Weldability Studies of Modified 70-30 CuNi Alloys

Varestraint tests, fabrication of actual weldments, and simulated weldability studies are performed on copper-nickel alloys modified by the addition of iron, beryllium, or chromium

BY PAUL W. HOLSBERG

ABSTRACT. The addition of either iron, beryllium, or chromium to 70-30 copper-nickel produces three high-strength modifications when properly heat treated. The weldability of these alloys has been investigated by use of simulated welding techniques, the Varestraint test, and fabrication of actual weldments.

The results of these studies indicate that cracking in the heat-affected zone will not be a problem for the iron and chromium modifications, but may be a problem in the beryllium modified alloy. Loss of strength would occur in the heat-affected zone of all three alloys in single pass welds.

Tests of multipass welds showed no loss of yield strength in the chromium modified alloy. A smaller loss than that occurring in single pass welds was noted for the multipass welds in the iron-modified alloy. No susceptibility to stress corrosion cracking in seawater was observed in the iron or chromium modifications in either the base metal or the simulated heat-affected zone.

Introduction

The inherent corrosion resistance and antifouling characteristics of 70-30 copper nickel (CuNi) alloy have led to satisfactory performance in many seawater applications. However, the low strength and high weight of the alloys leads to a significant weight penalty in weight critical applications.

Over the past several years, several manufacturers have been striving to develop new high-strength alloys based on the standard 70-30 CuNi alloy composition but modified by alloying additions and heat treatment. The alloys developed contain three different additions: iron, beryllium, and chromium. Each of these alloys is strengthened by a different mechanism. This paper presents the results of weldability tests which were performed on each of these modified alloys, together with the baseline results for standard 70-30 CuNi.

PAUL W. HOLSBERG is a Metallurgist with the Non-Ferrous Metallurgy Branch of the Navy Ship Research and Development Laboratory, Annapolis, Md.

Paper presented at the AWS National Fall Meeting held in Baltimore, Md. during Oct. 5-8, 1970.

Material

The chemical compositions of the alloys used in this investigation are presented in Table 1; the mechanical properties in the as-received condition are shown in Table 2.

Standard 70-30 CuNi (CA 715) is a single phase, solution hardened alloy. The alloy cannot be hardened by thermal treatments and can be strengthened only by cold work. Since strengthening due to cold work is lost during the heat of welding, the alloy is used in the annealed condition with a minimum yield strength of 18 ksi specified.[1]

The iron-modified alloy (CA 716) attains a yield strength of over 50 ksi. This strength is obtained by a complex thermal treatment consisting of annealing followed by a double stabilizing treatment. The manufacturer's treatment consisted of annealing one hour at 1515° F, water quenching, and stabilizing by holding one hour at 1110° F, furnace cooling to 930° F, holding 1 hr and air cooling. The alloy is not considered to be a precipitation hardenable alloy, as a second phase is not precipitated. Rather a continuous and periodic compositional variation appears throughout the structure.[2]

Yield strength on the order of 90 ksi is available in the beryllium-modified alloy (CA 717) by precipitation hardening.[3] Typically, the alloy is solution annealed for 1 hr at 1825° F, water quenched, and then aged for 3 hr at 950° F. The decreasing solubility of Be in CuNi with decreasing temperature permits this alloy to be precipitation hardened, with the 950° F aging treatment causing a complex copper-nickel-beryllide to form.[2] This alloy was supplied in the wrought form only as $^{1}/_{2}$ in. diameter extruded rod. Tests performed were

Table 1—Chemical Compositions of Modified 70–30 Cu Ni Alloys

Alloy	Designation	Ni	Fe	Be	Cr	Mn	Si	Ti	Zr	Pb	Zn
		Nominal chemical composition, wt-%									
70–30 Cu Ni	CA715[a]	30	0.5			1.00 Max				0.05 Max	1.00 Max
70–30 Cu Ni + Fe	CA716[a]	30	5.25			0.60					
70–30 Cu Ni + Be	CA717[a]	30	0.7	0.5							
70–30 Cu Ni + Cr	IN732[b]	30	0.10		2.8	0.7	0.1	0.05	0.15		

[a] Copper Development Association (CDA) designation.
[b] Producer's designation.

