EVALUATION OF P/M U720 FOR GAS TURBINE ENGINE DISK APPLICATION

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Abstract

Advanced aircraft engine turbine disk material needs the balance of creep/LCF, damage tolerant capabilities and economic feasibility for commercial implementation.
To incorporate an improved disk material for IHI newly designed aircraft engine, U720 in powder metallurgy + HIP+ Extrude + Isothermal Forge form have been processed and evaluated. This study shown that P/M U720 have capabilities of wide range of microstructure control to allow optimum mechanical properties for specific design requirement.

Introduction

Advanced aircraft gas turbine engines are pushing the capability of conventional materials and processes. For the increasing temperature of the high pressure compressor and turbine sections of new turbine engines, alloys such as Inconel718 and Waspaloy are losing their ability to meet the demanding weight and performance requirements. More highly alloyed nickel-base superalloys have been developed and demonstrated in both cast and wrought(C&W) and powder metallurgy(P/M) forms. Subsolvus Rene95 or AF115 are one of the representative P/M alloys for high performance engines HP/LP turbine disk. These disks are previously evaluated[1] and concluded that although these disk materials have high performance capabilities when we compare them with conventional alloy such as Inconel718 and Waspaloy, the potential will not meet the newly designed engines from the point of view of LCF/creep strength balance, damage tolerance capabilities and these cost.

Alloy U720 has been identified as an outstanding intermediate temperature material for potential future applications for both technical and economic reasons. U720 is a unique high temperature alloy in that both C&W and P/M forms are being commercially processed, although the P/M route offers greater microstructural and property flexibility, and control.

Developmental processing and evaluation efforts have been conducted to determine the mechanical property response of P/M U720 processed with various conventional and novel thermo-mechanical processing routes. The primary processing effects on grain size, primary and secondary gamma-prime size and morphology, and subsequent mechanical properties have been evaluated.

U720 has been shown to be capable of developing a wide range of properties through thermo-mechanical processing(TMP), grain size and microstructure control. The alloy content of U720 as compared to numerous advanced, very high temperature capable P/M nickel-base superalloys, also allows economic feasibility for commercial implementation.

Experimental Procedure

P/M U720 billet material was procured for TMP processing and metallurgical evaluations. The material investigated in this study was produced from -270 mesh powder which was subsequently HIP + extrusion consolidated into 165mm diameter billet form. The chemistry of the billet material used is shown in table I. Nominal chemistry for Rene95 and AF115 are also shown in the same table for reference.

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The Minerals, Metals & Materials Society, 1996

Table I Chemical composition of alloy used in this study (wt%)

	Ni	Cr	Co	Mo	W	Ti	Al	Hf	Nb	Zr	C	B
P/M U720	Bal.	15.6	14.6	3.0	1.24	5.05	2.55			0.03	0.008	0.03
AF115 [1]	Bal.	10.5	15.0	2.8	5.9	3.9	3.8	0.80	1.80	0.05	0.05	0.02
Rene95[1]	Bal.	13.0	8.0	3.5	3.6	2.5	3.5		3.5	0.05	0.06	0.01

Table II Solution and aging condition used in this study

Alloy	Process	Solution heat treatment	Aging
P/M U720	Subsolvus A	1377K/4 Hrs./Oil Quench	
	Subsolvus B	1377K/4 Hrs./Fan air cool	923K/ 24 Hrs. / Air cool
	Supersolvus A	1441K/4 Hrs./Fan air cool	+ 1033K/ 16 Hrs. / Fan air cool
	Supersolvus B	1441K/8 Hrs./Fan air cool	
AF115	Subsolvus	1448K/3 Hrs./Fan air cool	1033K/ 16 Hrs. / Air cool
Rene95	Subsolvus	1383K/1 Hrs./Oil Quench	1033K/ 8 Hrs. / Air cool

Forgings were produced by controlled isothermal forging methods. The use of isothermal forging combined with fine grain P/M material allows extremely high material utilization. The superplastic nature of P/M nickel-based superalloy billet materials allow near-net component processing. Isothermal forging techniques additionally offer very tight processing controls, which is required for many alloys, which have very narrow processing windows.
The forged materials were heat treated to produce variations in grain size, and secondary or cooling-rate gamma prime size. The heat treatment used to produce these variations incorporated combinations of subsolvus and supersolvus solution heat treatments, variations in solution hold times, and variations in cooling methods from the solution heat treatment cycle. The heat treatments used in this program are listed in Table II.

