TECHNICAL NOTES

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WELDING OF HIGH CHROMIUM STEELS

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The high chromium steels designed to resist various forms of corrosion are generally known under a large variety of trade names. Each name may apply to a group of alloys in which the percentage content of some element or elements varies according to the specific properties desired. The element chromium is the most important of the corrosion-resisting group. The other constituents such as nickel, silicon, manganese and carbon play an important part in this class of alloys, especially with regard to the welding problem. No attempt will be made to classify the different alloys according to their trade names as such a classification would require needless repetition and would be confusing. A brief description will be given of the different groups according to their composition and more generally accepted names. The welding procedure for a given group will therefore be much the same regardless of the slight variations in chemical composition which may exist within a certain group.

Rustless iron is considered here as that group of alloys containing between 12% and 20% chromium with less than .15% carbon, the balance being chiefly iron with normal amounts of manganese and silicon. Within this composition range there are two classes of alloys which are commercially available, the class being determined by the chromium content. The alloys containing 12-14% chromium constitute one type, and those with 14-20% chromium, the other type. Alloys containing 12-14% chromium are more susceptible to heat treatment than those containing 18-20% chromium. The resistance to corrosion increases with the chromium content.

Stainless steel belongs to the group containing 12-14% chromium with upwards of .2% carbon. The difference between rustless iron and stainless steel lies in the carbon content. Stainless steel is very susceptible to heat treatment, its corrosion resistance depending on its heat treatment and surface finish. On account of the air-hardening properties of the alloy, welds and metal adjacent to the weld in stainless steel will be hard and brittle. This brittle condition may be remedied somewhat by annealing followed by slow furnace cooling. After this treatment the metal will not have its maximum stainless properties which are developed only by quenching and drawing operations followed by proper surface finishing. On account of the hardness and brittleness of welds in stainless steel and the difficulty of properly heat treating and surface finishing the material after welding, stainless steel is unsuitable for welded parts subjected to corrosion, stress and vibration unless supported by other metals.

The addition of nickel to rustless iron produces another class of alloys. Nickel has a marked effect upon the physical properties of chromium iron alloys. The amount of nickel used varies from 7-12% in alloys suitable for aircraft construction. An alloy containing 16-18% chromium and 7-12% nickel is characterized by a combination of physical and corrosion-resisting qualities rendering it particularly suitable for aircraft production, since welds and metal adjacent to the weld in this material will be ductile and require no subsequent heat treatment. The chromium and nickel may be varied somewhat without materially altering its corrosion-resisting properties, which are dependent in large measure on the chromium content. About 1% each of manganese and silicon improve the welding quality of the higher chromium alloys with or without nickel.

All groups aforementioned are commercially available in the form of forged or rolled shapes. Seamless tubing is now available with all classes except the stainless steel. Welded tubing made from strip or sheet may also be obtained, especially in sizes under 3" in diameter. Relatively thin material will be used in aircraft work and for that reason the welding methods to be described will pertain more particularly to the thin gauges. It is practically necessary to use the oxyacetylene method of welding for material 16-gauge or lighter. Although the metallic arc method may be used with certain reservations, it is not generally applicable to the light gauge.

Approximately the same procedure may be followed in welding all classes of alloys herein described by the oxyacetylene method; the chief difference lies particularly in the after treatment. The general procedure will therefore be described and such details as necessary for any particular class will be brought out. In the discussion to follow, it is assumed that the material is in sheet form of 16-gauge or lighter.

It is desirable, where possible, to flange the edges which are to be welded; this is especially true for sheet lighter than 16-gauge. Butt welding without flanging the edges is permissible with sheet 16-gauge or heavier. A flange about 1/16" wide will furnish the requisite amount of material for melting down, thus eliminating the use of a filler rod. For filling small holes or reinforcing, welding rods of the same composition as the sheet being welded should be used. It is advisable to clean the scale from the edges to be joined and they should be painted or coated with a special flux developed for this class of work. This flux is now on the market under the trade name of "Cromaloy Flux." To obtain best results, the importance of this flux cannot be stressed too strongly. Wherever possible pickled material should be used, as this insures a surface free from objectionable oxide. At the present time the greatest application of welding to aircraft is in fuselage construction, which involves the welding together of various miter joints. With this construction the same design of joint can be welded in the chrome alloy tube as is now welded in ordinary tubes. Flanged joints are not used in welding together the ends of tubing.

A neutral oxyacetylene flame should be maintained during the welding operation, i.e., it should not contain an excess of either acetylene or oxygen. The neutral point is determined by the appearance of the inner cone of the flame and is easily recognized by those familiar with the use of an oxyacetylene blowpipe. An excess of acetylene especially should be avoided as it will cause an appreciable increase in the carbon content of the weld, increasing the hardness and lowering the ductility of the weld metal. An increase in carbon will also lower the resistance of the weld metal to corrosion. An excess of oxygen results in the formation of a refractory slag resulting in poor quality welds. Welding should be accomplished with a flame just large enough to secure satisfactory fusion, since a large excess of heat causes the metal to boil, resulting in porous welds.

