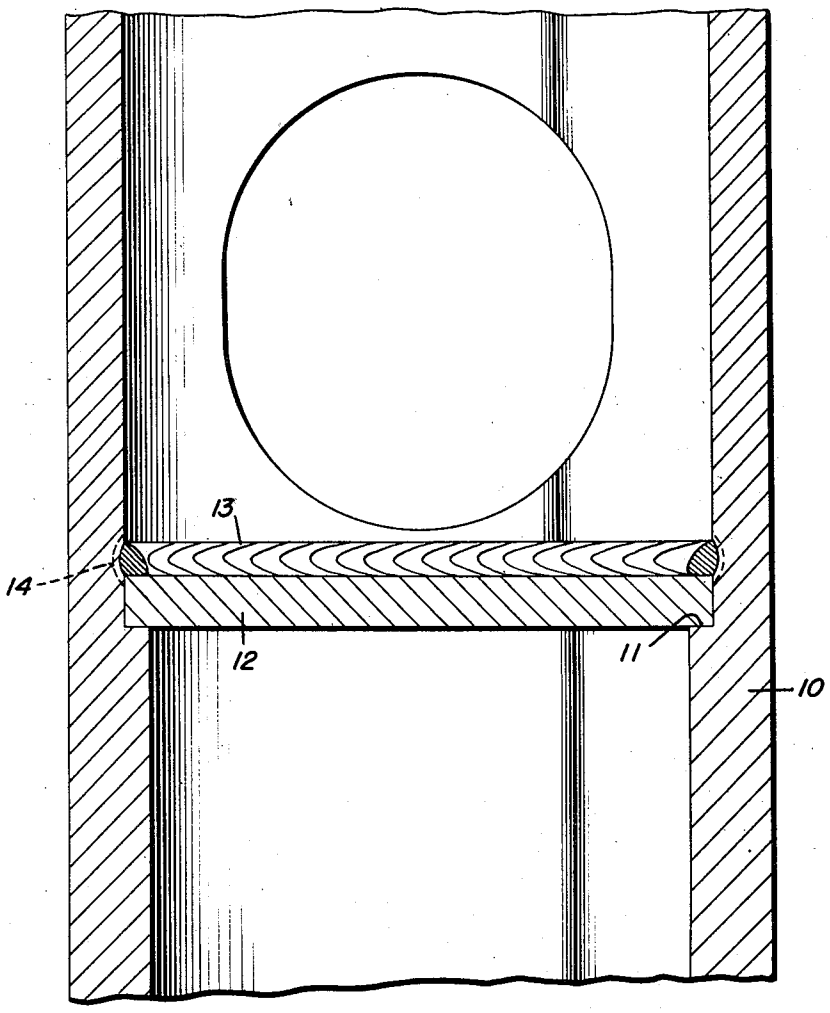
March 5, 1957 G. E. LINNERT ET AL 2,784,083

