

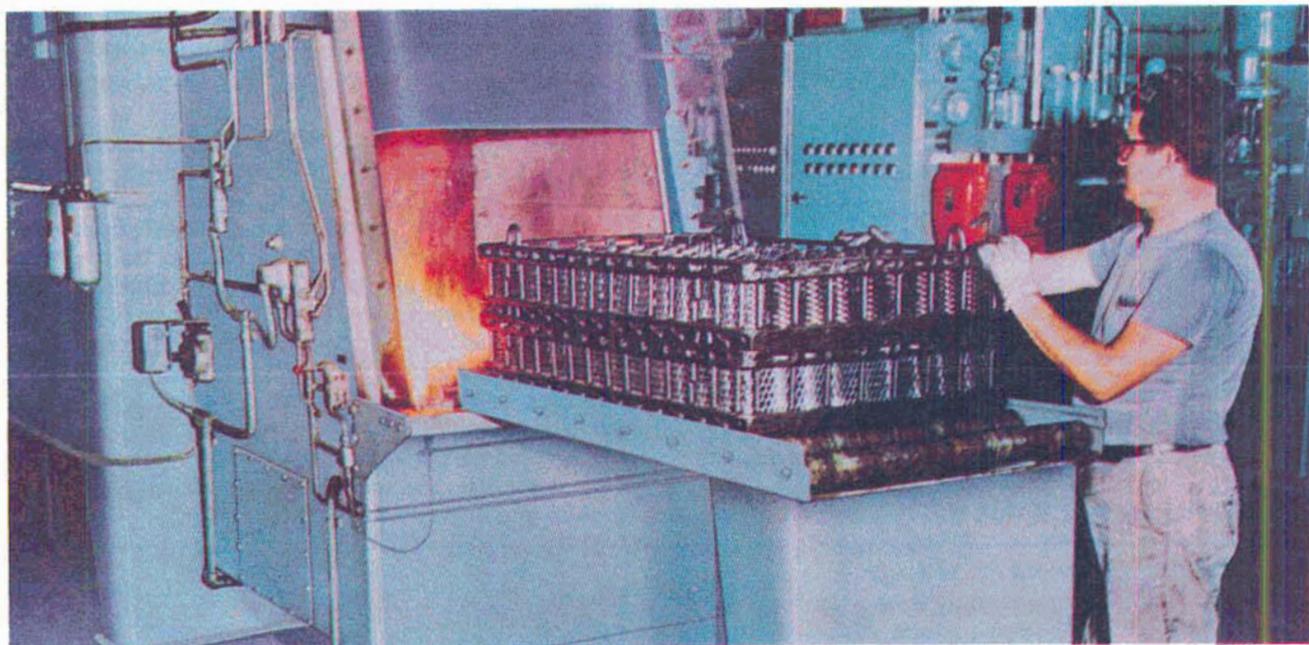
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# Metal Treating

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**WROUGHT HEAT RESISTING ALLOYS PROVIDE COST REDUCTION**

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**ROLLED ALLOYS INTERNATIONAL, INC.**   
*Heat and Corrosion Resistant Alloy Specialists*

# WROUGHT HEAT RESISTING ALLOYS PROVIDE COST REDUCTION

An article on advantages of cast alloys prepared by the Alloy Casting Institute, division of the Steel Founders Society, was published by Metal Treating Magazine earlier. The accompanying article is in response to an invitation by the Editors of Metal Treating to tell the story of wrought alloys.

Readers will undoubtedly evaluate the statements made by both sources as they apply to their own particular problems with heat resistant alloys of all types and compositions.

In the selection of a heat resisting alloy for a given application, frequently too much emphasis will be given one or two properties and others, equally or even more important, may be overlooked. To obtain the most economical life, all properties should be considered in relation to the requirements of the environment.

If either cast or wrought alloy may be practically used, both should be considered. Similar compositions in cast or wrought form have different physical properties and initial costs, and thus inherent advantages and disadvantages. Selection must be based upon all the factors. Your first cost may sometimes be the least significant factor you consider.

## Advantages of Cast Alloy

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 are inherently stronger at elevated temperatures in cast form.
3. Shapes — Some cast shapes cannot be produced in wrought form, or economically fabricated of wrought material which is available.