Mechanical properties evaluation were conducted and compared them with those of Rene95 and AF115.
Round bar tensile specimens were machined from heat treated forgings and tested at 673 and 923K. Round bar creep specimens were machined from the forgings and constant creep testing were conducted at the applied stress range of 600 ~ 1200MPa in anbient air at temperature up to 1023K. Axial smooth bar LCF specimens with 6.25mm dia. were machined and polished gage section. Axial strain control LCF tests were performed using 30CPM triangle wave and strain A ratio of 1.0 at the temperature of 673 and 923K, strain range of 0.8% ~1.2%.
To evaluate fatigue crack growth behavior, 1/2 CT specimens were machined from the forgings. Tests were performed using the sinusoidal wave at stress-ratio R value of 0.05 and frequency of 120CPM. In addition, to evaluate the time dependent fatigue crack growth behavior, tests at 923K, R value of 0.05, with 90sec.dwell at maximum load and 1.5sec. ramp up/down were performed.
Statistical database were generated for Rene95 and AF115[1] and supplied for comparison of mechanical capabilities with this study.
Metallographic analysis were conducted to allow correlation of the microstructures to the mechanical properties results.

Results/Discussion

Microstructure

Numerous alloy and property characterization efforts have been previously conducted on U720. These efforts range from initial alloy characterization in cast and wrought form[2], to efforts on alloy chemistry and processing condition effects on properties of cast and wrought U720[3,4,5]. A more limited number of investigations have been published regarding or comparing properties of P/M U720 materials[6,7]. Many of these previous investigations give good insight into the mechanical property potential of cast and wrought U720, while the current effort is focused on evaluating the property response of U720 in P/M HIP+Extrude+isothermal Forge form.

Microstructual feature of each materials produced in this study were shown in Figure 1. The grain size are listed in Table III, The subsolvus solution heat treatment produced fine grain structures due to primary gamma prime pinning effects, which resulted in limited gamma grain growth, The supersolvus solution heat treatments produced coarser grain size as a result of grain growth.

