Lower Cost Heat Treating

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Radiant tubes are used extensively in many types of industrial furnaces because they are an efficient means of heating, and contain the products of combustion thus permitting the maintenance of prepared atmospheres around the work in process. Such prepared atmospheres may vary through the range of "inert", such as nitrogen; "neutral", such as a reacted hydrocarbon atmosphere maintained in equilibrium to the carbon content of the steel being heated; or those intended to perform some definite alloying on the work, such as carburizing or nitriding.

The type of equipment in which radiant tubes are used varies greatly depending upon the work to be processed, the material handling system desired by the user, and the metallurgical function to be accomplished. The tubes may be mounted vertically or horizontally, and may be designed as "U", "O", "W", or straight-through types.

For the past several years, there has been a growing acceptance of radiant tubes fabricated of wrought materials. In the following paragraphs, the authors will discuss some of the potential advantages of wrought radiant tubes, and relate results of several installations wherein they have been evaluated, both in respect to wrought alloys versus each other, such as RA-333, RA-330, RA-600, and RA-309, and also wrought versus cast structures of similar compositions.

Probably the earliest and most extensive use of fabricated radiant tubes has been in annealing equipment for the steel and aluminum industries. Performance of RA-309 has been considered satisfactory, and it has been widely used.

Wrought tubes have been used also with good success in the controlled atmosphere furnaces utilizing straight-through tubes, which have become increasingly popular during the past fifteen years. These are frequently multi-purpose furnaces operating over a wide range of temperatures, and with various atmospheres, on successive work loads.

The wrought heat resisting alloys used for the straight-through tubes have been RA-600, RA-330, and to some lesser extent, RA-314. In general, all three materials appeared to have about equal service life, with one or another having some slight advantage in specific installations. Probably RA-330 has been used in greatest quantities based upon availability, initial cost and ultimate performance.

Although wrought radiant tubes have been successful in the two types of equipment described above, centrifugally cast alloy, assembled by welding to static cast return bends if other than a straight-through design, have been used far more extensively. Depending upon the service conditions, various alloys have been used, such as the Alloy Casting Institute's designations HT, HH, and HK, (Table I) as well as several proprietary alloys developed and patented by individual heat resisting alloy foundries.

The predominance of cast radiant tubes may be attributable to several factors:

1. The initial cost of a cast product is generally less than a similar item fabricated of wrought materials.

2. It is recognized that cast heat resisting alloys possess greater creep strength at operating temperatures than similar compositions in wrought form.

3. There is quite a bit of laissez faire attitude in mankind, and cast alloys were produced and used extensively for many years before comparable materials became available in wrought form.

From the above, it appears that greater creep strength is the only engineering advantage offered by cast radiant tubes.

The success of wrought materials in the straight-through tubes, the availability of newer wrought alloys offering improved resistance to carburization and increased creep strength, and no doubt the competitive pressures for the development of improved products, have all combined to prompt consideration of wrought materials for more extensive use as radiant tubes.

An analysis of the potential advantages offered by wrought alloys might be of interest.

Thin Wall Construction: Any thickness of material can be produced in wrought form, thus permitting thinner wall construction. In service, wall thicknesses of ⅛" to 3/16" have proved successful.

Heat resisting alloys are relatively poor conductors of heat. Theoretically, a lower thermal head will exist on a tube with thinner wall, and since strength diminishes rapidly with increasing temperature, the strength requirements may be reduced if the thermal head of the material can be lowered.

An increase in the efficiency of the radiant tubes may result also from thinner walls, and of course, initial cost may be reduced proportionately.

Uniform Wall Thicknesses: A tube fabricated from sheet or plate offers a uniform wall thickness throughout its entire cross section and length. Non-uniform cross sections promote thermal stresses which encourage distortion and localized hot spots, both of which may detract severely from radiant tube life.

