Centrifugally Cast Duplex Stainless Steel:
Discussion of Benefits

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Keywords: Centrifugal Casting, Lean Duplex, Cast vs. Wrought Properties

Abstract:

For more than 20 years, duplex stainless steel centrifugal castings have been supplied to OEMs and OEM suppliers. Applications have included hydraulic accumulator bodies and structural components for naval defense; bowls, cones and conveyors for decanter centrifuges; hydraulic cylinder bodies for marine applications and numerous components used in mining. The starting tubes used in the production of these components can be produced by several processes. Hot milled tubing, forged tubing, rolled and welded tubing, even tubing machined from bar stock can be used but many customers have found cost/value benefits by using centrifugal castings. In many cases, there is no sacrifice in corrosion resistance or in mechanical properties when compared to various competing wrought products. Through careful process control in charge make-up, melt and pouring practices and heat treatment, excellent repeatability can be achieved. While the mechanical properties of centrifugal castings are not always the equivalent of wrought products, very often the cast properties exceed the customers' requirements with significant cost savings.

The benefits of centrifugal castings include alloy flexibility, ability to provide heavy wall thicknesses (up to 100 mm), ability to provide non-standard sizes and quantity flexibility. This paper will offer a survey, in detail, of how design engineers and purchasing professionals can specify standard duplex alloys, super duplex and super austenitic alloys and newer lean duplex materials. Specific comparisons of cast versus wrought properties will be made with detail as to process control being given. Particular attention will be paid to how this process can achieve cost savings.

Chapter 1 - Introduction:

Chapter 1.1 Principles of centrifugal castings

When it comes to metal forming, casting metal can be one of the simplest, most cost-effective routes to a near net shape manufactured good. Centrifugal casting in particular has the capability of utilizing these desirable benefits during the production of cylindrical stainless steel products.

Centrifugal casting is a process where molten metal is funneled into a rotating mold (commonly 700 to 1300 rpm). The rotation of the die creates centrifugal force which thrusts the metal towards the mold wall.

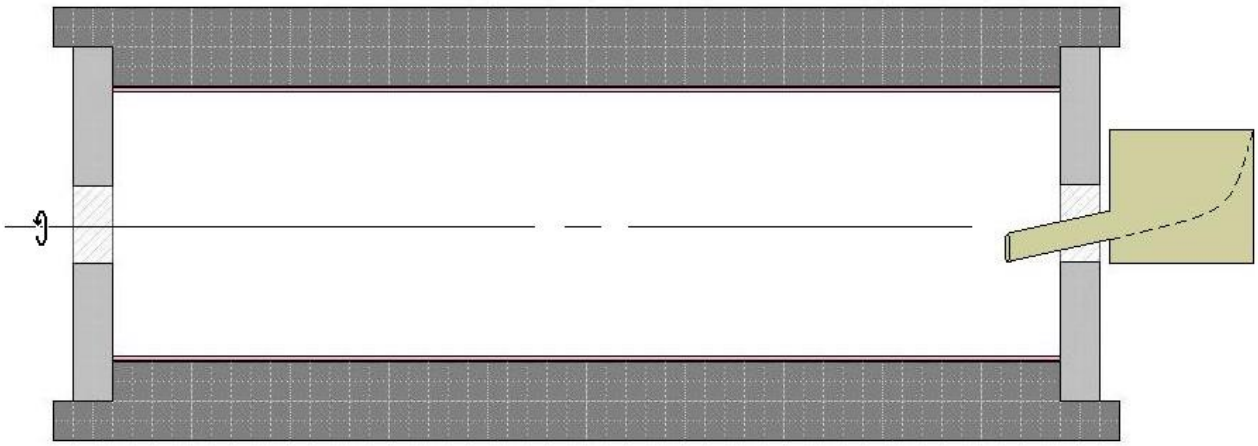

Figure 1: Cross-Section of a Horizontal Die with a Line Designating its Axis of Rotation.

Centrifugal casting can be performed horizontally or vertically. The aspect ratio of the part to be cast is what determines which of these two techniques are used. When the diameter of the desired part is large in comparison to the overall-length (ring shaped), vertical casting is most commonly used. Likewise, when the length is larger compared to the diameter (tube shaped), horizontal casting setups are used.

