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Alloy 10: A 1300F Disk Alloy

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August 2000

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ALLOY 10: A 1300F DISK ALLOY

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INTRODUCTION

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300F to 1400F temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, Allied Signal's Alloy 10, is a promising candidate for gas turbine engines to be used on smaller, regional aircraft. For this application, compressor/turbine disks must withstand temperatures of 1300F for several hundred hours over the life of the engine. In this paper, three key properties of Alloy 10, tensile, 0.2% creep, and fatigue crack growth , will be assessed at 1300F.

MATERIAL & TEST PROCEDURE

Alloy 10 is nickel-base superalloy, with a gamma prime content of about 55%. The composition is shown in Table 1. The disk used in this study was produced from argon atomized powder which was subsequently compacted, extruded, and isothermally forged. After forging, sections of the disk were given four different heat treatments. Half of the material was given a subsolvus solution heat treatment at 2075F/3HR, while the balance was given a near-solvus solution heat treatment at 2155F/3HR. Both solution treatments employed an initial cooling rate of 150F/minute. As a result of the two solution temperatures, the material given the subsolvus solution at 2075F had a grain size between ASTM 11 and 12, while the material given the near-solvus solution at 2155F had a grain size between ASTM 9 and 10. Photomicrographs of the two microstructures are presented in Figure 1 and, as expected, the material given the subsolvus solution has significantly more primary gamma prime than the material given the near-solvus solution. After solutioning half the material was given a stabilization treatment at 1550F/4HR and then aged at 1400F/8HR, while the other half was aged directly at 1400F/8HR after solutioning. Material given the stabilization treatment will be abbreviated as STAB and that given the direct age will be abbreviated as DA. As a result of this processing, four microstructural variants of Alloy 10 were produced: ASTM 11/STAB, ASTM 11/DA, ASTM 9/STAB and ASTM 9/DA. The stabilization treatment is employed to reduce residual stress levels and precipitate $M_{23}C_6$ carbides. In addition, stabilization tends to increase the size of the gamma prime precipitates, particularly the aging gamma prime.

Tensile, creep and crack growth specimens were machined from the disk after heat treating. The tensile and creep specimens were identical with a cylindrical gage section measuring 0.160" in diameter by 0.750" long. Tensile tests were run at 1300F at a strain rate of 0.5%/minute through yield. The ASTM 9 material was creep tested at 1300F/90KSI while the ASTM 11 material was creep tested at 1250F/115KSI and 1350F/70KSI. 1300F/90KSI creep data was estimated for the ASTM 11 material using a Larson-Miller approach.

Crack growth rates were measured using a K_B Bar test developed by Vanstone (Ref. 1). The K_B Bar had a rectangular cross section measuring 0.40" wide and 0.17" thick with a thin, semicircular surface flaw 0.015" in diameter located at the center of the 0.40" face. A precrack extending to a depth of about 0.030" (0.015" notch plus 0.015" crack) was introduced by high frequency cycling at room temperature before dwell testing at 1300F. The peak load for precracking and testing was held constant throughout at a stress level of about 100KSI. A tension-tension dwell cycle was employed during testing at 1300F with a 180 second dwell at peak load and an R-ratio of 0.1. Dwell crack growth rates were monitored using a DC potential drop technique from a K_{MAX} of 20 to 40KSI-IN$^{0.5}$ producing two distinct calibration points per test.

RESULTS & DISCUSSION

The 1300F tensile data for Alloy 10 is presented in Figure 2 and Table 2. Yield strength of material with the finer grain size, ASTM 11, was 165-170KSI while that with the coarser grain size, ASTM 9, was 155-160KSI. Ultimate strength displayed less variability, with all variants of Alloy 10 falling between 190-200KSI. For both yield and ultimate strength, stabilization consistently produced lower results for a given grain size. Ductility was greater than 14% elongation, 18% reduction in area, for all variants of Alloy 10 and increased as yield strength decreased.

