Dec. 30, 1969 G. L. VANEMAN ET AL 3,486,361

STRENGTHENING OF ELONGATED METAL SECTIONS

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FIG. 1

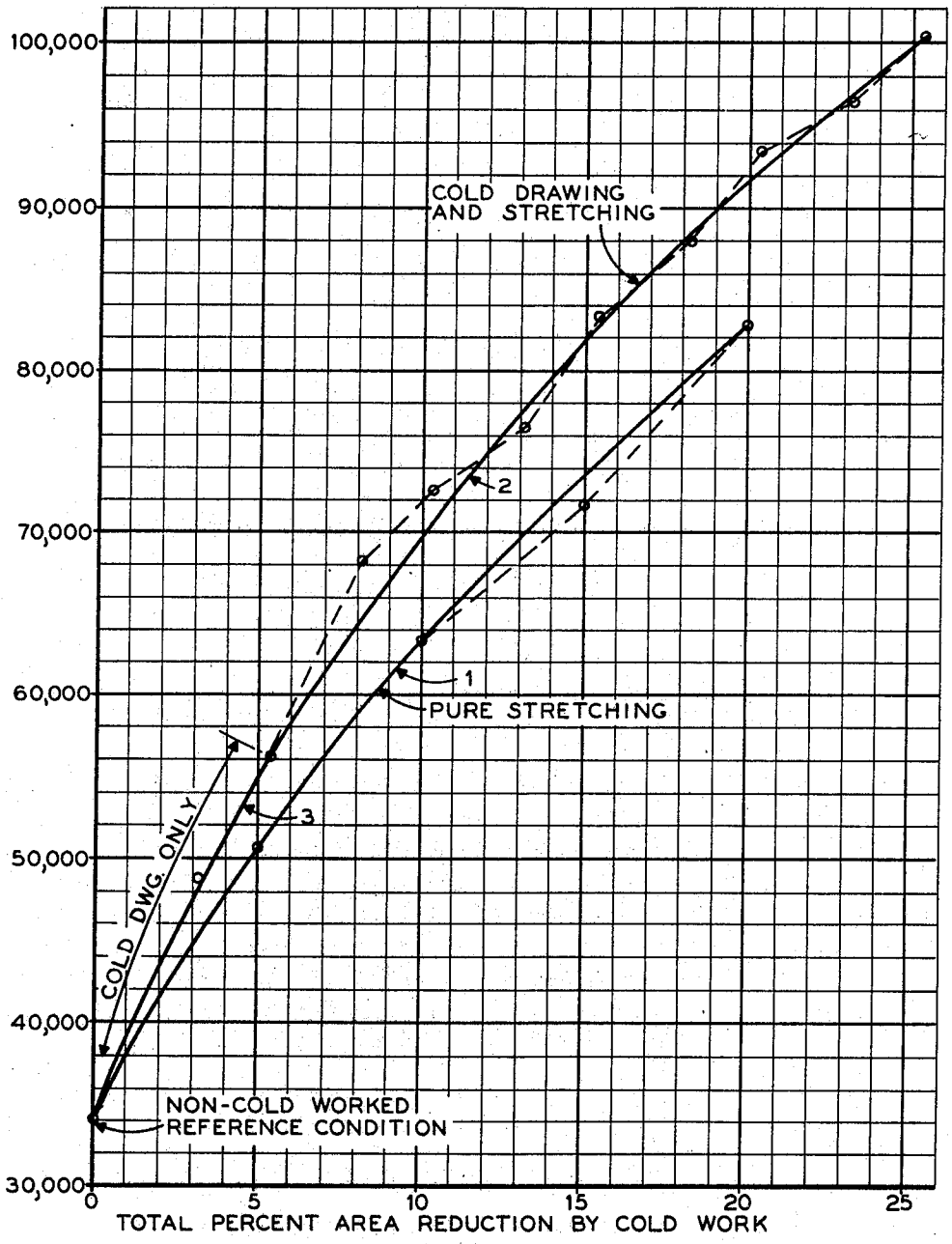

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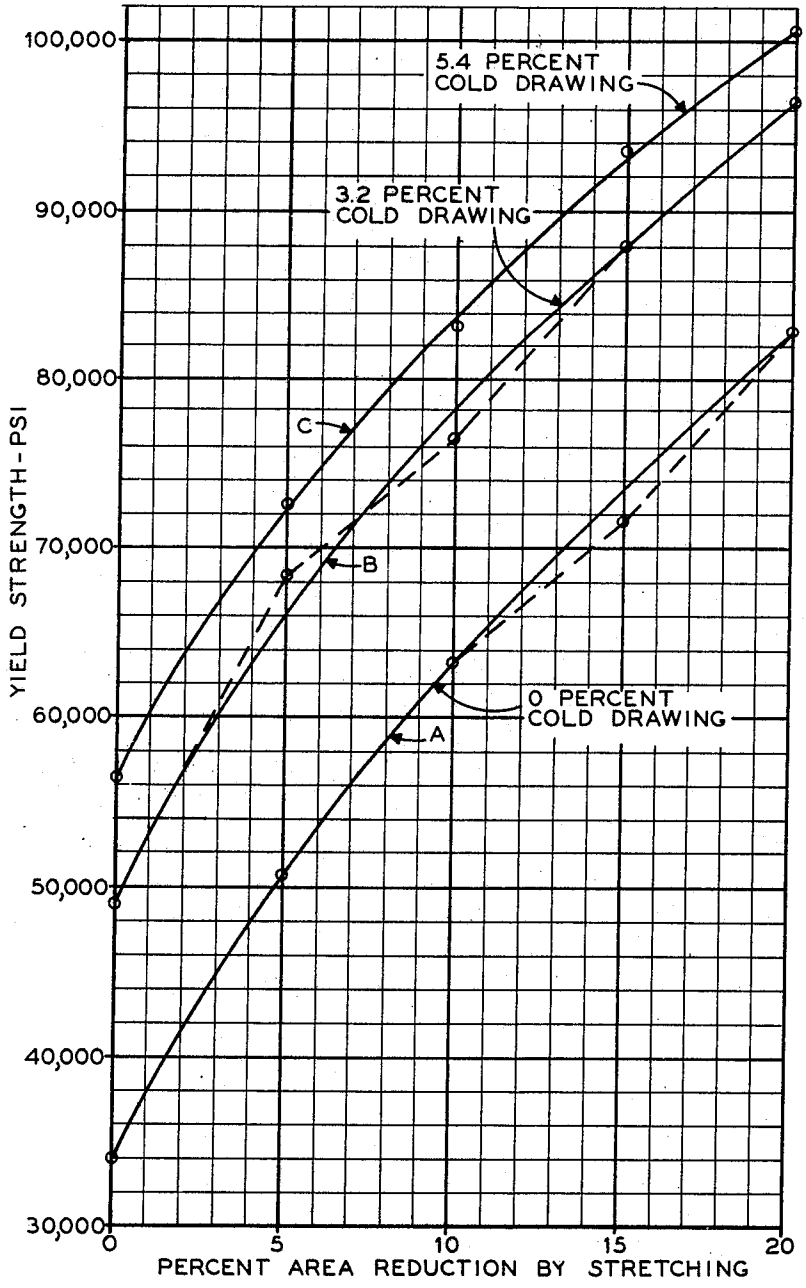
FIG. 2


100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
YIELD STRENGTH-PSI
0
5
10
15
20
PERCENT AREA REDUCTION BY STRETCHING
5.4 PERCENT COLD DRAWING
3.2 PERCENT COLD DRAWING
0 PERCENT COLD DRAWING
A
B
C

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3,486,361

STRENGTHENING OF ELONGATED METAL SECTIONS

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U.S. Cl. 72—278 6 Claims

ABSTRACT OF THE DISCLOSURE

A method of increasing the tensile and yield strengths of elongated metal sections of various cross-sectional shapes by subjecting them to a combination of cold drawing and stretching steps performed in accordance with an empirical cold work deformation-strength relation to achieve selected material strength values.

