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SUMMARY

A nickel-base alloy (TAZ-8B) has been developed which compares favorably in high-temperature strength with known high-strength nickel-base alloys. Although basically a cast material, the alloy also has workability potential.

By applying directional solidification techniques, test specimens were produced with a preferred columnar grain orientation. Grain boundaries transverse to the major stress axis were largely eliminated. Substantial increases in ductility, ultimate tensile strength, and stress-rupture life were obtained with the alloy in the directional polycrystalline condition, as compared with the random polycrystalline condition. For example, the 1400° F (1033° K) tensile elongation, which was 3 percent in the random polycrystalline form, was increased to 6 percent in the directional polycrystalline form. Ultimate tensile strength was similarly raised from 144 000 psi (993 MN/m^2) to 172 000 psi (1185 MN/m^2) at this temperature. The 1000-, 100-, and 10-hour use temperatures at 15 000 psi (103.4 MN/m^2) are 1785°, 1925°, and 2025° F (1247°, 1325°, and 1380° K), respectively, in the conventional random polycrystalline form and 1830°, 1940°, and 2040° F (1272°, 1333°, 1389° K) in the directional polycrystalline form.

On the basis of calculated electron-vacancy number, TAZ-8B would not be expected to form sigma phase. Only minor decreases in 1400° F (1033° K) ductility were observed after exposure for 1000 hours at 1600° F (1144° K). Tensile elongation decreased from 3.3 to 2.0 percent for the random polycrystalline material and from 6.5 to 6.0 percent for the directional polycrystalline material.

The application of directional solidification to TAZ-8B resulted in alloy properties which are of interest for potential advanced-gas-turbine-engine applications.

INTRODUCTION

Nickel-base alloys continue to be the workhorse materials for the hot components of gas-turbine engines. These components include turbine buckets, stator vanes, transition ducts, afterburner liners, and, in some advanced engines, the later compressor stages as well. A major factor in the evolution of gas-turbine engines has been the continued increase in high-temperature strength and ductility obtainable with nickel-base alloys. Increased high-temperature strength can be translated into higher operating temperatures and improved engine performance. Increased ductility can contribute to improved mechanical and thermal fatigue resistance, both extremely important factors in various turbine components, particularly turbine buckets. Research is in progress at the NASA Lewis Research Center to further extend the high-temperature capability of nickel-base alloys for gas-turbine and other elevated-temperature applications.

Earlier research at Lewis has resulted in several high-strength cast nickel-base alloys (refs. 1 to 7) culminating in the TAZ-8 series (refs. 5 and 7). Both TAZ-8 and TAZ-8A compare favorably in high-temperature strength with some of the strongest commercial nickel-base alloys. TAZ-8A also has excellent high-temperature oxidation resistance (ref. 7). Although these alloys are basically cast materials, they have workability potential. For example, limited unidirectional forging has been done successfully with small test samples (ref. 5), and 0. 020-inch (0. 0005-m) sheet has been rolled from cast slabs (ref. 7). Because of the interesting properties of these alloys, additional work was indicated to further enhance their high-temperature capability.

The first approach taken was to modify the nominal TAZ-8A composition which was 8 percent tantalum, 6 percent chromium, 6 percent aluminum, 4 percent molybdenum, 4 percent tungsten, 2. 5 percent columbium, 1 percent zirconium, 0. 125 percent carbon, 0. 004 percent boron, and the balance nickel. Columbium content was reduced to 1. 5 percent because data obtained during the development of TAZ-8A (ref. 7) suggested that small reductions in columbium could improve ductility without adversely affecting either oxidation resistance or strength. Also, 5 percent cobalt was added to further stabilize the gamma-prime (γ') phase (ref. 8). The resulting composition is referred to as TAZ-8B.

The second approach was to employ controlled directional solidification techniques with TAZ-8B. At high temperatures a frequent failure mode in cast nickel-base alloys is intercrystalline fracture along grain boundaries transverse to the major stress axis. VerSnyder and Guard have shown that improvements in strength and ductility can be obtained if such boundaries are eliminated (ref. 9). In that study, a normally brittle Ni-Cr-Al alloy was shown to have both high ductility and longer rupture life when a unidirectional columnar grain structure with preferred orientation was obtained by directional solidification. Also, Piearcey and VerSnyder showed that improvements in high-temperature strength and intermediate temperature ductility could be obtained with MAR-M 200 by directional solidification (ref. 10).

Extensive data were therefore obtained for the TAZ-8B alloy in both the random polycrystalline and directional polycrystalline forms. Rollability was also investigated. Tensile data were obtained to 2200° F (1478° K) and stress-rupture data to 2100° F (1422° K). The results of these studies together with comparisons with an earlier nickel-base alloy in the TAZ-8 series are presented.

EXPERIMENTAL PROCEDURES

Materials

The purities in weight percent, as reported by the supplier, of the various alloying elements used are as follows:

Nickel	99.9
Tantalum	99.7
Tungsten	99.9
Molybdenum	99.5
Chromium	99.8
Aluminum	99.88
Columbium	99.6
Cobalt	99.5
Carbon	99.5
Boron	99.5

Chemical analyses of typical heats of random polycrystalline TAZ-8B were made by an independent laboratory and are compared with the nominal composition in table I. The analyses indicated that the compositions were close to the nominal composition, except for carbon in one heat. Although a chemical analysis was not obtained for a heat of directional polycrystalline material, no differences in composition from a heat of random

TABLE I. - ALLOY COMPOSITION

TAZ-8B alloy	Composition, wt. %										
	Ta	Cr	Al	Mo	W	Cb	Co	Zr	C	B	Ni
Nominal	8	6	6	4	4	1.5	5	1	0.125	0.004	Balance
Typical heats	8.22	5.73	5.44	4.05	3.80	1.67	4.99	1.37	.145	.0034	Balance
	8.07	5.60	5.27	3.94	3.77	1.55	5.00	1.18	.071	.0022	Balance

polycrystalline material would be expected because the melting procedure was similar in each case.

