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A NEW SERIES OF NICKEL-BASE ALLOYS

FOR SERVICE ABOVE 1800° F

by John C. Freche and William J. Waters

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Nickel-base alloys play a major role in the aircraft industry where there is a continuing demand for high temperature materials. Their use in turbine engines as turbine buckets and various structural components of such engines fulfills a major need. With the advent of the space age the importance of this class of materials has assumed even greater proportions, as new high temperature requirements set by space and reentry vehicles must be met. Because of the pressing need to provide newer and stronger high temperature materials for such applications research is underway at the NASA Lewis Research Center to develop advanced-temperature nickel-base alloys. These efforts have led to the development of a promising new series of nickel-base alloys(1-4) with service capability above 1800° F.

These alloys are castable under argon and need not be vacuum melted. They are suitable for long periods of operation under high stress in oxidizing environments without protective coatings at temperatures above 1800° F. The strongest alloy developed to date(5) compares well in high temperature rupture strength with the strongest readily available nickel-base alloys* such as Nicrotung, Inconel (713C), the Udimet series, as well as the newer alloys, SM-200, IN-100, and TRW-1800. In addition, this alloy has sufficient ductility so that it may be worked to some extent at room

*Commercial alloy data are from reference 6 and commercial data folders.

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temperature and can be hot-rolled using specialized rolling techniques. Table I lists the nominal compositions of several NASA nickel-base alloys.

MELTING AND CASTING PROCEDURE

Induction melting was employed and laboratory size (approx. 3 lb) melts were made to provide test specimens for alloy evaluation. Melts were made in stabilized zirconia crucibles under an inert gas (argon) blanket. The crucible was surrounded by a graphite susceptor 1/2 inch thick. This served the dual purpose of retaining heat along the entire crucible as well as providing a deoxidizing atmosphere in the vicinity of the crucible. These alloys can also be melted under vacuum.

In casting, the melts were prepared from virgin materials; however, they should lend themselves to the production of remelt ingots. All of the alloying constituents were added as charging elements except for zirconium. Stabilized zirconia crucibles were used, which permitted zirconium to be picked up in the desired amount by reaction of the melt with the crucibles. For larger melts zirconium should be added as a charging element in order that the desired amount (1 percent) of zirconium can be more readily obtained in the final product. The alloys freeze in the temperature range of 2400° to 2500° F. Pouring temperature was approximately 3100° F.

To facilitate the investigation, investment-casting techniques were employed. In this way test specimens were quickly provided without the need for costly and time-consuming machining operations. Figure 1 illustrates a typical wax pattern assembly. A silica slurry with a commercial binder was employed to make molds, although equally good castings were obtained from zircon refractory shell molds. The surfaces of the cast test bars were excellent, and except for vapor blasting after removal from the molds, test bars were used without further preparation. Cutoff was usually done with an abrasive cutoff wheel. The alloys are machinable with tungsten carbide cutting tools; however, a preferred method of finishing is by grinding with silicon carbide wheels. As-cast hardnesses ranged from R_c 31 for the basic alloy to R_c 41 for the Ta, W, V modified alloy.

STRENGTH AND DUCTILITY

The stress rupture properties of several of the NASA alloys at 15,000 psi are compared in figure 2 using the notation given in table I. Both rupture life and use temperature have been significantly increased. For example, at 1800° F, rupture life has been extended from less than 100 hours for the basic alloy to over 1000 hours with the Ta, W, V modified alloy. Also, use temperature has been increased from approximately 1790° to 1915° F for a 100-hour life.

Figure 3 provides a comparison of the 15,000-psi rupture properties of the NASA Ta, W, V modified alloy with those of the strongest known cast nickel-base alloys. Only SM-200 has comparable strength properties. It is of interest that the high strength properties shown for the NASA alloy were obtained even though a simplified melting technique was used. A more sophisticated vacuum melting procedure is used for SM-200. In addition, the NASA alloy has considerable potential for workability. Cast 1/2 inch bars have been reduced 50 percent in diameter by cold-forging without edge cracking. Cast slabs of the alloy 0.100 inch thick have been reduced to sheets less than 10 mils thick with specialized rolling techniques by an independent investigator.

