Purchasing Duplex Stainless Steel Castings:

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Beyond Specifications

Duplex and superduplex stainless steels, henceforth referred to as "duplex" and "superduplex", offer the corrosion resistant alloy (CRA) industry a unique, added-value combination of corrosion resistance, excellent mechanical properties and cost reduction. Current applications for duplex and superduplex steels include offshore oil and gas, chemical processing, pulp and paper, flue gas desulphurization, mining, caustic production, desalination and transportation. Unlike other CRA's the development of cast duplex and superduplex parallels the history of its wrought counterpart, and could be considered to exceed it in diversity and fitness for purpose.

Whether components are being purchased for plant replacement or for a new CRA project, the consistent availability of castings – to meet increasingly short lead times, in specification, at a competitive price – is essential to their consideration as candidate materials. A perception exists with some purchasers of duplex, but especially superduplex components that, compared to wrought products, castings are both more complex and less mature, with a related decrease in confidence in both castings and foundries. Whether real or perceived, lack of confidence in a material can lead to overly conservative decisions, such as avoidance or over-specification, particularly in high-risk applications for which superduplex alloys should be the materials of choice. In these cases the added benefits of superduplex castings are either lost or seriously mitigated, increasing the life-cycle costs of the operation.

The purpose of this article is to make the selection of duplex and superduplex castings more predictable and cost-effective by addressing some of the key areas of concern regarding the quality and consistency of these materials. As with all perceptions, there is some truth to the concerns about purchasing duplex castings. Anecdotal evidence describes brittle castings, unweldable castings, leaking castings, castings that corroded prematurely, but these stories are exceedingly rare, given the tens of thousands of duplex and superduplex castings performing well in challenging applications. Responsibility for eliminating these rare problem castings lies with end users, manufacturers and foundries, and we can all do better! Let's start with an overview of duplex and superduplex casting procurement "musts".

- Decisions must be based on facts, not perceptions.
- Decisions must recognize the manufacturing and life cycle cost of the component, not the cost of the raw casting.

- Procurement activities must incorporate the identification and selection of competent foundries with proven records of duplex and more importantly, superduplex casting production.
- Procurement must involve all parties in the dialogue leading to final specification.
- Each "customer" must ensure that the final specification is sufficiently but not unnecessarily restrictive.
- Finally, the procurement process must result in an explicit and quantifiable contract that defines properties, not processes but contains sufficient checks to ensure that each casting meets the end user's requirements.

Getting started.

Regardless of whether the castings are for replacement parts, or part of a new project, the end user must initiate the procurement process by defining the basic requirements of component and material performance. These will be based on existing knowledge, parts history, process changes and upgrading strategies, with input from competent, experienced materials engineers and CRA specialists. When confronted by apparent anomalies, the huge database of industrial experience must be tapped to separate perception from fact.

Cheap or Economical?

Focusing primarily on the purchase price of the casting is an easy but potentially fatal exercise. Casting cost is a visible, negotiable factor that should be considered, but only in the total context of the casting application. Manufacturing costs, scrap costs, time penalties, risk costs, and life-cycle costs are less visible and much harder to quantify, but are potentially far higher, often orders of magnitude higher, than the casting cost. In addition to the monetary cost of an inferior casting, there is the added cost of the loss of reputation of the entire supply chain, including the end user's procurement team. Don't be cheap; be cost conscious. You cannot afford a bad casting, regardless of low purchase price and the negotiated "protection" of back-charges and penalties.

Invest in supplier selection!

It takes time and money, both scarce commodities, to create a short-list of competent foundries, but this is your due diligence. Castings are far more complex than wrought products - that is the negative side of their advantage - diversity and customization! They are purpose-designed and cast to near-net shape to provide both optimum component performance and reduced machining costs. Superimposed on this complexity is the added requirement of obtaining optimum component performance from the selected duplex or superduplex alloy. Competence in either good casting production or duplex/superduplex metallurgy alone is a necessary but insufficient condition for the production of high quality duplex/superduplex castings. Foundry competence must be confirmed in the production of duplex/superduplex castings in the size, shape, complexity and performance level required for the application. Foundry capability can be assured by following another set of procurement "musts".

- The foundry must have a documented record of successful production of duplex/superduplex castings of similar size and complexity, produced to similarly stringent criteria for casting quality and material performance.

