CASTINGS IN THE NEW MILLENNIUM

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ABSTRACT

Cast alloys will continue to be a necessary part of chemical processing equipment into the next millennium and beyond. However, casting users need to understand that there are unique and intentional differences between cast and wrought alloys. Just because a wrought alloy exists doesn't mean that a complementary cast alloy can be easily produced. However, by understanding the issues involved and by having everyone – from wrought producers to the end-users – working in cooperation with the foundries, we can achieve the goal of good quality complementary cast alloys.

INTRODUCTION

The future of castings is still bright despite numerous U.S. foundries closing their doors during the latter part of the 20th century. Because castings can offer a significant cost advantage over many fabricated wrought components, castings will continue to see extensive use in chemical process equipment. However, casting users need to understand that there are differences in the availability and properties of cast alloys versus their wrought equivalents and understanding these differences can lead to more cost effective use of each type of material and the avoidance of many problems.

Over the years numerous new cast alloys have been introduced and successfully been manufactured to satisfy the needs of industry. Introduction of these new alloys has not always gone smoothly, and in many cases numerous failures have occurred until the right processing parameters have been developed to provide consistent quality and corrosion properties in these cast alloys. The reasons for these startup difficulties will be reviewed, and some recommendations made to avoid many of these past problems.

FUTURE MATERIAL TRENDS

There have been significant strides made over the past quarter century in developing new alloys like the super austenitics and super duplex stainless steels but the authors like others[1] believe that we will see fewer such breakthroughs in the future. There are several reasons for this. First, there are fewer captive foundries whose R&D can be supported by the parent company. Secondly, for cost competitive reasons independent foundries do not have the resources for R&D nor the money to promote a new alloy. Therefore, any new alloy is more likely to come from the wrought producers than from foundries. Lastly, alloy developers in general have pushed the limits of existing corrosion resistant alloys (CRA's) to the edge of their ability to be manufactured without adverse effects. More likely any quantum improvements in materials will be in the area of polymers and ceramics[2], while any metallic improvements will be limited to minor enhancements or variations of existing alloys. The pressing issue for foundries has always been and will continue to be the ability to provide a multitude of alloys with acceptable quality in the timeframe demanded by the users of CRA's. Just because a wrought alloy exists doesn't mean that it will automatically or easily become a cast alloy.

WHAT'S NEEDED TO MAKE QUALITY CORROSION RESISTANT CASTINGS?

While casting technology is very ancient, consistent manufacture of quality corrosion resistant castings has been a more recent development. The ability of a foundry to make good corrosion resistant castings depends on the foundry's ability to develop certain processing parameters. The development of these parameters is certainly within the reach of many foundries but only if the economic drive exists to support the efforts to develop these parameters.

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
- Ability to accurately analyze the alloy
- Economic drive to produce parts

Good alloy castability consists of properties of the material that must be attained to make the alloy producible as a casting and this usually requires a modification of the wrought alloy's 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 of the casting little good to develop a material of outstanding corrosion resistance if it cannot be produced in a consistent manner as a cast shape.

A good castable alloy will be one that:

- Fills thin sections readily when cast into the mold cavity
- Displays minimal mold/metal interaction issues
- Has a good solubility for gases
- Has good resistance to cracking and tearing
- Has good dimensional stability

While numerous alloys are produced that have less than ideal castability, these alloys did have (and some still do have) poor reputations in industry. Several examples will be presented to reinforce the importance of good castability. First, 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 to this common industrial acid. The material was developed as a cast alloy in the late 1930's and quickly introduced into a wide range of services. As castings were produced in this alloy it quickly became evident that the material had poor resistance to cracking and tearing. It took the foundry industry 20 to 30 years to fully understand why this material was so prone to cracking and tearing and what needed to be done to avoid this problem. A second example is CD4McuN or UNS J93372, one of the earliest cast duplex stainless alloys. This material was developed in the early 1960's. In addition to good corrosion resistance, it has exceptional strength properties. Early experiences with this alloy were poor. Castings made from this material exhibited delayed brittle fractures and castings 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 problems.

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 these alloys 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 produce these alloys successfully the first time.

Continuing with the steps necessary to produce quality, corrosion resistant castings, the ability to weld castings is absolutely essential to their manufacture. While some casting techniques minimize the need for weld repairs in some casting 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 be able to be welded with filler materials that match mechanical and corrosion properties of the cast base metal. Equally important for most commercial applications is the ability to qualify weld procedures for the alloy to ASME Section IX requirements. Since shielded metal arc (SMAW) and gas tungsten arc (GTAW) are the processes most commonly used in the foundry industry, it is critical that welding procedures be able to 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. These 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 operations.

