This invention relates to well casing of steel whose physical characteristics are materially improved to resist more effectively the stresses to which it is normally subjected.

This application is a continuation-in-part of our copending application Serial No. 302,306, filed November 1, 1941.

In recent years the practice has been to drill very deep oil wells to tap oil-bearing strata, and usually the depth to which a well can be drilled is determined by the strength of the casing used to line the well. When in an oil well, casing is subjected to tremendous collapsing pressures at increased depths and it is heavily stressed longitudinally due to the weight of the casing string in pull-out operations, and also in supporting the string in some types of wells. Heretofore, various efforts have been made to increase the strength of well casing. These have included cold compressing plain steel casing to increase the yield point of its metal, and also resorting to the use of special alloy steels for making the casing. Increasing the wall thickness of the casing is objectionable because of increase in weight with attendant increase in cost.

The use of special alloy steels in the manufacture of well casing is objectionable due to expense, and, further, is often undesirable because of difficulties in welding, threading or other operations performed on casing during its manufacture or during its setting in a well.

In cold working plain steel well casing to increase its strength the prevailing practice is to reduce the diameter of the casing about four per cent by die pressure applied transversely to the outside of the casing. This method of cold working steel well casing not only requires relatively heavy and expensive machinery and the provision of a plurality of large and costly dies for various casing sizes, but we have found that it is characterized by imparting to the cold worked casing undesirable residual hoop stresses which materially reduce the collapse strength of the casing. Furthermore, when the metal of well casing is cold worked in this way its yield point in longitudinal tension is less than its yield point in transverse compression.

Apparatus for this cold working well casing comprises a plurality of cooperating dies, usually two, each formed with a casing-engaging groove of about 180 degrees and mounted for relative lateral reciprocation to and from a casing plastically to compress it, the casing being placed longitudinally in these dies and being squeezed over its full length by them. We have found that casing treated in this manner is not uniformly cold worked throughout its circumference. The cold working is greatest in those areas of the casing at and adjacent to the lines of joiner of the two-part dies, and the cold working is at a minimum in the portions of the casing at and adjacent to the valleys of the dies. Impact tests on specimens cut from the portions of such casings positioned at the lines of joiner of the dies show impact resistances materially below those of specimens cut from the second named portions of the casing. In other words, the portions of the casing at and adjacent to the lines of joiner of the dies have less ductility than the portions at and adjacent the valleys of the dies.

While this variation in impact resistance is in itself objectionable, particularly if the metal is so severely cold worked in the region of the joiner of the dies as to be objectionably brittle, the residual stresses in the casing arising from the nonuniform plastic flow of its metal are objectionable because they result in a distortion of the casing to such out-of-roundness as to reduce appreciably its resistance to collapse. Moreover, even if the cold working is circumferentially uniform, we have found that die-pressed casing has its inner wall fibers under residual compression stresses and its outer wall fibers under residual tension stresses so that when a ring of the casing is split the two ends of the ring spring apart showing the presence of undesirable residual hoop stresses which not only may cause out-of-roundness but which also may add to any collapsing stresses so as to cause premature collapse of the casing under pressure.

When well casing has been cold worked by die pressing it is often necessary subsequently to straighten it. This is usually done by cross-roller straightening apparatus which imparts further undesirable and objectionable residual stresses to the casing, and obviously increases its cost of manufacture.

The general object of our invention is to provide a stress-free well casing made of steel that is so cold worked and straightened that its collapse and longitudinal tensile strengths are materially greater than those of the same metal in an as-rolled, normalized, or annealed state, the metal of the casing having substantially the same impact and elongation values as in such state.

Well casing provided according to our invention comprises a longitudinally-stressed, hollow cylindrical body of steel having a substantially uniform transverse compression yield point throughout, which is appreciably higher than the
transverse compression yield point of the metal in an as-rolled, normalized, or annealed state, and having a longitudinal yield point in tension material higher than its transverse compression yield point, but having impact and elongation characteristics substantially identical to the metal in the as-rolled, normalized, or annealed state, the casing being substantially free of hoop stress, longitudinally straight and circumferentially round.

To effect these characteristics each length of well casing is cold worked by stretching it longitudinally, the ends of the casing being gripped and pulled longitudinally to reduce the outside diameter of the casing up to about two per cent, simultaneously to straighten the casing, to increase its yield point in circumferential compression, to render the casing substantially free from undesirable hoop stress, and to increase its longitudinal yield point in tension above that in circumferential compression.

It is known that tubes having a ratio of diameter to wall thickness of greater than about 30 offer a resistance to external collapsing pressures which is due primarily to what is generally termed "egg shell" effect. In such tubes the strength of the material forming them has little to do with their resistance to collapse. However, when the diameter to wall thickness ratio of a tube drops below about 30 the strength of the material forming the tube becomes important and the greater the resistance of the metal to compression the greater is the resistance to collapse of the tube. Therefore, the well casing provided according to our invention has a diameter to wall thickness ratio of less than about 30.

