

Aug. 25, 1942.

J. J. DUNN ET AL

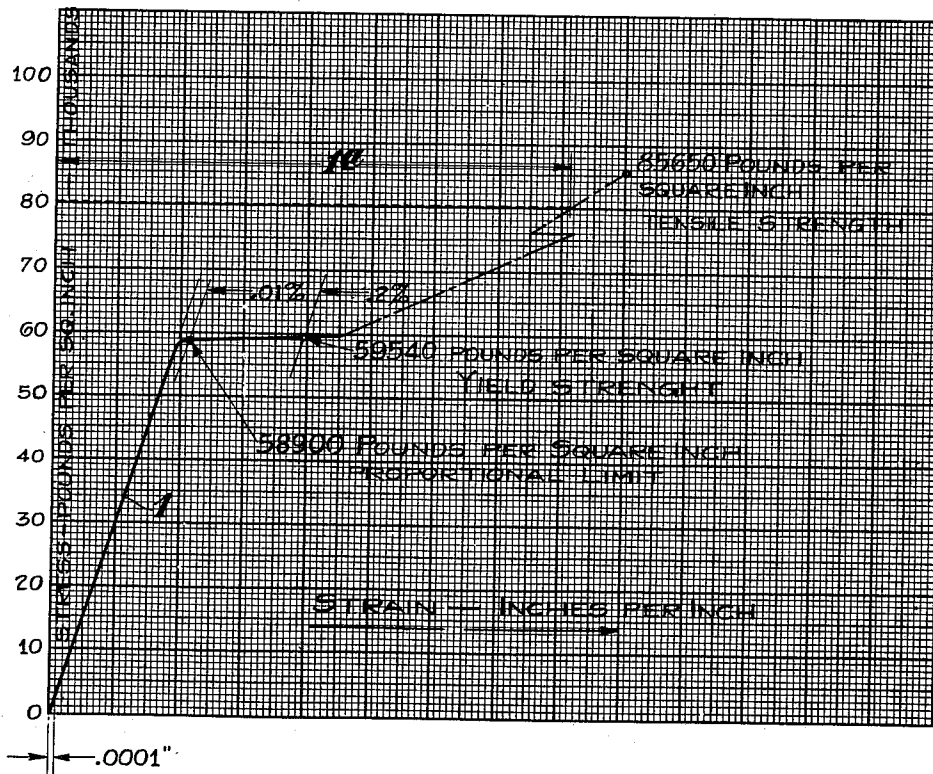
2,293,938

TUBULAR ARTICLE

Filed June 14, 1939

3 Sheets-Sheet 1

FIG. 1.



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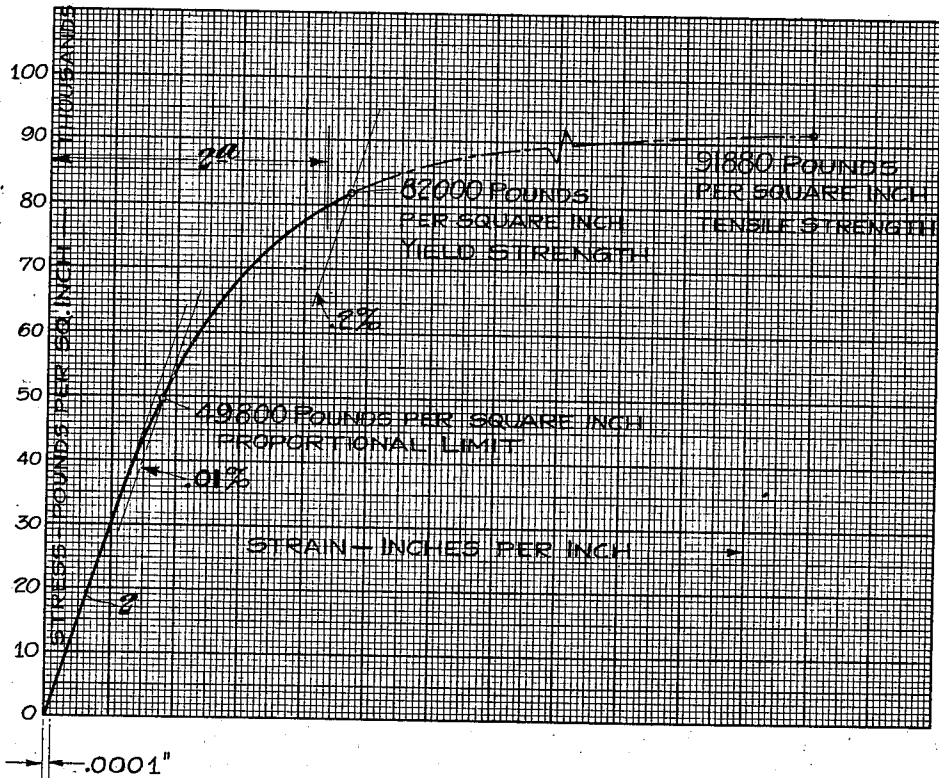
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TUBULAR ARTICLE