- The foundry must be registered to a current ISO9000 quality system. This does not ensure competence in casting production or duplex/superduplex metallurgy, but it provides the framework for assessing and improving process control, cost reduction, product quality and customer service. For certain jurisdictions, ISO Registrar competence may be an issue, such as the recently introduced PED requirement for registrar accreditation (see www.european-accreditation.org).

- The foundry must have not only the physical capability but, more importantly, the knowledge base to produce complex duplex/superduplex castings to the highest specifications. Duplex, but especially superduplex castings are metallurgically complex, but are readily controllable if the foundry understands and implements the following fundamentals.
  - Standards such as ASTM do not provide a recipe for an acceptable duplex stainless steel casting. Within the ASTM limits, the foundry can produce castings, with a wide range of properties, both acceptable and unacceptable! Remelting purchased ingot or plate, purchased to a general specification, is also no guarantee of an acceptable casting composition. The foundry must understand the basic metallurgy of duplex/superduplex alloys and apply that knowledge to design the specific composition that meets the customer's requirements.
  - Duplex/superduplex alloys are influenced primarily by the relationship between the ferrite-forming and austenite-forming elements. The Cr_{eq}/Ni_{eq} ratio used in ASTM A800 for austenitic stainless steels provides a starting point, but cannot be extrapolated to the range of 40-60% ferrite typical of most duplex/superduplex requirements. The foundry must have sufficient production data to create an empirical Cr_{eq}/Ni_{eq} equation that can be used for in-process composition control. This ratio, which also must consider the effects of supplementary elements such as Cu and W, is essential to the efficient, consistent production of castings with the correct ferrite content.
  - Knowledge of the influence of composition on the formation of sigma and other harmful phases is also essential, if duplex, but especially superduplex alloys are to be free of deleterious phases in heavy sections.
  - Corrosion resistance must be considered in alloy selection, production and testing. PREN (Pitting Resistance Equivalent Number) is used as a general ranking criterion for the resistance of CRA's to localized damage (pitting) caused by chlorides and other oxidizing species. The most common PREN equation is:

    $$PREN = \%Cr + 3.3(\%Mo) + 16(\%N)$$

    In a recent issue of Valve Magazine, Bodonaro, Bush and Spence (1) discuss this and other PREN equations and their relationships to specific corrosion environments. In a much earlier article, Okamoto (2) described a modified PREN equation that recognized the beneficial effects of W. The PREN is an empirical but indirect means, based on composition, of ranking and specifying the general pitting resistance of duplex/superduplex alloys. Pitting resistance can be assessed directly by the use of ASTM G48, which ranks CRA's by their critical pitting temperature (CPT) in a standard ferric chloride environment. The sensitivity of the CPT (of a representative test piece) to deleterious phases in duplex/superduplex alloys gives it the added advantage of evaluating the microstructure of the casting. Correct usage of the PREN and CPT in a casting order requires selection of the appropriate PREN equation and minimum PREN, and the specification of the CPT test method and acceptance criteria. If the CPT test is to be used for the detection of deleterious second phases, the test temperature must be appropriately close to that predicted by the alloy's PREN (>25 deg. C for duplex and >50 deg. C for superduplex).

- After considering corrosion requirements the foundry must understand the effect of the major elements in the PREN equation on ferrite content and the propensity of the alloy to form harmful second phases, such as sigma. A "balanced" alloy will readily meet both PREN and a wide range of microstructure criteria.
- Finally, to avoid gas porosity defects, the foundry must also understand and control composition, subject to other more important requirements, to ensure sufficient solid solubility of nitrogen is maintained throughout the casting.

- Composition alone cannot assure good castings; heat treatment is equally important. Selection of solution annealing temperature, within the prevailing specifications, exerts an influence on ferrite content that is important, albeit secondary to the effect of Cr_{eq}/Ni_{eq} ratio. Rapid cooling from the solution annealing temperature is vitally important in preventing the formation of sigma and other harmful second phases in heavy section duplex castings. Oven-to-quench transfer time, and quench tank capacity and agitation power are essential factors in foundry evaluation. (In the critical area of sigma prevention in heavy section superduplex alloys, near net shape castings offer a significant advantage over solid forgings.)

