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ABSTRACT

A nickel-base alloy based on the nickel-aluminum-tungsten system designated WAZ-20 was developed with high strength in the 2000° to 2200° F (1094° to 1205° C) range. It has a tensile strength of 20 000 psi (137.9 MN/m^2) at 2200° F (1205° C). Application of directional solidification techniques increased intermediate temperature tensile strength and generally increased ductility and stress rupture life The combination of properties of the alloy suggest that it may have potential for application to stator vanes of advanced gas turbine engines.

A NICKEL BASE ALLOY, WAZ-20, WITH IMPROVED STRENGTH IN THE 2000° TO 2200° F RANGE

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SUMMARY

A nickel-base alloy designated WAZ-20 with an incipient melting point of about 2375° F (1302° C) was developed. The nominal composition in weight percent is 17-20W, 6-7Al, 1.4-1.6Zr, 0.10-0.20C, balance Ni. It has a tensile strength of 20 000 psi (137.9 MN/m^2) at 2200° F (1205° C). This is greater than known cast nickel base alloys. Although basically a cast material, the alloy also possesses at least limited workability potential.

By applying directional solidification techniques, test specimens with a columnar grain structure parallel to the longitudinal axis were produced. Substantial increases in intermediate temperature tensile strength and generally increased ductility and stress rupture life were obtained with the alloy in the directional polycrystalline condition as compared to the random polycrystalline condition. The 100 hour use temperatures at 15 000 psi (103.4 MN/m^2) are 1945° F (1063° C) in the directional polycrystalline form and 1900° F (1038° C) in the random polycrystalline form.

No acicular embrittling phases were observed after 1000 hours exposure at 1600° F (870° C). The room temperature average notched Charpy impact strength for the directional polycrystalline material after such exposure was 20 foot-pounds (27 J) compared with 16 foot-pounds (22 J) in the as-cast condition. The average unnotched Charpy impact strengths were significantly higher, ranging up to 135 foot-pounds (183 J) for the aged directional polycrystalline material.

The combination of properties evidenced by WAZ-20 suggest that it may have potential for application to stator vanes of advanced gas turbine engines where inlet gas temperatures well in excess of 2000° F (1094° C) are anticipated.

INTRODUCTION

The necessity for higher turbine inlet gas temperatures to meet the increased performance requirements of advanced turbine engines places a premium upon materials that have improved strength at high temperatures. Of all the hot components of turbine engines, the stator vanes are subject to maximum gas temperatures, and their operating material temperatures are limited by material capability. Superalloys, nickel and cobalt based, continue to be the work horse materials for these hot components of gas turbine engines. However, to operate satisfactorily with these materials at the high temperatures encountered in advanced engines for the thousands of hours necessary to make such engines economically viable, requires cooling (ref. 1). If superalloys can be developed for stator vane application that can operate to temperatures well in escess of 2000° F (1094° C), advantages can accrue in the form of decreased performance penalties associated with the use of less cooling air.

Available nickel base alloys drop off sharply in strength above 1900° to 2000° F (1038° to 1094° C). This occurs because the gamma prime phase upon which these alloys primarily depend for high temperature strength, agglomerates or goes into solution in this temperature range (ref. 1) The tendency toward a sharp decline in strength above 2000° F (1094° C) detracts from the desirability of nickel base alloys as stator vane materials which are exposed to temperatures above 2000° F (1094° C) in advanced engines. One way of achieving higher strength material for use at these temperatures is to exploit cobalt base materials since cobalt has a higher melting point, 2720° F (1493° C) than nickel 2650° F (1454° C). This approach is currently under investigation at NASA Lewis Research Center and shows considerable promise (ref. 2).

Another approach, the results of which are described in this report, is to select a nickel alloy system with a higher melting point than presently used systems. To this end the nickel-tungsten system was chosen for investigation. For example, tungsten additions to nickel up to 35 weight percent increase the melting point of the resulting alloy approximately 103° F (57° C) over that of nickel (ref. 3). In order not to excessively reduce the melting point of the final alloy, the number of other alloying constituents was also limited to aluminum, carbon, and zirconium. The most favorable combination of alloying elements consistent with maintaining a high melting point, reducing density, and achieving sound castings with minimum segregation was determined experimentally to be 17 to 20 percent tungsten, 6 to 7 percent aluminum, 1.4 to 1.6 percent zirconium, 0.10 to 0.20 percent carbon, and the balance nickel. This alloy is referred to herein as WAZ-20, and it was evaluated in tensile, stress rupture, and impact tests in both a random and directional polycrystalline form. Microstructural stability and rollability were also investigated and metallographic studies were made. Data comparisons are presented with more conventional nickel base alloy systems.

MATERIALS, APPARATUS, AND PROCEDURE

Materials

The purities of the various alloying elements used as reported by the suppliers were as follows:

Ni . . . . 99.9 percent
W . . . . 99.9 percent
Al . . . . 99.88 percent
C . . . . 99.5 percent

Zirconium and trace amounts of other elements were picked up from the crucible during induction melting. Chemical analyses of typical heats of WAZ-20, both argon-vacuum and argon-double vacuum melted, were made by an independent laboratory and are compared with the nominal composition in table I. The random polycrystalline form of the alloy was obtained by argon induction melting followed by a single vacuum induction melt. The directional polycrystalline form was obtained by argon induction melting followed by a double vacuum induction melt. The analyses show that the compositions generally fell within or very close to the nominal composition specifications, although aluminum content was near the low side of the specified nominal values.

TABLE I. - ALLOY COMPOSITION

Alloy	Composition, wt. %							
	W	Al	Zr	C	Ni	Si	Fe	B
WAZ-20 (nominal)	17 - 20	6 - 7.0	1.4 - 1.6	0.10 - 0.20	Bal	----	-----	------
Typical heats of random poly- crystaline WAZ-20[a]	18.89	5.87	1.34	0.19	Bal	0.05	0.007	0.0003
	19.05	5.94	1.43	.20		.05	.01	.0004
	19.01	6.10	1.31	.19		.05	.008	.0004
	18.82	6.06	1.39	.19		.05	.007	.0005
	19.68	6.17	.81	.13	73.14	----	-----	.0002
	19.34	6.21	1.44	.12	72.83	----	-----	.0003
Typical heats of directional polycrystalline WAZ-20[b]	16.97	5.93	1.72	0.113	75.06	0.10		0.0003
	17.11	5.95	1.52	.113	75.08	.10		.0003
	17.90	5.85	1.70	.113	74.21	.11		.0003

[a]Argon, vacuum melted.
[b]Argon, double vacuum melted.

Melting, Casting, and Inspection Techniques

Melts were made in 50 kilowatt, 10 000 hertz, water-cooled induction units. Both double and triple melts were made. In all cases the initial melt was made under an inert gas (commercially pure argon) cover in stabilized zirconia crucibles. The average exposure time per melt between melt and crucible was approximately 20 minutes. Carbon and tungsten additions were made in the form of powders precharged into the cold crucible with nickel platelets. Aluminum was added in the form of granules after the initial charge had melted. The melt was subsequently superheated to approximately 3000° F (1650° C) and poured at 2900° F (1593° C) as determined by an optical pyrometer. The melts were poured into copper molds that were at room temperature to provide pigs for subsequent remelting. The second stage of the melting process was to remelt under vacuum. A pressure of 10^{-3} torr or less was maintained during melting and pouring. The molten alloy was superheated to approximately 300° F (1650° C) prior to pouring. Pouring temperature for the random polycrystalline form of the alloy as determined by optical pyrometer was $2850^{\circ}\pm25^{\circ}$ F ($1565^{\circ}\pm15^{\circ}$ C). Zircon shell molds preheated to 1600° F (870° C)

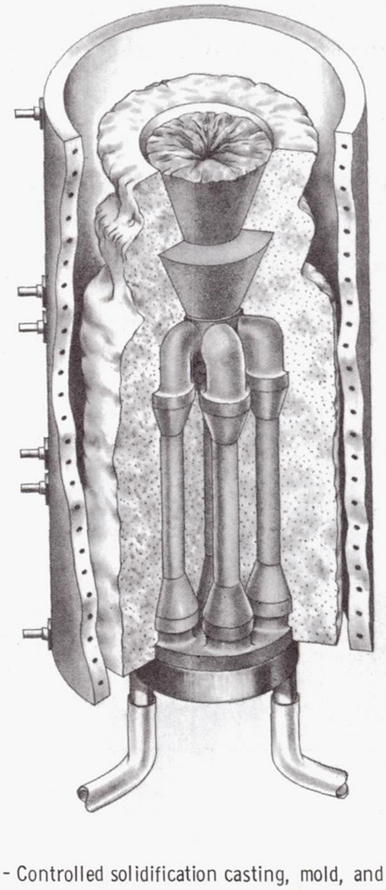

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Figure 1. - Controlled solidification casting, mold, and mold heater.

were used, to obtain test bars. In some cases the melts were poured into copper molds to provide pigs for the third stage of the melting process.

