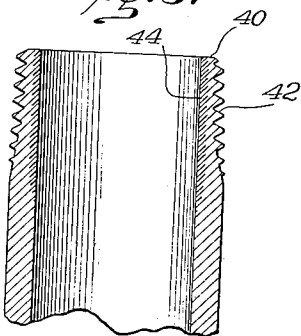


Fig. 3.



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INTERNALLY HARDENED STRUCTURE

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6 Claims. (Cl. 285—146)

This invention relates to cylindrical structures such as pipes subjected in use to axial stresses, and engine cylinders of the air-cooled type having heat radiating fins and one or more machined attachment ends, and particularly to tubular or cylindrical structures wherein increased strength and external machinability, and in some instances, lightness in weight, are desirable requisites.

In the case of internal combustion engines of the air-cooled type, the engine cylinders thereof operate at relatively high temperatures and in order to sufficiently cool the cylinders, radiating cooling fins on the external wall are provided. In aircraft cylinders strength and lightness of structure is essential and consequently the actual cylinder portion of a cylinder must be relatively thin and the cooling fins deep and closely spaced. It has also been the practice in order that the cylinder may have the highest wear resistance, to harden the same by nitriding, carborizing or by some other similar process. Such processes, however, require the heating of substantially the entire cylinder structure to a high temperature over a long period of time and because of the thin walled structure considerable difficulty arises as a result of warpage or distortion due to heat stresses, for the hardening is effected after the machining of the cylinder and its fin-forming grooves because such hardening processes when applied to thin walls cannot be sufficiently restricted in depth to permit the machining of deep fins subsequent to hardening upon the exterior of the cylinder without running into hardened metal. It has been proposed to construct such a cylinder of two members, one being a hardened internal cylinder sleeve relatively thin and the other an exterior jacket having fins, but in such structures the unequal expansion either due to difference in metals used or to the temperature gradients which also vary from time to time as well as the difficulty of effecting a physical heat conducting bond between the members obviously results in distinct disadvantages.

In the case of tubular pipe, particularly pipe subjected in use to axial tensile stresses, such as tubular structural members or pipe strings having externally threaded ends for connection with adjacent members through internally threaded couplings and the like, the characteristic of high strength is highly desirable, it being well known that the axial loading of such members or pipe, particularly thin-walled pipe, tends to decrease the diameter thereof through radial deformation and that the cutting of the pipe threads decreases

the normal strength of the pipe at the threaded regions due to the reduced cross-section incident to the removal of metal during the thread cutting operation.

The present invention is directed to novel cylindrical and tubular structures in which internal surface zones are provided with a hardness materially greater than that of the surrounding zones, and in which the depth of hardness and the character of hardness is such as to materially increase the yield strength thereof and thereby improve the normal strength of the structure while compensating at least in part for the loss in strength incident to external machining, the character or quality of hardness preferably being that which is produced by rapid electromagnetic induction heating and substantially instantaneous quenching. Through the use of rapid electro-magnetic induction heating and substantially instantaneous quenching, a definite thin hardened layer may be produced upon the internal wall of a cylinder or tubular member prior to the machining of its exterior surface and because it has been discovered that induction zone hardening definitely permits the metal outside of the hardened zone to retain its original characteristics, it is possible to harden an internal surface zone to a desired depth and thereafter cut cooling fins, threads or other surface configurations upon the exterior of the member to a depth extending substantially to the hardened zone, or to a desired depth short thereof, and this through simple machining operations involving simple machine cutting operations as distinguished from grinding operations which would otherwise be required if the hardened zone were not controlled to a definite depth as is possible through electromagnetic induction hardening. The presence of the stock from which the fins, threads or other surface configurations are to be cut maintains the member rigid during the zone hardening operation.

It is, therefore, an object of the invention to provide tubular and hollow cylindrical structures having an electro-magnetically induction hardened heat treated internal layer and in which the exterior is required to have some special configuration which may be machined, and in which the article is first internally zone hardened and subsequently machined.