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention relates in general to the manufacture of elongated metal sections such as are commonly produced by extrusion or rolling, and more particularly to a method of increasing the material strength of both the peripheral regions and interior regions of such metal sections by a combination of cold drawing and stretching cold working steps.

It is known that the tensile and yield strengths of many metals formed into lengths of various dixerent cross-sectional shapes can be increased above the values normally obtained in their initial as-formed conditions by subsequently subjecting them to cold drawing. It is also known from engineering strength of materials that a metal section when taken in an initial condition and plastically deformed by stretching beyond the elastic yield limit for such initial condition and then unloaded will exhibit a higher elastic yield limit when subsequently subjected to tension.

In general, the methods of strengthening materials by cold drawing alone and by stretching alone have their characteristic peculiarities, since they each provide physically distinctive material cold working modes. With cold drawing, the material is subjected to both tension along the drafting or longitudinal direction and inward peripheral compression in directions transverse to the drafting direction, whereas with stretching the material is subjected to substantially pure tension along the longitudinal direction. Thus, cold drawing involves a three-dimensional stress-strain relation whereas stretching involves a unidirectional stress-strain relation.

It has been found that the material strengthening effects of cold drawing are propagated into the material inwardly from the peripheral boundary surface thereof in such a manner that most of the strength increase due to cold drawing is concentrated in the peripheral regions or skin of the material and appears to a lesser extent throughout the interior regions or core portion of any given material cross section. Consequently, a metal section which is subjected to only cold drawing will have a highly strengthened skin and a core which is strengthened to a much lesser degree.

The amount of strengthening which can be produced by cold drawing alone is limited because the skin material becomes more brittle and less ductile as the percentage of cross-sectional area reduction due to cold drawing increases, and also because with conventional drafting equipment limitations, cold drawing beyond a 6 percent area reduction per pass is impractical, to to considerations such as section size and configuration, die design, lubrication, and draw bench capacity. Even with

multipass cold drawing procedures, a metal section of a given material composition and initial cross-section dimensions can only be subjected to a limited total percentage area reduction by cold drawing before skin cracking occurs. Skin cracking normally occurs before sufficient cold drawing effects appear in the core region to raise the strength thereof to a level comparable with that of the skin (before cracking).

It has been found from experience that the maximum amount of cold drawing that can be applied to a metal section of specific composition is also dependant upon the cross-sectional geometry and upon the thickness or depth measured from the peripheral surface inwardly to the centroid of the cross-sectional area, cylindrical bar sections being capable of sustaining more cold drawing than square sections, or those with sharp corners, and thinner sections being capable of more cold drawing than thick scections. As among metals, it has been generally realized that softer metals, such as copper and lead, are capable of much greater cold drawing than harder metals such as austenitic stainless steels.

The invention has particular applicability to the strengthening of relatively heavy metal sections such as are commonly produced by extrusion or rolling, although the method of the invention can be applied to relatively light section as well as those produced by means other than extrusion or rolling.

As is well known in the art, multipass cold drawing can be employed, as in the case of wire making, to reduce practically any size of bar stock to any final cross-sectional dimensions merely by using a sufficient number of consecutive drawing dies, provided, however, that the material skin hardness is relieved by annealing between successive passes. On the other hand, in the case of the invention, mere size reduction is not the objective, but rather the invention has as its primary objective the strengthening of the material. Therefore, in the practice of the invention the starting material stock has sufficient oversize in relation to the cross-sectional dimension of the ultimate product to allow for the transverse cross-sectional area reductions which are incidental to the cold working steps which are applied to the starting stock to produce a finished product having the desired strength characteristics.

