Dec. 29, 1964 E. S. NACHTMAN 3,163,285

PROCESS AND APPARATUS FOR THE PRODUCTION OF IMPROVED STEEL TUBING

Filed Dec. 7, 1960 2 Sheets-Sheet 1

FIG. 1

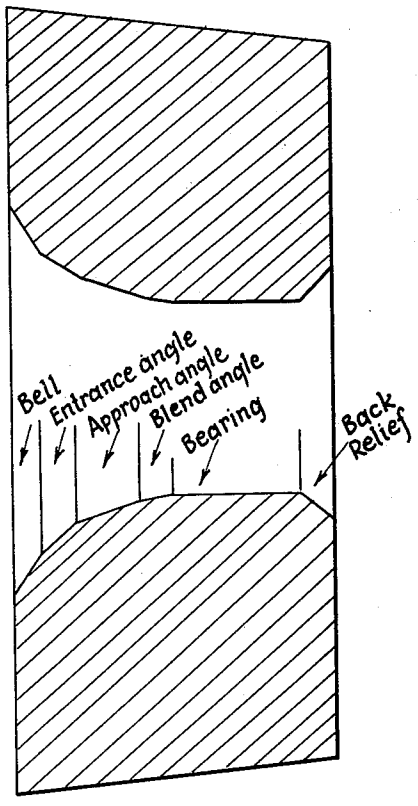
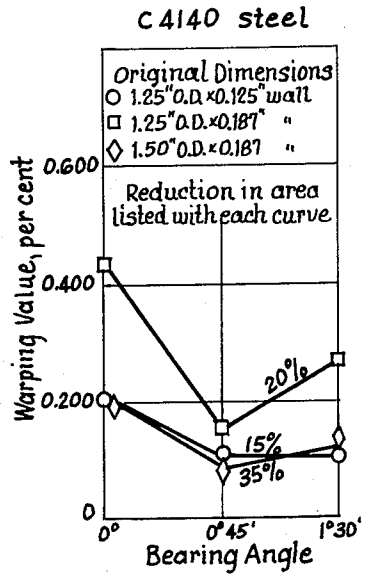


FIG. 2



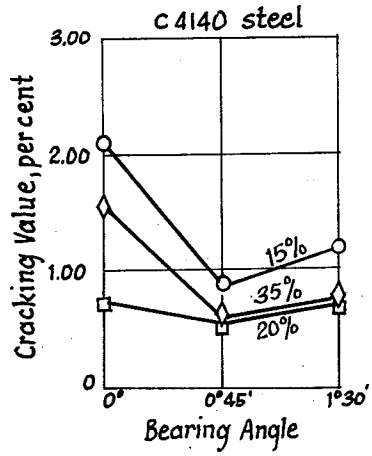


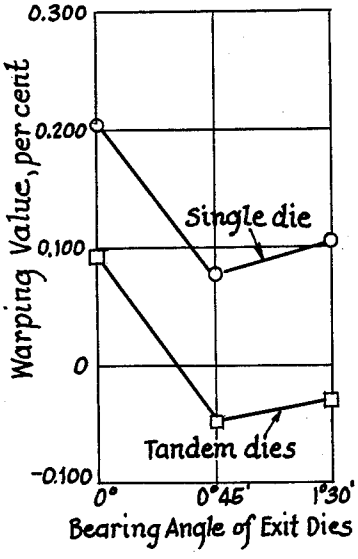
FIG. 3

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FIG. 4



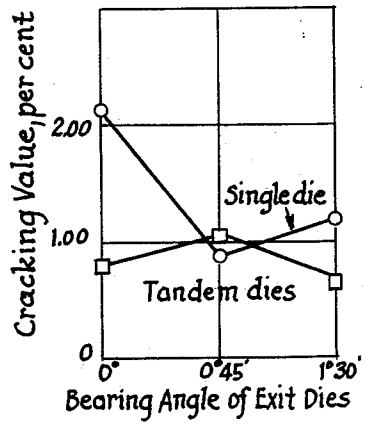
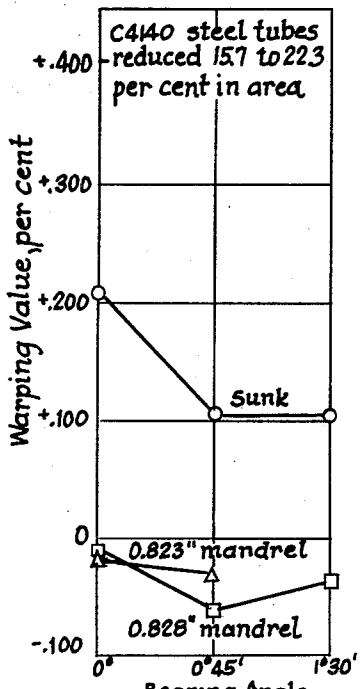


