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Assessment of NASA Dual Microstructure Heat Treatment Method for Multiple Forging Batch Heat Treatment

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February 2004

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Background:
NASA Glenn Research Center has developed a new method to produce dual microstructure disks, utilizing specially designed heat treat fixtures that enables conventional batch type heat treat processing with existing furnace facilities. This process is called dual microstructure heat treatment (DMHT). NASA, working closely with Ladish, has successfully demonstrated DMHT processing on small generic disks produced from alloy ME209 [Ref.1, 2, 3].

To date, the DMHT development and characterization work has been limited to single piece processing of a small generic disk shape. The intent of this experiment is to demonstrate the DMHT technology on multiple piece furnace batches on an actual production shape, the Rolls-Royce AE2100 stage 3 disk shape.

Summary:
NASA dual microstructure heat treatment technology previously demonstrated on single forging heat treat batches of a generic disk shape was successfully demonstrated on a multiple disk batch of a production shape component.

A group of four Rolls-Royce Corp. 3rd Stage AE2100 forgings produced from alloy ME209 were successfully dual microstructure heat treated as a single heat treat batch. The forgings responded uniformly as evidenced by part-to-part consistent thermocouple recordings and resultant macrostructures, and from ultrasonic examination.

Multiple disk DMHT processing offers a low cost alternative to other published dual microstructure processing techniques.

Material Investigated:
Customer: NASA.
Customer Purchase Order Number: C80000A and C74405A
Alloy: ME209 (P/M)
Input Billet Mults: Customer Supplied, 9 ¼” diameter
Forging: Ladish EP017, Rolls-Royce Corp. 3rd Stage AE2100

Process Description and Results:
Forge Description
Billet mults were single step isothermally forged into EP017 finish dies. Forge parameters were selected to facilitate metal flow and post forge supersolvus solution heat treat response. Figure 1 shows a representative forging. This forging is approximately 14 inches in diameter. Four forgings were produced for this investigation.

Figure 1

Heat Treat Description

Prior to dual microstructure heat treatment, the four forgings were each fitted with top and bottom steel heat sinks. These heat sinks serve two purposes. As the description suggests, the heat sinks conduct heat away from the disk bore region. Additionally, the heat sink provides a rigid, low-cost body to embed a thermocouple to monitor the thermal approach at the disk's bore surface. The heat sinks are protected from direct radiation from the furnace source by encapsulating them in a designed package of refractory insulation and steel pipe. Both sinks were designed with center locators to enable a uniform concentric coarsening response. Figure 2 shows the arrangement of components as a schematic for this experiment. Note that the experimental disks were also drilled and tapped at a rim location to enable embedded thermocouples to monitor disk rim temperatures. Figures 3 and 4 show photographs of the individual components prior to assembly.

The four disk assemblies (serials 2-5) were placed on a furnace tray as shown on Figure 5. These disks were arranged on the tray to represent a typical production setup for the solution cycle of disks.

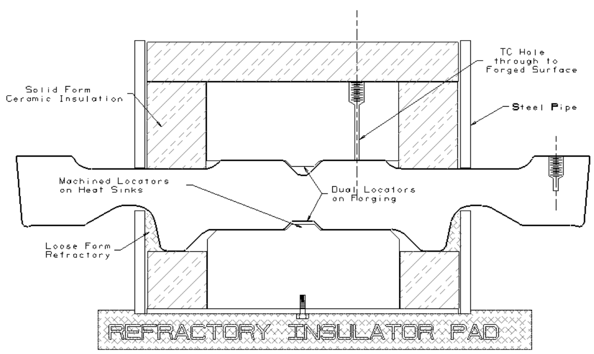


Figure 2.—DMHT Setup

Figure 3.—Disk top-side insulation components

Figure 4.—Disk bottom-side insulation components.

Figure 5.—Serials 2-5 DMHT setups on furnace tray.

The tray of assembled parts was given an initial mock heat-up uniformity assessment trial. The intent of this trial was to evaluate part-to-part heatup uniformity in the subsolvus regime prior to committing the parts metallurgically, i.e., to supersolvus heating and attendant grain coarsening.

The disks were placed directly into a furnace operating at 2075 °F (solvus is approximately 2115 °F for ME209). Thermocouples were placed at the rim and bore of each disk and monitored (as shown by Figures 2 and 5). The rim location was directly exposed to furnace source radiation; whereas, the bore heat sink location was well insulated. After approximately 2 ½ hours of exposure the tray was removed from the furnace and air cooled.

