CORROSION-RESISTANT CASTING ALLOYS

Development of corrosion-resistant casting alloys depends on a variety of factors, and the process may be assisted by rapid prototyping and other new technologies.

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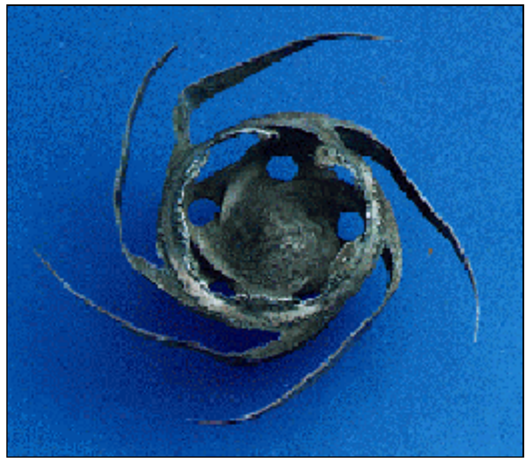

This corroded nickel impeller was in concentrated sulfuric acid for one day.

Many significant strides have been made over the past quarter century in developing new corrosion-resistant casting alloys such as the super austenitics and super duplex stainless steels, but it is unlikely that such breakthroughs will continue in the future. The reasons for this are many. For example, fewer R&D departments in captive foundries can be supported by the parent company.

Another reason is that independent foundries do not have the resources for R&D, or the money to promote a new alloy. Therefore, any new alloy is more likely to come from the wrought producers than from foundries. Furthermore, the fact that a wrought alloy exists does not mean that it will automatically or easily become a cast alloy.

Finally, alloy developers in general have pushed the limits of existing corrosion resistant alloys to the edge of their ability to be manufactured without adverse effects. It is therefore more likely that any improvements will be limited to minor enhancements or variations of existing alloys.

This article discusses the five factors that are critical to production of corrosion-resistant castings; issues important to the development of cast alloys from wrought compositions; and technologies that speed casting development, including rapid prototyping and solidification modeling.

Casting corrosion-resistant alloys

The ability of a foundry to make good corrosion resistant castings depends on its ability to adhere closely to appropriate processing parameters. This capability is certainly within the reach of many foundries, but only if the economic drive exists to support their efforts. Five basic properties and/or capabilities must be developed to produce quality, corrosion resistant castings. These five factors include good alloy castability, good weldability, good corrosion resistance, the ability to accurately analyze the alloy, and the economic incentive to produce parts.

Good alloy castability

To develop a good casting alloy from a wrought alloy usually requires a modification of the wrought alloy chemistry. It might seem unusual to discuss this variable first rather than good corrosion resistance, but it does neither the foundry nor the ultimate user little good to develop a material of outstanding corrosion resistance if it cannot be produced in a consistent manner as a cast shape.

Nevertheless, many alloys are commercially cast even though they have less than ideal castability. For example, CN7M or UNS N08007, commonly referred to as Alloy 20, has exceptional corrosion resistance. In sulfuric acid applications, few materials can match its broad chemical resistance. It was developed as a cast alloy in the late 1930's, and was quickly introduced into a wide range of parts. However, as castings of this alloy entered service, it quickly became evident that the material had poor resistance to cracking and tearing. Twenty to thirty years passed before the foundry industry fully understood why this material was so susceptible to cracking and tearing, and determined what needed to be done to avoid these problems.

A second example is CD4MCuN or UNS J93372, one of the earliest cast duplex stainless alloys, developed in the early 1960's. In addition to good corrosion resistance, it has exceptional strength. However, early castings of this alloy were inferior. They exhibited delayed brittle fractures, and were very difficult to produce with consistent dimensional properties. As with CN7M, the foundry industry eventually learned how to resolve these problems, but only after 15 to 20 years of on-and-off difficulties.

Similar problems still exist today for the newer duplex and high moly austenitic stainless steels. These stainless steels have been alloyed to the practical limits of current foundry technology, and as a result many foundries are experiencing difficulty in producing castings with acceptable quality and with the expected corrosion resistance. Therefore, it is important when purchasing these newer stainless steels and higher alloys in general, that purchasers choose foundries that are known to have the expertise to cast them successfully the first time.

Ease of weldability

Weldability is also absolutely essential to casting manufacture. Although some casting techniques minimize the need for weld repairs in some configurations, many of the castings that end up in pumps and valves are either weld-repaired or weld-fabricated at some stage of their manufacture. To have good weldability, the alloy must have good resistance to cracking and tearing during welding, and must be able to be welded with filler materials that match the mechanical and corrosion properties of the base metal.

