N80-21488

APPLICATION OF SUPERALLOY POWDER METALLURGY FOR AIRCRAFT ENGINES

R. L. Dreshfield, et al

Lewis Research Center
Cleveland, Ohio

1980

NASA Technical Memorandum 81466

(NASA-TM-81466) APPLICATION OF SUPERALLOY POWDER METALLURGY FOR AIRCRAFT ENGINES (NASA) 21 p HC A02/MF A01 CSCL 11F
N80-21488
Unclas
G3/26 46823

APPLICATION OF SUPERALLOY POWDER METALLURGY FOR AIRCRAFT ENGINES

R. L. Dreshfield and R. V. Miner, Jr.
Lewis Research Center
Cleveland, Ohio

Prepared for the
International Powder Metallurgy Conference
Washington, D.C., June 22-27, 1980

1. Report No NASA TM-81466	2 Government Accession No.	3 Recipient's Catalog No
4. Title and Subtitle APPLICATION OF SUPERALLOY POWDER METALLURGY FOR AIRCRAFT ENGINES		5 Report Date
		6 Performing Organization Code
7. Author(s) R. L. Dreshfield and R. V. Miner, Jr.		8 Performing Organization Report No. E-395
9 Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		10 Work Unit No
		11. Contract or Grant No
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13 Type of Report and Period Covered Technical Memorandum
		14 Sponsoring Agency Code

15. Supplementary Notes

Prepared for the International Powder Metallurgy Conference, Washington, D.C., June 22-27, 1980.

16. Abstract

Aircraft engine producers were attracted toward superalloy powder metallurgy for two reasons: First, it was thought that the improved homogeniety of consolidated powder billets would offer more uniformity in the final product than a cast billet. Second, it was recognized that powder metallurgy offerd a potential for low-cost near-net-shape manufacture of components such as disks. In the last decade, Government/Industry programs have advanced powder metallurgy-near-net-shape technology to permit the use of as-HIP turbine disks in the commercial aircraft fleet. These disks offer a 30% savings of input weight and an 8% savings in cost compared to cast-and-wrought disks. Similar savings have been demonstrated for other rotating engine components. A compressor rotor fabricated from hot-die-forged-HIP superalloy billets has demonstrated input weight savings of 54% and cost savings of 35% compared to cast-and-wrought parts. Engine components can be produced from compositions such as René 95 and Astroloy by conventional casting and forging, by forging of HIP powder billets, or by direct consolidation of powder by HIP. However, each process produces differences in microstructure or introduces different defects in the parts. As a result, their mechanical properties are not necessarily identical. Acceptance methods should be developed which recognize and account for the differences.

17. Key Words (Suggested by Author(s)) Powder metallurgy Hot isostatic pressing Superalloys	18 Distribution Statement Unclassified - unlimited STAR Category 26

19. Security Classif. (of this report)	20 Security Classif (of this page)	21. No of Pages	22 Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

E-395

APPLICATION OF SUPERALLOY POWDER METALLURGY FOR AIRCRAFT ENGINES

R. L. Dreshfield and R. V. Miner, Jr.

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

INTRODUCTION

Aircraft engine producers were attracted toward superalloy powder metallurgy (PM) for two reasons. First, it was thought that the improved homogeneity of consolidated powder billets would offer more uniformity in the final product than cast billets. Second, it was recognized that powder metallurgy offered a potential for low-cost near-net-shape manufacture of components such as disks. In the last decade, Government/Industry programs have advanced powder metallurgy-near-net-shape technology to point where turbine disks in the commercial aircraft fleet are produced by the hot isostatic pressing (HIP) of superalloy powder.

This paper will review recent PM superalloy activities conducted by the NASA Lewis Research Center which, in part, have contributed to the successful application of PM superalloys in aircraft gas turbines. Specifically, some of the results of the Materials for Advanced Turbine Engines (MATE) Program are presented. In addition, mechanical property comparisons are made for superalloy parts produced by as-HIP powder consolidation and by forging of HIP consolidated billets; and the effect of various defects on the mechanical properties of powder parts are shown.

DEVELOPMENT OF PM COMPONENTS

The MATE Program was initiated by NASA to accelerate the development of new materials technologies from the laboratory through engine demonstration tests. The work is accomplished under contract with aircraft engine manufacturers who in turn sub-contract with appropriate metal suppliers and fabricators. Two of the projects initiated in 1976 and one initiated in 1977 involve the development of superalloy powder metallurgy for rotating components in aircraft gas turbines. Two of the projects were performed by Pratt & Whitney Aircraft and the other by the General Electric Company.

