SELECTION OF CAST STAINLESS STEELS*

INTRODUCTION

The development of casting technologys has been driven by two distinct engineering perspectives. The first involves the potential economy of cast hardware relative to totally machined wrought parts and the second perspective is associated with metallurgical realities. The chemical composition and microstructure of some alloys is such that deformation processing of large ingots into wrought product forms would be problematic. In addition, the very nature of cast microstructure which in general is composed of large grains can provide benefits in high temperature creep applications.

Some common examples of stainless steel castings include valve and pump bodies, compressor wheels, propellers, turbine impellers, large pipe elbows, heat treating fixtures and food, paper and chemical processing equipment.

STAINLESS STEEL CASTING ALLOYS

Categories

Unlike the case of wrought alloy designators, cast stainless steels are not grouped according to microstructural types, but by the intended service environment. The general classification of stainless steel castings places these alloys in one of two categories: :corrosion-resistant alloys and heat-resistant alloys. The corrosion-resistant alloys have been designed primarily for service environments involving aqueous or liquid-vapour corrosives at temperatures generally less than 315°C. Use at extended temperatures upto 650°C in selected environments may also be considered.

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The heat-resistant alloys have been designed for use in service environments exceeding 650°C where aqueous corrosive do not exist. At these elevated temperatures, oxidation, sulfidation and carburization /decarburization are the environmental effects of consequence. High-temperature mechanical strength, creep and stress-rupture resistance, and mirostructural stability are the engineering requirements for these alloys. The high-temperature alloys are most readily distinguished from the corrosion-resistant alloys on the basis of carbon content (although other alloying elements may also vary considerably in response to service needs) with the high-temperature alloys containing 0.20 to 0.70 wt% C and the corrosion-resistant alloys generally containing less than 0.20 wt% C.

Nomenclature

Cast stainless steels are most often specified on the basis of composition using the designation system of High Alloy Product Group of the Steel Founders' Society of America. A cast stainless steel is specified by a group of alpha-numerics. The first letter of the designation indicates whether the alloy is intended primarily for liquid corrosion service (C) or high-temperature service (H). The second letter in either group of alloys indicates an approximate ratio of nickel to chromium with the ratio increasing in alphabetical order. (As the nickel content increases, the second letter of the designation progresses through the alphabet from A to Z.) The number immediately following the hyphen indicates the carbon content of alloy in hundredths of weight percent (also know as "points" of carbon). For the corrosion-resistant alloys, the carbon content indicated is the maximum allowable for the alloy. For the heat-resistant alloys the carbon content identified is the midpoint with an allowable range of ± 0.05 wt%. Finally, if further alloying elements are present, these are indicated by the addition of one or more letters as a suffix. Thus, the designation of CF-8M refers to an alloy for corrosion-resistant service (C) of the 19Cr- 9Ni type with a maximum carbon content of 0.08% that contain molybdenum (M). Table 1 list the chemical composition of common corrosion alloys.

WELDING AND WELDABLLITY OF CAST STAINLESS STEELS

Welding and Welding Processes

In general terms, there are two situations in which welding of stainless steel castings is required. One of these occurs before the casting ever leaves the foundry. Casting defects, such as hot tears, shrinkage cavities, and cold shuts are often observed in stainless steel castings. Certain specifications preclude the acceptance of these castings for service use without repair. Fusion welding is an appropriate method for repair of these casting defects. The defects, identified through one of several possible procedures (for example, dye penetrant, radiography, or ultrasonic inspection), are removed by machining or grinding, leaving a clean joint surface onto which weld filler metal is added to produce a sound final products. For small, near-surface defects autogenous welds (that is, no filler metal added) may be sufficient to eliminate the defects. A special case of repair welding is know by the term "upgrading". An "upgraded" casting is one that has been selectively welded in order to achieve a higher level of product specification acceptance.

The second situation requiring welding involves joining of casting to other hardware, cast or wrought, as part of engineering design. In this circumstance, the design rules for welding are similar to those for wrought alloys. Any of the fusion welding processes can be successfully employed in the welding of castings.

Most common are the arc welding processes, especially, autogenous and filler-metal-added gas—tungsten arc welding, shielded metal arc welding and gas metal arc welding. Fabrication involving the use of extremely large castings may employ electroslag welding as the only reasonable economic choice. Other processes, such as electron-beam welding, laser-beam welding and plasma arc welding are also appropriate choices in many instances. A wide range of filler metal exists for joining of various casting alloys. The choice depends on the specifics of the situation and whether the weld will be to similar or dissimilar alloy. The use of matching filler metal is generally suggested when welding like alloys. Where a matching consumable is not available common choices are 308L and 316L for the low-nickel-content corrosion-resistant austeintic alloys. For the higher nickel-content corrosion-resistant and heat resistant alloys, appropriate choices may be consumables (bare electrode for gas-tungsten arc welding and gas-metal arc welding) such as 20Cb-3 (AWS ER 320 / ER 320 LR), and Inconel Alloys 82 (AWS ERNiCr-3) and nickel alloys such as C-276 (AWS ER NiCrMo-4), Alloy 625 (AWS ER NiCrMo-3), 92 (AWS ERNiCrFe-6) and 182 (AWS ERNi CFe-3).

