technical monograph 39

A Reliable Base for High Nickel Equipment

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A Reliable Base for High Nickel Equipment

Insist that the makers of your high-nickel-alloy pumps or valves use castings prepared to specifications like these

Many chemical engineers that use high-nickel-alloy pumps, valves or other process equipment have insisted on a role in specifying the castings that the manufacturers use in making such equipment. They take that role because improperly prepared high-nickel-alloy castings can pose major problems, including poor weldability, poor casting integrity, and lower-than-expected corrosion resistance.

Casting difficulties can be avoided if the specification process is carried out properly. This requires a close working relationship involving the equipment manufacturer, the equipment customer and the foundry that makes the castings. This process has been used by Fisher Controls, and it has proven to be very successful[1,2].

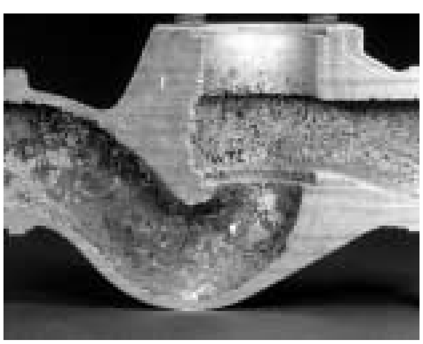
Cast is not wrought

Cast and wrought alloys often behave differently in identical service conditions. In particular, many cast alloys are not as corrosion-resistant as the wrought alloys that are commonly considered equivalent, such as those in Table 1. As Table 2 demonstrates, the composition of two equivalent alloys (for instance, cast alloy CN7M and wrought alloy N08020) can differ.

For an example of problems this can cause, consider two high-nickel materials, Alloy C and Alloy 20. The former is a standard material-of-construction for chlorine dioxide service; the latter was developed over fifty years ago for sulfuric acid service, and is still the standard in that usage. In wrought form, they behave well in those situations. But Figures 1 and 2 illustrate some of the corrosion problems seen with the cast alloys. Both show very severe intergranular corrosion and pitting of cast Alloy 20, CN7M, which has occurred in 3% to 98% sulfuric acid and 40-50% nitric acid.

In light of such differences, it is good practice to avoid use of wrought-alloy tradenames when specifying the material for equipment fabricated from castings. This, of course, implied a corollary: It is worthwhile for the equipment customer (even if a chemical rather than a mechanical engineer) to gain some familiarity with how various equipment components are fabricated — from castings, from forgings, from bar stock, or whatever the case may be.

Be aware that a given tradename may encompass a wide range of products. A prime example is Hastelloy, a Haynes International tradename often specified for corrosive applications. Saying “Hastelloy” is not specific enough to get the right material for corrosive service. Some 15 Hastelloy alloys have been produced over the years. The properties of some differ radically from the properties of others, so one alloy may perform well in a given environment while others may fail catastrophically. Commonly specified is Hastelloy C, but this is no longer produced; Hastelloy C276 is the “standard alloy C” that has been used in recent years. But there is also Hastelloy C4 and a newer alloy, Hastelloy C22. And, more to the point of this article, there are the cast Hastelloy C types; CW12MW, CW12M-1, CW12M-2, CW6M, CW2M and CX2MW. Each has its own composition and properties, and must be specified accurately to yield the desired results.



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FIGURES 1 (left) and 2 (right). Severe corrosion of valve parts that are made from castings vividly bears out the pitfall of confusing cast alloy with wrought alloy

Test procedures: dubious value

Some equipment customers in the chemical process industries have required that the foundry supplying the equipment manufacturer to apply specific tests to the high-nickel-alloy castings it produces. Most commonly required are two forms of non-destructive testing (NDT): radiographic testing (RT) of all pieces, and liquid-penetrant (LP) testing of all pieces. Unfortunately, such NDT is expensive and ineffective.

Radiographic testing does not work so well with high-nickel-alloy castings as with castings of carbon steel and stainless steel. The resolution is not good, due to the large grain size of the material and the behavior of X-rays with nickel alloys. As noted further on in this article, radiography should be used only for monitoring.

Liquid-penetrant testing is difficult on as-cast surfaces because of surface roughness and fine surface porosity. Fine porosity is common because of reactions between the molten material and the mold. Many hours of grinding and repeat LP testing can be spent trying to remove all of the test indications, whereas in fact these indications are generally shallow and have no detrimental effect. The truly relevant defects in nickel-alloy castings are generally visible to the naked eye.