The first project initiated at Pratt & Whitney Aircraft was for the JT8D-17 high pressure turbine disk.[1*] Primary objectives were to reduce the input material by 55 kg (30%) and finished part cost by 20% compared to the then bill of material, forged Waspaloy. Low carbon (LC) Astroloy powder was HIPed to near the ultrasonic inspection shape followed by heat treatment and machining to the final configuration. The finished part, which is about 47 cm in diameter is shown in figure 1.

The composition of low carbon Astroloy and other alloys to be discussed later are shown in Table 1. The mechanical property requirement for the disks are shown in Table 2. Prior work performed at P&WA had demonstrated that low carbon Astroloy could achieve these properties by HIP consolidation for 3 hours at 1215° C and a pressure of 105 MPa followed by the heat treatment shown in Table 2. The major work drive of the P&WA MATE Project, which is outlined in figure 2 was directed toward refinement of the container fabrication technology to provide a minimum weight shape for ultrasonic inspection. A photograph of the as-HIPed shape is shown in figure 3. This shape can be made reproducibly with a 2.5 mm envelope of excess material. The mechanical properties of the disks were characterized and one disk was installed in a ground based JT8D-17R and was subjected to 284 hours of testing including in excess of 1000 cycles between idle and take-off condition.[2] This PM Astroloy part has now replaced conventionally forged Waspaloy as bill-of-materials for new production of JT8D-17R turbofan engines.

The initial MATE Project at the General Electric Company had as its objective the reduction in cost of two PM René 95 components by 50% compared to conventional processing.[3] The aft shaft, shown in figure 4, for the high pressure turbine of the CF6 engine was to be HIPed directly to the ultrasonic inspection shape and could replace conventionally forged and machined Inconel 718. The second component addressed in the General Electric program is shown in figure 5. It is a hot die forging to near the ultrasonic inspection shape for the stages 5 through 9 compressor disks for the CFM-56 turbofan engine. The forged PM billet would replace conventional René 95 for the compressor disks.

The composition of powder René 95 is also shown in Table 1. The mechanical property requirements for both the as-HIP shaft and the HIP + hot die forged compressor disks are shown in Table 3. Note that the as-HIPed shaft is made to a lower strength requirement with properties comparable to Inconel 718.

The flow chart for the project is shown in figure 6. Areas addressed in the as-HIPed shaft development included shape-making technology, surface preparation for inspection, heat treatment and process variable studies and detailed mechanical property evaluation. The as-HIPed shape shown in figure 7 was produced for General Electric by the Crucible Research Center using a ceramic mold. Using the process developed, a 2.5-mm envelope could be maintained over the desired inspection shape. Potential benefits were a 50% input weight reduction with a 40% cost savings compared to a conventionally produced part.[3]

The compressor disk project was initially intended to develop a process which used an as-HIP preform for the forging. However, as the project developed, it became apparent that machining several preforms from a single HIPed log containing several forging multiples would be more cost effective. The program included evaluations of forging parameters, pre-forge heat treatments, HIP consolidation parameters, can removal, pre-forge surface preparation, and mechanical properties. The process identified in the program has demonstrated a capability

*References are listed at the end of the text.

for a 54% reduction in input weight with a 35% cost reduction compared to conventional processing.

The third PM project in the MATE Program, being conducted by Pratt & Whitney Aircraft, involves the fabrication development of as-HIP turbine disks for a high-bypass ratio turbofan engine using a recently developed alloy, MERL 76. The objective of this program is to reduce material cost as well as component weight, and to increase the rim temperature capability by 20° C. The mechanical property goals for PM-MERL 76 are shown in Table 4. One of the parts made in this project is shown in figure 8. This 600-pound disk shape is among the largest of the superalloy components for which direct HIP manufacturing has been attempted.

MECHANICAL BEHAVIOR

The amount and direction of deformation is significantly different in parts made by forging as compared to parts made by HIPing powder to near final shape. Because of these differences, it is reasonable to expect that their microstructures will be dissimilar. Figure 9 illustrates the different microstructures in LC Astroloy and René 95 produced by forging and by HIPing. As shown each powder alloy/fabrication method produces a unique microstructure. One would then expect that the mechanical properties should differ for these products. Lawley[4] has suggested that shear deformation of powder material is required to produce properties equal to those resulting from forging of ingots; and, therefore suggests that the "dynamic" property levels of as-HIP material should be inferior to forgings. Furthermore, mechanical properties are affected by "defects" which may be introduced during processing. The location and nature of "defects" might be expected to differ for as-HIP and mechanically worked products. While these issues are certainly not settled, we shall briefly show data to support these theses.

Mechanical properties. - Table 5 compares tensile and stress-rupture properties of HIP and forged and as-HIP forms of LC Astroloy and René 95.[5,6] For the René 95, the tensile and yield strengths at room temperature and 650° C are nearly equal, but the stress rupture life of the HIP and forged form is over four times that of the as-HIP product at 650° C and a stress of 1034 MPa.