Creep data for Alloy 10 was generated at several conditions, as previously stated. To present this data, a Larson-Miller plot has been constructed, Figure 3, showing the time to 0.2% creep, an important design consideration for disk operation. Recall that material with the ASTM 9 grain size was tested at 1300F/90KSI while the material with the ASTM 11 grain size was tested at 1250F/115KSI and 1350F/70KSI. Regardless of test conditions or grain size, stabilization is seen to have a detrimental effect on creep. A more direct comparison of all four microstructural variants can be made if one plots the time to 0.2% creep at 1300F/90KSI, by interpolating the data for material with the ASTM 11 grain size. The results of this comparison are presented in Figure 4. A significant spread in the data is evident, with the ASTM 9/DA material showing over 400 hours to 0.2% creep while that for the ASTM 11/STAB material is less than 40 hours. As previously stated, stabilization decreases time to 0.2% creep, a factor of about five for either grain size. Grain size is also seen to impact creep, with the time to 0.2% creep of the material with the ASTM 11 grain size being about half that of the material with the ASTM 9 grain size. While time to 0.2% was dramatically affected by stabilization, the rupture life showed a much smaller debit. For the material with the ASTM 9 grain size the rupture life was about 800 hours for the stabilized condition versus about 1000 hours for the direct age condition at 1300F/90KSI. Rupture ductility was about 10% reduction in area for both conditions.

The 1300F/180 second dwell crack growth rates of Alloy 10 with an ASTM 9 and ASTM 11 grain size were measured and are compared in Figure 5 for the direct age condition. As seen in this plot, the fine grain material has a dwell crack growth rate which is about 20 to 50 times greater than the coarse grain material. The mode of crack growth was primarily intergranular, Figure 6, in both cases. As with creep, stabilization was also found to be detrimental to dwell crack growth, with about a 10 to 20 fold increase in crack growth for Alloy 10 with the ASTM 9 grain size. While stabilization is generally found to be detrimental with respect to creep for most nickel-base disk alloys (Ref. 2), its effect on high temperature, dwell crack growth rate varies with alloy composition/processing (Ref. 3).

SUMMARY & CONCLUSIONS

Three key properties, tensile, 0.2% creep, and fatigue crack growth, of an advanced turbine disk alloy, Alloy 10, were measured at 1300F. Four commercially viable heat treatments were used to produce a variety of microstructures in this alloy. Of these four heat treatments, the coarse grain microstructure produced by a near-solvus solution heat treatment at 2155F/3HR followed by a direct age at 1400F/8HR had the best balance of properties. The 0.2% creep times and the fatigue crack growth rates with a tensile dwell were clearly superior for this coarse grain microstructure. While the yield strength of the coarse grain microstructure was slightly lower than the fine grain microstructure, the ultimate tensile strength, which dictates disk burst limits, was equivalent. A stabilization heat treatment, which is used to reduce residual stress levels and therefore improve disk machinability, was detrimental to creep and crack growth properties for this alloy, and should therefore be avoided or optimized if possible.

REFERENCES

1. Vanstone, R. H. and Richardson, T. L., Potential-Drop Monitoring of Cracks in Surface-Flawed Specimens, Automated Test Methods for Fracture and Fatigue Crack Growth, ASTM STP 877, 1985, pp. 148-166.

2. Bhowal, P. R. and Merrick, H. F., High Temperature Turbine Disk Material, N68335-94-C-0203 Interim Report, Naval Air Warfare Center Aircraft Division, March 1997.

3. Private Communications with Dr. T. P. Gabb, EPM Technical Lead for Disk Alloy Development, NASA Lewis Research Center, Cleveland, Ohio.

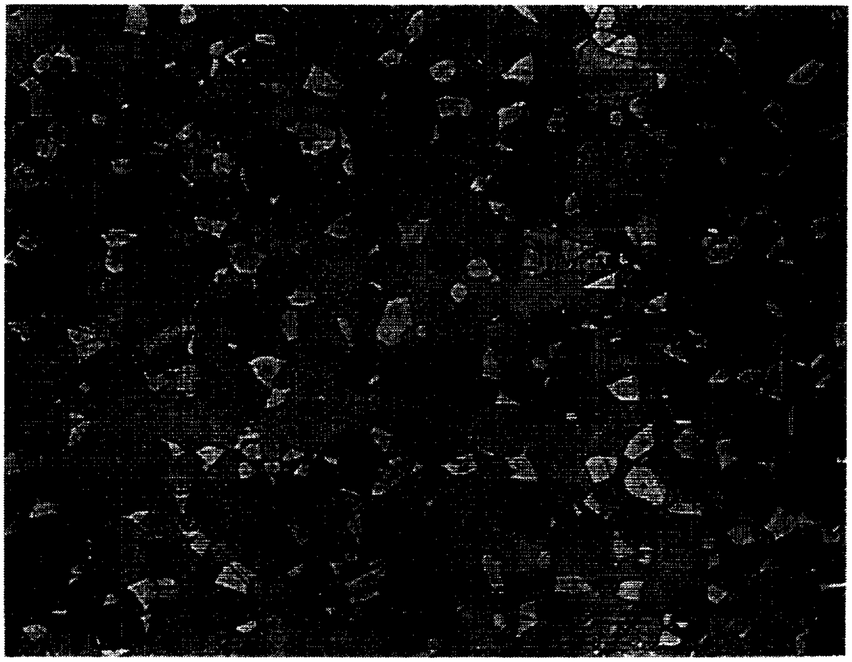
TABLE 1. COMPOSITION OF ALLOY 10 IN W/O.