Another critical element to produce consistent corrosion resistant castings is the ability to obtain an accurate and reproducible chemical analysis on the material. Good castability, weldability and corrosion resistance all depend on control of chemistry in a fairly narrow chemical range. To obtain good chemical analyses, reference standards must be available, preferably 8 to 10 at a minimum. These standards must bracket the expected control limits for the alloy for each element considered critical for control of the properties of the castings. The standards will include not only the major alloying additions like chromium, nickel, copper, and molybdenum but also trace elements like sulfur, phosphorus and carbon. Attempts to use a single reference standard to analyze chemical compositions of cast materials can result in significant errors if the chemistry of the cast material deviates only a slight amount from that of the single reference standard. Too many interactions occur between alloying elements in corrosion resistant castings to use a single sample to control alloy chemistry in a narrow range.

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 there must be some payback for the casting producer. A single order for a few castings might satisfy the casting user, but the casting producer cannot come close to covering his up front costs with a single order. Repeat business is needed for the castings to justify the investment in engineering and sampling time that must be made. It also will enable the foundry to recycle melt stock generated. For every pound of metal poured to produce a casting only 0.4 to 0.6 pounds of usable casting are obtained. The balance of the material must either be sold for scrap value or recycled back into more castings. For a single order the volume of castings produced will generally not permit material recycling during this limited casting-manufacturing window. The foundry must either raise the price of the casting to compensate for this excess material generated or recycle it into other commonly made cast alloys. Many of the corrosion resistant cast alloys contain additives like copper or tungsten. While these additives enhance the corrosion resistance of the alloy to which they are deliberately added, they can have disastrous effects on the ability to recycle excess material. Consider the use of copper in 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 of the excess cast material or lose $10 or more per pound selling this excess material in a scrap market where no market exists of this high copper material.

WHAT'S AVAILABLE TO PRODUCE A NEW CAST CRA

Most new CRA's are developed by wrought producers, many times in conjunction with the ultimate users of these materials. This is certainly the appropriate starting place since the bulk of the product sold will be in the form of plate, sheet, tube, bar, etc. Research and evaluation on the wrought alloy may proceed from several months 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 finds success in corrosion applications, an immediate need is created for equivalent cast products to produce items like pumps and valves. Basic data available to produce these castings include:

- General chemistry limits for wrought alloy
- Basic properties of the new wrought grade including corrosion resistance and mechanical data
- Limited data on weldability of the wrought grade
- A proprietary alloy name

There is little data available that is considered essential to the manufacturing 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 product manufacturers needed to produce quality wrought products. Data like basic alloy chemistry to make the alloy castable, maintain desired corrosion resistance and meet some reasonable mechanical property requirements must be developed. Weldability must 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 on casting might demand new or modified tooling be considered. While thermal requirements for wrought product might be known, no knowledge will be available 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 the desired, high quality cast part is to be produced.

MARKET EXPECTATIONS FOR NEW CAST ALLOYS

Hopefully, it is now appreciated that new cast CRA's, like their wrought counterparts, demand considerable effort in time and dollars to bring them on line even when the basic wrought alloys have been successfully produced. Unfortunately, experience with new alloys in the foundry industry indicates that this has often not been the case in the past.

Orders for new alloys come into the foundry with urgent requests for one or two parts in the shortest time possible. The orders are placed with unrealistic expectations of matching all properties and performance of the wrought alloy. Also, because of past problems with new alloys ordered by CRA users, the castings are ordered with extremely tight inspection requirements including the highest quality radiographic and penetrant inspection standards. No discussion of future expectations for the material is undertaken.

Obviously, the foundry will be hesitant to invest the needed resources to properly make this alloy. The end result, if the foundry is a good guesser, will be an alloy that gives good properties and meets all expectations. Unfortunately, in many cases both the cast alloy and the foundry often get a bad reputation and discourage general use and manufacture of a promising new alloy in the cast form.

CAN NEW CAST CRA's BE SUCCESSFULLY INTRODUCED?