Smooth Surfaces: The smooth surfaces of wrought materials may be advantageous in decreasing carbon absorption, and in resisting the typical "carbon attack" so frequently encountered in high methane atmospheres. The smooth surface should more easily shed soot deposits, also, minimizing the insulating effect and in turn promoting less thermal head and reduced carbon absorption.

Grain Size: Wrought heat resisting alloys are fine grained. Fine grained materials offer more barriers to the diffusion of carbon and/or nitrogen, thus promoting resistance to these destructive atmospheres.

Light Weight: In certain installations, the ease of handling and installing replacement radiant tubes of lighter con-

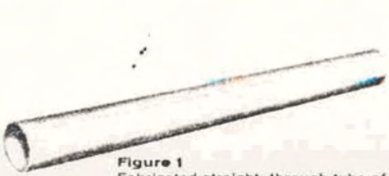

Figure 1
Fabricated straight-through tube of RA-333, typical of those used in cases I and II.

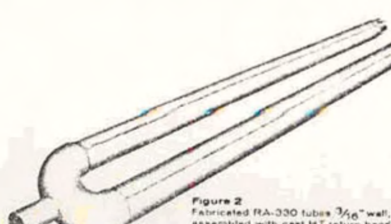

Figure 2
Fabricated RA-330 tubes 3/16" wall, assembled with cast HT return bend, typical of those used in case III and IV.

struction is considered a very significant advantage.

An analysis of the operating conditions under which radiant tubes must perform suggests that the properties of wrought materials mentioned above may be quite advantageous. It must be recognized, however, that many factors may influence the life of a radiant tube, beyond the material selection. For example, improper combustion of the burner, or misalignment of the burner with the tube, so that localized hot spots occur will materially reduce radiant tube service life. In general, the cyclic conditions encountered in batch type equipment are more severe than those in continuous furnaces. However in continuous furnaces, the radiant tubes at the charge end are usually on high fire constantly, and thus operate with a greater thermal head than those in the soaking or discharge zones. Consequently, tube life at the charge end is invariably shorter than in the other sections.

In carbonaceous atmospheres, heavy sooting is a significant factor. As mentioned briefly above, a soot deposit on the radiant tube becomes very effective insulation, increasing the tube temperature substantially. Installations are known wherein sooting occurs to the extent that some of the radiant tubes are completely buried with soot.

The removal of soot deposits is very influential on tube life. If removed by "burning out", and if this operation is not performed under close control, extremely high localized temperatures may result on the alloy tubes. Such high temperatures increase carbon absorption by the alloy, and in some cases may result in actual localized melting of the tube. Sooting may be minimized by proper control of the furnace atmosphere, but this varies greatly from one installation to another.

Improper installation of the tube, so that it does not have freedom for expansion and contraction, will result in early and excessive distortion, and again localized hot spots will result from the improper flow of the fuel-air mixture and products of combustion.

The workload processed in the furnace has a definite influence on radiant tube life, and of course varies from plant to plant.

It becomes obvious then, that a comparison of materials from which radiant tubes may be made must be obtained in a specific furnace, operating under typical production conditions. Further, the results should not be unduly influenced by any of the above mentioned conditions which may promote abnormally short life.

The following case histories relate the results of evaluation programs conducted under such conditions.

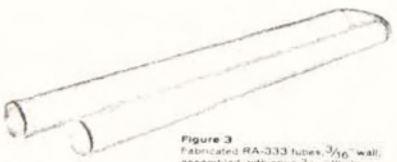

Figure 3
Fabricated RA-333 tubes, 3/16" wall, assembled with spun 3/16" thick return bend. As used in case V

EVALUATION PROGRAMS

CASE I: In one installation wherein a batch type furnace with vertically mounted straight-through tubes was used for carburizing and carbo-nitriding at 1500° to 1700°F, it was decided to compare RA-333 with the conventional wrought materials previously used. A new set of radiant tubes was installed in the furnace, alternately, and composed of 2 each of 5 different alloys. The tubes were 2¾" O.D., ⅛" wall, and 60" long (Fig. 1).