Co	Cr	Al	Ti	Mo	Ta	W	Nb	C	B	Zr
14.8	10.4	3.4	3.8	2.8	0.7	5.9	1.6	.030	.022	.090

TABLE 2. 1300F TENSILE PROPERTIES.

SAMPLE	.2% YIELD (KSI)	ULTIMATE (KSI)	ELONG. (%)	R. A. (%)
ASTM 11 DA	169	199	14	18
ASTM 11 DA	167	197	15	18
ASTM 11 STAB	166	193	15	19
ASTM 11 STAB	166	193	16	20
ASTM 9 DA	160	200	16	19
ASTM 9 STAB	156	196	19	23

2155F SOLUTION TREATMENT



2075F SOLUTION TREATMENT

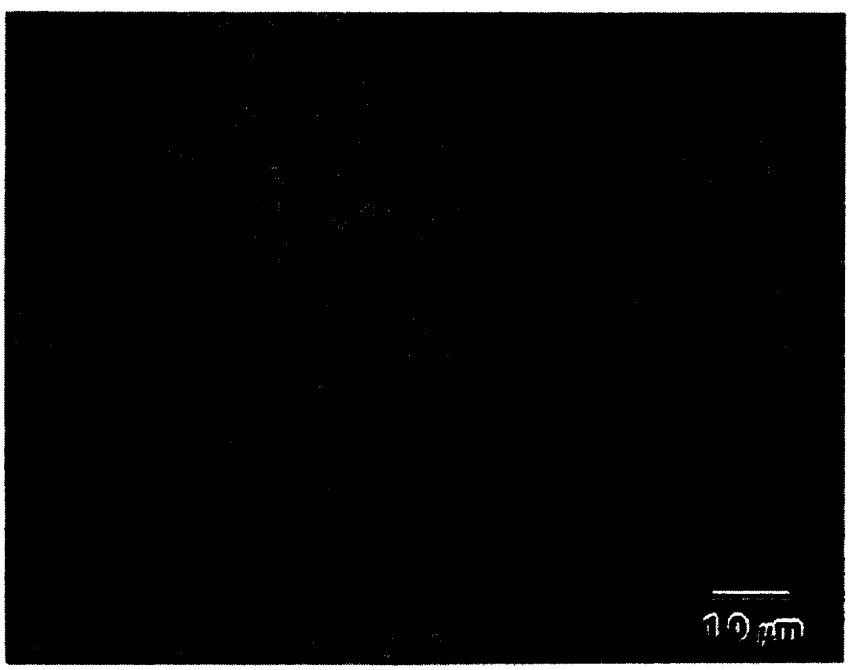


FIG. 1. MICROSTRUCTURE OF ALLOY 10.

