April 5, 1960 M. L. SAMUELS 2,931,744

METHOD OF GRAIN REFINING CENTRIFUGAL CASTINGS

Filed Aug. 26, 1957 5 Sheets-Sheet 1

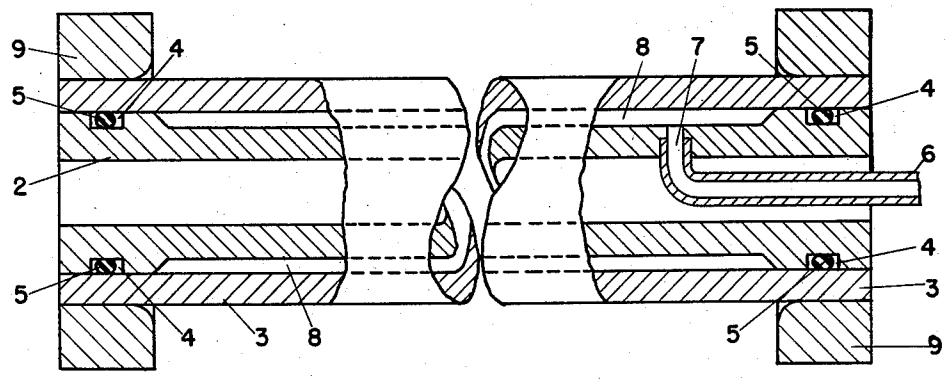


FIG. 1

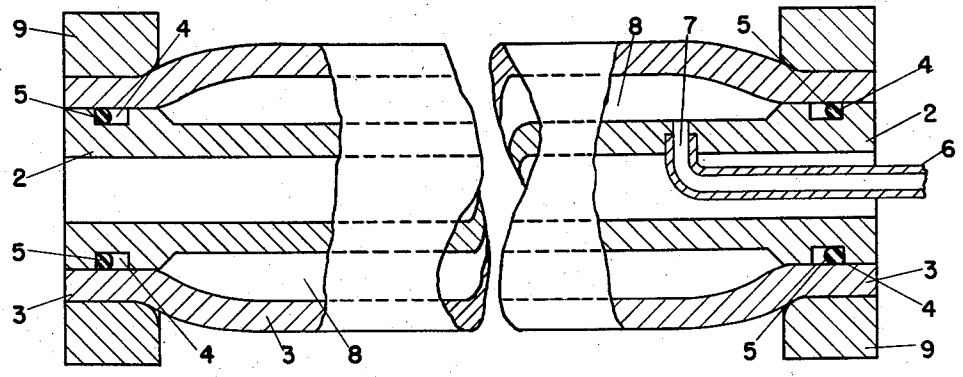


FIG. 2

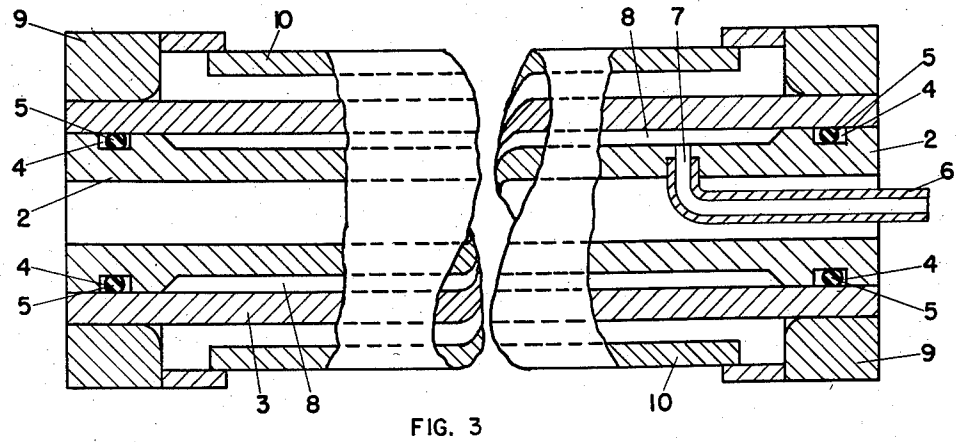


FIG. 3

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April 5, 1960 M. L. SAMUELS 2,931,744

METHOD OF GRAIN REFINING CENTRIFUGAL CASTINGS

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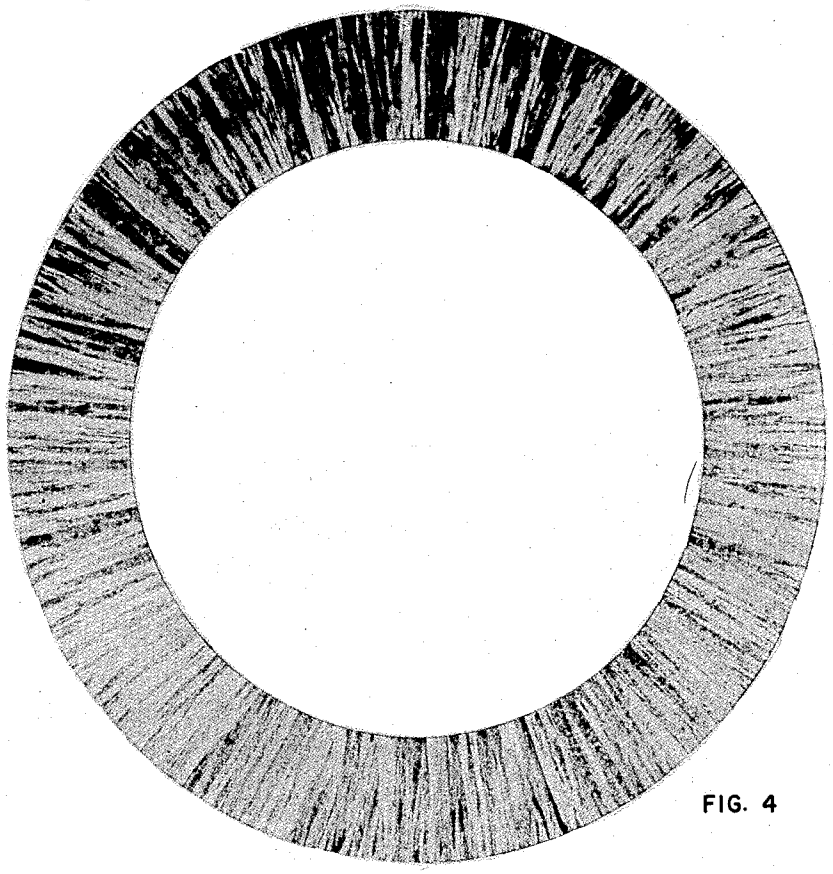