Chapter 2 - Benefits:

Chapter 2.1 Process Control

Significant cost savings can be a result of process control. Spuncast's control: All raw materials purchased are received and the chemistry evaluated. The chemistries are acquired through one of three methods: auditing pieces from various locations in that lot on the spectrometer, the purchased scrap comes with a certified chemistry, or a 100lb sample of material is melted down and a chemistry slug evaluated. This known/averaged chemistry creates the necessary control needed when working with low carbon alloys (such as Duplex). Charge

sequence and temperature control also play a large role in controlling process variables. Charge sequence can control the amount of elemental recovery, as well as the cycle time of each melt. Temperature control allows the melter opportunity to avoid superheating the melt, ultimately affecting the chemistry, and tap the furnace with the exact amount of superheating needed to pour the casting above but close to its liquidus temperature. Another way temperature control plays a key role is during the casting solidification process. Centrifugal casting promotes directional grain growth during solidification, as shown in the pictures below.

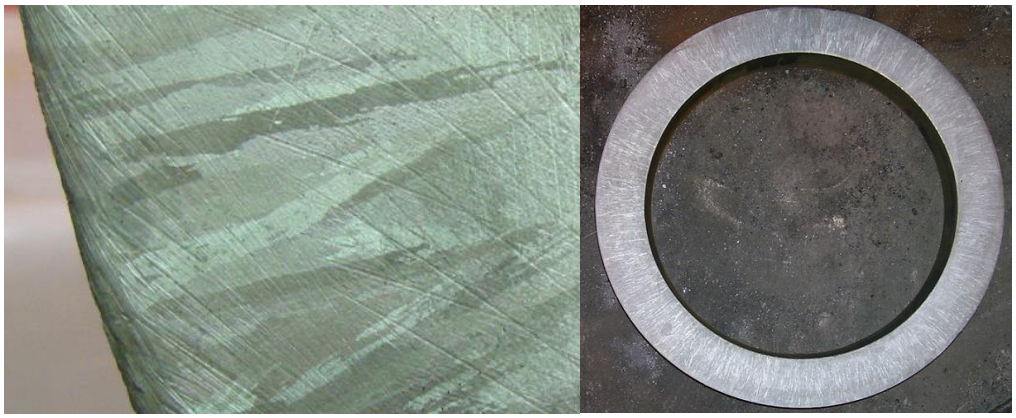

Figure 2: Casting cross-section macro-etched with Hydrogen Peroxide and Muriatic Acid, displaying direction solidification and grain growth from the outer diameter to the inner diameter.

Chapter 2.2 Secondary Refining:

The centrifugal forces promote metal cleanliness by forcing the non-metallics (less dense) to the inner diameter of the casting. As solidification takes place, the inner surface acts as a riser feeding the outer diameter with the metal it needs to produce a solid, dense casting. The less dense materials (the dirt, dross, or slag) that were forced to the bore of the casting can now be subsequently machined off. Since the use of gating and risers are eliminated, the production of these castings have an extremely high casting yield.

Chapter 2.3 Shapes and Sizes

Centrifugal casting is most appropriate when producing relatively simple cylindrical shaped parts. The list that follows shows the size ranges and limitations for the production of parts using this unique casting process.

Size Limits: [1]

Diameter: Up to 3 m (10 feet)
Length: 15 m (50 feet) length
Wall Thickness: 2.5 mm to 125 mm (0.1 - 5.0 in)
OD Tolerance: as fine as 2.5 mm (0.1 in)
ID Tolerance: can be 3.8 mm (0.15 in)
Surface Finish: from 2.5 mm to 12.5 mm (0.1 - 0.5 in) rms.

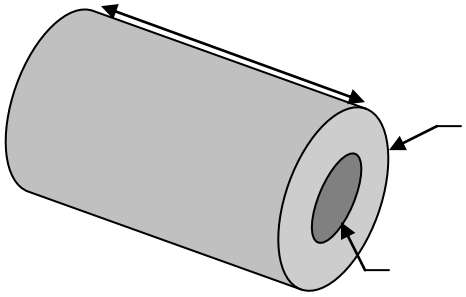

Chart1: Size Limitations for Centrifugal Casting

Utilizing a vertical casting orientation, more complex shapes are quite possible by the use of either chemically bonded sand inserts or investment (lost-wax) shell inserts.