STAINLESS STEEL CASTINGS

Filed Sept. 29, 1953 4 Sheets-Sheet 1

FIG. 1



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STAINLESS STEEL CASTINGS

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FIG. 2

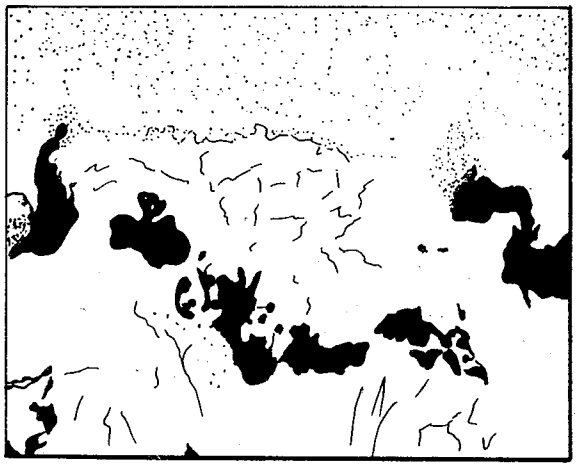


FIG. 3



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STAINLESS STEEL CASTINGS

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FIG. 4

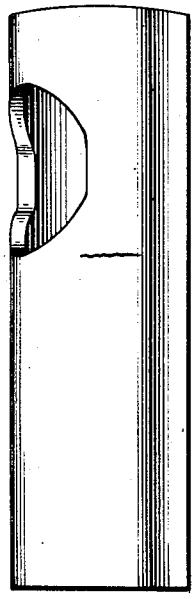


FIG. 5

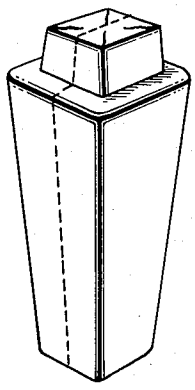


FIG. 6

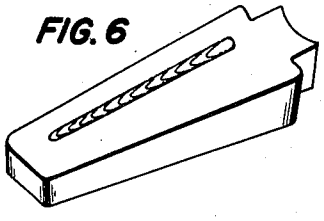


FIG. 8

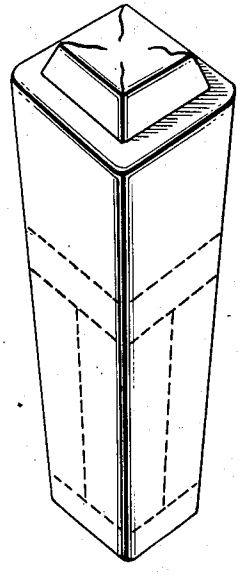
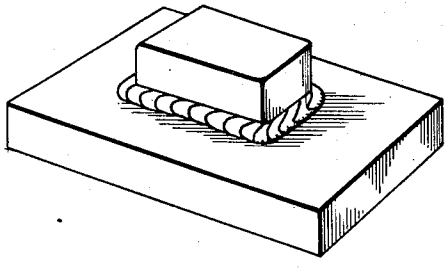


FIG. 7



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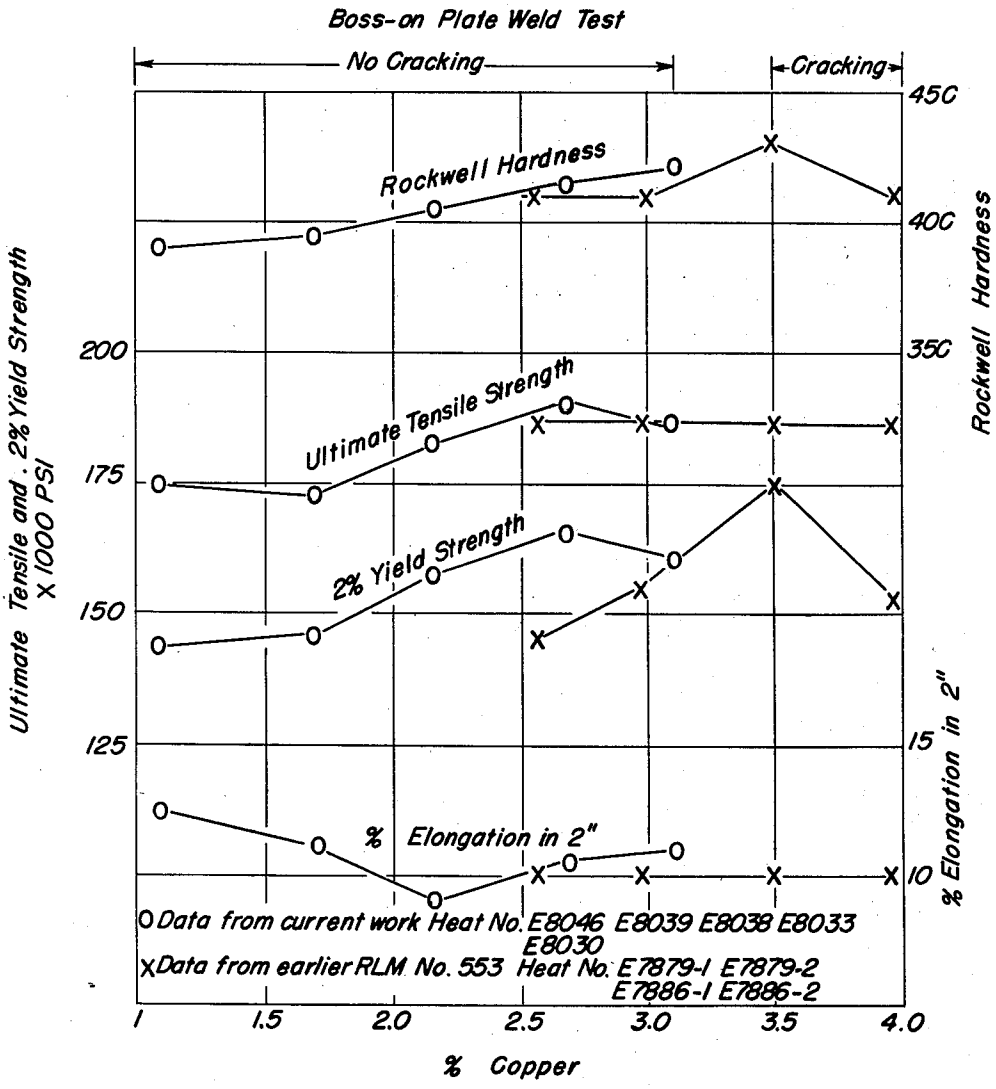
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STAINLESS STEEL CASTINGS