FIG. 5

FIG. 6



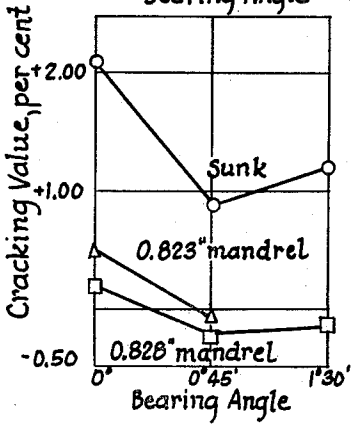


FIG. 7

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PROCESS AND APPARATUS FOR THE PRODUCTION OF IMPROVED STEEL TUBING

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Filed Dec. 7, 1960, Ser. No. 74,314
1 Claim. (Cl. 205—8)

This invention relates to the production of steel tubing, and it relates more particularly to a process and apparatus for the elimination of residual stresses in steel tubing. In addition, this invention relates to a system which permits the introduction in a controlled manner of desirable stress patterns in steel tubing, thereby improving the mechanical properties of the tubing.

In the production of steel tubing, it is often necessary to work the tubing to obtain desirable size and to achieve certain degrees of strength and hardness. It is known that in the working of steel tubing, as by drawing, stresses of considerable magnitude may be introduced, depending upon the amount of draft and chemistry of the steel. The presence of residual stresses in steel products has an important influence in processing the steel into the finished product, and the residual stresses existing also have considerable influence on the specification of certain materials for particular uses and applications. Cracking of the tubing might occur immediately as the work leaves the working apparatus, during subsequent processing into a finished product, in finished stock storage, or in final assembly of a finished product in which the steel unit may form an essential part. Such breakage in use not only forms a source of embarrassment to the supplier and damages the reputation of the manufacturer but, from a practical standpoint, unnecessarily increases the cost of materials by reason of the scrap rate involved.

It is therefore an object of the present invention to produce steel tubing without substantial residual stresses or with a controlled stress pattern, such that improved mechanical properties result.

It is an additional object of this invention to produce steel tubing on a dependable basis, free of detrimental stresses, and without expensive stress-relieving operations.

It is a further object of this invention to provide a method for enabling the elimination of cracking after the tubing leaves the working apparatus, during subsequent processing, in storage, or in final assemblage of the tubing into a steel unit.

These and other objects of this invention will appear more readily when considering the disclosure and claims and when considering the accompanying figures, in which—

FIGURE 1 is a cross-section of a typical die employed in the inventive tubing system;

FIGURES 2 and 3 graphically illustrate the effect of bearing angle of the die on the warping and cracking values of the worked tubing;

FIGURES 4 and 5 graphically illustrate the effect of bearing angle on work warping and cracking values when tandem drawing dies are employed; and

FIGURES 6 and 7 graphically illustrate the effect of bearing angle on the warping and cracking values when a mandrel is employed in conjunction with the die.

The present invention broadly relates to the working of steel tubes either by sinking of the tubing or when plug mandrels are employed. The invention relates more particularly to novel tube-drawing dies having tapered bearings, to mandrels having tapered surfaces, and to processes employing these dies and mandrels in various novel combinations. The combinations employed include the use of separate dies wherein individual drawing stages are employed with each die, or in the use of tandem dies wherein a single drawing stage is employed with the dies.

The use of the novel dies and the various arrangements thereof reduces the warping and cracking values of the tubing produced. These warping and cracking values are indications of the residual stress in the tubing, which stresses will ultimately control the ability of the tubing to perform satisfactorily under adverse loading conditions.