The method of the invention resides essentially in the steps of taking an elongated metal section, such as a bar, rod, extruded or rolled shape, in a substantially non-cold worked condition (i.e., not subjected to any previous cold working treatment) and subjecting the section to cold drawing to plastically deform it by an amount corresponding to a reduction in transverse cross-sectional area not exceeding the percentage area reduction limit at which skin failure occurs, and subjecting the section to longitudinally stretching to plastically deform it by an amount corresponding to a reduction in transverse cross-sectional area not exceeding the percentage area reduction limit at which continued elongation at constant tension load occurs, i.e., the necking-down limit.

In the practice of the invention, it has been found for the case of austenitic stainless steels that where the cold drawing area reduction is kept within 6 percent, and the stretching area reduction is kept within 20 percent, it makes relatively little difference whether the cold drawing step is performed first and the stretching step thereafter or vice versa. Preferably in the case of austenitic stainless steels, the cold drawing area reduction is within the range of 3 to 6 percent.

One of the advantages afforded by the invention is that it allows both the core region of the section and the peripheral region, or skin region, thereof to be raised to yield and tensile strength levels that are higher than

those which could be achieved with either the maximum permissible cold drawing area reduction or the maximum permissible stretching area reduction alone. The reason for such advantage is believed to reside in the differences between the cold drawing and stretching modes of cold work treatment. It has been amply supported by numerous tests and measurements that cold drawing produces a nonuniform distribution of strength over the cross-sectional area of the material, and for any given degree of cold drawing, the peripheral regions of the section will be more heavily cold worked and therefore have much higher strength than the central core region. The nonuniformity of work hardening varies directly with the size of the section, i.e., small or thin sections will harden more uniformly throughout, but the heavier, thick sections wll have markedly softer centers as compared with the peripheral material. This can be expected from the fact that in the performance of cold drawing the peripheral surface of the section is contacted and deformed by a die, whereas when the section is cold worked by pure stretching, the tensile load forces tend to distribute more uniformly over the cross-sectional area.

Such phenomena tend to support the theory that when a metal section is subjected to cold drawing, the deformation produced at its peripheral surface by the die is propagated inwardly toward the central region of the section until the effects of surface deformation are absorbed by rearrangement of the material microstructure. For a given percentage area reduction by cold drawing, the greatest degree of microstructure rearrangement will occur at the peripheral surface, and will progressively diminish toward the center of the section, thereby resulting in a strength distribution in which the maximum material strength is at the peripheral surface and the minimum material strength is at the center. Therefore, with any given cross-sectional shape metal section, it can be said that cold drawing contributes to the overall strength of the section primarily by raising the strength of the peripheral region thereof, and also by raising, to a leser extent, the strength of the core region thereof.

Presumably, any given material can undergo only a limited amount of microstructural rearrangement before failure, as borne out by the fact that with relatively heavy sections only a limited amount of cold drawing area reduction can be performed before peripheral surface cracking occurs. Therefore, with cold drawing alone, the maximum overall effective strength attainable in any section is limited by the strength which can be realized in the peripheral region before failure occurs. Consequently, when as in the prior art, a metal section is cold drawn to increase its strength, the core region of the section can only be strengthened to a limit imposed by the peripheral region failure limit, even though were it not for the fact that cold working of the core without simultaneous greater cold working of the peripheral region is impossible with cold drawing, the core region material might be strengthened to the same level as the peripheral region material.

One of the disadvantages realized in the use of cold drawing alone to strengthen metal sections is the fact that while a section thus treated will have a high overall average strength when it leaves the drafting bench, any subsequent machining away of its hardened peripheral region will result in a serious loss of strength. For example, where a 1½ in. diameter bar has been cold drawn to have a peripheral region ⅛ in. thick wherein the average material strength is 100,000 p.s.i., and a 1¼ in. diameter core region wherein the average material strength is 60,000 p.s.i., such bar will have an overall average strength of approximately 72,000 p.s.i. as measured with respect to its entire cross-sectional area. Should the bar subsequently have its peripheral region machined away, as by any circumferential cut ⅛ in. or greater in depth, the remaining reduced area portion of the bar would have only a strength of 60,000 p.s.i., i.e., that of the core region.

