# DUAL STRUCTURE TURBINE DISKS

# VIA PARTIAL IMMERSION HEAT TREATMENT+

J. M. HYZAK*, C. A. MACINTYRE** AND D. V. SUNDBERG**

*WYMAN-GORDON COMPANY
NORTH GRAFTON, MASSACHUSETTS 01536-8001

**GARRETT TURBINE ENGINE COMPANY
PHOENIX, ARIZONA 85010-5217

## ABSTRACT

A heat treat method has been developed to produce a dual structure turbine disk forging. The method is termed partial immersion treatment. It includes the partial immersion of a forging to a controlled depth in a high temperature (supersolvus) salt bath and total rotation of the forging so as to immerse the full rim section of the disk. The objective is to coarsen the grain structure in the rim of the disk while maintaining the as-forged, fine grain size in the bore. This is to improve the high temperature creep and stress rupture properties in the rim section without degrading strength and LCF properties of the bore.

Initial experiments on cast-wrought Astroloy forgings and powder-metallurgy AF2-1DA-6 forgings are described. The results show that uniform grain coarsening to a controlled depth can be achieved. Grain size in the Astroloy forgings coarsened from ASTM 8-10 to ASTM 1-3. The coarsened grain size in the AF2-1DA-6 forgings was ASTM 4 compared to the as-forged size of ASTM 10-12. Microstructural characterization of the coarse, fine and transition zones is included. Limited mechanical property data are presented. The results show a significant increase in creep and stress rupture properties in the coarse grain rim compared to the fine grain bore. There was also only a 10% decrease in tensile strength as a result of the coarsening heat treatment.

+ Patent applied for.

Superalloys 1988
Edited by S. Reichman, D.N. Duhl,
G. Maurer, S. Antolovich and C. Lund
The Metallurgical Society, 1988

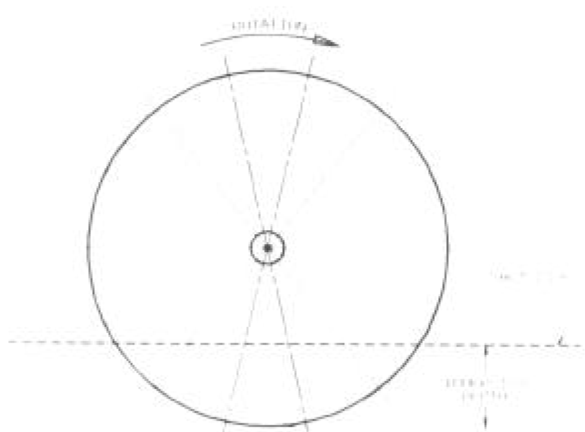
# INTRODUCTION

The drive to improve gas turbine operating efficiencies generally results in increased turbine inlet temperatures with a corresponding increase in the thermal and mechanical stresses experienced by the turbine components. Within this aggressive environment, the design lives of the turbine disks are predicated on a fine balance between high temperature strength and creep properties. The rim section of a turbine disk experiences the highest temperature and can be life limited by creep and stress rupture properties. The bore section, however, operates at lower temperature and higher stresses, and is designed to meet tensile strength and low cycle fatigue requirements.

Cast-wrought (C/W) and powder metallurgy (P/M) nickel base superalloys are generally selected for high temperature/high speed turbine disk applications. These alloys, while possessing excellent strength properties up to 650°C, are somewhat limited in creep resistance. This, of course, is attributable to the thermo-mechanical processing of the part. In general, billet conversion and turbine forging operations have been designed to produce a finished part with a fine grain size. This is for maximum strength and low cycle fatigue properties. As a result, creep properties suffer.

In some turbine disk designs it would be beneficial to produce a dual structure forging with a fine grain size in the bore region to optimize strength and LCF properties and a coarser grain size toward the rim for improved creep strength. Various processing routes have been proposed for this. These have included redesigning of the forging process to minimize the deformation in the rim during the finish forge operation, and selective heat treatments to coarsen the rim. This paper describes a post forge heat treating technique, termed partial immersion treatment (P.I.T.), developed to produce a dual structure turbine disk.