In order that the residual stresses could be measured, warping and cracking tests were employed. The warping test is one designed to show the tendency of a tube to distort because of residual longitudinal stresses. The test consists of cutting a diametral slot in the specimen to a prescribed length, usually four times the diameter. The diameter is measured before and after cutting, and the change in diameter is denoted as flare. Positive and negative flare values are used in the conventional sense as representing tensile and compressive surface stresses, respectively. The following formula is used to compute the warping value:

$$\text{Warping value, percent} = \frac{100 \times \text{diameter} \times \text{flare}}{(\text{slot length})^2}$$

This test is easily made and quite inexpensive, but it gives only a gross approximation of the warping tendency due to the longitudinal stress. It is qualitative rather than quantitative because the wall thickness should be taken into account in comparing different tubes.

For an estimate of the longitudinal stress, the tongue test was used. This test is performed by making two parallel slots in the long direction of the tubing. The isolated tongue will deflect to indicate the magnitude of the longitudinal stress. To get the maximum deflection, the width of the tongue should be 0.10 to 0.20 times the diameter of the tubing. For the 1 1/16-inch tubing tested in this program, the tongue width was 7/64 to 7/32 inch, and the length was four diameters, as it was for the warping test. The formula for calculation of the longitudinal stress is as follows:

$$\text{Estimated longitudinal stress, p.s.i.} = \frac{\text{modulus} \times \text{wall thickness} \times \text{flare}}{(\text{slot length})^2}$$

This formula is based on the assumption that the stress has an approximately linear distribution and is

equal in magnitude but opposite in sign at the inside and outside surfaces.

While the drawing of a tube through a die by sinking usually produces longitudinal stresses that may be undesirable, the tangential stresses are probably more important. Severe tangential stresses can cause bars or tubes to crack longitudinally. The cracking test was used to evaluate the tangential or circumferential stresses. In these experiments, the length of the cracking specimen was three times the diameter of the tubes. The tubular specimens were slotted on a radius along the whole length. The movement was measured and used to calculate the cracking value, which is defined as the percentage change in the circumference. The formula used to compute the cracking value is as follows:

$$\text{Cracking value, per cent} = \frac{100 \times \text{flare}}{\text{circumference}}$$

An estimated tangential stress may also be calculated by using the flare obtained in the cracking test and the following formula:

$$\text{Estimated tangential Stress, p.s.i.} = \frac{\text{Modulus} \times \text{wall thickness}}{1-\mu^2} \times \frac{\text{flare}}{\pi \times (\text{diameter})^2}$$

The formula assumes that the tangential stress is linear.

The specific dies and mandrels employed to illustrate the inventive concepts are set forth in Table I, and reference may be made to FIGURE 1 for an explanation of the terms employed. Symbols assigned to dies and tools in the following tables are purely arbitrary characters employed for purposes of identification in the testing procedures.

TABLE I

Dimensions of Experimental Dies and Mandrels

Die	Half Angle	Entrance Diam., inches	Exit Diam., inches	Length, inch
A340 [a]	0°	1.067	1.063	0.74
A250 [a]	0°45′	1.090	1.068	0.87
A341 [a]	1°30′	1.122	1.064	0.92
X1916	0°	1.033	1.034	0.75
X1917	0°	1.247	1.247	0.82
L18	0°	1.073	1.072	0.53

Mandrel No.	Taper—Half Angle	Exit Side Diam., inch	Entrance Side Diam., inch	Length, inches
A	0°	0.828	0.828	3+[b]
B	0°	0.823	0.823	3+[b]
C	0°	0.821	0.821	3.07
D	0°	0.817	0.817	3+[b]
E	0°	0.815	0.815	3.10
F	0°	0.741	0.740	3.15
G	0°45′	0.828	0.750	3.08
H	0°45′	0.706	0.792	3.15

[a] The blend angle for these dies is approximately 4°, the approach angle is 11 to 12°, and the entrance angle which is used for the large tubing is 19 to 20°.

[b] Not actually measured, but slightly greater than 3 inches.