Realizing the possibilities of losing all or a part of the high strength peripheral region material, it therefore becomes important in the treatment of metal sections for increased strength to use a process which not only gives a high overall material strength, but also gives a more uniform distribution of such strength throughout the entire cross-sectional area.

The invention provides a method whereby the favorable strengthening effects of both cold drawing and stretching are imparted to the metal sections treated and through the combination of such cold drawing and stretching steps some of their unfavorable individual limitations are avoided.

It is therefore an object of the invention to provide a method for increasing the tensile and yield strengths of elongated metal sections, such as are commonly produced in various cross-sectional shapes.

Another object of the invention is to provide a method as aforesaid which is adaptable for use with austenitic stainless steel sections such as those produced by either extrusion or rolling.

A further object of the invention is to provide a method as aforesaid which can be applied for strengthening metal sections of relatively heavy or thick cross-sectional dimensions.

A further object of the invention is to provide a method as aforesaid whereby greater overall material strength increases can be achieved than those heretofore possible with either cold drawing or stretching alone.

A further object of the invention is to provide a method as aforesaid whereby the strength of the core region of metal sections can be raised along with the strength of the peripheral regions thereof to achieve a more uniform overall cross-sectional strength distribution.

Still another and further object of the invention is to provide a method as aforesaid whereby predetermined post-treatment strength values can be obtained.

Other and further objects and advantages of the invention will become apparent from the following detailed description and accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

In the drawing:

FIG. 1 is a graph illustrating the yield strengths obtained in the core regions of typical austenitic stainless steel sections by treating same in accordance with the method of the invention, as compared with the yield strengths obtained in the core regions of similar sections strengthened by either cold drawing or stretching alone for various values of total percent cross-sectional area reduction by cold work.

FIG. 2 is a graph illustrating the same yield strength values obtained in FIG. 1, but compared on the basis of percent cross-sectional area reduction by stretching for 0, 3.2 and 5.4 percent area reduction by cold drawing.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

To determine empirically the effect of cold working by stretching, both alone and in combination with separately performed cold drawing, upon the tensile and yield strength properties of elongated steel sections, several section lengths were extruded from a billet of austenitic stainless steel having the following percentage composition:

	Percent
C	.049
Mn	1.72
S	.011
P	.016
Si	.49
Cr	18.58
Ni	9.20
Mo	.32
Fe	Balance

These extruded lengths were substantially of the same D-shaped transverse cross section, the area of which was approximately 1.9 square inches, and substantially uniform throughout the length for all extrusions.

The extruded lengths were divided into three groups, one group of which was subjected to a cold drawing pass giving a 3.2 percent reduction in area, a second group was subjected to a 5.4 percent reduction in area cold drawing, and the remaining third group was left in the as-extruded condition, i.e., in a substantially non-cold worked state.

Samples from each of these three groups were subjected to further cold working treatment by stretching and tested in accordance with the following example.

Example 1

To determine the strengthening possibilities and limitations afforded by stretching alone, cold drawing alone, and cold drawing in combination with separately performed stretching for various degrees of cold drawing and stretching, laboratory tensile tests were performed upon standard 0.505 in. diameter longitudinal tensile specimens cut and machined from the middle of sample section lengths taken from each of the as-extruded, lightly cold drawn (3.2% area reduction) and more heavily cold drawn (5.4% area reduction) groups. Individual tensile specimens from each of the three groups were then stretched in a tensile machine to respective 5, 10, 15 and 20 percent reductions in area, and then removed. A few days later these specimens were tested to fracture to determine their respective yield and ultimate tensile strengths. The results of these tests are presented in the following Table I:

