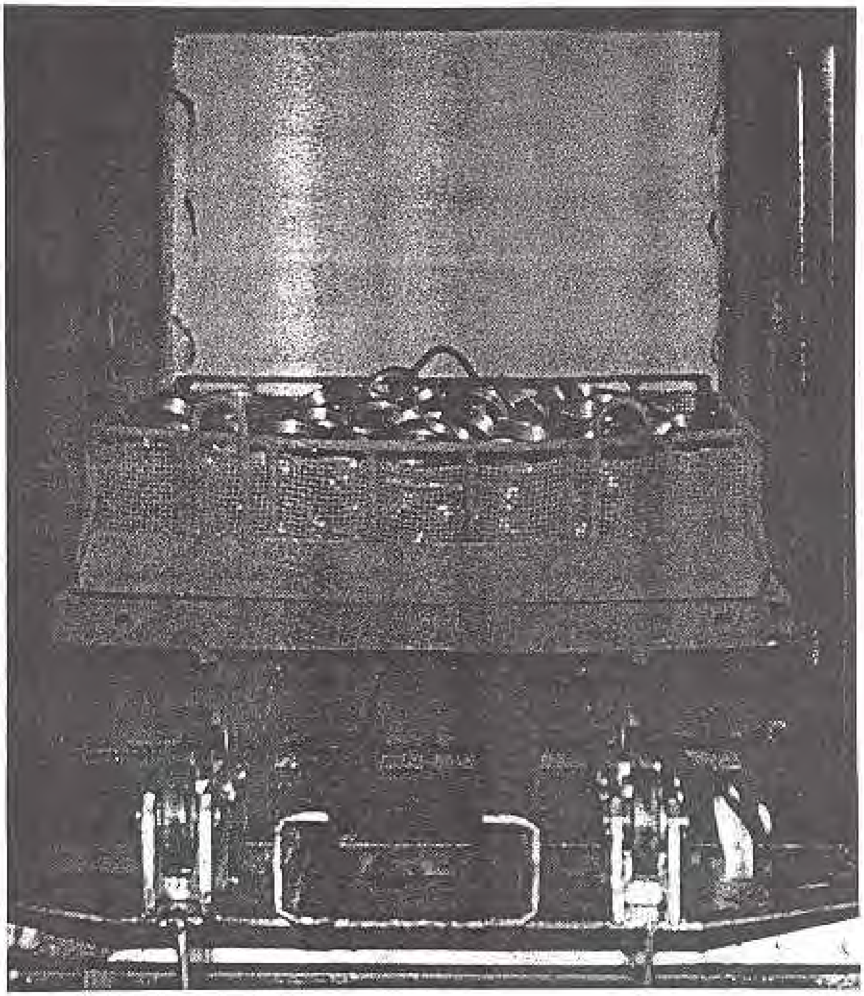
An Evaluation of Heat Resistant Alloy Furnace Components

By Gene R. Rundell

This article is based on an overlooked approach to the evaluation of heat resistant alloys in the heat treating industry: the use of controlled test data from the field.

To obtain data, materials of interest must be exposed to the same conditions. Conditions that affect alloy performance include not only the obvious ones of atmosphere, temperature, thermal cycling, and service life but also more subtle factors such as loading and mechanical abuse. The problem of trying to isolate extraneous factors from material factors may be simplified by including all materials of interest in one unit. (Materials of interest may involve alloy composition, surface condition, section size, and metallurgical properties.) Heat treating bar baskets which contain a number of similar components are possibly the best suited for this purpose. A typical bar basket is shown in Fig. 1.



Two heat treating job shops were selected to obtain field experience. Both perform a typical variety of heat treatments. The heat treatments involved atmospheres and quenching conditions damaging to heat resistant alloys via a combination of carburization and thermal fatigue.

Both shops do carbonitriding and carburizing, with occasional plain hardening. One shop did most of its carbonitriding at 1550 to 1600 F (845 to 870 C), while the other used temperatures in the range of 1500 to 1800 F (815 to 980 C), depending on case depth. Carburizing, a much smaller factor, was done at 1700 to 1750 F (925 to 955 C). Both shops oil quenched in the cycle, usually from a reduced temperature of 1550 F (845 C). The severity of thermal cycling was greater in one shop than the second judging from the amount of internal cracking (thermal fatigue) and from the lower service life.