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3 Sheets-Sheet 2

FIG. 2.



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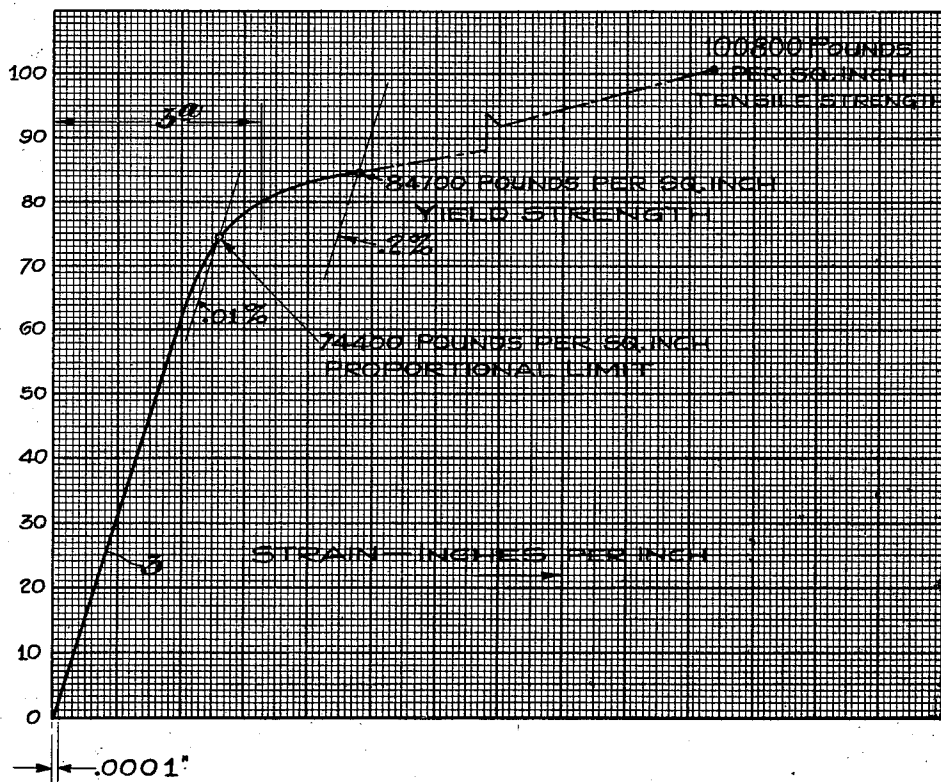
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TUBULAR ARTICLE

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3 Sheets-Sheet 3

FIG. 3.



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UNITED STATES PATENT OFFICE

2,293,938

TUBULAR ARTICLE

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3 Claims. (Cl. 138—47)

This invention relates to tubular articles and more particularly those which possess high physical properties, such as well-casings, drill-tubes and couplings.