Melting, Casting, and Inspection Techniques

Melts were made in 50-kilowatt, 10 000-cps (10 000-Hz) water-cooled induction units. A dual melting procedure was used. The initial melt was made under an inert-gas (commercially pure argon) cover. The procedure was similar to that described in references 1 to 5. Stabilized zirconia crucibles were used, and the pouring temperature as determined by an optical pyrometer was $3050^{\circ}\pm50^{\circ}$ F ($1948^{\circ}\pm28^{\circ}$ K). Melts were poured without argon protection into copper molds at room temperature. The second stage of the dual melting procedure was to remelt the alloy under vacuum and pour it into zircon ceramic shell molds. Pouring temperature for the random polycrystalline material as determined by means of an optical pyrometer was $3100^{\circ}\pm50^{\circ}$ F ($1978^{\circ}\pm28^{\circ}$ K). In casting the random polycrystalline material, the molds were preheated to 1600° F (1144° K). A pressure of 10 microns (1.33 N/m^2) or less was maintained during melting and pouring.

In making the directionally solidified castings, the controlled solidification apparatus illustrated in figure 1 was used. The apparatus consists of a three-zone resistance mold heater which surrounds the shell mold. A reusable copper chill block extends into the lower part of the shell mold and establishes the orientation and growth direction of individual grains. Introduction of an appropriate power input to each zone of the heater provided a smooth temperature gradient in the vertical direction. Immediately prior to pouring (pour temperature $2900^{\circ}\pm50^{\circ}$ F ($1867^{\circ}\pm28^{\circ}$ K), the temperature of the portion of the mold adjacent to the chill block was made approximately equal to the alloy melting temperature (2450° F (1618° K)), and the temperature at the top of the mold was 2750° F (1783° K). A lower pour temperature was used in casting the directionally solidified material in order to ensure that no leakage of the melt occurred at the interface between the chill block and the shell mold. Temperatures were determined by theromocouples located between the mold and the heater wall at intervals along the length of the mold. After pouring, power to the mold-heater zones was sequentially removed, and solidification proceeded vertically upward from the chill block.

All cast specimens were vapor blasted prior to inspection. All specimens were inspected by X-ray and by fluorescent-dye penetrant techniques before testing. Only defect-free bars were tested.

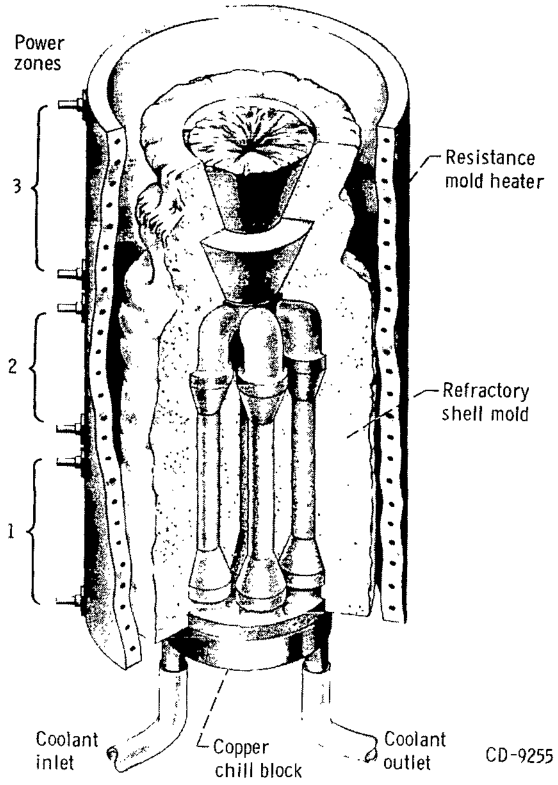


Figure 1. - Controlled solidification casting assembly.

Specimens

Random polycrystalline rupture and tensile bars were cast to final dimensions. The same type of specimen was used for both stress-rupture and tensile tests. These specimens had conical shoulders with a 20° included angle. The gage section was 1.20 inches (0.0305 m) long and 0.25 inch (0.00635 m) in diameter. Directional polycrystalline bars were cast to the same initial size and subsequently etched to reveal grain structure. The test section was reduced by grinding to 0.240-inch (0.0061-m) diameter to remove the etched surface layer which could be detrimental to properties because of grain-boundary attack. The random polycrystalline material was tested in the vapor-blasted condition because previous experience with this alloy series has shown that surface grinding has a negligible effect on properties. Charpy impact bars were cast slightly oversize and finish-machined to obtain the 0.394 by 0.394 inch (0.010 by 0.010 m) ASTM standard cross-sectional dimensions. Blanks for investigating rollability were cast to dimensions of 3 by 5 by 0.15 inch (0.076 by 0.127 by 0.0038 m).

Alloy Evaluation

Stress-rupture and tensile tests. - All stress-rupture and tensile data were obtained in air. The specimens were tested in the as-cast condition without protective coatings. Tensile tests were also conducted at room temperature, 1200° F (922° K), and 1400° F (1033° K) with test bars previously exposed for 1000 hours at 1600° F (1144° K) in air. The range of test conditions for stress-rupture tests was from 1800° to 2100° F (1255° to 1422° K) at 15 000 psi (103.4 MN/m^2) and from 1700° to 1900° F (1200° to 1311° K) at 25 000 psi (172.4 MN/m^2). Tensile tests were conducted over a range of temperatures from room temperature to 2200° F (1478° K).

Hardness. - Representative as-cast directionally solidified test specimens were sectioned transverse and parallel to the longitudinal axis. Rockwell A hardness readings were taken along each section. An average of five readings was taken as representative of the hardness in each direction. As-cast random polycrystalline specimens were sectioned transverse to the principal axis, and an average of five Rockwell A readings across the section was taken as indicative of the hardness.

Impact tests. - A standard Charpy impact tester was used to measure impact resistance at room temperature. Both V-notched (ASTM type A) and unnotched specimens were tested.

Rolling. - Cast blanks of TAZ-8B were cut into three sections 1 by 5 by 0.15 inch (0.025 by 0.127 by 0.0038 m). These sections were rolled into sheets approximately 0.020 inch (0.0005 m) thick. The blanks were rolled in one direction at 1900° F (1311° K) in a conventional 2-high mill at a surface speed of 80 feet per minute (0.41 m/sec). Reductions of 0.005 inch (0.00013 m) per pass, approximately 3 percent of the original thickness, were employed. Prior to each pass the blanks were heated to 1900° F (1311° K) in a protective (argon) atmosphere and transferred to the rolls as quickly as possible to minimize heat loss.