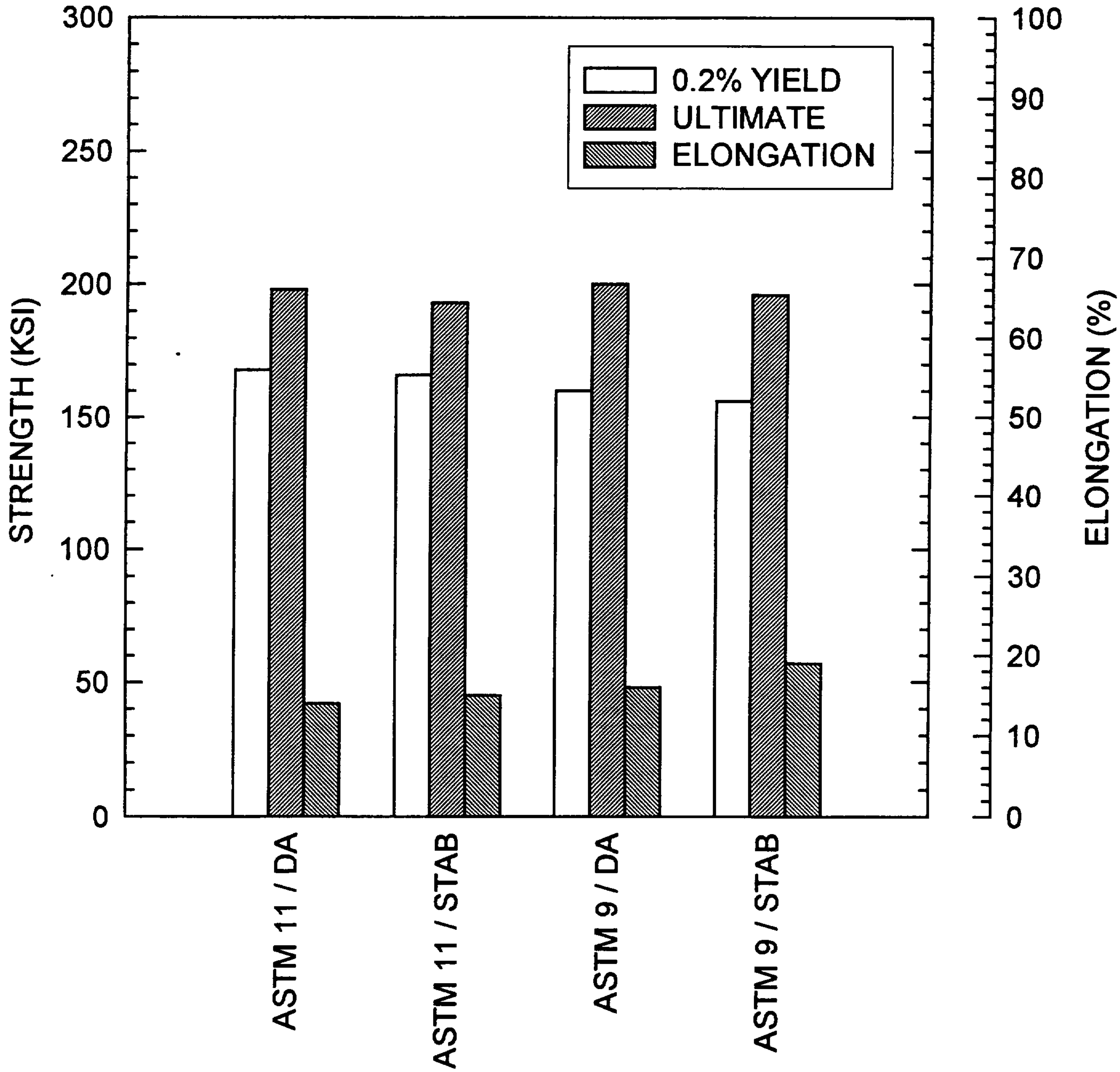


FIG. 2. 1300F TENSILE PROPERTIES.