A specific phase of this invention consists in the drawing of steel tubes by a sinking operation, that is, drawing the tubes without the use of a mandrel. In order to illustrate the advantageous results which may be achieved with the novel process and apparatus of this invention, 15 steel tubes were drawn employing single dies. The drawing conditions and results are shown in Table II. The composition of the specimens was as follows:

	Percent
C	0.40
Mn	0.83
P	0.012
S	0.014
Si	0.25
Cr	0.75
Mo	0.20

TABLE II

Tubes Drawn by Using a Single Die Without a Mandrel

Tube	Die	Bearing Angle	Tube Diam., inches	Reduction		Distortion Tests						
						Warping		Tongue		Cracking		
				Diam., Percent	Area, Percent	Flare, inch	Value, Percent	Flare, inch	Longitudinal Stress, p.s.i.	Flare, inch	Value, Percent	Tangential Stress, p.s.i.
C4140 STEEL TUBES												
2	A340	0°	1.252	15.9	16.7	+0.036	+0.208	+0.432	+90,600	+0.0694	+2.10	+83,400
28	A340	0°	1.250	15.8	17.2	+0.035	+0.204	+0.415	+85,400	+0.0716	+2.17	+84,000
34	A340	0°	1.243	15.4	22.2	+0.075	+0.435	+0.251	+73,500	+0.0241	+0.73	+40,100
8	A340	0°	1.504	30.3	35.7	+0.036	+0.209	+0.214	+63,700	+0.0499	+1.55	+85,700
1	A250	0°45′	1.252	14.7	15.7	+0.013	+0.077	+0.221	+46,000	+0.0295	+0.88	+34,300
26	A250	0°45′	1.250	14.5	15.6	+0.021	+0.124	+0.251	+51,000	+0.0307	+0.91	+34,900
29	A250	0°45′	1.251	14.6	17.0	+0.017	+0.101	+0.187	+38,200	+0.0273	+0.81	+30,900
30	A250	0°45′	1.250	14.6	16.8	+0.020	+0.120	+0.172	+35,100	+0.0277	+0.83	+31,300
33	A250	0°45′	1.243	14.2	19.8	+0.026	+0.154	+0.107	+31,200	+0.0187	+0.56	+30,300
7	A250	0°45′	1.504	29.0	34.4	+0.014	+0.083	+0.094	+28,000	+0.0202	+0.60	+33,300
3	A341	1°30′	1.252	14.9	16.1	+0.018	+0.106	+0.273	+57,000	+0.0402	+1.20	+47,300
32	A341	1°30′	1.243	14.2	20.0	+0.046	+0.269	+0.198	+57,200	+0.0235	+0.71	+38,000
9	A341	1°30′	1.504	29.2	32.2	+0.021	+0.124	+0.131	+38,600	+0.0251	+0.75	+41,900
40	X1916	0°	1.503	31.1	41.9	+0.017	+0.092	+0.1675	+44,600	+0.0494	+1.52	+77,700
42	L18	0°	1.252	14.4	14.8	+0.028	+0.167	+0.303	+63,000	+0.0716	+2.13	+82,400

It will be apparent when analyzing Table II, that substantial improvement in the warping and cracking values and in the amounts of longitudinal and tangential stresses is achieved when the tapered dies are employed. For example, it will be noted that the groups of specimens drawn through dies having bearing angles of 0° 45′ and 1° 30′ exhibit substantial decreases in longitudinal stress and tangential stress when compared to the specimens drawn through dies with zero bearing angles. FIGURES 2 and 3 graphically illustrate the improvements that are achieved, these figures being based on average values taken from Table II and on nominal percent reductions.

Table III illustrates the results that may be achieved using tandem dies or employing separate dies. In the use of the tandem dies, the successive reductions in the tubing are achieved by a single draw, whereas in the use of separate dies two separate draws were employed.

hibited in the specimens **31** and **39**, thus illustrating the value of tandem dies. Specimens **31** show superior properties relative to specimens **39** illustrating the value of the bearing angle even where separate dies are employed. Similar comparisons are available when considering specimens **43**, **44** and **45** relative to specimens **41**.