The tensile data of the Ta, W, V modified alloy are summarized in table II. Also shown are data at 2000° F for some of the stronger commercial nickel-base alloys and for several refractory metals. It is significant that, at 2000° F, the as-cast ultimate tensile strength of the Ta, W, V modified alloy exceeds that of the commercial nickel-base alloys as well as that of unalloyed refractory metals[7-10] in the recrystallized condition.

OXIDATION RESISTANCE

All of these alloys can be used at high temperature without protective coatings. The oxidation resistance at 1900° F of the Ta, W, V modified alloy is compared in figure 4 with that of another strong cast nickel-base alloy, Nicrotung, and a commonly used wrought nickel-base alloy, René 41. Although the NASA alloy has a relatively low chromium content (6 percent) compared with most other nickel-base alloys (9 to 22 percent), it has a moderate oxidation rate. Its relatively high aluminum content is an important factor in this regard. The NASA alloy shows a weight gain curve intermediate to that of Nicrotung and René 41. Some spalling of the oxide scale was observed with all of these alloys, however, it was more pronounced with the NASA alloy. This aspect is being investigated in order to achieve improved oxidation resistance.

METALLOGRAPHY

Photomicrographs of the Ta, W, V modified alloy are shown in figures 5 and 6 at magnifications of 250 and 750. The microstructure of the alloy in the as-cast condition is shown in figure 5. A fine dispersion of particles is evident throughout the matrix. Electron diffraction data indicate the presence of the Ni_3Al intermetallic compound phase, tantalum carbides, and molybdenum carbides. Figure 6 shows the alloy microstructure in the as-forged condition. The phases have been elongated as a result of the working process.

APPLICATIONS

The alloys in this series have potential for a variety of structural applications where high strength at high temperature is required. Although protective coatings are not necesaary to achieve lives of thousands of hours at high stress and high temperature, the use of coatings would further enhance the usefulness of these alloys for applications in severely corrosive environments. The aerospace field affords some of the most important applications for these alloys. These include turbine engine parts such as turbine buckets and stator vanes, as well as turbopump components. The excellent high temperature strength together with the degree of workability shown for the Ta, W, V modified alloy suggest that it could also be used for combustion chamber and tailpipe assemblies of jet engines as well as surface panels of space vehicles. The latter parts may be subjected to temperatures as high as 2000° F and above during reentry to the earth's atmosphere. With respect to the manufacture of these alloys, it is significant that simple casting techniques (inert gas cover) can be employed. This fact must be contrasted to the need for vacuum techniques in casting most nickel-base alloys and affords an advantage that may be important from an economic standpoint.

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TABLE I. - NOMINAL COMPOSITIONS OF NASA NICKEL-BASE ALLOYS (WEIGHT PERCENT)

NASA alloy designation	Ni	Ta	Cr	Al	Mo	W	V	Ti	Zr	C
Basic alloy	Bal.	--	6	6	8	-	---	---	1	-----
Ti modified alloy	Bal.	--	6	6	8	-	---	1.5	1	0.125
W, V modified alloy	Bal.	--	6	6	4	4	2.5	---	1	.125
Ta, W, V modified alloy	Bal.	8	6	6	4	4	2.5	---	1	.125

TABLE II. - SUMMARY OF TENSILE DATA

Alloy	Condition	Temperature, ^{o}F	Ultimate tensile strength, psi
NASA alloy			
Ta, W, V modified alloy	As-cast	78	134,500
		1800	80,100
		1900	55,700
		2000	49,200
		2100	34,400
	As-forged	78	158,300
		1800	58,500
		1900	48,900
		2000	39,800
		2100	18,200
Commercial alloys			
SM-200	As-cast	2000	47,000
IN-100	As-cast	2000	42,000
Refractory metals			
Tungsten	Recrystallized	2000	22,000 to 38,000
Tantalum	Recrystallized	2000	16,800
Molybdenum	Recrystallized	2000	25,000
Columbium	Recrystallized	2000	4,000 to 13,000