In the recent past, the petroleum industry, by way of example, has been faced with the difficulty of obtaining tubing which will withstand heavy service. The factors involved are high loads directed radially and longitudinally in both tension and compression. In very deep wells enormous external pressures tend to collapse the tubing. High resistance to collapse must therefore be maintained. Space limitations prohibit recourse to increasing the wall-thickness to the tubing; which would, of course, increase its resistance to collapse. This problem becomes extremely acute when working in wells approaching two (2) miles in depth. Not only are the pressures great at such a depth, but the weight of the strings of tubing is vastly increased. This extreme weight sometimes results in permanent deformation resulting in leaky joints and sometimes in actual rupture. In addition, the tubing must be able to resist severe shocks.

In order to ameliorate these difficulties, elaborate series of tests have been conducted by many investigators.

Some workers in the tubular arts advocate cold-working to increase the yield strength of the metal of the tube in compression in a circumferential direction, and also to increase its tensile yield strength in a longitudinal direction. It is undoubtedly true that collapse values are enhanced by cold-working. However, the yield strength of the material of a tube is an arbitrarily defined point on the curve of a stress-strain diagram; and has no more to justify its use as a factor in its resistance to collapse than any other point on the same curve. Mathematicians have shown that structures loaded under conditions of unstable equilibrium, as is the case of a slender strut or a tube under external pressure, have a critical load resistance that is a function of the stress-strain curve of the material such that the critical load depends not alone on the coordinates of the curve but also upon its slope. The fact that tubes having relatively large diameter/thickness ratios collapsed at stresses greatly under the yield strength was well known and led investigators to the use of separate formula for diameter/thickness ratios above and below a certain point (such as, for example, approximately 40 for low-carbon steel). The former (ratios above the said point) were recognized as elastic failures. In addition, we

have discovered that cold-working reduces the elastic properties of the tube to such an extent as to seriously impair its usefulness; and we wish not only to restore these properties to obtain an actual increase over the values prior thereto for reasons in addition to those concerned with collapse.

While the foregoing is only exemplary, it will be readily apparent that the increase of the physical properties of a tubular article of given material and dimensions is of great value. There are numerous ways of doing this, but they either unduly sacrifice some qualities to obtain others or are too expensive to practice. As an example of those entering into the latter category, attention is called to quenching and tempering, which should produce good results but its cost is, in many instances, prohibitive.

We have discovered that, in the art of making tubes which possess good ductility and other high physical properties, the predetermination of the proper relation of the value of unit stress at the beginning of permanent deformation and its value at yield strength is of extreme importance for its favorable effect on the slope of the stress-strain curve.

The unit stress at the beginning of permanent deformation is the stress at which the strain ceases to be proportional; and it is commonly referred to in mechanical testing as the "proportional limit." It has not, to our knowledge, been regarded by workers in the tubular arts as possessing any special significance.

Because of the well known experimental difficulty of determining this point with accuracy, we follow the usual conventional practice of allowing ourselves a minute permanent deformation in the test specimen to make certain that the proportional limit has been reached, and at the same time not greatly exceeded. The amount of permanent deformation varies with different investigators, and we find that it ranges from .0005% to .03%. We prefer to use .01%. Therefore, in any reference to "proportional limit" we are referring to a test wherein that value is associated with a permanent deformation of .01% within the limits of our ability to detect it. At the present time, it is our opinion that the most accurate way of obtaining this value is by what is known to mathematicians as the "Method of least squares."

The yield strength is the conventional .2% set value.

The Charpy impact values hereinafter referred to are the results of tests made on specimens

which are two-thirds the standard width due to limitations of tube size. These values are actual, no correction being made in the results to allow for the smaller specimen in our tests. The standard dimensions of the Charpy specimen are 10x10 millimeters in section with the "keyhole notch" 2 millimeters in diameter. The depth of the bottom of the keyhole notch is 5 millimeters below the surface, and the distance between the supports for the specimen in the testing machine is 40 millimeters.

Our discoveries have shown that tubes otherwise possessing very high physical properties will not perform to best advantage if they lack a high "proportional limit" in proper relation to yield strength.