Metallographic studies. - Photomicrographs of TAZ-8B were made in both the random and directional polycrystalline forms. The crystal orientation of the columnar grain structure was determined by X-rays.

PROPERTIES OF TAZ-8B

Tensile Data

The tensile properties of TAZ-8B in both the random and directional polycrystalline forms are summarized in table II and compared in figure 2 over a range of temperatures. The properties of TAZ-8A (ref. 7), the forerunner of TAZ-8B, are shown for

TABLE II. - SUMMARY OF TENSILE DATA

Temperature		Random polycrystalline form			Directional polycrystalline form		
°F	°K	Ultimate tensile strength		Elongation, percent	Ultimate tensile strength		Elongation, percent
		psi	MN/m^2		psi	MN/m^2	
70	295	143.7×10^3	991	5.0	153.7×10^3	1060	9.0
		142.0	979	3.0	152.2	1049	8.0
		[a]125.0	[a]862	[a]2.5	[a]137.0	[a]945	[a]4.5
1200	922	152.5×10^3	1052	3.5	173.2×10^3	1194	6.0
		135.8	936	3.0	170.5	1176	6.0
		[a]123.3	[a]850	[a]2.0	[a]163.2	[a]1125	[a]5.0
1400	1033	137.0×10^3	945	3.0	173.2×10^3	1194	4.0
		150.2	1036	3.0	171.3	1181	9.0
		[a]144.7	[a]998	[a]2.0	[a]157.8	[a]1088	[a]6.0
1600	1144	116.0×10^3	800	3.0	125.8×10^3	867	12.5
		123.3	850	1.0	125.0	862	12.0
		120.0	827	12.0			
1800	1255	79.6×10^3	549	4.0	80.5×10^3	555	16.0
		84.75	584	4.0	80.0	552	6.0
1900	1311	60.25×10^3	415	6.0	----------	-----	----
		63.1	435	8.0	----------	-----	----
2000	1366	41.5×10^3	286	3.0	43.8×10^3	302	23.0
		42.4	292	4.0	41.8	288	21.0
2100	1422	30.0×10^3	207	6.0	----------	-----	----
		26.2	181	1.0	----------	-----	----
2200	1478	7.66×10^3	53	2.0	----------	-----	----
		11.45	79	1.0	----------	-----	----

[a] Prior exposure for 1000 hr at 1600° F (1144° K).

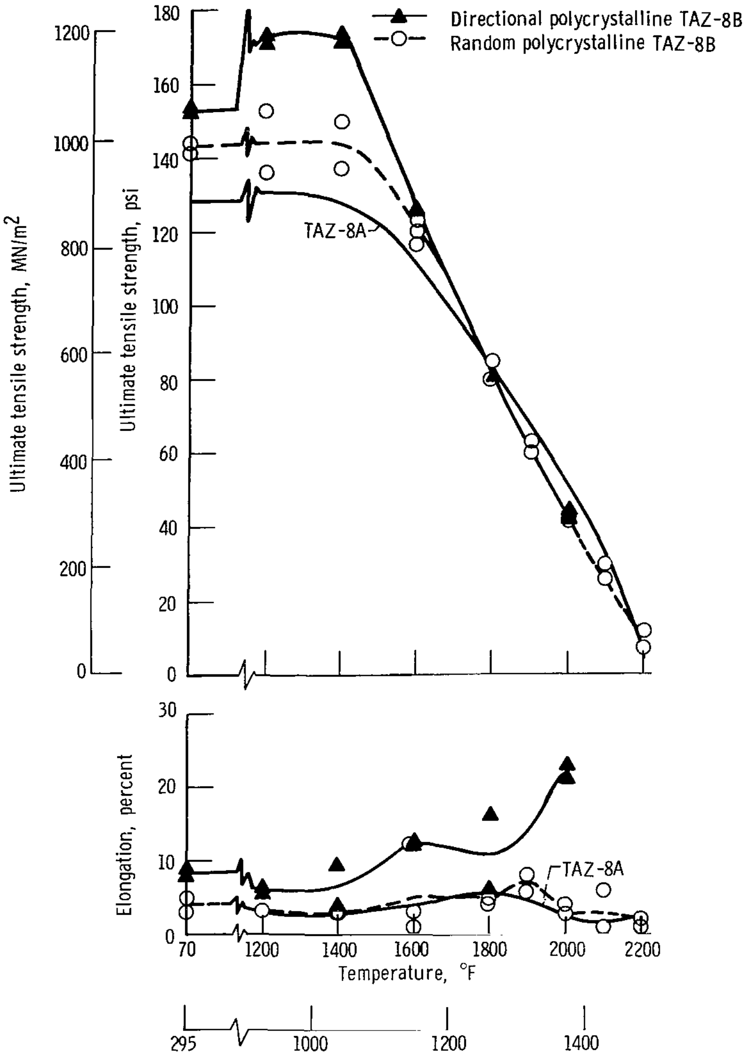


Figure 2. - Tensile properties of TAZ-8 alloy series.

comparison. The directional polycrystalline material shows an improvement in tensile strength in the 1200° to 1600° F (922° to 1144° K) range over the random polycrystalline material. Above 1600° F (1144° K) the strength values are similar. At 1400° F (1033° K), which is in a region of minimum ductility, directional solidification resulted in an increase in ultimate tensile strength from approximately 144 000 to 172 000 psi (993 to 1185 MN/m^2) and an elongation increase from 3 to 6 percent. Elongation is substantially higher for the directional polycrystalline material at all test temperatures and ranges from approximately 6 percent at 1200° F (922° K) to a maximum of 22 percent at 2000° F (1366° K).

A comparison of TAZ-8B and TAZ-8A shows the latter alloy to have substantially lower strength than either type of TAZ-8B to approximately 1800° F (1255° K) and slightly higher strength between 1800° and 2200° F (1255° and 1478° K). The maximum difference in strength occurs at 1400° F (1033° K) where TAZ-8A has an ultimate tensile strength of 128 000 psi (882 MN/m^2), random polycrystalline TAZ-8B, 144 000 psi (993 MN/m^2), and directional polycrystalline TAZ-8B, 172 000 psi (1185 MN/m^2). At 2000° F (1366° K), TAZ-8A has an ultimate tensile strength of 50 000 psi (345 MN/m^2), random polycrystalline TAZ-8B, 42 000 psi (289 MN/m^2) and directional polycrystalline TAZ-8B, 43 000 psi (296 MN/m^2).