The third stage of the melting process was employed only to make directionally solidified castings of the alloy. The controlled solidification mold and mold heater are illustrated in figure 1 and described in reference 4. Briefly, the three zone mold heater provides a smooth temperature gradient along the length of the mold. Grain growth is initiated from a water cooled copper chill block inserted at the base of the mold. The molten alloy was superheated to approximately 3000° F (1650° C) prior to pouring. The pour temperature was $2850^{\circ}\pm25^{\circ}$ F ($1565^{\circ}\pm15^{\circ}$ C). The temperature of the portion of the mold adjacent to the chill block was approximately 2450° F (1340° C). After pouring, power to the mold heater zones was sequentially removed, and solidification proceeded vertically upward from the chill block.

All specimens were vapor blasted. They were then inspected by X-ray and by fluorescent-dye penetrant techniques before test. Only defect-free bars were tested.

Rolling

Workability potential of WAZ-20 in the random polycrystalline form was evaluated by rolling. Blanks $4\frac{3}{4}$ by 3 by 0.13 inch (12 by $7\frac{1}{2}$ by $\frac{1}{3}$ cm) cast into a copper chill mold were rolled into strips ranging from approximately 0.020 inch (0.05 cm) to 0.040 inch (0.1 cm) thick. Figure 2 illustrates a typical cast blank and rolled sheet. The blanks were unidirectionally rolled at room temperature in a 4-high mill at a surface speed of 80 feet per minute (0.41 m/sec). Reductions of 0.001 inch (0.0025 cm) per pass, approximately 1 percent of the original thickness were employed. After every 0.005-inch (0.013-cm) reduction the work piece was heated in a protective atmosphere (argon) at 2200° F (1205° C) and cooled to room temperature before continuing the rolling process.

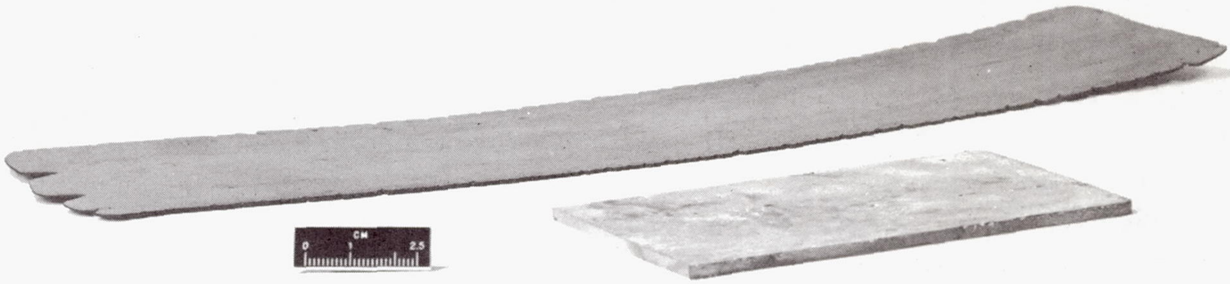

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Figure 2. - Cast blank and cold-rolled strip of WAZ-20.

Specimens

Random polycrystalline rupture and tensile bars were cast to final dimensions. The same type of specimen was used to determine both as-cast stress-rupture and tensile properties. These specimens had conical shoulders with a 20° included angle. The gage section was 1.20 inches long (3.05 cm) and 0.25 inch (0.635 cm) in diameter. Directional polycrystalline bars were cast to the same initial size and subsequently etched to reveal grain structure. The etched surface layer was removed by vapor blasting. Charpy impact bars were cast slightly oversize and finish-machined to obtain the 0.394 by 0.394 inch (1.0 by 1.0 cm) ASTM standard cross section dimensions.

Alloy Evaluation

Tensile and stress-rupture tests. - All tensile and stress rupture data were obtained in air. The specimens were tested without protective coatings. In the directionally solidified test bars, the grains were alined parallel to the longitudinal axis of the test bars. The range of tensile test temperatures was from room temperature to 2200° F (1205° C). Tests were conducted on a standard hydraulically operated tensile testing machine. The average strain rates ranged from 0.0015 to 0.03 inch per inch per minute (0.0015 to 0.03 cm/cm/min) and were calculated from the measured elongation after fracture and the total test time. It was shown in reference 5 that this type of test gives comparable results to those obtained with a mechanically operated tensile testing machine. Stress rupture tests were run at 15 000 psi (103 MN/m^2) over a range of temperatures from 1800° F (982° C) to 2100° F (1152° C).

Hardness. - Representative as-cast directionally solidifed test specimens were sectioned transverse and parallel to the longitudinal axes. 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 the average of 5 Rockwell A readings across each section was taken as indicative of the hardness.

Impact tests. - A standard Charpy impact tester was used to measure impact strength at room temperature. Both V-notched (ASTM Type A) and unnotched specimens of random and directional polycrystalline material were tested in the as-cast condition. In the directionally solidified test bars the grains were alined parallel to the longitudinal axis of the bar. Oversize cast bars were aged for 1000 hours at 1600° F (870° C), machined to standard impact specimen dimensions, and tested at room temperature.

Metallography. - Photomicrographs of WAZ-20 are provided in the as-cast, rolled, and aged condition. The etchant used to obtain the photomicrographs was 92 parts HCl, 3 HNO_3, and 5 H_2SO_4. The macroetch used to discern grain size and grain structure consisted of HCl with approximately 20 percent H_2O_2 (immersion etch). The incipient melting temperature was determined to be 2375° F (1302° C) by exposing samples cut from cast tensile bars for 1/2 hour at various temperatures from 2300° F (1260° C) to 2450° F (1343° C) in a heat treating furnace. Subsequent metallographic examination revealed that incipient melting was present at 2375° F (1302° C) and not at 2350° F (1288° C).

Density. - Several random and directional polycrystalline as-cast tensile test specimens were used to measure density by displacement of water. The measured values of density ranged between 3.23 and 3.29 pounds per cubic inch (8.95 and 9.1 g/cm^3).

RESULTS AND DISCUSSION

Tensile Properties

The as-cast tensile properties of WAZ-20 in both the random and directional polycrystalline form are compared in figure 3 over a range of temperatures. The directional polycrystalline material shows an improvement in tensile strength over the random polycrystalline material up to approximately 1800° F (982° C). The maximum improvement was 19 000 psi (131 MN/m^2) at 1600° F (870° C). Above 1800° F (982° C), the strengths are the same. Elongation was significantly increased (from 4 to 12 percent) by directional solidification at room temperature and test temperatures above 1600° F (870° C). Slight improvement occurred in the intermediate temperature range between 1200° F (649° C) and 1600° F (870° C) where the directionally solidified material had elongations ranging between 3 and 5 percent.