Table 2—Mechanical Properties of Modified 70–30 Cu Ni Alloys

Alloy	Designation	Tensile strength, ksi	Yield strength, ksi	Elongation in 2 in., %
		Typical mechanical properties		
70–30 Cu Ni	CA715	59	21	54
70–30 Cu Ni + Fe	CA716	89	50	44
70–30 Cu Ni + Be	CA717	130	89	12
70–30 Cu Ni + Cr	IN732	87	52	30

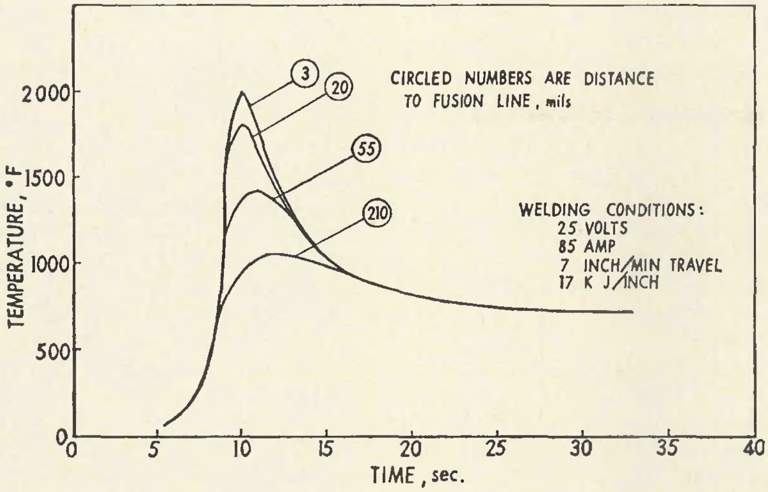

Fig. 1—Thermal cycles experienced by the heat-affected zone of 3/8 in. thick CA715 alloy plate

therefore limited by specimen size.

The chromium-modified alloy (designated IN-732 by the manufacturer) achieves a 50 ksi yield strength. The alloy is strengthened by a simple "annealing" treatment, i.e., air cooling from the annealing temperature, about 1800° F for the material used in these tests. The actual strengthening is thought to be by spinodal decomposition, a hardening process wherein a high-temperature, face-centered cubic structure decomposes into two face-centered cubic phases on cooling through the range 1400–800° F.[2] These two phases are very closely related, but not identical in lattice parameter and chemical composition. This reaction is controlled by diffusion over distances on the order of atomic dimensions and not by conventional nucleation and growth; therefore, the reactions appears to be almost instantaneous and to occur throughout the alloy.[4]

Procedure

Weldability of the CA715, CA716, and IN732 alloys was investigated by use of simulated welding techniques involving the Gleeble, by fabrication and test of actual weldments, and by use of the Varestraint test.[5] Limited studies of the CA 717 alloy by use of synthetic techniques were performed.

Before simulated welding studies could be performed, thermal cycles experienced by the heat-affected zone had to be determined. These cycles were measured by thermocouples embedded in holes drilled from the underside of a 0.375 in. thick, CA 715 plate to various distances from the weld fusion line of a bead-on-plate weld. The cycles measured, shown in Fig. 1, were determined for the following conditions: 85 amp, 25 ipm travel speed, 80° F preheat, shielded metal-arc process. These cycles are referred to hereafter by their peak temperatures.

Although no cycle with a peak temperature of 950° F was determined, it was approximated by a simple lowering of the peak temperature set in the Gleeble from 1100 to 950° F.

The following tests were performed on the simulated weld heat-affected zone with the Gleeble:

1. *Hot ductility test.* A 0.25 in. diameter specimen was broken (crosshead speed of 2 in./sec) at various temperatures on both the heating and cooling portions of a thermal cycle. A microswitch in the Gleeble was used to prevent current flow in the specimen during application of load since the specimen may be reduced in diameter and therefore undergo an increase in temperature during loading. The peak temperature used for the cooling studies was the zero ductility temperature. Reduction of area was determined as the measure of ductility.

2. *Tension test.* A 0.25 in. diameter specimen was run through a thermal cycle, or through two successive thermal cycles to simulate multipass welding. It was then removed from the Gleeble, reduced to 0.15 in. diameter over the central 0.5 in. and tested in tension. Due to the thermal gradient existing along the length of the specimen during the thermal cycle, a 0.03 in. gage length strain gage was applied to the center of the reduced region to measure strain for use in yield strength determination.