Chapter 2.4 Alloy Versatility Options at Spuncast and for Others

This casting process has the capability of being used when working with a wide variety of alloys. Here are a few of the alloy families used for centrifugal casting: Aluminum, Bronze/Brass, Heat Resistant, Iron, Nickel Based, Steel, and Stainless Steel.

Here is a more in-depth list of some of the alloys Spuncast has to offer.

- Irons
  - Gray
  - Ductile
- Low Alloy Steels
  - Plain Carbon
  - Ni-Cr, Ni-Cr-Mo
- Cobalt Base Alloys
  - Stellite 6 equivalent
  - N-155 Heat resitant alloy
- Nickel Base Alloys
  - Hastelloy X, C, S
  - Inconel 600, 625
- Stainless Steels
  - Austenitic (300 series)
    - CF8, CF3 (304, 304L)
    - CF8M, CF3M (316, 316L)
  - Martensitic (400 series)
    - CA15, CA40 (420)
    - CA6NM (410)
  - Precipitation Hardened Alloys
    - CB7Cu-1 (17-4PH)
    - CB7Cu-2 (15-5PH)
  - Duplex Stainless
    - CD4MCu
    - 2205 (CD3MN)
  - Heat Resistant Alloys
    - HF, HF Mod, HH, HK, HP, HP Mod, HU, etc.
  - Various proprietary alloys

Chapter 2.4 Advantage and Limitation

Table 1: Below is a list of advantages and limitations to acknowledge when selecting a form of product manufacturing.

	Advantages	Limitations
Forged Roll (Billet)	• Wrought Material Properties	• High material cost •Double Energy Costs •Significant amount of Machining.
Sand Casting	•Low Tooling Costs •Low Manufacturing Costs	•Strength Limitations •Micro-porosity •Inherent Inclusions
Centrifugal Casting	•Improved Proprieties •Secondary Refining (denser) •Directional Solidification	• Shape and Size

Centrifugal castings can be more cost effective than forgings and have properties that surpass those of most other casting processes. This centrifugally cast dense structure creates castings with a longer life. These parts also can withstand greater loads and impacts without fracturing.

Chapter 3 – Properties and Applications:

3.1 Cast Duplex Applications:

Here are a few samples of centrifugally cast Duplex Stainless Steel parts:

Decanter Centrifuges

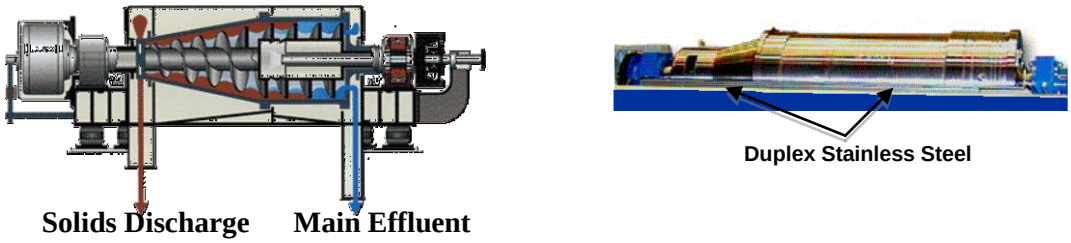

Figure 3: Decanter Centrifuges - Separating solids from liquids plays a key role in countless industrial, food and waste treatment processes.