Bar Basket Materials And Their Evaluation

Bar baskets were fabricated from RA 330, RA 333, and alloys A, B, C, and D. They represent two types of alloys and include the most common materials used for carburizing conditions. One type is made up of iron-nickel alloys containing about 15 to 23% chromium and is represented by RA 330, and

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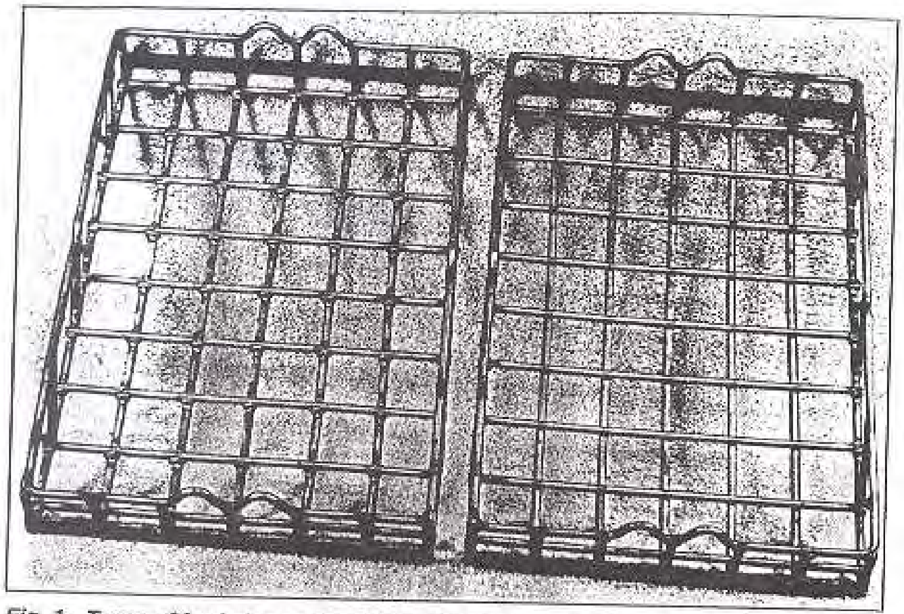

Fig. 1—Types of baskets used in field performance tests. Runner bars, long members at bottom of basket, are subject to sliding wear. In basket at left, crossbars are joined to runner bars with weld metal in addition to pressure weld.

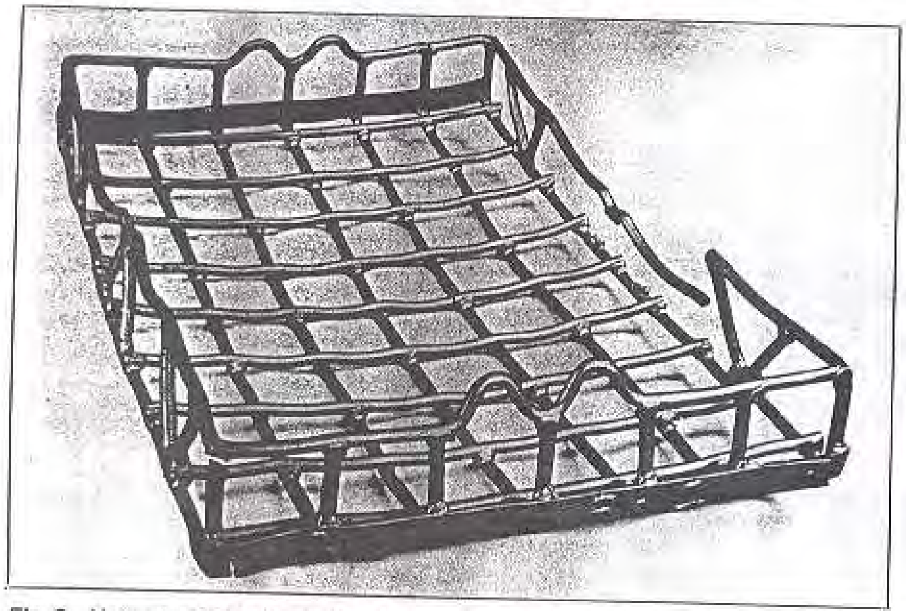

Fig. 2—How a basket looked after nine months of carbonitriding, carburizing, and plain hardening in a job shop. Floor was originally pressure welded without filler. In making repairs, filler metal was added. Damage included distortion, weld failures, breakage.

alloys C and D. The second type is nickel base having more chromium than iron, and is represented by RA 333, and alloys A and B. Both types are commonly modified with silicon to increase carburization resistance, as in RA 330, RA 333, and alloy D. Aluminum is added to B for resistance to carburization. Tungsten, molybdenum, and cobalt are added to RA 333 for strengthening.

Heat resistant alloys of substantially lower nickel content such as AISI types 309 and 310 are generally not suitable in carburizing environments. Use of silicon as in type 314 renders them susceptible to embrittlement from sigma phase.