In all cases the yield strength will be higher than the "proportional limit," but some tubular articles intended to possess high physical properties have a very high yield strength coupled with a very low "proportional limit." Such an article has, according to our discoveries, a lowered resistance to permanent deformation under stress; although its ductility (or toughness) may enable it to resist severe shock. Our invention therefore teaches the desirability of a predetermined high proportional limit properly related to the yield strength. Yield strength alone we have found to be insignificant in comparison.

It is among the objects of the present invention to provide tubular articles having accurately predetermined proportional limits (or value of unit stress at permanent deformation).

Another object is to predeterminately regulate the proportional limit with respect to the yield strength. The regulation will, of course, depend on the ultimate use for which the tubular article is intended.

Another object is the provision of an article of the class described which also possesses suitable ductility (or toughness).

The foregoing and further objects will be apparent after referring to the drawings, in which:

Figures 1, 2 and 3 are mechanical testing diagrams illustrating the stress-strain characteristics of a tubular article after each step of our method.

The tubular article of the invention is enabled to withstand higher working stresses, or loads. That is to say, the same working stresses, or loads, can be imposed on our tubular article with substantial increase over a given factor of safety; or conversely, higher working stresses, or loads, can be imposed on it with the same factor.

We have applied the method of the invention to a kind and size of tubing which is at the present time used in large quantities and has properties which are well known. The tubing is known in the trade as American Petroleum Institute's grade D; it is 7 inches in outside diameter; has a wall thickness of .332 of an inch; and is used in lengths varying between 20 feet and 40 feet. We have found the following analyses of steel and physical properties to be representative:

Carbon	Per cent	40
Manganese	do	1.30
Silicon	do	.15
Remainder	(substantially iron) do	98.15
Tensile strength	lbs. per sq. in.	104,140
Yield strength	do	62,450
Proportional limit	do	55,000
Ductility (toughness as determined by the Charpy impact test)	ft. lbs.	14.6
Collapse pressure	lbs. per sq. in.	5,080

According to our discoveries, both the proportional limit and yield strength should be higher. Greater ductility (or toughness) is also desirable because of occasional brittle-failures.

In order to increase these values we first obtain a steel of desirable characteristics. The steel may vary within wide limits but should preferably be in a substantially completely deoxidized condition. If, however, such a steel is not used, the increased proportional limit and yield strength will be obtained, but the ductility will be lower. We have found that steels containing .20% to .35% carbon, .75% to 1.50% manganese, and .05% to .30% silicon and .03% to .10% aluminum may be employed to obtain the advantages of the present invention. Alloying elements which do not harden by precipitation, (such as nickel, molybdenum, chromium and vanadium) may be added if desired to improve ductility. However, no alloying elements which harden upon precipitation (such as copper, nitrogen, tungsten, and molybdenum if used in large amounts) should be employed for the reason that they will have an unfavorable effect on the stress-strain characteristics of the metal. The steel is formed into a tube as, for example, by hot-rolling.

After the formation of the tube it is cold-worked a predetermined amount and finally heat-treated to a predetermined degree; the temperature of the tube being in all cases below its lower critical point. That is, after the hot-rolled tube is obtained from steel of a certain analysis, the cold-working and heat-treatment are regulated with respect to each other to obtain predetermined results. The necessary cold-working may be accomplished by any suitable method such as, for example, reduction or expansion with from between 5% to 10% change in diameter.

As an illustration of the teachings of the invention, a steel of the following analysis was obtained.

	Per cent
Carbon	.26
Manganese	1.30
Silicon	.13
Aluminum*	.043
Remainder (substantially iron)	98.297
*(showing substantially complete deoxidation).	