Even with 100% RT and LP testing, many conventionally produced nickel–alloy castings become scrapped during machining. Their poor weldability makes it impossible to successfully weld-repair minor sand and slag inclusions uncovered during machining. Cracks will develop around the weld-repair heat-affected zone (HAZ); the weld and HAZ must then be ground out and re-welded; again, a new crack will appear. The process continues until finally the casting is scrapped. This, of course, results in long delays.

Laying the groundwork

Apart from realizing that cast material is different from wrought and that NDT is not to be applied indiscriminately, the equipment customer can also benefit from becoming familiar with a systematic procedure for assuring high-nickel-alloy casting quality. Such a procedure is summarized in the rest of this article. Three preliminary steps lay the groundwork. Then come seven points that are related to specification of the castings themselves.

The first preliminary step consists of evaluating and qualifying foundries. An excellent evaluation tool is a weldability test that involves the test plate spelled out in ASTM Material Specification A494, Supplemental Requirement S22, and Paragraph 22.1.2(3).

The plate, shown on the right side of Fig. 3, is a difficult casting to pour because of the large difference in section thickness between the base of the weld cavity in the center of the plate and the overall 1-in, thickness of the plate.

The poured plate should be solution-heat-treated by the foundry, then shipped to the equipment manufacturer’s plant. There, the cavity should be filled with a matching-composition weld filler material. The welder and the procedure for this step should be qualified to an accepted standard, such as Section IX of the ASME Boiler and Pressure Vessel Code.

Next, test bars 3/8 in. thick should be cut from the plate and bend-tested over a 1 1/2-in. mandrel per ASTM A494, producing a U-bend as seen on the left side of Fig. 3. Any cracks over 1/8 in. on the test bar, other than small edge tears, are cause for rejection. Also examine the test bars closely for fine cracks along the casting grain boundaries or dendrite boundaries: In castings of less than optimal quality, dozens are often seen. In such a case, the foundry should be rejected.

The correlation between weldability and casting integrity is excellent because the processes are similar: In both, liquid metal solidifies and cools to room temperature with stresses generated that exceed the yield strength of the material. If a casting has good weldability, it will also have high integrity and few cracks or shrinkage defects.

Once a qualified foundry (or more than one) has been selected, the next step’s to arrange for casting patterns (including gates, risers and other accessories) that will be dedicated solely to high-nickel-alloy service.

Most patterns used by valve and pump manufacturers are produced and rigged to pour carbon-steel and stainless–steel castings. This is natural, as the tonnage in the steel and stainless steels far exceeds that for the high-nickel alloy materials. However, the use of such pattern equipment for high-nickel alloys is unacceptable, due to differences in solidification properties. The shrinkage rates differ only slightly, but the gates, risers and other accessories must be considerably different.

Recent developments with urethane resins make it much more economical to duplicate pattern equipment quickly. First, the urethane is used to produce a negative imprint from existing equipment; then, a new positive pattern is made from this negative. An unlimited number of duplicates can be made from the one negative.

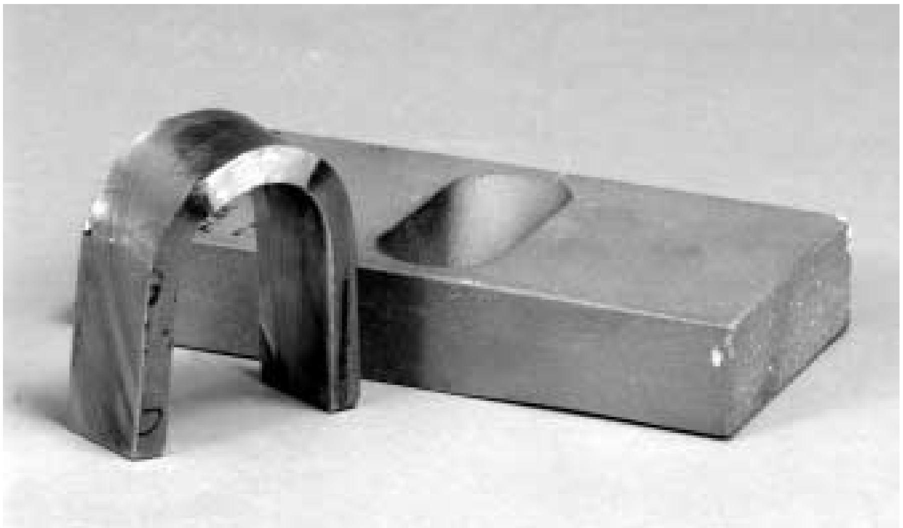

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Figure 3. In foundry evaluation, a casting (right) is filled with weld filler, then sliced to yield a bar for bend-testing

