WROUGHT HEAT RESISTING ALLOYS PROVIDE COST REDUCTIONS

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Abstract

The selection of high temperature materials can be a difficult task. A wide variety of materials exist. Each possesses their own set of advantages and disadvantages. Too often the focus of materials selection is too narrow with only one or two issues being considered. To obtain the most economical life all properties should be considered in relation to the intended service environment. In many applications either cast or wrought alloys can be practical choices. Similar compositions in cast or wrought form, however, can have major differences in physical properties and initial costs. Comparisons between the properties and cost of cast and wrought heat resistant alloys will be made. Common heat treating equipment utilizing heat resistant grades will be discussed, along with the typical failures encountered and the materials properties most substantially affecting service performance.

IN THE SELECTION OF HEAT RESISTING ALLOYS, frequently too much emphasis is placed on one or two properties, while other equally important properties are overlooked. In order to get the most economical life, all properties need to be considered.

When a cast or a wrought alloy may be practically used, both should be considered. Similar chemical compositions are available in both cast and wrought forms. Large differences in physical properties and initial costs can exist, however, between cast and wrought alloys with nearly identical chemistries.

Advantages of Cast Alloys

1. Initial Cost - Since a casting is essentially a finished product as-cast, its cost per pound is less than a fabricated shape.
2. Strength - Similar compositions in the cast form are inherently stronger at high temperatures than their wrought counterparts.
3. Shapes - Some cast shapes cannot be produced in wrought form, or economically fabricated from available wrought products.

Advantages of Wrought Alloys

1. Availability - There is practically no limit to section sizes available in wrought form. Most alloys are readily available from stock in many forms.
2. Thermal fatigue resistance - The fine grain microstructure of wrought alloys promotes better thermal fatigue resistance.
3. Soundness - Wrought alloys are normally free of internal and external defects such as shrinks, cold shuts, and porosity.
4. Surface finish - The smooth surface of wrought materials can be beneficial in avoiding focal points for the initiation of corrosion or areas for stress concentration in fatigue situations.
6. Ductility - Wrought components can routinely be restraightened in order to increase service life.

While greater high temperature strength is one of the inherent advantages of cast alloys, perhaps too much emphasis has been placed on this point in selecting castings over wrought materials. Rarely is strength the lone requirement. It might not even be the major one; a large number of failures are a result of brittle fracture and not stress rupture or creep.

The potential deficiency of cast alloys with respect to thermal fatigue resistance and soundness, is receiving increased recognition. In the petrochemical industry for example, a trend has developed to replace cast furnace components with wrought alloys. This in spite of greater initial cost and lower strength, in order to gain ductility and soundness.

Should a cast alloy suffer from thermal fatigue to the extent that 75% of its cross section has fractured it has also lost 75% of its load carrying ability. A wrought alloy, though initially weaker, may possess the stronger structure in service, if it

Table I. Nominal Compositions of Some Cast and Wrought Heat Resistant Alloys

		Percent								
Cast Designation	Wrought Designation	Ni	Cr	Mn	Si	C	Mo	Co	W	Other
HH		12	26	0.5	1.2	0.4				
	309	13	23	1.6	0.8	0.05				
	RA 253 MA®	11	21	0.6	1.7	0.08				N 0.17 Ce 0.04
HK		20	25	0.6	1.4	0.4				
	310	20	25	1.6	0.5	0.05				
	800H	31	21	0.4	0.9	0.06				Ti 0.6
HT		35	17	0.9	1.7	0.5				
HU		38	18	0.9	1.7	0.5				
	RA330®	35	19	1.5	1.2	0.05				
	RA330HC®	35	19	1.5	1.2	0.40				
SUPER 22 H®		48	28	1	1.5	0.45		5	3	
	RA333®	45	25	1.5	1	0.05	3	3	3	

resists thermal fatigue better.

Composition

Table 1 lists the compositions of some common cast and wrought heat resisting grades. A comparison of those that are similar in nickel and chromium content may be of interest:

HH-309-RA 253 MA

These chromium-nickel alloys are susceptible to formation of the embrittling sigma phase in the 1100-1600°F. Chromium promotes the formation of sigma, while nickel and nitrogen retard sigma formation. The slightly lower chromium content of the wrought alloys, slows the formation of sigma phase. This allows them to remain ductile longer. The nitrogen addition in RA 253 MA slows the precipitation of sigma phase further, while adding to the high temperature strength of the alloy.