Figure 4 shows a comparison of the as-cast tensile properties of random polycrystalline and directionally solidified WAZ-20 and our earlier alloy TAZ-8B (ref. 4) over a temperature range from 1800° F (982° C) to 2200° F (1205° C). Comparison is made over this rather limited range of temperatures to emphasize the strength advantage of WAZ-20 at very high temperatures. At 2200° F (1205° C) this alloy has an ultimate tensile strength of 20 000 psi (137.9 MN/m^2), about twice that of TAZ-8B. The random and directional polycrystalline forms of each alloy give coincident tensile strength curves. The TAZ-8B curve tends to drop off rather sharply in strength above 2000° F (1094° C), whereas the decrease in strength with increasing temperature is less marked for WAZ-20. Elongation of directional WAZ-20 was fairly constant, about 10 percent over the temperature range shown and substantially above the random WAZ-20 and TAZ-8B curves. Directional TAZ-8B had a higher elongation at 2000° F (1094° C) about 22 percent, and approximately the same elongation as directional WAZ-20 at both 1800° F (982° C) and 2200° F (1205° C).

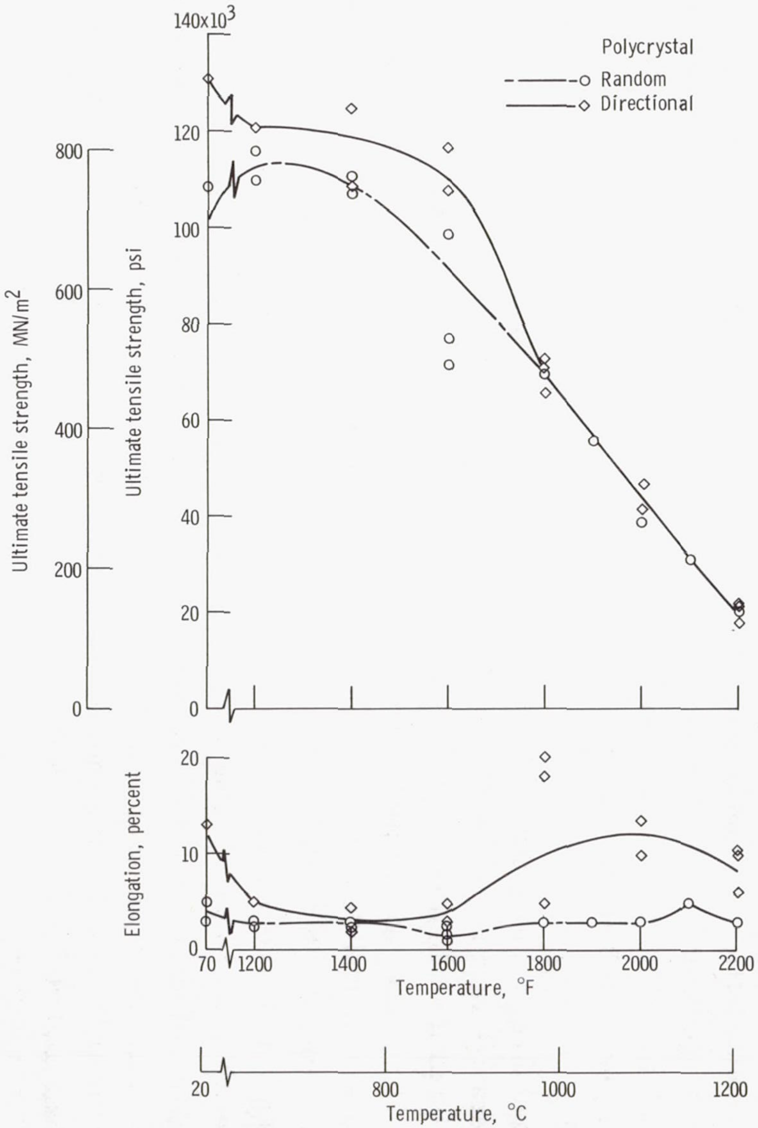


Figure 3. - Tensile properties of WAZ-20.

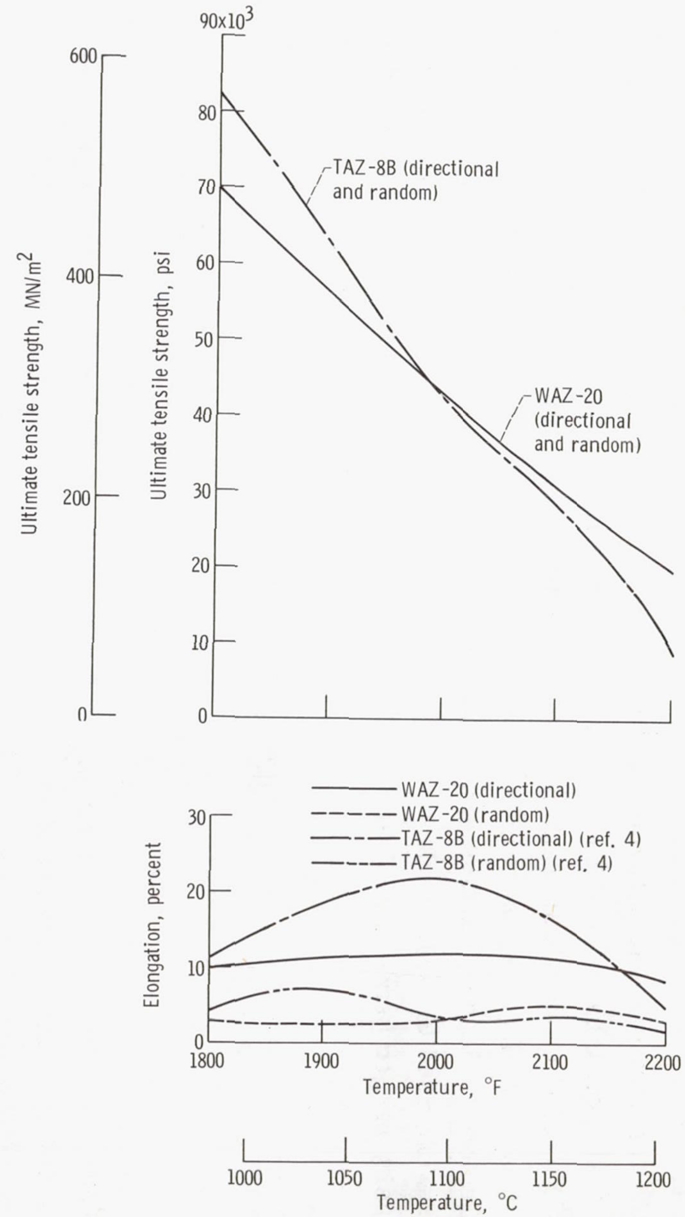


Figure 4. - Comparison of tensile properties of WAZ-20 and TAZ-8B.

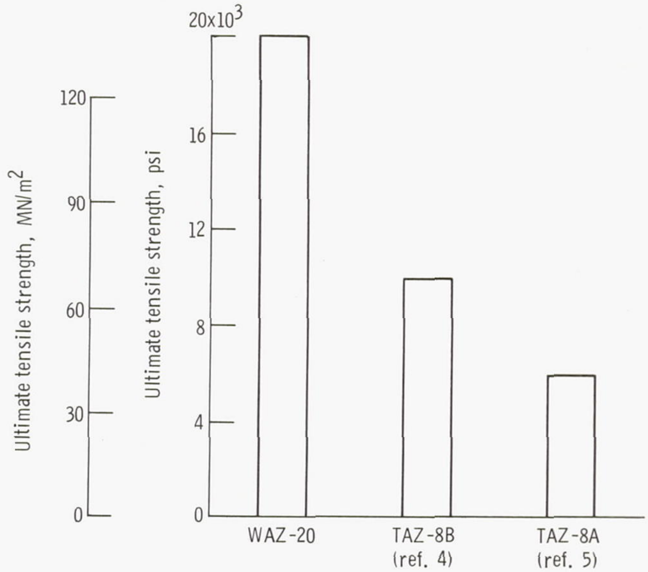


Figure 5. - Ultimate tensile strengths of cast nickel base alloys at 2200° F (1205° C).