Equally important for most commercial applications is the ability to qualify weld procedures to ASME Section IX requirements. Because shielded metal arc (SMAW) and gas tungsten arc-welding (GTAW) are the most common processes, it is critical that welding procedures be developed in at least one and preferably both of these practices.

Good resistance to chemical attack is a given requirement for corrosion-resistant castings. In general, the cast alloy must exhibit corrosion resistance comparable to the wrought product that it is complementing. To develop this corrosion resistance, the cast producer must understand the interaction between chemical composition, thermal history, and corrosion resistance. Such interactions will likely be different for the cast alloy than the wrought alloy. For example, a wrought alloy was developed that exhibited excellent resistance to 98% nitric acid. This wrought alloy was optimized as a wholly austenitic alloy with a nominal 4% silicon level.

To produce a cast alloy with equivalent corrosion resistance, the silicon level had to be increased to 5% and the chemistry balance had to be altered so that the alloy contained several percent ferrite in its microstructure. If the wrought chemistry had simply been duplicated, the cast material would have had inferior corrosion resistance and would have been extremely susceptible to cracking and tearing during casting and welding.

Accurate chemical analysis

Good castability, weldability, and corrosion resistance all depend on control of chemistry in a fairly narrow range. Therefore, the ability to accurately analyze alloy chemistry is critical. To generate reliable chemical analyses, reference standards must be available, preferably eight to ten at a minimum. These standards must bracket the expected control limits for the alloy for each element considered critical. The standards should include not only the major alloying additions such as chromium, nickel, copper, and molybdenum, but also trace elements such as sulfur, phosphorus, and carbon.

Attempts to rely on a single reference standard to analyze chemical composition can result in significant errors if the chemistry deviates only a slight amount from that of the single reference standard. Too many interactions are possible between alloying elements in corrosion-resistant castings to depend on a single sample to control alloy chemistry in a narrow range.

Economic viability

The final factor and probably the greatest incentive needed to produce a quality corrosion resistant casting is economic viability. As noted earlier, considerable up-front effort must be made to produce a quality corrosion-resistant casting. To support this up-front effort, some payback must be possible to the casting producer. A single order for a few castings might satisfy the customer, but the producer cannot come close to covering his up-front costs with a single order. Repeat business is needed to justify the investment in engineering and sampling time. It also will enable the foundry to recycle melt stock.

For every pound of metal poured, only 0.4 to 0.6 pounds of usable casting are produced. The balance of the material must either be sold for scrap or recycled back into more castings. For a single order, the volume generally does not permit material recycling during this limited window. The foundry must either raise the price to compensate for excess material, or recycle it into other cast alloys.

However, recycling is not always a straightforward process. Corrosion-resistant cast alloys contain additives such as copper or tungsten, which enhance corrosion resistance of the alloy to which they are deliberately added, but they can have disastrous effects on the ability to recycle excess material. For example, copper is added to cobalt-base alloys to enhance corrosion resistance. Several corrosion resistant cast alloys contain this element, yet the vast majority of cobalt alloys produced do not contain copper, and many have fairly low permissible residual levels. If the foundry produces a corrosion resistant cobalt alloy with copper added to enhance corrosion resistance, it must either be able to count on repeat business in this alloy to enable recycling, or lose $10 or more per pound selling in a scrap market where no buyers exist.

After corrosion-resistant wrought alloys have been designed, complementary casting alloys must be developed to produce parts such as joints, pumps, and valves. Foundries must typically make large investments of time and money to acquire accurate data for casting alloy development.

Cast alloys based on wrought

Most new corrosion-resistant casting alloys are developed by wrought producers, many times in conjunction with the ultimate customer. This is certainly the appropriate starting place, since the bulk of the product sold will be in the form of plate, sheet, tube, and bar. Research and evaluation of the wrought alloy may proceed for several months up to several years, and certainly costs the wrought producer a considerable investment in time and resources. The end result is a proprietary, if not patented, alloy with chemistry optimized to produce high quality, low-cost wrought products.

When the new alloy becomes successful in corrosion applications, an immediate need is created for equivalent cast products to produce parts such as pumps and valves. Basic data available to produce these castings include general chemistry limits for wrought alloys; basic properties of the new wrought grade, including corrosion resistance and mechanical data; limited data on weldability of the wrought grade; and a proprietary alloy name.