FIG. 4

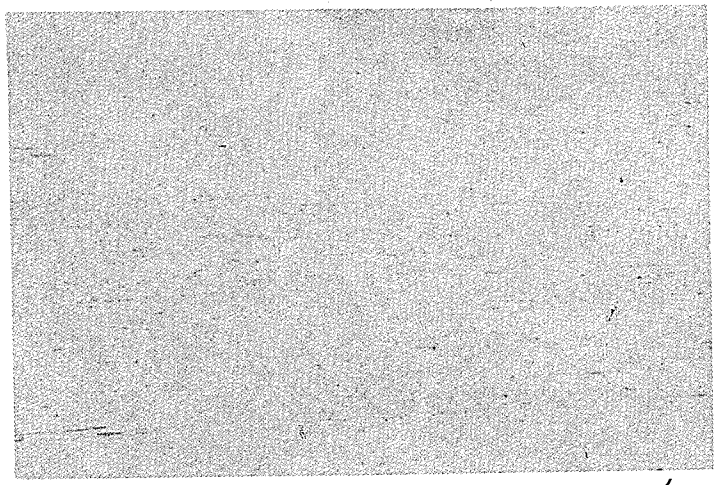


FIG. 5

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METHOD OF GRAIN REFINING CENTRIFUGAL CASTINGS

Filed Aug. 26, 1957 5 Sheets-Sheet 3

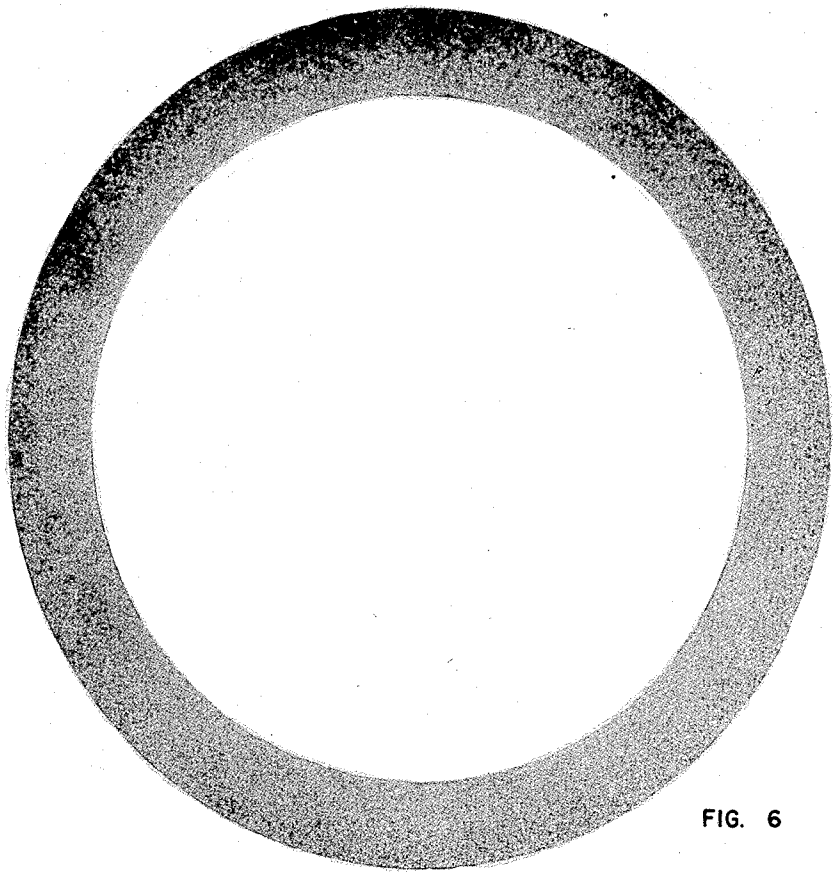


FIG. 6

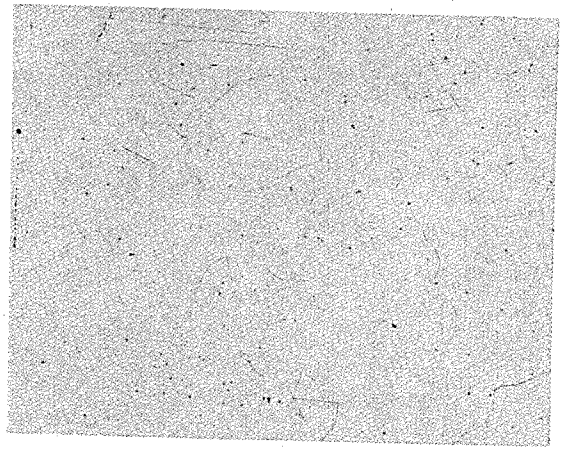


FIG. 7

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April 5, 1960 M. L. SAMUELS 2,931,744