HK-310

Again a major difference in the chemistries of these two materials is the carbon content. The properties related to each carbon content remain the same as those given in the discussion of 309 vs. HH.

Another major difference is the silicon content. HK limits silicon to 2.00 max. while RA310 sets a limit of 0.75 max. It is known that silicon enhances the resistance to both oxidation and carburization, which is desirable. The drawback of silicon is it also promotes the formation of sigma phase. The chemistry of 310 is such that it is fully austenitic and therefore the weld bead will be free of ferrite, unlike welds made in the lower 300 series stainlesses. Ferrite imparts resistance to weld solidification cracking. Silicon in concert with residual phosphorus can promote the weld solidification cracking. For these reasons, the silicon is restricted to mitigate both weld fissuring and embrittlement from sigma. It should be noted that the silicon in RA310 is controlled more tightly than that of AISI 310. AISI 310 allows up to 1.5% Silicon. RA310 is produced to additionally meet the requirements of AMS 5521G, which sets a limit of 1.00 silicon.

HT, HU - RA330, RA330HC

Comparing the HT and HU compositions to RA330, you will see again a variance in carbon. The chromium content of RA330 is similar to HU, higher than HT, but with a more narrow range. The nickel content of RA330 is similar to HT and slightly lower than HU castings.

Taking a look at silicon additions, RA330 has a higher content than 309 or 310 and actually approaches that of the castings. Since RA330 is fully austenitic and immune to sigma phase formation, a larger silicon addition is possible without the detrimental side effects seen in 310.

RA330HC is the high carbon version of RA330. It has a nominal carbon content of 0.40%. This amount falls within the range of carbon for HT and HU. RA330HC is utilized where strength critical. The most common application is for belt pins in cast-link furnace belts. The increased strength of RA330HC provides greater resistance to “crankshafting”. The high carbon content maximizes shear strength, while retaining enough ductility to help prevent a mechanical-thermal fatigue failure. In addition to the chemistry, this alloy receives a special high temperature annealing treatment. RA330HC is not suited for formed and welded fixtures intended for liquid quenching service.

Super 22H - RA333

There is no standard ACI alloy composition to RA333, but there are comparable proprietary cast alloys. One of these would be Super 22H. RA333 due to its chemistry is one of the stronger wrought alloys available for high temperature service.

RA333 contains the low carbon and 1-1/4% nominal silicon for the characteristic they impart, as previously discussed. The 3% each of tungsten, cobalt, and molybdenum are strengthening agents. The combination of 45% nickel, 25% chromium, and silicon results in outstanding resistance to oxidation and carburization.

Grain Size and Its Effects on Properties

Tables 2 and 3 list the typical stress-rupture and creep strengths of each alloy at various temperatures. It should be noted that the cast compositions offer greater strength. It is also apparent that is not so much a result of chemistry differences, but from the coarse grain structure inherent to cast materials.

If maximum strength is the greatest concern, wrought alloys can be produced to have coarse grains. Discretion must be exercised in specifying such a microstructure as there is a sacrifice to other properties, notably thermal fatigue and carburization resistance. 800H is one such material that is produced with coarse grains in order to maximize strength. It should also be noted that 800H is also strengthened by its Al and Ti additions. Tables II and III provide a comparison of creep and stress rupture properties for some common cast and wrought grades.

Wrought alloys commonly prove more economical than cast alloys in terms of life vs. cost because of better thermal fatigue resistance related to their finer grain size.

Table II. 10,000 Hr Stress Rupture Strength, psi

	1400°F	**1600°F**	**1800°F**
HH	4800	2150	860
309	4800	1600	560
RA 253 MA	5200	2500	1150
RA85H	5000	2100	900
HK	8800	3800	1700
310	4500	1500	660
HT	8400	3700	1700
HU		3300	1800
800H	7300	3500	1200
RA330	4300	1700	630
SUPER 22 H			2900
RA333	9200	3100	1050

Table III. Minimum Creep Rate, 0.0001 Percent per Hour

	1400°F	**1600°F**	**1800°F**
HH	6300	3900	2100
309	3400	1400	220
RA 253 MA	5000	2300	890
RA85H		2200	700
HK	10200	6000	2500
310	3300	1100	280
HT	8000	4500	2000
HU	8500	5000	2200
800H	6000	3600	1000
RA330	4300	1700	630
SUPER 22 H		4800	3200
RA333	6400	2700	880