3. *Stress corrosion test.* A 0.42 in. square by 5 in. long specimen was run through one or two thermal cycles, removed from the Gleeble, notched and fatigue cracked to a total depth of about 0.14 in., and tested. The test consisted of immersing the notched area in 30 ml of natural seawater held in a plastic cup and statically loading the specimens as cantilever beams.[6] The stress is calculated as *MC/I*, with stress concentrations due to the notch neglected. If failure did not occur after 1000 hr of test, the specimen was step loaded to failure in air.

Varestraint tests[7] of the alloys were also conducted. Briefly, this test is performed by bending a cantilevered 2 by 12 in. by *t* specimen around a radiused die block while an argon-

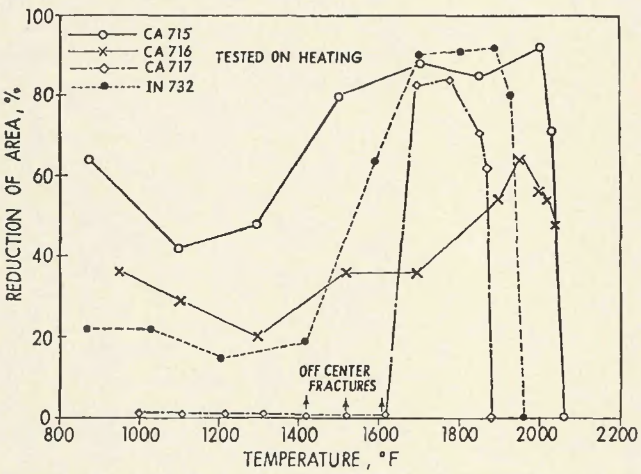

Fig. 2—Hot ductility data representing "On Heating" test conditions

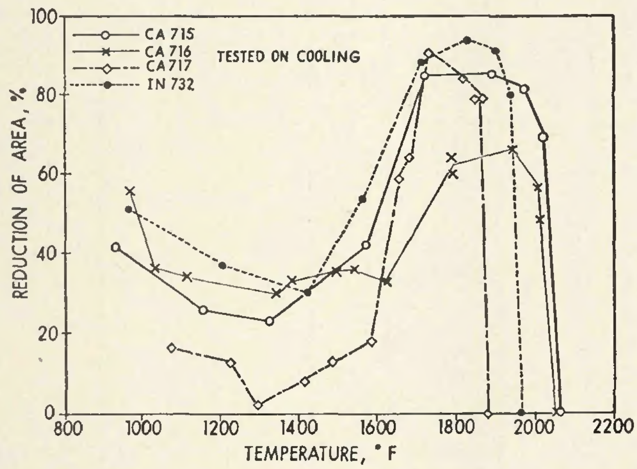

Fig. 3—Hot ductility data representing "On Cooling" test conditions

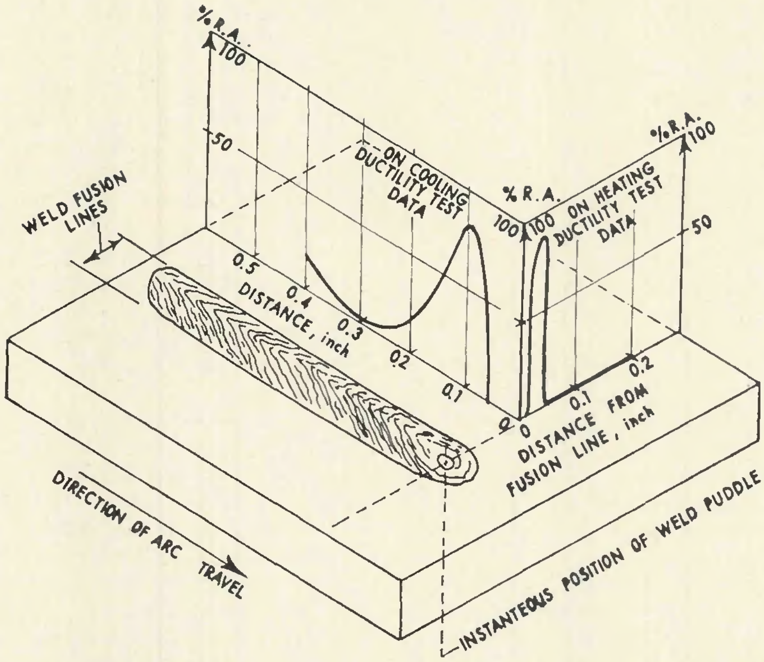

Fig. 4—Relationship between plots of "On Heating" and "On Cooling" hot ductility test data with respect to a bead-on-plate weld for CA717 alloy

