### ISOCON MANUFACTURING OF WASPALOY TURBINE DISCS

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## Summary

Waspaloy is a vacuum melted age hardenable nickel base alloy with good strengths and elevated temperature properties for use as compressor and turbine rotor components for turbine engine applications. Advanced turbine engine requirements through defect tolerant designs require a manufacturing approach which provides increased ultrasonic inspection capabilities and cost effectiveness. By using a combination of isothermal press and conventional harmer forging techniques, the "ISOCON" manufacturing approach has been developed for Waspaloy turbine discs which meets these requirements while maintaining mechanical property and microstructural conformance.

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

#### Introduction

Today's turbine engine builders have goals to produce engines with improved life by using defect tolerant designs. These design requirements in Waspaloy turbine discs demand critical nondestructive inspection techniques while maintaining a high level of mechanical properties and cost effectiveness. A manufacturing procedure has been developed for a thirty inch diameter Waspaloy turbine disc which meets and exceeds these goals. This manufacturing approach has been entitled "ISOCON".

ISOCON is a two step manufacturing approach which utilizes isothermal press and conventional hammer forging techniques. The initial forging sequence is performed isothermally in order to produce a uniform microstructure which is required for stringent ultrasonic inspection techniques. The final forging sequence is performed on a hammer for improved tensile strengths and refined contour outline.

# Background

Prior to the introduction of ISOCON, large Waspaloy turbine discs were forged using a multiple (five) step manufacturing sequence. Forging temperatures and reductions produced a duplexed or necklaced microstructure. The grain size in cross sectioned discs ranged from average ASTM 3 to 6 (rating all grains) with variations in the percentage of duplexing from the disc's bore to the rim. See Figure I.

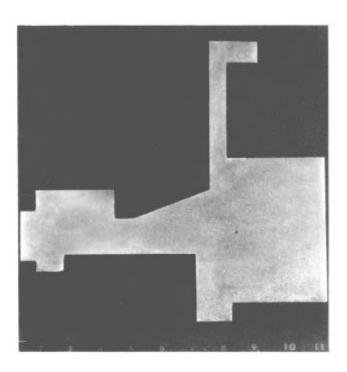
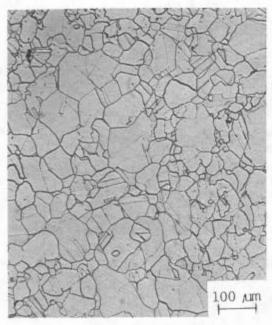


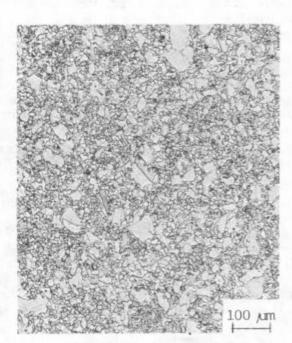
Figure 1: Macroetched Radial Section From a Multiple Step Forged Waspaloy Turbine Disc

The mechanical properties were typical of conventionally forged Waspaloy discs solution heat treated, stabilized, and aged. Room temperature tensile strengths were nominally 150 Ksi (1035 MPa) yield (0.2% offset) and 198 Ksi (1365 MPa) ultimate. Total plastic strain at 23 hours from creep tests were nominally 0.14% (rim, tangential) when tested at a temperature of 1240°F (670°C) and 80 Ksi (550 MPa) stress.

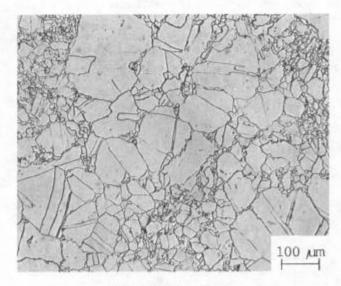
Ultrasonic inspection was performed to the equivalent of 100% of a 0.025 in. (0.064 mm) diameter flat bottom hole (FBH) standard. Approximately 10% of the discs were rejected due to indications which were associated with melt related defects. Also noted were discs which displayed increased noise or hash levels in the bore and rim areas. Microstructural review of the areas with increased noise noted coarse grains and variations in the percentage of duplexing. See Figure II.







LOCATION: MID-RADIUS



LOCATION: RIM

FIGURE 2: MICROPHOTOGRAPHS FROM A MULTIPLE STEP FORGED WASPALOY TURBINE DISC

#### ISOCON

Improvements necessary for upgraded turbine engines through defect tolerant designs required more sensitive ultrasonic inspection techniques while still maintaining a high level of mechanical property conformance and cost effectiveness. By combining Ladish Co.'s 10,000 Ton isothermal press and a 125,000 MKg hammer, Waspaloy high pressure turbine discs were manufactured which met the upgraded engine requirements. This manufacturing approach has been entitled "ISOCON".

The manufacturing sequence initially attempted, utilized a fourteen inch diameter Waspaloy billet (approximately 1,000 lbs.) which was isothermally press forged to a preform shape. The forging temperature was selected to dynamically recrystallize the billet to a uniform (controlled) grain size. This microstructural uniformity would therefore reduce the variation in ultrasonic noise levels from the bore to the rim of the discs.

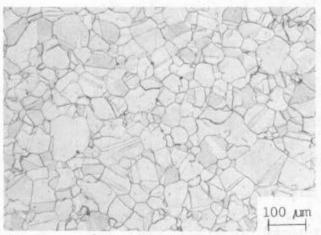
Mechanical property evaluation after heat treatment of the preform configuration (solution, stabilize, age) however revealed low 0.2% offset yield strengths which at room temperature ranged from 122 Ksi to 131 Ksi (840 MPa to 900 MPa). Consequently the conventional hammer final forge operation was introduced. Forging temperatures and reductions were selected to increase strengths without significantly altering the uniform microstructure produced during the preform forging step.