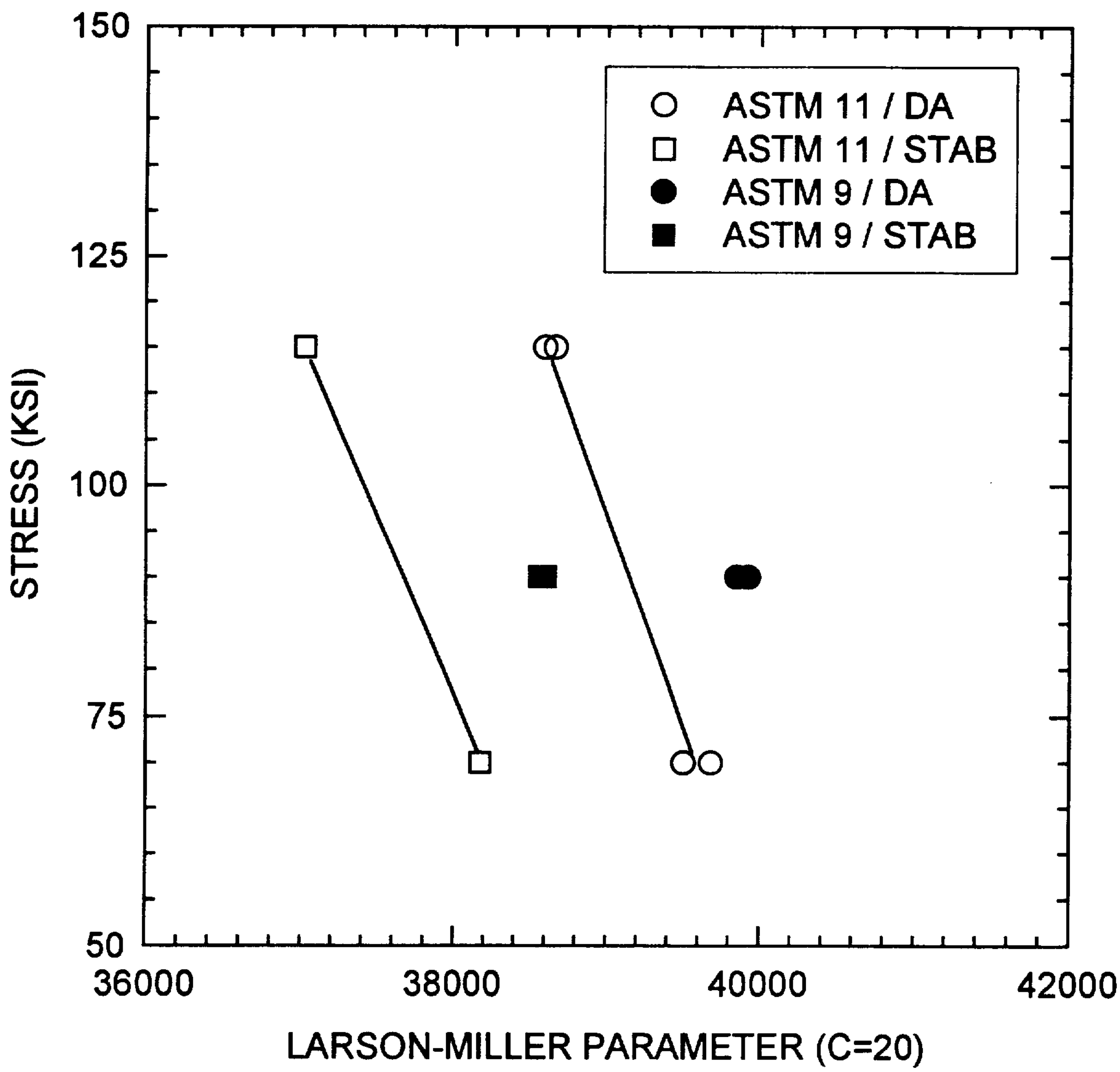


FIG. 3. LARSON-MILLER PLOT FOR ALLOY 10.