This steel was hot-rolled into a tube having an outside diameter of 7 $\frac{1}{8}$ inches and a wall thickness of .322 of an inch. The tube thus obtained had the following physical properties:

Tensile strength	lbs. per sq. in.	85,650
Yield strength	do	59,540
Proportional limit	do	58,900
Ductility (toughness as determined by the Charpy impact test)	ft. lbs.	26.5
Collapse pressure	lbs. per sq. in.	4,710

The stress-strain characteristics of the hot-rolled tube are illustrated in the diagram of Figure 1 of the drawings. This diagram is an accurate 500 to 1 scale representation of actual test results. In this diagram the numeral 1 designates the strain undergone by the specimen at stress values taken at predetermined intervals. It will be noted that the specimen reached its .01% proportional limit at approximately 58,900 lbs. per square inch following a substantially straight line, after which the line 1 curved therefrom until the yield strength of 59,540 lbs. per square inch was reached. After the yield strength of the material was reached the line

1, although broken, continues to symbolically represent the stress-strain characteristics of the specimen up until the tensile strength of 85,650 lbs. per square inch was reached. The results show that in its present condition the proportional limit is approximately 99% of the yield strength, and the yield strength is approximately 69% of the tensile strength. Thus, the product of the ratio of the yield strength to the tensile strength (69%) multiplied by the ratio of the proportional limit to the yield strength (99%) is .6831 (or approximately 68:100). The line 1^a is a linear illustration of the amount of strain at a stress of 80,000 lbs. per square inch. The figure of 80,000 lbs. per square inch is arbitrary and could be any other stress which is greater than the proportional limit and less than the yield strength.

From the foregoing it will be noted that the steel used is inferior to, and less costly than, the steel of the analysis of the American Petroleum Institute, grade D, previously mentioned; and in addition its yield strength, tensile strength, and collapse pressure are of a decidedly lower order. In its present hot-rolled condition it does not meet the present physical requirements of the American Petroleum Institute for grade D casing. It should, however, have a tensile strength in hot-rolled condition of at least 65,000, and preferably 85,000 lbs. per square inch or more if the results of our method are to be obtained.

After hot-rolling the tube was cold-reduced to an outside diameter of 7 inches and wall thickness of .332 of an inch. This amount of cold-reduction is approximately 8.2% as related to change in diameter and was obtained by rolling; although the other methods of cold-working could have been substituted therefor.

Immediately after cold-reduction, the tubing was found to possess the following properties:

Tensile strength	----- lbs. per sq. in.	91,880
Yield strength	----- do	82,000
Proportional limit	----- do	49,800
Ductility (toughness as determined by the Charpy impact test)	----- ft. lbs.	24.5
Collapse pressure	----- lbs. per sq. in.	6,180

The stress-strain characteristics of the hot-rolled and cold-worked tube are illustrated in the diagram of Figure 2 of the drawings which, like Figure 1, is an accurate 500 to 1 scale representation of actual test results. In this diagram the numeral 2 designates the strain undergone by the specimen at stress values taken at predetermined intervals. It will be noted that the specimen reached its .01% proportional limit at approximately 49,800 lbs. per square inch following a substantially straight line, after which the line 2 curved therefrom until the yield strength of 82,000 lbs. per square inch was reached. After the yield strength of the material was reached the line 2, although broken, continues to symbolically represent the stress-strain characteristics of the specimen until the tensile strength of 91,880 lbs. per square inch was reached. The reason for breaking the line 2 after the yield strength is reached and up to the tensile strength is due to the fact that the scale of the drawings is so small in comparison with the degree of elongation. The results show that in the present condition the proportional limit is approximately 60% of the yield strength and the yield strength approximately 89% of the tensile strength. Thus, the

product of the ratio of the yield strength to the tensile strength (89%) multiplied by the ratio of the proportional limit to the yield strength (60%) is .5340 (or approximately 53:100). The line 2^a is a linear illustration of the amount of strain at a stress of 80,000 lbs. per square inch.

A comparison of the physical properties of the tube, prior to and after cold-reduction, discloses the fact that some of the physical properties were improved; while others were lowered. Ductility decreased slightly, but not enough to impair quality. However, the proportional limit decreased to such an extent that the usefulness of the tube was seriously impaired.