However, little data is available that is considered essential to the manufacture of quality castings. The foundry or foundries asked to produce cast products in these new alloys must develop much of the same data that the wrought manufacturers needed. Such data includes basic alloy chemistry to make the alloy castable, maintain levels of corrosion resistance, and meet some reasonable mechanical property requirements. Weldability must also be established, and weld procedures developed to meet ASME requirements.

Standards required for chemical analysis must be custom made, since at best one or two standards might be available commercially. The shrinkage rate for the material as it solidifies and cools to ambient temperature must be determined, to decide if near net shape dimensional requirements may demand new or modified tooling. Although thermal requirements for wrought products could be known, no data will be available about whether the cast product will respond to these same thermal treatments in an equivalent manner. These and other questions lead to a series of investments for the cast producer that must be made if a high quality cast part is to be produced.

Advanced technology

Several new technological developments can allow foundries to shorten their development time. Such technologies as stereolithography, solidification modeling, and computational systems design can shorten the development time and reduce the cost of developing new alloys significantly over traditional empirical methods.

Stereolithography is a means of rapid prototyping polymeric replicas that can then serve as an investment casting pattern to produce the final metallic part. Rapid prototyping is also suitable for making tooling for investment castings in a much shorter time, so that multiple samples can be made without having to make each directly from the rapid prototyping equipment. This technology has greatly improved a foundry's ability to produce and test new casting designs in a much shorter time frame.

Solidification modeling programs allow a foundry to take a CAD drawing of a part and, through modeling of shrinkage characteristics, determine the optimum gating and risering system for that part. Solidification modeling allows foundries to produce castings with the minimum number of gates and risers, yet produce a sound, quality part, usually on the first attempt, and at a lower cost.

Material development also benefits greatly from advances in computer technology. Better computers and computerized instrumentation enable research on a molecular and even atomic level. This nanotechnology, and computerized instruments such as the scanning probe microscope, allow observation and manipulation of atoms and molecules to make new or existing materials with enhanced properties. Today, this technology is already moving from the universities into commercial reality.

Computational systems design can shorten the development time and reduce the cost of developing new materials significantly over the traditional empirical method. This can

allow for the development of custom materials for low volume applications for which empirical methods would have been too costly and impractical. Soon, foundries may be able to use this technology to shorten the development time when designing complementary cast alloys from wrought alloys.

This article is based on *Castings for the New Millennium*, a paper presented at the 2001 NACE conference in Houston last March.

Computational systems design can shorten development time.

Table 1 - Composition of selected Ni-Cr-Mo alloys*

	C	Cr	Fe	Mo	Si	Mn	W	Cb	Al	Cu
N26625	0.06	20-23	5.0	8-10	1.0	1.0	-	3.15-4.5	-	-
N26455	0.02	15-17.5	2.0	15-17.5	0.8	1.0	1.0	-	-	-
N10276	0.02	14.5-16.5	4-7	15-17	0.08	1.0	3-4.5	-	-	-
N26022	0.02	20-22.5	2-6	12.5-14.5	0.8	1.0	2.5-3.5			
N06059	0.01	22-24	1.5	15-16.5	0.10	0.5	-	-	0.1-0.4	0.5
N30107	0.07	17-20	3.0	17-20	1.0	1.0	-	-	-	-
N06200	0.01	22-24	3.0	15-17	0.08	0.5	-	-	0.5	1.3-1.9

**Individual values are maximums*

Table 2 - Corrosion test rates in mils per year of selected Ni-Cr-Mo alloys

	Sulfuric acid			**Hydrochloric acid**	
UNS	**20%, 225°F (107°C)**	**50%, 202°F (94°C)**	**Conc., 230°F (110°C)**	**5% 175°F (79°C)**	**20% 148°F (64°C)**
N30107	31	16	11	13	11
N26455	82	17	42	21	13
N26022	116	52	77	43	20
N10276	54	13	13	28	14
N06455	62	13	56	21	11
N06022	54	16	62	46	23

N06200	5	6.4	17	22	28

Table 3 - Crevice corrosion temperature*

UNS	CCT, °C (°F)
N06200	95 (203)
N06022	83 (181)
N10276	69 (156)
N26022	67 (153)
N30107	62 (144)
N06455	36 (97)
N26455	30 (86)

**MTI critical crevice corrosion temperature above which crevice corrosion is observed in 6% $FeCl_3$,*