United States Patent

Schneider et al.

[15] 3,650,848

[45] Mar. 21, 1972

[54] PRODUCTION OF FERRITIC STAINLESS STEEL WITH IMPROVED DRAWING PROPERTIES

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[22] Filed: **June 18, 1969**

[21] Appl. No.: **834,404**

[52] **U.S. Cl.** **148/12**

[51] **Int. Cl.** **C21d 7/02**

[58] **Field of Search** 148/12

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[57] **ABSTRACT**

Ferritic stainless steel of the 430 series is produced to have improved drawing properties by procedure in which in a two-stage cold reduction of the hot-rolled band, with an intermediate anneal, the second stage effects reduction of at least about 80 percent, following at least about 30 percent reduction in the first stage. The finally annealed sheet is substantially non-earing and when the first stage reduction is at least in the vicinity of 40 percent, the sheet is also characterized by deep drawing property.

15 Claims, 5 Drawing Figures

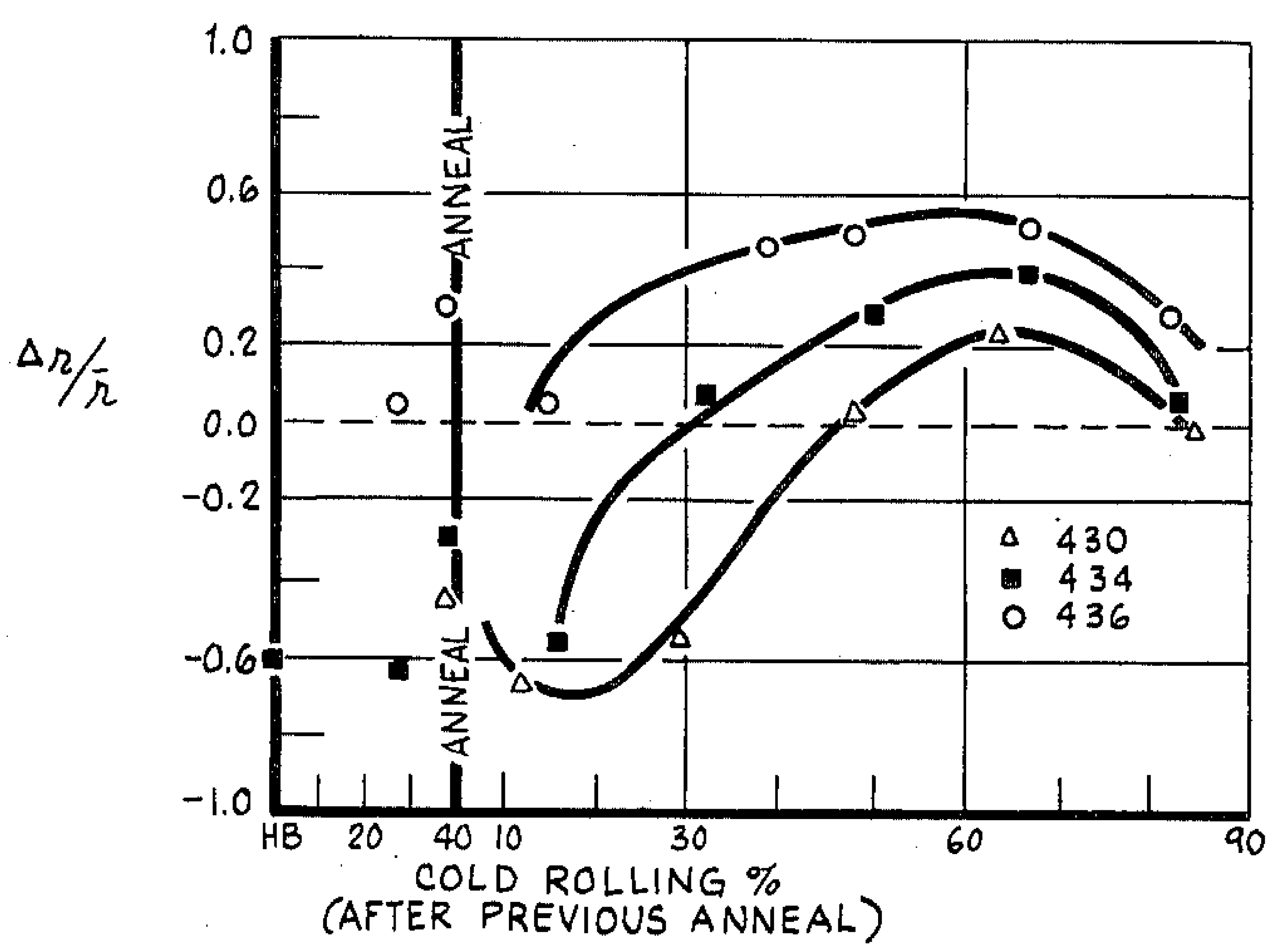
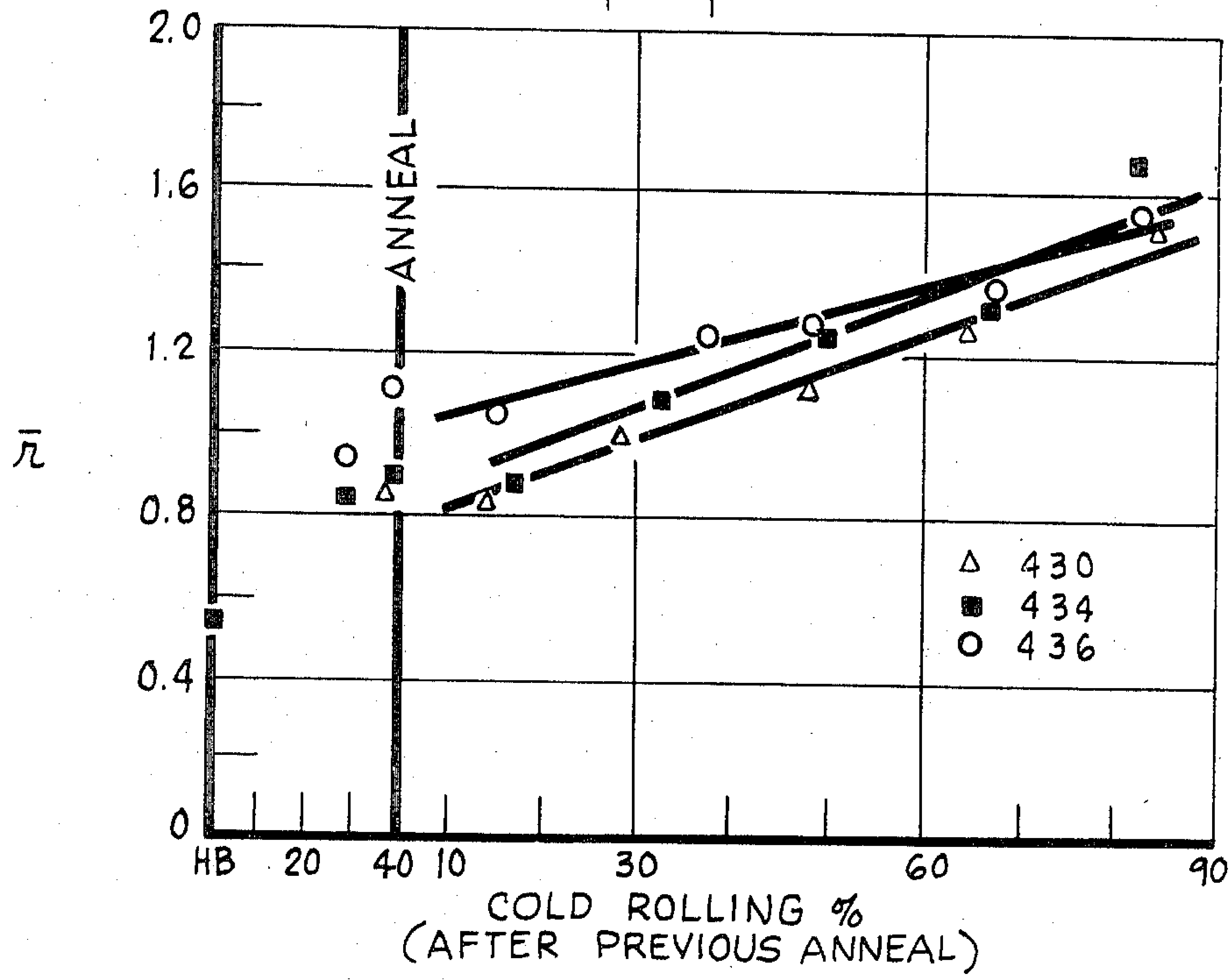