Another object is to provide a tubular member or structure, particularly of the type subjected in use to axial tensile stresses, in which a radially outer layer of the metal thereof is readily machinable, with a means for increasing the

normal resistance of the structure to tensile failure and to radial deformation, which means is in the form of an integral layer of metal at the inner surface thereof zone hardened to a hardness of materially greater hardness than the outer layer and of such quality of hardness as to increase the yield strength of the structure.

A further object is to provide such a tubular structure in which the internal zone-hardened layer of metal is of such increased yield strength as to compensate at least in part for the loss in strength occasioned by the removal of surface metal in external machining of the same.

The above and other novel features of the invention will appear more fully hereinafter from the following detailed description when taken in conjunction with the accompanying drawing. It is expressly understood, however, that the drawing is employed for purposes of illustration only and is not designed as a definition of the limitation of the invention, reference being had for this purpose to the appended claims.

In the drawing wherein like reference characters indicate like parts,

Figure 1 illustrates a section through a cylinder having substantially the configuration required by air-cooled internal combustion engines.

Figure 2 illustrates a step in the process of forming such a cylinder from a blank of uniform annular cross-section throughout its length.

Figure 3 illustrates a pipe structure in which the process has application.

Referring to Figure 2 there is illustrated in section a cylindrical blank which may be a forging or casting from which an engine cylinder is to be formed. The blank is machined to a uniform bore and preferably to a uniform wall thickness and the internal bore is then hardened to a depth of approximately a tenth of an inch or less by electromagnetic induction heat treating apparatus illustrated, the apparatus comprising a coil 10, preferably a flux concentrating core 12 and an associated annular quench 14 adapted to quench the heated zone almost instantaneously after heating progressively. The apparatus which may be employed is similar to that disclosed in a copending application Serial No. 277,996, filed June 8, 1939, now Patent No. 2,281,333, issued April 28, 1942, and the details thereof need not be described further.

The cylinder blank for air cooled engines must be composed of a material which, when hardened, will not lose its hardness through a range of temperatures up as high as 550° F. Such a material as that constituted by S. A. E. 4140 has such properties. Also a material similar thereto but in which the carbon content is increased to about .50%, the chromium content reduced to about .55% and the molybdenum increased to .75% with as much as 1% of silicon will be found to withstand the working temperatures of such cylinders. The blank, after having preferably been machined to a proper external cylindrical and internal bore dimension, is hardened internally to a uniform depth and thereafter may be drawn for a period of time at a temperature substantially the maximum to which the cylinder may be subjected in use. During the hardening operation, the thick wall of the blank maintains the cylinder against any possibility of distortion or warping. The heated layer is raised to a plastic state and consequently when it cools from quenching will be forced to adhere to its original shape because of the backing metal which has not been affected by the heat treatment.

After hardening the inner surface zone of the blank, external cooling fins and mounting flanges may be formed by machining grooves in the exterior of the blank. It will be found that because of the controlled depth of hardening, the grooves cut for the purpose of forming the cooling fins may be cut substantially to the hardened wall or to any degree less without danger of running into even slightly hardened material. This is important in the cutting of deep narrow grooves such as are required to effect the formation of a great many closely spaced cooling fins for if there were danger during the machining operation of the cutting tools striking a hard spot deep down within a groove between adjacent cooling fins, fracture of the cooling fins during the machining operation would almost surely result.

As is illustrated in Figure 2, the blank 16 is provided with a hardened internal layer 18, and referring to Figure 1, grooves 20 are turned in the external unhardened portion of the blank after hardening of the internal surface zone in order to form closely spaced fins 22 and such end attachment threaded portions as 24 or flanges as at 26 as may be desirable.

Where threaded ends are desired, a peculiarity in the structure resulting from the hardening operation described permits of unusual lightness at this point, and this is because the internal layer of hardened material is under a residual trapped compressive stress, and due to its hardness has a greatly increased yield strength. This greatly increased yield strength renders it unnecessary to increase the thickness of the tube to compensate for the loss of strength that would usually appear to be necessary as a result of the weakening effect of the thread grooves, and yet the hardened layer is so restricted as to leave the remainder readily machinable as in thread cutting.