At last report the conventional alloys had been removed from service after 7 to 8 months' life, and the RA-333 was still in service after 26 months.

As the result of the performance of RA-333 tubes in this test program, the user was prompted to specify the alloy as original equipment in a new furnace subsequently purchased. This second furnace has been in continuous operation for 17 months, without a tube replacement. These tubes were also ⅛" wall thickness.

CASE II: In a commercial heat treating plant in the mid-west, two batch type controlled atmosphere furnaces with straight-through tubes are used for carburizing, carbo-nitriding, and clean hardening, at 1450° to 1700°F. Through the years, numerous alloys of both wrought and centrifugally cast compositions had been used. The use of centrifugally cast HT alloy had become more or less standard, with an average life of about 18 months.

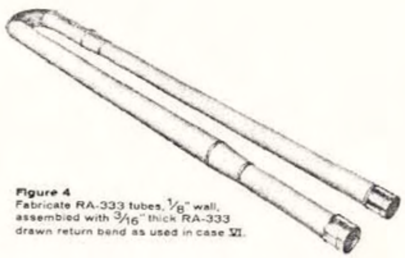

Figure 4
Fabricate RA-333 tubes, ⅛" wall, assembled with 3/16" thick RA-333 drawn return bend as used in case VI.

After an initial test installation of fabricated RA-333 tubes, they have been adopted as the standard for the two furnaces and sufficient experience has been obtained to indicate a life expectancy of 24 to 33 months, with an average of 28 months.

CASE III: One of the earlier installations of horizontally mounted fabricated radiant tubes, in a continuous carburizing furnace, was in a plant producing automotive parts. Operating temperature is 1700° to 1750°F.

Original equipment consisted of 5/16" thick centrifugally cast tubes with static cast return bends from which an average life of 6 to 9 months was obtained. A total of four furnaces have been equipped with radiant tubes fabricated of RA-330 alloy in conjunction with static cast HT return bends. The tubes were fabricated of 3/16" plate, and are 4⅞" I.D. x 7'1" long (Fig. 2).

Records have been kept which indicate service life in the range of 18 to 24 months. One tube was recently removed after 26 months, and found to be still in serviceable condition. Life comparisons

Figure 5
Fabricated RA-333 "O" tube with spun return bends as used in case VII.

were made on tubes installed in the same location within the furnace.

CASE IV: Similar tubes fabricated of RA-330 in conjunction with cast HT return bends have been used successfully for several years in a midwestern plant carburizing tractor parts, in a continuous furnace operating at 1700°F. In this installation, horizontally mounted, RA-330 "U" tubes have given an average increase of 50% service life. The tubes are fabricated of 3/16" plate, and the cast return bends are 5/16" thick. Sizes of tubes vary from 5½" to 6" O.D., and from 6½ ft. to 7 ft. long.

CASE V: A large manufacturer of oil-well drill bits operates several continuous pusher furnaces for deep-case carburizing at 1775°F. Original centrifugally cast "U" tubes were 5/16" wall, with ½" thick return bends. Life of the cast radiant tubes ranged from 8 to 12 months, and a conversion to fabricated RA-333 tubes was begun approximately 3 years ago. These tubes were completely wrought, having formed and welded tubes with spun return bends 4" I. D. on 8" centers, 6' long, all of 3/16" RA-333 plate (Fig. 3). The original tubes are still in service at this writing.

CASE VI: A somewhat unusual problem was encountered by a manufacturer of heavy duty gears, carburizing in pit type furnaces at 1750°F. The radiant tubes in these furnaces are vertically mounted, around the circumference of the furnace chamber. Although the cast tubes, with which the furnaces were originally equipped, did not fail from burnout until after 5 years, they did "rack" or deform sufficiently that a complete rebrick of the furnaces was necessary about once a year. Completely fabricated "U" tubes of RA-333 have been installed in several furnaces. The oldest set has been in service 24 months, with no apparent signs of deterioration, and most significantly, no distortion. The user reports considerable advantage of the lighter tubes in making replacement installation and anticipates appreciable reduction in maintenance costs on the furnace brickwork. In this case the "U" tubes are ⅛" wall, "stepped" from 3½" to 4½" O.D. x 88½" long (Fig. 4).