Fig. 1.



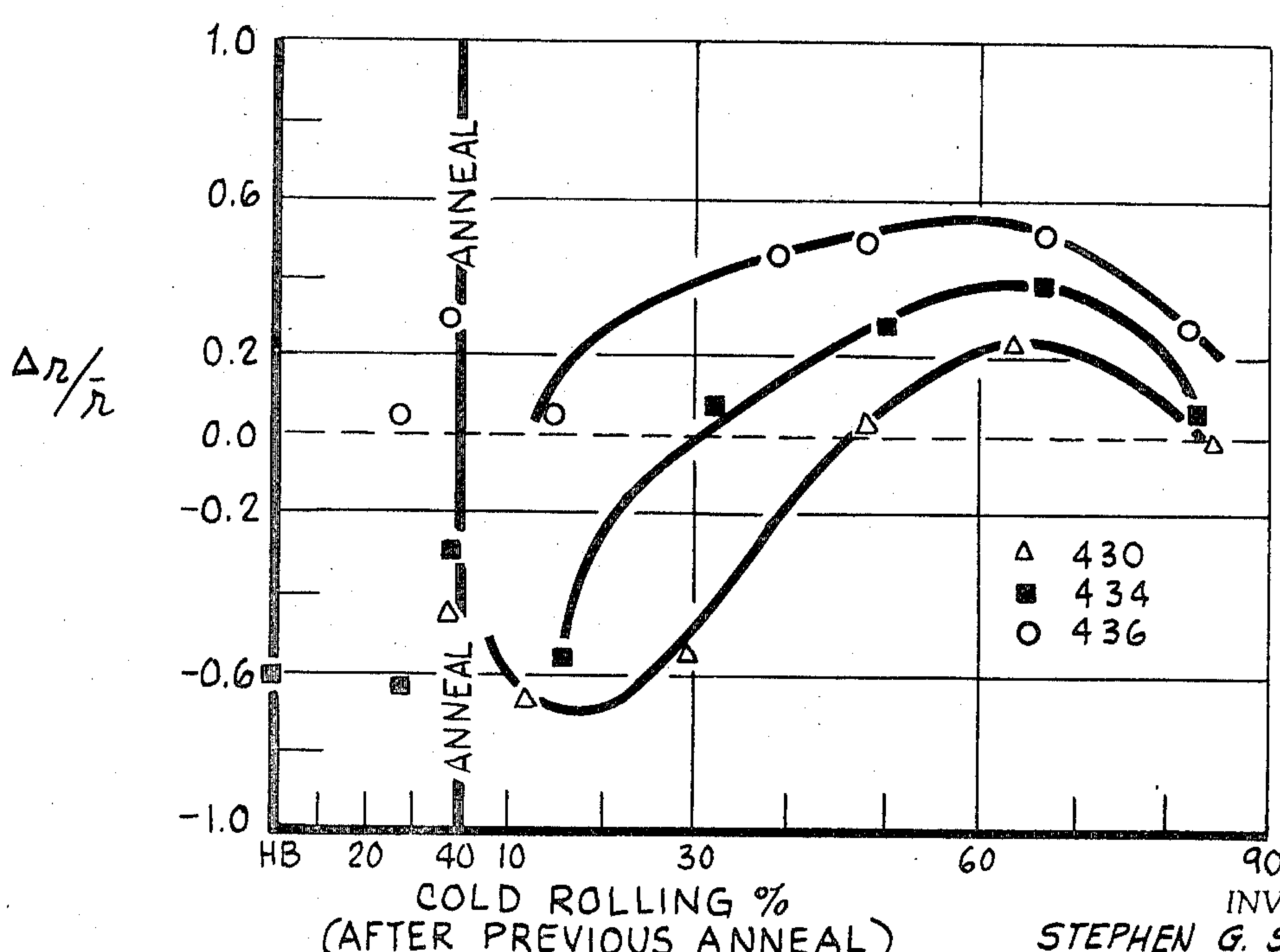


Fig. 5.

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Fig. 2.