The concept is shown schematically in Figure 1a. The forging is supported on a shaft through the center. The rim section of the forging is then immersed to a controlled depth in a high temperature (supersolvus) salt bath. The disk is rotated such that there is complete immersion (360° rotation) of the rim section. Grain coarsening occurs in the rim as a



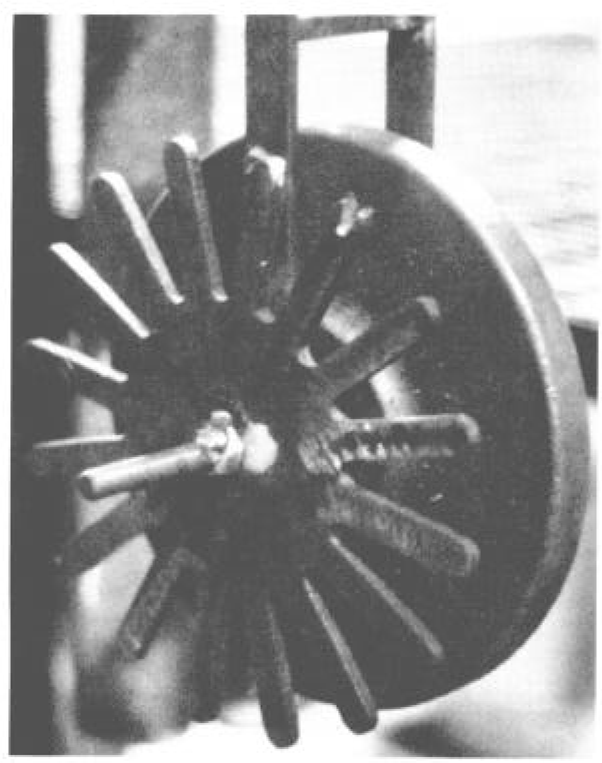


Figure 1. a) Schematic of Partial Immersion Treatment process; b) Spoke fixture for incremental rotation of forging.

result of the supersolvus heat treatment while the fine grain, as forged structure in the bore is maintained.

The partial immersion treatment is envisioned as a production process where several forgings can be supported on one shaft and heat treated at the same time. The salt bath temperature would be well controlled, ±2°C, as would the depth of immersion. The rotational speed of the forging in the salt bath would also be closely monitored so as to produce uniform, reproducible grain coarsening. This paper describes the initial experiments in the development of the partial immersion treatment to produce a dual microstructure disk. Fine grain forgings made from a P/M alloy (AF2-1DA-6) and a C/W alloy (Astroloy) were given the partial immersion treatment. The results include microstructural characterization of the coarsened zone, and mechanical property comparisons between coarse and fine grain microstructures.

## EXPERIMENTAL DETAILS

### PARTIAL IMMERSION TREATING

Heat treatments were performed in a commercial high temperature salt bath measuring 71cm X 94cm X 152cm deep. The temperature control and uniformity were within ±2°C. Disks were generally suspended on a steel shaft and lowered into the bath via an overhead crane; depth of immersion was controlled visually. Because this was the initial feasibility study for using P.I.T., the forgings were rotated manually rather than by a continuous drive motor (now in operation).

The forgings were heat treated in one or two revolutions over a 1-3 hour period. As a result, the forgings were incrementally advanced. A fixture with radial spokes was designed to aid in this manual advance (Figure 1b). Depending on the part diameter, forgings were rotated from 10° to 15° per advance. Forgings were held above the salt bath (≈550°C) before and after the P.I.T. immersion to minimize the thermal stresses.

## MICROSTRUCTURAL CHARACTERIZATION

### P.I.T. Astroloy Finish Forging

The initial experimental application of the partial immersion treatment was to coarsen the rim of a C/W Astroloy forging. The partial immersion treatment was performed after the finish forge operation. The geometry of the forging is shown in Figure 2a. This forging had an as-forged grain size of ASTM 8-10 with less than 10% unrecrystallized grains as large as (ALA) ASTM 5. This grain size results in good strength and LCF life but poor creep properties. The goal was to coarsen the grain size in the rim

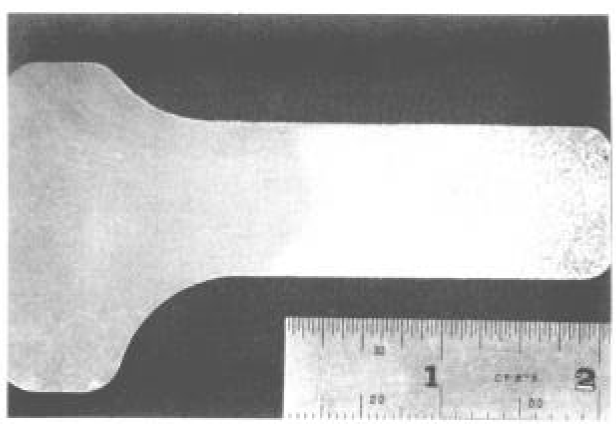


Figure 2. a) Geometry of Astroloy finish forging; b) Radial slice of forging after P.I.T.

to a depth of 50mm, as measured from the outside diameter.

