ASSESSING WORK-BASKET ALLOYS FOR VACUUM FURNACES

A commercial heat treating company draws on its experience and test results to determine which high-temperature alloys to use for vacuum furnace baskets.

By ROGER A. JONES

In most heat treating operations, some method must be devised to hold the workload in the furnace. When a large number of small pieces must be held, a basket usually is used. The basket generally is constructed of 1/2- or 3/8-in. diameter material and is lined with a wire mesh. If the weight of the pieces is great enough, the rod/mesh basket is reinforced on the bottom with suitable bar supports.

The baskets are supported in the furnace by a work grid made of flat alloy bar between 1 1/4- and 2-in. high and between 1/4- and 5/8-in. thick. Baskets aren't needed for larger pieces that can be supported by the grids alone.

The grids and baskets introduce a mass that must be heated and then cooled, which requires additional electrical energy to heat and additional time to cool the workload. Occasionally, the work—with or without baskets—may be supported directly by the furnace hearth rails.

If the mass of the supporting structure can be reduced, the heat treating operation can save both time and direct energy costs. To this end, Solar Atmospheres Inc., an affiliate of Vacuum Furnace System Corp., conducted a series of tests to determine what savings could be realized by using alloys that would reduce the mass of the supporting structures.

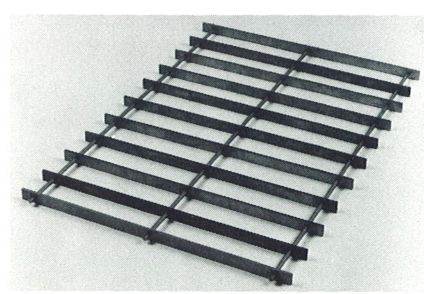
All the tests were run in a VFS model HL36 furnace, which has a hot zone measuring 24 in. x 24 in. x 38 in. deep. The furnace was chosen because it is one of the most common size production furnaces and was appropriate to hold the baskets used to compare the different alloys.

During a basket's useful life, failure most likely will occur at a weld or bend point, which requires rewelding.

The baskets were fabricated from straight rod, bent to shape and MIG- and/or TIG-welded together with an alloy similar to the rod itself. Special alloy rods were used because of their ability to support a given load (in this case, up to 2,000 lbs.) at operating temperatures typically between 400°F/204°C and 2200°F/1204°C with an upper limit of 2300°F/1260°C for the alloys considered.

Type 304 stainless was used for

A basket, constructed of alloy rod and lined with wire mesh, holds small pieces ready for the furnace.



A typical work grid for supporting baskets is made of flat alloy bar in varying thicknesses.

Figure 1

Nominal Chemical Composition of Alloys (wt.%)

Alloy	Ni	Co	Fe	Cr	Mo	W	Mn	Si	Al	C	B	Others
No. 1	57	5*	3*	22	2	14	0.5	0.4	0.3	0.10	0.015*	La-0.02
No. 2	37	3*	33	25	2.5*	2.5*	0.7	0.6	0.1	0.05	0.004	Cb-0.7, N-0.20
No. 3	61	-	14	23	-	-	0.3	0.2	1.4	0.05	-	-
No. 4	35	-	43	19	-	-	1.5	1.2	-	0.05	-	-

* approximation

Solar Atmospheres Inc. studied four high-temperature alloys of various chemical compositions to determine which ones best suited the company's needs for vacuum furnace baskets.

the wire mesh liner because its temperature limit also is 2300°F/1260°C. It could be used because of the mechanical support given by the 1/2- or 3/8-in. diameter alloy rod basket. Above 2300°F/1260°C or with extra heavy loads, molybdenum bars and/or grids also were used in conjunction with the alloys being tested to give additional support. Moly is good to more than 3000°F/1649°C.

In a brazing application, Refrasil cloth was used to prevent the work from attaching to the basket.

Depending upon the various combinations of thermal and mechanical stresses, and the number of duty cycles, a furnace basket can last up to six years. During its useful life, however, occasional rewelds must be made, usually at a weld or bend point where failures normally occur.