shielded tungsten arc travels down the specimen (heat input—18,000 joules/in.). In the present study, supplemental argon shielding from a trailing shielding was used. The specimen thickness was nominally 0.25 in. However, because of the warpage in the CA 716 and IN 732 alloys during machining, these specimens were finished undersized, with thickness 0.190 and 0.225 in. respectively. Total length of all cracks present, both on the as-welded surface and 10 mils below this surface, was measured at X50 as an index to hot cracking. Three specimens were tested for each strain level.

In addition to Gleeble and Varestraint studies, weldments were also fabricated. Flat transverse tension specimens from four-pass automatic gas tungsten-arc welds in 0.25 in. thick plate were tested in the as-welded conditions. The welding conditions were 200 amp, 10 v, 4 ipm travel speed. In addition to the usual information, yield strength of the weld metal and heat-affected zone were determined with 0.03 in. strain gages attached to the bottom of the plate. Two-pass gas tungsten-arc butt welds in 1 in. pipe with weld reinforcement intact were also tension tested. Two pipelines of each alloy with 23 welds of wrought pipe to similar composition cast fittings were fabricated. All welds were made by the gas tungsten-arc process with filler metals recommended by the suppliers. The welding parameters used were developed by the Navy Ship Research and Development Laboratory (NSRDL), Annapolis, Md.

Table 3—Effect of Thermal Cycles on Yield and Tensile Strengths[a]

		Thermal cycle(s), °F							
Alloy	Strength	As rec'd.	950	1100	1400	1800	2000	2000 + 950	2000 + 1400
CA715	Yield	26	24	27	29	27	28		
	Tensile	60	58	59	61	58	61		
CA716	Yield	53	52	49	31	30	28		28
	Tensile	91	89	87	70	69	69		69
CA717	Yield	88	88	84	71	37	b		
	Tensile	130	128	126	120	70	b		
IN732	Yield	52	53	53	52	42	42	43	42
	Tensile	83	88	88	82	75	75	78	75

[a] Average of triplicate tests.
[b] Partial melting occurred in these specimens.

Table 4—Results of Stress-Corrosion Cracking Tests Performed on the Simulated Heat-Affected Zone[a]

		Peak temperature of thermal cycle, °F					
Alloy	Stress, ksi	As rec'd.	950	1100	1400	1800	2000
CA715	Sustained 1000 hr in seawater	88	78	75	84	80	80
	Bend strength in air	116	120	107	114	111	116
CA716	Sustained 1000 hr in seawater	152	150	142	111	90	96
	Bend strength in air	175	185	170	160	155	144
IN732	Sustained 1000 hr in seawater	127	117	97	93	87	104
	Bend strength in air	187	168	181	162	177	165

[a] All results are the average of duplicate tests.

Results and Discussion

Gleeble Studies

The results of hot ductility tests conducted on all four alloys are presented in Figs. 2 (on heating) and 3 (on cooling). The curve for the CA 715 alloy is in general agreement with curves developed by previous investigators,[8] although the zero ductility temperature determined is lower (2060° F) than those previously determined (2150° F). However, since the nominal solidus of the alloy is 2140° F,[9] it is felt the 2060° F temperature is correct.

Of particular interest is the zero ductility experienced on heating by the CA 717 alloy. In fact, the specimens broken in the range 1400–1600° F fractured away from the centerline in lower temperature regions. This brittleness could not be related to any metallographic features; however, all low-ductility fractures were intergranular.

Figure 4 is a diagram which illustrates the relationship between the heating and cooling test data with respect to a weld bead (after Matthews). Data for the CA 717 alloy are plotted. Distances from the fusion line rather than temperatures are used for the ordinates. The distances were determined from Fig. 1 for the "on heating" curve and from the travel speed for the "on cooling" curve. It becomes apparent that hot cracking at comparatively large distances from the weld fusion line could be a problem with this alloy. Cracking of this type has been observed in cast 70-30 CuNi.[10] The remaining modified alloys compare favorably with the CA715 and, hence, no heat-affected zone cracking problems would be anticipated.