## Advantages of Wrought Alloy

1. Section size — There is practically no limit to

section sizes available in wrought form.

2. Thermal Fatigue Resistance — The inherently fine grained microstructure of wrought alloys promotes better thermal fatigue resistance.

3. Soundness — Wrought alloys are normally free of internal and external defects such as shrinks, porosity, and cold shuts.

4. Surface finish — The smooth surface of wrought alloys may be beneficial in avoiding focal points of concentrated, or accelerated, attack.

5. Availability — Wrought alloys are available from stock in many forms.

While greater high temperature strength is one of the inherent advantages of cast alloys, perhaps too much emphasis has been given this characteristic in the selection of cast over wrought structures. Rarely is strength the only requisite, and it might not even be the major one; there may be more failures due to brittle fracture from thermal fatigue than due to stress rupture or creep.

The potential deficiency of cast alloys with respect to thermal fatigue resistance and soundness, is receiving increasing recognition. In the petro-chem industry for example, among others, a trend is developing to replace cast furnace components with wrought alloys, in spite of greater initial cost and lower strength, in order to gain ductility and soundness.

(Continued on next page)

TABLE I  
COMPOSITION OF SOME CAST AND WROUGHT  
HEAT RESISTING ALLOYS

ACI cast Designation	Wrought	PERCENT									
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Chromium	Nickel	Molybdenum	Cobalt	Tungsten
HH		0.20-0.50	2.00 max.	0.04 max.	0.04 max.	2.00 max.	24.0-28.0	11.0-14.0	0.50 max.	-	-
	RA-309	0.08 max.	2.00 max.	0.045 max.	0.03 max.	1.00 max.	22.0-24.0	12.0-15.0	-	-	-
HK		0.20-0.60	2.00 max.	0.04 max.	0.04 max.	2.00 max.	24.0-28.0	18.0-22.0	0.50	-	-
	RA-310	0.08 max.	2.00 max.	0.045 max.	0.03 max.	0.75 max.	24.0-26.0	19.0-22.0	-	-	-
HT		0.35-0.75	2.00 max.	0.04 max.	0.04 max.	2.50 max.	15.0-19.0	33.0-37.0	0.50 max.	-	-
HU		0.35-0.75	2.00 max.	0.04 max.	0.04 max.	2.50 max.	17.0-21.0	37.0-41.0	0.50 max.	-	-
	RA-330®	0.08 max.	2.00 max.	0.03 max.	0.03 max.	0.75-1.50	17.0-20.0	34.0-37.0	-	-	-
	RA-330-HC	0.35-0.45	2.00 max.	0.03 max.	0.03 max.	0.75-1.50	17.0-20.0	34.0-37.0	-	-	-
HX		0.35-0.75	2.00 max.	0.04 max.	0.04 max.	2.50 max.	15.0-19.0	64.0-68.0	-	-	-
	RA-333®	0.08 max.	2.00 max.	0.03 max.	0.03 max.	0.75-1.50	24.0-27.0	44.0-47.0	2.50-4.00	2.50-4.00	2.50-4.00

RA-330 and RA-333 are registered trademarks of Rolled Alloys, Inc.

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

### Composition

Table I lists the compositions of the most popular cast and wrought heat resisting alloys. A comparison of those that are similar in nickel and chromium content may be of interest:

#### HH-RA309

These chromium-nickel alloys are susceptible to formation of the embrittling sigma phase in the 1100-1600°F range. Since chromium promotes formation of sigma and nickel retards it, the wrought alloy contains a little less chromium and a little more nickel to reduce (but not eliminate) its susceptibility to sigma. It will be noted the range for chromium in RA309 is only 2% vs. 4% in HH.

The major difference in composition, however, is in the carbon content. Carbon, in the form of chromium carbides, precipitates over a wide temperature range, most readily when the alloy is held at, or passes slowly through, the 1200-1400°F temperature range. The chromium carbides are quite stable and are not redissolved at temperatures under 1850°F, so solution at lower operating temperatures does not occur. Therefore carbide precipitation may be progressive with each cycle.

The presence of precipitated carbides results in embrittlement of the alloy and reduces its ability to absorb mechanical or thermal shock. In addition, the carbon combines with many times its own weight of chromium, depleting the matrix of that element which is required for oxidation resistance so that oxidation may proceed freely, particularly intergranularly.