METHOD OF GRAIN REFINING CENTRIFUGAL CASTINGS

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FIG. 8





FIG. 9

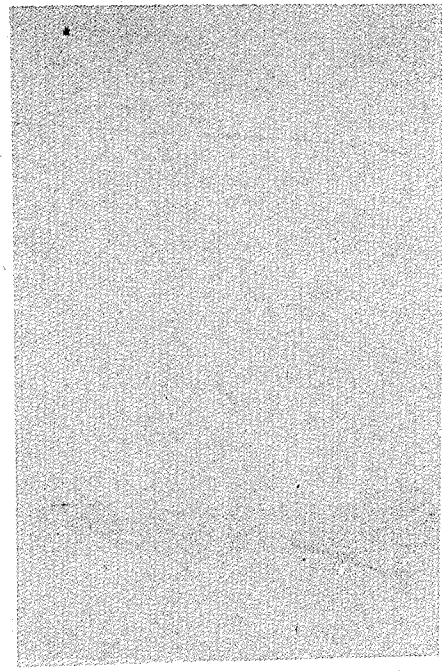


FIG. 10

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METHOD OF GRAIN REFINING CENTRIFUGAL CASTINGS

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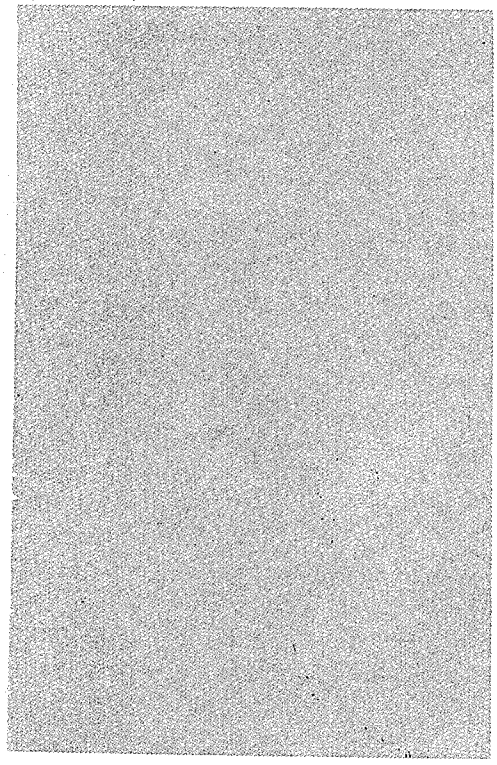


FIG. 11

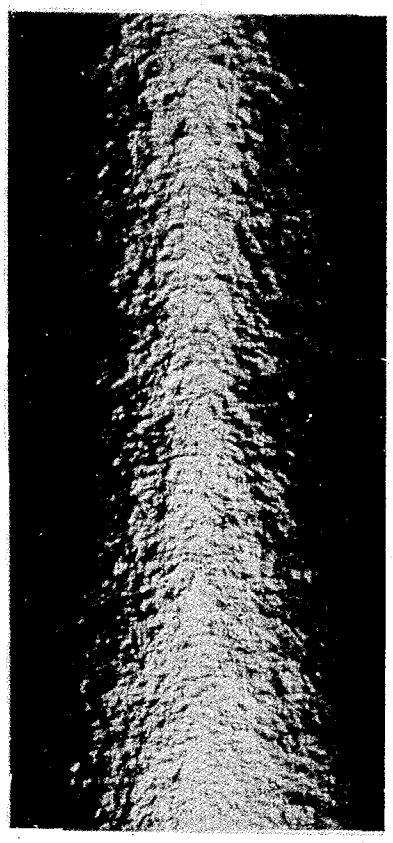


FIG. 12

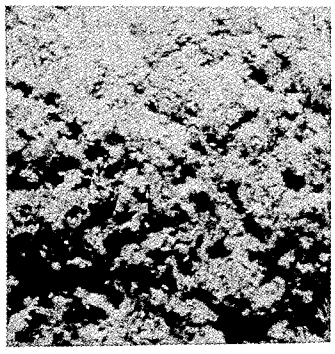


FIG. 13

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United States Patent Office 2,931,744 Patented Apr. 5, 1960

2,931,744

METHOD OF GRAIN REFINING CENTRIFUGAL CASTINGS

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Application August 26, 1957, Serial No. 680,298

6 Claims. (Cl. 148—11.5)

This invention relates to improving physical characteristics of certain metal products, and more particularly it relates to refinement of grain structure of ductile metal tubular castings and to the greatly improved resulting products.

In recent years centrifugal tubular castings have gained widespread acceptance for varied applications, while at the same time considerable progress has been made in techniques of casting and in casting quality. Such gains, however, have to a large extent been confined to castings of metal which undergo recrystallization, or allotropical conversion of crystal form, with change in temperature alone. This is primarily for the reason that there is considerable concern among most engineers as to the reliability and/or acceptability of castings of metals. The concern is based largely on the fact that a casting of any metal results in a product having a coarse crystalline structure, either columnar in metal mold centrifugal castings or random in sand mold castings. It is generally believed that such coarse crystalline structure is deleterious as regards a number of important properties and, due to the coarse crystalline structure, castings do not possess tensile strengths sufficiently high for compliance with the usual code specifications.