The first forging was partial immersion treated in a 1163°C salt bath, 20°C above the nominal $\gamma'$ solvus of the Astroloy stock (as determined by differential thermal analysis). The disk was immersed 50mm, as measured from the rim of the disk. The part was rotated 360° in 16 manual advances over 90 minutes. After removal from the salt bath, the disk was air cooled.

After the P.I.T., the disk was given a standard partial solution and age heat treatment for Astroloy: 1115°C/4 Hrs./Quench; 871°C/8 Hrs./AC; 982°C/4 Hrs./AC; 649°C/24 Hrs./AC; 760°C/8 Hrs./AC. The disk was sectioned radially. The etched macro slice is shown in Figure 2b. The depth of coarsening was 50mm as measured at mid-thickness. There was a 3mm difference in depth of coarsening between the mid-thickness and surface locations.

Figure 3 shows representative photomicrographs of the rim (coarsened), bore (uncoarsened) and transition regions. The coarsened grain size was ASTM 1-3. The transition from fine to coarse grain size occurred very abruptly with few grains of an intermediate size. Due to the chemical segregation (banding) in this cast-wrought alloy, the radial location of the transition from coarse to fine varied through the thickness depending on the local chemistry ($\gamma'$ solvus). This nonuniformity in coarsening in the transition zone is shown in Figure 3c.

A second Astroloy disk was partial immersion treated. Again the immersion depth was 50mm in a 1163°C salt bath. The disk was rotated in increments of 10° with 2.5 minutes between advances. The disk was rotated a total of 450° in 112 minutes.

The forging was subsequently given a partial solution and age heat treatment, as before, and sectioned through mid-thickness to reveal the coarsening. The macro section, shown in Figure 4, had several interesting characteristics. First, the depth of coarsening (Loc. A) was uniform around the disk. The grains coarsened to ASTM 1-3 up to the depth of immersion (50 mm). There was also no significant difference in coarsening in the overlap region, that section of the disk immersed twice.

Secondly, there was a radial etch pattern (Loc. B) in the coarsened zone over three-fourths of the disk; in the remaining quarter, the etch response was uniform. The radial spokes were due to variations in gamma prime morphology produced during the P.I.T. from the incremental advance used in rotating the disks. That is, as each pie-shaped section was rotated out of the salt bath there was a gradient in cooling rate in that section and, as a result, a difference in $\gamma'$ density. The quarter without spokes was that section of the forging in the salt bath at the conclusion of the P.I.T. that was uniformly cooled when the disk was lifted out of the salt bath. It is thought that continuous rotation of the disk in the salt bath to replace the manual incremental advance will eliminate this nonuniformity in microstructure. It may also allow for more control of the cooling rate from the supersolvus temperature.

Also apparent in Figure 4 is a circumferential pattern of preferred grain coarsening (Loc. C). These "tree rings" were a result of the inhomogeneity (chemical banding) in the C/W Astroloy billet stock. The degree of chemical homogeneity in an alloy will affect the uniformity of grain coarsening. In this regard, the P/M alloys should coarsen more uniformly than the C/W nickel-base superalloys.