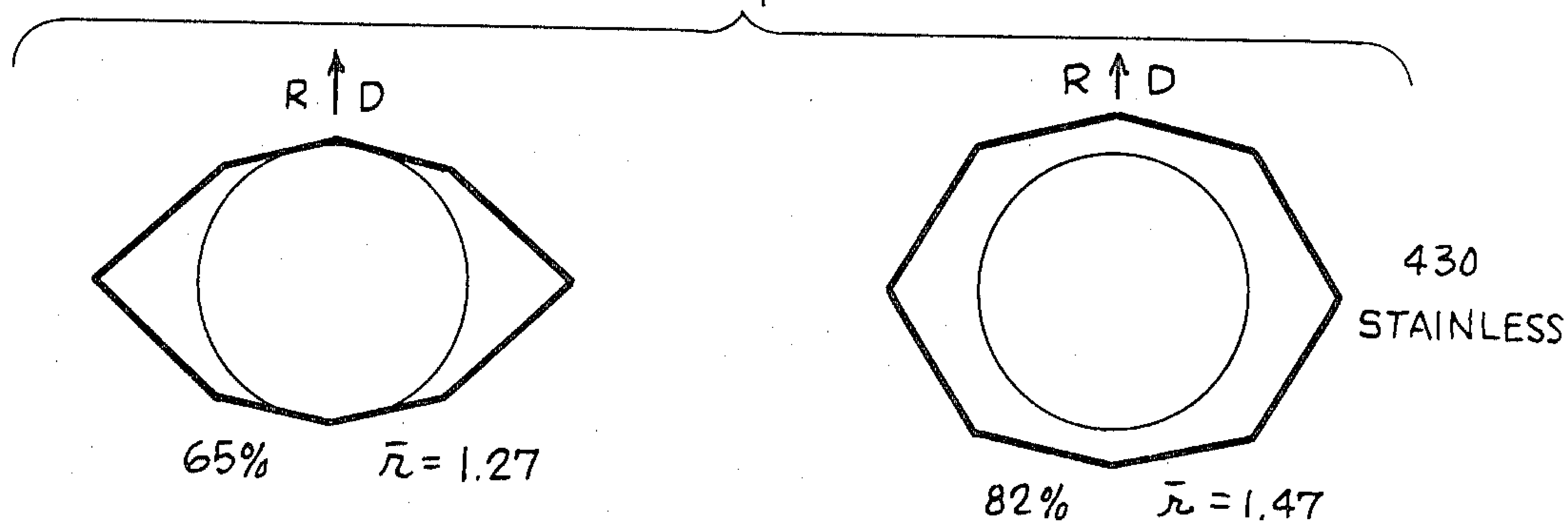


Fig. 3.

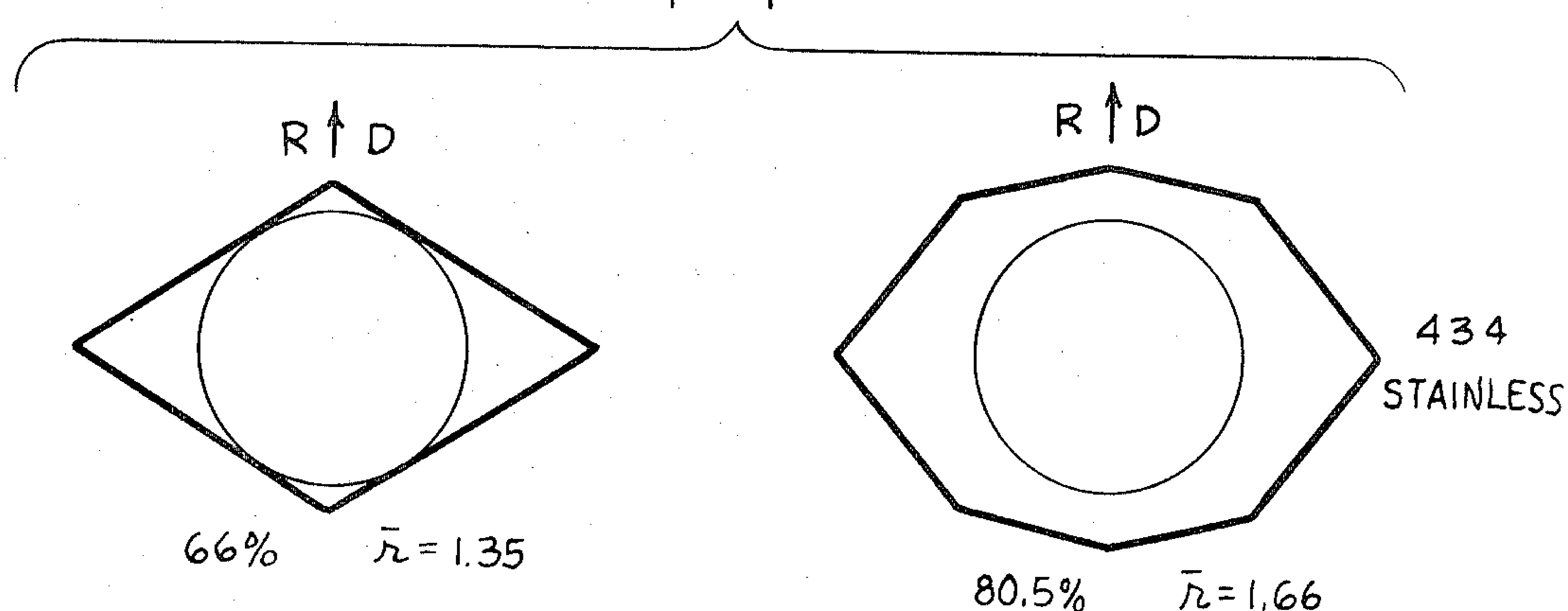
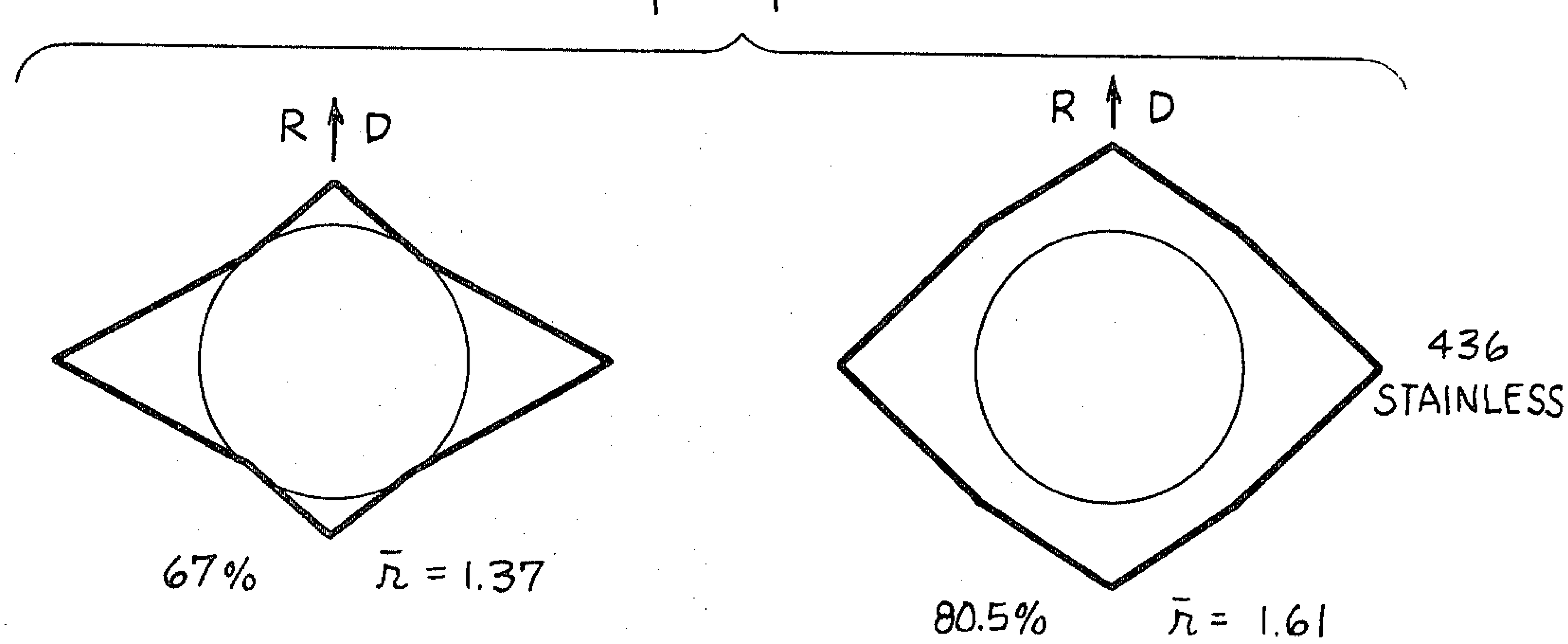