A considerable number of stainless cast metals can be subjected to heat treatment to bring about recrystallization and a final structure of fine grains, thus removing the objection based on grain size. Included in this group, and possessing "critical points" or allotropical conversion of crystal form with change in temperature, are the ferritic and martensitic steels. For a large number of applications, and particularly today when more and more tubing is required for high temperature and high pressure usage, the austenitic steels are required due to their superior ductility, high-temperature strength, and corrosion resistance.

Castings of austenitic steels have not, however, found ready acceptance in a great number of applications due to the disadvantages mentioned, and instead austenitic forgings have been used when the properties of such metals are required for tubing. Forgings of austenitic steels are not without their disadvantages, however, the most noteworthy of which are the extremely high cost as compared to castings, and the directionality or anisotropic effect for wrought steels, an effect not inherent with cast steel. As regards cost, and by way of example, the only source of seamless wrought cylinders of long lengths in size ranges of about 20 inches to 48 inches in diameter is from hot forging from the ingot stage. Such operations are extremely involved and costly, and the resulting tubes must of necessity demand unusually high prices. Regarding directionality, this anisotropic effect is reflected not so much on tensile strength

as on loss of ductility in tension tests and by loss of toughness in impact tests. Such effect, therefore, works contrary to the reasons for choosing austenitic steels over ferritic and martensitic steels in the first place.

A principal object of this invention is, accordingly, to provide a method whereby the properties of tubular castings of ductile metals can be improved to overcome the objections noted for such castings;

Another principal object is to provide tubular shapes of ductile metals without the disadvantages heretofore possessed by such shapes;

Still another object is the provision of a method for making tubular products having greatly improved physical properties from castings of ductile metals which do not possess the property of recrystallization upon change in temperature alone;

A still further object is to provide a method for treatment of castings of ductile metals which do not undergo recrystallization on change of temperature alone, whereby the normal coarse crystalline structure thereof is converted into a fine grained crystalline structure;

An additional object is the provision of a method for changing the crystalline structure of centrifugally cast austenitic steel tubular castings from large columnar crystals to fine grained crystals, with the attendant improvement in physical properties, and to the resulting improved tubular product.

With the above objects in view, and others which will become apparent from the following specification, the invention will now be described in detail, reference being made to the accompanying drawings in which:

Figure 1 is a view partly in section of an apparatus which may be employed in the method of this invention, and in which the casting is in position to be expanded;

Figure 2 is a view similar to Figure 1, but after the casting has been expanded;

Figure 3 is a view of another apparatus similar to that illustrated in Figure 1, but with a dimension-controlling envelope;

Figure 4 is a photograph of a macroetched stainless steel casting about ¾ actual size;

Figure 5 is a photomicrograph of the casting of Figure 4, etched, at 100 diameters' magnification;

Figure 6 is a photograph of the casting of Figure 4, macroetched, after expansion and annealing in accordance with this invention, about ½ actual size;

Figure 7 is a photomicrograph of the expanded and annealed casting of Figure 6, etched, at 100 diameters' magnification;

Figure 8 is an actual size photograph of a macroetched conical tensile specimen, after annealing;

Figure 9 is a 6 diameter magnification photograph of the specimen of Figure 8, taken near the junction of recrystallized and unaffected metal;

Figure 10 is a photomicrograph at 1000 diameters' magnification of a section of hot rolled seamless tubing, unetched;

Figure 11 is a photomicrograph at 1000 diameters' magnification of a section of a cold expanded and annealed tube;

Figure 12 is an actual size photograph showing the surface appearance of a stainless steel tube after cold expansion;

Figure 13 is a more detailed view of the surface shown in Figure 12, photographed at 2 diameters' magnification.

The objects are attained by this invention whereby tubular castings are subjected to internal pressure to expand

them appreciably and to a degree sufficient to substantially deform the cast crystalline structure, followed by annealing sufficient to effect substantially complete recrystallization. The expansion of the tubular castings is essentially conducted under such conditions that the outer surface is free and unconfined. Preferably, the expansion is achieved by application of hydrostatic pressure to the inside of the casting, after closing both ends. The expanded tube is finally heated to the known annealing temperature for the particular metal, and water quenched.

Prior to this invention, there was no basis for a prediction that metal tubes could be treated in such manner to effect such drastic grain refinement. Known methods of cold deformation are entirely different. In this invention, for example, radial stresses are applied to the cylinder rather than the axial stresses of prior cold working methods. Furthermore, the outer surface of the cylinder is free and unconfined, and the internal pressure subjects every part of the cylinder, including any existing slightly defective areas, to rigorous stresses. In conventional methods the material is confined between two working surfaces at the point where cold plastic deformation is effected, e.g. between two rolls in cold rolling, between a mandrel and die in cold drawing, and between a die and hammers in cold swaging or rocking. This support between two working surfaces is, of course, much more favorable toward heavy cold working without rupture than unrestrained expansion. Prior methods of hydraulic expansion of metal cylinders offered no assurance that the method of this invention could be practiced, due to the limited amount of cold work effected by such prior methods.

A suitable arrangement for effecting the cold expansion of a cast cylinder according to this invention is shown in the drawings, Figures 1 and 2. In the specific means illustrated, a core piece **2** is prepared with the outside diameters near both ends only slightly (.002"–.003") smaller than the inside diameter of the cylindrical casting **3**. The inside diameter of the remainder of the core piece, between the two ends, is less than at the ends. Grooves **4** are provided on the periphery of the core piece **2**, near the ends, and O-ring gaskets **5** are placed in each of the two grooves. The casting **3** is then slipped over the core piece **2**. A tube **6** connects a source (not shown) of high pressure water to an opening **7** through the wall of core piece **2**, communicating with the space **8** between the core piece and the casting. Heavy hold-down rings **9** are fastened around the outside of the casting opposite the grooves **4** and gaskets **5** to prevent expansion of the cylinder at the ends.