The tensile elongation of random polycrystalline TAZ-8B was generally the same as that of TAZ-8A over the entire temperature range. The directional polycrystalline TAZ-8B, however, showed substantial increases in ductility over TAZ-8A at all test temperatures. These increases ranged from a factor of two at 1200° F (922° K) to more than five at 2000° F (1366° K).

Stress-Rupture Data

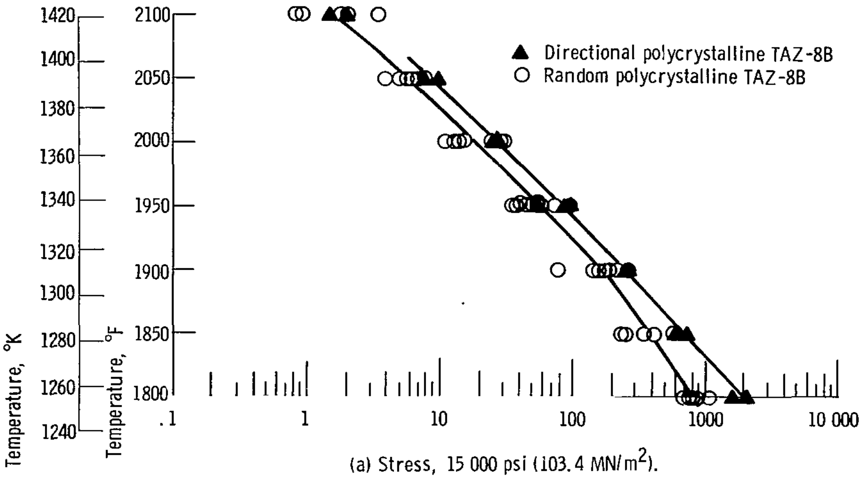
All the stress-rupture data are summarized in table III. Figure 3 illustrates the stress-rupture properties of TAZ-8B in the random and directional polycrystalline forms. For the most part, the directional polycrystalline material shows longer life. This improvement is significant at 1800° F (1255° K) and 15 000 psi (103.4 MN/m^2) (fig. 3(a)), where average life was increased approximately two-fold, from 800 to 1800 hours.

The effects of the two types of structure in TAZ-8B may also be compared on the basis of use temperature. At a stress of 15 000 psi (103.4 MN/m^2) the 1000-, 100-, and 10-hour use temperatures are respectively, 1785°, 1925°, and 2025° F (1247°, 1325°, and 1380° K) in the random polycrystalline form and 1830°, 1940°, and 2040° F (1272°, 1333°, and 1389° K) in the directional polycrystalline form. The beneficial effect on life of the directionally oriented columnar grain structure tends to be reduced as temperatures increase. Similar trends were observed at a higher stress level. At 25 000 psi (172.4 MN/m^2) (fig. 3(b)), the directionally oriented material has approximately a two-fold life advantage at 1700° F (1200° K). This advantage is negligible at 1900° F (1311° K).

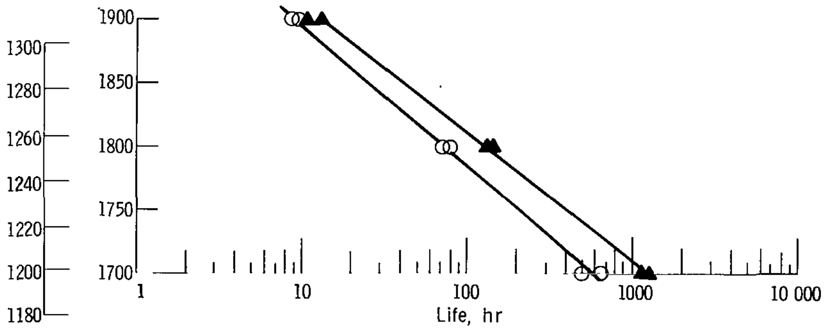
The progress that has been made in improving rupture life of the TAZ-8 alloy series is shown in figure 4. The life for a stress of 15 000 psi (103.4 MN/m^2) at both 1800° and 1900° F (1255° and 1311° K) for directional polycrystalline TAZ-8B is almost three times that of random polycrystalline TAZ-8A. At 2000° F (1366° K) and 15 000 psi (103.4 MN/m^2), directional polycrystalline TAZ-8B has about twice the life of random polycrystalline TAZ-8A.

TABLE III. - SUMMARY OF STRESS-RUPTURE DATA

Stress		Temperature		Random polycrystalline form	Directional polycrystalline form
psi	MN/m^2	°F	°K	Life, hr	
15 000	103.4	1800	1255	1036.9	2075.3
				755.9	1607.9
				679.1	------
				792.7	------
				816.1	------
		1850	1283	406.0	598.5
				225.8	724.9
				567.6	------
				331.8	------
				240.0	------
		1900	1311	138.8	256.2
				154.6	245.8
				186.1	------
				76.7	------
				251.9	------
				211.4	------
				186.6	------
		1950	1339	39.3	46.4
				53.4	91.3
				37.0	82.3
				47.2	------
				39.4	------
				55.5	------
				48.6	------
				34.5	------
				48.3	------
				44.9	------
				71.0	------
				90.1	------
15 000	103.4	2000	1366	13.5	24.3
				29.2	24.1
				10.6	------
				12.7	------
				23.9	------
				26.7	------
				15.1	------
		2050	1394	4.8	9.2
				3.7	7.2
				7.5	------
				6.3	------
				5.7	------
				5.4	------
		2100	1422	3.3	1.9
				1.9	1.4
				1.7	------
				.9	------
				.8	------
25 000	172.4	1700	1200	481.6	1225.8
				629.8	1162.7
		1800	1255	67.9	136.8
				77.2	144.2
		1900	1311	9.6	10.7
				8.6	13.1



(a) Stress, 15 000 psi (103.4 MN/m^2).



(b) Stress, 25 000 psi (172.4 MN/m^2).

Figure 3. - Comparison of stress-rupture properties of random and directional polycrystalline TAZ-8B.