Metallurgical Considerations

Castings are metallurgically more complex than wrought alloys. Segregation during dendritic solidification can lead to local variations in both chemical composition and microstructure. The vast majority of the heat-resistant alloys will terminate solidification with the formation of a eutectic like carbide constituent that remains upon cooling of casting to room temperature. This microstructural constituent helps to augment the creep resistance of this group of alloys. Subsequent heat treatment of these alloys is not common.

Many of the lower-nickel-content corrosion resistant alloys (for example, CF-3, CF-8M, and CB-7Cu) will have a duplex microstructure consisting of ferrite island in a matrix of either austenite or martensite. Postcasting solution heat treatment used to prepare corrosion - resistant alloys for service are insufficient to homogenize the microstructure. The inhomogeneous microstructure of both groups of alloys will tend to promote relatively wide areas of partial melting adjacent to the fusion zone when compared with similar wrought alloys.

Table 1: Composition and typical microstructures of corrosion-resistant stainless steel casting alloys

Alloy Designation	Wrought alloy type	ASTM specification	Most common end-use mircostructure	Composition, %					
				C	Mn	Si	Cr	Ni	Other
Chromium steels									
CA-15	410	A743, A217, A487	Martensite	0.15	1.00	1.50	11.5-14.0	1.0	0.50 Mo
Chromium-nickel steels									
CB-7CU-1	...	A747	Martensite, age hardenable	0.07	0.70	1.00	15.5-17.7	3.6-4.6	2.5-3.2 Cu; 0.20-0.35 Nb; 0.05 N max
CE-30	312	A743	Ferrite in austenite	0.30	1.50	2.00	26.0-30.0	8.0-11.0	.....
CF-3	304L	A351, A743, A744	Ferrite in austenite	0.03	1.50	2.00	17.0-21.0	8.0-12.0	.....
CF-3M	316L	A351, A743, A744	Ferrite in austenite	0.03	1.50	2.00	17.0-21.0	8.0-12.0	20.3-3.0 Mo
CF-8	304	A351, A743, A744	Ferrite In austenite	0.08	1.50	2.00	18.0-21.0	8.0-11.0	
CF-8C	347	A351, A743, A744	Ferrite in austenite	0.08	1.50	2.00	18.0-21.0	9.0-12.0	No
CF-8M	316	A351, A743, A744	Ferrite in austenite	0.08	1.50	2.00	18.0-21.0	9.0-12.0	2.0-3.0 Mo
CH-20	309	A351, A743	Austenite	0.02	1.50	2.00	22.0-26.0	12.0-15.0	.....
CK-20	310	A743	Austenite	0.20	2.00	2.00	23.0-27.0	19.0-22.0	.....

Martensitic Stainless Steel Castings

Special consideration exist for the welding of martensitic stainless steel castings (CA-6 NM, CA-15, CA-40 and CB-7Cu-1, and CB-7Cu-2).

Quench cracking and a marked reduction in mechanical properties (especially ductility and impact toughness) may result from the welding of these alloys. Corrosion resistance may also be detrimentally affected by thermal cycle that material undergoes in the fusion zone and heat-affected-zone (HAZ) of welds.

Suggested welding practice often calls for preheating and postheating of most of the martensitic alloys. Alloys CA-15 and CA-40 required preheating temperature in the range of 200° to 315°C and a postweld heat treatment range of 100° to 150°C and a PWHT temperature range of 590° to 620°C. The higher preheating temperature should be used when welding thicker sections and higher carbon compositions of these alloys.

The PWHT for these alloys is a tempering operation intended to restore ductility and thoughness at the expense of strength and hardness. Because of the broad range of potential tempering temperatures, a wide range of PWHT properties are possible.

Alloy CB-7Cu (1 and 2) has not suggested preheat temperature, but a range (480° to 590°C) of PWHT temperature is recommended. In case of this alloy the PWHT is an aging operation. In order to recover properties in the welded product, a full solution anneal (1040°C, oil quench), followed by aging is required. Direct aging without solution annealing will not fully restore preweld properties. The higher aging temperatures result in the lower strength but also provide the highest ductility and toughness.

Welding Defect

The two most serious problems in the welding of stainless steel castings either during the repair of casting defects or for subsequent attachment to other structure, are solidification hot cracking and heat affected zone (HAZ) hot cracking. Both of these phenomena involve separation of grain boundaries due to the presence of a wetting liquid phase and sufficient mechanical imposition.