Vacuum Specialists

Solar, which specializes in vacuum heat treating, brazing and nitriding, looked at four alloys commonly used in vacuum furnace baskets. The composition of each of these alloys is shown in Figure 1.

The major factors considered were yield strength, thermal expansion and creep rupture strength. Figures 2, 3 and 4 include the data for these three parameters.

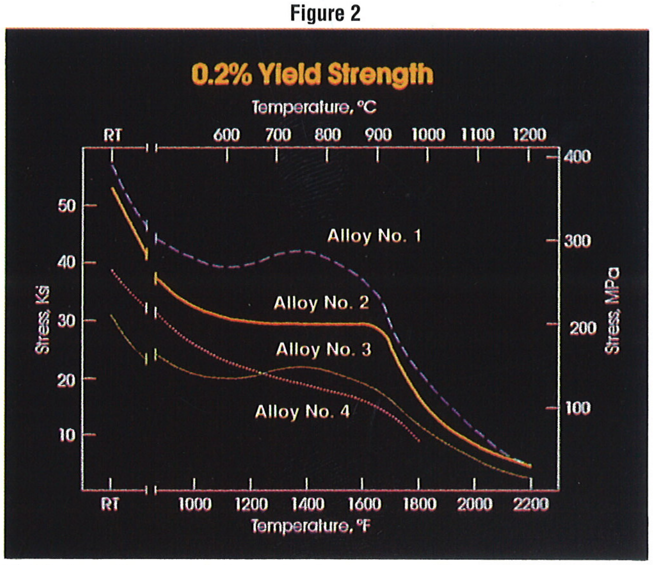
Because of the rupture strengths and yield strengths involved, comparable baskets of alloy No. 1 required a combination of 1/2- and 3/8-in. diameter rods. Alloy No. 2 baskets required only 3/8-in. diameter rods, and No. 4 required 1/2-in. diameter rod construction throughout. Baskets made of alloy No. 3 already had been in use for some time at Solar and were not constructed for this test, although existing data from literature was analyzed.

All the new baskets were 24 in. (W) x 36 in. (L) x 5 in. (D). The basket made of alloy No. 1 weighed 49 lbs., the basket constructed of No. 2 weighed 33 lbs., and the one made of No. 4 weighed 55 lbs. Each basket could support a 350-lb. load at an operating temperature of 2150°F/1177°C.

As one might expect, however, performance is commensurate with cost.

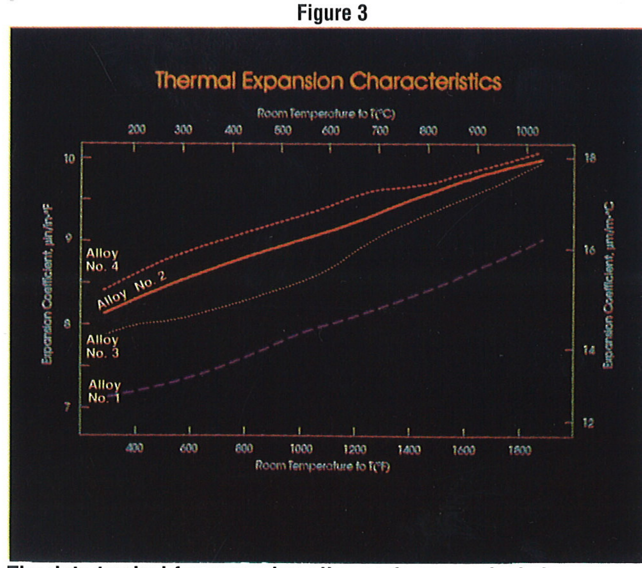
Using alloy No. 4 as a base, alloy No. 1 is about 200 percent more costly and alloy No. 2 is about 60 percent more expensive on a per-pound basis. This increased cost, though, is offset by the energy sav-

Figure 2



Yield strength, one of the major factors considered when assessing the alloys, is tracked for each of the four alloys evaluated in this study.

Figure 3



The data tracked for assessing alloy performance includes thermal expansion characteristics for each of the four evaluated alloys.

ings and decreased cycle times realized because of the lower mass of the baskets and/or grids, and the extended life of the baskets, grids and furnace.