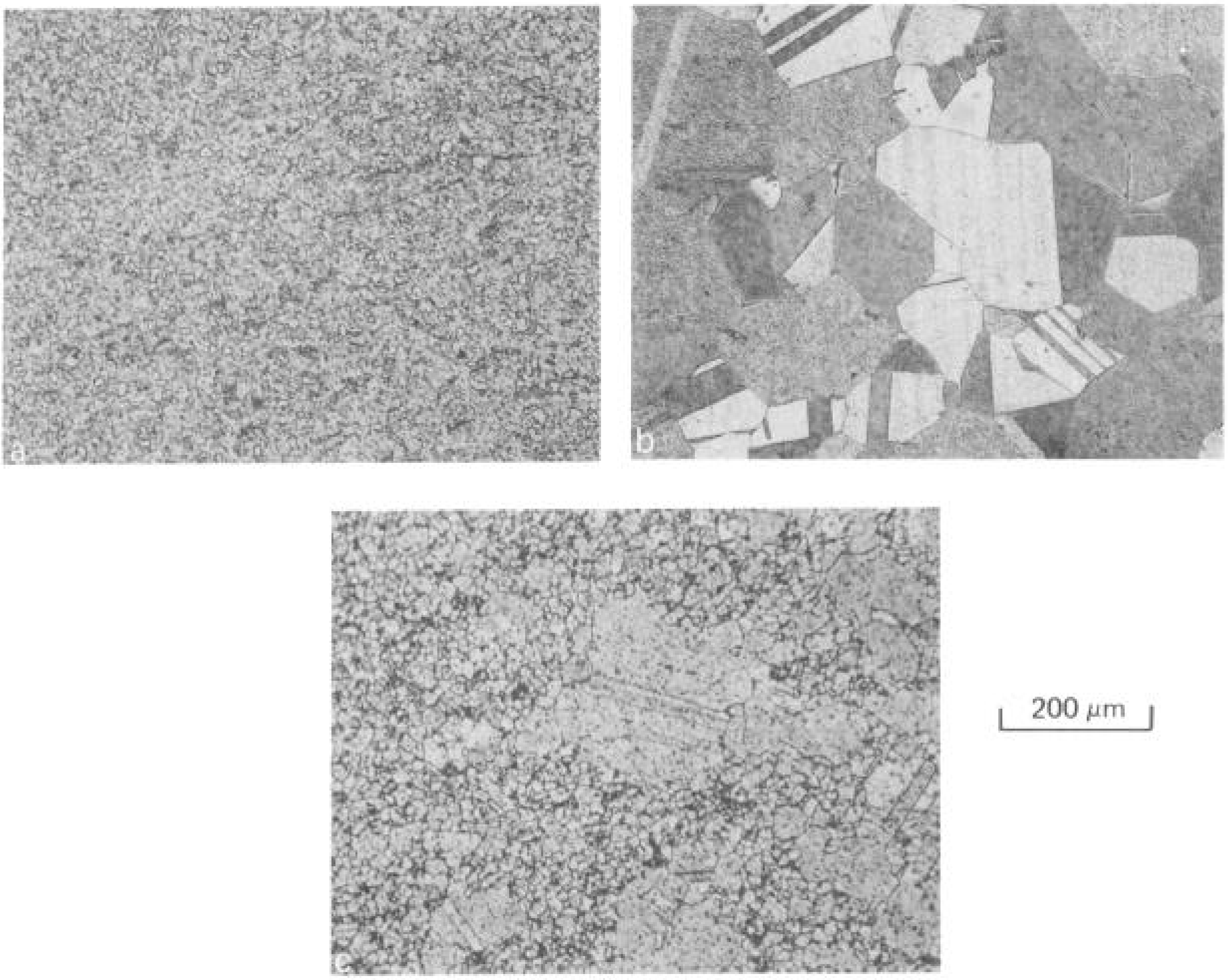



Figure 3. Microstructure of Astroloy forging after P.I.T.; a) fine grain, b) coarse grain, and c) transition regions.

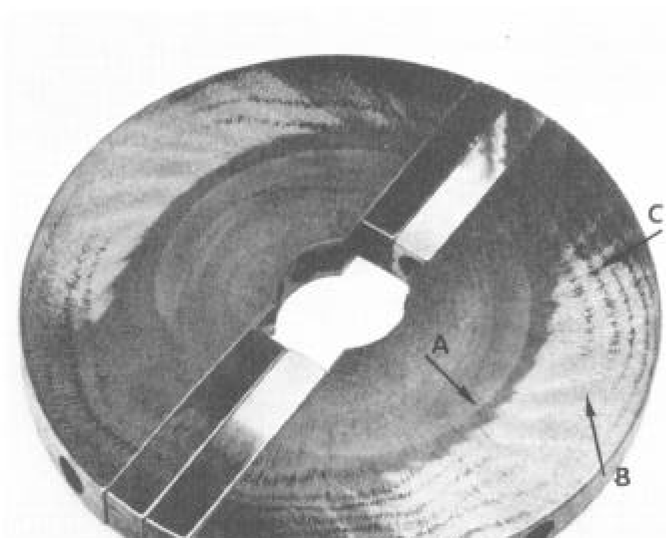



Figure 4. Macro etched Astroloy finish forging after P.I.T., A) depth of coarsening, B) radial etch pattern, and C) circumferential "tree rings"