Filed Sept. 29, 1953 4 Sheets-Sheet 4

FIG. 9



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United States Patent Office

2,784,083

Patented Mar. 5, 1957

2,784,083

STAINLESS STEEL CASTINGS

George E. Linnert and William C. Clarke, Jr., Baltimore, Md., assignors to Armco Steel Corporation, a corporation of Ohio

Application September 29, 1953, Serial No. 382,982

3 Claims. (Cl. 75—125)

Our invention relates generally to precipitation-hardening stainless steels, and more especially is directed to either static cast or centrifugal cast alloys of improved welding properties.

An object of our invention is to provide a high alloy precipitation-hardenable stainless steel, which metal alloy can be readily, certainly and predictably welded, and this in both its still cast and in its centrifugally cast form, the resulting weld displaying high strength both through the weld itself and in the adjacent base metal, particularly in the "underbead" region, which improved qualities are readily obtained with certainty and without necessity for additional manipulative steps.

Another object is to provide a precipitation-hardened stainless steel alloy casting, the welded metal displaying both highly advantageous mechanical properties and the quality of impermeability towards fluids, and this both in the weld itself and in the surrounding metal, necessary welding operations being conducted simply and rapidly and with minimum complexity, at low cost, and with desirable, certain and predictable results.

Yet another object is to produce a satisfactory weld in precipitation-hardenable stainless steels which have been preliminarily cast either by still or centrifugal processing, and this without appreciable impairment of the desirable physical properties of the metal undergoing welding.

Other objects and advantages in part will be obvious and in part more fully pointed out hereinafter during the course of the following description, particularly when considered in the light of the accompanying drawings.

Our invention accordingly resides in the composition of metals, in the welds produced, both in the weld itself and in the immediately adjacent base metal, and in the welded products, the scope of the application of all of which is more fully set forth in the claims at the end of this specification.

In the several views of the drawings, wherein we have illustrated certain matters pertaining to our invention, and facilitating understanding thereof:

Figure 1 is a section through a welded plunger piston made from ordinary 17–4 PH (17% chromium, 4% nickel precipitation-hardenable stainless steel) centrifugal cast metal tubing, and disclosing underbead cracking or failure;

Figure 2 is a microphotograph, magnified 100 times, of the weld of Figure 1 showing severe underbead cracking;

Figure 3 discloses at 250 magnification the early stage of underbead cracking in the case of a bead-on-plate weld test specimen of centrifugally cast 17–4 PH steel;

Figure 4 is a photograph of a plunger tube, six inches diameter, formed of centrifugally cast 17–4 PH steel, depicting development of circumferential cracking in the tube wall at the point of welding;

Figure 5 discloses, in perspective, an induction-melted test ingot showing the method of splitting which we employ in preparing test specimens;

Figure 6 shows the specimen prepared for bead-on-plate weld test, as taken from the ingot of Figure 5;

Figure 7 shows a boss-on-plate weld test, using another portion of the ingot of Figure 5;

Figure 8 is a view, somewhat similar to Figure 5, but showing the method of sectioning and dividing an induction-melted ingot of somewhat larger size and weight than that shown in Figure 5; while

Figure 9 is a graph disclosing certain pertinent data, experimentally derived according to the practice of our invention.