Test Method

Five chromel/alumel thermocouples (Type K) with Refrasil insulated wires were attached by wiring the junction to each basket—one in each corner and one in the center of the basket bottom. The temperatures of the five thermocouples were averaged to provide the basket temperature. Heating and cooling tests were conducted in one-basket and four-basket configurations.

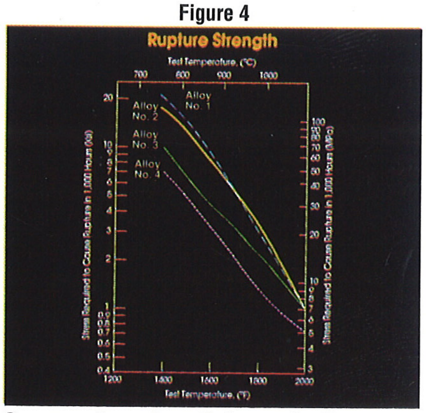
The furnace was heated from ambient to 1975°F/1080°C at a rate of 50°F/28°C per minute. The basket made of alloy No. 2 heated faster than the other alloys because of its lighter construction. Figure 5 shows the one-basket heat rate. A similar test was run for the four-basket configuration.

The baskets were cooled in argon gas at -5 in. of Hg. The cooling rates for the single-basket test are shown in Figure 6 and those for the four-basket test in Figure 7. As in heating, the cooling rates were substantially better with baskets made of alloy Nos. 1 and 2 than with the other alloys because of their lighter construction.

Heating Energy Study

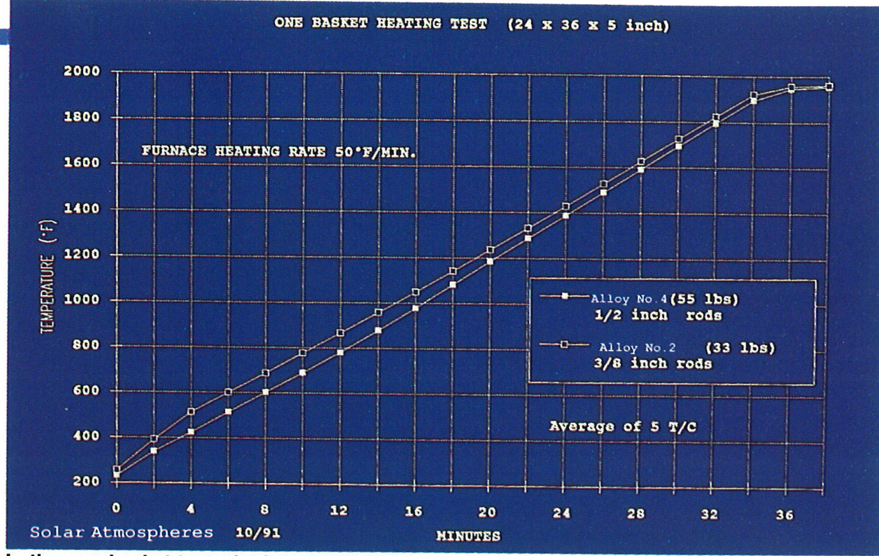
A five-year extrapolated heating-energy utilization study was done using computer-generated calcula-