Reference to Table IV indicates substantial improvement in the warping and cracking values even without the tapers, although the tapers are shown to further improve the residual stress concentrations. It is noted that in the case of tube **38**, reductions as low as 0.2% in the second stage improve the residual stress amounts, and tests indicate that reductions greater than about 3% in the second stage will not significantly improve this property. The value of the second stage reduction is independent of the amount of the first stage reduction, and reductions in the

TABLE III

Tubes drawn by Using Tandem Dies or Two Dies Separately

Tube	First Die		Second Die		Tube Diam., inches	Reduction		Distortion Tests						
								Warping		Tongue		Cracking		
	No.	Bearing Angle	No.	Bearing Angle		Diam., Percent	Area, Percent	Flare, inch	Value, Percent	Flare, inch	Longitudinal Stress, p.s.i.	Flare, inch	Value, Percent	Tangential Stress, p.s.i.
TWO DIES SEP.														
31A	A250	0°45′			1.501	28.9	33.6			+0.070	+20,900	+0.0203	+0.61	+33,700
31B			A340	0°	1.067	0.094	0.98	+0.025	+0.148	+0.104	+31,000	+0.0096	+0.29	+15,700
39A	A340	0°			1.502	30.2	34.6	+0.043	+0.250	+0.2125	+63,900	+0.0500	+1.52	+86,500
39B			X1916	0°	1.047	0.96	0.18	+0.065	+0.371	+0.215	+64,800	+0.0188	+0.58	+33,300
41A	A250	0°45′			1.250	14.6	14.9	+0.010	+0.059	+0.2155	+45,100	+0.0281	+0.84	+32,000
41B			A250	0°45′	1.068	0.1	0.7	+0.005	+0.027	+0.107	+22,600	+0.0201	+0.60	+23,400
TANDEM DIES														
35	A340	0°	X1916	0°	1.502	31.1	36.9	+0.022	+0.126	+0.061	+18,000	+0.0192	+0.59	+33,500
38	A250	0°45′	A340	0°	1.502	29.0	34.6	+0.017	+0.101	+0.0775	+23,000	+0.0156	+0.47	+25,800
44	L18	0°	A340	0°	1.251	14.8	17.7	+0.016	+0.092	+0.085	+17,600	+0.0272	+0.81	+30,900
43	L18	0°	A250	0°45′	1.252	14.8	16.3	−0.008	−0.047	+0.281	+41,300	+0.0353	+1.05	+40,600
45	L18	0°	A341	1°30′	1.250	14.8	15.5	−0.005	−0.030	+0.098	+20,100	+0.0221	+0.66	+25,600

The steel composition of the specimens was the same as that employed above. An analysis of the results reveals that no substantial difference in properties results when employing tandem or separate dies. There are, however, results which show a substantial improvement in the warping and cracking values and in the longitudinal and tangential stresses, which improvements are due to the light reduction taken in the final working operation. It is additionally revealed that these same properties are improved over and above the improvement achieved by the light reduction when tapered dies are employed. The improvement in the amounts of longitudinal and tangential stresses in the warping and/or cracking values is achieved whether the first, second, or both of the dies are tapered. The tests amplify the value of the tapers, in addition to showing the advantageous results that can be achieved when employing a second light reduction on the drawn products.

In considering the specific results shown in Table III, it will be noted that a reduction in longitudinal stress and tangential stress is effected in specimens **35** and **38** when these specimens are compared with the stresses exneighborhood of from 10% to about 50% reduction in area are contemplated in this phase of the invention.

With reference to the specific values in Table IV, it will be noted that the use of positive bearing angles provides superior results for thin wall tubes as seen in considering the values in the first grouping. Under the heading "Dies in Tandem," the values illustrate the improvements that can be achieved with this arrangement. Under the heading "Drawn in Separate Stages," the use of two dies, each having a positive bearing angle, is indicated to be preferable to the use of a single die.

The heavy wall tubes also exhibit clear improvements as illustrated by the first group of samples wherein the sample **31A** drawn through a die having a positive bearing angle is shown to have properties superior to the other samples. Under the heading "Dies in Tandem," the use of a positive bearing angle provides improvements when comparing specimen **38** with specimen **35**. Again, where the specimens **39B** and **31B** were drawn in separate stages, the positive bearing angle again illustrates the point that improved properties can be achieved where this angle is employed.