On-Ship
Hydraulic Accumulators

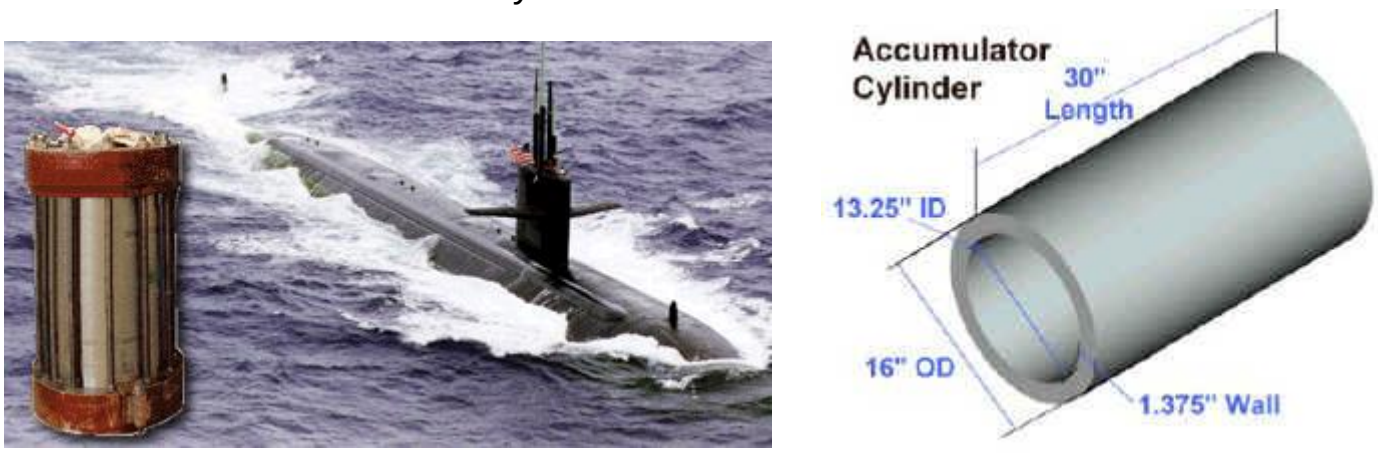

Figure 4: On-Ship Hydraulic Accumulators - Energy storage basin in which hydraulic fluids are held under pressure by a peripheral source.

Slurry Pump Bushings

Figure 5: Duplex slurry pump bushings are an essential because of their strength and resistance to corrosion and wear.

3.2 Duplex Stainless Steel Property Comparison:

Mechanical Property Comparison: Wrought vs. Centrifugally Cast

The primary U.S specification for cast duplex stainless steels is ASTM A890. There are eight grades within this specification. To date there is no accepted specification

for a cast lean duplex. The following data is a comparison of achievable cast properties to wrought specifications for duplex grades 4A and 1B. These two were selected because they both have an abundance of history and data available. There are other duplex grade properties available, but the information is fairly limited.

	UTS (MPa)	UTS (ksi)	Yield (MPa)	Yield (ksi)	Elongation (%)
Spuncast Avg.	802.5	116.4	557.1	80.8	32.7
Wrought Spec. (S32205)	760	110	550	80	15

3.2.1 Grade 4A

1.4462 - 2205 – J92205

Table 1: Mechanical property summary for 70 cast and heat treated tensile bars (1120^{o}C Water Quench)

	UTS (MPa)	UTS (ksi)	Yield (MPa)	Yield (ksi)	Elongation (%)
Spuncast Avg.	731	106	534	77.4	28.4
Wrought Spec. (S32550)	621	90	450	65.3	25.0

3.2.2 Grade 1B
1.4462 - 255 – J93372

Table 2: Mechanical property summary for 16 cast and heat treated Tensile bars (1120^{o}C Water Quench)

Several wrought material grades have recently been introduced that accomplish cost saving by lowering the amount of Ni, but none of these were designed for castability (specifically centrifugal casting). Spuncast has been developing a chemistry to maximize mechanical properties while minimizing the use of expensive raw materials (i.e. – Molybdenum, Nickel, etc.)