The AISI 309 specification permits 0.20% maximum carbon, but all RA309 is normally produced to 0.08% maximum, conforming with AMS 5523-5650 and AISI 309S specifications. With a nominal 0.05% carbon, there is insufficient carbon for much carbide precipitation to occur.

#### HK-RA310

Here again it will be noted that the range for both nickel and chromium is narrower for the wrought alloy, but in this case both fall within the HK range.

A major difference in composition is the carbon content, the effects of which are the same as those discussed for the RA309—HH alloys.

Another major difference is the silicon content, 0.75% maximum vs. 2.00% maximum. It is well recognized that silicon enhances resistance to both oxidation and carburization, which is desirable. However, it is also very potent in promoting sigma formation, which may well be undesirable, and silicon is restricted in RA310 for this reason. It might be surmised that the oxidation resistance of RA310, possibly with a little less chromium and silicon than HK, would equal or surpass that of HK after the latter has suffered chromium depletion due to carbide precipitation.

Perhaps it should be noted that the AISI 310 specification permits 0.25% maximum carbon and

1.50% maximum silicon, but all RA310 is produced to the more restrictive specifications, conforming with AMS 5521-5651 specifications.

#### HT, HU-RA330, RA330-HC

"Type 330" is frequently mentioned as being the wrought counterpart of HT or HU alloys. It should be noted that there has never been a "type 330" specification issued by the American Iron and Steel Institute (AISI). For years various producers of stainless steels, in listing the analysis of "type 330," have differed on its composition. Until such a specification is issued the use of "Type 330" as a specification may result in a different composition than expected.

Comparing the HT and HU compositions with RA330, you will see that carbon content is the major difference. The chromium content of RA330 is similar to HU, higher than HT, and has a narrower range. The nickel content of RA330 is similar to that of HT, slightly lower than that of HU, and also has a narrower range.

The silicon content of RA330 is higher than in the chromium-nickel wrought alloys, RA309 and RA310, and closer to that of the cast alloys.

Since RA330 is fully austenitic and immune to sigma phase formation, advantage can be taken of the recognized influence of silicon on resistance to oxidation and carburization without fear of embrittlement from sigma.

RA330-HC is a high carbon version of RA330 worth special mention. It will be noted the carbon content is within the HT-HU specification.

RA-330-HC is used where strength is a major requirement. The most familiar application is pins in cast-link furnace belts where the increased strength provides resistance to "crankshafting." Much research has been completed on this alloy to develop the maximum combination of strength with ductility at elevated temperature. Too little strength results in excessive crankshafting, and too little ductility may lead to mechanical-thermal fatigue failure. The combined properties are the result of a special annealing treatment.

If more strength than offered by RA330-HC is required for such an application, RA333-SA (Solution Annealed) is available.

Because of their reduced ductility, compared to that of "mill annealed" material, RA330-HC and RA333-SA are not suggested for quenching applications. (However, they should have thermal fatigue resistance equal to or greater than the cast compositions with higher carbon content and even larger grain size.)

In general, the wrought alloys have a narrower specified range for the alloying elements than do the ACI cast compositions. This should result in less variation in properties from heat to heat; also, when the specified range is wider than required with good melting practice, there may be a tendency for a producer to melt to the low side of the range rather than aim for the "nominal."

#### RA333

There is no standard ACI alloy composition comparable to RA333 which is a patented composition, although there are competitive proprietary alloys in both cast and wrought form. It should be considered here, however, because it also is being adopted increasingly for applications that have been traditionally cast alloys.

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

#### Strength at Temperature vs. Grain Size.

Tables II and III list the typical stress-rapture and creep strength of these alloys at various temperatures. It will be noted the cast compositions offer greater strength, but from the above discussion it is apparent this is not due so much to variations in analysis, but to the very coarse, as-cast, grain size.

Elevated temperature strength of wrought materials can be increased appreciably by grain coarsening or "solution treating," as indicated in the tables.

If maximum strength is the major requirement, wrought alloys may be produced in the coarse grained condition; however, discretion must be exercised in specifying such a microstructure because there is a sacrifice of other properties, notably resistance to carburization and thermal fatigue.