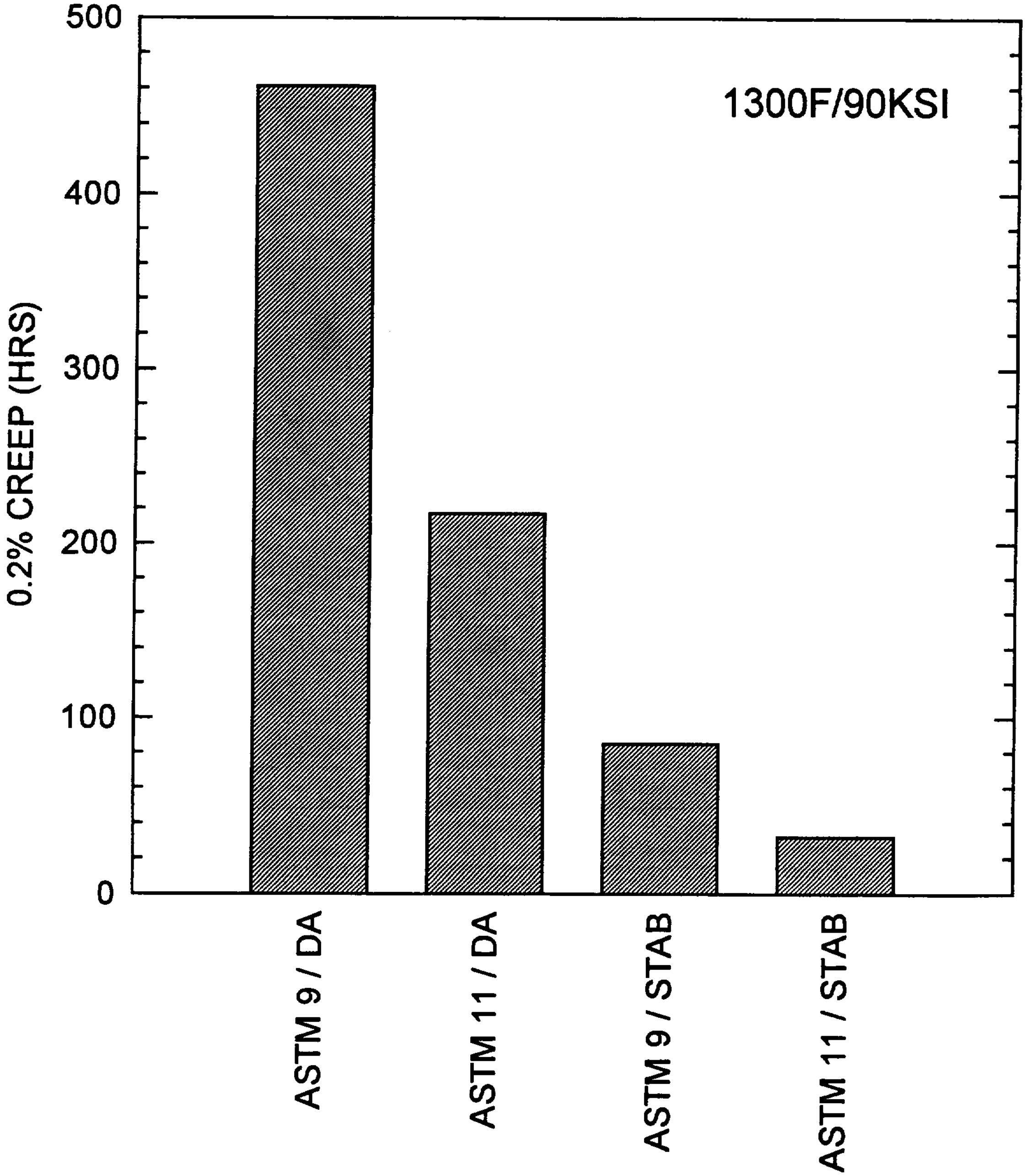


FIG. 4. TIME TO 0.2% CREEP.