3.3 ‘SCLean’

SCLean - Spuncast’s Cast Grade of Lean Duplex

Table 3: SCLean – Nominal Chemistry

C	Mn	Si	P	S	Cr	Ni	Mo
0.025	4.2	0.68	0.02	0.005	22.25	1.5	0.49

W	Cu	Nb	V	Al	Zr	N
0.013	1	0.06	0.05	0.005	0.007	0.19

Table 4: Mechanical property breakdown for tensile bars cut from the heat treated castings (1120°F Water Quench)

Test Sample	UTS (MPa)	UTS (ksi)	Yield (MPa)	Yield (ksi)	Elongation (%)	Furnace / HT
1 - 7489	639	92.71	483	70.01	32.31	1120°C WQ
2 - 7490	632	91.71	476	69.06	39.20	1120°C WQ
3 - 7496	628	91.12	470	68.17	34.56	1120°C WQ
4 - 7497	623	90.35	486	70.45	32.13	1120°C WQ
Average	*630*	*91*	*479*	*69*	*34.6*	

Stress-Stain Diagram

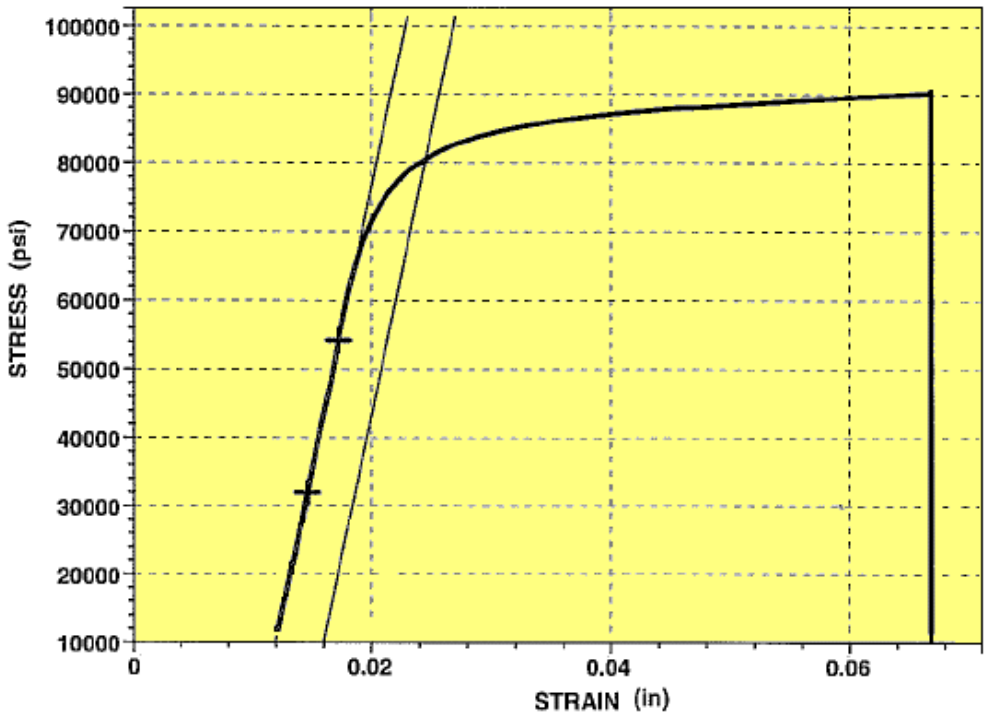

Figure 6: Stress-Strain curve recorded from one of the SCLean tensile bars pulled (Sample 1-7497).

As stated earlier, maximizing mechanical properties while minimizing the use of expensive raw materials was the primary objective. One without the other (mechanical properties / lower cost per lb) is of no use.

The previously shown mechanical properties were made at the following price:
SCLean = $1.67 / Kg (based on $44.31/Kg Ni - LME)

For reference: That same week had the following prices:
CD4MCuN = $ 3.88 / Kg
Duplex4A = $ 4.54 / Kg

Chapter 4 - Conclusion:

Centrifugal castings use directional solidification and pressure from the centrifugal force to create castings with a denser more sound structure exhibiting superior physical properties to that of statically poured castings.

It has been made clear that centrifugal casting is a versatile process with benefits in the areas of mechanical properties and overall process cost-effectiveness. The utilization of this process can be beneficial when producing a variety of products. One particular example shown was the specific development of SCLean as a “castable” lean duplex.

Chapter 5 - Reference(s)

[1] eFunda - http://www.efunda.com/ - July 2nd, 2007
http://www.efunda.com/processes/metal_processing/centri_casting.cfm?search_string=centrifugal%20casting