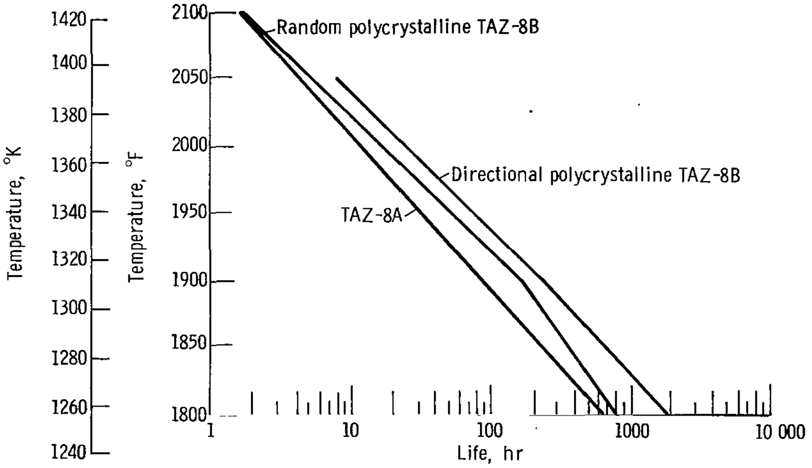


Figure 4. - Comparison of stress-rupture properties of TAZ-8 alloy series. Stress, 15 000 psi (103.4 MN/m^2).

Workability

Workability potential of TAZ-8B in the random polycrystalline form was demonstrated by rolling cast slabs 0.15 inch (0.0038 m) thick at 1900° F (1311° K) into strips approximately 0.020 inch (0.0005 m) thick. No edge cracking of the sheet occurred during the rolling operation. The alloy has rollability characteristics similar to those of TAZ-8A (ref. 7). No attempt was made to optimize the rolling procedure. The techniques employed were essentially the same as those which proved to be acceptable for TAZ-8A. Also, no attempt was made to cast directionally solidified slabs for rolling evaluation.

Although the alloy was successfully rolled, it is not a wrought alloy in the conventional sense. It should be emphasized that the process of making sheet by rolling a thin cast slab is a somewhat specialized one. The fine grain size that can be obtained in a thin slab contributes to rollability of the alloy in that impurities that normally segregate at grain boundaries are more widely distributed. The results of this investigation suggest that the alloy may be worked under closely controlled conditions and thereby fulfill requirements that cannot normally be met by the usual wrought high-strength nickel-base alloys.

Impact Resistance

The Charpy impact resistance of TAZ-8B in both the as-cast random polycrystalline and directional polycrystalline forms is shown in table IV. The unnotched Charpy im-

TABLE IV. - SUMMARY OF CHARPY IMPACT RESISTANCE DATA

Alloy	Impact resistance							
	Unnotched				V-notched			
	Measured values		Average		Measured values		Average	
	ft-lb	N-m	ft-lb	N-m	ft-lb	N-m	ft-lb	N-m
TAZ-8B								
Random polycrystalline	42.0 38.0	57.0 51.5	40.0	54.0	6.0 6.5	8.1 8.8	6.2	8.5
Directional polycrystalline	39.0 43.0	53.0 58.0	41.0	55.5	13.0 12.0	17.5 16.5	12.5	17.0
TAZ-8A	19.0 20.0 34.0	26.0 27.0 46.0	24.0	33.0	----	----	----	----

pact resistance of the random polycrystalline material was about the same as for the directional polycrystalline material, 40 foot-pounds (54 N-m) as compared with 41 foot-pounds (55.5 N-m). The impact resistance of the notched directional polycrystalline material was twice that of the notched random polycrystalline material, 12.5 foot-pounds (17 N-m) as compared to 6.2 foot-pounds (8.5 N-m). The improved impact resistance is associated with the generally improved ductility of the directionally oriented material. It suggests that directionally solidified turbine blades made from this alloy would be more resistant to catastrophic failure from foreign-object damage than conventionally cast TAZ-8B.

Hardness

Rockwell A hardness values for TAZ-8B are listed in table V. For the random polycrystalline material, the average hardness was 71.8. For the directional polycrystalline material, average hardness along the longitudinal section was 71.7, and 71.8 along the transverse section. If a standard conversion table for steel is used, the average Rockwell A hardness values cited would be equivalent to Rockwell C values of approximately 42 to 43. These data indicate that the grain orientation has essentially no effect on the macrohardness of TAZ-8B.

It is interesting that there was a negligible effect of prolonged exposure at 1600° F (1144° K) on hardness. The random polycrystalline material had an average hardness of 71.4 after 1000 hours at 1600° F (1144° K). After a similar exposure, the average hardness of the directional polycrystalline material was 71.5.

TABLE V. - SUMMARY OF HARDNESS DATA

Form	Rockwell A hardness	
	Range of measured values	Average
TAZ-8B (as cast)		
Random polycrystalline	71.3 to 72.1	71.8
Directional polycrystalline		
Transverse section	71.1 to 72.3	71.8
Longitudinal section	71.3 to 72.0	71.7
TAZ-8B exposed 1000 hr at 1600° F (1144° K); transverse section		
Random polycrystalline	71.0 to 71.8	71.4
Directional polycrystalline	71.2 to 71.7	71.5

Microstructural Stability

Service requirements for nickel-base alloys in gas turbine applications include long exposure times of the order of several thousands of hours at temperature. Such exposure can alter the phases present as well as their morphology. Formation of the sigma phase after long service exposure in the 1450° to 1700° F (1061° to 1200° K) temperature range has been observed in some advanced high-strength, high-temperature nickel-base alloys (ref. 11). The formation of this phase can significantly reduce tensile ductility and decrease creep-rupture life.

It has been shown (ref. 12) that it is possible to predict with reasonable accuracy whether or not an alloy will form sigma phase by calculating the electron-vacancy concentration $\overline{N}_v$ of the residual matrix after other phases such as gamma-prime (γ') and the carbides have precipitated. Various assumptions must be made as to the manner in which the elements present in the alloy are partitioned in forming the carbides, borides, and the gamma-prime phase. The amounts of the various elements remaining after such phase formation, scaled to 100, are equivalent to the residual matrix composition. Electron-vacancy numbers are assigned to each element. The average electron-vacancy number $\overline{N}_v$ of the residual matrix is then determined by summing the products of the atomic fraction of each element times its electron-vacancy number. If the calculated average electron-vacancy number is below the cutoff point for stability as determined from experimental data for representative nickel-base alloys, sigma phase would not be expected to form.