This trial showed excellent part-to-part heating consistency, as shown by Figure 6. In addition, the rim quickly reaches temperatures near the set point, while the bore temperature, as measured by the heat sink thermocouple lags considerably. This temperature lag between the bore relative to the rim enables rim-to-bore dual microstructure processing.

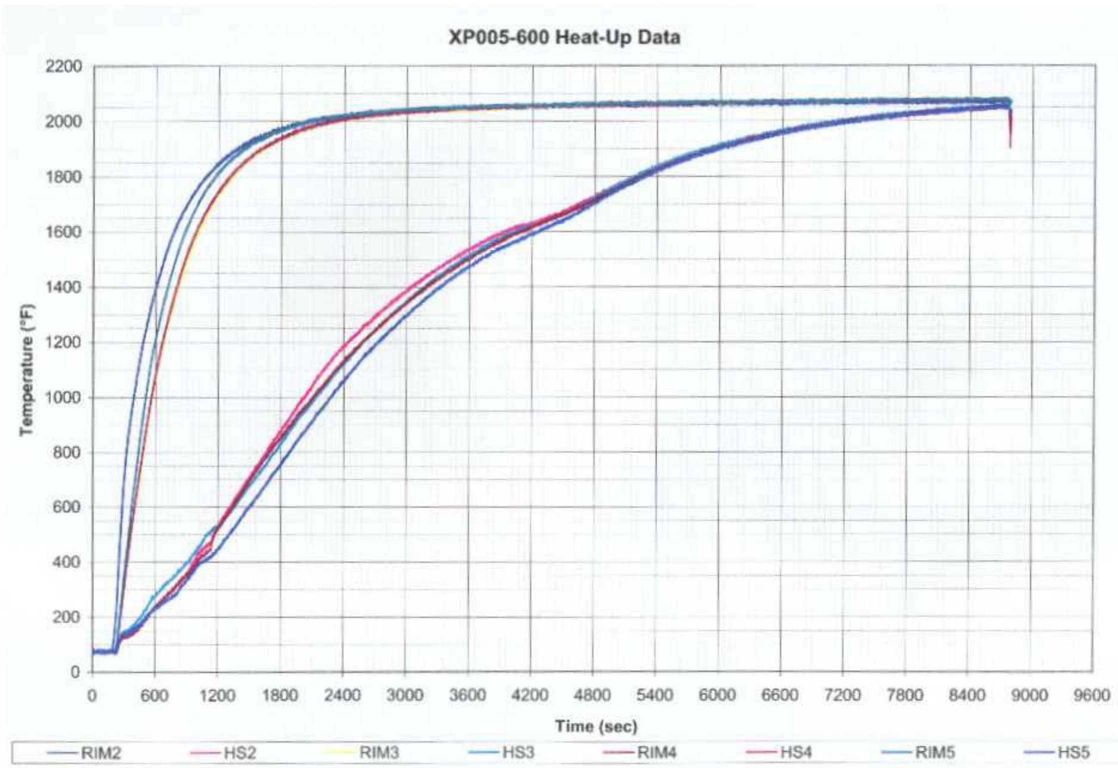


Figure 6.—Experimental DMHT heating profiles. Four disks, rim and bore locations.

With the verification of excellent part-to-part temperature consistency, the tray of assembled parts were then DMHT processed, by placing into a furnace operating at the supersolvus temperature of 2175 °F. Similar to Figure 6, the disk rim temperatures quickly reached temperatures near the furnace set point, temperatures in excess of the solvus, causing grain coarsening. The parts were removed from the furnace when bore thermocouples approached 2100 °F (subsolvus) and air cooled.

After the DMHT cycle that set a dual microstructure the disk assemblies were disassembled, i.e., the insulating components were removed from each disk. The bare disks were then heat treat solutioned at 2075 °F, 3 hours total furnace time (approximately 2 hours at temperature), and oil quenched (45 second transfer).

Material for mechanical property testing was further aged at 1500 °F, 8 hours at temperature and air cooled.

Cross Sectional Macrostructural Review:

A full radial cross sectional slice was removed from serials 2-4 and etched to review macrostructure. The depths of coarsening as revealed by macrostructure was consistent at 0° and 180° and from piece to piece, see Figures 7-9.