Studies have indicated that wholly austenitic stainless steel casting alloys are more susceptible to the formation of these types of defects than are duplex ferrite plus austenite alloys. In particular a wide range of low-nickel corrosion-resistant casting alloys having welds that solidify with ferrite as the primary solidification phase are much more resistant to hot cracking than are alloys that solidify with austenite as the primary solidification phase.

In many studies examining both the fusion zone and HAZ hot cracking behaviour of stainless steel casting alloys, the presence of sulphur and phosphorus has universally been identified with increased cracking susceptibility. To a somewhat lesser extent, so have silicon and niobium. Carbon can also be detrimental although not all studies have reached the same conclusion. It can be said that if there is sufficient carbon present to result in the formation of terminal-stage, euteic like constituent, then the hot cracking susceptibility will increase up to the point where level of carbon content can limit the utility of the weld joint for an engineering application.

Each of these elements appears to increase cracking susceptibility in two possible ways. The first is by promoting the formation of low melting-point constituent and the second is by acting as a surfactant which promotes wetting of solidifying grain boundaries.

Either phenomenon will promote an increased tendency toward fusion zone or HAZ hot cracking.

A specific concern in the welding of corrosion-resistant stainless steel casting is the production of a sensitized microstructure. Sensitization occurs in stainless steel alloy when chromium-rich phase-M_{23} C_6 carbides, sigma, chi, and Laves phase-precipitate during exposure to temperatures between 400° and 900°C. The precipitation of these constituents can result in a local depletion of chromium (and also molybdenum), lowering the corrosion resistance to a point where corrosion-induced failure of casting can result. Primary among the phases of concern is the M_{23} C_6 carbide (with M being primarily chromium). Percipitation of carbides at grain boundaries can occur during fusion welding cycle at sites in both HAZ and the fusion zone. Because the kinetics of precipitation are proportional to the carbon concentration, low-carbon grades (such as CF-3 or CF-3M) have been developed that can experience welding without producing a sensitized microstructure.

A final metallurgical consideration involves the welding of casting that have seen extended service at relatively high temperatures for a variety of reasons. Casting may have to be rewelded sometimes during their service lifetime. This can pose a difficult problem if the temperature environment has modified the alloy microstructure so that additional constituents are present that adversely affect alloy ductility. It is always preferable to heat treat the casting to remove these unwanted mircostructural features. This process may require solutionizing at temperatures above 1000°C and may be impractical for large castings. If solution heat treatment is not an option then special care must be taken to ensure that the new weld joint design will have the lowest possible level of inherent restraint.

Weld Parameters

From an understanding of the metallurgical behaviour of stainless steel casting alloys given above, general rules for fusion welding can be inferred. Low-heat-input processes are almost universally suggested for alloys that are far from homogeneous, a high-heat input process would produce flatter thermal gradients outside of the fusion zone, creating a wider zone of partial melting and greater microstructure sensitivity to HAZ hot cracking. The greater total shrinkage strain associated with the solidification of a large (high-energy-input) weld can create a restraint situation more likely to result in fusion zone solidification cracking. The flatter thermal gradients of higher-energy-input welds reduce the cooling rates through the carbide precipitation temperature range, resulting in higher likelihood of a sensitised structure in the corrosion-resistant alloys.

For the same reasons, low interpass temperatures are generally employed in the welding of these alloys. Interpass temperatures below 200°C are common. For critical applications (especially among corrosion-resistant alloys), interpass temperatures of less than 150°C are often specified. Spraying casting with water between passes is not uncommon for the austenitic corrosion-resistant alloys.

Preheating of casting prior to welding is almost never required and generally not suggested atleast for

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JOINING OF DISSIMILAR STEELS

Sometimes it becomes necessary to weld a stainless steel to a mild or low alloyed steel.

The dilution of the weld metal by the base material must then be considered to avoid the formation of hard brittle structures.

This is done by using a welding consumable with different composition to both base materials.

Mild steel filler metal will result in a high alloyed martensitic microstructure on the stainless steel side of the weld. Filler metal of the same composition as the stainless steel will result in the same microstructure on the mild steel side. This microstructure will result in extensive cracking, often very difficult to observe.

Instead the correct filler metal shall be "overalloyed" stainless steel or Ni-based alloys to secure a ductile weld metal. These filler metals can tolerate a substantial dilution from the mild steel without hardening.

Joints between stainless steel and creep resisting chromium molybdenum steels for work above 200°C should preferably be welded with a nickel base filler material to prevent carbon migration from the creep resisting steel to the austenitic material, because decarburisation of the Cr-Mo-steel will lower its creep strength.

Preheating shall not be performed on austenitic stainless steel, since this will promote carbide precipitation in the grain boundaries and the formation of sigma-phase (a hard and brittle phase that dramatically increases the risk of cracking).