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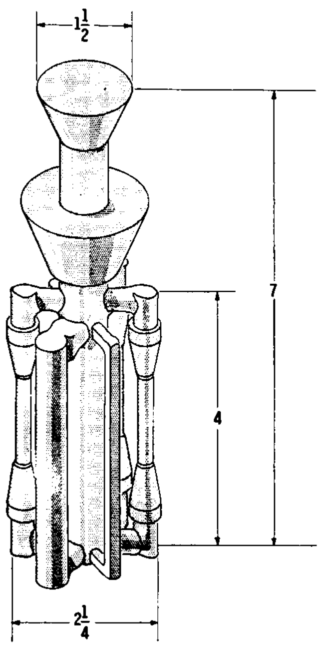

Fig. 1. - Assembly of wax patterns for stress-rupture, swage, and impact bars. (All dimensions in inches.)

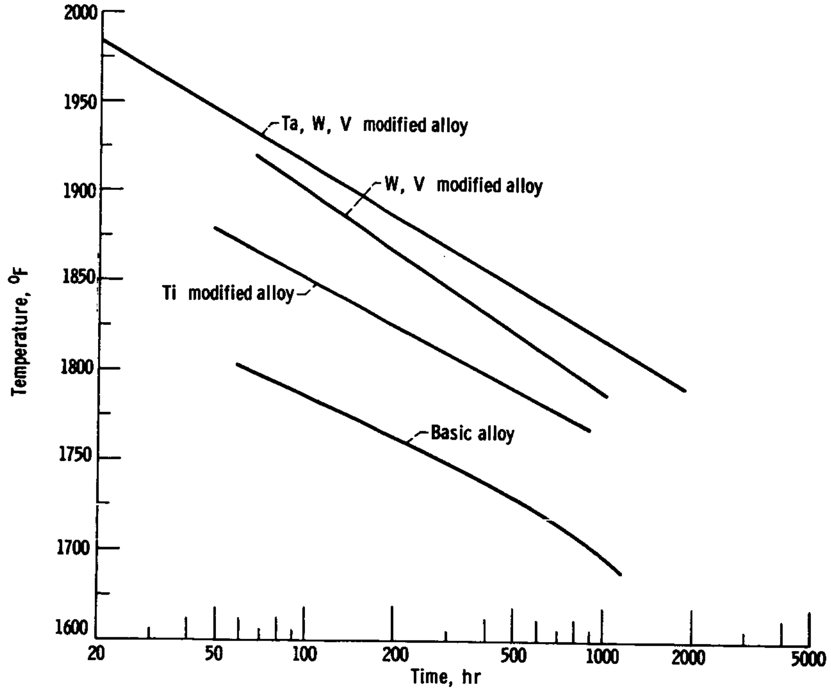

Fig. 2. - Stress-rupture properties of NASA nickel-base alloys at 15,000 psi.