As a further indication of the comparative strengths of representative nickel base alloys at high temperature, a bar chart comparison of ultimate tensile strengths at 2200° F (1205° C) is shown in figure 5. At this temperature, as stated earlier, the tensile strength of WAZ-20 is about twice or more that of the other alloys.

Stress Rupture Data

Figure 6 shows a comparison of the 15 000 psi (103 MN/m^2) rupture properties of WAZ-20 in the random and directional polycrystalline form. The directionally solidified material had twice the life of the conventionally cast (random polycrystalline) material up to 2050° F (1120° C). At 2100° F (1152° C) both forms of the alloy had the same life. When compared on the basis of use temperature, the 15 000 psi (103 MN/m^2), 100 hour use temperatures are 1945° F (1063° C) for the directional polycrystalline form and 1900° F (1038° C) for the random polycrystalline form. The 1000 hour use temperature for the directional polycrystalline form of the alloy is 1795° F (980° C).

The 15 000 psi (103 MN/m^2) stress rupture properties of directionally solidified WAZ-20 and TAZ-8B (ref. 4) are compared in figure 7. The rupture curves cross at 1930° F (1055° C) with the WAZ-20 curve having higher rupture lives above this temperature. These results are in keeping with the tensile property comparison of these alloys made in figure 4.

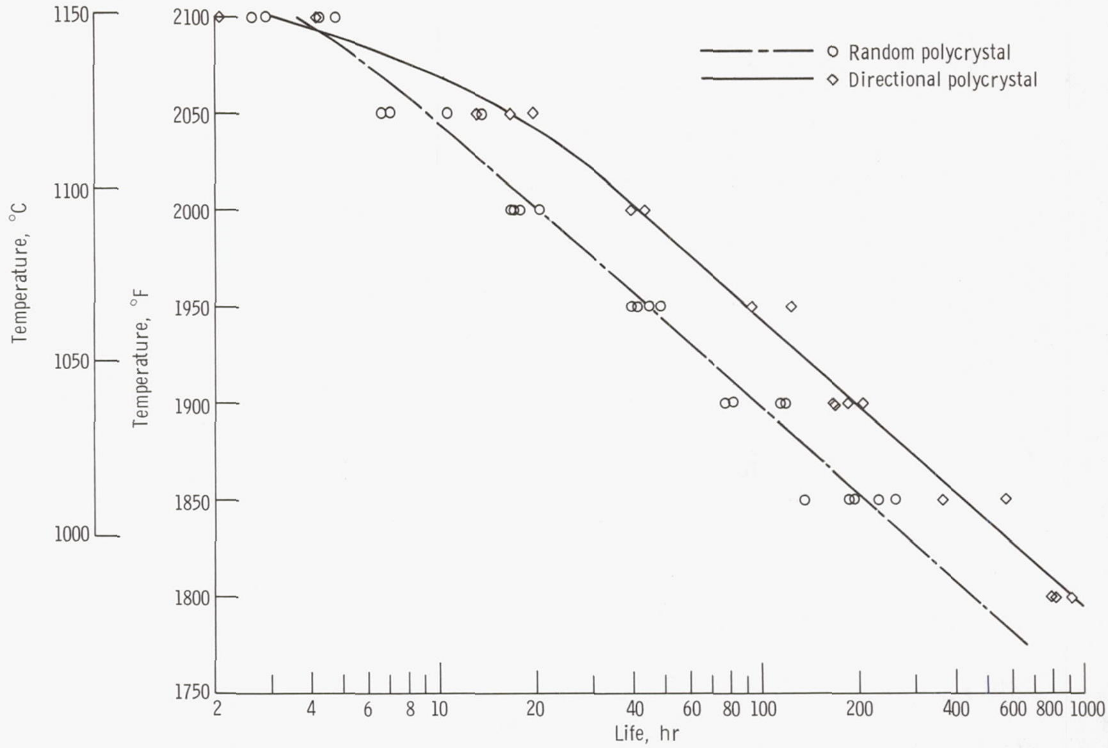


Figure 6. - Stress rupture properties of WAZ-20 at 15 000 psi (103.4 MN/m^2) in random and directional polycrystalline form.

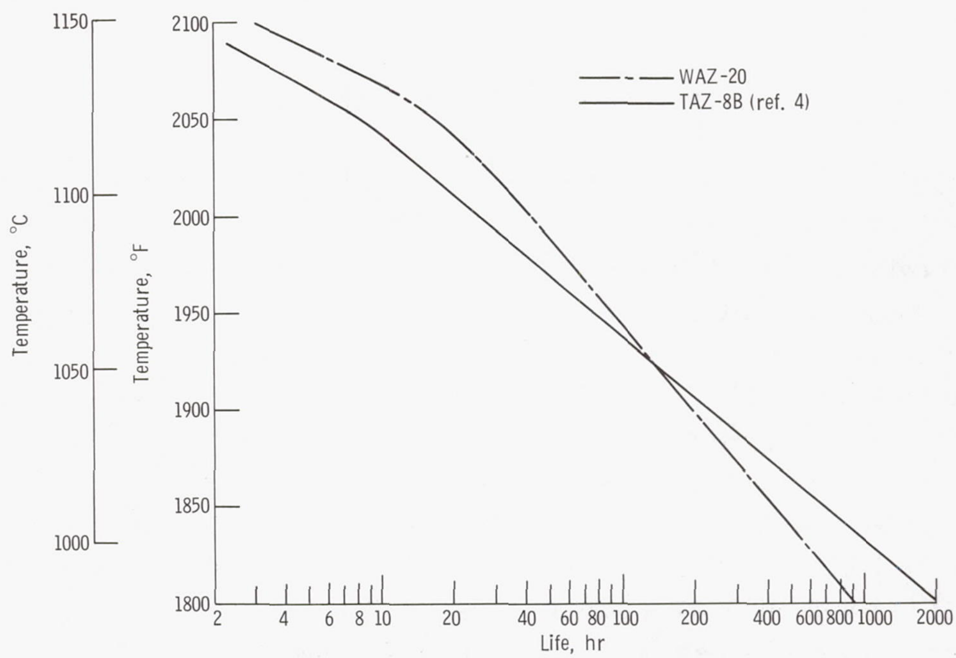


Figure 7. - Stress rupture properties of two directionally solidified nickel base alloys, WAZ-20 and TAZ-8B, at 15 000 psi (103.4 MN/m^2).

Consideration of the ability of WAZ-20 to maintain relatively high strength at temperatures of 2100° F (1149° C) and 2200° F (1205° C) suggests that the alloy might have potential for stator vane applications in advanced engines where very high turbine inlet temperatures are required. Of course, a suitable protective coating would be required for this or any currently available alloy if it were to be used in an engine environment at such temperatures for long (thousands of hours) periods.

Despite the fact that WAZ-20 does not contain chromium, it has reasonably good oxidation resistance. No oxidation tests were run with this alloy, however the long rupture lives obtained in stress rupture tests in air at temperatures up to 2100° F (1149° C) substantiate that the alloy has considerable oxidation resistance. On the basis of visual comparisons of tested stress-rupture specimens, however, WAZ-20 is not as oxidation resistant as TAZ-8A (ref. 5), one of the more oxidation resistant high strength nickel base alloys.