In addition to the commercial heat resistant alloys listed above, the bar baskets included several experimental modifications of RA 330. These modifications include aluminum and silicon. Composition variants are shown in Table I.

Four baskets of identical design and material were fabricated using 0.5 in. (13 mm) diameter bar. The floor of the basket (Fig. 1) is made from a series of bars in one direction, with these connected by a series of bars crossing on top and tied in by pressure welds. Two baskets were made with filler metal added to the pressure welds, and two without. The bottom set contacts the surface on which the basket rests. They are referred to as runner bars to distinguish them from crossbars. Because runner bars are exposed to sliding wear they are not identical to crossbars in service. However, a bar basket does provide good comparative information on materials. Each shop was supplied with a set of baskets, one as-pressure welded, and one with filler added.

Twelve materials were selected for evaluation, as either crossbars or runner bars. Because there were 16 locations, four materials were exposed as both crossbars and runner bars. The materials are listed in Table I corresponding to their position in the bar basket. The general condition of one of the baskets after nine months of service is shown in Fig. 2. Service conditions were severe enough to cause numerous weld failures, considerable distortion, and occasional fracture of the bar member itself.

The bar basket shown in Fig. 2, and a second one from the same shop were taken from service after nine months. All of the crossbars and runner bars from both baskets were examined metallographically from full transverse cross sections of the bars at two locations along the length of the bar (32 samples per basket). Runner bars were also sectioned in the longitudinal direction. A 2 in. (50 mm) length of each bar was removed for chemical analysis of carbon near the surface.

The full cross section was examined metallographically to assess the extent of carburization, the severity of internal

Table I—Composition and Location of Materials in Bar Baskets

Alloy[1]	Condition[2]	Location in Basket	Composition, %[3]							
			C	Si	Mn	Ni	Cr	Ti	Al	Other
B	HRAP	Crossbar	0.02	0.17	0.2	61	21.5	0.34	1.30	—
RA 330	ACG	Crossbar	0.05	1.3	1.5	36	19.4	—	—	—
D	ACD	Crossbar	0.05	1.4	1.3	35	14.9	—	—	—
330-1	ACG	Crossbar	0.07	0.4	1.4	36	18.5	—	—	—
330-2	ACG	Crossbar	0.09	0.4	1.4	36	18.5	—	0.22	—
330-4	ACG	Crossbar	0.11	0.4	1.4	36	18.5	—	0.74	—
330-5	ACG	Crossbar	0.10	1.2	1.4	36	18.5	—	1.1	—
330-13	ACG	Crossbar	0.08	3.2	1.4	36	18.5	—	—	—
RA 333	ACG	Crossbar	0.06	1.4	1.7	45	25.5	—	—	3.0 W, 3.0 Mo, 3.0 Co
B	HRAP	Runner bar	0.02	0.17	0.2	61	21.5	0.34	1.30	—
A	HRAP	Runner bar	—	—	—	(75)	(15)	—	—	—
C	HRAP	Runner bar	0.04	0.25	0.95	31	21.3	0.42	0.42	—
RA 330	HRAP	Runner bar	0.07	1.1	1.9	35	18.8	—	—	—
RA 333	ACG	Runner bar	0.06	1.4	1.7	45	25.5	—	—	3.0 W, 3.0 Mo, 3.0 Co
RA 330	ACG	Runner bar	0.05	1.3	1.5	36	19.4	—	—	—
D	ACD	Runner bar	0.05	1.4	1.3	35	14.9	—	—	—

[1] *Alloys are listed in the sequence in which they are located in the bar basket. In Fig. 2, the runner bars are shown longitudinally. Their listing above is from left to right in Fig. 2. The crossbars are shown from top to bottom.*

[2] *HRAP = hot rolled, annealed, and pickled; ACG = annealed and centerless ground; ACD = annealed and cold drawn.*

[3] *Bal Fe.*

cracking from thermal fatigue, and external cracking (see Fig. 3). The three factors were recorded by photographing all of the cross sections. In general, differences among various materials are readily apparent, although not easy to quantify.

To compare material performance, it was necessary to rate the extent of damage from each of the above factors. Rating is done separately for carburization, thermal fatigue, and external cracking by assigning a number from one to four in increasing order of severity and averaging the rating from both baskets. The performance is treated as the sum of each of the above characteristics. Although carbon analysis is shown in Tables II and IV, it was not used for the rating of carburization. Carburization was rated from the depth and the extent of the case shown in etched cross sections, as illustrated in Fig. 3.