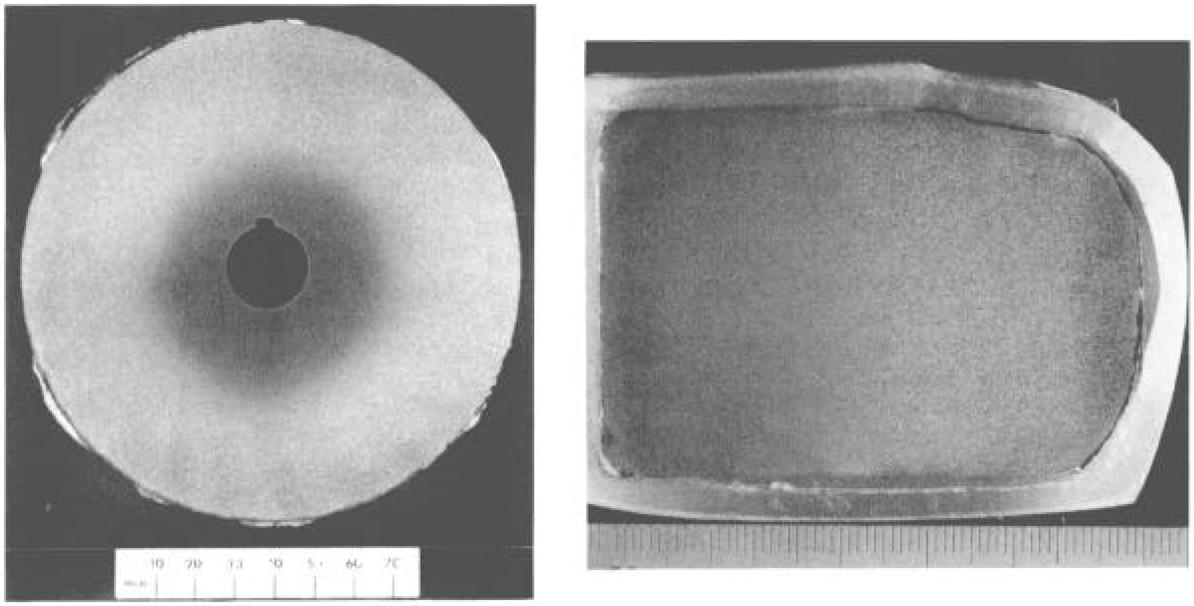


Figure 5. AF2-1DA disk after P.I.T.; a) full view and b) radial section.