The $\overline{N}_v$ for TAZ-8B was calculated to be 2.27 according to assumptions similar to those of method $\overline{N}_{v,9}$ (ref. 13). In calculating $\overline{N}_v$ by this method, it was assumed that half the carbon forms MC carbides and half forms M_6C. The gamma-prime composition is given by the following expression:

$$N_{2.95}(Mo + W)_{0.05}(Al, Ti, Ta, Cb, Zr, 0.5V, 0.3Cr)$$

where Cr is the original atomic percent of Cr in the alloy and the amounts of the other elements have been reduced by the formation of borides and carbides. On the basis of these calculations, TAZ-8B would be expected to be sigma-free since the safe upper limit for $\overline{N}_v$ appears to be 2.59 (ref. 13). Although TAZ-8A is also predicted to be sigma free by this method ($\overline{N}_v$, 2.26), there is some evidence that the mu phase, which can cause embrittlement, may occur in this alloy (private communication from Dr. J. Radavich, Micro-Met Labs Inc., West LaFayette, Ind.). The similarity in composition between TAZ-8A and TAZ-8B suggests that the latter alloy may form the mu phase.

In addition to predicting the possibility of sigma phase formation by electron-vacancy-number calculations, tensile data were obtained to determine if embrittlement

TABLE VI. - EFFECTS OF 1000-HOUR EXPOSURE IN AIR AT 1600° F

(1144° K) ON TENSILE PROPERTIES OF TAZ-8B

TAZ-8B alloy form	Test temperature		Ultimate tensile strength				Elongation, percent	
	°F	°K	psi	MN/m²	psi	MN/m²	Unexposed (as cast)	Exposed
			Unexposed (as cast)		Exposed			
Random polycrystalline	70	295	143.0×10^{3}	986	125.0×10^{3}	862	4.0	2.5
	1200	922	144.0	993	123.2	849	3.3	2.0
	1400	1033	143.6	990	144.7	998	3.3	2.0
Directional polycrystalline	70	295	153.0×10^{3}	1055	137.0×10^{3}	945	8.5	4.5
	1200	922	171.8	1185	163.2	1125	6.0	5.0
	1400	1033	172.2	1187	157.8	1088	6.5	6.0

occurred. Tensile tests were made with specimens of the alloy in both the random and directional polycrystalline forms after they had been exposed for 1000 hours at 1600° F (1144° K). The microstructures after such exposure are described in a subsequent section on metallography. Table VI shows the ultimate tensile strength and percent elongation values obtained after exposure compared with those in the as-cast condition. In general, small decreases in elongation were observed after exposure for both the random and the directional polycrystalline materials. The drop in ductility suggests that despite its low electron-vacancy number the alloy is probably slightly unstable after long exposure. This effect is less deleterious in the directional polycrystalline form than in the random polycrystalline form. Thus, the lowest ductility obtained from the exposed directionally solidified material (4.5 percent at room temperature) was greater than the highest ductility obtained from unexposed random polycrystalline material (4 percent at room temperature). It is possible that the instability reflected by these data resulted from a reaction other than sigma formation, such as precipitation of carbides of mu phase formation.

Oxidation Resistance

The alloy was not subjected to conventional oxidation tests, and, thus, oxidation rates were not determined. However, visual examination of tested stress-rupture specimens and the specimens exposed for 1000 hours at 1600° F (1144° K) for stability studies indicated that the oxidation resistance of TAZ-8B was good. On a qualitative basis, its oxidation resistance is comparable to that of TAZ-8A. For the limited number of directional polycrystalline and random polycrystalline specimens that were directly comparable, there was no noticeable difference in oxidation resistance. However, the exact effect of directional solidification on the oxidation resistance of TAZ-8B remains to be investigated.

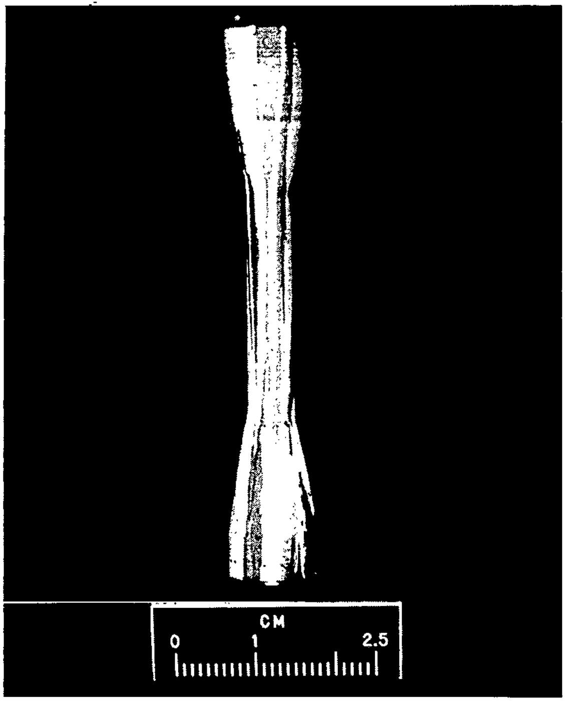
Metallography

Macrographs of a directionally solidified tensile test bar of TAZ-8B are shown in figure 5. The grains are columnar and extend along the length of the bar. The macrograph of figure 5(b) is a magnified view of a transverse section of the test bar. Many individual grains can be distinguished. An X-ray diffractometer pattern taken from the end of a directionally solidified test bar showed that the reflections from (100) planes were substantially enhanced. This result indicated a high degree of orientation of the [100] direction perpendicular to the chill.