And now, as conducive to a more thorough and complete understanding of our invention, it may be noted that during the past several years a certain class of stainless steels, on the border line of austenitic range, containing approximately 17% chromium, 4% nickel, 4% copper, and remainder iron, and known in the industry as the 17–4 PH stainless steels, have achieved remarkable success in the industry, accompanied by rapid and complete acceptance for many and varied uses. This is particularly true when those alloys are in the wrought form. For these alloys display high resistance to corrosion and are easily, uniformly and predictably precipitation-hardenable when subjected to controlled heat treatment directed to that objective.

As a corollary to the uniform success achieved by these steels in their wrought form, consistent and increasing demand has grown for castings of this precipitation-hardenable alloy. And a number of foundries producing high-alloy steel castings have now ventured into the use of 17–4 PH alloys for the production of castings.

Serious difficulties have been experienced, however, when attempts are made to arc-weld castings of the 17–4 PH grade. These difficulties are typically evidenced by an uncontrolled tendency of fluid-handling cast products thus welded to leak in the region of the weld. By consequence, these welded products can not be depended upon to restrain and contain liquids in certain and reliable manner. And this tendency towards leakage has been observed to grow within the welded article, with the passage of time.

Surprisingly enough, failure to an extent severe enough to display itself in practical manner by leakage in the region of the weld apparently does not occur in the weld itself. Rather, such leaking apparently takes place in the metal, immediately under the weld itself. Accordingly, this is known in the industry as "underbead" cracking. With the first discovery of this tendency towards cracking, during the course of early exploration of the use of these alloys for castings, extensive investigations were then undertaken to ascertain the underlying cause of such failures. And a variety of minor variances of such failure were encountered, attendant upon the particular type of casting and upon particular use for which the products were intended.

Almost invariably the failures were attended by intergranular cracking in the cast base metal adjacent the weld. Illustrative of this is the specimen according to Figure 1. In this disclosure, typical and illustrative of difficulties characteristic of prior art practice, we disclose a section through a welded plunger piston formed from a tube nine inches outside diameter with wall thickness of $\frac{9}{16}$ of an inch at the point of welding. In construction, a tube **10** was formed by centrifugally casting 17–4 PH stainless steel. The piston was thereafter produced by welding transversely across the interior of this tube, at a determined zone intermediate its length, a

baffle disc 12 seated on an annular shoulder 11 provided on the interior face of the tube. An arc-weld deposit 13 is provided annularly about the top surface of the baffle disc 12 and serves mechanically to tie down the baffle disc 12 in position within the tube.

Now, an essential requirement of such piston, typical of the prior-art, is that it be liquid-tight to the extent that no seepage can occur from one face of the baffle disc 12 to the other. In practice, however, fluids would circumvent the weld 13 by seeping through the tube wall in the region 14 closely adjacent and underlying the weld, this detrimental phenomenon being observed whenever the underbead cracking became continuous. In some instances the extent of this underbead cracking, or failure in the base metal itself, is quite severe. And this is shown, illustratively, in the microphotograph of Figure 2. While spasmodic, such leakage was highly detrimetal so as concerns certainty and predictability of operational results. Moreover, effective lubrication becomes a problem.

Accordingly, the industry directed exploratory work towards investigating these failures, which were characterized largely by the consistency of their occurrence. Unfortunately, only negative results attended. And these results proved important only in emphasizing the necessity for future exploration.

Illustratively, it was determined that no contamination of the 17–4 PH material was occasioned with tramp elements such as tin or silver. And for a while it was considered that important content of precipitation-hardenable elements, light in weight, such as aluminum, might be the source of such difficulty. Exploring this possibility, however, and omitting aluminum additions from the composition of the alloy, and with both the chromium and nickel contents brought into better conformity with the precise 17–4 PH analysis specification, lower casting temperatures were employed, this latter to explore whether the particular centrifugal method of casting employed might be the cause of such failure. The results were uniformly unfavorable however. In virtually every instance, underbead cracking was encountered.