The average ratings from two bar baskets used in the one shop for nine months are summarized in Tables II and III. Two baskets, used in a second shop, were removed from service after two years. Only the cross bars from one of these baskets and only the runner bars from the other were obtained for examination. Results from service in the second shop are summarized in Table IV.

Performance of Two Baskets After Nine Months Service

Carburization, summarized in Table II, varied from light and spotty to deep and continuous. Thermal fatigue (internal cracking) was not present in some materials; however, there were extensive networks of cracks in other alloys. External cracking also varied from none to deep cracks around the entire periphery. The three types of damage are summarized in Table III.

Runner bars show more damage than crossbars when they are compared for the same four materials, Table III. A series of experimental alloys, coded as 330-1 through 330-5, were severely damaged by a combination of carburization, fatigue, and external cracking. A fifth alloy in this series, containing over 3% silicon, was damaged much less severely.

Alloy A showed the greatest resistance to cracking in a runner bar even though it carburized deeply. In general, most materials that carburized also cracked externally. An alloy having a high rating as a runner was the best alloy in the series of crossbars, RA 333. The alloy of next highest rating, based on both locations, was RA 330 (as centerless ground). There is no clear beneficial effect of surface finish on performance — neither from the cold drawn

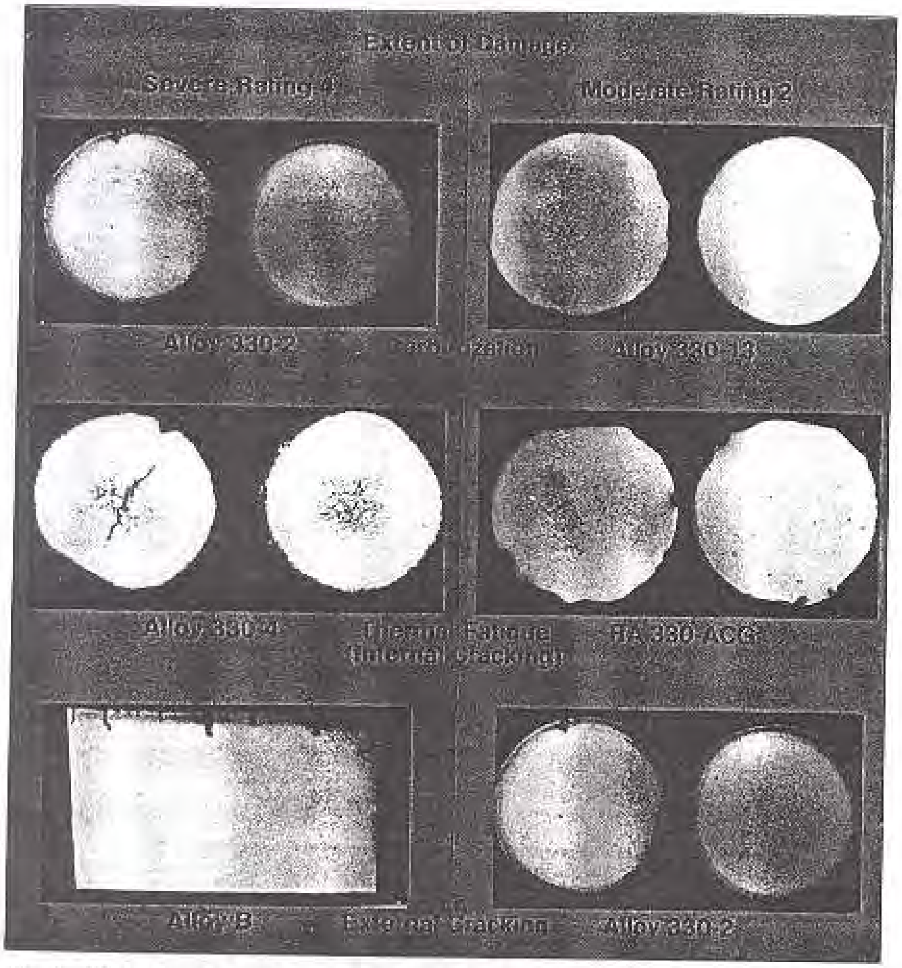

Fig. 3—Etched cross sections of various 0.5 in. (13 mm) in diameter basket bars. They show examples of severe rating (4) and moderate rating (2) damage by carburization, thermal fatigue, and external cracking.

finish of alloy D nor the centerless ground finish of RA 330.

As mentioned, alloys that carburize most severely also tend to develop the most severe external cracks, the exceptions being alloy A and possibly alloy D. The fact that several members having deep external cracks showed little internal cracking suggests that external cracking relieves thermal stresses that lead to internal fatigue cracking.