TABLE IV

Effect of Two-Stage Reduction in Tubes Drawn Using Conventional and Tapered-Bearing Dies

Tube	First Die			Second Die			Distortion Values	
	No.	Angle	Reduction, percent	No.	Angle	Reduction, percent	Warping, percent	Cracking, percent
THIN-WALL TUBES [a]								
42	L18	0°0′	14.8				+0.167	+2.13
2, 28	A340	0°0′	16.7				+0.206	+2.13
1, 26, 29, 30	A250	0°45′	15.7				+0.107	+0.87
3	A341	1°30′	16.1				+0.106	+1.20
DIES IN TANDEM								
44	L18	0°0′	14.8	A340	0°0′	2.9	+0.092	+0.81
43	L18	0°0′	14.8	A250	0°45′	1.5	−0.047	+1.05
45	L18	0°0′	14.8	A341	1°30′	0.7	−0.030	+0.66
DRAWN IN SEPARATE STAGES								
41A	A250	0°45′	14.9				+0.059	+0.84
41B	A250	0°45′	14.9	A250	0°45′	0.7	+0.027	+0.60
HEAVY-WALL TUBES [b]								
8, 39A	A340	0°0′	35.7				+0.230	+1.53
40	X1916	0°0′	41.9				+0.092	+1.52
7, 31A	A250	0°45′	34.4				+0.083	+0.60
DIES IN TANDEM								
35	A340	0°0′	35.7	X1916	0°0′	1.2	+0.126	+0.59
38	A250	0°45′	34.4	A340	0°0′	0.2	+0.101	+0.47
DRAWN IN SEPARATE STAGES								
39B	A340	0°0′	34.6	X1916	0°0′	0.18	+0.371	+0.58
31B	A250	0°45′	33.6	A340	0°0′	0.98	+0.148	+0.29

[a] Nominal dimensions were 1¼-inch OD x ⅛-inch wall.
[b] Nominal dimensions were 1½-inch OD x 3/16-inch wall.

FIGURES 4 and 5 are made up from average values compiled from the data in Table III. These figures illustrate the improvement which is obtained in the cracking and warping values when a slight bearing angle is employed in the die, and also illustrate the advantage of the double draw as opposed to the use of a single die.

The data shown in Table V illustrates the results that are obtained when drawing tubing while employing a plug mandrel. The use of a mandrel is ordinarily resorted to where it is desired to control the wall thickness of the drawn product and/or the inner diameter of the product. The specimens used in this portion of the work had the same composition as that noted above.

TABLE V

Tubes Drawn by Using a Mandrel

Tube	Die	Bearing angle	Mandrel		Tube Diam., inches	Reduction		Distortion tests						
								Warping		Tongue		Cracking		
			Diam., inch	Shape		Diam., percent	Area, percent	Flare, inch	Value, percent	Flare, inch	Longitudinal Stress, p.s.i.	Flare, inch	Value, percent	Tangential stress, p.s.i.
C4140 STEEL TUBES														
20	A340	0°	0.828	Cyl.	1.250	14.9	22.3	−0.0005	−0.003	+0.042	+8,000	+0.0063	+0.19	+6,800
50	A340	0°	0.828	Cyl.	1.249	14.7	20.7	−0.003	−0.018	−0.027	−6,100	+0.0029	+0.09	+3,200
49	A340	0°	0.823	Cyl.	1.251	14.9	19.0	−0.003	−0.018	+0.078	+15,500	+0.0162	+0.49	+17,800
57	A340	0°	0.820	Cyl.	1,249	14.8	17.0	+0.004	+0.024	+0.119	+23,800	+0.0188	+0.56	+20,800
54	A340	0°	0.817	Cyl.	1.250	14.9	18.9	+0.026	+0.153	+0.347	+69,700	+0.0583	+1.75	+64,900
58	A340	0°	0.814	Cyl.	1.249	14.8	15.2	+0.022	+0.127	+0.307	+62,700	+0.0462	+1.38	+52,500
21	A340	0°	0.740	Cyl.	1.501	29.1	39.2	+0.001	+0.006	+0.018	+4,800	+0.0060	+0.18	+8,820
22	A340	0°	[a] 0.828	Tap'd.	1.250	14.6	18.6	−0.013	−0.077	−0.112	−21,800	+0.0134	+0.40	+14,400
56	A340	0°	[b] 0.828	Tap'd.	1.250	14.3	16.7	−0.012	−0.071	−0.043	−8,500	+0.0151	+0.45	+16,700
59	A340	0°	[a] 0.828	Tap'd.	1.250	14.7	17.5	−0.014	−0.083	−0.133	−26,500	+0.0087	+0.26	+9,500
15	A250	0°45′	0.828	Cyl.	1,250	14.7	18.9	−0.006	−0.036	−0.068	−13,000	−0.0057	−0.17	−6,090
51	A250	0°45′	0.828	Cyl.	1,250	14.8	19.9	−0.014	−0.080	−0.101	−19,800	−0.0083	−0.25	−8,900
23	A250	0°45′	0.823	Cyl.	1.250	14.7	18.2	−0.005	−0.030	−0.68	−13,000	−0.0022	−0.07	−2,400
24	A250	0°35′	0.740	Cyl.	1.501	29.2	40.0					+0.0018	+0.06	+2,740
19	A341	1°30′	0.828	Cyl.	1.248	14.7	20.1	−0.006	−0.036	−0.098	−18,500	−0.0049	−0.15	−5,200