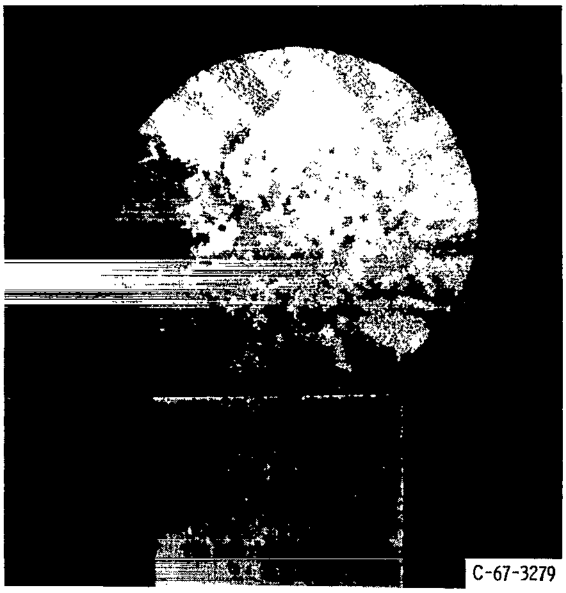
Directional polycrystalline TAZ-8B in the as-cast condition is shown at a magnification of 250 in figure 6. Although grain boundaries were evident at low magnification, they were not apparent at a magnification of 250. Both the sections parallel and perpendicular to the growth direction show the same general features: a matrix containing a finely dispersed gamma-prime precipitate and large primary gamma-prime nodules (large white particles). A few carbides or carbonitrides (small angular-shaped white particles) are present. The latter were more easily observed in unetched specimens. Figure 7 shows that the random polycrystalline and directional polycrystalline structures are similar on a microscale. At a magnification of 750 the gamma-prime precipitate in the matrix was clearly resolved.

The microstructures of TAZ-8B in both the random and directional polycrystalline forms after exposure for 1000 hours at 1600° F (1144° K) are shown in figure 8. No embrittling acicular phase was observed in either sample. There was no evidence of agglomeration of the gamma-prime phase.

The microstructure of as-rolled, TAZ-8B, 0.020-inch (0.0005-m) sheet is illustrated in figure 9 at a magnification of 250. The section shown is parallel to the rolling direction. The massive primary gamma-prime particles prevalent throughout the as-cast structure as well as the carbides have been markedly deformed in the rolling direction. The microstructure has clearly been refined by rolling as compared with the as-cast material, and there is no evidence of recrystallization.

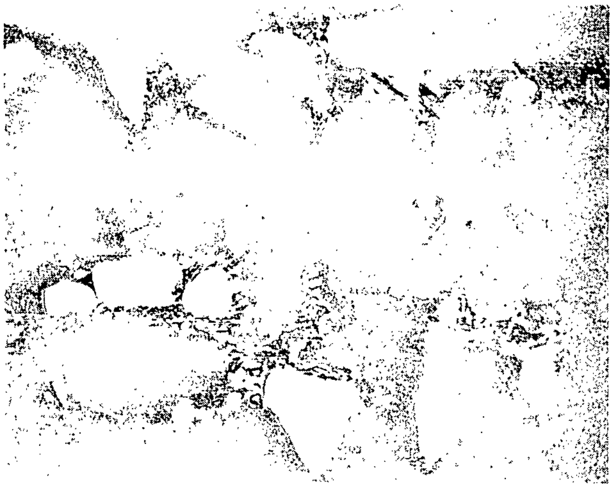


(a) Parallel to crystal growth direction.

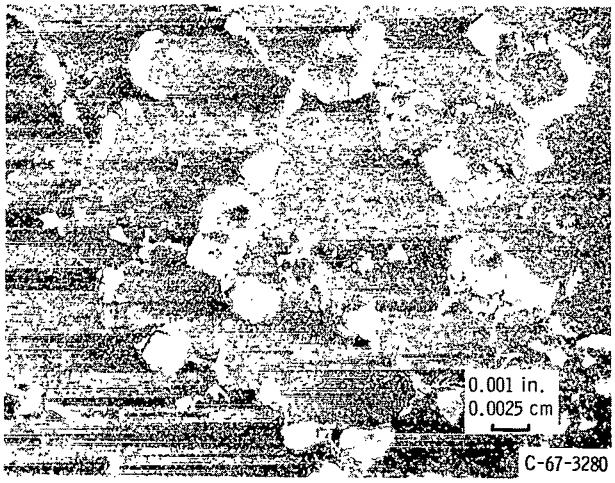


(b) Perpendicular to crystal growth direction.

Figure 5. - Macrographs of directionally solidified TAZ-8B test specimen. Etchant, 95 percent hydrochloric acid and 5 percent hydrogen peroxide.

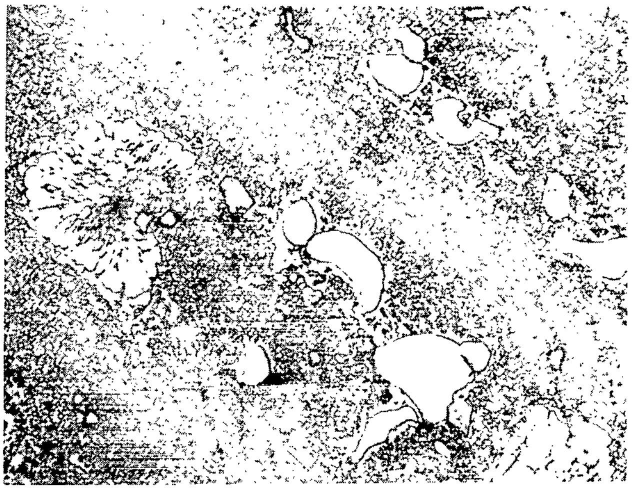


(a) Parallel to crystal growth direction.

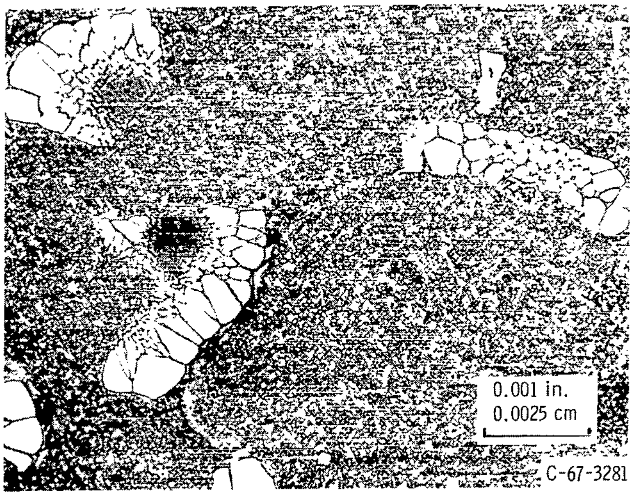


(b) Perpendicular to crystal growth direction.

Figure 6. - Micrographs of directional polycrystalline TAZ-8B as cast. Etchant, 36.5 percent water, 36.5 percent glycerine, 18 percent nitric acid, and 9 percent hydrofluoric acid (electrolytic). X250.