Figure 4



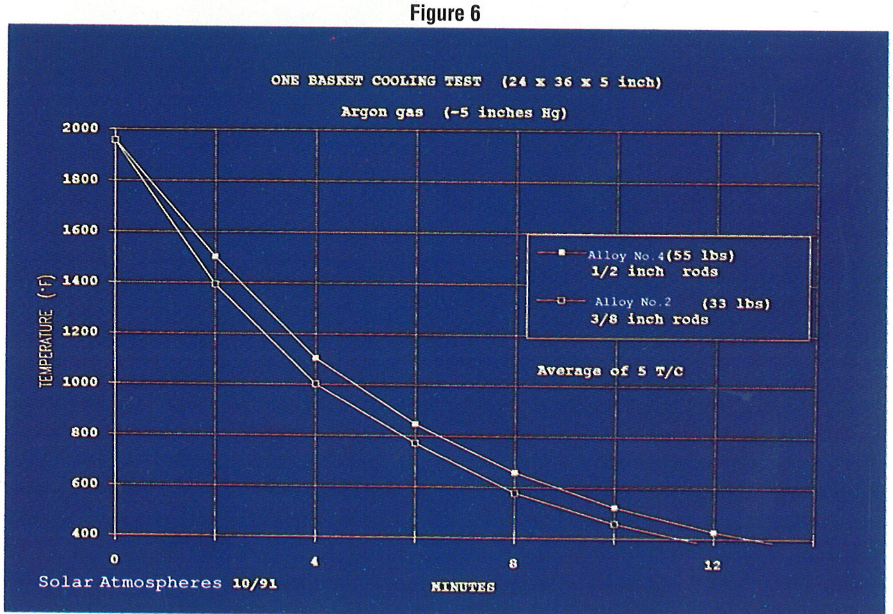
Creep rupture strength for each alloy is studied as part of Solar Atmospheres' project.

Figure 5



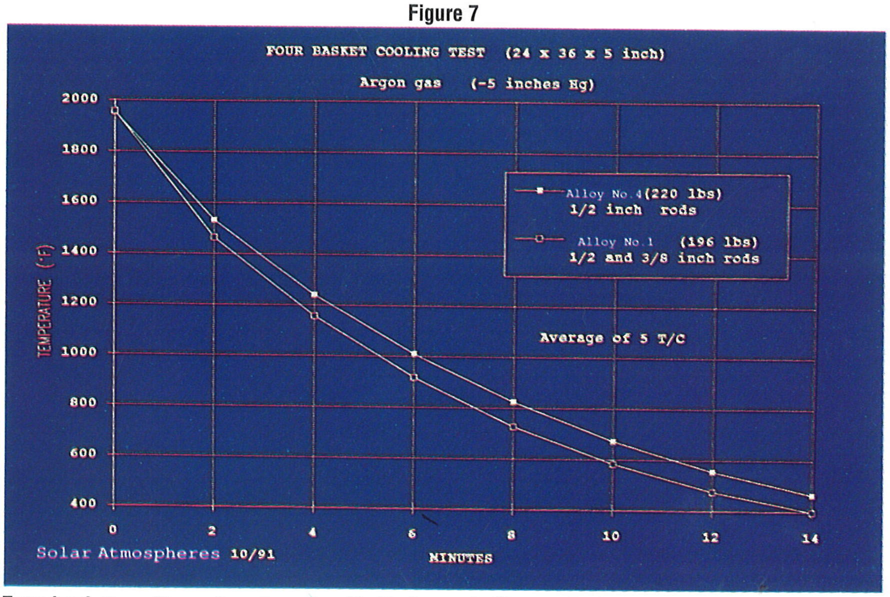
In the one-basket test, the heat rate for lighter-construction baskets is faster.

Figure 6



As with heating, the cooling rates are substantially faster for lighter-weight baskets.

Figure 7



Four-basket cooling rates show results that are similar to single-basket cooling.

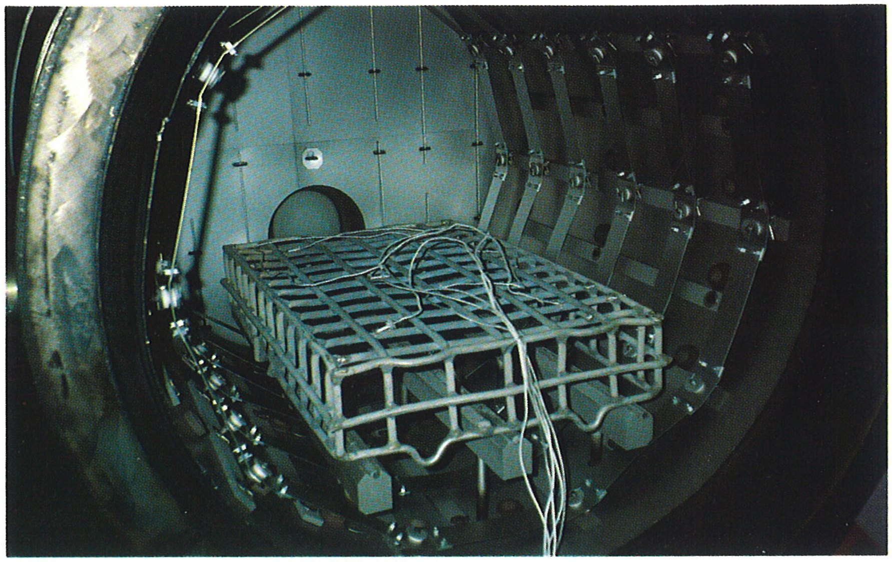
tions based on the specific heat of the alloys using an integrated average of four baskets in the 100°F/38°C to 2000°F/1093°C temperature range. Using a 38-in.-deep horizontal vacuum furnace at four runs a day, five days a week, we arrived at a total of 5,200 runs in five years.