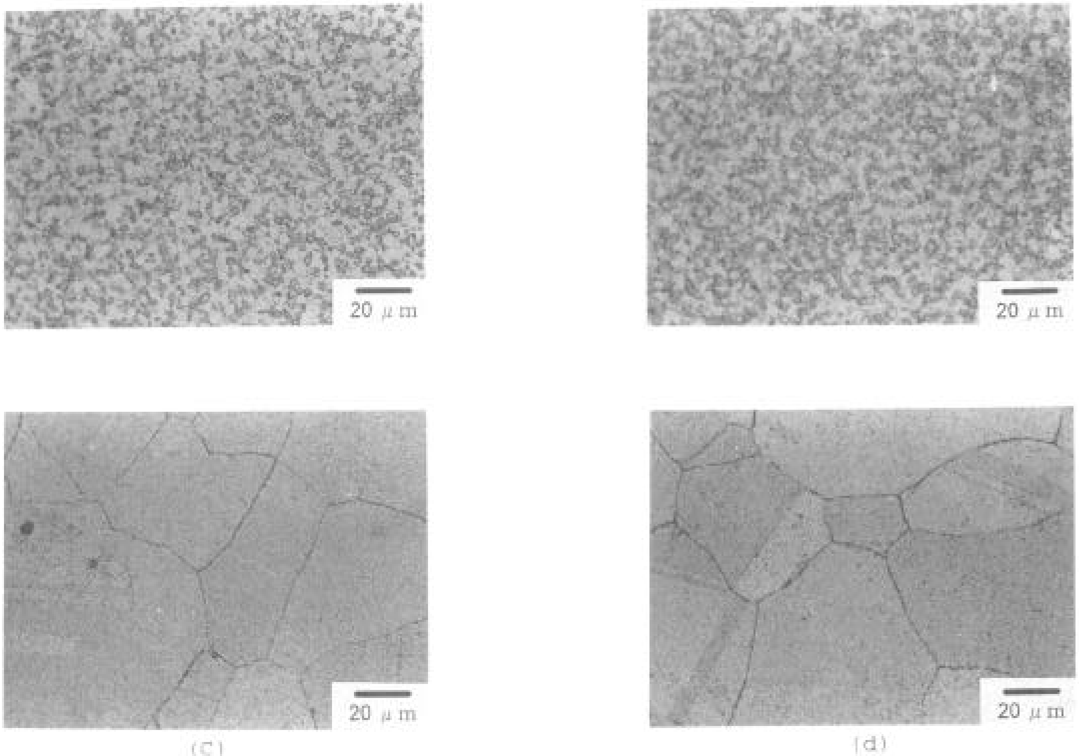

Figure 1 Microstructure of each tested P/M U720; (a)Subsolvus A, (b)Subsolvus B, (c)Supersolvus A and (d)Supersolvus B

Table Ⅲ Grain Size of tested P/M U720

	ASTM #
Subsolvus A	13
Subsolvus B	13
Supersolvus A	6
Supersolvus B	5

Tensile and creep properties

The average 0.2% yield strength and Larson-Miller parameter plot for creep resistance are presented in figure 2 and figure 3 respectedly , plotted with statistical data from Rene95 and AF115.

Subsolvus processed P/M U720 show equal or superior tensile capabilities to AF115 and approaching those of Rene95 at 673K, although those are lower at 923K and poor creep capabilities are shown, which are lower than Rene95. Subsolvus A, which were experienced faster cooling after solution, increase the yield strength than subsolvus B. There are no remarkable difference in creep capabilities between subsolvus A and B.

Supersolvus processed P/M U720 loose tensile capabilities but greatly enhanced creep strength, which are enough exceed to Rene95 and approaching to those of AF115, especially at higher temperature test condition.

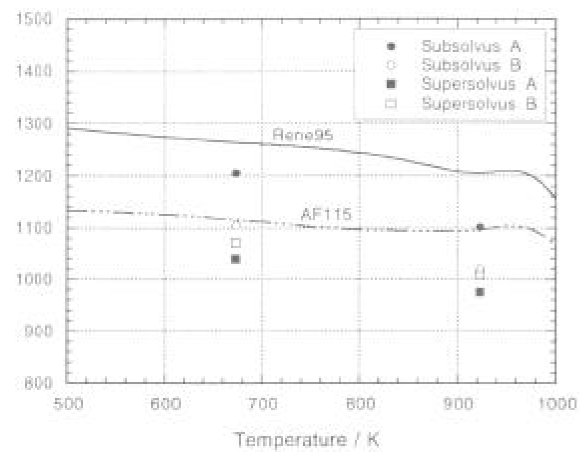

Figure 2 Tensile properties comparison between P/M U720 and AF115,Rene95

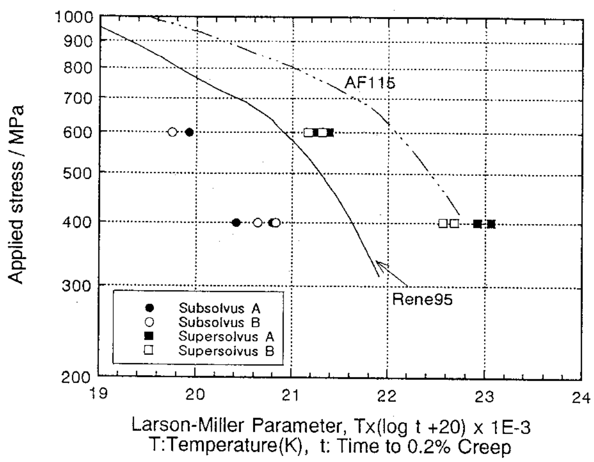

Figure 3 Larson-Miller comparison of 0.2% Creep time between P/M U720 and AF115,Rene95

LCF and fatigue crack growth properties

LCF and fatigue crack growth capabilities are summarized in figure 4, figure 5, and figure 6 respectedly. Subsolvus processed P/M U720 show LCF capabilities equivalent to the AF115 and Rene95 at 673K. Although supersolvus U720 loose LCF potential, the crack growth rate were about two times or more slower than subsolvus U720 and AF115.