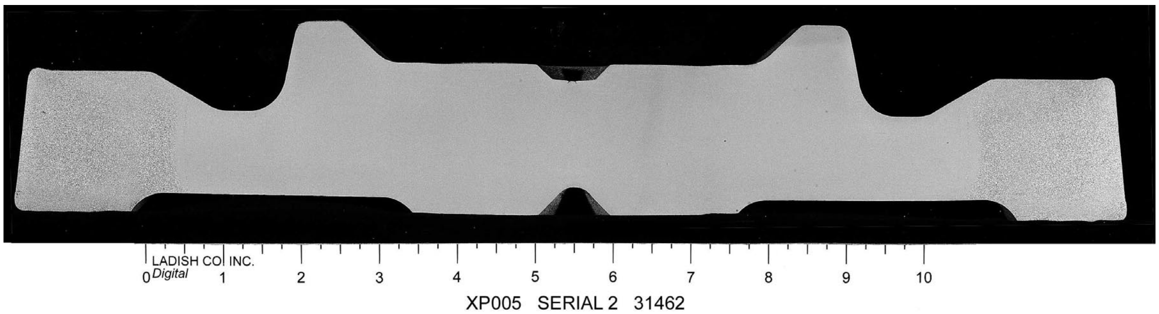


Figure 7.—Full radial macrostructure, serial 2

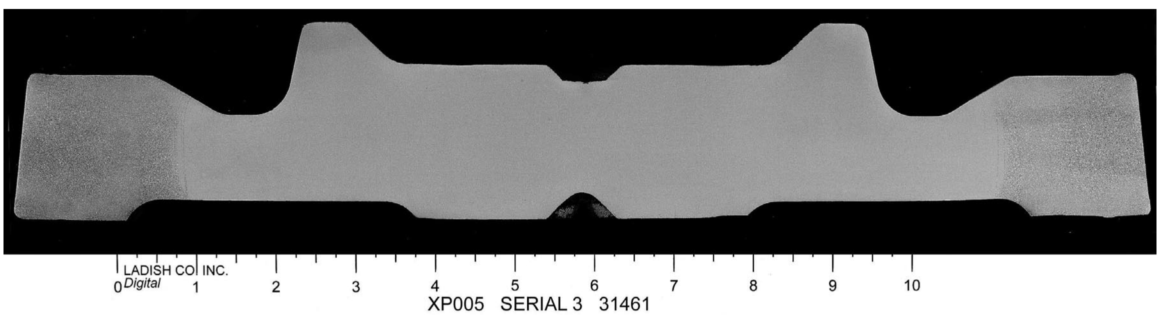


Figure 8.—Full radial macrostructure, serial 3

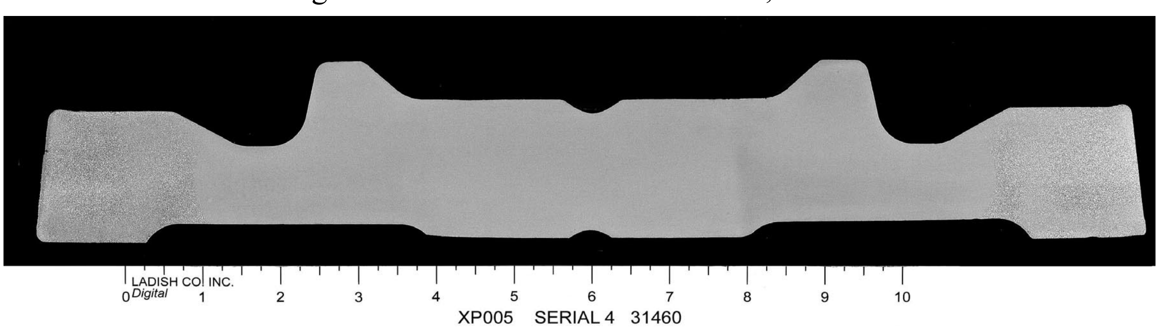


Figure 9.—Full radial macrostructure, serial 4

Microstructural Characterization

NASA performed detailed grain size measurements at rim, web and bore at locations as shown on Figure 10. Results are presented in Table 1 and Figure 11.