An the effect of various heat-treatments on the welded castings also was tried. In these experiments various test specimens as received in the cast state were first subjected to precipitation-hardening treatment, and then to weld test. Other tests were conducted upon specimens of like composition, but which were annealed before welding. All suggested treatments, however, were uniformly ineffective, these including a solution-heat treatment, a 1200° F. over-age annealing treating, and a treatment including pre-heating to 650° F.; all these were ineffective in eliminating the susceptibility to cracking which heretofore has been characteristic of these cast 17–4 PH alloys.

An important object of our invention, therefore, is to avoid the many difficulties confronting the art in achieving weldable precipitation-hardening stainless steel castings and to accomplish the foregoing in simple, ready and predictable manner, with minimum of expense in treatment and in materials employed.

Referring now to the practice of our invention, we find that in the melting of the 17–4 PH alloys, containing about 17% chromium, about 4% nickel, 4% copper and remainder iron the precipitation-hardening qualities giving rise to controlled increase in strength, are imparted largely by the presence of the copper. And within reasonable limits, increase of copper is attended by important increase in the desirable physical properties of the alloy, incident to subsequent precipitation-hardenable heat treatment, usually in the form of treatment to which the metals are subjected after working to final form.

We have found that it is just this copper phase which is included in the steel to impart thereto the desirable precipitation-hardenable qualities—the copper precipitating out as in the form of an intermetallic compound upon proper heat treatment—that, surprisingly enough, occasions the undersirable welding qualities in the cast metal.

Test sections were taken from a number of centrifugally cast tubes in the regions of weld. Exhaustive tests were thereupon made in an effort to determine whether weldability varied from casting to casting. In this connection, actual weld specimens were made up and thereupon tested in three conditions; first, as received; next, when re-annealed at 1900° F.; and thirdly, upon re-annealing at 1200° F. for a period of four hours. All such specimens however, displayed underbead cracking. Illustrative of this are the microscopic fissures disclosed in Figure 3, and which were found in the cast metal adjacent the weld. And while the degree of cracking was not so severe as in some cases, and while a careful metallographic examination was required to detect this defect, it was determined authoritatively that this lesser degree of cracking was properly attributable to the lower stresses in the simple bead-on-plate type specimens which were employed. They could not properly be regarded as comprising any tangible improvement in weldability.

Further tests on a centrifugally cast tube, which incidentally had six inches exterior diameter and which is shown in Figure 4, disclosed that upon welding, circumferential cracks appeared in the tube wall near the internal welded baffle plate. By metallographic examination of sections taken from the cracked portion of the tube, we demonstrated that the cracking had initiated at the root of the weld joint where the now-familiar intergranular cracking was present in the base metal heat-affected zone. In most such welding operations, and to avoid contamination of either the alloy metal or the base metal in the region of the weld by tramp elements, the welding rod employed was formed from the 17–4 PH heat.

Now, in some such instances, we observed that in the region of the fissures there were copper-colored pools of small size, and comprising an unidentified phase in the microstructure of the 17–4 PH cast material. And it appeared that the cracking initiated at these pools. Some of the test specimens heretofore referred to, however, appeared under the microscope to be free of these small pools of copper-colored phase. And we were inclined to the conclusion from specimens containing only the early stage of cracking, that no clear-cut relationship existed between the copper-colored pools on the one hand and the undesirable and detrimental intergranular cracks, on the other hand.

We have found, however, that if the copper content of the alloy is maintained at a value ranging up to a maximum critical value of 3% by weight, the resulting alloys may be arc-welded in the as-cast condition without encountering the undesirable underbead defect heretofore harassing all attempts to weld 17–4 PH steels in cast form. And our investigations amply demonstrated that when the copper content is maintained at the critical value between 1% and 3%, more especially between approximately 2.0% and 3.0% and particularly about 2.5% to about 3.0%, these new steels can be cast and thereafter successfully welded, while maintaining substantially unimpaired the desirable physical qualities imparted to the products through precipitation-hardening techniques. Our stainless steel castings consist essentially of 15.0% to 18.5% chromium, 2.8% to 5.6% nickel, 1% to 3% copper, carbon not exceeding 0.12%, and remainder substantially all iron. Preferably, our castings consist essentially of 15.0% chromium, or even 16.0% to 17.0% chromium, with 3% to 4% nickel, although this may amount to 2.8% to 5.6% as previously noted, with copper 2% to 3% and remainder iron. In general the carbon content preferably is 0.07% maximum.