Fig. 4.



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PRODUCTION OF FERRITIC STAINLESS STEEL WITH IMPROVED DRAWING PROPERTIES

BACKGROUND OF THE INVENTION

This invention relates to methods of producing ferritic stainless steel sheet, of the grades sometimes called 17-chrome, having a chromium content in the range of 14 to 18 percent, and more specifically ferritic stainless steel known as the A.I.S.I. 430 series, exemplified by types 430, 434 and 436. The invention is explicitly concerned with the production of cold-rolled sheet of such grades, having improved formability, in particular deep drawability.

Whereas these 430 grades of stainless steel are of advantage for corrosion resistance and have been useful in unmodified sheet condition or with a minimum of shaping, their deformation has tended to be less than fully satisfactory. They are not ordinarily considered to be adapted for deep drawing, any more than rimmed low carbon steel, and indeed the so-called earing is too high to be acceptable for most operations of that sort. As will be understood, earing is the creation of a scalloped or deep wave-like contour along the edge of a deep-drawn shape, involving a waste of metal and even leading to weakness or cracking at localities between the projecting ears. In commercial practice, processing of ferritic stainless steels has changed little over a period of many years, and variations which have occurred have been chiefly dictated by final surface requirements or by changes in cold rolling equipment. Hence improvement in formability of the product has not occurred by deliberate modification of processing to that end, especially since little appears to have been done in investigation of the physical metallurgy or other effects or characteristics of these steels, as might have a bearing on formability.

Conventionally sheet production of ferritic stainless steel has involved hot rolling and annealing, followed by cold rolling to finish gauge, then usually a bright anneal, being continuous heating and cooling in a special inert atmosphere, and finally in most cases temper rolling to harden or improve the mechanical properties at the surface without significant further reduction. The cold rolling has usually involved two stages, with an intermediate anneal between them. The two-stage cold reduction has followed various practices, as for instance: about 50 percent reduction in the first stage and 50 to 65 percent or 70 percent in the second stage; or an average of up to about 55 percent or a little more in each stage. While the resulting sheet has a fine appearance and good corrosion resistance, its fields of use have been limited, as explained above, by shortcomings in forming or formability.

Accordingly, the present invention is designed to improve the forming properties of these grades of stainless steel, and to afford methods of treatment or processing whereby such improvement is achieved, most especially for the attainment of a product which is substantially non-earing when drawn. In particular, an important object is to produce a ferritic stainless steel which has excellent deep drawing properties, characterized by a high average-r value ($\bar{r}$), a recognized indicator or measurement of such properties, and which is essentially non-earing, e.g., in that the percent earing as determined in cups or the like made in standard deep draw tests is acceptably very low.

SUMMARY OF THE INVENTION

To these and other ends, it has been discovered that in these ferritic stainless steels, being body centered cubic metals, deep drawability is determined by the crystallographic preferred orientation or texture occurring in the final product, and that appropriate crystal orientation or texture, for deep drawing substantially without earing, may be optimized by procedure embracing controlled cold rolling and recrystallization operations. More particularly the invention comprises a method which is presently contemplated practice, involves subjecting the so-called hot band, after annealing, to two stages of cold rolling reduction, separated by an intermediate anneal and followed by a final anneal, specifically such that at least a certain degree of reduction (or more) is effected in the first stage, e.g., at least about 30 percent and for attainment of true deep drawing property at least about 40 percent, while the cold reduction in the second stage is carried to a high percentage that is critical for the desired results (including low earing), being at least about 80 percent, and where feasible may be higher, e.g., a reduction at or approaching 90 percent. The hot rolling operation can be as is now conventional for this metal, being continuous hot rolling as in regular mill practice; the thickness of the hot rolled band should be left at a value to suit the selected ultimate finish gauge of the cold reduced strips, having in mind the relatively considerable total extent of cold reduction, measured in percentage, required by this invention. Thus a thicker hot band than heretofore employed may be required at least for production of the thicker values among selected finish gauges.