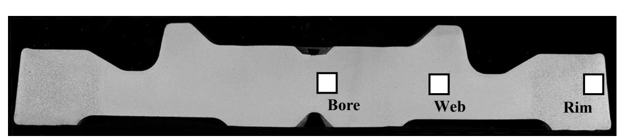
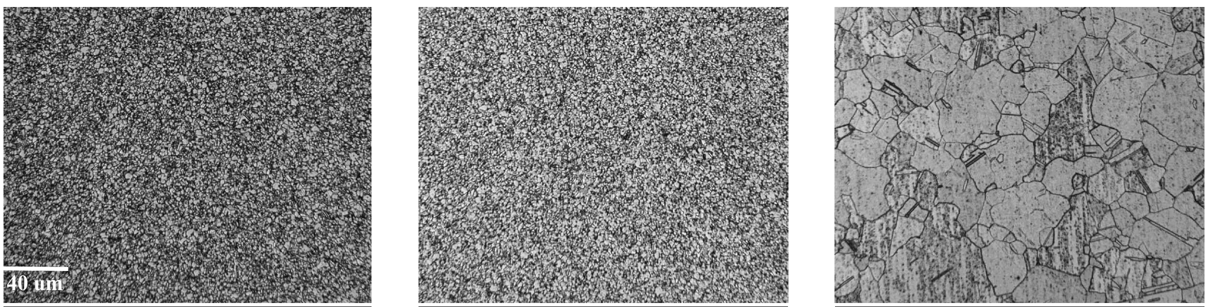


Figure 10

Table 1.—Grain Size (ASTM)

Avg. - 11.70 Std Dev - 0.30	Avg. - 11.07 Std Dev - 0.33	Avg. – 4.92 Std Dev - 0.39
Bore	Web	Rim



Bore Web Rim

Figure 11.—Representative microstructure

Mechanical Properties

A fully heat treated disk (2075 °F Mock DMHT + 2175 °F DMHT + 2075 °F/3 hrs TFT/oil quench + 1500 °F/8 hrs at temp/AC) was sectioned and tested. Testing was performed by Metcut (NASA funded). Testing included 1200 °F tensiles, 1200 °F/150ksi stress rupture, and low cycle fatigue (1200 °F, R = 0.0, .33Hz/10Hz, triangular waveform). Specimens for each type of test were taken from coarse grained rim, fine grain bore and coarse-fine grain transition region. Specific test plan and results are attached as Appendix A. The results of the testing were in line with expectations for fine grain and coarse grain microstructures. Further, there was no indication of any unusual property deficit in the grain transition region

Ultrasonic and Etch Inspections:

After DMHT heat treatment, serial 5 was machined into a rectilinear shape suitable for NDE examinations (NASA P.O. C74405A). The intent for the ultrasonic examination was to assess the ability to precisely locate the grain transition zone. Both longitudinal and shear wave techniques were used. The examination was limited to interrogation from a single surface, as shown by Figure 12.

Results from both longitudinal and shear wave sonic examinations showed that the transition zone could be easily detected by ultrasonic examination. Additionally, results showed that the depth of coarsening was highly consistent 360° around the disk. Results from one specific scan are depicted in Figure 13. This scan represents a radial-circumferential view of C-Scan output from a longitudinal wave scan [10Mhz, calibrated on a #1 FBH (80% screen height) with 15 db’s added].