Wrought alloys frequently prove more economical than cast alloys in terms of life vs. cost because of better thermal fatigue resistance, related to fine grain size.

#### Other Physical Properties

The other physical constants such as coefficients of expansion, specific heat, conductivity, etc. may be considered dependent upon chemical analysis and sufficiently equal between similar cast and wrought compositions for the purpose of this discussion. However, in considering one analysis vs. another, these constants can be quite important.

For example, non-uniform expansion and contraction results from non-uniform heating and cooling, creating severe thermal stresses. Under such conditions, an alloy with a low coefficient of expansion is preferable to one with a greater expansion rate.

#### Section Size

Heat resisting alloys are relatively poor conductors of heat. Particularly in quenching environments, severe thermal stresses may exist due to thermal gradients. A lower coefficient of expansion reduces such thermal stresses, and a fine grained microstructure improves the alloy's ability to absorb them.

The magnitude of temperature gradients and thermal stresses is also dependent upon the cross-sectional thickness. Many of the successful performances of fabricated wrought alloy may be related to reduced thermal stresses in thinner cross-sections. Frequently a cross-section less than can be cast is adequate, and excess mass only shortens life.

#### Case Histories

Through the years a pattern (or habit) seems to have developed as to which furnace items would be cast, or fabricated from wrought alloys. Items of thinner cross-section than could be cast, such as screens, bar frame baskets or sheet containers were logically made of wrought materials. In many cases the lighter sections were preferred because the net to gross load ratio was increased resulting in a lower cost per pound of product

	1400°F	1600°F	1800°F
HH	6500	3800	2100
RA-309	-	2750	1500
HK	12000	6000	2800
RA-310	-	3700	2150
HT	12000	8900	4400
HU	-	5200	2900
RA-330 Mill Annealed	7000	3100	1250
Solution Treated	9000	3700	1500
HX	-	4000	2200
RA-333 Mill Annealed	13500	5200	2100
Solution Treated	15000	7000	2600

	1400°F	1600°F	1800°F
HH	3000	1700	1100
RA-309	2000	500	-
HK	10200	6000	2500
RA-310	2500	300	-
HT	8000	4500	2000
HU	8500	5000	2200
RA-330 Mill Annealed	3600	1900	520
RA-330 Solution Treated	5700*	2700	900*
RA-330-HC	7000*	2600*	700
HX	6400	3200	1600
RA-333 Mill Annealed	6200*	3100	900
RA-333 Solution Treated	11,000*	4300	1300

\*Extrapolated.  
Source of data for cast alloy in Tables II and III, ACI data sheets, Alloy Casting Institute, 300 Madison Avenue, New York, New York 10017.  
Data for RA-330 and RA-333 is from original test data.  
Data for RA-309 and 310 is from published sources.

shipped. After all, it costs as much to heat treat a pound of alloy as a pound of work, but only the work is sold.

More recently wrought fabrications appear to be invading many applications that have been traditionally cast alloys.

Some examples will be of interest.

#### Grids and Trays

In a continuous pusher furnace where each tray pushes the entire furnace load, strength of the tray is obviously a major consideration. This may dictate a casting.

Thus far a design in wrought alloys, with adequate strength, at a practical cost, has not been developed for this use. The configurations are relatively low cost in castings compared to the labor cost of fabricating.

Quite possibly the availability of recently introduced extruded shapes such as I-beams, tees, and channels with the section modulus they offer, will make another appraisal of such applications worthwhile.

Individual grids or trays for batch furnace operations, however, are another story — if carefully analyzed. Here, strength becomes less important in relation to thermal fatigue, inherent soundness, and resistance to localized surface attack from atmosphere or salt.

Figure 1 illustrates a wrought, fabricated tray for a batch type carbonitriding furnace. Three such trays, measuring 16" x 30" are coupled together to make one 30" x 48". Typical loads average 1350#. Operation is carburizing and carbonitriding, 1600-1750°F, followed by direct oil quench.