### RESULTS

The ISOCON manufacturing approach has successfully produced thirty inch diameter Waspaloy turbine discs, 3.5 in. (rim) to 5.0 in. (bore) in thickness, which have conformed to the mechanical, microstructural, and ultrasonic inspection requirements for upgraded turbine engines. ISOCON manufacturing has also reduced the number of forging sequences from multiple (five) steps to two steps thereby becoming a more cost effective process.

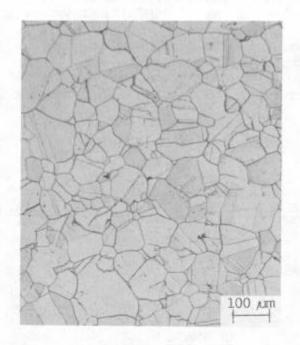
### PHYSICAL PROPERTIES

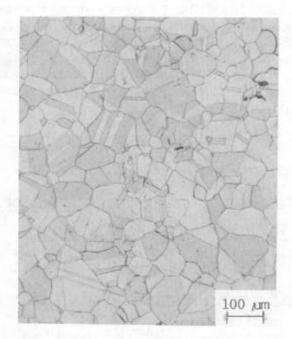
Visual inspection of a cross section macroetched radial section revealed a uniform structure throughout the disc. Microstructural review showed a slightly wrought uniform average grain size (rating all grains) ranging from ASTM 4 to 6. There was approximately two ASTM grain size difference from the extreme outer diameter (rim to the bore. See Figures 3 & 4.



LOCATION: RIM

FIGURE 3: MICROPHOTOGRAPHS OF ISOCON TURBINE DISC





LOCATION: BORE

LOCATION: MID-RADIUS

FIGURE 3 : (Cont'd)
MICROPHOTOGRAPHS OF ISOCON TURBINE DISC

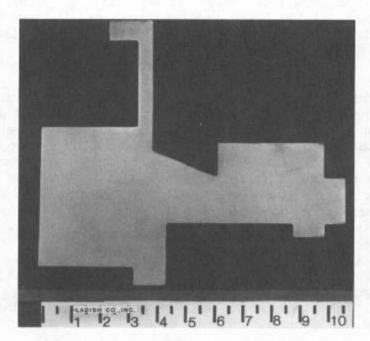


FIGURE 4: MACROETCHED RADIAL SECTION OF ISOCON TURBINE DISC

Tensile properties after heat treatment (solution, stabilize, age) as shown in Table I, revealed approximately a 10 Ksi (69 MPa) improvement in room temperature yield strengths (0.2% offset) when compared to values obtained from the isothermally preformed disc. However, in comparison to multiple step, conventionally forged discs, approximately a 7 Ksi (48 MPa) decrease in yield (0.2% offset) was noted. Tensile properties however, have shown excellent isotropic characteristics due to the microstructural uniformity.

TABLE I: AVERAGE TENSILE PROPERTIES FROM ISOCON TURBINE DISCS

#### ROOM TEMPERATURE

LOCATION DIRECTION	(0.2% O	FFSET)	ULTIMATE	%El.(4D) %R.A.
	Ksi	(MPa)	Ksi (MPa	
Rim Axial	$\overline{141}$	972	194 1338	<del>3</del> 23 31
Mid-Radius Radial	143	986	197 1358	<b>2</b> 0
Bore Tangential	143	986	194 133	8 24 31

### ELEVATED TEMPERATURE TENSILE (1000°F)

LOCATION	DIRECTION	(0.2% OFFSET)	ULTIMATE	%El.(4D)	%R.A.
		Ksi (MPa)	Ksi (MPa)		
Rim	Tangential	127 876	178 1227	21	28
Mid-Radius	Radial	128 883	176 1214	20	27
Bore	Tangential	127 876	177 1220	- 20	25

Total plastic strain at 23 hours from creep tests (rim, tangential) ranged from 0.06% to 0.10% when tested at a temperature of 1240% (670%C) and 80 Ksi (550 MPa) stress. Creep life to 0.20% extension has consistently exceeded 100 hours and has shown significant improvement when compared to multiple step, conventionally forged turbine discs.

# ULTRASONIC INSPECTION

Ultrasonic inspection of the ISOCON rectilinear machined discs when inspected to the equivalent of 100% of a 0.025 inch (0.064 mm) diameter FBH standard has shown a 3 db improvement rejection limit capability utilizing a 5 MHZ transducer in comparison with the multiple step, conventionally forged turbine discs. Inspection of "critically strained" areas of the discs consistently reveal noise levels as low as -28 dbs (0.010 in. average diameter) when inspected using a 10 MHZ transducer. These ultrasonic inspection levels have been possible due to uniform grain size developed during the isothermal manufacturing sequence.

Disc rejections have been significantly reduced when compared to the multiple step, conventionally forged discs even though the ISOCON discs have been inspected to more critical inspection levels. Only one sonic indication has been associated with a melt related defect in over two hundred turbine discs manufactured to date.

# CONCLUSION

ISOCON manufacturing of large Waspaloy turbine discs is a reproducible and cost effective manufacturing approach for advanced turbine engine designs. A large number of turbine discs have been manufactured and are currently being utilized in European and American commercial turbine engines. ISOCON manufacturing allows turbine discs to be critically

ultrasonic inspected while maintaining mechanical property and microstructural conformance. ISOCON manufacturing has also led to other evaluations for forging age hardenable nickel base alloys which require defect tolerant designs utilizing controlled structures.

## ACKNOWLEDGMENT

The author wishes to thank all the people of Ladish Co., Inc. for their help and cooperation in making ISOCON manufacturing successful.