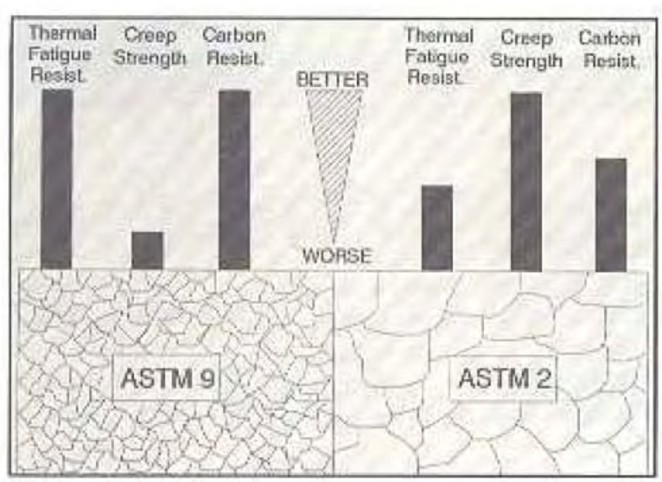

Figure 1 - Effects of grain size upon the properties of heat resistant alloys.

Section Size

Heat resistant alloys are relatively poor conductors of heat. In quenching service this becomes highly important. Severe thermal stresses can arise from thermal gradients within the material. A lower coefficient of expansion reduces the thermal stresses and a fine grained microstructure helps the alloy absorb them.

The magnitude of thermal gradients and stresses are heavily dependent upon the cross-sectional thickness. The successful applications of fabricated alloy components can often be linked to reduced thermal stresses resulting from thinner cross-sections. Frequently, a thinner cross-section than can be cast is adequate and the additional mass only serves to shorten life.

Case Histories

Throughout the years a pattern has developed as to which furnace items should be cast and which should be fabricated.

Items of thinner cross-section than are castable such as screens, bar frame baskets, and shrouds were fabricated from wrought materials. In many cases the lighter sections were preferred because of the lower weight. This improved the net to gross load ratio resulting in a lower cost per pound of product shipped. After all, it costs as much to heat treat a pound of alloy as a pound of product, but only the work can be sold.

More recently wrought fabrications have increasingly been utilized in traditionally cast applications. Some examples may be of interest.

Rotary Retorts

In the heat treatment of small parts such as roller bearings, screws, and nuts a continuous process utilizing a rotary retort is utilized. One such furnace used for carburizing roller bearings has used HT cast retorts for several decades.

The cast retorts have traditionally been 1 inch thick. Typically, the failure mode has been from a phenomenon referred to as coking. As the carburizing atmosphere diffuses into the retort wall, it can accumulate in voids in the cast alloy. These pockets of gas lead to blow outs and ultimately fracturing of the retort. Average service life was figured to be 8000 hours.

A 5/8" thick fabricated retort made of RA330 was installed. The lighter construction brought the cost of the RA330 fabrication to within 10% over the cost of the cast retort. After 15,000 hours in service the wrought retort was still usable, but was removed from service for evaluation.

Figure 2 - 5/8 in. thick RA330 rotary retort. Operated 15096 hours in furnace for carburizing roller bearings. 1 in. wall cast retort averaged 8000 hours

In addition, to improving the service life an added bonus of the wrought fabrication was the flexibility it allowed in the design. Clearances in the furnace were such that a larger retort could be utilized. Increasing the size of the cast retort was not attempted due to the high costs associated with producing a new pattern. The volume of the retort was increased enough to process of 20% more bearings. Thus, the economy of the wrought fabrication was further improved.

Figure 3 - View of a completed RA330 rotary retort ready for shipment.

Grids and Trays

In a continuous pusher furnace where each tray pushes the entire furnace load, it is of little surprise that strength is of great importance. This may dictate that a casting be used. Up to now an economical design using wrought alloys possessing adequate strength, has not been developed. The configurations are of relatively low costs as castings when compared to the labor costs associated with fabrications.

Individual grids or trays associated with batch furnaces do have potential for both wrought and cast versions. Here strength is of less importance when compared to thermal fatigue, material soundness, and resistance to localized surface corrosion from salts or atmosphere.