Various types of apparatus may be used to produce our improved cold worked oil well casing. For example, we may use screw or fluid actuated apparatus of various kinds to stretch the casing longitudinally, but one very satisfactory apparatus includes a pair of gripping or clamping elements of the same general structure as the clips used to support a string of casing in a well, which gripping elements are mounted so as readily to be secured to the opposite ends of a length of well casing to be stretched. One of the gripping elements is usually fixed and the other is mounted for movement longitudinally of the casing under the action of an hydraulic raior piston. Preferably, we provide a gauge in connection with the hydraulic mechanism for indicating the total force applied by the hydraulic mechanism. Thus, we are able to stretch longitudinally the casing so as to raise the yield point of its metal to a desired predetermined amount of its ultimate strength.

By way of example, by forming well casing of steel having from 0.2 to 0.6 carbon, 0.5 to 1.5 manganese, 0.05 to .3 phosphorus, 0.1 to 2 sulfur, 0.5 to 0.6 silicon, and the remainder substantially iron, which steel normally have a yield point in transverse compression of from 35,000 to 75,000 pounds per square inch and an ultimate strength of 80,000 to 120,000 pounds per square inch, we are able to raise the as-rolled, normalized, or annealed state yield point in compression by the stretching operation up to 70,000 to 100,000 pounds per square inch. The yield point of the steel can be increased by cold work stretching up to any desired percentage of the ultimate strength, as for example, 60 to 65 per cent.

Usually, the cross section of the casing in square inches is determined and this figure is divided into the total force applied by the hydraulic mechanism to give the stress per square inch applied to the casing. For example, if the gauge pressure on the hydraulic mechanism is 3180 pounds per square inch and the cross section of the piston of the hydraulic mechanism is 154 square inches, the total pull exerted by the hydraulic mechanism is 493,400 pounds. If the cross section of the casing in square inches is 5.4317 then the total load applied to each square inch of the casing is 90,100 pounds per square inch. With a steel having a yield point in an as-rolled, normalized, or annealed state of 55,000 pounds per square inch and an ultimate strength of 100,000 pounds per square inch, subjecting the casing to a longitudinal load of 9,100 pounds per square inch will increase the yield point of the casing to approximately 90,100 pounds per square inch without affecting the ultimate strength of the casing. These are yield points in longitudinal tension, and are somewhat higher than the corresponding yield points in transverse compression which are about 88 per cent of the longitudinal yield points. For supporting long lengths of casing in some types of wells, and for pulling casing from wells, it is highly desirable to have its longitudinal tensile stress as great as possible.

From the foregoing it will be understood that we stretch steel well casing, formed usually of ordinary steel, under a longitudinal force which will raise the yield points of the casing, both in transverse compression and in longitudinal tension, from its original yield points in an as-rolled, normalized, or annealed state to points which are much higher and which may approach the ultimate strength of the casing.

We have found that in longitudinally stretching casing in the manner described the outside diameter of the casing is reduced ordinarily in the neighborhood of between about one-half and two per cent, and usually in the neighborhood of about one per cent. The casing may originally be formed slightly over size so that when it is stretched longitudinally its finished outside diameter will be well within prevailing standards and tolerances.

We have found that treating well casing as heretofore described not only effects a desired cold working of the casing steel to increase its yield point in both compression and tension to any desired values and with the ultimate strength of the steel, and does so uniformly throughout the casing, which increase materially improves the resistance of the casing to collapse and to pull, but we have found that the resulting casing possesses various noteworthy characteristics. First, the casing is accurately and rapidly straightened simultaneously with the cold working. Second, we have found that the casing is circumferentially rounded in the stretching operation. Often, seamless well casing, and even casing made by other methods such as electrically welded casing, may be slightly oval after final manufacturing steps. The action of the stretching operation pulls the casing to circumferential roundness. Third, well casing strengthened and cold worked as herein disclosed is free of undesirable residual hoop stresses. There is no tendency for the casing to be pulled out of round by residual stresses, which out-of-roundness may reduce its resistance to collapse as above stated.

Further, there are no residual hoop stresses present in the casing which add to externally applied collapsing forces in the use of the casing. Fourth, we have found that the hardness and resistance
of the stretched casing to impact has either not been changed or has been altered in such a small manner that the change is not appreciable or harmful. Fifth, our cold worked and straightened well casing has suffered either no decrease in per cent elongation or only such minor changes in per cent elongation have occurred as not to be appreciable. In fact, the hardness, the per cent elongation, and the impact resistance of our cold stretched and straightened casing are substantially identical to the hardness, the per cent elongation and impact resistance of the metal in an as-rolled, normalized, or annealed state prior to cold working. Sixth, no change in microstructure is apparent in the cold worked and straightened casing. Seventh, no change in flattening test results is noticeable in the cold stretched and straightened casing.