With procedure as just outlined, product sheet is obtainable having essentially minimum earing and very preferably, excellent deep drawing property, with essentially minimum earing, e.g., $\bar{r}$ values in the range of greater than 1.4 and above, for drawability, and values of $\Delta r/\bar{r}$, a recognized measure of earing tendency, which are numerically not substantially greater than about 0.2, or at most definitely below 0.3. The texture of the sheet, in its ultimate recrystallized form after the described cold reduction and final anneal, shows a large preponderance of the so-called [111] crystal planes substantially aligned with the plane of the sheet, for instance as found by X-ray examination, from which it appears that the ratio of intensities of [111] to [100] planes rises to very high values with the stated, preferred program of cold reduction, such values being representative of deep drawability. The improved properties have been demonstrated by actual drawing tests, and at the same time, other mechanical properties, such as yield and ultimate strengths, uniform and total elongations, and the strain hardening exponent, do not appear to be adversely affected, as compared with the same stainless steels produced as strip by conventional processing.

Additional features of the methods of the invention are set forth in the more detailed description hereinbelow, with reference to specific examples and to the graphical presentation of measured results as illustrated in the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing variation of $\bar{r}$ (average-r) with percent cold reduction for stated steels and conditions;

FIGS. 2, 3 and 4 are polygonal graphs respectively related to three grades of stainless steel and illustrating r values in different directions of the strip, for different amounts of cold reduction; and

FIG. 5 is a graph showing variation of $\Delta r/\bar{r}$, as an indicator of earing, with percent cold reduction for stated steels and conditions.

DETAILED DESCRIPTION

The stainless steels of the 400 series, more particularly the 430 series, which are sometimes described as having 14 to 18 percent chromium (carbon up to about 0.12 percent, balance iron except for incidental or minor elements) and which are usually considered "straight chromium" steels (e.g., nickel not above 0.5 percent), are generally ferritic in nature and are primarily exemplified by chromium content from about 16 to 18 percent, with carbon not more than 0.08 percent. In a special sense, the present invention has been demonstrated to be notably effective with essentially straight chromium grades (about 16 to about 17.5 percent), having not more than about 0.3 percent nickel and carbon and not above 0.08 percent, and in some instances with minor amounts (e.g., less than 1 percent), permitted or intentionally included, of elements such as silicon, columbium and molybdenum, balance being essentially iron except for incidentals as apparent from examples below.

As explained above, these steels have usually shown no better than mediocre formability, but with the present methods can be processed to achieve deep drawability with essential freedom from earing, as determined by measured indicators as well as by practical tests or standard drawing operation, absence of earing being generally here considered to be less than about 5 percent earing on standard cup tests. In such tests producing straight-sided, cylindrical, deep-drawn cups, percent earing is determined as the quotient of the difference between maximum and minimum heights, from the cup bottom, of the eared or wavy upper edge, divided by the average of such heights.

Characteristics of deep drawing are generally determinable from r values in various directions of the plane of the finished metal sheet. The term r is the coefficient of normal plastic anisotropy, being a measure of the resistance of a sheet to thinning during stretching, and specifically being the following ratio of natural logarithms of dimensional ratios of a specimen:

$$r = \frac{\ln\ (W_0/W_f)}{\ln\ (T_0/T_f)}$$

r is measured with respect to a selected direction along the specimen defined as length L, the values W_o, W_f and T_o, T_f being the original and final width and thickness of the specimen, relative to a linear draw that effects a selected elongation (in L), for example 15 percent or 20 percent. As will be understood, the term T_o/T_f can also be expressed as the product of W_f/W_o multiplied by a factor derived from the elongation, e.g., 1.15 where the latter is 15 percent.

Conventionally r is determined, in separate specimens of a given strip, for directions parallel to the rolling direction (r_o), transverse of the latter (r_{90}) and a 45° to it (r_{45}), one 45° measurement being indicative of both such. The average r value, $\bar{r}$, is a criterion of deep drawability, being simply one fourth of the sum of r_o, r_{90} and twice r_{45}. Δr, which is an indication of earing, is a measure of the variations of r which occur as a function of orientation relative to the rolling direction. It is defined as:

$$\Delta r = (\text{one-half})(r_o + r_{90} - r_{45})$$

Since it is found that the percent earing, i.e., in a cup test as explained above and through a range up to an undesirably excessive value of 18 percent, is directly proportional to the ratio $\Delta r/\bar{r}$, the latter expression is taken as best measurement of expected earing.

In general, useful deep drawability requires sheet having $\bar{r}$ at least equal to about 1.4, and advantageously more, as 1.5 and above. For a useful nonearing attribute, the numerical value of $\Delta r/\bar{r}$ should be significantly less than 0.3, and may advantageously be defined as not more than about 0.2, e.g., for earing less than about 5 percent. The value of this ratio is taken in an absolute numerical sense, as it can sometimes be a negative quantity, so that references here to a $\Delta r/\bar{r}$ value of not more than about 0.2 mean any value in the calculated approximate range of −0.2 to +0.2. As will be apparent below, the methods of the present invention afford stainless steel sheet product having good properties of deep drawability without earing, evidenced by measurement under the foregoing standards.

For present purposes, hot rolling practice for the selected stainless steel may be as presently followed in commercial operation, for instance rolling at temperatures in the range of 2,200° to about 1,600° F. This should be continuous hot rolling, as in standard commercial procedure, meaning that the hot slab is processed in continuous sequence, without cooling, through the required roughing stand or stands and the desired finishing stands or passes. The resulting band is thereafter preferably annealed in conventional manner, e.g., by so-called box anneal, as with a slow heating to the selected temperature, for example about 1,500° F. and holding at such temperatures for a number of hours, followed by slow cooling to room temperature. The hot band is then pickled and ready for cold rolling. As explained above, the extent of hot reduction is chosen to yield a thickness of the hot band, for instance 0.12 to 0.2 inch, which will provide the desired finish gauge of the cold strip, taking account of the total extent of cold reduction required.

As outlined above, the improved process embraces a critically significant cold rolling program, advantageously interrupted by an intermediate anneal, a necessary feature of the invention (and critically so, for non-earing) being that the second stage consist of a sequence of passes that provides a reduction of at least about 80 percent, or in a range upwards of 80 percent, as to 90 percent or more. The first stage of cold rolling, e.g., the sequence of cold passes that is applied to the annealed hot band and that is followed by the intermediate anneal, should provide at least about 30 percent reduction, and if good deep drawability is required, this stage should achieve more than 35 percent reduction, quite preferably about 40 percent or more. Thus there are two stages of cold rolling as defined, and a final anneal.

The intermediate anneal (between the stages) can be essentially conventional, e.g., as for getting the metal to a conventionally selected temperature of about 1,500° F. for sufficient time to achieve recrystallization, and is usually followed by pickling. Likewise, standard procedure can be followed for the final anneal. For example it may be a conventional bright anneal,— the final cold passes, if desired, being effected with highly polished rolls to give the strip a mirror-bright finish. The bright anneal, for instance, may comprise treatment at 1,450° to 1,750° F., e.g., 1,550° F., in the usual inert atmosphere for the purpose, such as hydrogen or a mixture of nitrogen and hydrogen.