Water pressure is then applied to space **8** to effect expansion of the cylinder as shown in Figure 2. After expanding to the desired increase in diameter the pressure is released, the hold-down rings **9** are removed, and the core piece **2** taken out of the expanded casting. The expanded cylinder is then annealed and the unexpanded ends cropped off.

Pressure levels requirde can be estimated fairly closely through use of the formula:

$$ST=\frac{P\times D}{2t}$$

in which

ST represents hoop stress in pounds per square inch,
P represents gage pressure in pounds per square inch,
D represents the outside diameter of the cylinder and
t represents wall thickness.

Since the cylinder will not be expanded to its breaking point, and the increase in diameter partially counteracts cold work strengthening, actual gage pressure required will be somewhat below the calculated pressure.

For many service applications, the expanded and annealed cylinder can be used in that condition without further machining. Inasmuch as the operable metals do not balloon up, but rather strengthen in the most severely worked areas to then cause deformation to take place in areas less severely stressed, the tendency is toward relatively uniform expansion. When high dimensional precision in the finished product is required, the expanded and annealed cylinder is machined.

For applications requiring high precision, a die **10** can be employed such as that illustrated in Figure 3. The die is bored to the required inside diameter, equal to the outside diameter to which the casting **3** is to be expanded, and placed around the casting. The die merely prevents some parts of the cylinder from slightly exceeding the desired diameter while other parts are still slightly undersized; The die consequently permits less cut depth in final machining to specified sizes. The die or container is not a working surface, but is merely a dimension-controlling envelope. All useful work, as far as conditioning for recrystallization is concerned, is completed before the expanding cylinder **3** contacts the inner wall of the container **10**.

There are, of course, several ways of sealing the cylinders for cold expansion other than that specifically illustrated. Such sealing means, including those which permit expansion of the entire length of the casting, are well known.

Apparatus and means for accomplishing heat treatment of cylinders are well known and are not specifically illustrated. Any heat treating arrangement which permits heating of cast cylinders to the required temperature, followed by water quenching, is satisfactory. Nevertheless, the heat treating or annealing step constitutes an essential feature of this invention, and is required in order to relieve the stresses effected by cold expansion and to effect the recrystallization.

The austenitic stainless steels all require a high temperature "solution" anneal for optimum corrosion resistance in any case. After cold expansion in accordance with this invention, the known and standard anneals do a completely satisfactory job of removing work-hardening effects and promoting recrystallization and grain refinement. Standard annealing temperatures for the various austenitic steels are listed in several reference handbooks, including, for example, "The Making, Shaping and Treating of Steel," 6th edition, page 1322.

The invention is applicable to all highly ductile materials which undergo no grain refinement upon heat treatment alone and which possess the property of hardening and strengthening upon cold deformation. The latter property is important in that it eliminates materials which will not work harden (become stronger with increased cold plastic deformation) and which will balloon in the thinnest area causing rupture before much change is effected in areas where the wall thickness is slightly greater. With materials which do work harden, the thinnest part of the wall will first expand and become strengthened, temporarily halting expansion at this point. The thicker areas next expand beyond the yield strength, resulting eventually in substantially uniform expansion over the entire tube.

Particularly suited for the invention are the AISI 300 series stainless steels, copper and copper alloys (the brasses and bronzes) and many nickel base alloys.

Cold expansion in accordance with this invention is normally a room temperature operation ranging from about 50° F. to about 100° F. Lower temperatures tend to reduce the amount of cold expansion necessary to result in recrystallization during the subsequent anneal but they also increase the tendency to rupture during the expansion step. Higher temperatures call for greater degrees of expansion to achieve the same results. Wide variations from normal room temperature introduce unnecessary complications and difficulties which may well be avoided.

Speed of cold expansion is not particularly critical except that explosive rates should be avoided. A maxi-

mum rate of outside diameter increase of ½" per minute is safe and this varies the total time of expansion automatically with the diameter of the casting. For example, the fastest time in which a 10" outside diameter casting should be expanded to 12" outside diameter (20% increase) would be four minutes, whereas the fastest time for expansion of a 40" casting to 48" diameter (also 20% increase) would be 16 minutes. Normally, the times involved will tend to be somewhat slower.

As already mentioned, one of the important features of this invention is the reduction in grain size of cast metals brought about by cold expansion and annealing. Figure 4 shows the very long columnar grains which are typical of metal mold castings of the type with which the invention is concerned. The illustration is an actual size photograph showing the macrostructure from a metal mold centrifugal casting of Type 304 stainless steel. Many of these individual crystals or grains run completely through the wall thickness, and, in castings of greater wall thickness, the crystals are still longer. Another indication of the size of crystals can be seen by reference to Figure 5, which is a photomicrograph of the casting of Figure 4, etched, at 100 diameters' magnification. By way of comparison, wrought items are normally purchased by reference to grain sizes (Nos. 1–8) as specified by the American Society for Testing Materials. ASTM Grain Size No. 1 refers to a structure having from ¾ to 1½ grains per square inch as viewed at 100 diameters, while Grain Size No. 8 refers to a structure having from 96 to 192 grains. Thus the ratio between grains shown in Figure 4 and ASTM No. 8 size is about 1000 to 1 or more. The ratio between grains shown in Figure 4 and ASTM No. 1 size is about 100 to 1.