Introduction of new CRA's does not have to be as difficult as current market practices make it. Many foundries are technically capable of and eager to introduce new alloys to expand their business and give themselves a niche market to serve. However, one must first ask whether a matching cast alloy is truly needed. Because of the development issues previously discussed, foundries tend to standardize on certain alloys for economies of scale. For example, wrought 304 stainless steel is very commonly used in the chemical industry but cast 304 (CF8) is less common and usually more expensive than cast 316 (CF8M). The reason for this is that CF8M has equal or better corrosion resistance than CF8 in practically every service, thus a foundry can produce more CF8M castings less expensively. The reverse is true in the wrought industries where raw material costs are more influential on pricing than processing parameters.

Another good example is the Ni-Cr-Mo alloys of which there are several (Table 1). Some contain tungsten, copper or niobium which, as mentioned earlier, can cause the foundry problems in being able to recycle the excess metal as well as analyzing these alloys accurately. As a result, most foundries prefer to standardize on one of these Ni-Cr-Mo alloys.

While there are certainly specific services where one of these alloys may excel, there are many other services where several of these alloys will be suitable. Some of these newer Ni-Cr-Mo alloys have been designed to provide increased resistance to pitting and crevice corrosion as indicated by their high critical crevice temperature (Table 2). However, in some of the more common services one finds that some of the older Ni-Cr-Mo alloys work well and sometimes better than the newer versions (Table 3). So, again, a user must ask whether a specific cast Ni-Cr-Mo alloy is really necessary to match the wrought equipment. If it is, then the key is to give foundries the economic incentives to develop these new alloys and give them a reasonable time frame for research and development before ordering must meet delivery schedules and quality requirements.

NEW TECHNOLOGY

There are several new technological developments that can allow foundries to shorten their development time for many of the issues previously discussed. 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 the traditional empirical methods.

Stereolithography is a means of rapid prototyping that can be used to make polymeric replicas that can then be used as an investment casting pattern to produce the final metallic part. Rapid prototyping is also being used to create 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.

Another technology that is seeing greater use in foundries today is the use of solidification modeling programs. These programs allow a foundry to take a CAD drawing of a part and through solidification modeling of an alloy's shrinkage characteristics, determine the optimum gating and risering system for that part. Solidification modeling is taking what used to be an art and turning it into a science. This science is allowing foundries to produce castings with the least amount of gates and risers but yet produce a sound, quality part, usually on the first attempt, and at a lower cost.

Like the previous areas of technology already discussed, material development is also benefiting greatly from advances in computer technology. Better computers and computerized instrumentation are allowing us to conduct alloy and polymer research on a molecular and even atomic level.[3] This nanotechnology and computerized instruments like the scanning probe microscope allow us to observe and manipulate atoms and molecules to make new or current materials with enhanced properties. Today, this technology is already moving from the universities into commercial reality.[4, 5] This 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 bw 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 of creating complementary cast alloys from wrought alloys.

CONCLUSIONS

Solutions for these problems are relatively simple to state, but certainly challenging to implement.

- First, be realistic as to what can be done in the short term. Just because a wrought alloy exists, do not assume the technology to produce an equivalent cast form exists.
- Second, consider the economic realities of limited production of many new alloys. It may not always make economic sense to produce a new cast alloy particularly if an existing cast alloy already fills the corrosion niche of this new alloy. Low per pound alloy costs that drive the production of high volume wrought products may not offset the upfront costs to develop and produce a few corrosion resistant castings if a substitute cast alloy already exists and that the foundry has a good track record of producing.
- Third, if the new alloy is needed because it fills a unique niche or because high volume use of castings justify its development as a cast alloy, give the foundry a chance to develop process parameters to successfully produce this material. Where possible, encourage joint efforts between wrought producers and cast producers when alloys are under development rather than demand performance just a few weeks before the castings are needed.
- And finally, there is a significant difference between the concepts low price and low cost. When it comes to buying corrosion resistant castings the difference had better be known.

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TABLE 1
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 3
MTI CRITICAL CREVICE TEST ABOVE WHICH CREVICE CORROSION IS OBSERVED IN 6% $FeCl_3$, 24 HOUR EXPOSURE

UNS	CCT °C
N06200	95
N06022	83
N10276	69
N26022	67
N30107	62
N06455	36
N26455	30

TABLE 2
Ni-Cr-Mo ALLOYS

	Corrosion Test				
	Sulfuric Acid			HCl	
UNS	**20%, 225° F**	**50%, 202° F**	**Conc., 230° F**	**5% 175° F**	**20% 148° F**
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