Figure 7 shows the time depend tendency of fatigue crack growth capabilities for both sub-/supersolvus U720. Higher time dependent tendency were seen in the supersolvus forgings.

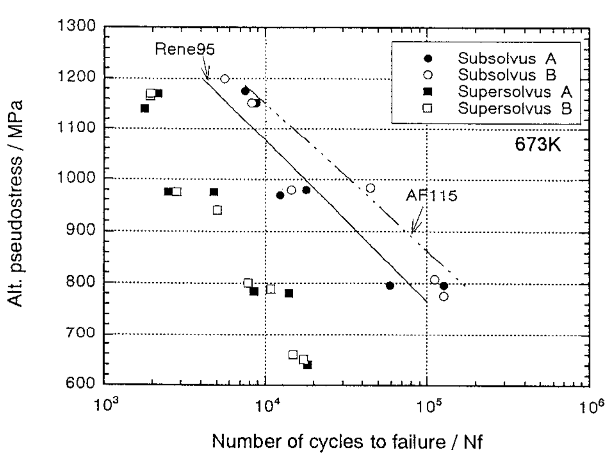

Figure 4 LCF properties comparison between P/M U720 and AF115, Rene95 at 673K.

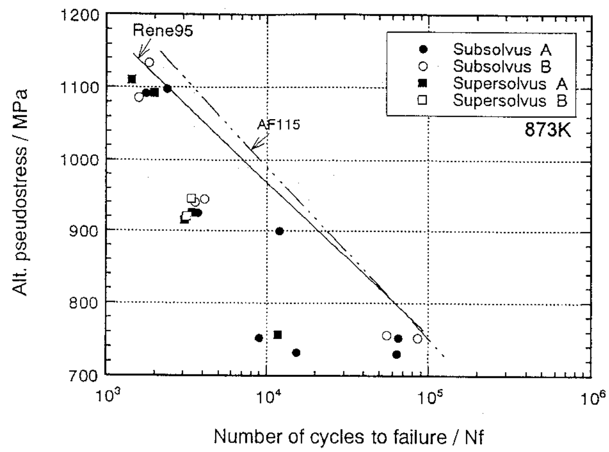

Figure 5 LCF properties comparison between P/M U720 and AF115,Rene95 at 873K.

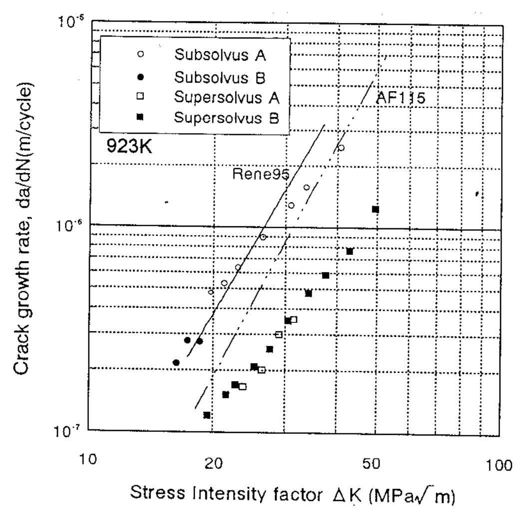

Figure 6 Fatigue crack growth properties comparison between P/M U720 andAF115, Rene95.

Discussions

The grain size influence on mechanical properties is well documented[8,9].Efforts have been directed in other programs to utilize grain size to optimize properties such as damage tolerance[4,10].The grain size effects are very apparent in the current effort when comparing all of the properties evaluated. A debit is seen in tensile strength and LCF for the intermediate grain size material as compared to the fine grain processed material. A corresponding increase in creep and crack growth rate is seen for the intermediate grain P/M U720.