Impact Strength

The Charpy room temperature impact strengths (notched and unnotched) of WAZ-20 in the random and directional polycrystalline form are shown in table II. The directional

TABLE II. - ROOM TEMPERATURE CHARPY IMPACT STRENGTHS OF WAZ-20

Macrostructure	Alloy condition	Unnotched				Notched			
		Measured values		Average		Measured values		Average	
		ft-lb	J	ft-lb	J	ft-lb	J	ft-lb	J
Random polycrystalline	As-cast	32, 35	44, 48	34	46	10, 11	14, 15	10	14
	Aged[a]	80, 88	109, 120	84	114	14, 18	19, 24	16	22
Directional polycrystalline	As-cast	89, 92	121, 125	90	123	16, 17	22, 23	16	22
	Aged[a]	>110, 135	>150, 183	135	183	20, 20	27, 27	20	27

[a]1000 hr at 1600° F (870° C)

polycrystalline material has about $1\frac{1}{2}$ to 2 times the impact strength of the random polycrystalline material both in the as-cast or aged condition. It is particularly significant that the alloy after aging for 1000 hours at 1600° F (870° C) showed greater impact strength than in the as-cast condition. Any embrittling effects that might be expected due to elevated temperature exposure did not materialize. Figure 8 illustrates two WAZ-20 directionally solidified impact bars after test. Both were unnotched and one was

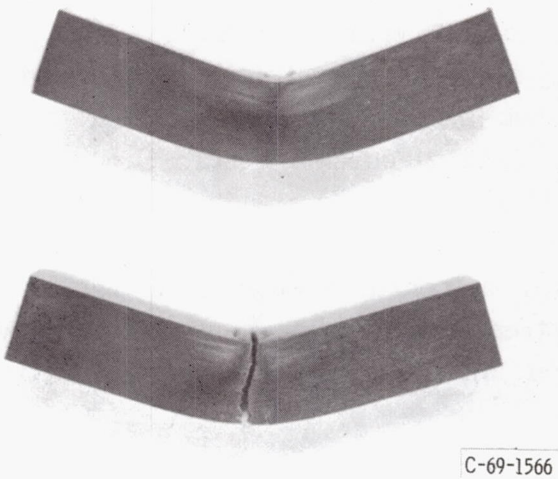


Figure 8. - WAZ-20 directionally solidified Charpy test bars after test. Unfailed bar was first aged 1000 hours at 1600° F (870° C) and had >110 foot-pounds (>150 J) room-temperature impact strength. Failed bar was as-cast and had impact resistance of 89 foot-pounds (121 J).

tested in the as-cast condition, the other after aging. The remarkable impact strength of the aged bar is apparent in that it failed to break on the application of 110 foot-pounds (150 J). By way of comparison, the average notched impact strength of as-cast random and directional polycrystalline WAZ-20, 10 and 16 foot-pounds (14 and 22 J), respectively, are considerably higher than those of TAZ-8B, which had impact strengths of 6.2 and 12.5 foot-pounds (8 and 17 J) (ref. 4). The excellent impact strength of this alloy suggests that it would be resistant to foreign object damage in engine applications, even after long time elevated temperature exposure.

Workability

Workability potential of WAZ-20 in the random polycrystalline form was demonstrated by rolling chill cast slabs 0.13 inch (0.33 cm) thick into strips 0.040 inch (0.1 cm) to 0.020 inch (0.05 cm) thick. No edge cracking of the sheet occurred during rolling. The alloy has somewhat better rolling characteristics than TAZ-8A (ref. 5) and TAZ-8B (ref. 4). No attempt was made to optimize rolling procedure or 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 cast thin slab is a somewhat specialized one. The fine grain size that can be obtained in a thin chill cast slab contributes to rollability of the alloy in that impurities that normally segregate at grain boundaries are more widely distributed. The limited work done suggests that the alloy may be worked under closely controlled conditions.

Hardness

Rockwell A hardness values for WAZ-20 are given in table III. A standard conversion table for steel was used to obtain equivalent Rockwell C values. There was no difference between the hardness of the as-cast random and directional polycrystalline form of the alloy, each having an average Rockwell A hardness of 67.5 (Rockwell C 34). No significant difference was observed between the hardness of the as-cast directional polycrystalline material along the growth direction (Rockwell A 67) and transverse to the growth direction (Rockwell A 67.5). This suggests that grain alinement had essentially no effect on the hardness of the alloy. The directionally solidified material after aging for 1000 hours at 1600° F (870° C) however, showed a slight decrease in hardness to Rockwell A 66.2, suggesting greater ductility, and is in agreement with the improved impact resistance observed after such an age. The as-rolled sheet material had the highest hardness, Rockwell A 74.4 (Rockwell C 47).

TABLE III. - HARDNESS DATA

Macrostructure	Alloy condition	Hardness range, Rockwell A	Average Rockwell A	Converted Rockwell C
Random polycrystalline	As-cast	66.7 - 67.8	67.5	34
	Aged	67.0 - 67.8	67.4	34
	As-rolled sheet	74.0 - 74.9	74.4	47
Directional polycrystalline	As-cast[a]	67.3 - 67.8	67.5	34
	As-cast[b]	66.8 - 67.2	67.0	33
	Aged[a, c]	66.2 - 66.2	66.2	31

[a]Perpendicular to growth direction.
[b]Parallel to growth direction.
[c]Aged 1000 hours at 1600° F (870° C).

Metallography

Macrographs of a random and directionally solidified tensile test bar of WAZ-20 are shown in figure 9. The grains are columnar in the directionally solidified bar and extend along the length of the bar.