The effect of thermal cycles on

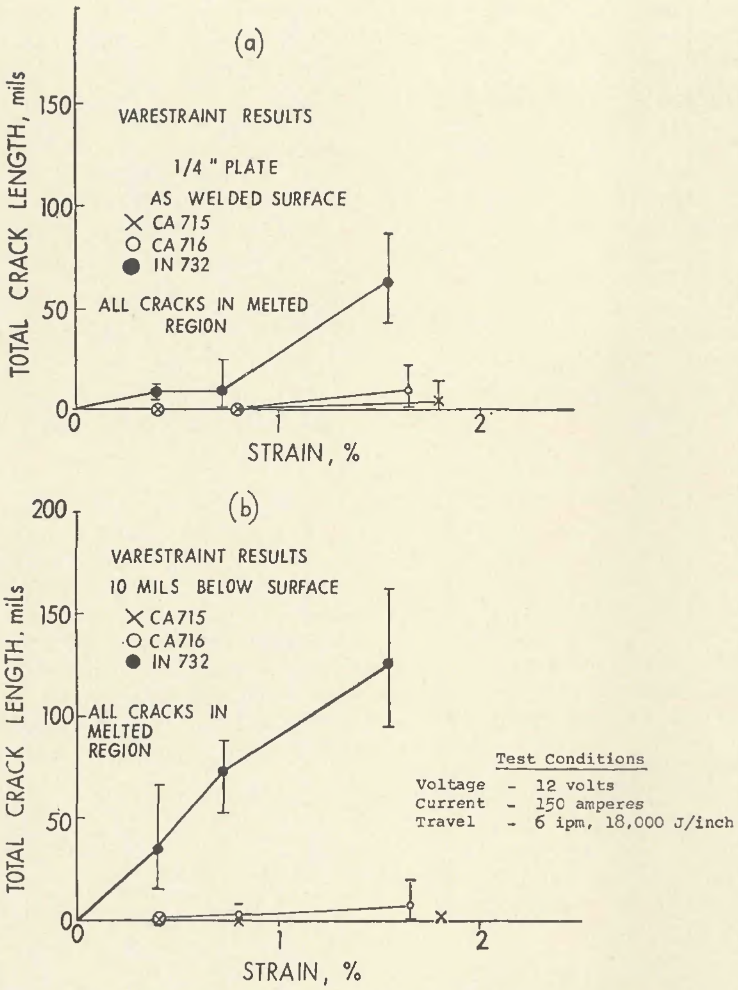

Fig. 5—Varestraint test results for modified copper-nickel alloys

Table 5—Results of Tension Tests Across the Weld—Average of Duplicate tests on 4-Pass Gas Tungsten-Arc Welds, As-Welded

Alloy	Tensile strength,[a] ksi	Yield strength (0.2% offset), ksi: 2 in. gage	Heat-affected zone	Weld metal[b]
CA715	56	32	32	28
CA716	64	42	49	38
IN732	80	55	55	50

[a] All specimens failed in weld metal.
[b] Yield strengths determined with 0.03 in. strain gages attached to heat-affected zone and weld metal portions of test length.

Table 6—Results of Tension Tests of 2 Pass Gas Tungsten-Arc Butt-Welded Pipe, As-Welded

Alloy	Tensile strength, ksi: Un-welded[a]	Welded[a,b]	Loss in Tensile strength, %
CA715	55	55	0
CA716	89	69	22
IN732	88	83	6

[a] Average of 2 determinations.
[b] Tested with reinforcement intact.

yield and tensile strengths of the four alloys is shown in Table 3. Tensile strengths are considered valid as the fractures occurred in the uniformly heated region. The effects of single thermal cycles will be explored first. The overaging and annealing effects of the thermal cycle are quite apparent for the CA717 alloy. (The 2000° F cycle produced partial melting of the specimen and consequently invalid results on testing.) A low strength heat-affected zone would be produced in single pass welds in this material. A similar but somewhat smaller loss in strength would be expected in the CA716 alloy, while a still smaller loss would occur in the IN732 alloy. The low strength CA715 alloy is unaffected by weld thermal cycles.

A previous investigation[11] has shown that single pass welds in IN732 develop a minimum yield strength of 40 ksi. However, multipass welds were shown to develop a minimum yield of 50 ksi. Therefore specimens of IN732 were given double cycles, first to 2000° F, and then to either 1400 or 950° F, and tested. No strengthening due to the second cycle was observed. The CA716 alloy was also evaluated by a double cycle (2000 + 1400° F) and also showed no strengthening.