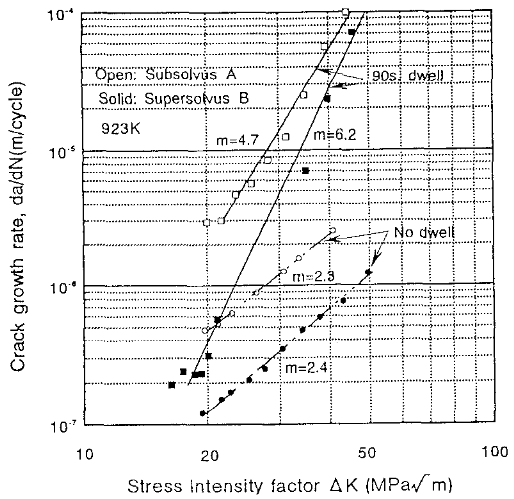

Figure 7 Dwell time effect on fatigue crack growth properties of P/M U720

SEM observation for the tested U720 in this study are shown in figure 8. The primary gamma prime morphology for the P/M U720 forgings processed in this effort were seen to be greatly modified by heat treatment, which is not surprising since sub- and supersolvus heat treatments were investigated. The supersolvus heat treatment cycles, which also included a second, subsolvus solution heat treatment produced uniform spherical gamma prime particles approximately 0.3-0.6 micron meters in diameter. The completely subsolvus processed forgings contained very large, angular primary gamma prime with an average particle size of 1-4 micron meters.

From previous work[11], it is known that cast and wrought U720 properties are greatly influenced by the cooling rate imposed after solution heat treatment. A near 15% increase in room temperature yield strength is seen from increasing the solution cooling rate from 0.27K/sec to 3.24K/sec for a variety of solution temperatures and aging conditions. The secondary, or cooling-rate gamma prime has also been previously shown to be greatly dependent on variations in cooling rate from the solution heat treat temperature. The secondary gamma prime size for U720 has been shown to be approximately 0.08 micron diameter spherical particle at 3.24K/sec cooling rates, and approximately 0.37 micron diameter irregular particles at 0.27K/sec.

A corresponding shift in properties and secondary gamma prime size is seen between the forgings produced in this program which were heat treated using oil quench and fan air quench cooling techniques; although the range in cooling rate variation for these materials is less than that noted above in the previous characterization effort and the size variation of secondary gamma prime is approximately 0.08 to 0.2 micron meters and around 9 % increase of 673K yield strength were seen in subsolvus A.

Fatigue crack growth rate of subsolvus P/M U720 is more than two times faster than those of supersolvus material at 923K. When we compare the time dependency of both grain size material , m-factor of each data in Paris-equation are also indicated in figure 7. Although there is little difference of m-factor for both material at 120CPM(no dwell time)test condition, higher effect of hold time on m-factor were seen in the corser grain material than fine grain material. The difference of tensile properties of this temperature range may affect this phenomena rather than creep-fatigue interaction. And these facts indicate the crack grew by intergranular fracture mode. More detail analysis would be necessary on the material microstructure/chemistry.

For advanced applications of P/M U720, processing must be optimized to achieve the best balance of properties, residual stress, overall disk performance, and cost. To allow for such process selection and optimization, efforts similar to the current program must be undertaken to fully understand alloy/process interactions.