The decrease in grain size effected in accordance with the method of this invention is shown by reference to Figure 6 which is an actual size photograph (macro-etched) of the casting shown in Figure 4, but after expanding the outside diameter about 15.5% and annealing. It will be observed that the coarsely columnar crystals evident in Figure 4 have been completely replaced by much smaller equiaxed crystals. This fact is still further illustrated in Figure 7, a photomicrograph of the structure of Figure 6, taken at 100 diameters' magnification. The degree of crystal size reduction is clearly evident from a comparison of Figures 5 and 7.

Grain size is important only because of the properties affected thereby. The effects of coarse grain size are manifested in several ways: (1) somewhat lower mechanical properties, (2) increased susceptibility to grain boundary corrosion, (3) inferior machining characteristics, and (4) rough or "orange peel" surface developing upon severe cold forming or deep drawing a finished machined article.

The effect of grain size on room temperature mechanical properties, while generally accepted, is illustrated by a series of experiments utilizing identical metal compositions but with different grain sizes. One portion of a single 500 lb. electric furnace heat was poured into a dry sand static mold, producing the well known keel block type of casting, and then the other portion was poured into a heavy metal mold rotating at high speed to produce a typical centrifugal casting. A part of the centrifugal casting was subsequently subjected to a hot forging operation to produce ⅞" rounds after a 4 to 1 reduction. This experiment thereby provided specimens possessing three different grain sizes: (1) coarsely columnar from the metal mold centrifugal casting, (2) coarse but randomly oriented grains of intermediate size from the static sand mold, and (3) fine equiaxed grains from the hot forged rods. All three materials originated directly from the same heat of steel so variations in minor compositional elements such as hydrogen, oxygen, or nitrogen, were virtually eliminated. Five steels were included in the experiments, and the mechanical properties are shown in Table I, in each case after water quenching from 1900° F.

Table I

Steel	Grain Type*	Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Elongation, Percent	Red. of Area, Percent	V-notch Charpy Impact, Ft. Lbs.	Brinell Hardness
ACI HF Alloy	1	41,900	95,500	40.0	37.3	52.0	212
ACI HF Alloy	2	49,750	94,250	13.5	15.9	19.0	223
ACI HF Alloy	3	50,000	110,250	45.0	64.2	120.0	207
AISI Type 316	1	28,400	66,750	57.0	57.5	120.0	149
AISI Type 316	2	39,875	83,500	42.5	40.1	79.5	170
AISI Type 316	3	34,400	80,750	55.0	76.3	120.0	143
ACI HT Alloy	1	39,100	85,000	11.0	9.2	5.5	201
ACI HT Alloy	2	45,500	70,000	3.5	4.7	5.5	207
ACI HT Alloy	3	43,750	106,000	29.0	44.3	45.0	186
AISI Type 304 ECL	1	32,250	73,250	58.0	71.8	120.0	137
AISI Type 304 ECL	2	33,500	72,000	53.5	67.5	120.0	134
AISI Type 304 ECL	3	40,750	89,250	56.5	74.4	120.0	159
ACI HH Alloy	1	46,250	79,750	8.0	8.5	3.5	217
ACI HH Alloy	2	47,370	70,000	3.0	2.3	5.5	217
ACI HH Alloy	3	56,750	113,000	35.0	47.8	62.5	217

*1=centri-coarse; 2=static-coarse; 3=forging-fine.

With respect to inferior grain boundary corrosion resistance, the consensus of metallurgists is in line with that of Pierce and Grossman, The Book of Stainless Steels, Thum, published by American Society for Metals, page 164:

"Grain size is a potential factor in intercrystalline corrosion. When material is fine grained, the grain boundary extent being this much greater, the severity of attack in any individual grain boundary is less than in coarse grained material."

Machinability, and especially the ability to take on a fine finish without special techniques, is also favored by fine grain. This statement refers to 300 series austenitic stainless steels which are soft and "draggy" by nature, rather than to carbon and low alloy hardenable steels.

"Orange peel" or pebbly surfaces after deep drawing or severe cold forming are to be expected from coarse grain materials. Slip or deformation take place along crystallographic planes so the coarser the grain, the rougher will be the surface after cold forming. Fine grained material deforms in exactly the same manner, but with smaller crystals the slip planes are too short to produce surface roughening. It will be apparent that freedom from "orange peel" is highly desirable on tubular products which are finish machined and then subjected to one of several types of cold forming operations by the ultimate user.

I have chosen to describe the limits of this invention in terms of percentage increase in outside diameter necessary to effect a given grain size and, consequently, a given physical property. The relationship between grain size, and physical properties and percentage increase in diameter is illustrated in Table II which gives the properties obtained by expanding the casting shown in Figures 4

and 5 by 15.5% to give the grain sizes illustrated in Figures 6 and 7.

Table II

Treatment Prior to Testing	Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Percentage Elongation	Reduction of Area, Percent
As Cast Structure	26,500	72,200	65.3	64.8
Expanded 15.5% Annealed	34,000	82,650	67.1	73.2

The results in Table II show generally superior properties for the fine grained structure, both higher strength and better ductility, whereas in normal steels, which undergo phase change with temperature, increased strength is obtained at the expense of elongation, reduction of area, and impact resistance.

Utilizing the percentage of expansion of outside diameter as the means of expressing the required treatment, it then becomes a question as to what percentage of expansion is necessary to achieve particular physical properties with a casting of a given metal, after annealing. The data applicable to AISI Type 316 stainless steel is shown in Table III. Each specimen was cold expanded to the extent shown (outside diameter) and then annealed at 1950° F. and water quenched.