Strongly supporting and bearing out our conclusions, we

conducted tests, the basis of which and the results therefrom observed being listed in the following Table I:

TABLE I

Chemical analyses of materials

No.	Description	C	Mn	P	S	Si	Cr	Ni	Cu	Al
1	9" Cent. Cast Tube Cross Section	.038	.59	.016	.024	.52	15.17	5.97	3.87	.12
	Inside Surface			.016	.022				3.66	
	Outside Surface			.018	.026				3.50	
2	8" Cent. Cast Tube Cross Section	.021	.50	.020	.020	.28	16.30	4.32	3.98	.004
	(By W. B. Coleman)	.034	.50	.018	.013	.28	216.41	4.41	4.03	.10
3	Port Openings from Centrifugal Cast Tubes.									.003
4										.003
5										.003
6										.003
7	6" Cent. Cast Tube Cross Section	.030	.56	.021	.013	.40	16.66	4.34	3.58	.01
	(By U. S. Pipe & Fdry.)	.022	.58	.011		.61	16.12	3.99	3.84	
8	Induction-melted 2½" Square Ingots	.064	.69	.018	.016	.35	15.80	4.32	2.56	
9		.065	.67	.019	.017		15.80		2.98	
10		.057	.59	.019	.016	.40	15.76	4.35	3.50	
11		.058	.58	.019	.016		15.84		3.98	

In these tests, which were conducted in the background of the consistently poor weldability displayed by the centrifugally cast 17–4 PH material even after it was subsequently subjected to extensive annealing treatments, we investigated the influence which the copper content of the alloy might have on the welding characteristics of this metal when in cast form. To this end, we cast in the laboratories four induction-melted 17–4 PH ingots, each 2½ inches square, and weighing ten pounds. The copper contents of these ingots (see Table I for detailed initial data) were respectively 2.5, 3.0, 3.5, and 4.0%, the ingots being identified in Table I as samples Nos. 8 through 11, inclusive.

In the course of our experiments, we split the ingots longitudinally, as by saw-cutting, thereby obtaining test specimens for weld-testing which were of convenient size, and also providing two simple yet different types of weld-test specimens. The ingot itself is shown in Figure 5, and the weld-test specimens are shown in Figures 6 and 7, respectively. And these test specimens were provided for each composition.

While considering the foregoing, it is to be kept in mind

that the quality of precipitation-hardenability is a most important feature. Accordingly, we made Rockwell hardness tests on these specimens both in the pre-cast condition, and also following the annealing and precipitation-hardening heat treatments. Data concerning the mechanical properties and weld-cast results are given in the following Table II:

TABLE II

Properties of induction-melted ingots 17–4 PH containing progressive variations in copper content

Ingot No.	Copper Content, percent	Condition [1]	Mechanical Properties [2]				
			Ult. Tens. Str., p. s. i.	.2% Yld. Str., p. s. i.	Elong., percent in 2"	Red. in Area	Rockwell Hardness
1*	2.5	As-Cast					38-C
		C+Hardened					40-C
		Annealed					33-C
		Ann.+Hard	188,000	145,000	10	35	41-C
2*	3.0	As-Cast					38-C
		C+Hardened					41-C
		Annealed					33-C
		Ann.+Hard	188,000	155,000	10	42	41-C
3*	3.5	As-Cast					39-C
		C+Hardened					42-C
		Annealed					32-C
		Ann.+Hard	188,000	175,000	10	45	43-C
4*	4.0	As-Cast					41-C
		C+Hardened					41-C
		Annealed					33-C
		Ann.+Hard	187,000	153,000	10	39	42-C

Weld test results [3]:
1* Bead-on-plate, no cracking; boss-on-plate, no cracking.
2* Bead-on-plate, no cracking; boss-on-plate, no cracking.
3* Bead-on-plate, toe crack and underbead cracking; boss-on-plate, toe and underbead cracking.
4* Bead-on-plate, underhead cracking; boss-on-plate, toe and underbead cracking.