CASE VII: Operating conditions for radiant tubes in steel mill annealing furnaces, at first glance, do not appear to be very demanding. Control temperature of the furnace load is relatively low, and when the furnace utilizes an inner cover, the atmosphere on the exterior of the radiant tubes is only air, and only products of combustion exist within the tubes, neither of which are considered particularly destructive to heat resisting alloys. The 26 to 27 hours per cycle results in lengthy life as measured in hours or months, even though the number of cycles might be few. Actually, of course, measurement of service life of items such as radiant tubes is much more accurate if done in terms of cycles rather than time.

If consideration is given to the very massive loads processed in such equipment however, and the long period during which the radiant tubes are on high fire and thus operating at a high thermal head, it will be realized that the relatively low control temperature of the workload can be misleading in respect to the operating conditions encountered by the radiant tubes.

One large steel mill operating furnaces with "O" tubes recognized the high cost of their tube maintenance and initiated a carefully controlled program to evaluate tubes of various materials.

Several newly rebuilt furnaces were equipped with new radiant tubes of several compositions, including RA-309, RA-330, RA-600, and RA-333. The "standard" RA-309 tubes were constructed of 3/16" plate in the burner leg and ⅛" sheet in the exhaust leg. All the other alloys were fabricated from ⅛" sheet throughout (Fig. 5). Each cycle run in each furnace was carefully logged, so that a complete record of the total cycles obtained on each type of radiant tube would be available. Because of the long cycles, this test program has been in process for almost four years. The most economical material has yet to be selected, upon conclusion of the test program, but all of the alloys tested were superior to the RA-309 used for so many years. The RA-333 tubes are still in service after doubling the *best* life obtained on RA-309.

TABLE I

NOMINAL COMPOSITION OF HEAT RESISTING ALLOYS

	ACI CAST DESIGNATIONS			WROUGHT ALLOYS					
	HT	HH	HK	RA-333	RA-330	RA-600	RA-314	RA-310	RA-309
Carbon	0.50	0.35	0.40	0.05	0.05	0.05	0.05	0.05	0.05
Nickel	35.0	12.0	20.0	45.0	35.0	76.0	20.0	20.0	14.0
Chromium	15.0	25.0	26.0	25.0	19.0	16.0	25.0	25.0	23.0
Silicon	1.5	1.0	1.0	1.25	1.25	0.30	2.5	0.5	0.8
Molybdenum	—	—	—	3.0	—	—	—	—	—
Tungsten	—	—	—	3.0	—	—	—	—	—
Cobalt	—	—	—	3.0	—	—	—	—	—

SUMMARY

The authors have attempted to review specific installations where carefully conducted tests have established the merits of wrought fabricated radiant tubes, for both vertically and horizontally mounted applications.

Although only a few case histories are cited, comparable results have been received in numerous other plants.

Generally, the tests were conducted to establish the merits of RA-330 and/or RA-333 alloy, and both have proved successful in comparison with previously used materials. Almost without exception, when RA-333 has been compared with RA-330, the former has proved economical in spite of its higher initial cost.

It should be emphasized that each piece of equipment has its own peculiarities in respect to operating conditions, and it cannot be concluded that experience gained in one plant will necessarily be duplicated in another.

However, in view of the increasing pressures to reduce maintenance and operating costs, the substantial expenditures for heat resisting alloys to maintain high temperature equipment, and the high cost of lost production during shutdown for replacement of failed parts, it is believed that all users of furnaces will be interested in the results of these evaluations and will want to give careful consideration to the possibility of reducing their own maintenance costs through similar programs.