In comparing the two criteria for carburization shown in Table III, it will be noted that the metallographic rating does not reflect the same change from one alloy to another as does carbon content. This is undoubtedly due to the inherent differences in the way it is measured. The increase in carbon content is based on the outer 1/16 in. (1.6 mm) layer of the basket member. The metallographic rating does not make a distinction between carburized layers from 1/32 to 1/16 in. (0.8 to 1.6 mm) in depth. Thus several alloys showing a continuous case varying in depth between 1/32 and 1/16 in. (0.8 to 1.6 mm) would all be rated as 4, but would obviously have different carbon contents.

Results From a Second Shop After Two Years Service

Damage to the two baskets supplied to the second heat treating shop is summarized in Table IV. Only the crossbars of one basket and the runner bars from the other were returned. Thus the comparison between the two components is from one basket to another. A comparison of the basket members used in the first shop for nine months to the second shop for two years indicated that carburization ratings were similar for most alloys. However, the amount of thermal fatigue damage was much less in the second shop, even though the baskets were in service for two years. This is reflected in the lower over-all ratings (reduced damage).

It is noteworthy that alloy B showed no carburization after nine months, but was heavily carburized after two years. Alloy RA 330 (hot rolled, annealed, and pickled) showed the most severe internal cracking after nine months, but none in the second shop after two years. The very severe cracking in the first shop for RA 330 may be due to its placement as the center runner bar and to the general distortion of the basket in service (Fig. 2). This resulted in the center runner supporting most of the load, with an attendant increase in thermal and mechanical stresses.

In addition to micro-examination, one set of runner bars was analyzed for carbon after two years in service. The increase in carbon content is shown in Table V. Alloys containing deliberate alloy additions to retard carburization were generally superior to unmodified nickel-chromium-iron alloys. This is particularly evident in the carburization resistance of silicon modified alloys, RA 330 and RA 333.

Laboratory Evaluation Vs Field Performance

Use of five experimental bars, with modifications of aluminum or silicon to a base composition similar to RA 330, affords an opportunity to compare service performance to laboratory tests using the increase in carbon as the criterion. The five materials are identified as 330-1, 330-2, 330-4, 330-5 and 330-13 in Table I, with the chemical modifications highlighted by shading. Laboratory tests were at 2000 F (1095 C) for 100 h. The increase in carbon content for the five alloys containing composition variants is summarized as follows:

Variant to 18.5 Cr-36 Ni Alloy	Carbon Increase, % Laboratory	Carbon Increase, % Field Service
0.35 Si	0.86	1.85
0.35 Si, 0.22 Al	0.88	1.18
0.35 Si, 0.74 Al	0.28	0.70
1.2 Si, 1.1 Al	0.30	0.22
3.2 Si	0.10	0.13
None, commercial RA 330 with 1.3 Si	—	0.29

Laboratory tests result in the same general ranking as service data. In both cases silicon retards carburization. Aluminum is beneficial at low silicon, but does not appear to be useful when added at 1.2% silicon. An addition of 3.2% silicon is more useful than combined additions of silicon and aluminum.

The beneficial effect of silicon has generally been recognized by the industry for many years and is documented in several investigations. In wrought alloys, additions of silicon to type 310 stainless steel markedly improve carburization resistance. Payson and Savage performed pack carburizing tests at 1650 F (900 C) on type 310 containing 1.2, 1.7, and 2.2% silicon.[1] The amount of carbon in the carburized layer was found to be 2.96, 2.00, and 0.37% respectively.

Avery and Wilks conducted methane gas carburizing tests in 30% methane and 70% nitrogen at 1760 F (960 C) for 100 h.[2] They found that a silicon addition of 2.12% in HK cast alloys was effective in reducing carbon from 2.8% at low silicon to 0.5% at 2.12% silicon. A further increase to 3% silicon had only slight additional benefit. The utilization of silicon for this purpose is reflected in a number of heat resistant alloys including type 302B (2.5% Si), type 314 (2.2% Si) and RA 330 (1.25% Si).