Table III

Percent Expansion	Yield Strength, p.s.i.	Ultimate Strength, p.s.i.	Percent Elongation	Reduction of Area, Percent
0	32,200	69,900	54.3	72.0
2	33,800	70,500	56.5	68.0
4	34,400	72,100	57.9	69.2
6	35,500	72,100	48.6	69.5
8	37,000	75,500	53.6	66.0
10	36,200	79,800	61.4	68.3
12	36,900	81,400	65.0	70.1
14	36,200	82,200	64.3	72.0
16	36,200	82,200	62.8	72.2
18	36,600	83,000	62.8	68.9
20	36,600	83,500	64.3	71.6
22	37,200	83,200	62.1	73.1
24	36,500	83,600	62.8	72.2
26	37,500	84,300	62.1	70.9
28	37,900	84,600	63.6	72.8
30	37,200	84,500	65.0	70.4
32	37,600	84,800	63.6	70.7
34	37,200	84,900	61.4	68.5
36	37,500	85,200	60.7	70.7
38	37,000	85,800	62.1	68.5
40	37,300	84,800	66.4	71.7
42	37,600	84,800	69.3	69.4
44	36,400	85,200	67.1	71.7
46	37,300	85,800	67.1	71.4
48	37,400	85,800	66.4	69.7
50	36,700	83,400	65.8	74.0
52	37,200	85,800	64.3	70.5

These data show that only a little recrystallization is effected by expansion up to about 8%. From 8% to about 16% the most rapid rate of change in recrystallization occurs. Expansion beyond about 18 or 20% results in small increases in strength by virtue of a slight decrease in the recrystallized grain size, but the phenomenal change associated with the disappearance of the coarse cast grain size occurs between about 8 and 16% expansion. These data indicate, therefore, that a Type 316 stainless steel cylinder, expanded at least about 16% and annealed, will exhibit a refined or recrystallized grain size with all the virtues pertaining to small grain products.

Similar data obtained with stainless steels of other compositions indicate that the same order of expansion is applicable as with Type 316. Since a survey such as that described for Type 316 is laborious and time-consuming, a simpler and quicker means is helpful in determining the minimum degree of expansion required for recrystallization upon subsequently annealing. In going from one type of "300 series" austenitic stainless steel to another, for example, or in taking up a new alloy, some simple means for determining the minimum amount of expansion required for recrystallization is considered a necessity. A method has been devised based on the fact that expansion according to this invention is basically a novel means of effecting cold working.

According to the method devised, a conical specimen is machined to predetermined dimensions. The specimen is then pulled apart in a tensile machine, annealed, split longitudinally, and macroetched as shown in Figures 8 and 9. Knowing the breaking load and the original cross-sectional area at the point where the recrystallization and unaffected structures meet, it is then possible to establish rather closely the load required to produce recrystallization. Using the data thus obtained as a guide, tensile rods are then stressed at three levels: (*a*) at the load corresponding to the transition from coarse to fine grains, (*b*) at a load somewhat higher, and (*c*) at a load somewhat lower. Elongation values are listed for these stressed but unbroken tensile rods. The rods are then annealed, remachined into standard tensile specimen and tested. The test results are used to determine what minimum expansion in diameter should be reached upon expanding the corresponding tube.

It will be apparent to those skilled in the art that expression of the degree of cold working, to be effected by the method of this invention, in terms of percentage increase in outside diameter necessarily limits the method to relatively large cylinders and to thinner walls in the smaller size range. This is for the reason that in smaller cylinders, with relatively thick walls, the percentage increase in inside diameter will be considerably greater than for the outside diameter. Inasmuch as the maximum degree of cold deformation effective to give recrystallization is limited only by the point of rupture of the cylinder, the method can be applied to cylinders of any size so long as minimum expansion of the outside diameter does not subject the inside diameter to sufficient expansion to cause rupture. Smaller diameter and thicker wall cylinders can be treated according to this invention by stepwise expansion, however. That is, the cylinder can be expanded to an intermediate degree, annealed, and then subjected to additional expansion and annealing steps until the desired degree of grain refinement is achieved.

Another novel feature of this invention concerns the fact that cold working is accomplished without either elongating or shortening the cast cylinders or having any contact with unyielding dies or hammers on either the outside or the inside diameter surfaces as is the case in cold drawing or swaging. The coarse crystals adjust themselves to accommodate the increase in diameter through block movements in an outward rather than in a longitudinal direction. This results in a characteristic coarsely crinkled or heavy "orange peel" effect on both the outside and inside diameter surfaces.

Similarly the internal crystal structure responds to the novel method of cold working in a characteristic manner. When tubular products are cold worked by conventional methods (e.g. cold drawing or cold swaging) the individual crystals are deformed in approximately the same proportion and in the same direction, i.e., if a cylinder is elongated and reduced in wall thickness, the individual crystals are likewise elongated to about the same degree. Since the effects of this crystal elongation are not completely removed even upon a subsequent anneal, anyone familiar with these well known metallurgical principles will see the advantages of avoiding the preferred orientation inherent in conventional cold drawn cylinders. In our cold expanded casting, involving no significant change in length, the individual crystals are not elongated to any substantial degree in a longitudinal direction.