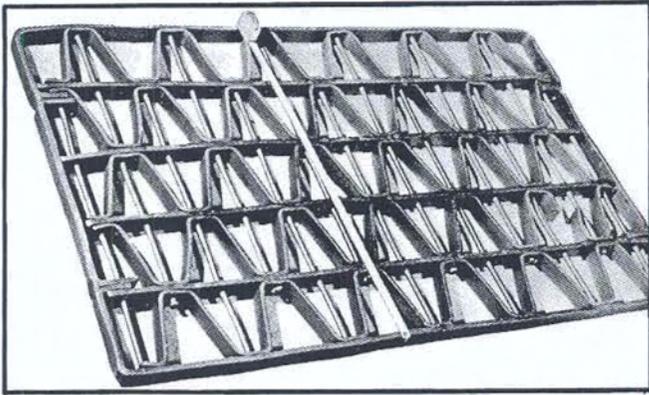


Figure 1

Cast HT alloy required periodic repair of fractures by welding after 170 cycles, and failed after 500 cycles. The RA300 fabricated trays served 600 cycles without repair, and gave a total life of 1200 cycles.

In addition to the greatly increased life, the tare weight of the tray was reduced.

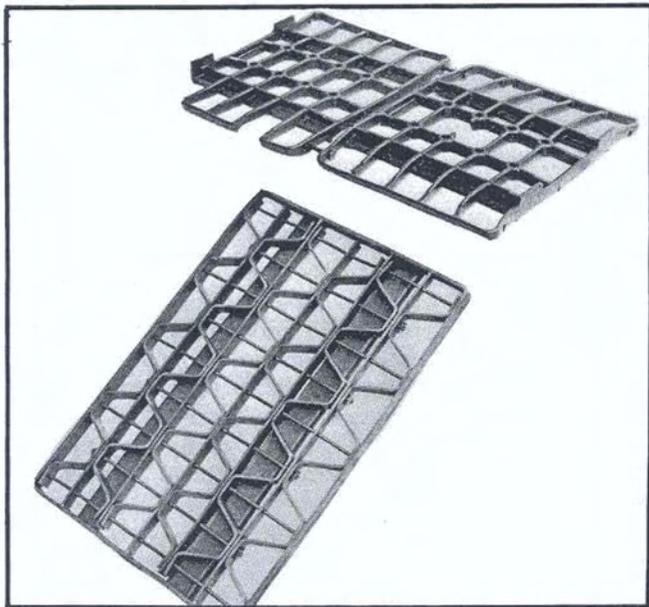


Figure 2

Figure 2 illustrates a similar tray design fabricated of RA330 and the cast HT tray is the replacement. Used for carburizing with direct oil quench, previous cast trays provided service life ranging from four to eight months.

When photographed, this cast tray had been in service six months and had been repaired, and it was scrapped after eight months. The RA330 tray had been in service eight months without repair, and shows little deterioration.

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

Figure 3 is a vivid illustration of thermal fatigue and surface attack. The cast grid was used in a gantry furnace at temperatures to 1850°F, neutral atmosphere, with salt, oil, and brine quenches.

When the new grid had received only a few cycles, a part was received for heat treating that required a larger grid, so the RA-330 sawed plate was formed and added to the outside of the grid.

The cast sections reveal surface attack from the salt and soot deposits entrapped in the surface imperfections. Thermal fatigue fractures in the center of the cast

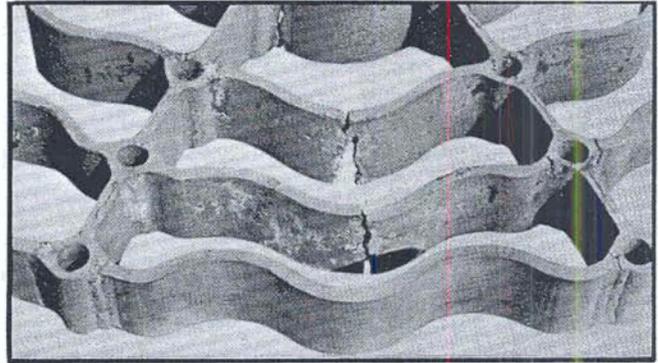


Figure 3

sections follow the planes of weakness in the dendritic structure formed by solidification of the molten metal from the surface to the center.

The wrought member, having received practically the same exposure, is unaffected — the saw marks are still visible.

### Radiant Tubes

The use of wrought radiant tubes is not new. They have been used in non-carburizing atmospheres extensively.