In a threaded pipe end for example, and where the pipe is subjected to axial stresses, such as in thin-walled pipe sections connected together by internally threaded couplings, the weakening effect of the threaded end can be offset by hardening an internal annular layer of the metal of the pipe which is of such longitudinal extent as to extend under the threaded portion, just as in the case of the cylinder previously described. In Figure 3, this structure is illustrated. The pipe end 40 is provided with external threads 42, which in effect reduce the cross-section of the pipe and consequent strength. Through the internally hardened layer 44, which has a correspondingly increased yield strength, the yield strength of the pipe end despite the reduced cross-section is the same as the rest of the pipe and without the necessity of enlarging the end. Thus, the integral zone hardened layer 44 of metal, spaced from the roots of the threads 42 and extending longitudinally of the pipe within the threaded region, provides, due to its increased yield strength, a means for increasing the normal resistance of the pipe to tensile failure and to radial deformation and collapse, which is of particular advantage at the threaded region inasmuch as the increased resistance to radial deformation due to the increased yield strength decreases the tendency of the pipe threads to pull out of the connecting couplings or other member during the presence of heavy axial tensile stresses. Although the inner zone hardened layer of metal is shown in Figure 3 as termi-

nating near the innermost end thread in which the yield strength of the threaded region of the pipe may be increased at least to that of the remainder of the pipe, such layer may, as in the case of the engine cylinder, extend from end to end of the pipe to increase the normal strength of the pipe as a whole while compensating at least in part for the loss in strength at the threaded region. The threads may be just as easily cut after the hardening, as in a plain unhardened pipe, for the zone in which the threads are cut is unchanged by the hardening of the inner surface zone.

A tubular member formed in the manner described may have a hardened internal layer of substantially uniform depth and of substantially uniform hardness throughout for the reason that through the rapid heating of the internal layer and almost instantaneous quench following the heating the back metal acts simultaneously with the quench to form an additional quench so that heat is withdrawn from the heated layer on both sides thereof, the internal bore being cooled by the quenching fluid and the inner transition zone between the hardened layer and the unhardened portion being cooled by the mere exchange of heat from the heated zone into the unheated zones. For this reason it is preferable although not entirely essential that the section of the tubular member to be internally hardened be substantially uniform in thickness from end to end so that the quenching effect of the back metal may be uniform throughout the heated region. Thus, uniform motion of the heat treat head through the length of the bore, while inducing a uniform current and uniform quenching, results in a hardened zone of uniform depth. In practice, laminated core extensions 28 and 30 are preferably employed for the purpose of controlling the end effect at either end of the tubular member so that a uniform depth of hardening may be effected from end to end. The use of extensions is illustrated in the patent above referred to.

After the internal hardening operation and the external machining operations are completed, the internal bore, in the case of the cylinder, may be ground or honed as the case may be to a true cylindrical mirror-finished internal cylindrical wall. If the alloy S. A. E. 4140 be employed, the initial hardness in the internal layer may be Rockwell C 60 and after drawing the same may have been reduced to around 51 Rockwell C if the drawing temperature is substantially 550° F. The other alloy specifically referred to may be hardened by heating to a temperature of 1560° F. and after extended use at a temperature of 550° F. or after a prolonged draw at this temperature will still retain a Rockwell hardness of about 57 C.

Thus it will appear that exceedingly tough alloys may be employed for making up cylinder structure, which alloys may be hardened internally without rendering the external metal too hard to machine. As a result, the hardening operation may be effected at a time when the piece has sufficient cross-section to maintain its shape during the hardening operation, whereas if the piece were machined first and subsequently hardened, the area heated during the hardening operation would in a thin walled cylinder constitute substantially the entire cross-section of the cylinder, thus permitting warpage and distortion.

It is to be understood that the hardness of the

internal layer of metal, both in the case of the cylinder and the pipe, should be that which will give the most efficient results in use. In the case of the pipe and other tubular structures not subjected to high temperatures like that of the engine cylinder, the hardness of the internal layer may be drawn, for example, to as low as 30 Rockwell C, as desired, depending, of course, on the amount of increased yield strength desired to be imparted to the tubular structure in question.