The cold-reduction was followed by heat-treating at a low temperature. More specifically, it comprised heating the tube to a temperature of four hundred degrees centigrade (400° C.) for a period of one hour. We have found that a heat-treatment such as will heat the work-piece to a temperature of from between 300° C. and 500° C. may be employed to obtain the advantages of the present invention. The temperature and time may be varied in inverse proportion, but the former must be, as before stated below the lower critical point.

The following improved physical properties were obtained:

Tensile strength	----- lbs. per sq. in.	100,800
Yield strength	----- do	84,700
Proportional limit	----- do	74,400
Ductility (toughness as determined by the Charpy impact test)	----- ft. lbs.	22.1
Collapse pressure	----- lbs. per sq. in.	7,090

The stress-strain characteristics of the hot-rolled, cold-worked and heat-treated tube are illustrated in Figure 3 of the drawings which, like Figures 1 and 2, is an accurate 500 to 1 scale representation of actual test results. In this diagram the numeral 3 designates the strain undergone by the specimen at stress values taken at predetermined intervals. It will be noted that the specimen reached its .01% proportional limit at approximately 74,700 lbs. per square inch following a substantially straight line, after which the line 3 curved therefrom until the yield strength of 84,700 lbs. per square inch was reached. After the yield strength of the material was reached the line 3, although broken, continues to symbolically represent the stress-strain characteristics of the specimen until the tensile strength of 100,800 lbs. per square inch was reached. The results show that in the present condition the proportional limit is approximately 88% of the yield strength and the yield strength approximately 84% of the tensile strength. Thus, the product of the ratio of the yield strength to the tensile strength (84%) multiplied by the ratio of the proportional limit to the yield strength (88%) is .7392 (or approximately 74:100). The line 3^a is a linear illustration of the amount of strain at a stress of 80,000 lbs. per square inch.

This finished tube not only meets, but greatly exceeds, every physical requirement of the American Petroleum Institute for grade D casing, including those not herein specifically set forth.

The microstructure of the material having these improved results was substantially the same as that of the hot-rolled metal. That is to say, the microstructure, so far as can be determined with present day microscopes, is not visibly changed. The material will withstand approxi-

mately 40% more stress without permanent deformation and had very much greater ductility to withstand abuse, such as shock, than the usual American Petroleum Institute grade D product. The improved physical properties showed increases over the properties immediately after cold-reduction in yield strength, tensile strength, proportional limit, and collapse pressure. The slight decrease in the ductility is insignificant. The improved relationship of the proportional limit to the yield strength is the dominating factor in the great increase in the collapse value.

According to a modified form of the method of the invention, the tubular articles may be normalized subsequent to their formation and prior to the cold-working step. This will, of course, enhance the quality of the work-piece. This modified method therefore comprises forming the tube, normalizing the formed tube, cold-working the normalized tube, and heat-treating the cold-worked tube at a temperature below its lower critical point. The normalizing temperature may be, for example, from 825 to 900 degrees centigrade. The physical properties of the work-piece which were enhanced by the normalizing step will be evidenced in the finished article and its resultant microstructure will be the same as that of the normalized metal.

We have not illustrated the specific stress-strain characteristics of the tube after the normalizing step for the reason that the slope of the stress-strain curves will be substantially those of the diagrams of Figures 2 and 3.

It is old in the art to cold-draw tubes and subsequently heat-treat them at low temperatures. Such articles are known in the art as "mechanical tubes" and are used for many different purposes. They are kept in stock in anticipation of future demand, and are eventually cold-reduced to obtain a desired size or to provide a good surface. The heat-treatment is employed to eliminate to a desired extent the brittleness imparted by the cold-reduction. The desired factors are therefore to obtain a certain size or surface and at the same time only a limited brittleness.