[1] Condition: Annealing treatment, 1900° F–1 hr.-oil quench-hardening treatment, 900° F–1 hr. air cool.

[2] Mechanical properties: Tensile values obtained from a single sub-size specimen .250" diameter round x 2" gage length.

[3] Weld test results: Details of bead-on-plate weld test and boss on plate weld test are presented in Figure 5. Extent of cracking determined by both microscopic examination of surface at weld area and metallographic examination. Weld tests conducted only in as-cast condition.

The data of Table II amply evidences a marked decrease in susceptibility of the cast 17–4 PH alloy to hot-cracking in the base metal heat-affected zone with a lowering of the copper content. And illustratively, the samples containing 3.0% and 2.5% copper displayed no tendency to form either toe-cracks or underbead cracks in the cast base metal adjacent to and in the region of the weld. Additionally we find that the hardness and tensile properties of the alloy do not vary in significant manner with the changes in copper content within the limits noted.

So successful were the initial experiments that we conducted further experiments, attended by most favorable and satisfactory results. Thus we made up five 25 pound induction-melted ingots of 17–4 PH analysis, with copper content respectively analyzing 3.0%, 2.68%, 2.16%, 1.70%, and 1.09%. We cast these

melts in ingots of three inches by three inches cross-section. The complete analysis of these heats forms the subject of Table III.

TABLE III

Chemical analysis of 17–4 PH induction melted ingots with progressive variations in the copper content

MELTING SPECIFICATION FOR ARMCO 17-4 PH

C	Mn	P	S	Si	Cr	Ni	Cu
.05 max.	.70 max.	.04 max.	.03 max.	.70 max.	16.00/17.00	3.00/4.00	3.25/4.00

CHEMICAL ANALYSES

Heat No.	C	Mn	P	S	Si	Cr	Ni	Cu
E7886-2								3.98
E7886-1	.057	.59	.019	.016	.40	15.76	4.35	3.50
E7879-2								2.98
E7879-1	.064	.69	.018	.016	.35	15.80	4.32	2.56
E8030	.041	.77	.017	.011	.47	16.35	4.00	3.10
E8033	.044					16.09	4.07	2.68
E8038	.041					16.36	4.07	2.16
E8039	.039					16.51	4.06	1.70
E8046	.040					16.09	4.10	1.09

In Table II there are, for comparative purposes, certain analytical data from specimens **8** to **11** of Table I.

The ingots analyzed according to Table III were sectioned in the manner illustrated in Figures 5 and 8, this to permit preparation of specimens suitable for tensile, hardness and welding tests. The mechanical test data obtained, including full weld data, is given in Table IV.

In the course of our research we conducted the weld tests with a boss-on-plate specimen, of which Figure 7 is illustrative. The welded joint was thereafter sectioned and examined metallographically for cracking. It appears from Table IV that where the copper content was in excess of 3.0%, both toe- and under-bead cracking was encountered in the boss-on-plate tests, while under-bead cracking was observed in bead-on-plate tests. This was true for both 3.50% and 3.98% copper contents, toe-cracking also being observed for those specimens having 3.50% copper. Quite on the contrary, no cracking was observed in specimens having 3% or less copper.

Thus, in brief summary, cast ingots of 17% chromium, and 4% nickel stainless steels were made up having a copper range from 1.0 to 4.0%. And these ingots were subjected to a simple, yet highly restrained welding test. In the course of these tests it was observed that ingot material containing 3.50 and 3.98% copper, respectively, i. e. above 3% copper, displayed underbead cracking. On the contrary, all material having less than 3% copper disclosed no evidence of cracking. This figure is highly critical. And although the optimum mechanical properties are obtained when the copper content is within 3.25 to 4.0% nevertheless our alloy possesses in large measure the same useful mechanical properties observed in the 17–4 PH material while vastly improving the welding properties of this alloy. This is illustrated in Figure 9.

For the first time, therefore, we achieve weldable, precipitation-hardenable stainless steel castings. We provide precipitation-hardened castings of good welding

TABLE IV

Properties of 17–4 PH induction melted ingots containing progressive variations in copper content

Heat No.	Copper Content, Percent	Condition (1)	Specimen Size	Mechanical Properties				
				U. T. S., p. s. i.	.2% Y.S., p. s. i.	El. in 2", Percent	R. A., Percent	Rockwell Hardness
E7886-2* [1]	3.98	A						C38
		B						C40
		C						C33
		D	.250" ϕ	187,000	153,000	10.0	39.0	C41
E7886-1* [2]	3.50	A						C39
		B						C42
		C						C32
		D	.250" ϕ	188,000	175,000	10.0	45.0	C43
E7879-2* [3]	2.98	A						C38
		B						C41
		C						C33
		D	.250" ϕ	188,000	155,000	10.0	42.0	C41
E7879-1* [4]	2.56	A						C38
		B						C40
		C						C33
		D	.250" ϕ	188,000	145,000	10.0	35.0	C41
E8030* [5]	3.10	A						
		C						C32.5
		D	.505" ϕ	184,500	161,400	12.0	24.9	C42.0
		D	.505" ϕ	188,300	163,800	10.0	20.2	
E8033* [6]	2.68	A						
		C						C32.0
		D	.505" ϕ	191,700	166,100	10.0	26.0	C41.5
		D	.505" ϕ	189,500	166,400	11.0	28.9	
E8038* [7]	2.16	A						
		C						C32.0
		D	.505" ϕ	182,000	157,300	8.0	21.3	C40.5
		D	.505" ϕ	183,000	157,400	10.0	23.2	
E8039* [8]	1.70	A						
		C						C32.0
		D	.505" ϕ	173,600	145,900	10.0	23.7	C39.5
		D	.505" ϕ	173,400	147,900	12.0	25.2	
E8046* [9]	1.09	A						
		C						C36.0
		D	.505" ϕ	174,800	143,400	13.0	32.5	C39.0
		D	.505"	174,300	144,900	12.0	27.5	

*Weld Test Results:
[1] Bead-on-plate, underbead; boss-on-plate, toe and underbead cracking.
[2] Bead-on-plate, toe crack and underbead cracking; boss-on-plate, toe and underbead cracking.
[3] Bead-on-plate, no cracking; boss-on-plate, no cracking.
[4] Bead-on-plate, no cracking; boss-on-plate, no cracking.
[5] Bead-on-plate, boss-on-plate, no cracking.
[6] Bead-on-plate; boss-on-plate, no cracking.
[7] Bead-on-plate; boss-on-plate, no cracking.
[8] Bead-on-plate; boss-on-plate, no cracking.
[9] Bead-on-plate; boss-on-plate, no cracking.

(1) Condition: A—as cast; B—as cast + 900° 1 hr. air cool; C—as cast + 1900° 1 hr. oil quench; D—as cast + 1900° 1 hr. oil quench + 900° 1 hr. air cool.

characteristics and great strength and hardness. And this is true for both still and centrifugal castings. The resulting castings display physical properties, including those of precipitation-hardening, Rockwell hardness, ultimate tensile strength, 0.2% yield strength and percent elongation in 2 inch specimens substantially corresponding to material of much higher copper contents, yet welding qualities are vastly improved and underbead bracking is effectively avoided.

All the foregoing, as well as many other highly practical advantages attend the practice of our invention.

For reasons which are obvious, we intend the foregoing disclosure to be considered as merely illustrative, and as comprising no form of limitation.

We claim as our invention:

1. Stainless steel castings possessing precipitation-hardening and good welding characteristics consisting essentially of about 15.0% to 18.5% chromium, carbon not exceeding about 0.12%, about 2.8% to 5.6% nickel, about 1% to 3% copper, and remainder iron.

2. Precipitation-hardened welded castings consisting essentially of about 16.0% to 17.0% chromium, about 3% to 4% nickel, about 2.0% to 3.0% copper, and carbon not exceeding 0.12%, and remainder iron.

3. Precipitation-hardened welded castings consisting essentially of about 16% chromium, carbon not exceeding about 0.07%, 4% nickel, about 2% to 3% copper, and remainder iron.

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