Although the invention has been described in conjunction with materials having specific compositions and specific temperatures have been suggested in conjunction with those materials as well as specific depths of hardening, it is to be understood that the invention is not limited thereto but may be embodied in various modified structures. As many changes in the process and structure may be effected without departing from the spirit of the invention as will be apparent to those skilled in the art, reference will be had to the appended claims for a definition of the limits of the invention.

What is claimed is:

1. A tubular structural member comprising a one-piece tubular portion of that character which is subjected in use to axial loading and having a wall thickness which is but a fraction of its internal diameter, and having its wall composed of integral inner and outer annular layers of metal of physical characteristics so widely different as to materially increase the normal resistance of said portion to failure from the creation of axial stresses arising from such axial loading, said inner layer being under a state of trapped residual stress and having a substantially uniform hardness throughout its radial depth and throughout substantially the length of said wall portion, which hardness is manifoldly greater than that of said outer layer as measured on the Rockwell C scale and of that quality characterized by rapid electromagnetic induction heating and substantially instantaneous quenching, the metal of said outer layer being of such low hardness as to be readily machinable by machine cutting operations and retaining substantially the original hardness characteristics of said tubular portion.

2. A cylindrical tubular metal structure having the metal in an annular zone adjacent the inner surface thereof for a portion at least of its length materially harder as measured on the Rockwell C scale than the metal of the zone surrounding it, said structure having a region of reduced cross-section in said surrounding zone, the quality of hardness of the metal of said inner zone being that which is characterized by rapid electromagnetic induction heating and substantially instantaneous quenching and the radial depth of said inner zone being such that the yield strength of said portion at said region of reduced cross-section is equal at least to that which would exist in said region in the absence of hardening of said inner zone and reduction in cross-section of said surrounding zone, whereby to increase the normal strength of said portion as reduced in cross-section and to offset the decreased strength thereof occasioned by the reduction in cross-section of said outer zone in said region.

3. A one-piece cylindrical structure having an annular wall of a metal hardenable by heating and quenching and composed of integral inner and outer annular layers of metal of the same composition throughout extending substantially

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from end to end thereof, said outer layer having machined portions therein resulting in a non-uniform radial thickness of said outer layer, said inner layer having a hardness which is substantially uniform throughout its radial depth and materially greater than that of said outer layer as measured on the Rockwell C scale and being of such radial thickness and having such quality of hardness as to constitute a means for increasing the yield strength of said inner layer an amount sufficient to increase the strength of said structure as a whole while compensating for the loss in strength occasioned by the production of said machined portions.

4. A cylindrical tubular metal structure having exterior end threads and an annular layer of the metal of its inner wall of a hardness and of a yield strength materially greater than the hardness and yield strength, respectively, of the remainder of the metal surrounding it, said threads being in said surrounding metal and the length of said layer of greater hardness and yield strength being different from that of said threads, said layer of metal of greater hardness and yield strength constituting a means for compensating for the weakening effect of the threads in said surrounding metal on said structure and for increasing the normal strength of said structure at the region of said threads.

5. A one-piece tubular metal structure having for a portion at least of its length from one end

the metal of an annular layer of substantially predetermined radial depth originating at the inner wall of a hardness different from that of the metal surrounding it, said surrounding metal within said portion being of relatively low hardness and having external machined portions therein which effect a reduction in cross-sectional area and a consequent reduction in strength of said first portion throughout its machined region, said first portion comprising said annular layer being of such greater hardness than that of said surrounding metal and said annular layer being of such radial depth as to increase the normal strength of said first portion as machined an amount sufficient to substantially offset said reduction in strength.

6. In a tubular structure having an exteriorly threaded end portion and which is to be subjected to axial stresses in use, means for compensating for the loss in strength of said structure due to the presence of the threads therein, comprising an integral layer of metal adjacent the inner wall thereof and extending longitudinally a substantial distance beyond said threads and being sufficiently harder than the thread carrying metal to increase the yield strength of said structure at said threaded end portion to at least substantially that of the remainder of said structure.

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