As illustrative of the characteristics and advantages of our improved well casing, the following specific example is given. Four lengths of 5½ inch outside diameter well casing having an average wall thickness of .330 inch were made alike in every respect of steel having the following analysis: carbon .47, manganese 1.05, phosphorus .017, sulfur .003, silicon .23, and the remainder substantially iron. Three of the lengths, namely those identified below as Nos. 1, 2 and 3, were cold worked and straightened as heretofore described. The length identified below as No. 4 was not treated after hot forming. The degree of cold working and the result of tests made of the four lengths are shown in the following table:

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension load lbs. per square inch</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td>Bending physicals:</td>
<td>80,700</td>
<td>84,100</td>
<td>90,100</td>
<td>None</td>
</tr>
<tr>
<td>Longitudinal tension yield lbs. per square inch</td>
<td>31,600</td>
<td>33,900</td>
<td>37,700</td>
<td>60,400</td>
</tr>
<tr>
<td>Transverse compression yield lbs. per square inch</td>
<td>81,100</td>
<td>83,700</td>
<td>78,600</td>
<td>56,800</td>
</tr>
<tr>
<td>Tensile lbs. per square inch</td>
<td>108,000</td>
<td>108,700</td>
<td>100,200</td>
<td>108,300</td>
</tr>
<tr>
<td>Percent elongation in two inches</td>
<td>21.5</td>
<td>22.0</td>
<td>22.0</td>
<td>22.0</td>
</tr>
<tr>
<td>Charpy impact ft. lbs.</td>
<td>17.9</td>
<td>18.0</td>
<td>17.3</td>
<td>18.5</td>
</tr>
<tr>
<td>Flattening per cent reduction</td>
<td>60.0</td>
<td>63.0</td>
<td>60.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Collapse lbs. per square inch</td>
<td>7,500</td>
<td>7,200</td>
<td>7,200</td>
<td>6,400</td>
</tr>
<tr>
<td>Internal hoop stress lbs. per square inch</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>9,740</td>
</tr>
<tr>
<td>Per cent reduction in O.D.</td>
<td>5.4</td>
<td>.81</td>
<td>.92</td>
<td>0</td>
</tr>
<tr>
<td>Brinell hardness</td>
<td>223</td>
<td>223</td>
<td>225</td>
<td>223</td>
</tr>
</tbody>
</table>

1 Tension loaded.

We provide a less expensive and a particularly improved well casing possessing needed, and avoiding undesirable characteristics.

We claim:

1. A well casing made of steel and having a ratio of diameter to wall thickness of less than about 30, the casing while cold having been uniformly stretched longitudinally beyond its yield point and thereby permanently elongated by applying tension to its ends, and consequent upon such stretching the metal of the casing being characterized by having its yield point in transverse compression materially higher than and its hardness and ductility substantially the same as in its hot worked condition, and by having its yield point in longitudinal tension greater than that in transverse compression, and the metal of the casing having uniform and like internal stresses throughout its wall thickness and as a consequence thereof being free from residual hoop stresses.

2. A well casing having a ratio of diameter to wall thickness of less than about 30 and made from steel containing from about 0.20 to 0.60 per cent carbon, from about 0.50 to 1.50 per cent manganese and from about 0.65 to 0.95 per cent silicon, the remainder being substantially iron, the casing while cold having been uniformly stretched longitudinally beyond its yield point and thereby permanently elongated by applying tension to its ends, and consequent upon such stretching the metal of the casing being characterized by having its yield point in transverse compression materially higher than and its hardness and ductility substantially the same as in its hot worked condition, and by having its yield point in longitudinal tension greater than that in transverse compression, and the metal of the casing having uniform and like internal stresses throughout its wall thickness and as a consequence thereof being free from residual hoop stresses.

3. A well casing having a ratio of diameter to wall thickness of less than about 30 and made from a steel which in its hot worked condition has a yield point in transverse compression of from about 35,000 to 75,000 pounds per square inch, the casing while cold having been uniformly stretched longitudinally beyond its yield point and thereby permanently elongated by applying tension to its ends, and consequent upon such stretching the metal of the casing being characterized by having a yield point in transverse compression of from about 70,000 to 100,000 pounds per square inch and by having its hardness and ductility substantially the same as in its hot worked condition, and by having its yield point in longitudinal tension greater than that in transverse compression, and the casing having uniform and like internal stresses throughout its wall thickness and as a consequence thereof being free from residual hoop stresses.

4. A well casing made of steel and having a ratio of diameter to wall thickness of less than about 30, the casing while cold having been uniformly stretched longitudinally beyond its yield point and thereby permanently elongated by applying tension to its ends, and consequent upon such stretching the metal of the casing being characterized by having its yield point in transverse compression materially higher than and its hardness and ductility substantially the same as in its hot worked condition, and by having its
yield point in longitudinal tension greater than that in transverse compression, and consequent upon such stretching the metal of the casing having uniform and like internal stresses throughout its wall thickness and as a consequence thereof being free from residual hoop stresses, round and straight.

5. The method of making, from hot worked steel tubing, well casing free from residual hoop stresses and having a ratio of diameter to wall thickness of less than about 30, the step consisting of uniformly stretching the tubing longitudinally while cold beyond its yield point by applying tension to its ends and thereby permanently elongating it and imparting to the metal thereof a yield point in transverse compression materially higher than when in its hot worked condition while maintaining the hardness and ductility of the metal thereof substantially the same as in its hot worked condition, and thereby also imparting to the metal of the stretched tubing a yield point in longitudinal tension greater than in transverse compression.

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