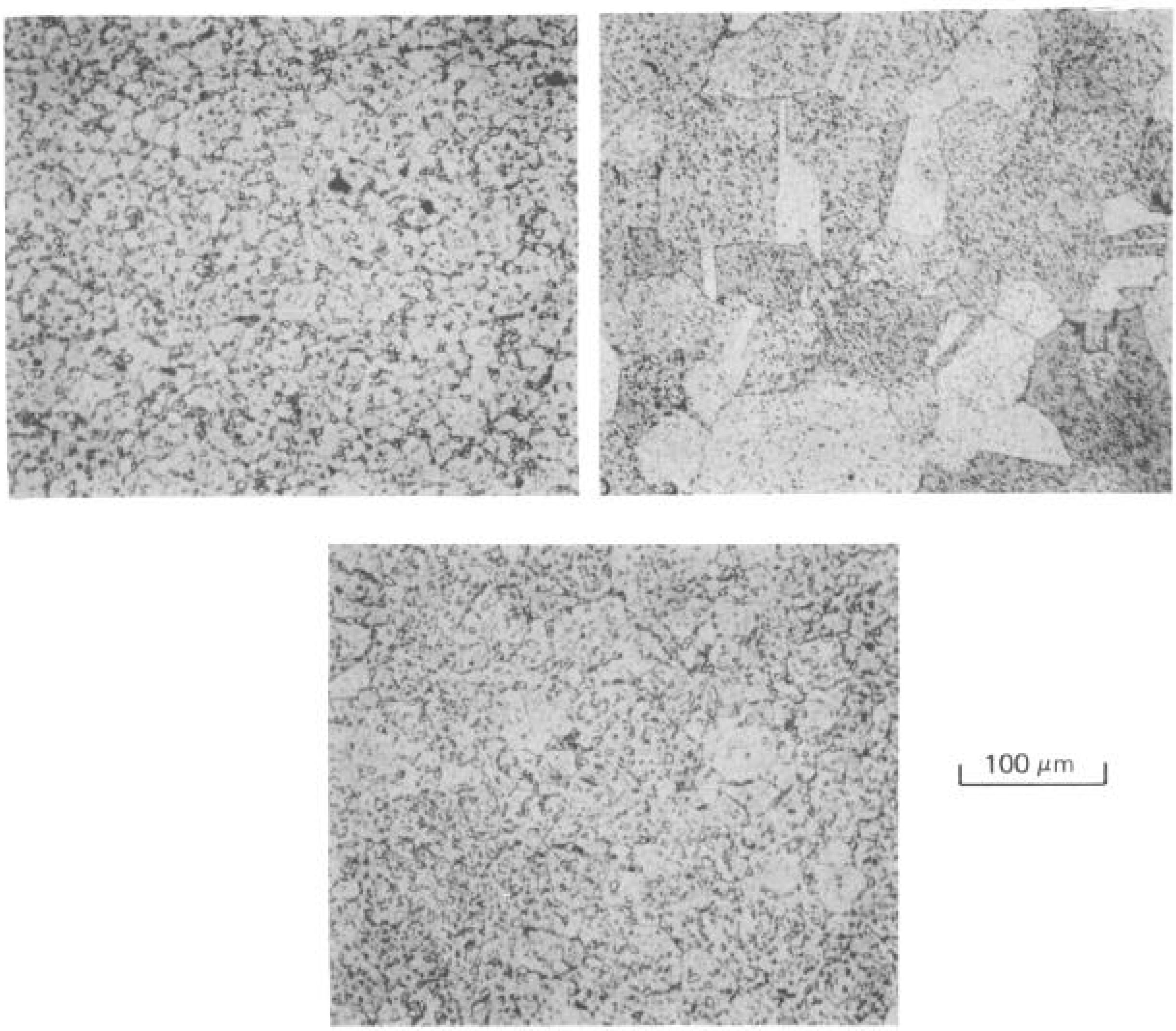



Figure 6. Microstructure of P/M AF2-1DA-6 forging after P.I.T.; a) fine grain, b) coarse grain, and c) transition zone.

P.I.T. AF2-1DA-6 Finish Forging

The partial immersion treatment was also used to develop a dual grain structure in fine grain P/M AF2-1DA-6 forgings. Small diameter (5.5" Ø) turbine disk forgings were hot die forged from 4" Ø CAP plus extruded AF2-1DA-6 billet stock. The as-forged grain size was uniformly ASTM 10-12. The goal was to coarsen the grain size in the outer 33mm of the disk.

Forgings were immersed to a depth of 39mm, as measured from the outer diameter, in a 1232°C salt bath. The γ' solvus is nominally 1220°C for this alloy. The parts were rotated manually, as before, using a 24 spoke fixture (15° per increment). The disks were rotated a total of 540° in 216 minutes. A centerhole with a keyway to lock the forgings to the drive axle was introduced in these experiments. One AF2-1DA-6 forging is shown in Figure 5a. The orientation of the disk in the photograph (keyway up) is the same as when it was initially immersed in the salt bath. The uniformity of the coarsening was very good. Although not pronounced in this example, the P/M AF2-1DA-6 forgings exhibited similar etching characteristics after P.I.T. to those shown by the C/W Astroloy forgings. There were radial spokes over three-fourths of the disk and a uniform etching region in the last quarter.

A radial slice taken from the AF2-1DA-6 disk is shown in Figure 5b. The uniformity of coarsening through the thickness of the forging was good. The grain size coarsened to ASTM 4 to a depth of 31mm. Beyond the coarse grain zone there was a 9mm wide transition region over which the grain diameter decreased to the initial ASTM 10 size. The transition from fine grain to coarse grain was much more gradual in this P/M forging than in the C/W Astroloy disk due to the greater chemical homogeneity of the P/M billet stock. The forging was given a partial solution and age treatment (1149°C/2 hrs/FAC; 760°C/16 hrs/AC) after the P.I.T. Representative photomicrographs are presented in Figure 6 of the coarse grain, fine grain and transition regions.

P.I.T. Astroloy Blocker Forging

As already described, the initial P.I.T. experiments focused on the rim coarsening of finish (shape) forgings. An additional experiment was performed to determine the feasibility of grain coarsening the rim section of a blocker (preform) forging, and subsequently forging the part to the finish shape. The objective was to impart some work to the coarse grain-fine grain transition region without significantly affecting the coarsened microstructure in the rim. A blocker shape was designed so as to minimize the forging reduction in the rim section during the finish operation. The blocker shape is shown in Figure 7; the finish geometry is the same as shown in Figure 2a.

The blocker forging was given a partial immersion treatment in a 1163°C salt bath to a depth of 56 mm. It was rotated a total of 720° (two rotations) in increments of 10° (rotation). The total time for coarsening was 486 minutes.