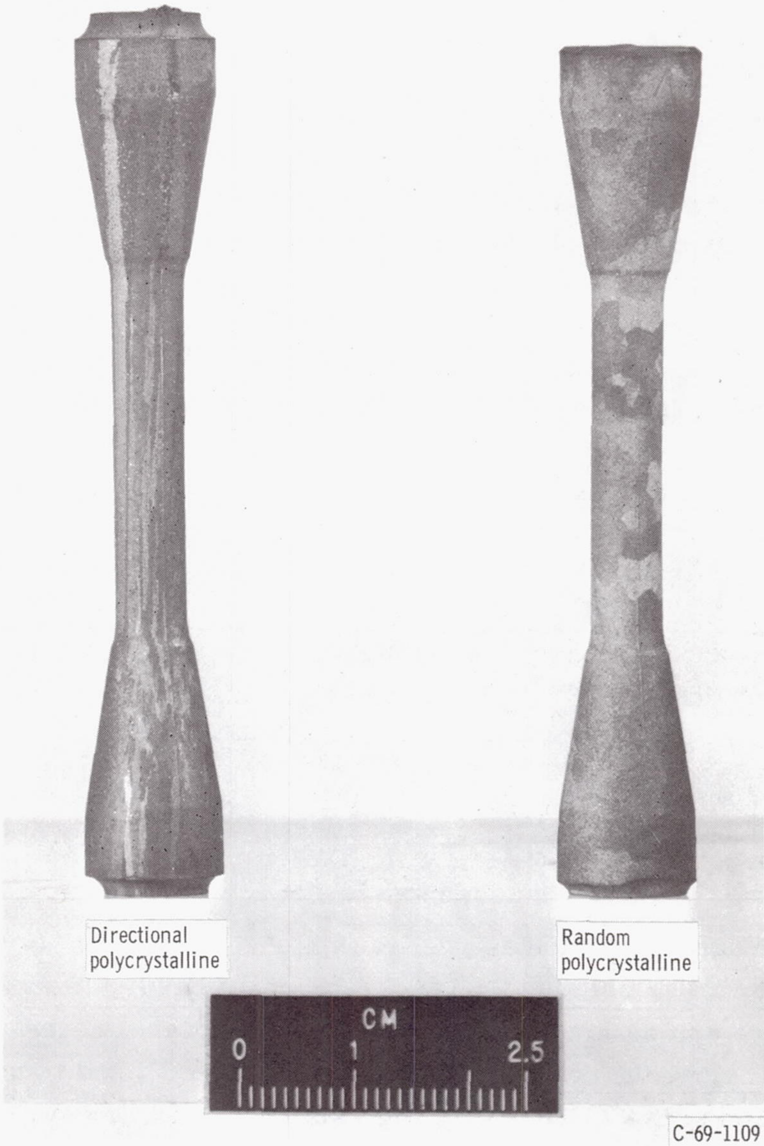
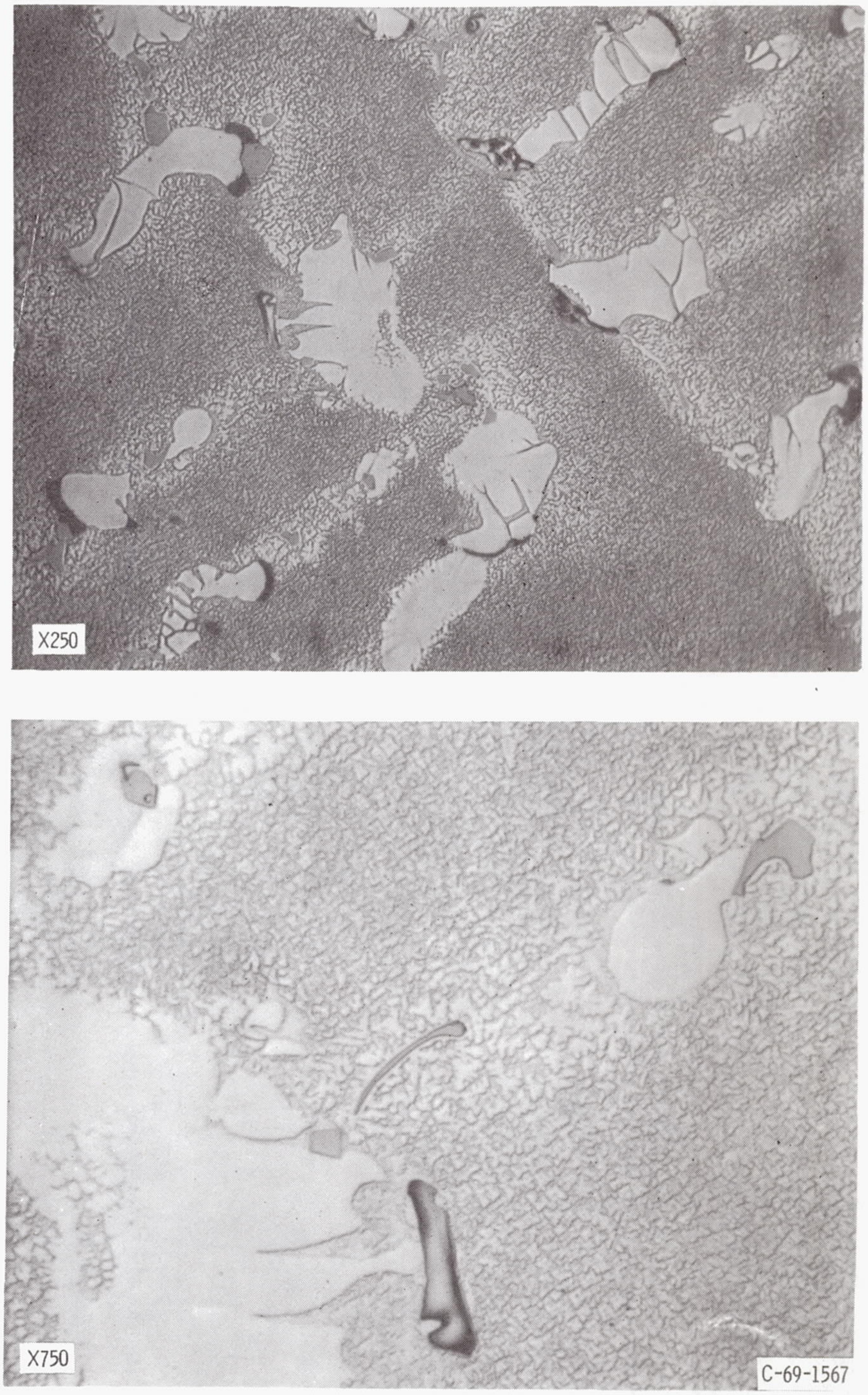


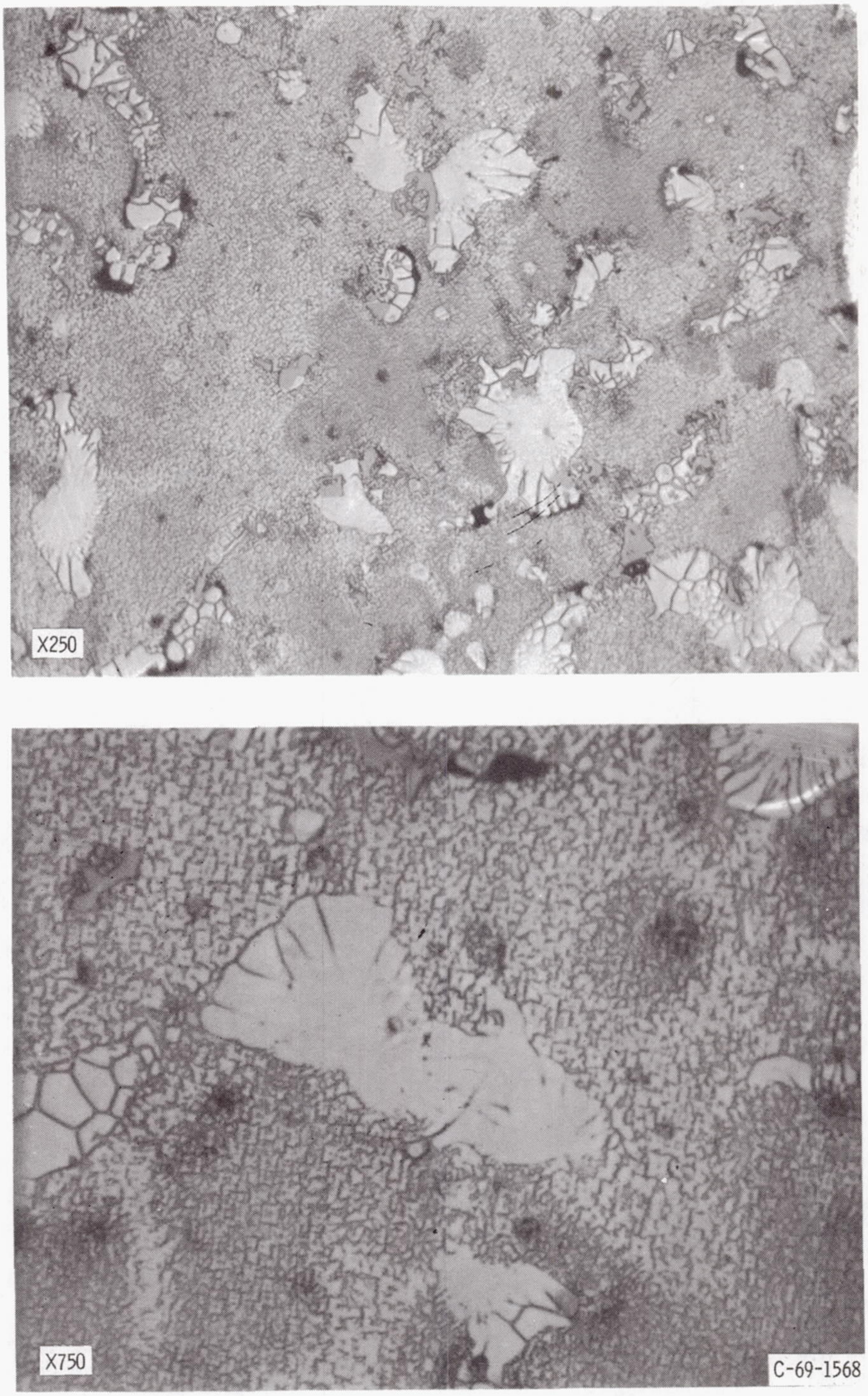
Figure 9. - Macrograph showing directional and random polycrystalline tensile test specimens of WAZ-20.