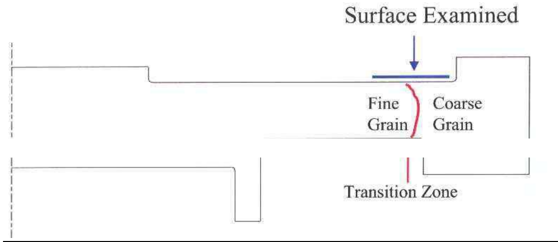


Figure 12.—UT scanned surface

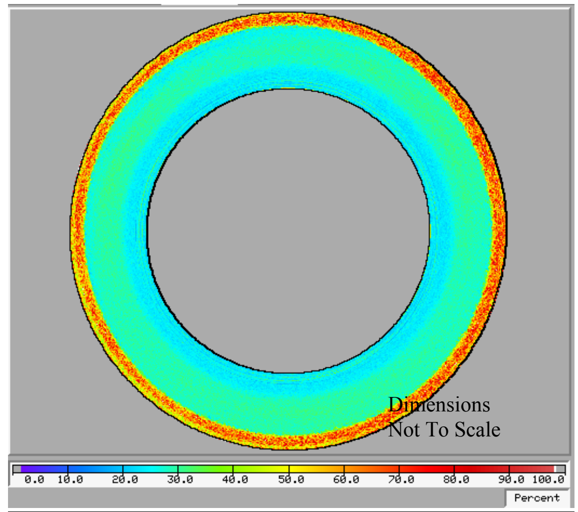
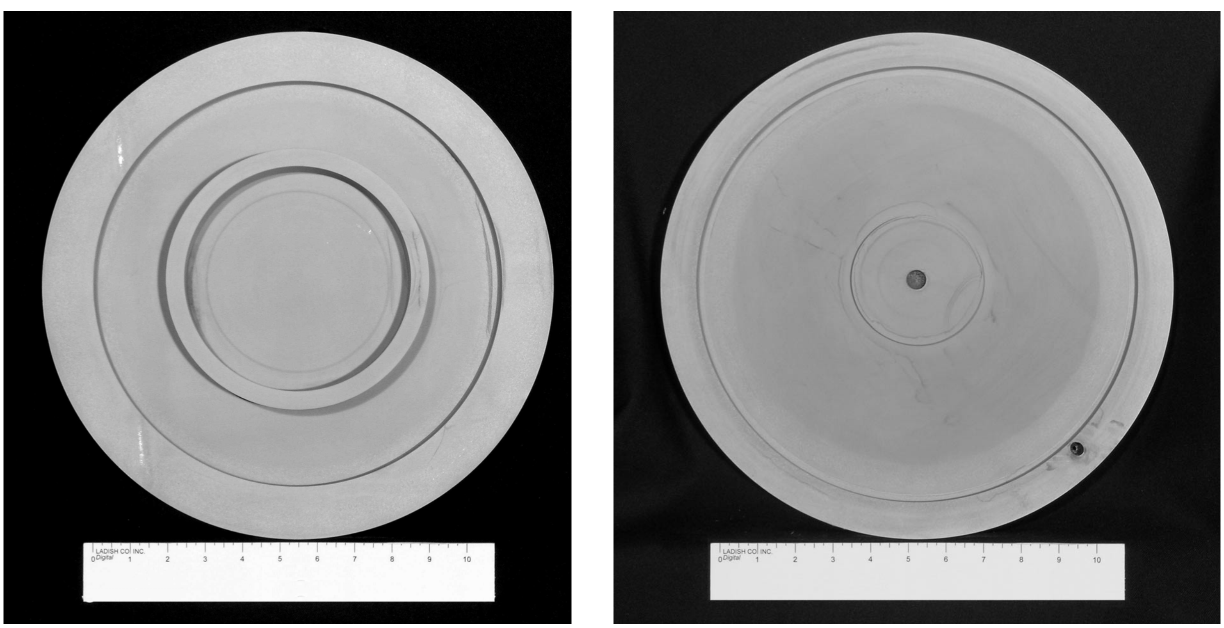


Figure 13.—Longitudinal Wave,
C-Scan Output

After UT examination, this serial was etched to review macrostructure (Figure 14). The etched forging confirmed the UT results, i.e., the depth of coarsening as revealed by macrostructure was consistent 360° around the disk.