An exception to this is fetritic or ferritic-martensitic 13% Cr-steel and ferritic 17-25% Cr-steel, where a pre heating temperature of 150-200°C decreases the risk of cracking.

JOINING DISSIMILAR STAINLESS STEELS TO EACH OTHER

This combination may occur in several constructions. Generally, it is not too difficult to achieve sound welds. However, some major aspects have to be considered:

- Consider the Schaeffler diagram.

  The calculated weld metal composition must not fall into any of the areas containing martensite. If the weld metal falls into the fully austenitic area, special precautions against hot cracking have to be taken unless the weld metal is alloyed with more than 4% manganese.

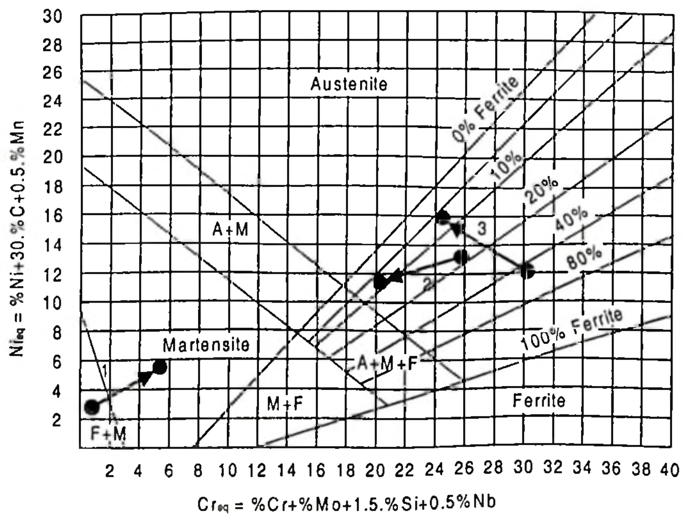

Fig. 1. Structural changes in the weld metal due to dilution by molten parent material.

- When welding stabilized stainless steel (alloyed with either Nb or Ti) to non-stabilized steel, the consumables should be either stabilized or low carbon grades. Under no circumstances should non-stabilized high carbon grades be used!
- Welding should be performed with limited heat input.

No.	Parent metal	Weld metal
1	Mild steel	Super alloyed stainless 23Cr12Ni2.5Mo
2	Stainless 18Cr 12Ni2.8Mo	Mild steel
3	Tool steel	Over alloyed stainless 29Cr9Mo

WELDING OF CLAD STEEL

A clad-material, consisting of a mild or low-alloy steel backing faced with stainless steel, usually from 10 to 20% of the total thickness, combines the mechanical properties of an economic backing material with the corrosion resistance of the more expensive stainless facing. This facing usually consists of austenitic stainless steel of the 18/8 or 18/10 type, with or without additions of molybdenum, titanium and niobium, or a martensitic stainless steel of the 13% chromium type.

- The backing steel should be welded in the normal manner with a matching consumable. If covered electrodes are used well dried low hydrogen electrodes should be preferred.

Complete Welding from Clad Side

- When the carbon steel weld metal is one layer short of the cladding a transition layer should be welded with an over alloyed filler type, like 23%Cr/12%Ni or similar.
- The cladding should be welded with matching filler material. Try to minimize diluting the clad weld.

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the corrossion-resistant alloys, because the sensitization impact of such processing is similar to the use of high-energy-input welding parameters. In the case of heat-resistant alloy castings, preheating can be used to reduce the magnitude of thermal shrinkage strains but again this benefit comes at the expense of a wider zone of partial melting. There is no known formula for preheating temperature and welding parameters for given alloy that can ensure the preclusion of welding defects. Because of this technological limitation, the use of preheating prior to welding of these alloys is questionable.

Postweld solutionizing of corrosion-resistant alloys is always recommended. For the heat treatable alloys (for example CB-7Cu), a complete solutionizing and aging heat treatment is recommended to re-establish baseline properties. Where PWHT is not possible, it is even more important to weld using low-heat-input parameters.

Where direct fusion welding is not appropriate, as in the case of an extremely hot-crack- sensitive casting, other approaches might prove useful. One option is to "butter" the area of the crack-sensitive casting joint, using a consumable of a less crack-sensitive material. This buttering involve surfacing the casting locally with a consumable before fabricating the actual weld joint. With no joint present during the buttering operation the restraint on the solidifying surface pass and the underlying HAZ of the casting can be quite small and defects (fusion zone and HAZ hot crack) may be avoided. This surfaced area can be built up slowly to a thickness where it can then be prepared as a joint for subsequent welded attachment. As another option an insert of a less hot-crack-sensitive alloy can be inserted or friction welded into the mating surfaces of the hot crack sensitive casting. This insert could then be prepared for subsequent fusion welding to the required structure. These option are contingent upon the availability of consumable materials that are acceptable in the service environment.