TABLE I

Treatment condition	Total percent area reduct. by cold work	Yield strength (p.s.i. for 0.2% offset)	Ultimate tensile strength (p.s.i.)
As-extruded	0	34,000	80,000
Extruded+5% stretch	5	50,600	80,200
Extruded+10% stretch	10	63,400	87,200
Extruded+15% stretch	15	71,600	87,800
Extruded+20% stretch	20	82,900	91,400
Cold drawn 3.2%	3.2	48,800	82,709
Cold drawn 3.2%+5% stretch	8.2	68,400	87,600
Cold drawn 3.2%+10% stretch	13.2	76,600	89,500
Cold drawn 3.2%+15% stretch	18.2	88,100	95,800
Cold drawn 3.2%+20% stretch	23.2	96,500	99,800
Cold drawn 5.4%	5.4	56,300	84,200
Cold drawn 5.4%+5% stretch	10.4	72,600	87,000
Cold drawn 5.4%+10% stretch	15.4	83,300	91,000
Cold drawn 5.4%+15% stretch	20.4	93,500	103,250
Cold drawn 5.4%+20% stretch	25.4	100,500	103,300

It should be noted that the foregoing yield and tensile strength values are actually those which exist within the core regions of the original full size cross-section samples by reason of the fact that the peripheral regions of the samples had been machined away to the standard 0.505 in. diameter specimen size to accommodate stretching and testing in a standard tensile machine. Hence, the tabulated strength values are conservative values because they reflect only the contribution of stretching and cold drawing steps upon the core, and more particularly the strengthening effect of cold drawing, which is predominantly concentrated in the peripheral regions, has been considered only to the extent that it appears in the core. The actual overall strengths of the treated metal sections will be actually higher than that indicated for their respective core regions because of the higher strength of their peripheral regions.

An analysis of the data presented in Table I indicates that cold drawing to 3.2% and 5.4% area reductions alone results in yield strength increments of 14,800 p.s.i. and 22,300 p.s.i., respectively, over the basic 34,000 p.s.i. yield strengths for the non-cold worked state, and that stretching alone to 5%, 10% 15% and 20% area reductions results in yield strength increments of 16,600 p.s.i., 29,400 p.s.i., 37,600 p.s.i. and 48,900 p.s.i., respectively, over the same basic 34,000 p.s.i. yield strength value.

The graphical illustration of yield strength versus total percent area reduction by cold work shown by curves **1, 2** and **3** of FIG. 1 was obtained by plotting the yield strength data of Table I. Curve **1** represents the yield strengths obtained by pure stretching alone performed upon those samples which were not subjected to any cold drawing. For a conservative evaluation, giving maximum credit to the technique of strengthening by stretching alone, curve **1** was smoothened somewhat by ignoring the deviation presented by the test yield strength for 15 percent area reduction stretching, which as indicated by the dashed straight lines connecting the 15 percent stretch point with the 10 and 20 percent stretch points, would seem to signify, at least for the type material tested, that a somewhat less beneficial strengthening effect would be obtained for the 10–20 percent stretch range than shown by the solid curve portion drawn for that range. Likewise, curve **2**, which shows the strengthening effect obtained by combinations of cold drawing and stretching steps, has been drawn as a solid smooth curve generally averaging out the deviation presented by individual test data points connected by dashed straight lines. It was found that by drawing curve **2** in such manner, a closer termnial coincidence with curve **3** was obtained, curve **3** being drawn on the basis of yield strength data obtained for 0, 3.2 and 5.4 percent area reduction by cold drawing alone, with the as-extruded state being taken as 0 percent cold drawing and 0 percent stretching.

FIG. 1 therefore shows unequivocally that for the same total percent area reduction a cold working treatment process that includes a cold drawing step produces a greater yield strength than one having merely stretching alone, and that where the yield strength desired exceeds that which can be obtained using only cold drawing, such greater yield strength can be obtained by adding a stretching step.

FIG. 2 shows three curves A, B, and C plotted from the same yield strength data presented in Table I and plotted in FIG. 1, except that curves A, B, C are plotted as a function of the percent area reduction due to stretching, for 0 percent cold drawing (pure stretching), 3.2 percent cold drawing and 5.4 percent cold drawing, respectively. Actually, curve A is a duplicate of curve **1** in FIG. 1 since both represent the yield strength effects of pure stretching.