Once the dedicated pattern equipment has been produced, try-out castings should be poured for each pattern-alloy combination. These castings should be radiographed and destructively tested by sectioning. This determines whether there are any inherent casting defects, such as shrinkage, that would crop up in most castings poured from these patterns. If inherent defects are found, pattern-rigging modifications can be made at this point.

On to the specifications

The three steps of selecting a foundry, arranging for dedicated patterns and testing those patterns set the stage for preparing the actual specifications for the castings. These specifications must be imposed at the time the castings are ordered from the foundry. Conventional ASTM and ASME specifications that cover castings are inadequate by themselves, and must be supplemented by the equipment customers (or equipment manufacturers) own specifications. That way, the corrosion resistance will nearly approximate that of the wrought forms in most environments.

1. *Raw material*: Specification of the metal to be poured must embrace both composition and quality. The composition specification varies, of course, with the alloy to be used; but in some cases, the allowable maxima should be more stringent than the standard compositions listed in Table 2.

For instance, for CN7M (the cast version of Alloy 20), the maxima should include 0.03% of carbon, 1.0% for silicon, 0.03% for phosphorus, and 0.015% for sulfur. And for CW2M (a new cast version of Alloy C, which avoids some inherent corrosion problems found in CW12MW(4)), the sulfur maximum should be 0.015%.

As for preparing the raw-material specification with regard to quality, a key treatment to be specified is argon-oxygen-decarburization (AOD) refining. This is relatively new foundry process, offering the close control that is critical for high-nickel-alloy castings. The metal is first melted in an electric arc or induction furnace, as is the normal practice. Then the molten metal is poured into a refractory-lined AOD vessel. There, submerged tuyeres (nozzles) permit the injection of argon, oxygen, nitrogen and combinations thereof. The process gives simultaneous decarburization (C <0.015%), deoxidization, desulfurization (S <0.01%), degassing and reduction of metallic oxides in the slag, to produce a cleaner and more-uniform molten metal. Castings made from it boast high impact-toughness and good weldability.

When CN7M alloy is to be used, either the melt itself must be AOD refined or else AOD-refined ingots (available from a number of suppliers) must be employed as melt stock. Use of scrap material is prohibited. Gates and risers from heats poured of this material cannot be reused without again going through an AOD. For CW2M and M35-1, the use of virgin high-purity melt stock or AOD refined material is required, and use of any scrap material is prohibited.

2. *Heat qualification*: The previously described weldability test used for foundry qualification is also recommended for qualifying each heat. This approach is more realistic than trying to impose specifications regarding all the many activities related to foundry

practice. The test plate is poured with each heat, and solution-heat-treated per the specification. Then the foundry welds the test plate, sections the bar, and runs the bend test. Per ASTM A494, the maximum crack size permitted is 1/8 in. anywhere in the base material or weld HAZ.

3. *Pouring temperature*: The one item directly related to foundry operation that should be included is the pouring temperature. It is sufficient to specify that the minimum pouring temperature be used. This must be consistent with the size of the castings, the type of mold material, the alloy being melted, and a number of other factors.

4. *Visual inspection*: The castings should be visually inspected in accordance with ASTM procedure A802(5), with specially fabricated plastic plates for reference standards as regards roughness, porosity and other surface properties. Acceptance level 1 or 2 should be specified, as is appropriate for the specific castings.

This is a new procedure, which offers advantages over the Manufacturers Standardization Society procedure MSS-SP-55(6). The latter has been the most commonly used visual-examination specification, but it contains no acceptance criteria.

5. *Weld repairs*: It is everyone's goal to eliminate weld repairs. As a practical matter, however, some will usually be required for cosmetic blemishes. Because of the critical nature of these castings, it is very important to specify the weld procedure carefully.