Micrographs of directional polycrystalline WAZ-20 in the as-cast condition are shown at magnifications of 250 and 750 in figure 10. Although grain boundaries were evident at low magnification (fig. 9) they are not readily apparent at these magnifications. Both the section parallel to and perpendicular to the growth direction show the same general features: a matrix containing a gamma prime γ' type precipitate and large primary γ' type nodules. Some carbides are also present. The microstructure of the as-cast random polycrystalline form of the alloy is shown in figure 11. It is apparent from figures 10



(a) Parallel to crystal growth direction.

Figure 10. - Microstructure of as-cast directional polycrystalline WAZ-20.



(b) Perpendicular to crystal growth direction.

Figure 10. - Concluded.

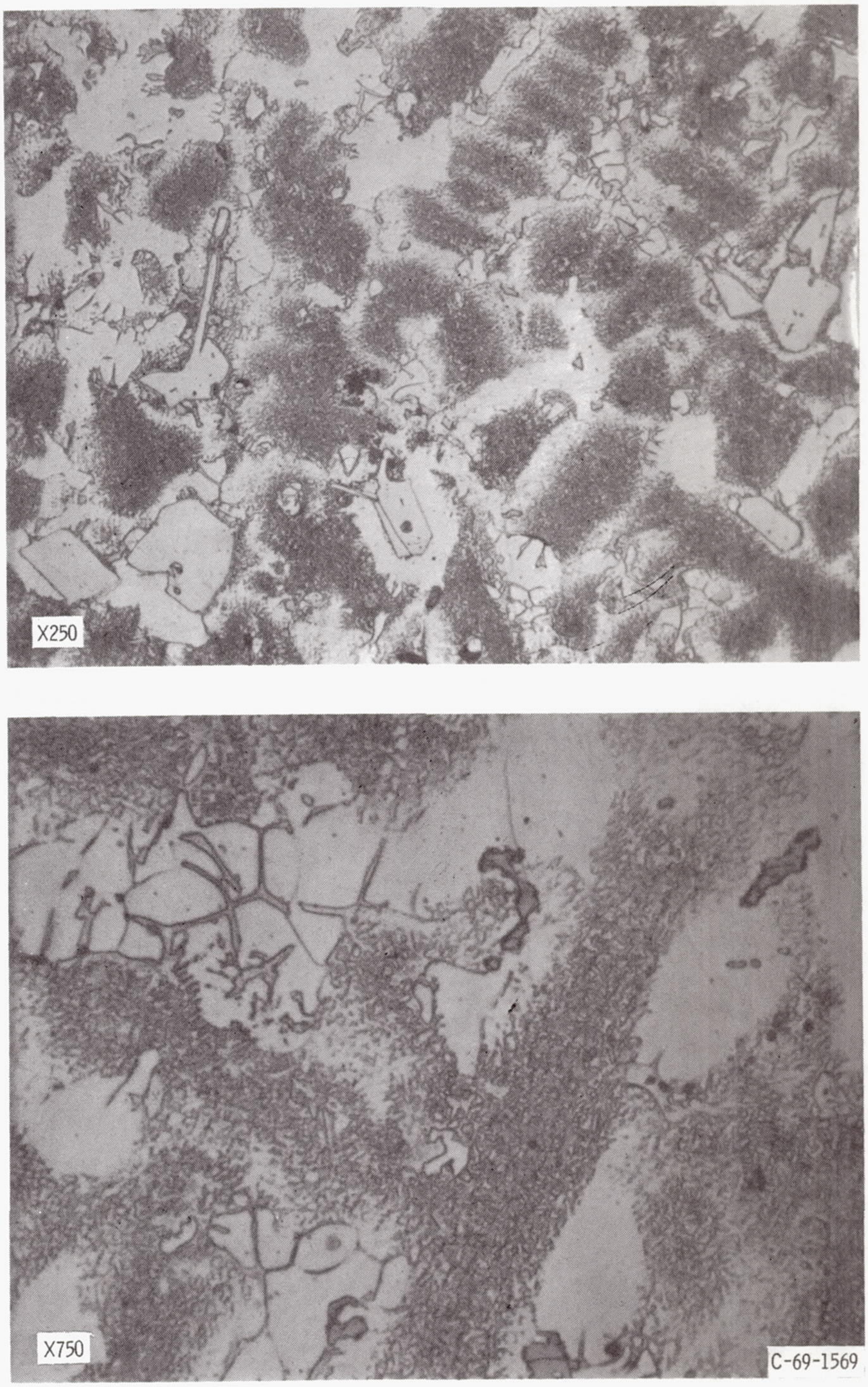


Figure 11. - Microstructure of as-cast random polycrystalline WAZ-20.

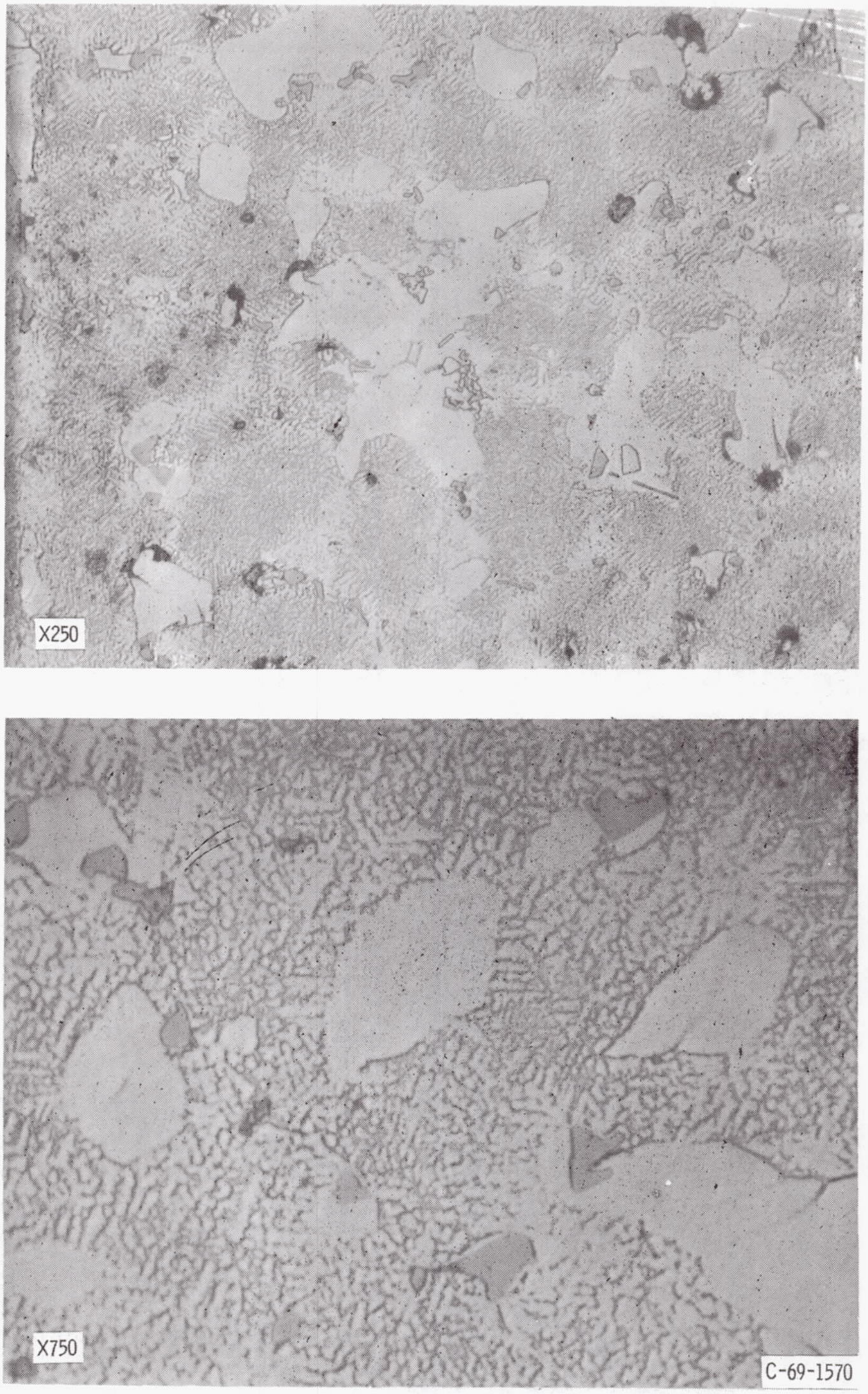


Figure 12. - Microstructure of random polycrystalline WAZ-20 after exposure for 1000 hours 1600° F (870° C).