Rustless iron has a tendency to be brittle in the weld metal and in that portion of the base metal adjacent to the weld as a result of the high temperature attained during welding. Rustless irons, particularly the 12-14% chromium grade, are subject to air hardening and require annealing to restore toughness to the weld metal and base metal adjacent to the weld. Proper subsequent heat treatment will remedy the brittleness to a large extent. However, it is not always possible to apply a heat treatment because of size or other features of construction. Good results are obtained by heating the welds to 650-

750°C for one-half hour and cooling slowly. The torch is often utilized for applying the heat where it is not possible to employ furnaces. When using the torch for annealing, great care must be exercised so as not to heat the material above 800°C. Heating to just below the critical point is necessary in order to soften rustless iron. The material after heating to 650-750°C may be air-cooled. The benefit to be derived from torch annealing will depend on temperature and time of heating. Usually about five minutes within the above temperature range will do some good.

Rustless irons which contain appreciable amounts of nickel are not subject to this brittleness and are quite ductile in the "as welded" condition. These alloys are austenitic under all conditions of heat treatment, consequently they do not air harden. Weld metal cooled either rapidly or slowly is consequently malleable and ductile and requires no heat treatment. However, the tensile strength and ductility are enhanced by a water quench from 1050°C. On account of distortion, it would not be feasible to apply this treatment to aircraft welds.

In order to show what results may be obtained with welds in the various types of alloys discussed, three compositions in the form of 18-gauge sheet were used as follows, all material being annealed before welding to ensure starting with material in the same condition. The rustless irons containing 12-14% chromium and 14-20% chromium with no nickel were annealed at

750°C, a temperature commercially used. The nickel containing rustless iron was annealed at 1050°C to impart maximum ductility.

1. Rustless Iron 12-14% Cr.

Carbon	.11%
Manganese	.33%
Silicon	.39%
Chromium	12.30%
Thickness	.054"

Surface condition - pickled
Annealed 30 minutes at 750°C, air-cooled.

2. Rustless Iron 14-20% Cr.

Carbon	.08%
Manganese	.29%
Silicon	1.05%
Chromium	17.21%
Thickness	.053"

Surface condition - pickled
Annealed 30 minutes at 750°C, air-cooled.

3. Rustless Iron 16-18% Cr. 7-12% Ni.

Carbon	.12%
Manganese	.32%
Silicon	.13%
Chromium	17.42%
Nickel	7.58%
Thickness	.046"

Surface condition - pickled
Annealed 1 hour at 1050°C, water-quenched.

Welds were made by the flange method using 1/16" wide flanges. The flanged edges to be welded were painted with a water paste of "Cromaloy Flux," clamped in a jig to ensure alignment of the edges, and welded with a neutral oxyacetylene flame. Only enough heat was used to obtain satisfactory fusion. The melting down of the two 1/16" flanges gave a weld 1/8" to 3/16" wide with 50-75% reinforcement. It was not advisable to grind off the reinforcement on account of the danger of producing thin areas at the edge of the weld. Coupons from welds in each type of material were tested in the "as welded" condition and after torch and furnace annealing; the temperatures for furnace annealing were the same as for the sheet before welding. Bends were made transverse to the line of welding which gave an indication of the ductility of the weld and adjacent metal.

The tensile properties of the sheet and welds before and after annealing were determined on coupons $1\frac{1}{2}$" wide. A welded test piece is nonhomogeneous, the weld having a higher yield point than the base metal. When such a test piece is tested in tension, the base metal adjacent to the weld is not free to elongate due to the propping or staying action of the stiffer weld metal. Consequently, the per cent elongation obtained in a tensile test of a welded coupon does not necessarily express the true ductility of the weld metal or metal adjacent to the weld. When the weld has a higher yield point than the base metal, no appreciable lateral contraction takes place at the weld. As a measure of the ductility of the weld metal, bend tests are used, the test being evaluated by measuring directly the per cent elongation in the outside fibers. On account of the thinness of the sheet it was impossible to measure the per cent elongation in the outside fibers in the bend test. The angle of bend was therefore measured. This method of evaluating the bend test does not give quantitative data, but does show the relative ductility of the welds in the different types of alloys.