The tubular article of our invention always has a predetermined proportional limit which is not only increased over the hot-rolled and cold-worked values but is raised to at least 65,000 lbs. per square inch. The proportional limit is in addition predeterminedly regulated with respect to the yield strength of the tube. That is to say, the proportional limit shall always be at least 75% of the yield strength and the yield strength shall always be at least 75% of the tensile strength. Furthermore, in any test piece the relation of the yield strength and the proportional limit to the tensile strength shall always be such that the product of the ratio of yield strength to tensile strength multiplied by the ratio of the proportional limit to yield strength is preferably at least 70:100; or with a minimum proportional limit of 65,000 lbs. per square inch the products of the ratios shall be at least 65:100.

Moreover, the finished tube always possesses a collapse value which is increased over the hot-rolled and cold-worked values of the same tube provided the failures are not elastic; its microstructure is always substantially the same as that of the same tube prior to the cold-working step; and its ductility is always sufficient to enable it to withstand a Charpy impact test of 16 ft. lbs. on a longitudinal specimen.

We co-relate the factors of metal, cold-working and heat-treatment to obtain minima properties. For example, in "oil country goods" (i. e., drill-pipe, and well casing) we regulate the factors to obtain a finished tubular article having a tensile strength of at least 95,000 lbs. per square inch; a yield strength of at least 75,000 lbs. per square inch, which is at least 75% of the tensile strength; and a proportional limit of at least 65,000 lbs. per square inch.

Furthermore, the relation of the yield strength and the proportional limit to the tensile strength shall always be such that the product of the ratio of yield strength to tensile strength multiplied by the ratio of the proportional limit to the yield strength is at least 65:100, with a minimum proportional limit of 65,000 lbs. per square inch. Moreover, the ductility of such articles (oil country goods) will always be sufficient to withstand a Charpy impact test of 16 ft. lbs. on a longitudinal specimen.

No one has, to our knowledge, attempted to obtain tubing having these predetermined physical properties. Our explanation is that no workers in the art of metallic tubes had, until the present time, discovered the significance of the value of proportional limit and its proper relationship to yield strength. According to the teachings of the invention, we are able to increase these physical properties within predetermined accurate limits. By so doing, a wide range of usage is opened to cheaply-made tough and elastic tubes.

It should be readily appreciated by those skilled in the art that the invention is not confined to well-casing, which was used solely as an example, but applies to all metallic tubular articles.

This application is a continuation-in-part of our application Serial No. 80,214, filed May 16, 1936.

While we have shown and described several specific embodiments of our invention, it will be understood that we do not wish to be limited exactly thereto, since various modifications may be made without departing from the scope of our invention, as defined by the following claims.

We claim:

1. A cold-worked and heat-treated well-casing having high resistance to collapse and high ductility, said well casing being composed of substantially deoxidized steel containing carbon and manganese in appreciable amounts, said steel as a result of said cold-working and heat-treatment having a stress-strain curve in which the proportional limit thereof is at least 65,000 pounds per square inch, the said curve being such that the proportional limit is at least 75 per cent of the yield strength and the latter is at least 75 per cent of the tensile strength.

2. A cold-worked and heat-treated well-casing having high resistance to collapse, said well casing being composed of substantially deoxidized steel containing carbon and manganese in appreciable amounts, said steel as a result of said cold-working and heat-treatment having a stress-strain curve in which the proportional limit thereof is at least 65,000 pounds per square inch, the said curve being such that the proportional limit is at least 75 per cent of the yield strength and the latter is at least 75 per cent of the tensile strength, the ductility of the steel of said oil well casing being sufficient to withstand a Charpy impact test of 16 foot pounds on a longitudinal specimen.

3. A cold-worked and heat-treated well-casing

having high resistance to collapse and high ductility, said well-casing being composed of substantially deoxidized steel containing carbon and manganese in appreciable amounts and no precipitation hardening elements, said steel as a result of said cold-working and heat-treatment having a stress-strain curve in which the pro-

portional limit thereof is at least 65,000 pounds per square inch, the said curve being such that the proportional limit is at least 75 per cent of the yield strength and the latter is at least 75 per cent of the tensile strength.

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