For the LC Astroloy, it can be seen that, except for the ultimate strength of 650° C, the strengths of the as-HIP material were generally about 10% below the HIP + forged form. Figure 10 provides a comparison of the low cycle fatigue behavior of these alloys.[5,6] For lives typical of commercial engine design of about 10^5 cycles, the mechanically worked products appear to have greater strain range capability than as-HIP products.

Defects in PM superalloys. - During the development of the powder metal superalloy products discussed earlier, it became apparent that defects may be introduced during processing that are different from those related to conventional processing. Defects associated with the PM process include the introduction of foreign materials such as ceramic material from the melting process, metals of different compositions from earlier atomization runs, and argon gas which may be introduced during atomization or subsequently during HIP if a container should leak. The effects of intentionally introducing oxides, foreign alloys and argon is as-HIP René 95 are described in reference 3. The mechanical tests performed in that study were room temperature and 650° C tensile, stress rupture at 650° C with a stress of 965 MPa, and smooth bar low cycle fatigue with alternating stresses between 490 and 685 MPa at 540° C. The results of the study are summarized in Table 6. The degradation caused by the materials defects ranges from severe for all properties by large oxides to little change for a superalloy of different composition. For the oxide inclusions, the severity of the property degradation was shown to be related to the area of the defect and the location of the defect (i.e., surface or subsurface) with large surface defects being the most detrimental to low cycle fatigue life. This is illustrated in figure 11. As a result of this and similar findings in related work, the Air Force has initiated programs at General Electric[7] and Pratt & Whitney Aircraft to develop manufacturing methods for improved powder cleanliness, contracts F33615-78-C-5225 and F33145-79-C-5006.

The presence of controlled amounts of argon in a part was briefly discussed earlier. When argon (or other insoluble gases) are introduced in a part, thermally induced porosity may result. That is, when the part is reheated, the gas may expand creating gas-filled pores. During the performance of the MATE Project described in reference 1, a steel can leak during the HIP cycle causing thermally induced porosity (TIP) levels in excess of the specified maximum. The resulting pressing was studied at the Lewis Research Center to determine the effects of excessive TIP which occurred as the result of an actual manufacturing incident and the results are reported elsewhere.[8]

Selected results from that study are shown in figure 12. The difference in properties between the rim and bore of the disk pressing is attributed to a porosity gradient with the bore having about 1½% greater porosity. For the part examined, the integral test ring was located near the rim of the disk, however, the container leak was believed to have occurred near the bore. One might envision a situation where a part could pass inspection yet regions remote to the test ring might be defective. It is, therefore, recommended that TIP tests be taken from several radial and circumferential regions of as-HIP parts prior to acceptance for use.

CONCLUDING REMARKS

The field of PM superalloys is clearly a maturing technology having qualified rotating components for manned flight. As is typical in materials technology, the commercial state-of-the-art tends to advance faster than our fundamental understanding of the related material science. For PM superalloys, the technology exists to manufacture as-HIP high strength parts to within 2.5 mm of an ultrasonic inspection envelope. However, one should note that for the as-HIP LC Astroloy and René 95 programs discussed, the as-HIP alloy replaced a conventional alloy of lower strength capability. That is, as-HIP Astroloy replaced conventional Waspaloy and as-HIP René 95 replaced conventional Inconel 718. The most apparent and logical reason for this approach is that of conservatism in the application of new materials and processes to aircraft engines. Another reason is that it might be expected that a heat treated as-HIP alloy would have a microstructure and mechanical properties different from a mechanically worked alloy. For example, it has been shown in several investigations that as-HIPed can be produced which have static strengths equal to forged material, of similar composition. However, the data base does not provide convincing evidence that they have equal static ductilities, fatigue, or creep resistance. A better understanding of the difference between PM products and conventionally produced parts is needed, particularly, with respect to microstructural effects and the control and effect of defects on product performance.

REFERENCES

1. R. D. Eng and D. J. Evans, PWA-5574-12-VOL-1, Pratt & Whitney Aircraft Group, East Hartford, Conn., March 1978 (NASA CR-135409).

2. R. D. Eng and D. J. Evans, PWA-5574-37-VOL-2, Pratt & Whitney Aircraft Group, East Hartford, Conn., January 1979 (NASA CR-135410).

3. W. R. Pfouts, C. E. Shamblen, J. S. Mosier, R. E. Peebles, and R. W. Gorsler, R79AEG416, General Electric Company, Cincinnati, Ohio (NASA CR-159802).

4. Alan Lawley, "Processing-Structure-Property Relationships in Consolidated Powders," Rapid Solidification Processing: Principles and Technologies, R. Mehrabian, ed., Claitor's Publishing Division, Baton Rouge, La., 1978, p. 306.