Fabricated trays have been used in batch type carbonitriding furnaces. One such tray measures 16" x 30". Three trays are coupled together to create one tray 30" x 48". Average loads are 1350 pounds. A typical cycle consists of carbonitriding at 1600-1750^{o}F, followed by a direct oil quench.

Cast HT alloy required periodic weld repair of fractures after 170 cycles, and suffered complete failure after 500 cycles. RA330 fabricated trays served 600 cycles prior to repair and lasted a total of 1200 cycles.

In addition to increased service life and lower maintenance costs, the tare weight of the tray was also reduced.

Figure 4 shows a similar tray design fabricated of RA330 and the cast HT tray it replaced. The service was for carburizing with a direct oil quench, previous cast trays lasted for four to eight months.

When Figure 4 was taken, the cast tray had been in service for six months and had been repaired. It was scrapped after eight months. The RA330 tray was used eight months without repair and shows little deterioration.

The initial costs of the cast and fabricated trays were surprisingly competitive.

Figure 4 - View of serpentine RA330 tray and the cast HT tray that it replaced for use in carburizing service followed by an oil quench.

Figure 5 is a classic example of thermal fatigue cracking and surface attack. The cast grid was used in a gantry furnace at temperatures up to 1850^{o}F, neutral atmosphere, with quenches in salt, oil, or brine.

The original grid was cast HT material. After only a few cycles, a larger part than the grid required heat treatment. To enlarge the grid, RA330 sawed plate was formed and added to the outside of the grid.

The cast portion of the grid suffered surface attack from the salt and soot deposits entrapped in the surface imperfections. Thermal fatigue fractures occurred at the center of the cast sections.

The wrought portion of the fixture, seeing the same exposures is relatively unaffected. In fact, saw cutting marks are still visible on the plate.

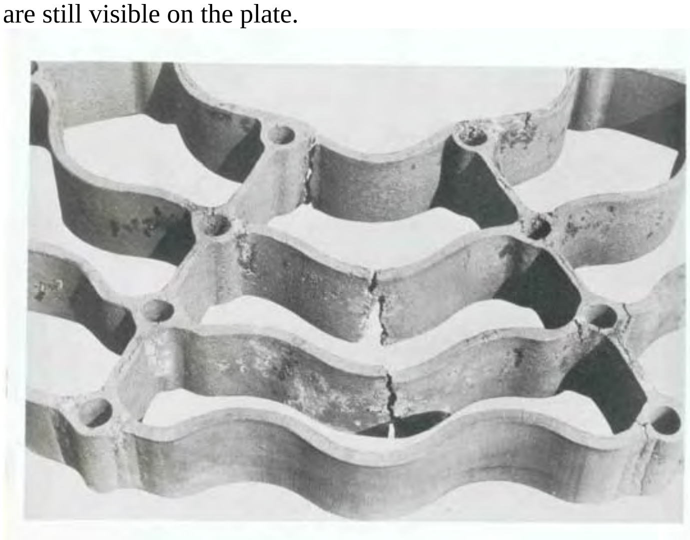

Figure 5 - Cast HT grid displaying thermal fatigue damage after usage in a gantry furnace. RA330 wrought plate was welded to expand the grid (bottom piece). Note the RA330 did not suffer cracking.

Radiant Tubes

The usage of wrought radiant tubes is certainly not a new practice. They have been used in non-carburizing service extensively.

When vertical straight tubes for batch type carburizing furnaces were introduced in the late 1940s they were and remain predominantly thin wall wrought alloy tubes.

Centrifugally cast radiant tubes are able to be produced to wall thickness of 1/8" thick. The majority of cast tubes, however, are still to 1/4" or 5/16" wall. Wrought radiant tubing is typically 1/8 or 3/16" wall.

Strength is not as great a factor as some would believe in radiant tubing. Radiant tubes require enough strength to support their own weight. It is a common mistake in believing that heavier sections translate into greater strength at temperature. One must take into consideration that doubling the thickness of a tube also doubles its weight. In doing so the unit stress on the tube remains roughly the same.

Additionally, a thinner tube will achieve greater heat transfer. Improved heat transfer can allow lower firing rates and reduce the metal temperatures of the radiant tubes. By operating at lower temperatures, the alloy will have greater creep strength.