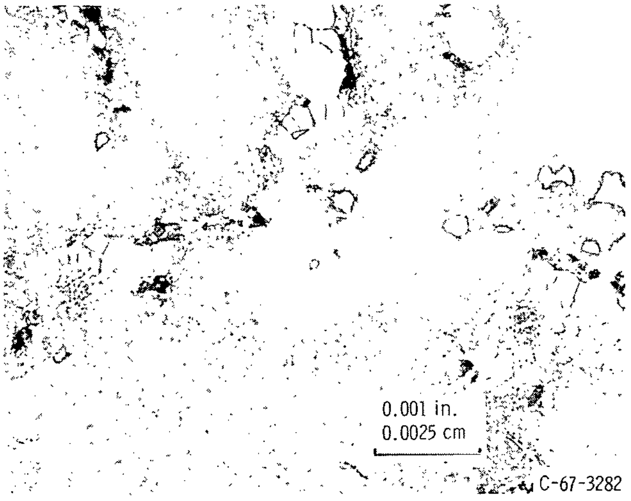
(a) Random polycrystalline.



(b) Directional polycrystalline.

Figure 7. - Micrographs of random and directional polycrystalline TAZ-8B as cast. Specimens taken perpendicular to tensile specimen axis. Etchant, 36.5 percent water, 36.5 percent glycerine, 18 percent nitric acid, and 9 percent hydrofluoric acid (electrolytic). X750.

(a) Random polycrystalline.



(b) Directional polycrystalline.

Figure 8. - Micrographs of random and directional polycrystalline TAZ-8B after exposure for 1000 hours at 1600° F (1144° K). Sections taken perpendicular to tensile specimen axis. Etchant, 36.5 percent water, 36.5 percent glycerine, 18 percent nitric acid, and 9 percent hydrofluoric acid (electrolytic). X750.

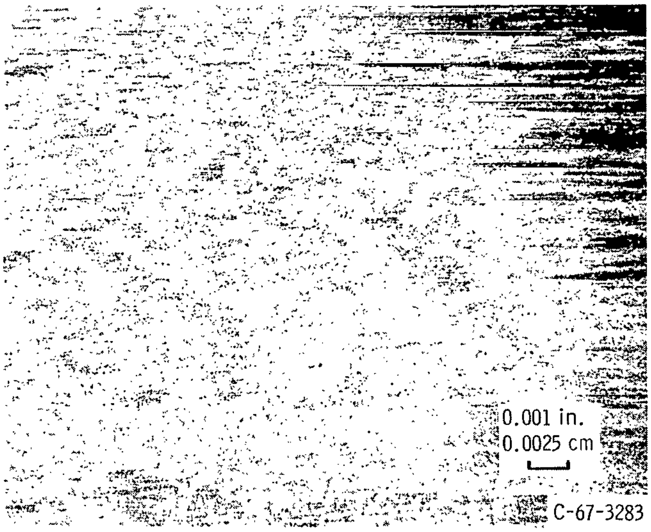


Figure 9. - Microstructure of hot-rolled 0.020-inch (0.0005-m) TAZ-8B alloy sheet. Etchant, 36.5 percent water, 36.5 percent glycerine, 18 percent nitric acid, and 9 percent hydrofluoric acid (electrolytic). X250.

CONCLUDING REMARKS

It has been demonstrated that directional solidification techniques can be usefully applied to the TAZ-8B alloy. The improved properties obtained as a result of the oriented columnar grain structure enhance the potential of the alloy for application to turbomachinery components.

SUMMARY OF RESULTS

From this investigation to provide a nickel-base alloy with improved high-temperature capability for gas-turbine and other elevated-temperature applications, the following results were obtained:

1. A high-strength nickel-base alloy (TAZ-8B) was developed. Its nominal composition in weight percent is 1.5 columbium, 8 tantalum, 6 chromium, 6 aluminum, 4 molybdenum, 4 tungsten, 5 cobalt, 1 zirconium, 0.125 carbon, 0.004 boron, and the balance nickel.

2. The application of directional solidification techniques to the alloy resulted in substantial increases in intermediate-temperature (1200° to 1600° F (922° to 1144° K)) tensile strength, substantially improved ductility over the entire temperature range studied (1200° to 2200° F (922° to 1478° K)), and generally increased stress-rupture life. For example, at 1400° F (1033° K) the tensile strength and elongation of the direc-

tional polycrystalline TAZ-8B were 172 000 psi (1185 MN/m^2) and 6 percent, respectively, compared with 144 000 psi (993 MN/m^2) and 3 percent for random polycrystalline TAZ-8B. At a stress of 15 000 psi (103.4 MN/m^2) the 1000-, 100-, and 10-hour use temperatures for the random polycrystalline material are 1785°, 1925°, and 2025° F (1247°, 1325°, and 1380° K), respectively, and for the directional polycrystalline material they are 1830°, 1940°, and 2040° F (1272°, 1333°, and 1389° K).

3. TAZ-8B was hot-rolled from random polycrystalline cast slabs 0.15 inch (0.0038 m) thick to a thickness of approximately 0.020 inch (0.0005 m) in a conventional rolling mill. The reduction obtained indicates the alloy has at least limited workability potential.

4. The alloy exhibits good room-temperature impact resistance in the unnotched condition. The average unnotched impact resistance was 40 and 41 foot-pounds (54 and 55.5 N-m) for the random polycrystalline and directional polycrystalline materials, respectively. In the notched condition, impact resistance was improved two-fold by directional solidification. The directional polycrystalline material had a notched impact resistance of 12.5 foot-pounds (17 N-m) as compared with 6.2 foot-pounds (8.5 N-m) for the random polycrystalline material.

5. On the basis of calculated electron-vacancy number, TAZ-8B would not be expected to form sigma phase.

6. Only minor decreases in 1400° F (1033° K) ductility were observed after exposure for 1000 hours at 1600° F (1144° K). In the random polycrystalline material tensile elongation decreased from 3.3 percent before exposure to 2.0 percent after exposure and in the directional polycrystalline material from 6.5 to 6 percent. However, the decreases noted suggest that some type of instability may occur in this alloy with aging.

Lewis Research Center,
National Aeronautics and Space Administration,
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