The specific heat in BTU/lb./°F was considered, keeping in mind that all 1/2-in.-diameter rods were used for the alloy No. 4 basket, a combination of 1/2-in.- and 3/8-in.-diameter rods for No. 1 basket, and all 3/8-in. diameter rods for the No. 2 basket. The values are integrated averages. The heating energy utilization summary, shown in Figure 8, was calculated by converting the BTUs to KWHs to arrive at the cost of electrical energy for each basket. Compared to alloy No. 4 and using a rate of 10 cents per KWH, the savings on electricity over five years with alloy No. 2 is $703 per basket and with No. 1 it is $291.

Substancial Savings

When additional energy-related factors are considered, such as more furnace throughput and extended furnace and basket life, the total savings can be substantial.

In the Solar Atmospheres study, baskets first were constructed with alloy No. 1 and then No. 2. A conservative approach was taken on lightening the construction of the baskets, allowing more risk for the No. 2 alloy because of relative cost, which resulted in No. 1 being placed in an unfavorable cost position.



For the study, five chromel/alumel thermocouples (Type K) with Refrasial insulated wires , were attached to the basket, wiring a junction in each corner and in the center of the bottom.

No attempt was made to place any of the alloys in a more favorable position than the others. The intent was to determine what reduction in long-run costs could be achieved by lighter basket construction. We found this cost savings could be increased by using alloys with chemistries that permit superior heating and cooling performances.

Based on its experiences with the four alloys, Solar Atmospheres has new production baskets constructed of either alloy No. 1 (Haynes 230) or No. 2 (Haynes HR-120). Because experience is the teacher, Solar continues to experiment with work baskets and grids made of alloys that permit lighter construction. The performance of each alloy studied is being tracked in actual production. Over time and with additional data, more definitive conclusions can be made. HT

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Figure 8

Summary of Heating Energy Use

	Alloy No. 4	Alloy No. 1	Alloy No. 2
CONSTRUCTION	ALL 1/2"	1/2" AND 3/8"	ALL 3/8"
SPECIFIC HEAT BTU/(LBS)(°F)	.127	.122	.138
TEMP RANGE	100°F TO 2000°F	100°F TO 2000°F	100°F TO 2000°F
WEIGHT OF 4 BASKETS	220 LBS	196 LBS	132 LBS
BTU PER RUN	53,086	45,432	34,610

The heating energy utilization summary was calculated by converting BTUs to KWHs to arrive at the cost of electrical energy per basket.

Figure 9

5-Year Savings Per Basket

	Alloy No. 4	Alloy No. 1	Alloy No. 2
BTU PER RUN	53,086	45,432	34,610
5 YEAR BTU TOTAL	276 MILLION	236.2 MILLION	180 MILLION
KILOWATT HOURS	80,812	69,159	52,704
COST OF ELECTRICITY ($.10 PER KWH)	$ 8,081	$ 6,916	$ 5,270
SAVING PER BASKET	-----	$ 291.00	$ 703.00

Using a rate of 10 cents per KWH, alloy No. 2 represents a five-year electricity cost savings of $703 per basket, compared to alloy No. 4.