In specific examples of the method, including comparative tests utilizing other rolling programs, three types of ferritic stainless steel hot bands were employed, all having been produced by regular mill operation as explained above (hot rolling finished at about 1,700° F., coiled at about 1,300° F.). These bands and thicknesses were respectively: type 430, 0.131 inch; type 434, 0.126 inch; and type 436, 0.135 inch. Their analyses were as follows (balance Fe, except as noted below) in weight percent:

Type	C	Cr	Ni	Cb	Mn	Si	Mo
430	0.065	16.30	0.26	0.04	0.30	0.45	0.22
434	0.081	16.30	0.27	0.04	0.325	0.43	0.76
436	0.065	16.20	0.23	0.32	0.28	0.52	0.76

Besides chromium, metals intentionally included (in the above table) were columbium (for grain refining) in type 436 and molybdenum (for resistance to pitting corrosion) in types 434 and 436, although the presence of some others (e.g., Mn and Si) may be deemed functional in a minor but not necessary sense. The actual compositions also showed other elements incidentally present, as often in melts of these stainless steel grades, one example being Cu up to 0.075 percent, V about 0.02 percent, Co about 0.03 percent, O_2 up to 0.003 percent, N_2 up to 0.04 percent, Al up to 0.06 percent. It may be noted in passing that type 435 of this series, to which the invention is deemed applicable, differs from the above in having intentional inclusion of columbium, but not molybdenum.

All of the hot bands were annealed in a box type anneal with an atmosphere of nitrogen, by heating over a period of twelve hours to reach the annealing temperature of 1,550° F. where they were held for eight hours and thereafter cooled to room temperature over a time of ten hours. The bands were then pickled in an aqueous solution of hydrogen peroxide and hydrochloric acid.

One length of each hot band was cold rolled to about 30 percent (or less) reduction, and bright annealed. The remainder of each band was cold rolled to about 40 percent reduction (or a little less), one portion being bright annealed without further treatment. After subjecting the major part of each 40% cold-reduced strip to an intermediate anneal and pickling, separate lengths of each so-treated strip were subjected to different, further cold reductions, i.e., as a second stage, amounting respectively and approximately to 15 percent, 30 percent to 35 percent, 48 percent, 66 percent and 81 percent, followed in each instance by a bright anneal. The actual measured reductions differed from these average values by not more than about 1 percent or so. After the first stage of cold rolling (approximately 40 percent) the thicknesses were: type 430, 0.083 inch; type 434, 0.077 inch; type 436, 0.082 inch. The strip lengths reduced by about 66 percent in the second stage had thicknesses of 0.026 to 0.029 inch, and those reduced by about 81 percent had thicknesses of 0.015 to 0.016 inch.

The intermediate anneal consisted of an anneal in an exothermic atmosphere at 1,450° F. for five minutes, with subsequent pickling in an essentially conventional bath for this stage, being an aqueous solution of 15 percent nitric acid and 2 percent hydrofluoric acid. The bright anneal, for all lengths of strip, was effected at 1,450° F. for 30 minutes in a dry hydrogen atmosphere, followed by cooling in such atmosphere. As representative of a common requirement of production, although not understood to affect the drawing properties appreciably, all lengths of bright annealed strip were temper rolled to a reduction between 1 percent and 1½ percent.

The finished cold-rolled products were tested for a variety of mechanical properties, including yield and ultimate strengths, elongation, and strain hardening exponents. The values found appeared to be independent of the different rolling programs used, and were satisfactory for stainless steel at all levels of reduction herein noted as related to the present invention, in the sense of being comparable to currently produced stainless steel products of these grades.

Tests and determinations were made of the value of r for each of the finished product strips, in the rolling, transverse and 45° directions, based in all cases on 15 percent elongation. The average-r values, i.e., $\bar{r}$, were determined by computation in each instance, and likewise the values of Δr and $\Delta r/\bar{r}$ as explained above. The significance of these determinations is illustrated in the drawings, in reference first to FIGS. 1 and 5, being graphs of $\bar{r}$ (average-r) and $\Delta r/\bar{r}$ respectively, against program and percent reduction, of cold rolling. Each plotted point represents the terminus of cold reduction for a given strip, the points being triangles for 430 grade strips, squares for 434 grade and circles for 436 grade. Each graph is divided into two sections by a vertical line representing the intermediate anneal; the narrow band on the left indicates steels processed without such anneal, and the area on the right, the steels that had it. The horizontal scale at the left represents percent cold reduction after the pre-rolling anneal, and the scale on the right represents percent reduction after the intermediate anneal. The point plotted in each extreme left-hand line represents the property of the annealed type 434 hot band.

Taking the criteria of an $\bar{r}$ value of at least about 1.4 for acceptable deep drawability, and of a value of $\Delta r/\bar{r}$ in the vicinity of 0.2 (or less) for acceptable absence of earing, it will be seen from FIG. 1 that for all of the plotted values of second stage cold reduction following a cold reduction of about or approaching 40 percent in the first stage, the deep drawing index ($\bar{r}$) in general attains a notably high value only when the reduction in the second stage approaches or reaches about 80 percent. For achieving a significant non-earing character, i.e., a low earing tendency as stated, FIG. 5 shows (from the same set of tests) that the second stage reduction must be carried to at least about 80 percent. In other words, none of the strips showed the desired absence of earing, nor the combination of such property with true deep drawability, at appreciably lesser percentages of reduction in the second stage.

FIGS. 2, 3 and 4 show the development of r values in another graphical fashion, wherein such values in the longitudinal, 45° and transverse directions (relative to rolling) are plotted as a function of angle around the rolling direction, respectively for the 430, 434 and 436 grades, and in each figure, separately for strip cold reduced (after the intermediate anneal) by about 65 percent and about 80 percent. The magnitude of r is the distance from the center, in the indicated directions, and the reference circle in each plot is for an r value of one. Although the values would be fully shown by plotting a single quarter, they are duplicated around 360° for ready understanding. It is only at values of r greater than one that the metal strains preferentially in the plane of the sheet, as it must to prevent so-called necking and fracture in a deep drawing operation. As will now be understood, high r values in each of the three directions of a quarter, more or less uniformly, are required to provide effective deep drawing (i.e., a high average r) with absence of earing. These diagrams, drawn with measured, individual values of r, demonstrate how the several types of the 430 series failed to meet such criteria at 65 percent reduction, but essentially reached them at 80 percent and above.