Since FIGS. 1 and 2 represent core region yield strength values, the curves **1, 2, 3**, A, B, C can be used to determine how much stretching is required, either alone or in combination with a given percentage area reduction by cold drawing separately performed, in order to achieve a desired yield strength in a metal section having a composition equivalent to that in the foregoing example, or a different composition with similar cold working properties, and the values thus determined will be conservative ones due to the fact that the peripheral region strength will be higher due to the effect of cold drawing.

The same criteria as applies to selection of cold drawing and stretching step combinations in the case of treating a metal section to achieve a predetermined yield strength also applies in the case of treating the section to meet predetermined ultimate tensile strength criteria. Curves similar to the curves shown in FIGS. 1 and 2 can be constructed from the ultimate tensile strength data set forth in Table I, such ultimate tensile strength curves being omitted herein for the sake of simplicity and because in most practical applications of the invention, yield strength will be the guiding criteria.

As can be appreciated by the artisan, the specific graphical data presentation of FIG. 1 and 2 is merely being given by way of example as to how to practice the invention, although such data can be used with a reasonable degree of accuracy for any metal having cold working characteristics equivalent or similar to those of the

austenitic stainless steel alloy specified in the example. Because of the vast number of different metals and alloys, it would be impractical to provide herein comparable graphs for all materials to which the invention is applicable. For any particular metal or alloy, graphs corresponding to FIGS. 1 and 2 can be formulated by following the test procedure given in the example, and once the test data for such graphs has been obtained, they can be used to emprically determine the yield as well as ultimate tensile strength values for given percentage air reductions by cold drawing and stretching steps, and vice versa. It has been found in the testing of specimens similar to those of the example that it makes relatively little difference in the final results as to whether the cold drawing or stretching step is performed first.

From the foregoing description, it will become apparent that the invention is susceptible of other obvious modifications and variations. However, the invention is intended to be limited only by the following claims in which we have endeavored to claim all inherent novelty.

What is claimed is:

1. A method of increasing the strength of an elongated metal section which comprises the steps of subjecting the section to cold drawing to plastically deform same by an amount corresponding to a reduction in transverse cross-sectional area not exceeding the percentage area reduction at which failure occurs in the peripheral regions of the section, and subjecting the section to longitudinal stretching to plastically deform same by an amount corresponding to a reduction in transverse cross-sectional area not exceeding the percentage area reduction limit at which continued elongation at constant tension load occurs.

2. The method according to claim 1 wherein said metal section is initially in a non-cold worked state and in said cold drawing step is cold drawn to a cross-sectional area reduction not exceeding 6 percent, and in said stretching step is longitudinally stretched to a cross-sectional area reduction not exceeding 20 percent.

3. The method according to claim 2 wherein said metal section is cold drawn to a cross-sectional area reduction within the range of 3 to 6 percent.

4. The method according to claim 2 wherein said metal section is first subjected to said cold drawing step and then subjected to said stretching step.

5. The method according to claim 2 wherein said metal section is first subjected to said stretching step and then subject to said cold drawing step.

6. A method of increasing the strength of both the core region and the peripheral region surrounding the core region of an elongated metal section having material properties and transverse cross-sectional dimensions which limit the extent to which the section can be cold worked by cold drawing alone and also the extent to which the section can be cold worked by stretching alone, which comprises the steps of subjecting an elongated metal section having such material properties and transverse cross-section dimensions to longitudinal stretching to plastically deform same by an amount less than the cold work limit for stretching alone, and subjecting the section to cold drawing to plastically deform same by an amount less than the cold work limit for cold drawing alone, whereby said longitudinal stretching step contributes to the overall strength of the section by raising the strength of the core and peripheral regions thereof by a substantially uniform amount corresponding to the plastic deformation due to stretching, and said cold drawing step contributes to the overall strength of the section primarily by raising the strength of the peripheral region thereof, and to a lesser extent by raising the strength of the core region thereof.

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