Subsequent to the rim coarsening the blocker was hammer forged to its finish geometry. The resultant macrostructure is shown in Figure 8. In terms of final grain size, forging a grain coarsened blocker was successful. The coarse grain size in the rim section was maintained with no recrystallization (necklacing) noted. The coarsened grain size was ASTM 0-2 while the fine grain region was generally ASTM 10. The shape of the boundary between coarse and fine grain regions was also generally vertical, as desired. There was, however, a wide transition zone between

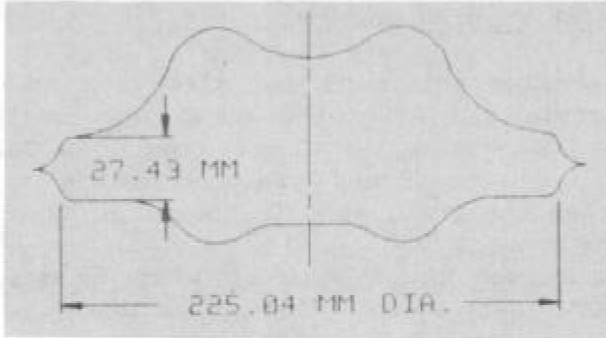



Figure 7. Geometry of Astroloy blocker forging.

the fully coarse and fully fine grain regions. This zone, measuring 125 mm, contained a mixture of fine (ASTM 10) and coarse (ASTM 0-2) grains. This nonuniform coarsening was due mostly to the chemical inhomogeneity (tree rings) in the Astroloy stock.

Although the grain size results were encouraging, there were some drawbacks to this approach. The blocker shape was much more difficult to coarsen to a controlled depth due to its thicker sections. Immersion times 5X greater than used for the finish forge geometry did not produce coarsening to the depth desired in finished shape. In addition, the poor forgeability of the coarse grain microstructure required special handling in the forge shop.

## Mechanical Properties Comparison

The objective of the partial immersion treatment is to improve the high temperature creep and rupture properties in the rim of disk forgings compared to the original fine grain properties. Testing has been performed to determine the level of properties that can be attained. In general, the alloy's standard partial solution and age heat treatment has been used after the P.I.T. It is recognized that modifications to these procedures may further improve the properties. These changes may include better control of the cooling rate from the supersolvus heat treatment and the use of a subsolvus stabilization before the partial solution treatment so as to increase the fineness of the $\gamma'$ precipitation.

### C/W Astroloy Forging

The Astroloy finish forgings were given a partial immersion treatment

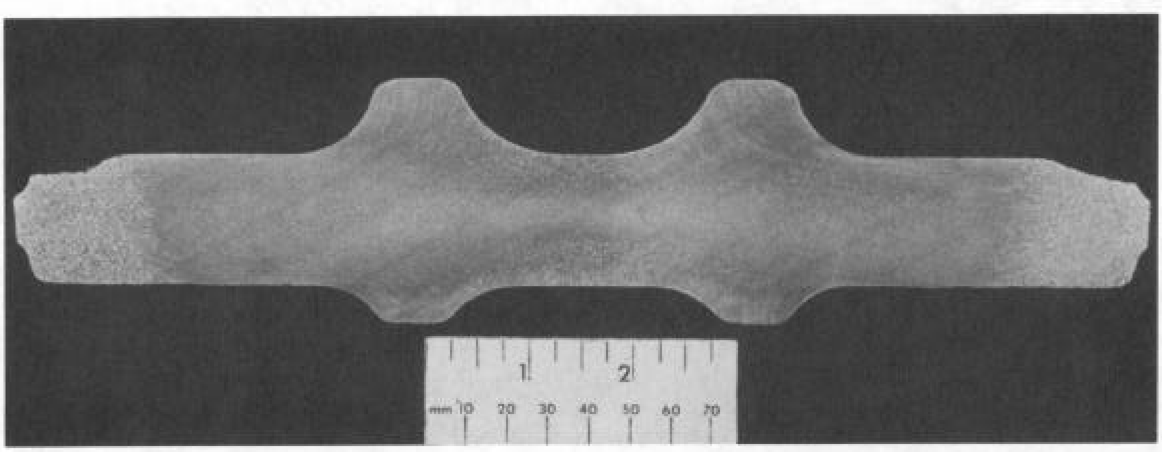


Figure 8. Macro slice of Astroloy blocker forging after P.I.T. and subsequent finish forge operation.

and subsequent full heat treatment as described earlier. The coarsening of the Astroloy forgings increased the 760°C/586 MPa stress rupture life 5X in the rim compared to the properties in the fine grain bore region. "Fir tree" testing was also performed. Dovetail slots were machined from material taken from the rim coarsened and the fine grain regions of the forging. These were tested at elevated temperature via dead weight loading of inserted dummy blades. The time to failure increased 10X for the rim coarsened material compared to the fine grain microstructure. In addition, there was only a 10% decrease in the room temperature and 760°C tensile properties in the coarse grain region.