The welder and weld procedure must both be qualified with respect to ASME Section IX, mentioned above. Air-arc gouging for excavation of defects should be prohibited within 1/8 in. of the casting surfaces because this process generates a great deal of heat. Grinding with a carbide tool, machining or careful hand grinding are recommended for material removal. LP examination of the excavated area is recommended both before and after welding. Any test method in ASTM Specification E165 is acceptable. Maximum acceptable indications are 3/16 in. and 1/8 in. for linear and rounded indications, respectively(7).

The filler material should be carefully specified. Recommended American Welding Society (AWS) filler materials are NiCu-7 for the M35-1 material, NiCrMo-7 or NiCrMo-l0 for CW2M, and 320LR for CN7M. These filler materials all have good ductility in the as-welded condition.

Minimum-heat-input procedures should be used. So should small-diameter electrodes, stringer beads, 250^{o}F (121^{o}C) maximum interpass temperatures, and minimum current settings.

6. *Heat treatment*: Whereas M35-1 can be used in the as-welded condition, all CW2M and CN7M castings must be solution-heat-treated following all foundry weld repairs. Unfortunately, ASTM specifications are sometimes lacking as regards the temperature and time-at-temperature for the solution-annealing process. CW2M should be solution annealed at 2,250^{o}F (1232^{o}C) for one hour per inch of thickness and water quenched; CN7M should be solution annealed at 2,150^{o}F (1177^{o}C) for one hour per inch of thickness, and water quenched.

7. *Nondestructive testing (NDT)*: Radiography should be used solely as a monitoring process. Ten percent of the castings poured from each pattern should be radiographed per ASTM A494 Supplementary Requirement S2. The acceptance criteria should be level 3 for Categories A, B and C. For Categories D-G, no cracking, hot tears or inserts are permitted.

If defects other than random sand and slag inclusions are found, all remaining castings should be radiographed, then repaired or scrapped. The patterns should be modified to correct the problem. If a random-type defect, such as sand, slag or porosity, is found by radiography, a second casting should be selected at random and radiographed. If defects are found then all the remaining castings should be radiographed. If the second casting is clean, then no further radiography is necessary.

Table 1. This is a listing of the common high nickel casting alloys with ACI cast designations, tradenames of the wrought "equivalents", generic designations and wrought alloy UNS numbers

ACI Designations	Wrought Tradenames	Generic Designations	UNS Number for Wrought Alloy
CN7M	Carpenter 20Cb3	Alloy 20	N08020
CW12MW	Obsolete Hastelloy C	Alloy C	N10002
CW2M	New Hastelloy C	Alloy C4	N06455
CX2MW	Hastelloy C22	Alloy C22	N06022
CW6MC	Inconel 625	Alloy 625	N06625
CY40	Inconel 600	Alloy 600	N06600
CZ100	Nickel 200	Alloy 200	N02200
M25S	S-Monel	Alloy S	– – –
M35-1	Monel 400	Alloy 400	N04400
N12MV	Obsolete Hastelloy B	Alloy B	N10001
N7M	Hastelloy B2	Alloy B2	N10665

Table 2. Compositions of the high nickel casting alloys and wrought "equivalents" described in this paper.

GRADES AND COMPOSITION					
% Elements	**CN7M**	**N08020**	**CW12MW**	**CW2M**	**N10276**
C, max.	0.07	0.07	0.12	0.02	0.02
Mn, max.	1.5	2.0	1.0	1.0	1.0
Si, max.	1.5	2.0	1.0	0.8	0.08
P, max.	0.04	0.045	0.04	0.03	0.04
S, max.	0.04	0.035	0.03	0.03	0.03
Cu	3-4	3-4	– – –	– – –	– – –
Mo	2-3	2-3	16-18	15-17.5	15-17
Fe	bal.	bal.	4.5-7.5	2 max.	4-7
Ni	27.5-30.5	32-38	bal.	bal.	bal.
Cr	19-22	19-21	15.5-17.5	15-17.5	14.5-16.5
Cb	– – –	8 X %C	– – –	– – –	– – –
W	– – –	– – –	3.75-5.25	1 max.	3-4.5
V	– – –	– – –	.2-.4	– – –	0.35 max.

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