1. Rustless Iron - 12.30% Chromium

Sheet as received coupon	lb. per sq.in. Yield point	Ultimate strength	% elongation in 2" over weld	Remarks
R 1 - 1	53,000	78,200	36.0	% elongation taken over fracture
2	54,300	79,100	31.0	"
	Bend test		180°	
Sheet annealed				
R 1 A - 1	49,100	77,400	33.0	"
2	48,600	77,000	34.0	"
	Bend test		180°	
As welded				
R 1 A W-1	-	23,800	0	Broke in sheet adjacent to weld
2	32,400	43,700	4.0	"
3	-	16,800	0	Broke in sheet and weld
	Bend test		33°	
Torch annealed				
R I T A-1	55,350	76,400	6.5	Broke in weld
	Bend test		85°	
Furnace annealed				
R I F A -1	46,700	70,000	6.0	Broke in edge of weld
2	43,400	76,200	7.5	" " sheet
3	43,900	77,200	9.5	" " "
4	46,700	65,300	4.0	" " edge of weld
5	46,700	75,800	11.0	" " sheet and edge of weld
6	41,600	60,200	4.5	Broke in weld. Weld cracked.
	Bend test		140°	

2. Rustless Iron - 17.21% Chromium

Sheet as received coupon	lb. per sq.in. Yield point	Ultimate strength	% elongation in 2" over weld	Remarks
E N - 1	62,400	76,400	31.5	% elongation in 2" over fracture
2	64,700	77,800	31.0	"
	Bend test		180°	
Sheet annealed				
E N A - 1	46,700	75,400	30.0	"
2	46,650	74,700	28.0	"
	Bend test		180°	
As welded				
E N A W-1	-	47,400	0	Broke in edge of weld Coarse crystalline
2	-	27,200	0	"
3	41,500	53,400	1.0	"
	Bend test		25°	
Torch annealed				
1	-	68,250	5.5	Broke in sheet adjacent to weld
2	46,100	65,300	4.0	"
3	49,100	73,300	9.0	Broke in sheet outside 2" gauge marks
	Bend test		110°	
Furnace annealed				
E N F A-1	-	74,490	11.0	Broke in sheet adjacent to weld
2	55,000	71,100	8.5	Broke in weld
3	52,700	74,500	12.5	" " sheet
4	-	73,990	14.0	" " "
5	49,100	75,300	13.0	" " "
6	46,200	73,250	10.5	" " "
	Bend test		150°	

3. Rustless Iron - 17.42% Chromium, 7.58% Nickel

Sheet as received coupon	lb. per sq.in. Yield point	Ultimate strength	% elongation in 2" over weld	Remarks
S A - 1	54,400	104,000	68.5	% elongation in 2" over fracture
2	52,600	100,300	67.5	"
	Bend test		180°	
Sheet annealed				
S A A - 1	-	105,400	74.0	"
2	58,800	103,300	63.0	
	Bend test		180°	
As welded				
S A A W-1	55,500	65,000	14.0	Broke in sheet at edge of weld
2	57,000	68,200	15.5	"
3	50,250	65,500	16.0	"
	Bend test		150°	
Torch annealed				
S A T A-1	51,500	63,800	10.5	"
2	49,300	52,200	7.0	"
	Bend test		140°	
Furnace annealed				
S A F A-1	55,800	74,100	24.5	"
2	-	72,500	23.5	"
3	56,000	80,400	29.0	"
4	58,000	70,300	23.5	"
5	55,600	74,100	23.5	"
6	57,000	72,600	22.5	"
	Bend test		180°	

Bend angles up to 35° indicate brittle material; 85-110° may be considered as indicating good ductility; 140-180° bends indicate excellent ductility. From a consideration of the tensile and bend tests, it may be seen that welds in rustless irons of either the 12-14% chromium or 14-20% chromium grades are brittle and void of any appreciable ductility in the "as welded" condition. Considerable toughness may be imparted to the welds by torch annealing at a dull red heat for five to fifteen minutes followed by air cooling. Torch annealing of the 12-14% grade will give results about on a par with furnace annealing. In the tensile test 10% elongation in 2" over the weld seems to be about the maximum ductility obtainable on annealed welds in 12-14% chromium rustless irons.

Rustless irons containing 16-18% chromium together with about 1% silicon do not air-harden so readily as the 12-14% grade after welding. They are, however, liable to excessive grain growth at high temperatures and for this reason welds and sheet adjacent to the weld in high chromium rustless irons are considerably reduced in ductility. Torch annealing or furnace annealing at temperatures of 650-750°C will impart softness and ductility to welds in 14-20% chromium rustless iron. Alloys containing about 1% silicon are more easily welded than those containing less than 0.5%. Welds in both types of rustless iron will yield approximately the same values after annealing; namely, yield point 42,000-55,000 lb./sq.in. ultimate strength

65,000-75,000 lb./sq.in.; % elongation in 2" over weld 4-14%.

Rustless iron containing 16-18% chromium and 7-12% nickel is austenitic and does not harden or become brittle in cooling rapidly or slowly from the welding temperature. Welds in this material are consequently ductile and require no after treatment. In the "as welded" condition, welds in this alloy will have a yield point of 50,000-60,000 lb./sq.in.; ultimate strength of 65,000-70,000 lb./sq.in. with about 15% elongation in 2" over the weld. Welds in this material may be bent through an angle of 140-180° indicating very good ductility. Since welds in this alloy show the best combination of strength and ductility in either the "as welded" or annealed condition, it is considered the best alloy to use for welded construction. It can be obtained in the form of either welded or seamless tubing which would be the material used for fuselage construction. Weld strength and ductility of the same order as obtained on the 18-gauge sheet should be obtained in welded tubing of this composition.

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