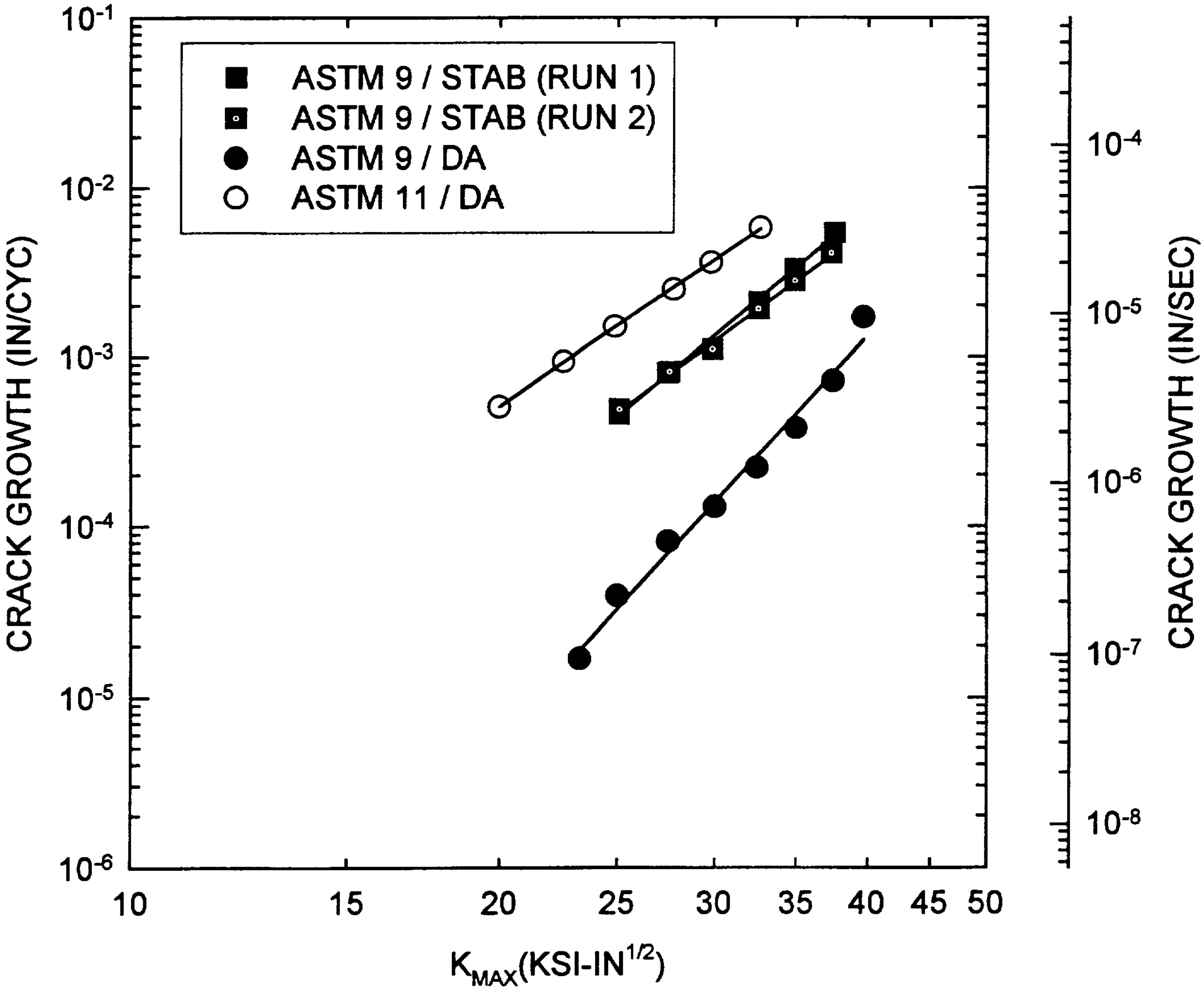


FIG. 5. 1300F/180SEC CRACK GROWTH RATES.

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13. ABSTRACT ***(Maximum 200 words)***

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300F to 1400F temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, Allied Signal's Alloy 10, is a promising candidate for gas turbine engines to be used on smaller, regional aircraft. For this application, compressor/turbine disks must withstand temperatures of 1300F for several hundred hours over the life of the engine. In this paper, three key properties of Alloy 10, tensile, 0.2% creep, and fatigue crack growth, will be assessed at 1300F.

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ASTM 9 GRAIN SIZE (2155F SOLUTION TREATMENT)

ASTM 11 GRAIN SIZE (2075F SOLUTION TREATMENT)

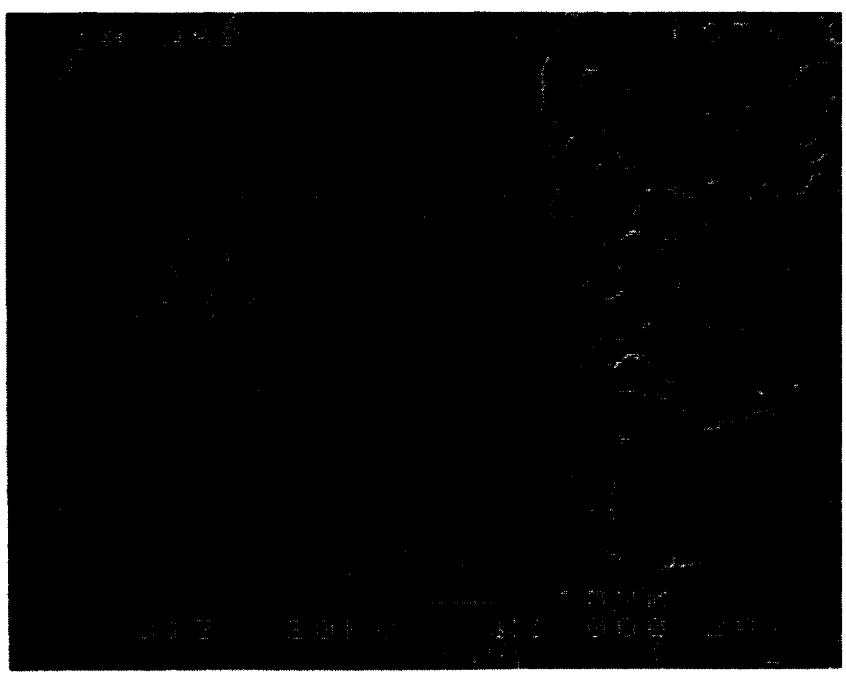

FIG. 6. FRACTURE SURFACES OF CRACK GROWTH SPECIMENS.