Another important feature of this invention is that cast cylinders are converted into cylinders having the desirable mechanical properties of wrought products, but without imparting directional properties. Wrought prod-

ucts commonly originate from large ingots by great reductions in cross-sectional area and corresponding elongations either through hot forging or rolling and/or cold finishing passes. Selective freezing in the large ingot results in primary dendrites consisting of large proportions of the highest melting element or phase, iron for example, with lower melting constituents, such as compounds of phosphorus, sulphur, and carbon, being concentrated to some degree in the interdenritic or interstitial areas. When the ingots are rolled out, non-metallic inclusions and the comparatively impure interstitial metal areas are elongated, thinned and flattened in the same proportion. When the non-metallic inclusions are flattened out, they occupy a greater percentage of the cross-sectional area, so ductility in specimens taken at right angles to the direction of rolling is decreased. Figure 10 is an illustration of the effect on non-metallic inclusions of forging operations. The elongated non-metallic inclusions are clearly evident at several parts of the photograph (×1000) which is an unetched section from hot rolled seamless tubing used in the recoil mechanism of U.S. Army tanks. The marked cross-sectional reduction and elongation from the ingot stage to a relatively thin walled cylinder has flattened and elongated the inclusion.

Neither such inclusions, nor the frequently associated banding, influence ductility much in the case of specimens taken in the longitudinal direction, but properties are quite different when specimens are taken at right angles to the rolling or forging direction.

Steels differ as to this banding or fiber, varying with the cleanliness and purity of the steel as well as the percent reduction from the ingot to the final product. However, virtually all commercial wrought products do show different properties when tested in directions parallel to and at right angles to the direction of working, i.e. they are not isotropic. Non-metallic inclusions are commonly pointed to as the major cause for directional properties, but in at least some instances a two-phase microstructure, if present at the time of rolling, results in distinct banding or layering of the two microscopical constituents. In certain instances, these structural constituents exhibit markedly different mechanical properties, so that directional characteristics are present to an extreme degree.

In contrast to wrought materials, castings do not show directional properties, i.e. they are isotropic, since they are not subjected to mechanical working. The cold expanded and annealed cylinders of this invention are changed in shape so little that they are also isotropic. For example, a Type 304 stainless steel casting 6.59" O.D. by 5.21" I.D., 6' in length, was cold expanded to an O.D. of 7.75" (17.6% increase), annealed by heating to 1950° F. and water quenching, and tested in both the transverse and longitudinal directions with the following results:

Table IV

Test Direction	Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Elongation, Percent	Reduction of Area, Percent
Longitudinal	43,600	85,050	45.0	46.8
Do	43,600	86,000	49.0	41.4
Transverse	40,400	85,450	50.5	47.1
Do	43,600	85,550	50.0	54.0

Figure 11 is a photograph (×1000) of an unetched section of the cold worked cylinder the properties of which are shown in Table IV. The dramatic difference in effect on non-metallic inclusions will be seen by comparison with Figure 10.

The cold expansion of cast cylinders in accordance with this invention possesses another important advantage, distinct from the grain refinement and attendant improvement in mechanical properties. That is, the cold expansion helps overcome long-standing prejudices against the use of castings for critical services. Even with the best of non-destructive testing and inspection, there is a fear that some under-surface defect, e.g. a hot tear or blowhole, may be present and result in sudden failure of a hazardous nature. Since metal tubing is never intentionally placed in service under stresses above its yield strength, these cold-expanded cylinders will already have been subjected to stresses far in excess of service expectancy. Any gross defect will lead to failure during the cold expansion in manufacture. The method of this invention therefore constitutes a more rigorous proof test than any used heretofore for castings.

The process of this invention also provides a means for forming large diameter seamless tubing or cylinders from smaller castings. By cold expanding, annealing, and re-expanding and annealing several times, a very large increase in diameter is obtainable. Repeated expansions with intermediate annealings will result in somewhat smaller grain sizes than is the case with a single expansion. The cold deformation is not additive, however, since annealing removes cold work introduced by the preceding expansion, and restores ductility. The second and successive expansions, however, will be applied to cylinders having comparatively small grain sizes and when an equal degree of cold expansion is added, it is equivalent to a somewhat greater cold reduction on the coarse grain casting. While no further appreciable decrease in grain size will result from annealing and repeating the expansion, the increase in cylinder diameter is accomplished.

We claim:

1. The method for producing tubular metal articles of a work-hardenable ductile metal the grain size of which cannot be reduced by heat treatment alone, having an average grain size no larger than ASTM No. 1 and having isotropic physical properties which comprises, expanding a centrifugally cast tube of said metal at least about 16 percent in outside diameter by the application of uniform radial pressure simultaneously throughout the interior of said cast tube while the outside of said cast tube is unconfined, heating the so expanded cast tube to a temperature to effect recrystallization of grain crystals and then quenching said recrystallized tube.

2. The method as defined in claim 1 in which the ductile metal is selected from the group consisting of austenitic steels, brasses, bronzes, and nickel base alloys.

3. The method as defined in claim 1 in which the ductile metal is an austenitic stainless steel.

4. The method as defined in claim 1 in which the ductile metal is AISI Type 316 stainless steel.

5. The method as defined in claim 1 in which the ductile metal is AISI Type 304 stainless steel.

6. A tubular article at least about 8 inches in outside diameter and at least about one-half inch in wall thickness, consisting of a work-hardenable metal the grain size of which cannot be reduced by heat treatment alone, said article resulting from cold expansion of a centrifugally cast tube of said metal followed by heat treatment to effect recrystallization, the average grain size of said article being no larger than ASTM No. 1, non-metallic inclusions in said metal having the shape and characteristics common to castings of said metal, and the physical properties of said article being substantially isotropic.

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