When vertical, straight through radiant tubes in batch type carburizing furnaces were introduced in the late 40's; they were, and still are, predominately thin wall, wrought alloy.

Centrifugally cast alloy has dominated the market, however, in horizontally mounted radiant tubes in controlled atmosphere heat treating furnaces, in annealing, and galvanizing furnaces. This may be changing. At present, fabricated radiant tubes may be the fastest growing usage of wrought alloy.

Perhaps no one has really established how thick — or thin — the wall should be on a radiant tube. The centrifugal casting process has a limitation on thinness. In addition, it is rather well recognized that some amount of metal on the inside of a cast tube is unsound and contributes nothing.

Strength is not as much a factor as may be believed. Radiant tubes need to support only their own weight. Fear is often expressed that thinner walls will be too weak, but essentially if the wall thickness is doubled, the weight is about doubled so unit stress remains the same (for simplification, the effect on section modulus of a thicker or thinner wall, assuming the same O.D., is being ignored here, although it is recognized that it does exist).

If better heat transfer can be achieved with a thinner wall so the surface temperature is reduced, then more strength is retained by the cooler tube.

Strength sufficient to support its own weight is important. Many wrought radiant tubes in the ferrous and non-ferrous metals industry have been type 309. It will be noted that RA330, for example, has about four times as much creep strength at 1600°F as RA309. This, plus its greater oxidation resistance, makes it a logical candidate to replace RA309 for more economical service.

Fabricated wrought tubes, being formed from sheet or plate, are uniform in wall thickness. Centrifugally cast or extruded tubes may be less than perfect in concentricity — and non-uniform cross-sections, can lead to thermal stresses and deformation.

The smooth surface of wrought tubes is believed by some users to be beneficial in minimizing "carbon at-

tack" in carbonaceous atmosphere. The freedom from sigma and minimization of carbide precipitation may also be an asset in RA333 or RA330 compared with the cast alloys with higher carbon content.

Finally the lighter weight of thin wall tubes is considered an advantage when removal and replacement are required.

The proof, as always, is in the performance.

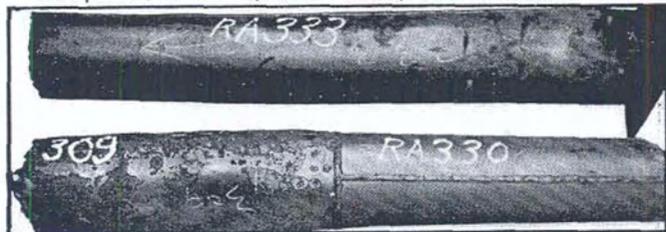


Figure 4

Figure 4 illustrates a trial fabricated radiant tube removed from a 5 row pusher malleablizing furnace (cut in two for photographing). It is a horizontal, straight through design approximately 20 feet long. It was made up in sections with RA333 nearest the burner followed by a section of RA330, and then a section of RA309. All 3 materials were .120" thick. There is no doubt the RA309 lacks the strength to resist creep and oxidation resistance, compared with RA330 and RA333, in this environment.

Based on the evaluation of a few wrought tubes of various alloy combinations in this furnace, the user has purchased several tubes of .120" wall RA330, replacing cast HK.

The inferiority of RA309 — or superiority of RA330 and RA333 — for radiant tubes has been proven also in many other installations.

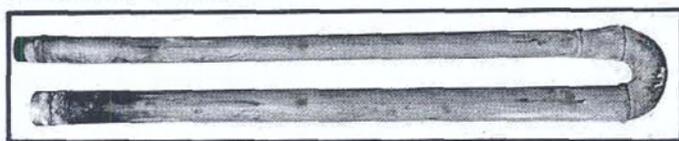


Figure 5

Figure 5 illustrates a trial RA333 radiant tube 3/16" thick, removed from a continuous carburizing furnace after four years service. It was removed because the furnace was dismantled and replace. Cast HT tubes had averaged two years life.

Based on this evaluation, the user purchased and has in service some RA333 tubes.