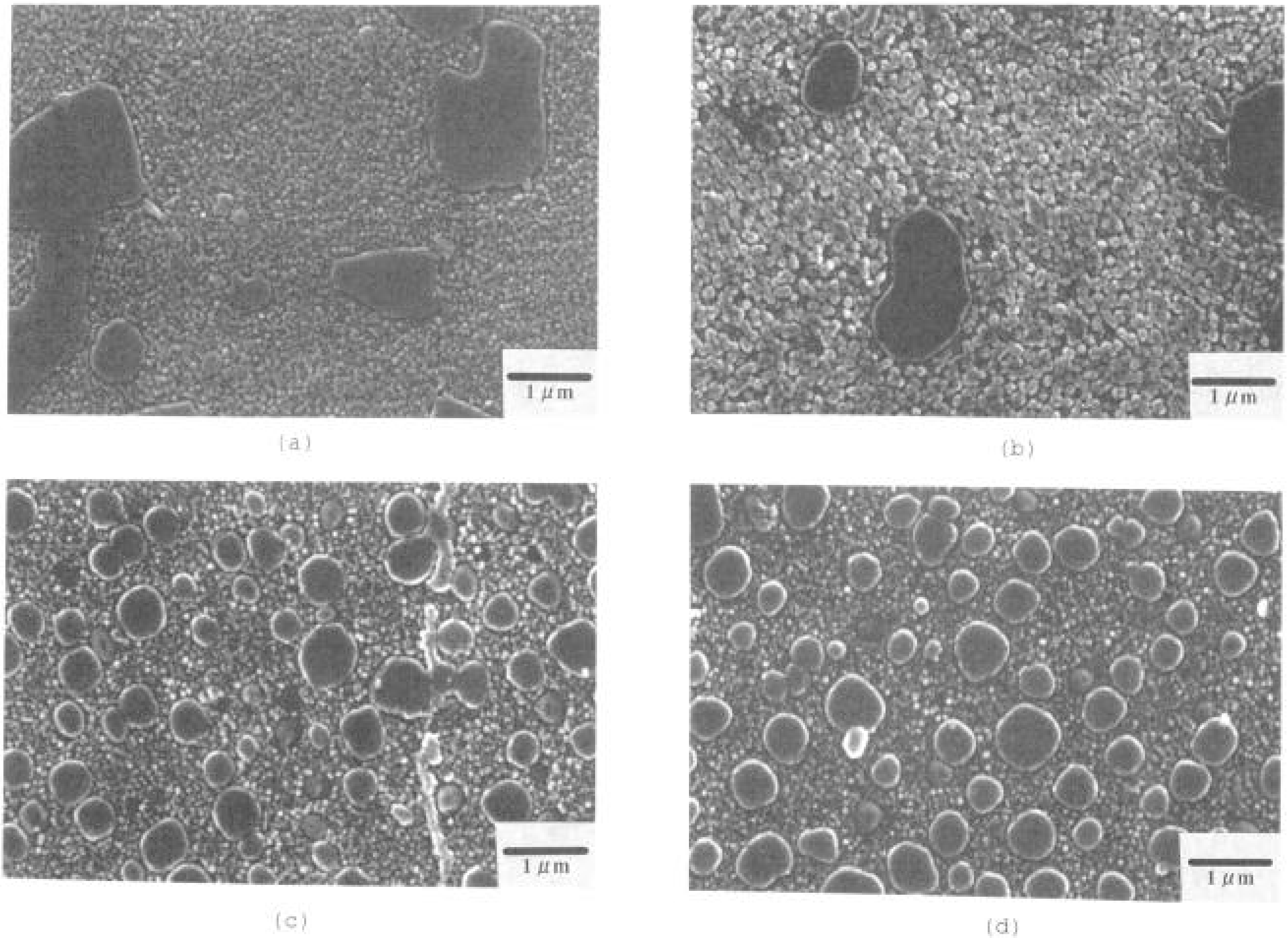

Figure 8 Gamma prime morphology and distribution for (a)Subsolvus A, (b)Subsolvus B (c)Subsolvus A, and (d)Subsolvus B heat treated P/M U720.

Conclusions

P/M U720 material has been shown to be readily processable by isothermal forging methods. Resultant microstructures and mechanical properties can be manipulated through variations in forging and heat treatment practices.

P/M U720 forgings processed to fine grain, high strength conditions show tensile properties above AF115 and approaching those of fine-grain Rene95;LCF properties equal or superior to fine-grain Rene95 and approaching those of AF115 at 673K, but are somewhat lower at 923K; and creep behavior which is below that of fine-grain Rene95 and AF115.

Intermediate grain size processed P/M U720 forgings resulted in reduced tensile and fatigue properties, but greatly enhanced creep response, which was shown to be superior to fine-grain Rene95 for all creep test conditions and superior to AF115 for high temperature creep test conditions.

Fine grain U720 showed equivalent fatigue crack growth capabilities to those of AF115. Intermediate grain U720 enhanced the crack growth resistance two times as fine grain P/M U720.

This evaluation program has shown that both grain size, and gamma-prime size and distribution can be altered during the processing of P/M U720 forging to allow optimization of mechanical properties and this material can be applied various design type of components.

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