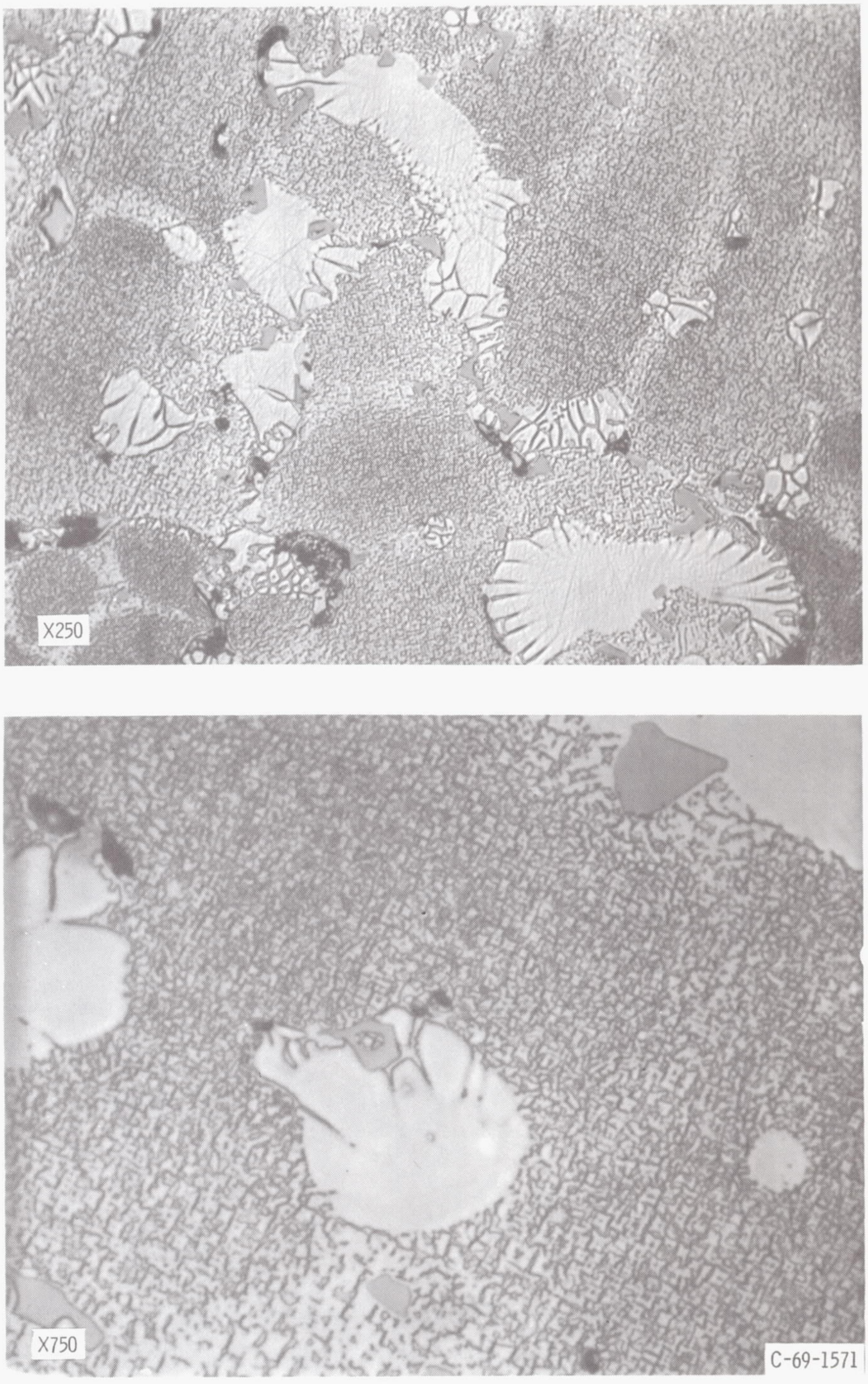


Figure 13. - Microstructure of directional polycrystalline WAZ-20 after exposure for 1000 hours at 1600° F (870° C).

and 11 that the directional and random polycrystalline structures have similar features.

The microstructures of WAZ-20 after exposure for 1000 hours at 1600° F (870° C) are shown for the random polycrystalline material in figure 12 and for the directional polycrystalline material in figure 13. No embrittling acicular phase was observed in either sample. Coarsening of the γ' type precipitate was evident.

Figure 14 illustrates the microstructure of as-rolled WAZ-20 0.040 inch (0.10 cm) sheet at a magnification of 250. The section shown is parallel to the rolling direction. The cast structure has been markedly altered by the rolling operation and has a fibered appearance.

Figure 14. - Microstructure of as-rolled 0.040-inch (0.10 cm) WAZ-20 sheet.

SUMMARY OF RESULTS

The following results were obtained from this investigation to provide a nickel base alloy with improved strength at temperatures above 2000° F (1094° C) for potential application to stator vanes of advanced gas turbine engines:

1. A new, high-strength nickel-base alloy, WAZ-20, was developed. Its nominal composition, in weight percent, is 17-20 tungsten, 6-7 aluminum, 1.4-1.6 zirconium, 0.10-0.20 carbon, and the balance nickel.

2. The alloy has substantially higher tensile strength at 2200° F (1205° C) than known cast nickel base alloys. Its ultimate tensile strength at 2200° F (1205° C) is 20 000 psi (137.9 MN/m^2).

3. The application of directional solidification techniques to the alloy resulted in substantial increases in intermediate temperature tensile strength, generally improved ductility, and increased stress rupture life in comparison to the random polycrystalline form of the alloy. For example, at a stress of 15 000 psi (103 MN/m^2), the 100 hour use temperatures are 1945° F (1063° C) for the directional polycrystalline material, and 1900° F (1038° C) for the random polycrystalline material.

4. WAZ-20 has excellent room temperature impact strength both as-cast and after aging. The directional polycrystalline form of the alloy has substantially higher impact strength than the random polycrystalline form. Average Charpy notched impact strengths for the as-cast alloy were 10 and 16 foot-pounds (14 and 22 J) in the random and directional polycrystalline form, respectively. After aging for 1000 hours at 1600° F (870° C), they were 16 and 20 foot-pounds (22 and 27 J), respectively. The unnotched impact strengths were significantly higher and ranged from 34 foot-pounds (46 J) in the as-cast random polycrystalline form to 135 foot-pounds (183 J) in the aged, directional polycrystalline form.

5. WAZ-20 was hot-rolled from random polycrystalline chill cast slabs 0.130 inch (0.33 cm) thick to a thickness of 0.20 inch (0.05 cm) in a conventional rolling mill. The reductions obtained indicate the alloy has at least limited workability.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 7, 1969,
120-03-01-03-22.

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