The results of stress-corrosion cracking tests for the CA715, CA716, and IN732 alloys are presented in Table 4. No failures were observed after 1000 hr of testing in seawater at the stress levels indicated. The high stress levels for certain of the CA716 tests were a result of deeper notches (0.18 in.) than the desired 0.14 in., giving higher stress for equivalent loads. The specimens were then loaded to failure in air to determine bend strengths as indicated in the table.

Bend angles on the order of 30 deg were obtained before failure. However, severe notch blunting due to plastic flow at the root of the notch had occurred long before failure. With the possible exception of the high-stress CA716 tests, it is felt that the stress levels used for seawater tests were below the level where significant notch blunting occurred. On the basis of these short-term tests, no stress-corrosion cracking problems are anticipated in either the base metal or heat-affected zone of the CA716 or IN732 alloys.

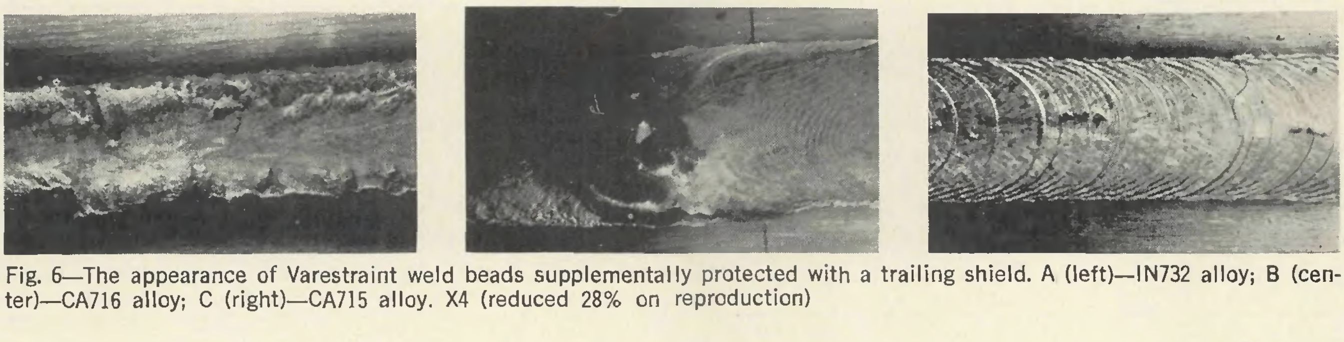

Fig. 6—The appearance of Varestraint weld beads supplementally protected with a trailing shield. A (left)—IN732 alloy; B (center)—CA716 alloy; C (right)—CA715 alloy. X4 (reduced 28% on reproduction)

Varestraint Test

The results of the Varestraint tests for the CA715, CA716, and IN732 alloys are presented in Fig. 5 where total crack lengths as determined on the welded surface and 10 mils below this surface are shown. All cracking was found to be in the melted region, i.e., no cracks were found in the heat-affected zone. The use of filler metal, therefore, could be expected to alleviate hot cracking problems

The appearance of the weld beads produced during Varestraint testing are shown in Fig. 6. It should be remembered that a trailing shield utilizing argon was used. The CA715 alloy welds were bright and shiny; both the CA716 and IN732 alloys showed what appears to be oxides on the welds. This feature is discussed in the next section.

Fabrication and Test of Weldments

The results of transverse tension tests conducted on four pass automatic gas tungsten-arc welds in 0.25 in. thick plates of CA715, CA716, and IN732 alloys are presented in Table 5. Weld reinforcements were removed before testing; all specimens failed in the weld metal. The yield strength (measured over a 2 in. gage length) of the CA716 is reduced while the yield strength of IN732 is essentially unaffected. The tensile strengths of both alloys are reduced, the reduction being more severe for the CA716 alloy.

The yield strengths of the heat-affected zones in the alloys do not show as great reductions as predicted by the Gleeble tests. Several factors may account for the discrepancy. First, the multi-cycle (more than two cycles) effects of four passes may increase the strength; the strain gages were attached to the bottom of the plate where these effects would be felt. Second, the higher heat input (30 kilojoules/in.) used in the welded plate would produce slower cooling rates in the welds and allow more time for strengthening reactions to occur. Finally, triaxial stress conditions in the heat-affected zones may have resulted in an apparent strengthening.