Specific values found in a series of tests carried out as above described and embraced in the graphic presentation of FIGS. 1 to 5 inclusive are as follows:

Strip Type and Test No.	1st percent reduction	2nd percent reduction	$\bar{r}$	Δr	$\Delta r/\bar{r}$
430-2	37.4	----------	.856	−.388	−.453
430-6	36.6	65.1	1.265	.295	.233
430-7	36.6	81.9	1.477	−.009	−.006
434-2	39.4	----------	.883	−.263	−.298
434-6	39.4	66.2	1.343	.511	.380
434-7	39.4	80.5	1.662	.102	.061
436-2	39.6	----------	1.064	.322	.303
436-6	39.6	67.1	1.372	.717	.523
436-7	39.6	80.5	1.609	.445	.277

The headings and identifying numbers being as explained earlier, the tabulation shows results with three each of the strips of grades 430, 434 and 436, having various rolling programs, and all terminated with a bright anneal. It will be understood that the strips identified as Test No. 2 (e.g., 430–2) had only one stage of cold rolling, i.e., with no intermediate anneal or second rolling stage. Since all of the tests with strip carried only to lesser percentages of reduction in the second stage showed even lower values of r than the reductions of about 65 percent, such data are here omitted, although embodied in FIGS. 1 and 5. The table also shows the values of Δr, which are likewise considered a quantitative representation of earing, but it is presently believed that the ratio $\Delta r/\bar{r}$ is a better indicator. As already noted the strips that were carried to a cold reduction of 80 percent or more in the second stage showed values of $\bar{r}$ sufficiently high to afford deep drawing properties, the same being essentially true with respect to absence of earing, as indicated by low values of $\Delta r/\bar{r}$. Although in the latter respect the stated earing index was not as low as a preferred value of 0.2 for the type 436 steel in the 80.5 percent reduction operation, the earing was nevertheless usefully low in that the value was significantly under 0.3. These and other data demonstrated, however, that by carrying the second-stage cold reduction to a somewhat greater extent, e.g., 85 percent, $\Delta r/\bar{r}$ could be brought down to less than 0.2 for this 436 grade, such mode of operation being therefore presently preferred.

As indicated hereinabove, the various produced strips were also subjected to X-ray crystallographic examination, whereby the crystal orientation was determined by the inverse pole figure method, such figure being a diagram that represents the frequency relative to random, at which selected crystallographic planes occur parallel to the surface of the tested sample. Such determinations are made with data collected by known X-ray techniques using a suitable diffractometer scan. These X-ray tests fully confirmed the determinations of $\bar{r}$ value set forth above, specifically in that the frequency of the [111] planes parallel to the surface increased with increase of cold rolling after the interanneal and likewise, in general, the ratio of [111] to [100] intensities increased, indeed at a faster rate, rising to very high values at reductions of 80 percent and above. Parallelism of the [111] planes relative to the sheet surface, in differentiation from the [100] planes, has been found to be indicative of the existence of superior drawing properties in other steels, as for example aluminum killed, low carbon steels.

The numerical results discussed above and reported in the drawings demonstrate the attainment of desirable absence of earing, with achievement of good deep drawing properties, in the several grades of ferritic stainless steel of the 430 series, when processed by a cold rolling sequence of the character described, including a second stage extended to about 80% reduction or more. Actual drawing operations, including standard cup tests, were found to confirm these conclusions in all particulars, with earing under, and usually well under, 5 percent.

The results of procedures according to the invention were further demonstrated by tests in the mill with two commercially produced hot bands, taken from the same heat of type 434 stainless steel. The chemistry was of conventional character for this type, including carbon 0.057 percent, chromium 16.70 percent, manganese 0.36 percent, molybdenum 0.83 percent, nickel 0.27 percent, copper 0.17 percent, silicon 0.44 percent, and the usual lesser or trace amounts of other elements. The hot bands were produced by continuous hot rolling from slab, in accordance with standard mill practice, and were box annealed, then blasted and pickled, in accordance with such practice. The two hot bands were identified as coils 1 and 2, the band of coil 1 being 0.187 inch thick and that of coil 2 being 0.125 inch thick.

Coil 1 was cold rolled on a reversing mill to a reduction of 52 percent, and a thickness of 0.090 inch. Coil 2 was also cold rolled on the reversing mill to the same thickness of 0.090 inch, with a reduction approximately 30 percent. The strip of each coil was then continuously annealed at 1,550° F. and pickled in a solution of nitric and sulfuric acids. The coils were then each rolled on a Sendzimir mill to a thickness of about 0.018 inch, the cold reduction in this second stage being just above 80 percent (actually, 80.4 percent and 81.5 percent respectively). At appropriate stages in the required, numerous passes of the Sendzimir mill, rolls of successively smoother or more polished surfaces were employed, as is conventional for superior surface finish of the strip. Finally each coil was bright annealed in a standard manner, i.e., at 1,550° F. for 30 seconds, and temper passed between 1 percent and 1½ percent.

Samples of these experimental coils, after completion of processing, were examined and tested for structure and various properties. Both strips showed mechanical properties of yield and ultimate strengths within the range of normal commercial products of type 434, the same being true for total and uniform elongation, and for the strain hardening exponent. The strips revealed extremely fine, equiaxed grain structure, being ASTM 11 for coil 1 and ASTM 10 for coil 2, as compared with ASTM 8 found in the past in commercial type 434.

Values related to drawing properties were found as in the following table (also including the approximate cold reduction sequence):

	Cold reduction, percent				
	First stage	Second stage	$\bar{r}$	Δr	$\Delta r/\bar{r}$
Coil 1	52	80	1.61	−0.007	−0.004
Coil 2	30	80	1.30	0.14	0.11

It is apparent that both sheet products were essentially nonearing character, having values of $\Delta r/r$ well under 2; this was confirmed by flat bottom drawn cup tests (the standard Swift Cup Test), which showed 2.6 percent earing for coil 1, and 2.4 percent earing for coil 2. Deep drawability was achieved for coil 1 in accordance with a special feature of the invention, but it will be appreciated that the minimal earing shown for coil 2 (with r too low for deep drawing) is nevertheless of significant advantage, i.e., for stainless steel of ordinary, limited drawing property. Such steel can be used for many articles requiring only a relatively moderate draw, with economy of metal and avoidance of processing difficulties.