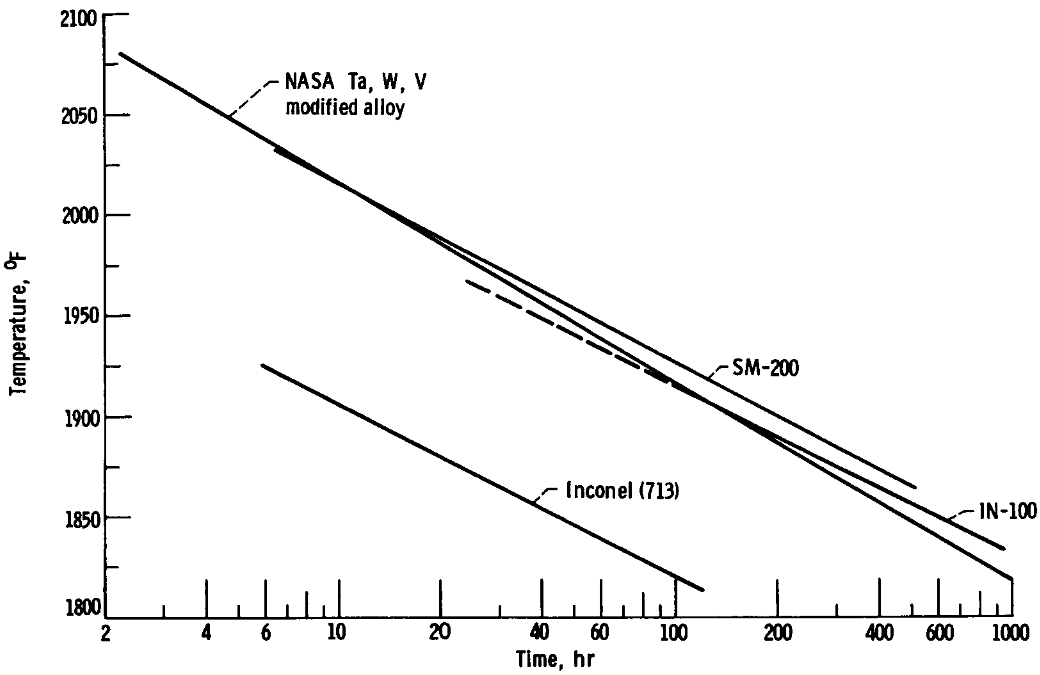

Fig. 3. - Stress-rupture properties of several nickel-base alloys at 15,000 psi.

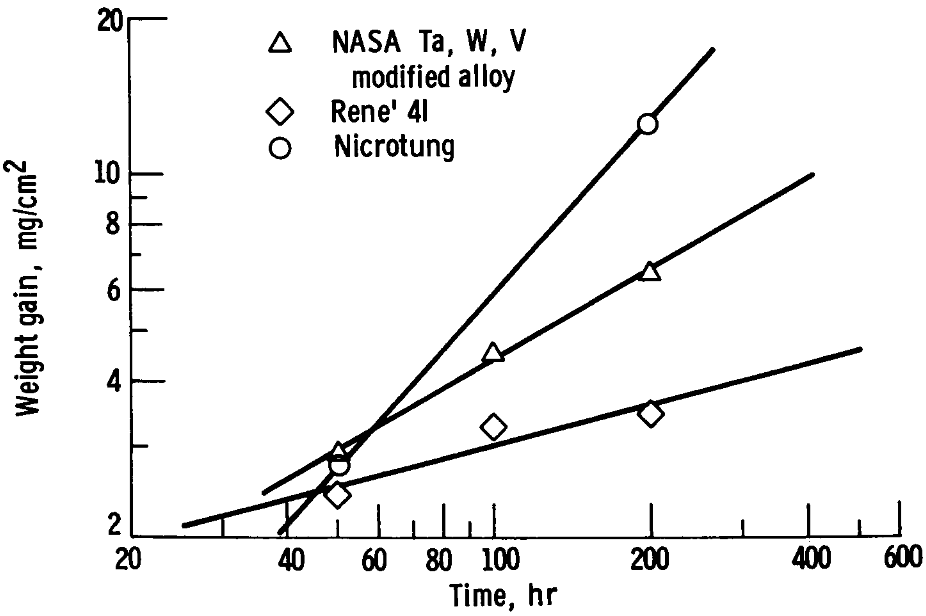

Fig. 4. - Oxidation behavior at 1900° F of - representative - nickel-base alloys.

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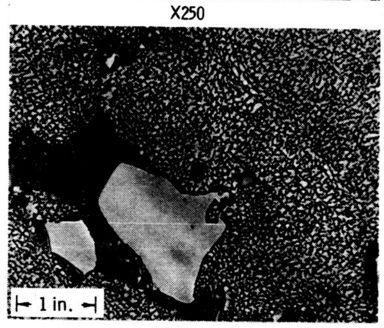
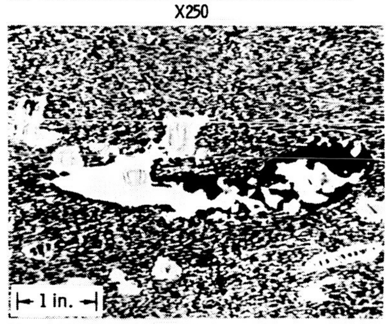
X250



X750

Fig. 5 - As-cast microstructure of the Ta, W, V modified alloy.

X250



X750

Fig. 6. - As-forged microstructure of the Ta, W, V modified alloy.