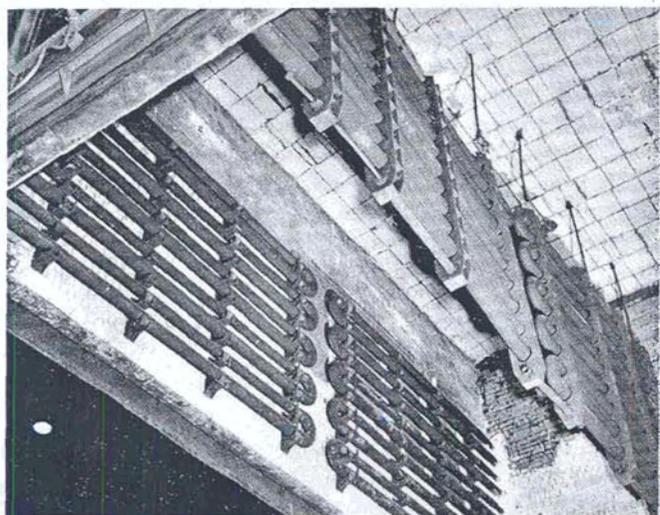


Figure 6

Figure 6 illustrates wrought radiant tubes of RA330

that replaced cast HH alloy tubes of 5/16" wall in a multi-stack steel mill annealing furnace. Loads and cycles of the furnace were logged after installation of the RA330 tubes until the break-even point for life vs. cost was reached. Replacement of cast tubes with RA330 is continuing in this mill.

The maintenance personnel are enthusiastic about the easier installation due to the lighter weight.

Of interest in this furnace is the massive cast tube supports which have to be heated and cooled every cycle along with the tubes and workload. Less weight in the tubes should permit a reduction in the mass of the supports.

These are only a few of many case histories available documenting the economical performance of wrought radiant tubes.

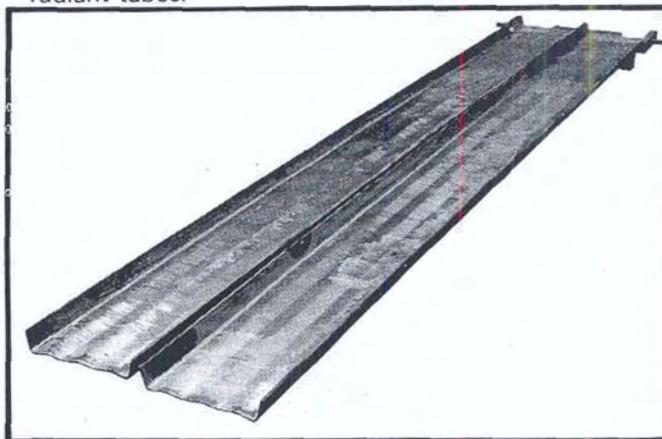
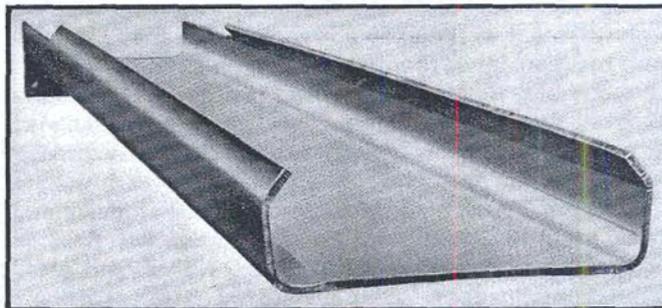


Figure 7



Shaker Hearths

Figure 8

Figure 7 illustrates a twin RA330 shaker hearth 24" overall x 132-1/2" long fabricated of 1/4" plate, used mostly for clean hardening. At the time of photographing these hearths had been in service 27 months. Previously used cast HT alloy failed in 3 to 5 months.

Figure 8 illustrates also one of a twin shaker hearth used for clean hardening and carbonitriding. Cast HX originally used gave erratic life ranging upward from 3 months. The user has 3 such furnaces in which RA333 has been used for five years or more, with life ranging from 18 to 22 months. It is stated a life increase of at least 30% has been obtained. These were originally 3/8" plate, since reduced to 5/16". (The radiant tubes in these furnaces are RA333, also.)

In summary, it must be emphasized that both cast and wrought alloys offer certain advantages. Both are necessary. Greatest economy of operation results when cost per hour of service, or the cost of the product being processed, is the least regardless of initial cost of the alloy. To achieve this, all of the properties of an alloy must be considered when specifying, rather than following a habit "because we have always done it this way."