By way of summary, a sheet product (of the defined ferritic stainless steel of the 430 series, e.g., with crystal structure of body-centered cubic type) which is substantially non-earing when drawn may be obtained by employment of a two-stage cold rolling procedure wherein the reduction in the second stage is at least about 80%, after a first stage reduction of at least about 30%. In order to achieve such product which also has significant deep drawability the reduction in the first cold rolling stage (that is followed by above-stated second stage) should be carried to more than 35 percent, i.e., advantageously at least about 40 percent or higher, as for example to 50 percent and upwards; this is confirmed by various tests above, including operation with the first stage reduction extended to the region of 50 percent to 55 percent.

It will be noted, moreover, that the invention is not limited to excessively thin product or excessive total reduction, but affords convenient working ranges for the cold rolling procedure as regards extent of reduction to obtain the desired results (including higher values in one stage or the other), so that practicable hot band thicknesses can be utilized as required to obtain any of a considerable range of thicknesses of the ultimate product sheet which are suitable for good drawing. Thus selection of conditions can readily be such that the total or overall reduction from the hot band to the final sheet produced by the second sheet is no more than needed, as for instance in the above examples appreciably less than 95 percent, indeed not more than about 90 percent in any of them.

It will therefore be seen that the present invention affords production of ferritic stainless steel having greatly improved formability in the respects noted, without lessening of other desirable properties, either in strength, hardness, appearance or otherwise. Indeed as stated, the products are also shown to have a very fine grain structure, e.g., ASTM 10 or above, as compared with commercial products at about ASTM 8, and thus improved in the sense of avoiding or diminishing objectionable surface effects, such as the so-called orange peel effect, on deformation.

It is to be understood that the invention is not limited to the specific operations herein described but may be carried out in other ways without departure from its spirit.

We claim:

1. A method of producing substantially non-earing sheet from straight chromium ferritic stainless steel containing 14 to 18 percent chromium which has been hot rolled and annealed, comprising subjecting said steel to only two cold-rolling stages separated by intermediate annealing, the first of said stages consisting in cold reducing the steel by at least about 30% and the second of said stages consisting in cold reducing the intermediate-annealed steel by at least about 80%, and finally annealing the cold-reduced steel.

2. A method as defined in claim **1** for producing sheet having deep drawing property represented by an $\bar{r}$ value greater than 1.4, in which said first stage consists in cold reducing the steel by at least about 40%.

3. A method as defined in claim **1**, in which said stainless steel contains about 16 to 17.5 percent chromium, not more than about 0.3 percent nickel and not more than about 0.12 percent carbon, and in which said first and second cold-rolling stages are respectively effected to reductions of substantially more than 35 percent and in the range of 80 percent and above.

4. A method as defined in claim **3**, in which said stainless steel is type 430.

5. A method as defined in claim **3**, in which said stainless steel is type 434.

6. A method as defined in claim **3**, in which said stainless steel is type 436.

7. A method of producing deep drawing, substantially non-earing sheet from ferritic stainless steel of the 430 series which has been hot rolled and annealed, comprising cold rolling the steel, to a reduction of more than 35 percent, then intermediate annealing, then cold rolling the steel to a further reduction of at least about 80 percent, and finally annealing the cold-reduced steel to produce the aforesaid deep drawing sheet, the cold rolling reduction of said hot rolled and annealed steel consisting of the aforesaid two stages of cold reduction interrupted only by said intermediate anneal.

8. A method as defined in claim 7, in which said stainless steel contains about 16 to 17.5 percent chromium, not more than about 0.3 percent nickel and not more than about 0.12 percent carbon, and in which said first cold-rolling stage is effected to a reduction substantially greater than 35 percent to produce a final sheet having deep drawing property represented by an $\bar{r}$ value greater than 1.4.

9. A method as defined in claim 7, in which said first cold-rolling stage is effected to a reduction of at least about 40%.

10. A method as defined in claim 7 for producing substantially non-earing sheet having deep drawing property represented by an $\bar{r}$ value of at least about 1.5, in which said first and second cold-rolling stages are respectively effected to reductions of at least about 40 percent and in the range of 80 percent and above.

11. A method of producing substantially non-earing sheet from straight chromium ferritic stainless steel containing about 16 to about 18 percent chromium, comprising continuously hot rolling said steel from slab to a hot band of thickness not greater than about 0.2 inch, annealing said hot band, cold rolling said band in a first stage to a reduction of at least about

30 percent, then intermediate annealing the resulting strip, then cold rolling said strip in a second stage to a reduction in the range of about 80 percent and above to provide a value of $\Delta r/\bar{r}$ of the final sheet not substantially greater than about 0.2, and finally annealing the cold-reduced steel from the second stage to produce the aforesaid substantially non-earing sheet, the cold rolling reduction of said annealed hot band consisting of said first and second stages interrupted only by said intermediate anneal.

12. A method as defined in claim 11, for producing deep drawing sheet, in which said first cold-rolling stage is effected to a reduction in the range of about 40 percent and above a value of $\bar{r}$ in the final sheet of at least about 1.5.

13. A method as defined in claim 12, in which said hot band annealing, said intermediate annealing and said final annealing are effected at temperatures in the range of at least about 1,450° F. and above.

14. Stainless steel sheet consisting of straight chromium ferritic stainless steel containing 14 to 18 percent chromium, having deep drawability without substantial earing and having an $\bar{r}$ value of at least about 1.4 and a value of $\Delta r/\bar{r}$ of substantially less than about 0.3, and produced by the method of claim 7.

15. Stainless steel sheet consisting of straight chromium ferritic stainless steel containing about 16 to about 18 percent chromium, not more than about 0.12 percent carbon and not more than about 0.3 percent nickel, having deep drawability without substantial earing and having an $\bar{r}$ value of at least about 1.5 and a value of $\Delta r/\bar{r}$ not substantially greater than about 0.2 and produced by the method of claim 12.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,650,848 Dated March 21, 1972

Inventor(s) STEPHEN G. SCHNEIDER, FRANK A. HULTGREN and WILLIAM F. BARCLAY

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 1, line 72, after "which", "is" should read --in--

Col. 3, line 41 (in formula) "r_{45}" should read --$2r_{45}$--

Col. 6, line 43, "r" should read --$\bar{r}$--

Col. 7, line 69, after "were" insert --of--

line 70, "$\Delta r/r$" shoud read --$\Delta r/\bar{r}$--

Col. 8, line 1, "r" should read --$\bar{r}$--

Col. 10, line 12, after "above" insert --to provide--

Signed and sealed this 11th day of July 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents