

[54] **COPPER-NICKEL ALLOYS OF HIGH-YIELD STRENGTH**

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[56]

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[57]

ABSTRACT

Corrosion-resistant, cast (and wrought) copper-nickel alloys containing special amounts of nickel, chromium and silicon are characterized by high-yield strengths—e.g., from about 40,000 and upwards of 50,000 p.s.i. This compares with substantially less than 40,000 p.s.i. for conventional copper-nickel alloys in commercial use. Heat treatment not required to develop strength; thus, associated problems are obviated.

15 Claims, 2 Drawing Figures

Fig. 1.

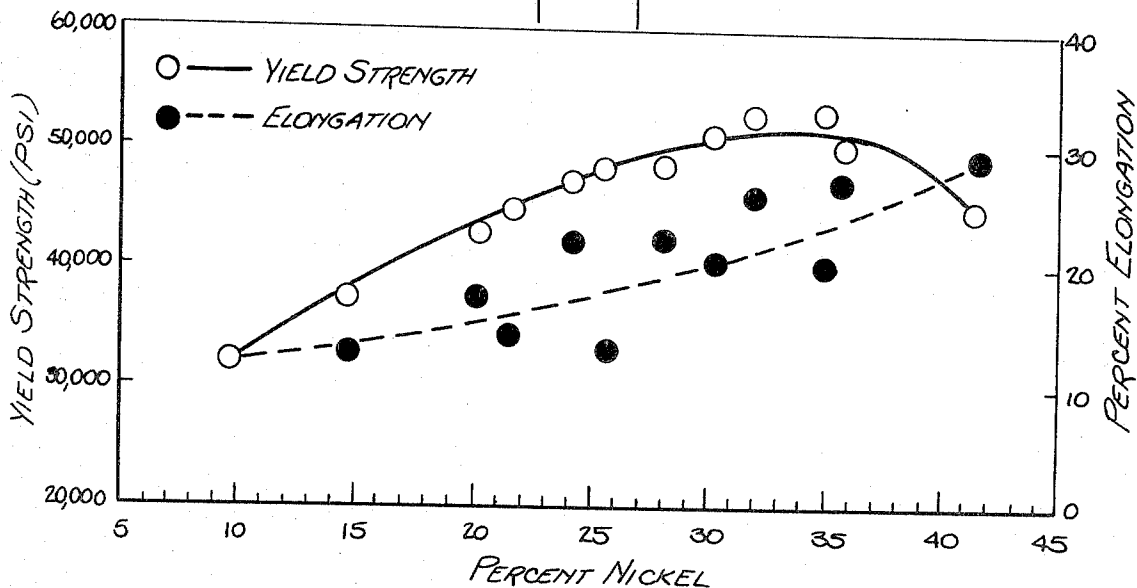
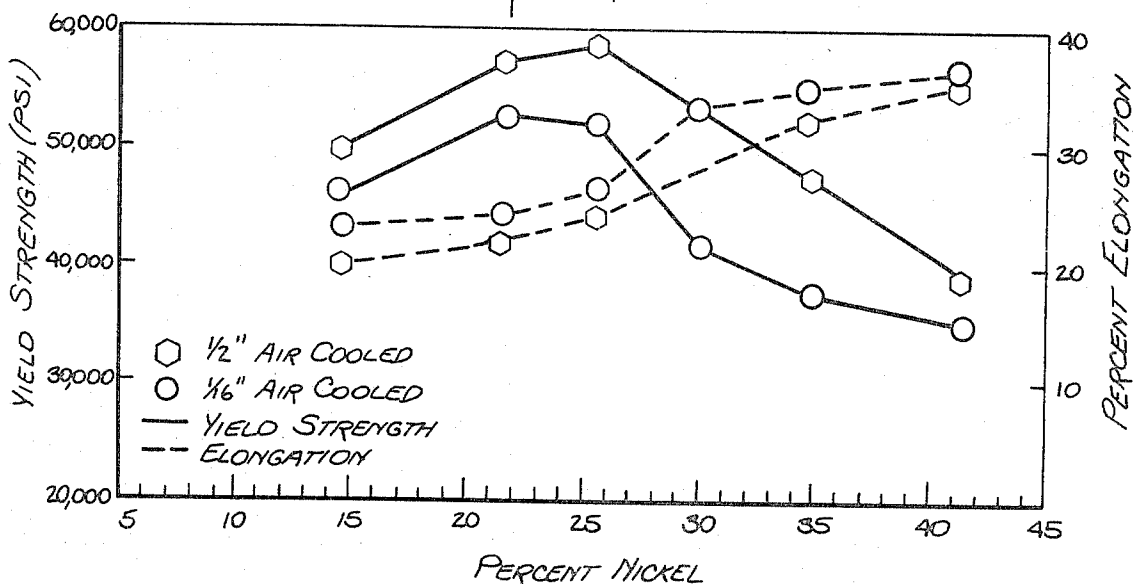


Fig. 2.



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COPPER-NICKEL ALLOYS OF HIGH-YIELD STRENGTH

Cast copper-nickel alloys by virtue of their excellent resistance to the corrosive effects of salt water, good weldability, adequate ductility, etc., have found extensive application in marine environments for a most considerable number of years. Propellers, impellers, housings, flanges, elbows, tees, etc., are illustrative of such cast articles, articles which find constant use. Commonly termed "cupronickels," these alloys have served well but labor under the drawback of affording but limited yield strengths, about 15,000-18,000 p.s.i. being typical. There is one cast alloy of higher yield strength, about 30,000 p.s.i., but it is of the heat treatable type and suffers from other drawbacks, e.g., it is section size sensitive. Thus, under operating conditions which by necessity demand higher strength materials, currently available cast copper-nickel alloys are, of course, unsuitable. Accordingly, the present invention is addressed primarily to the specific objective of boosting this strength plateau to as high as 50,000 p.s.i., but doing so while maintaining an acceptable level of other desirable properties for which the conventional cast cupronickels are noted.

Incident to the subject development, one of the approaches initially pursued was the recent technological advance brought about in respect of the "wrought" copper-nickel alloys of the 70/30 type as described in an article authored by F. A. Badia, G. N. Kirby and S. R. Mihalsin, Transactions of the ASM, Vol. 60, pp. 395-408 (1967). Incorporation of chromium in amounts from about 2.4 to 3.8 percent was found upon simple air cooling to result in a most substantial yield strength increase in respect of the standard wrought alloys—from a chromium-free level of about 18,000 p.s.i. to over 40,000 p.s.i. for alloys at the lower end of the chromium range and to over 50,000 p.s.i. for alloys of higher chromium. Yield strength aside, this prior development offered other significant commercial advantages. For example, age hardening (as theretofore elsewhere proposed) was not required. And, elimination of heat treatment is particularly beneficial in respect of welded structures for reasons too well documented to dwell upon herein. But it should be at least pointed out that to heat treat substantial size castings is impossible at times and usually difficult at best. Thus, problems attendant such heat treatments were avoided—the alloys being—so to speak—self-dispositive.

It soon became apparent, however, that what seemed to be the answer for the "wrought" alloys was not the panacea for the cast versions. Cast copper-nickel alloys containing, say, 3 percent chromium, were objectionable for various reasons, including the fact that they were characterized by poor fluidity and microporosity. Too, though not all applications require cast alloys which are weldable, at the 3 percent chromium level weld cracking was experienced virtually every time. And at lower percentages of chromium, weld cracking too often occurred to remove the serious concern and uncertainty as to whether a given cast alloy would be weld-safe.

In any event, it has now been discovered that cast copper-nickel alloys of exceptionally high yield strength can be obtained provided the alloys are of special composition, particularly with regard to chromium and silicon, and also nickel, as detailed herein. These alloys are devoid of detrimental second phases and microporosity, exhibit good fluidity, afford satisfactory ductility and toughness, do not require hardening heat treatments and if a proper amount of zirconium is present, are readily weldable. Moreover, the high level of yield strength, 40,000 p.s.i. and above, consistently obtains throughout a relatively wide range of cast section sizes, e.g., one-half to 2 inches in thickness. Thus, alloy strength is insensitive to section size, an excellent attribute of any cast alloy. In addition, it is particularly noteworthy that as an attendant feature of the overall invention and as a direct consequence of the research conducted in respect of the cast alloys, a new group of high strength "wrought" cupronickels also evolved as will be described herein.

It is an object of the present invention to provide high strength, cast copper-nickel alloys.

The invention also contemplates providing corrosion-resistant, weldable, copper-nickel alloys in both the cast and wrought forms possessing yield strengths in excess of about 40,000 and as high as 50,000 p.s.i. or more, the alloys also being characterized by satisfactory ductility, toughness, etc.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawing in which:

FIGS. 1 and 2 depict curves illustrating the effect of nickel content on yield strength and tensile elongation of cast and wrought copper-nickel-chromium-silicon alloys, respectively.

Generally speaking and in accordance herewith, the present invention contemplates high strength copper-nickel alloys containing (in percent by weight) about 9 percent or 10 to 38 percent nickel, with the proviso that the nickel content is (a) at least 20 percent, and most advantageously at least 28 percent, for cast alloys, but (b) does not exceed 30 percent, and most beneficially is not in excess of 27 percent, for alloys in wrought form, about 1 to 2.1 percent chromium, about 0.2 to 0.6 percent silicon, up to 0.8 percent zirconium, up to 3 percent manganese, up to 0.5 percent titanium, and the balance essentially copper. In applications requiring cast alloys to be welded, the alloys should contain about 0.05 percent zirconium or more. In addition, up to 5 percent cobalt, up to 1 percent columbium, up to 0.5 percent aluminum, up to 2 percent tin and up to 2 percent zinc can be present. Small amounts of carbon can be tolerated. However, constituents such as bismuth, lead, selenium, tellurium, sulfur, nitrogen, hydrogen, etc., should be maintained at low levels consistent with good processing practice. Too, the use of calcium for deoxidation purposes is not recommended since it tends to detract from ductility and impact resistance, and has brought about heat affected zone (HAZ) cracking upon welding.

The respective roles of chromium and silicon apparently involve an interplay therebetween, a coaction or cooperative effect which is thought to produce a synergistic result. By way of background in understanding this aspect, the authors of the ASM article mentioned herein established that copper-nickel alloys (1/16-inch sheet) of the 70/30 type and which contained but 1.2 percent chromium exhibited a low yield strength of 29,400 p.s.i. upon air cooling. It was not until an amount of chromium above about 2.5 percent was used that a yield strength on the order of 50,000 p.s.i. was achieved. To be sure, alloys subjected to a vermiculite cool offered higher strength at corresponding chromium levels but, as will be appreciated by those skilled in the art, such cooling methods are highly undesirable and, in a commercial sense, quite impractical.

In the same treatise the authors further reflect that attempts were made to use supplemental elements in an endeavor to attain still higher strengths. Silicon was one of such auxiliary constituents but it was not found to impart any appreciable benefit, a point since confirmed as will be shown by data herein.

In accordance with the present invention, however, a contra effect is seemingly involved. With substantially lower chromium contents and provided silicon is present in an amount of at least 0.2 to 0.6 percent, high yield strengths are readily achieved. In this connection, when chromium is at the lower end of its range, say from 1 to 1.25 percent, a minimum silicon content of at least 0.35 percent is most advantageous in reaching the highest yield strength. Conversely, when the silicon content is from about 0.2 percent to about 0.35 or 0.4 percent, the minimum chromium content should be about 1.4 percent. For cast alloys, chromium levels above about 1.7 percent do not offer any appreciable benefit in strength, a range of 1 or 1.2 to 1.7 percent being highly satisfactory for both cast and wrought alloys. While in some instances the silicon content may be as high as 0.7 percent, it is deemed beneficial that the silicon content not exceed 0.6 percent to thereby minimize the possibility of weldability difficulties.

The amount of nickel present must be controlled depending upon whether a cast or wrought alloy is desired. The nickel

content should not be less than 20 percent for cast alloys; otherwise, unacceptably low yield strengths can result. It is considerably significant that the nickel content be at least 28 percent for castings since it has been determined that in cast alloys nickel imparts its maximum strengthening effect over a range of about 28 to 35 percent. Moreover, within this latter nickel range the alloys are more ductile, notwithstanding they concurrently exhibit greater strength. This is in contrast to usual metallurgical behavior in which increases in strength are attained at the expense of ductility. The effect of nickel in respect of cast alloys as to strength and ductility is graphically depicted by the curves in FIG. 1. These curves are based on a

was used. On ladling, the alloys tend to form a relatively heavy skin. To offset this, the use of a baffled ladle (teapot) is recommended since it simulates bottom pouring and minimizes interference from this surface skin.

Testing consisted of a determination of tensile properties, duplicate 0.252-inch diameter tensile bars being used. The compositions, yield and tensile strengths and tensile elongation are given in table I. [Included in table I are wrought alloys D, E and G taken from the ASM Transactions' article (alloys 7, 8 and 3) referred to above herein.] Alloys identified by numerals are within the scope of the cast alloys of the invention whereas those preceded by a letter are not.

TABLE I

Alloy	Percent							P.s.i.		El., percent
	Ni	Cr	Si	Mn	Fe	Zr	Cu	Y.S.	U.T.S.	
A	30.6	<0.1	<0.03	0.3	0.9	N.A.	Balance	14,500	48,200	44
B	31.1	<0.1	0.34	0.6	0.7	N.A.	do	17,900	50,800	47
C	31.3	<0.1	0.34	0.15	0.55	.13	do	18,500	50,400	39
D	29.5	3.15	0.15	0.66	0.73		do	56,000	89,900	26
E	30.3	3.55	0.34	0.70	0.94		do	57,900	92,900	26
F	30.4	3.25	0.48	0.7	<0.1	N.A.	do	51,600	78,900	21
G	31.8	1.20	0.07	0.5	0.68		do	29,400	69,300	35
H	14.8	1.37	0.45	(0.4)	(0.7)	.10	do	37,100	59,000	13
J	21.4	1.65	0.04	0.41	0.70	N.A.	do	32,700	58,000	29
1	30.7	1.25	0.36	0.5	0.9	N.A.	do	50,100	79,000	27
2	30.1	1.55	0.52	0.7	0.1	N.A.	do	54,200	83,700	27
3	31.6	1.95	0.44	0.7	0.1	N.A.	do	50,300	77,600	25
4	30.0	2.00	0.51	0.8	0.4	N.A.	do	50,600	79,100	24
5	21.7	1.47	0.45	0.42	0.69	.11	do	44,800	67,800	14
6	25.7	1.50	0.45	(0.4)	(0.7)	.10	do	48,200	71,500	13
7	35.0	1.60	0.47	(0.4)	(0.7)	.10	do	52,900	81,600	20
K	41.6	1.50	0.50	0.42	0.69	.11	do	45,000	75,000	29

NOTES.—N.A.=None added. Balance=Balance of composition essentially copper and impurities. Figs. in parentheses=Nominal.

group of alloys in which the constituents, apart from nickel, were maintained over the following narrow ranges of composition: 1.37 to 1.6 percent chromium, 0.35 to 0.6 percent silicon, 0.4 to 0.54 percent manganese, to 0.69 to 0.9 percent (nominal) iron, balance copper and impurities.

The role of nickel in the wrought alloys is in marked contrast with its function in the cast versions. As is illustrated in FIG. 2, nickel confers its strongest influence with respect to strength over the range of about 18 percent or 19 to 27 percent. As can be seen from the curves, a loss of strength is experienced with nickel contents above about 27 percent in the wrought alloys. This nickel role not only differs from its mode of behavior in the cast alloys but is also quite different from that role portrayed in the high-chromium alloys discussed in the ASM article referred to above herein. In the case of these latter alloys, a minimum nickel content of 28 or 30 percent was much preferred for best overall properties, including strength. That this is not the case with the subject alloys is clear from FIG. 2, which also indicates that ductility does not diminish as the strength is increased by higher nickel levels. As with the cast compositions, ductility also increases. The curves in FIG. 2 are based on alloys containing, in addition to the varied nickel content, 1.37 to 1.5 percent chromium, 0.45 to 0.5 percent silicon, 0.4 to 0.42 percent manganese, about 0.7 percent iron, with the remainder being copper and impurities.

For the purpose of giving those skilled in the art a better appreciation of the invention, the following illustrative data are given.

Using a high-frequency induction furnace and magnesia crucible, a series of cast copper-nickel alloys were prepared in which electrolytic copper, electrolytic nickel, electrolytic iron and remelt stock were used as a basic charge. Upon forming a melt, 0.05 percent silicon was introduced as a preliminary deoxidation step and to minimize subsequent loss of more reactive metals. At a temperature of about 2,500° F. manganese (electrolytic or ferroalloy), chromium (vacuum grade or as a Ni-50 percent Cr master alloy) and silicon were added. Upon reaching a temperature of about 2,550° F. a final deoxidant, usually 0.05 percent titanium, was plunged into the bath and thereafter the melts were poured into a ladle and then into dry sand molds. A single keel block pattern ($\frac{3}{4}'' \times 6\frac{3}{4}'' \times 10''$)

In respect of the data in table I, alloy A is representative of a conventional cast cupronickel alloy, the yield strength thereof being at a low 14,500 p.s.i. Increasing the silicon content to an amount within the invention, to wit, 0.34 percent, (alloys B and C) did not impart any appreciable strengthening effect to conventional alloy A. This is consistent with prior art findings, although it is to be understood that such findings also reflect that considerably higher silicon contents do confer high strength in cast cupronickels (T. E. Kihlgren, Trans. Amer. Foundrymen's Assn., Vol. XLV, pp. 225-260, 1937). For example, yield strengths of 50,000 p.s.i. have been reached in respect of standard alloys but with silicon levels of about 0.75 percent or more, silicon percentages at which welding difficulties tend to ensue.

Alloys D and E (alloys taken from the ASM treatise) reflect that in wrought high-chromium cupronickels (3-3.5 percent chromium) increasing the silicon content from 0.15 percent (alloy D) to 0.34 percent (alloy E) did not result in any significant increase in yield strength. Using alloys D and E as a basis of general comparison, cast alloy F of high chromium content also shows this same type of behavior. Alloy H is indicative of the fact that raising the chromium level to 1.2 percent in wrought low-silicon alloys leaves much to be desired by way of strength. With respect to alloys H and J, the former illustrates that for cast alloys nickel contents on the order of about 14.8 percent fail to afford a minimum yield strength of 40,000 p.s.i., irrespective of the fact that both the chromium and silicon levels are otherwise well within the subject invention. Alloy J demonstrates that though the percentages of nickel and chromium be within the scope of the invention low yield strengths still obtain in the presence of silicon contents appreciably below about 0.2 percent.

In contrast to alloys A through J, it will be observed that the alloys within the invention, alloys 1-7, all afford a minimum yield strength of at least 40,000 p.s.i., in many instances at least 50,000 p.s.i., together with a good tensile elongation. Alloy 1 manifested the ability to absorb approximately 75 foot pounds (average of three tests) of impact energy (C.V.N.) at room temperature. It might be mentioned that alloy K is included to show that beyond a nickel percentage of about 38 percent yield strength drops with increased nickel content.

With regard as to what might be expected concerning consistency of strength over a fairly wide range of section size, in table II shown below there are data given for alloys both outside the invention (alloys M, N and O) and alloy 8, an alloy within the invention. These data show that alloys meeting the compositional requirements of the invention are relatively insensitive to section size as opposed to the considerable variance experienced with those alloys the chemistry of which departs from the invention as in the case of alloys M and N (low silicon) and alloy O (low chromium). The data are based upon 1/2-inch and 2-inch thick wedges approximately 7 inches in length. Machined tensile specimens were obtained from the middle of each cast plate for purposes of comparison. Apart from the chemistry given in table II, alloy No. 8 contained 0.20 percent zirconium and each of the alloys contained titanium in an amount up to about 0.1 percent; otherwise, the balance of the compositions was copper plus impurities.

higher ductility would be required up to 27 percent or 28 percent nickel can be used while still retaining a very high strength plateau. It should be pointed out that whereas alloy H represents a composition outside the present invention for cast alloys it is nonetheless within the wrought alloy compositions contemplated. The converse is true with respect to alloy 7 for, as can be seen, the strength level has dropped below the 40,000 p.s.i. minimum. This downtrend continues at higher percentages of nickel as evident from alloy K and FIG. 2. While, as indicated before herein, there are numerous applications in which cupronickel castings are not welded, there are nonetheless substantial areas of utility in which weldability becomes of paramount significance. In accordance herewith, provided the cast alloys contain zirconium in an amount of about 0.05 Percent or higher, satisfactory weldability characteristics follow. This is illustrated by the following examples and data.

TABLE II

Alloy	Percent					Cast Section, inches	P.s.i.			El. percent
	Ni	Cr	Si	Fe	Mn.		Y.S.	U.T.S.		
M.....	34.4	1.65	0.04	0.76	0.40	1/2	32,700	64,800	27	
							2	41,300	70,100	21
N.....	29.5	1.70	0.04	0.74	0.42	1/2	39,300	61,300	15	
							2	42,000	69,200	19
8.....	29.6	1.55	0.27	0.76	0.51	1/2	47,700	77,800	29	
							2	48,800	76,800	24
O.....	30.6	0.80	0.31	0.63	<0.1	1/2	33,300	64,800	26	
							2	43,700	72,700	25

With regard to wrought alloys contemplated herein, a series of specimens was prepared in the manner described in connection with the alloys in table I. Thereafter, the cast ingots were soaked at a temperature of about 1,900° F. for 1 hour, hot-rolled down to a 1/4-inch thickness, air-cooled, cold-rolled to one-eighth inch thick, annealed for 1 hour at 1,700° F., air-cooled, cold-rolled to 1/16-inch strip, and finally annealed at a temperature of approximately 1,700° F. for 1 hour followed once again by air cooling. To simulate the cooling rate to be expected in respect of 1/2-inch plate, a second group of specimens involved inserting a 1/16-inch piece of strip between two 1/4-inch pieces which were then bolted together. This sandwich structure was then annealed at 1,700° F. for 1 hour and air cooled to room temperature. The 1/16-inch strip was removed and tensile tested, the results being reported under the caption—1/2" Air Cool—in table III together with the results of the first series (one-sixteenth inch) of specimens. (Alloys 9 and 10 contained 0.1 percent and 0.02 percent zirconium, respectively, the other alloys containing zirconium in amounts given in table I. Each of the alloys contained up to 0.1 percent titanium).

EXAMPLE I
A copper-nickel casting containing about 28.7 percent nickel, 1.37 percent chromium, 0.39 percent silicon, 0.36 percent manganese, 0.60 percent iron, 0.02 percent titanium, and the balance essentially copper, no zirconium having been added, was subjected to an autogenous TIG bead welding test. This is employed more as a screening test and involves running a bead on the surface of a plate specimen using a tungsten inert electrode. In the instant case, a travel speed of about 16 inches per minute was used, the shielding gas being argon supplied at a volume of 25 cubic feet per hour. A 1/4-inch tungsten electrode was employed, the arc length being about 0.05 inch. The bead surface was ground, etched, and then examined at a magnification of about 10 to 30. A crack was found in the weld joint with several cracks being found in the heat affected zone (HAZ). This evidence reflected that the weldability characteristics of the alloy would not be satisfactory for applications requiring weldable castings, (particularly since the conditions of the TIG bead procedure are not at all severe) although the alloy would be suitable for cast articles which were not to be welded.

TABLE III

Alloy	Percent					1/16" air cool			1/2" air cool		
	Ni	Cr	Si	Fe	Mn	Y.S., K s.i.	U.T.S., K s.i.	El. percent	Y.S., K s.i.	U.T.S., K s.i.	El. percent
9.....	9.6	1.02	0.60	(0.7)	(0.4)	41.9	64.1	17	50.1	70	16
II.....	14.8	1.37	0.45	(0.7)	(0.4)	46.6	68.8	24	49.5	70.6	21
						46.5	68.5	23	50.1	69.6	20
5.....	21.7	1.47	0.45	0.69	0.42	52.3	78.4	24	57.2	80.1	22
						52.7	79.1	25	57.2	79.4	23
6.....	25.7	1.50	0.45	(0.7)	(0.4)	51.8	83.3	26	58.7	88.7	24
						51.7	83.1	28	58.2	88.6	24
10.....	30.3	1.63	0.39	0.89	0.41	41.5	77.2	33			
						40.8	76.3	33			
7.....	35.0	1.50	0.47	(0.7)	(0.4)	37.7	74.9	35	47.6	83.6	30
						37.4	74.6	33	46.6	82.4	35
K.....	41.6	1.50	0.50	0.69	0.44	34.0	73.0	36	39.1	77.0	36
						34.7	73.2	36	38.5	75.6	35

The data given in table III considered together with the curves in FIG. 2 reflect that excellent strength and combinations of strength and ductility are readily obtainable. Where strength is of paramount consideration a nickel range of from 17 to 23 percent is extremely satisfactory. Where a somewhat

EXAMPLE II

A cast plate of composition similar to that used in example I but to which zirconium was added was also subjected to the TIG bead test. The plate specimen contained about 29.0 percent nickel, 1.30 percent chromium, 0.37 percent silicon, 0.35

percent manganese, 0.06 percent iron, 0.03 percent titanium, and 0.03 percent zirconium, the balance being essentially copper. Again, a crack was found in the weld although no crack was found in the heat affected zone. Cast plates five-eighths inch in thickness by 2½ inches in width and about 4 inches long of the same alloy composition were butt welded. The plates were beveled along the 4 inches edge at an angle of about 30° and were placed upon a copper-faced steel platen, the distance therebetween being maintained at about one-sixteenth inch. The plates were restrained by clamping to the platen. A flux-covered electrode successfully employed in welding the previously developed high-chromium (2.4-3.8 percent) wrought cupronickels was used, the composition of the flux being as follows: 20 percent calcium carbonate, 20 percent chromylite, 19 percent manganese carbonate, 10 percent chromium, 19 percent titania 4 percent of a master nickel-silicon (28 percent silicon) alloy, 5 percent of a master nickel-titanium alloy (26 percent titanium) and 3 percent bentonite, with 15 percent sodium silicate solution having been added as a binder. The flux was baked on a core wire containing 31.8 percent nickel, 0.69 percent manganese, 0.60 percent iron, 0.10 percent silicon, 0.26 percent titanium, the balance being essentially copper.

Neither a preheat nor a post weld heat treatment was employed and the temperature between passes was below 200° F. Upon examination, no cracks were found in the weld or heat affected zone. This together with the TIG bead test indicated that a slightly higher zirconium content should be used, if the alloy were to be used in environments necessitating highly satisfactory weldable cast alloys.

EXAMPLE III

Both TIG bead and butt welding tests were conducted as in example II in respect of a cast plate(s) containing 0.06 percent zirconium, the balance of the composition consisting of about 29 percent nickel, 1.37 percent chromium, 0.39 percent silicon, 0.35 percent manganese, 0.60 percent iron, 0.03 percent titanium and with the remainder being essentially copper. No evidence of cracking was found in the weld joint or in the heat affected zone in either test.

While the foregoing demonstrates the value of zirconium as to weldability, the amount thereof should be controlled in cast alloys so as not to exceed, say, about 0.28 percent, since it has been determined that at least in cast alloys it detracts from toughness. This is illustrated by the data given in table IV.

TABLE IV

Alloy	Percent								C.V.N. (ft.-lbs.)
	Ni	Cr	Si	Mn	Fe	Ti	Zr	Cu	
11.....	28.7	1.37	0.39	0.36	0.60	0.02	N.A.	Balance...	60, 58, 57
12.....	29.0	1.30	0.37	0.35	0.60	0.03	0.03	do.....	61, 57, 52
13.....	29.0	1.37	0.39	0.35	0.60	0.03	0.06	do.....	72, 54, 46
14.....	28.7	1.40	0.36	0.35	0.61	0.04	0.06	do.....	50, 50, 43
15.....	30.1	1.78	0.55	0.40	0.80	-----	0.06	do.....	33, 36, 41
16.....	29.2	1.78	0.52	0.45	0.82	0.04	0.20	do.....	15.5, 16, 18
17.....	29.8	1.80	0.48	0.40	0.80	0.04	0.27	do.....	15, 15, 16.5

NOTE.—The compositions for Alloys 11, 12 and 13 are those given in Examples I, II and III, respectively. N.A.=Not added.

It is clear from the above data that relatively high zirconium levels impair the ability of the alloys to absorb impact energy. Accordingly, it is considerably advantageous to maintain the zirconium content such that it does not exceed 0.10 percent or 0.15 percent in cast alloys. For good workability and other benefits, zirconium should also be used in the wrought alloys in an amount of at least 0.01 percent or 0.02 percent.

As previously indicated herein the cast alloys can be used in such applications as propellers, impellers, housings, etc. With regard to the wrought alloys, salt water piping, heat exchangers, tube sheets, condensers, etc., are illustrative of various uses to which these alloys can be put. Of course, the wrought alloys can be produced in various mill forms, including strip, sheet, plate, bar, rod tubing, wire, extruded shapes, etc.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

We claim:

1. A copper-nickel base alloy characterized in having a yield strength of at least about 40,000 p.s.i. in both the cast and wrought conditions, the yield strength obtaining throughout the section sizes of from at least one-half inch to 2 inches in thickness, said alloy consisting essentially of from about 9 to 38 percent nickel, the nickel content being at least 20 percent in cast alloys but not in excess of 30 percent for alloys in the wrought condition, about 1 to 2.1 percent chromium, about 0.25 to 0.7 percent silicon, up to 0.8 percent zirconium, the zirconium not exceeding about 0.28 percent in cast alloys, up to 3 percent manganese, up to 0.5 percent titanium, up to 5 percent cobalt, up to 1 percent columbium, up to 0.5 percent aluminum, up to 2 percent tin, up to 2 percent zinc and the balance essentially copper, the silicon and chromium are correlated such that when the silicon content is from 0.2 percent to about 0.35 percent the chromium content is at least 1.4 percent and when the chromium is from 1 to 1.25 percent the silicon is at least about 0.35 percent.
2. An alloy in accordance with claim 1 in which the silicon content does not exceed about 0.6 percent.
3. An alloy in accordance with claim 2 in which the nickel content is at least 28 percent for cast alloys and not in excess of 27 percent for alloys in the wrought condition.
4. A cast alloy in accordance with claim 2 in which the nickel content is from 28 to 35 percent.
5. A cast alloy in accordance with claim 2 in which zirconium is present in an amount of at least about 0.05 percent, whereby weldability is enhanced.
6. A cast alloy in accordance with claim 5 having high resistance to impact by virtue of the fact that the zirconium content, if any, does not exceed 0.15 percent.
7. A cast alloy in accordance with claim 3 in which the chromium content does not exceed about 1.7 percent.
8. A cast alloy in accordance with claim 7 in which the chromium is at least 1.2 percent.
9. A wrought alloy in accordance with claim 2 in which the nickel content is from 19 to 27 percent.

10. A wrought alloy in accordance with claim 2 in which the nickel content is from 17 to 23 percent.
11. A wrought alloy in accordance with claim 3 in which the chromium content does not exceed about 1.7 percent.
12. A wrought alloy in accordance with claim 11 in which the chromium is at least 1.2 percent.
13. A wrought alloy in accordance with claim 12 in which the nickel content is from 19 to 27 percent.
14. A wrought alloy in accordance with claim 13 containing at least 0.01 percent zirconium.
15. As a new article of manufacture, a welded structure in which at least one welded component is formed from an alloy in accordance with claim 5.

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