Finally, the lighter weight of the thin walled tubes aids in the installation and replacement of the radiant tubes.

Strength sufficient to support its own weight is important. Many wrought tubes have traditionally been type 309 stainless. It should be noted that 253MA and RA85H have 3 to 4 times the creep strength of 309 stainless. Higher strength in combination with these alloys' improved oxidation resistance make them logical candidates to replace 309 for more economical service.

In carburizing service, the smooth surface of wrought tubes is believed to be advantageous in minimizing "carbon attack". A rougher surface allows more surface area exposed to the carburizing media and also is more prone to soot accumulation.

Figure 6 shows the firing leg of a trial fabricated radiant tube removed from a 5 row pusher malleablizing furnace (cut in two for the illustration). It is a horizontal, straight through design approximately 20 feet in length. It was made up of one section of RA333 nearest the burner, followed by an RA330 section, and finally a 309 section.

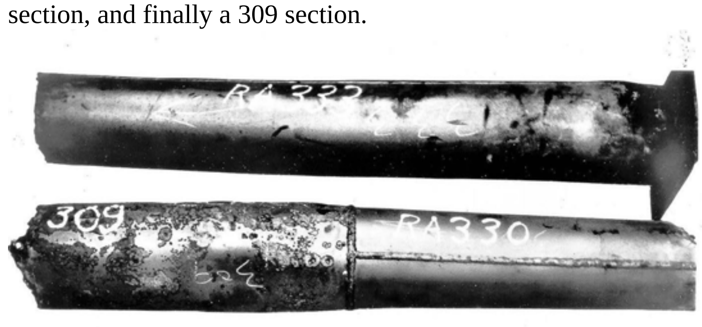

Figure 6 - Firing leg fabricated using three test lengths of three different alloys; RA333, RA330 and 309.

As the illustration shows 309 lacked the oxidation and creep resistance of RA333 and RA330 in this application. Based on the evaluations, the end user selected RA330 tubes fabricated from 1/8 inch sheet to replace cast HK tubes 5/16” in thickness.

Figure 7 - 3/16” wall RA333 radiant tube after 4 years of service.

Figure 7 illustrates a trial RA333 tube 3/16” thick. This tube was in service for four years prior to its removal. It was removed only because the furnace was being replaced. Cast HT tubes averaged two years life. RA333 was selected for the new furnace unit based on the trial.

Figure 8 - Horizontal U-tubes fabricated from RA330 material. These tubes replaced cast HH tubing.

Figure 8 shows a set of wrought RA330 tubes that replaced cast HH tubing in a multi-stack steel mill furnace. The HH tubes were 5/16” wall. Loads and cycles were tracked to determine when the break even life was met. Replacement of cast tubes with wrought was continued once the trial was completed. The maintenance personnel were pleased with the ease of replacing the lighter wrought tubes.

Shaker Hearths

Figure 9 shows a twin RA330 shaker hearth 24 x 132.5 inches. These hearths were used mainly for clean hardening. At the time of the photograph the hearths were in service for 27 months. Previously cast HT had fractured in 3 to 5 months.

Figure 9 again shows one of two twin shaker hearths used for both clean hardening and carbonitriding. Cast HX hearths gave erratic life amounting to as little as 3 months service. This user has tried RA333 in three furnaces over a five year period. Life ranged from 18 to 22 months.

Figure 9 - Twin RA330 shaker hearths used in a clean hardening operation.

Figure 10 - RA333 shaker hearth taken from a twin shaker furnace. Hearth was fabricated from 3/8” plate.

The original thickness of the hearth shown in Figure 10 was 3/8”. This has subsequently been reduced to 5/16”, which has further improved the economy of the RA333 construction. Incidentally, the radiant tubes for these furnaces are also RA333 material.

Conclusion

It must be emphasized that both castings and wrought fabrications possess certain advantages. Both are necessary. Greatest economy of operation results when cost per hour of service or the total cost of the product being processed is the least regardless of the initial costs of the alloy components involved. To achieve this, all of the properties of an alloy must be considered when specifying an alloy and not by acting out of habit .

Acknowledgment

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References

B. Macleod, Wrought Heat Resisting Alloys Provide Cost Reduction, *Metal Treating*, Vol 25 No. 2 (June-July 1974)