[a] Mandrel was allowed to slip past the end of the bearing of the die 1/2 inch.
[b] Mandrel was positioned in the die so that the maximum diameter was adjacent to the exit end of the bearing section of the die.

It will be seen, when studying this data, that the use of a mandrel significantly reduces the residual stress. It is significant to note that when tapers are employed in the die and/or in the mandrel, significant amounts of compressive stresses (indicated by the negative sign) are produced, and that with a tapered die and a cylindrical mandrel, compressive stresses are introduced at the inside and at the outside of the tube. It is well known that compressive stresses will improve the fatigue life of metals, improve their general corrosion resistance, and also improve the resistance to stress corrosion cracking.

With reference to the specific values shown in Table V, it will be noted when comparing specimens **20**, **50**, **49**, **57**, **54** and **53** with specimens **15**, **51**, **23** and **19** that distinct improvements in the longitudinal and tangential stress are available when employing a positive bearing angle. When comparing specimens **21** and **24**, similar improvements in the tangential stress are also to be noted.

FIGURES 6 and 7 illustrate the effect of the bearing angle on the warping and cracking values where cylindrical mandrels are employed, and the figures also compare residual stress with percent reduction obtained by a mandrel draw as opposed to the residual stresses occurring after sinking.

The dies and mandrels of the foregoing examples having the disclosed tapers are particularly suitable for the improvement in amounts of residual stresses and for the introduction of desirable stress patterns. However, tests have indicated that variations in bearing angle taper in the dies may be from about 0°30′ to about 2° and still provide satisfactory results, while tapers up to about 1° will give the best results insofar as mandrel tapers are concerned.

It is contemplated that the instant process will be applicable to carbon and alloy steels generally of varying tubular cross-sections, and of any well-known diameter. Although the invention has been described with reference to cold drawing, processes of tube drawing under other conditions are contemplated, for example, processes which include drawing of steel at temperatures between about 100° F. and the lower critical.

It will further be understood that the die and mandrel tapers of this invention are peculiarly adaptable to other well known tube producing processes, particularly extrusion. Extruded tubing, having been forced through dies comprising the inventive concepts heretofore set forth likewise exhibits improved mechanical characteristics over tubing produced in conventional extrusion type. This is particularly true with regard to warping and cracking values. A tube so extruded may be then drawn through a second die in the manner heretofore set forth in order to achieve the advantages of this concept of the invention. Extruding conditions, including ram pressure, temperatures, etc. are conventional.

It will be understood that the foregoing process and apparatus has been described with reference to specific examples and that changes may be made therein without departing from the scope of this invention, especially as defined in the following claims.

I claim:

In a method of drawing tubular products wherein a mandrel is operatively associated with a die to effect reduction in the wall thickness of the tubes being drawn, the improvement comprising providing a die member having an inlet and an outlet portion and a bearing portion, the inner diameter of said die member at said bearing portion decreasing progressively toward said outlet portion in a manner such that a line intersecting the axis of said die and lying parallel to the inner surface of said bearing portion forms an angle within the range of 0° 45′ to 1° 30′, and advancing the tubular product through said die to effect reduction in the cross sectional area during passage through the bearing.

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