- Competence in casting technology must play an equal role with metallurgy in the consistent and efficient production of high-specification, high-risk duplex/superduplex castings. In addition to metallurgical competence, a qualified foundry must demonstrate the following equally important abilities.
  - Understanding and practice of directional solidification principles to ensure consistently acceptable casting soundness at lowest cost.
  - The use of special solidification aids such as chilling, padding, tapering and other proprietary techniques further enhance quality, without any cost penalty.
  - Appropriate control of tooling and molding to ensure consistent casting dimensions and acceptable surface finish.
  - Special casting processing procedures (probably confidential) that recognize the unique requirements of duplex, but especially superduplex, alloys.
  - Qualified casting NDE and repair procedures that include appropriate defect identification, confirmation of defect removal, defect repair mapping, weld repair using certified procedures and welders, NDE of the weld repairs, and appropriate PWHT. Repaired castings should meet all specifications, with the possible

exception of weld metal ferrite content. The overwhelming dominance of fabrication welding (without PWHT) has resulted in the "overalloying" of most duplex/superduplex weld consumables. When subjected to a solution anneal/water quench, overalloying will result in a lower weld metal ferrite content.
  - Alloy-specific production and inspection plans, starting with first article approval and ending with pickling, passivation and protection of completed castings.

- To confirm that its plant and expertise can be translated into good castings, the foundry should have the following analytical capabilities.
  - Preliminary and final melt analysis covering all major and minor elements, especially nitrogen, to meet all specifications and special requirements including PREN, ferrite content and freedom from deleterious phases in heavy sections.
  - Mechanical testing, to meet all applicable specifications – international, national and project-specific.
  - Corrosion testing (ASTM G48).
  - Microstructure analysis to determine ferrite content (per ASTM E562) and confirm freedom from harmful second phases.
  - Supplementary ferrite measurement by magnetic response analysis. (This procedure offers both nondestructive measurement of ferrite in castings and confirmation of the absence of sigma phase in the ferrite by comparison with metallographic ferrite measurements. However, instrument calibration and surface preparation require knowledge and experience.)

- The importance of supplier qualification has had long but insufficient recognition. Recently this process has become more prevalent as manufacturers and end users recognize the multiplicity of benefits arising from the purchase of castings from competent foundries. The Norsok standard M650, introduced in the 1980's, is a good example of the evolution of high alloy procurement practices. The original Norsok standard stressed materials testing. In its latest form, Rev 2 (3), the emphasis has switched to the evaluation of supplier capabilities and competence. In addition to providing a basis for testing and supplier evaluation, M650 also identifies the responsibilities of each partner in the supply chain. Major end users are either following the M650 process or developing similar procedures for the upstream qualification of CRA manufacturers.

Specifications … and beyond.

The selection and qualification of competent suppliers of duplex and superduplex castings provides the downstream participants in the supply chain with sufficient confidence to take advantage of the added benefits offered by these materials. All members the supply chain, from end user to foundry, will benefit if this confidence enables the necessary commercial transactions to be augmented by a "partner/stakeholder" relationship dedicated to rational cost reduction and added value improvements. Specifications and testing must remain the framework of the procurement process, but substantial benefits can accrue from consultations with competent, proven supply chain partners.

- Increased foundry competence reduces specification and testing requirements.
- Competent foundries can assume greater responsibility for component quality.
- Competent foundries may be able to assist with upstream production issues.
- Competent foundries can reduce lead times and costs through the more efficient production of more consistent castings.
- Competent foundries can not only help reduce costs but also add value.

Specifications are the start of the procurement journey. The great commercial advantages lie beyond specifications. Choose your traveling companions well!

The selection of a foundry partner involves the evaluation of information that ranges from relative and subjective to quantifiable and objective. In contrast, the creation of an RFQ specifying castings must be objective and unambiguous, with clear testing instructions yielding measurable outputs that can be checked against acceptance criteria. As the recipient of numerous evaluation forms and hundreds of RFQ's, the author has attempted to distill these activities into two checklists. They are available by e-mail from his address listed below.

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References.

1. Christine Bordonaro, Don Bush, Tom Spence, "Materials Q & A", Valve Magazine, Fall 2002, Vol. 14, No. 4, pp. 56.

2. H. Okamoto, "The Effect of Tungsten and Molybdenum on the Performance of Superduplex Stainless Steels." Proc. Int. Conference on Application of Stainless Steels, June, 1992, Vol. 1, p 360.

3. Norsok Standard "Qualification of Manufacturers of Special Materials", M-650, Rev. 2, July 1998, Norwegian Technology Standards Institution, Oscarsgt. 20, Postbox 7072 Majorstua N-0306 Oslo, NORWAY. (http://www.nts.no/norsok)

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