Tension tests were also performed on butt-welded 1 in. pipe. Two passes using manual gas tungsten-arc welding were required to complete the joints, which were tested in the as-welded condition with the reinforcement intact. The results are presented in Table 6. Again the tensile strength of both alloys is reduced, the reduction being more severe for the CA716 alloy. All failures took place in the weld metal and heat-affected zone.

Two 1-inch pipelines were fabricated from the CA715, CA716, and IN732 alloys. The pipelines involved 23 manual gas tungsten-arc welds each between wrought pipe and cast fittings. All welds were inspected visually and by dye penetrant. No cracking was observed in any joint in the pipelines, or was any cracking apparent in any of the welded plate or pipe which was tension tested. During welding it was noted that the weld puddle in the CA716 and IN732 alloys had a cloudy appearance and the finished welds had oxides similar to those observed in the Varestraint test present on the surfaces. However, these oxides did not interfere with the production of sound welds. The welding parameters used were developed by NSRDL and may not represent optimum conditions, but perfectly satisfactory welds were produced.

Conclusions

On the basis of the results presented it is concluded that:

1. The heat-affected zone of the CA716 and IN732 will not be susceptible to hot cracking. No cracking was observed in the Varestraint test, and hot ductility behavior was similar to the CA715 alloy.

2. The heat-affected zone of the CA717 alloy may be susceptible to hot cracking in regions which are heated in the range 1000–1400° F, as shown by hot ductility testing. The material was of insufficient size to verify this conclusion by Varestraint testing.

3. Tension testing of Gleeble specimens has indicated loss of strength in the heat-affected zone of single pass welds in the CA716, CA717 and IN732 alloys. The yield strength of the heat-affected zone of multipass weldments equaled the parent plate for IN732 and was higher than single pass strengths determined for the CA716. However, the higher strengths determined for these multipass welds were not duplicated in Gleeble tests.

4. No susceptibility to stress corrosion cracking in seawater was observed in 1000 hr tests for either the base metal or the simulated heat-affected zone in the CA715, CA716, or IN732 alloys.

5. The CA716 and IN732 alloys produce a cloudy weld puddle and oxides on the finished weld bead. However, sound welds were produced in both alloys.

Acknowledgements

The author wishes to thank Mr. C. P. Youngren and G. F. Phipps for their technical assistance. The assistance of Mr. G. A. Wacker in preparation of this manuscript is gratefully acknowledged. Appreciation is extended to Navy Ship Systems Command, Code 03422, for permission to publish this work.

References

1. MIL-T-16420 J(SHIPS), Tube 70-30 and 90-10 Copper-Nickel Alloy, Seamless and Welded, March 1965.
2. Crisi, J. R., "Influence of Alloy Elements on the Mechanical Properties of Copper-Nickel Alloys," Master's Thesis, Brooklyn Polytechnic Institute, June 1969.
3. Development Preview Bulletin No. 4100, The Beryllium Corporation.
4. Badia, F. A., G. N. Kirby, and J. S. Michalism, "Strengthening of Annealed Cupro-Nickels by Chromium," Transactions Quarterly, 60 (3), 395, Sept. 1967.
5. Savage, W. F., and Lundin, C. D., "The Varestraint Test," WELDING JOURNAL, 44 (10), Research Suppl., 433-s to 442-s (1965).
6. Brown, B. F., "A New Stress Corrosion Cracking Test Procedure for High-Strength Alloys," Materials Research and Standards, Vol. 6, No. 3, pp. 129-133, March 1966.
7. MIL-STD-00418 B(SHIPS), Mechanical Tests for Welded Joints, Nov. 1967.
8. Matthews, S. J., "Weldability Observations in 70-30 Copper-Nickel Tubesheet Material," WELDING JOURNAL, 47 (4), Research Suppl., 155-s to 161-s (1968).
9. Metals Handbook, 1948 edition, American Society for Metals, 1948.
10. Lee, J. W., Nichols, E. E., and Goodman, S., "Varestraint Testing of Cast 70 Cu-30 Ni Alloy," WELDING JOURNAL, 47 (8), Research Suppl., 371-s to 377-s (1968).
11. Peterson, W. A., "Weldability of a Chromium Strengthened Copper-Nickel Alloy," *Ibid.*, 48 (10), Research Suppl., 425-s to 430-s, 1969.