The effect of silicon in iron-nickel-chromium alloys in this work is shown in Table V by comparing the carbon contents

Table II—Performance of Materials Rated by Severity of Carburization After Nine Months Service

Alloy	Condition[1]	Carburization, Visual[2]	Increase in Carbon Content, %[3]
		Crossbars	
B	HRAP	Light, spotty (1.5)	0.02
RA 330	ACG	Light, occasionally deep, spotty (2.5)	0.29
D	ACD	Light and deep, spotty (2.5)	0.33
330-1	ACG	Deep, continuous case (4)	1.85
330-2	ACG	Deep, continuous case (4)	1.18
330-4	ACG	Deep, continuous case (4)	0.70
330-5	ACG	Deep, continuous case (3.5)	0.22
330-13	ACG	Not deep, spotty to continuous (2.5)	0.13
RA 333	ACG	Nil (1.5)	0.01
		Runner Bars	
B	HRAP	Deep on side contacting hearth (2.5)	0.07
A	HRAP	Deep on side contacting hearth (3)	0.27
C	HRAP	Deep on side contacting hearth (3.5)	0.31
RA 330	HRAP	Deep on side contacting hearth (2.5)	0.08
RA 333	ACG	Medium depth on side contacting hearth (2)	0.05
RA 330	ACG	Deep, spotty, occasionally continuous (3)	0.30
D	ACD	Deep on side contacting hearth (3.5)	0.30

[1] *HRAP = hot rolled, annealed, and pickled; ACG = annealed and centerless ground; ACD = annealed and cold drawn.*

[2] *Number following comments is a severity rating from least severe (1) to most severe (4).*

[3] *Increase is based on difference in original and final carbon contents. Final analysis taken from outer 1/16 in. (1.6 mm).*

Table III—Severity of Damage to Materials After Nine Months Service

Alloy	Condition[1]	Severity of Damage[2] Rated Individually by... Carburization (From Table II)	Thermal Fatigue	External Cracking	Over-all (Combined) Rating[3]
		Crossbars			
B	HRAP	1.5	1	3	5.5
RA 330	ACG	2.5	2	1	5.5
D	ACD	2.5	2	1	5.5
330-1	ACG	4	4	4	12
330-2	ACG	4	3	3	10
330-4	ACG	4	4	2.5	10.5
330-5	ACG	3.5	3	3	9.5
330-13	ACG	2.5	2	1	5.5
RA 333	ACG	1.5	1	1	3.5
		Runner Bars			
B	HRAP	2.5	1.5	4	8.0
A	HRAP	3	1.5	1	5.5
C	HRAP	3.5	1.5	4	9
RA 330	HRAP	2.5	4	3	9.5
RA 333	ACG	2	1	2.5	5.5
RA 330	ACG	3	1.5	3	7.5
D	ACD	3.5	3	3	9.5

[1] *HRAP = hot rolled, annealed, and pickled; ACG = annealed and centerless ground; ACD = annealed and cold drawn.*

[2] *Severity rating of 1 is least severe; 4, most severe.*

[3] *Best is 3, poorest is 12.*

Table IV—Severity of Damage to Materials After Two Years Service

Alloy	Condition[1]	Severity of Damage[2] Rated Individually by... Carburization	Thermal Fatigue	External Cracking	Over-all (Combined) Rating[3]
		Crossbars			
B	HRAP	4	Nil (1)	4	9
RA 330	ACG	3.5	Nil (1)	Nil (1)	5.5
D	ACD	3	Nil (1)	1	5
330-1	ACG	—	—	—	—
330-2	ACG	4	Nil (1)	1	6
330-4	ACG	3	Nil (1)	1	5
330-5	ACG	2	Nil (1)	1.5	4.5
330-13	ACG	2	Nil (1)	1	4
RA 333	ACG	—	—	—	—
		Runner Bars			
B	HRAP	—	—	—	—
A	HRAP	4	Nil (1)	Nil (1)	6
C	HRAP	4	Nil (1)	4	9
RA 330	HRAP	2.5	Nil (1)	1.5	5
RA 333	ACG	2.0	Nil (1)	1	4
RA 330	ACG	2.5	Nil (1)	1	4.5
D	ACD	—	—	—	—

[1] HRAP = hot rolled, annealed, and pickled; ACG = annealed and centerless ground; ACD = annealed and cold drawn.

[2] Severity rating of 1 is least severe; 4, most severe.

[3] Best is 3, poorest is 12.

Note: Crossbars were taken from one basket, runner bars from a second basket.

Table V—Carburization of Runner Bars After Two Years Service

Alloy	Condition[1]	Increase in Carbon Content, %[2]
B	HRAP	0.34
A	HRAP	0.92
C	HRAP	2.36
RA 330	HRAP	0.28
RA 333	ACG	0.16
RA 330	ACG	1.27
D	ACD	0.62

[1] HRAP = hot rolled, annealed, and pickled; ACG = annealed and centerless ground; ACD = annealed and cold drawn.