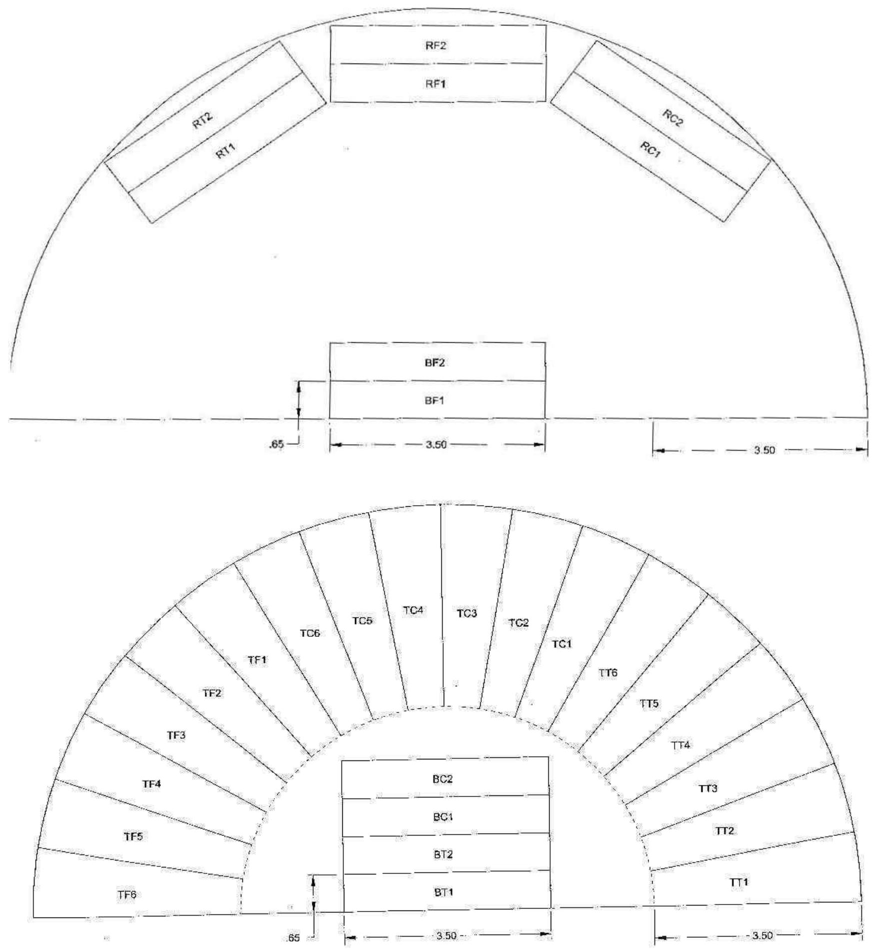
Bottom-Side View Top-Side View

Figure 14.—Full disk macrostructure, serial 5

References:

1. J. Gayda, T. Gabb, P. Kantzos and D. Furrer, "Heat Treatment Technology for Production of Dual Microstructure Superalloy Disks", NASA/TM—2002-211558.
2. D. Furrer and J Gayda, "Dual-Microstructure Heat Treatment", Advanced Materials and Processes, July 2003, pp. 36-39.
3. J. Gayda and P. Kantzos, "High Temperature Burst Testing of a Superalloy Disk with a Dual Grain Microstructure", NASA/TM—2004-212884.

APPENDIX A



Test Specimen Removal Plan

1200F Tensile Test Results

Specimen Identity	U.T.S. (ksi)	0.2% Y.S.	% Elong.	% R.A.
BT1	217	171	11	12
BT2	215	170	11	14
RT1	214	160	16	16
RT2	210	155	12	14
TT1	214	159	12	12
TT2	214	160	14	17
TT3	214	160	13	16
TT4	214	160	13	16
TT5	215	161	13	16
TT6	215	160	12	16

Stress Rupture Test Results

MRAI Number	Specimen Ident.	Temp. (°F)	Stress (ksi)	Results	Duration (Hours)	Elongation (%)	Reduction of Area (%)
SR78421	BC1	1200	150.0	Frac/Gage	130.8	3.3	5.2
SR78445	BC2	1200	150.0	Frac/Gage	186.8	4.5	3.1
SR78422	RC1	1200	150.0	Frac/Gage	218.9	3.9	7.4
SR78460	RC2	1200	150.0	Frac/Gage	273.0	2.8	6.2
SR78423	TC1	1200	150.0	Frac/Gage	207.4	3.1	6.9
SR78456	TC2	1200	150.0	Frac/Gage	197.9	3.5	4.5
SR78491	TC3	1200	150.0	Frac/Gage	265.0	3.3	5.0
SR78492	TC4	1200	150.0	Frac/Gage	213.5	3.2	5.3
SR78461	TC5	1200	150.0	Frac/Gage	89.6	3.2	6.9
SR78424	TC6	1200	150.0	Frac/Gage	276.8	3.7	7.9

Cyclic Fatigue Data

Dynamic Ratio: R = 0
Frequency: 0.33 Hz / 10Hz
Test Temperature: 1200F
Waveform: Triangular

Specimen Identity	Stress Max. (ksi)	Stress Alt. (ksi)	Cycles	Results	Test Hours
BF1	160.0	80.0	1,742,498	Removed	48.4
BF2	160.0	80.0	700,880	F,AR,SS	19.5
RF1	160.0	80.0	59,097	F,AR,S	1.6
RF2	160.0	80.0	9,369	F,G,S	0.3
TF1	160.0	80.0	61,813	F,AR,S	1.7
TF2	160.0	80.0	50,101	F,G,S	1.4
TF3	160.0	80.0	64,640	F,G,S	1.8
TF4	160.0	80.0	90,014	F,AR,S	2.5
TF5	160.0	80.0	48,622	F,AR,S	1.4
TF6	160.0	80.0	61,509	F,G,S	1.7

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

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