Twenty high temperature LCF tests were performed in the grain size transition region. Specimens were oriented radially so as to contain coarse grain, fine grain and the transition zone microstructures in the gage section. All specimens failed in the coarse grain region well removed from the transition zone. Fracture initiated in the near-surface region, and the crack advanced initially in a Stage I crystallographic mode. The LCF lives were also typical of coarse grain Astroloy forgings. These results showed that the transition zone was not a site for preferred crack initiation.

### P/M AF2-1DA-6 Forgings

Initial mechanical property comparisons between fine and coarse grain AF2-1DA-6 microstructures were made using pancake forgings given monolithic heat treatments. Properties generated from dual structure disks given the partial immersion treatment were to follow and were not yet available.

The fine grain properties were generated from pancake forgings given a partial solution and age heat treatment which retained the ASTM 10 grain size. Other pancake forgings were first grain coarsened at 1218°C/1 hr/AC and then given the same partial solution and age treatment. The resultant coarsened grain size was ASTM 4 ALA 3.

The smooth bar stress rupture properties showed a clear benefit to the coarse grain structure. At 704°C and 758 MPa, the average time to failure increased over 5X, compared to fine grain results. At 760°C and 586 MPa the advantage of the coarse grain structure increased 10X. Similar results have been reported for improvements in notch stress rupture times with grain coarsened microstructures (Ref. 1).

As expected, there was a decrease in room temperature and elevated temperature (593°C) tensile strengths with the coarsened grain size compared to fine grain properties. However, this reduction in yield and ultimate strengths at both temperatures was less than 10%. There was also a small increase in tensile ductility.

## CONCLUSIONS

The partial immersion heat treatment has been developed as a means of producing a dual structure turbine disk forging with a coarse grain microstructure on the rim while maintaining the fine, as-forged microstructure in the bore. Partial immersion of a forging in a salt bath is a controllable process which can produce coarsening to a uniform depth over the full diameter of the part. In the C/W Astroloy forgings, the transition from coarse to fine grain was abrupt and was dependent on the chemical homogeneity of the billet. The P/M AF2-1DA-6 forgings had a larger transition zone with grain size coarsening from ASTM 10 to ASTM 4 occurring more gradually.

This early development study has relied on slow, manual rotation of the forgings in the salt bath. This has produced some nonuniformity in $\gamma'$ distribution, and less than optimum mechanical properties. Even with this limitation, the increase in high temperature creep and stress rupture properties in the coarse grain region compared to the fine grain properties has been dramatic. The stress rupture lives increased 5X in Astroloy and up to 10X in AF2-1DA-6 with only a 10% decrease in tensile strengths.

Further development of the partial immersion treatment will include automated continuous rotation of the disk forgings. This should produce increased uniformity in the part and more flexibility in processing. Improved properties may be produced by controlling the cooling rate of the coarsened zone through the $\gamma'$ solvus temperature. Hard fixturing of the disks during the P.I.T. will also improve the control over depth of coarsening.


## ACKNOWLEDGEMENTS

The partial immersion heat treatment was conceived of by W.H. Couts, Jr. of the Wyman-Gordon Company. The partial solution heat treatments were performed at Sun Steel Treating, South Lyon, Michigan. Mr. Sergay Poborka of SST has contributed significantly to the development of P.I.T. The partial immersion treating and mechanical property testing of the AF2-1DA-6 forgings were performed as part of Air Force Contract F33615-81-C-5042, "Manufacturing Technology for P/M Superalloy Disks with Low Strategic Material Content". The principal engineer (prime contractor) was Mr. R. M. Gasior, of Cytemp Specialty Steel Division. The principal investigators (subcontractor) were Messrs. R. R. Paulson and C. C. Berger of Avco Lycoming/Textron.


## REFERENCES


1. F. R. Dax, R. M. Gasior and D. J. Willebrand, "Manufacturing Technology for P/M Superalloy Disks with Low Strategic Material Content" (Report 1R-152-2 (XIX), Cytemp Specialty Steel Division, February, 1987).