[2] From outer $\frac{1}{16}$ in. (1.6 mm) of cross section.

of low silicon alloy C (0.25% Si) to RA 330 with 1.1% Si. Alloy C showed an increase of 2.36% carbon, RA 330 an increase of 0.28%.

Discussion of Field Trial Results

An implicit assumption in this work and that of others is that carbon analysis of surface layers is a good measure of service performance. It has the advantages of convenience and quantitative analysis that permit comparison of various materials. The increase in carbon is often shown as a function of distance from the exposed surface. These profiles indicate that carburized cases have high carbon close to the surface, about 3%, and that carbon decreases with increasing distance, gradually approaching that of the starting material.

Experience based on numerous failure investigations suggests that carburization of heat resistant alloys renders them susceptible to failure, as opposed to assuring rapid failure. The most common consequence of very high carbon at the surface is a form of oxidation termed green rot. Areas adjacent to chromium carbides are selectively oxidized. Attack is often deep and reduces the effective cross section of the component.

The second important consequence is reduced mechanical properties such as ductility. Heat treating bar baskets used for quenching must be able to accept high stresses in service. The amount of thermal fatigue damage is illustrated in Fig. 3. Retention of ductility is not only important in accepting thermal stress in service but also in the ability to be cold straightened.

How much carbon is damaging?

This question cannot be answered simply. It depends upon the alloy and service conditions. Alloy RA 333 has been found to carburize completely through the wall of radiant tubes and still perform very well if there is no mechanical abuse at room temperature. In the present case, both RA 333 and alloy A were found to resist selective oxidation of carburized surfaces. This is shown in the photomicrographs in Fig. 4. Other alloys, best exemplified by alloy C, are susceptible to oxidation of the carburized layer. This oxidation is shown in the Fig. 4 photomicrograph as an oxide finger about 8 mils (0.2 mm) deep, and the extension of the process is shown on a macro scale in Fig. 3.

The details of carburized layers of three heat resistant alloys illustrate varying consequences of carburization as far as green rot is concerned. They also illustrate that carburized layers have a microstructure consisting of large amounts of carbide in a matrix of austenite.

From the standpoint of ductility, the amount of carbon that is damaging at the surface is most likely between 0.5 and 3%. One heat resistant alloy is provided with 0.5% carbon for strength. Although it is not intended for bar heat treating baskets, it has been inadvertently used and has given satisfactory service.

Results of Field Trials: What They Mean

Use of different heat resistant alloys in the same heat treating bar baskets indicates that material performance can be compared. The approach should be applied at more than one test site, and ideally should involve more than one fabricated basket.

Location within the bar basket can affect the apparent material performance. Generally, our experience based on four baskets placed in two job shops suggests that each alloy should be included on at least two components. A method of rating the severity of damage by metallographic examination of full cross sections was used, providing a broad perspective of damage at a moderate expenditure of time.

The effect of silicon in retarding carburization has been demonstrated for two commercial materials having similar nickel and chromium and dissimilar silicon contents.

Of the commercial alloys tested, RA 333 was found to be most resistant to carburization, with alloy A and alloy C being the least resistant. Alloy A showed the greatest resistance to external cracking on runner bars where conditions of carburization and sliding are most severe. There were no consistent, pronounced differences in thermal fatigue resistance.

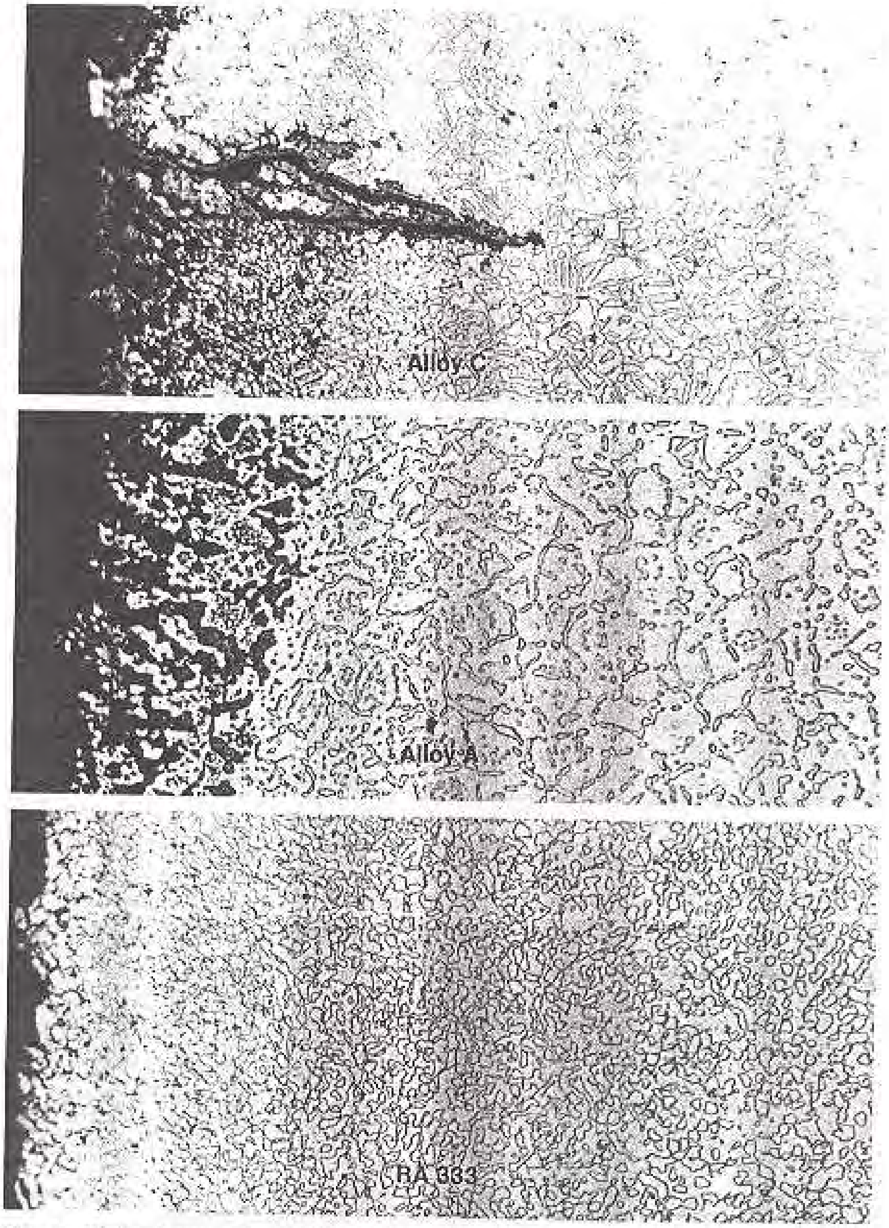

Fig. 4—Photomicrographs (250X) of the carburized cases of three heat resistant alloy runner bars. That of alloy C shows deeply carburized area. Carbon content is probably above 2% near the surface. Bar showed numerous, deep external cracks. Note darkened outer zone below crack where selective oxidation had occurred. The alloy A runner bar was carburized deeply on the hearth side but did not crack. Oxidation is about 3.5 mils (0.09 mm) deep, but does not penetrate in individual fingers of oxide as in alloy C. Carbides of alloy A tend to be blocky and disconnected. The RA 333 photomicrograph is of the hearth side of the runner bar. Carbon content in this area is obviously high. There's no evidence of external cracking or oxidation of carburized layer.

Judging from the performance of four baskets used in two test sites, RA 333 was rated as the best material. Alloy A and RA 330 ACG were rated next highest. Alloy B performed well as a crossbar for nine months service; however, it was the worst crossbar member after two years service. Alloy C showed the poorest performance in both test sites. It was severely carburized and showed deep external cracking.

For More Information: You are invited to contact the author directly by letter or telephone. Mr. Rundell is manager of customer service, Rolled Alloys, 125 W. Sterns Rd., Box 310, Temperance, Mich. 48182; tel: 313/847-0561.

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Abstract

The performance of six commercial heat resistant alloys in heat treating service has been evaluated by metallographic examination of similar components taken from bar baskets containing all six alloys. Duplicate baskets were placed in service in a heat treating job shop for nine months. The full cross section of each alloy member, 0.5 in. (13 mm) in diameter, was examined for damage by carburization, external cracking, and thermal fatigue (internal cracking). A rating system was applied to express the relative amount of damage and is illustrated from macrographs of several members. These individual ratings for three types of damage were weighted equally. Over-all performance was taken as the sum effect of the three types of damage and represents both baskets of the set. The metallographic rating for carburization was supplemented by carbon analysis of surface layers 0.062 in. (1.6 mm) thick.

A similar heat treating job shop was selected for use as a second test site, and baskets were placed in service for two years.

Alloys containing intentional silicon addition such as RA 333 and RA 330 were most resistant to carburization. Aluminum in 601 is useful, but less effective after two years. Over-all damage was most severe in 800 and least severe in RA 333.

The commercial alloys included are as follows:

RA 333
RA 330
600 — identified in text as alloy "A"
601 — identified in text as alloy "B"
800 — identified in text as alloy "C"
35-15 — identified in text as alloy "D"

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