5. B. A. Cowles, D. L. Sims, and J. R. Warren, FR-10299, Pratt & Whitney Aircraft Group, W. Palm Beach, Fl., October 1978 (NASA CR-159409).

6. V. Shahani and H. G. Popp, General Electric Company, Cincinnati, Ohio, June 1978 (NASA CR-159433).

7. R. F. Halter, W. R. Pfouts, and C. A. Shamblen, Manufacturing Methods for Improved Superalloy Powder Production, General Electric Company, Cincinnati, Ohio, Presented at Metals Technology Advisory Group Meeting, Daytona, Fl., Sept. 25-27, 1979.

8. R. L. Dreshfield and R. V. Miner, Jr., NASA TM 79263, 1979.

TABLE 1. - POWDER ALLOY COMPOSITIONS

Nominal weight percent	René 95	Astroloy	MERL 76
Ni	Balance	Balance	Balance
Al	3.5	4.0	5.0
Ti	2.5	3.5	4.3
Cb	3.5	-----	1.4
Cr	13.0	15.0	12.4
Co	8.0	17.0	18.5
Mo	3.5	5.0	3.2
W	3.5	-----	-----
Hf	-----	-----	.4
C	.07	.04	.02

TABLE 2. - MECHANICAL PROPERTY REQUIREMENTS FOR HIP ASTROLOY POWDER DISKS

[Heat treatment, 1105° C/3 hr air cool + 870° C/8 hr air cool + 980° C/4 hr air cool + 650° C/24 hr air cool + 760° C/8 hr air cool.]

	0.2 Percent yield strength, MPa	Ultimate strength, MPa	Elongation, percent	Reduction in area, percent
Room temperature	826	1241	15	11
538° C	758	1103	15	18
Stress-rupture at 732° C/552 MPa: 23 hr and 8 % elongation				
0.1 % Creep at 704° C/510 MPa: 100 hr				

TABLE 3. - MECHANICAL PROPERTY REQUIREMENTS FOR PM RENÉ 95 PARTS

(a) As-HIP HP turbine aft shaft; heat treatment, 1120° C/1 hr 816° salt quench[a] + 870° C/1 hr air cool + 650° C/16 hr air cool

	0.2 Percent yield strength, MPa	Ultimate strength, MPa	Elongation, percent	Reduction in area, percent
Room temperature	1035	1275	10	12
650° C	860	1000	8	10
Stress-rupture at 650° C/965 MPa: 25 hr and 2 % elongation				

(b) HIP + force compressor disk; heat treatment, 1095° C/1 hr oil quench + 760° C/16 hr air cool

	0.2 Percent yield strength, MPa	Ultimate strength, MPa	Elongation, percent	Reduction in area, percent
Room temperature	1240	1586	10	12
650° C	1151	1425	8	10
Stress-rupture at 650° C/1034 MPa: 25 hr and 2 % elongation				

[a]Rapid air cool may also be used.

TABLE 4. - MECHANICAL PROPERTY REQUIREMENTS FOR PM MERL 76

[Heat treatment, 1163° C/2 hr oil quench + 870° C/0.67 hr air cool + 980° C/0.75 hr air cool - 650° C/24 hr air cool + 760° C/16 hr air cool.]

	0.2 Percent yield strength, MPa	Ultimate strength, MPa	Elongation, percent	Reduction in area, percent
Room temperature	1034	1482	15	15
704° C	1014	1172	12	12
Stress-rupture at 732° C/1650 MPa: 23 hr and 5 % elongation				
0.2 % Creep at 704° C/552 MPa: 100 hr				

TABLE 5. - MECHANICAL PROPERTIES OF POWDER METALLURGY SUPERALLOYS

Alloy	Form	Temperature, °C	Ultimate telsile strength, MPa	0.2 Percent yield strength, MPa	Reduction in area, percent	Elongation, percent
René 95	HIP + Forge	23	1629	1179	23	18
	As HIP	↓	1636	1214	15	16
Astroloy	HIP + Forge	↓	1517	1055	23	27
	As HIP	↓	1379	936	31	27
René 95	HIP + Forge	650	1480	1122	14	13
	As HIP	↓	1514	1120	17	16
Astroloy	HIP + Forge	↓	1261	975	25	38
	As HIP	↓	1234	881	36	31

René 95 : Stress-rupture at 650°C/1034 MPa

Form	Life, hr	Reduction in area, percent	Elongation, percent
HIP + Forge	278	4	2.0
As-HIPed	70	Not reported	---

TABLE 6. - EFFECT OF DEFECTS ON AS-HIP RENÉ 95

Defect	Mechanical property				
	Tensile		Stress rupture		Low cycle fatigue life
	Strength	Ductility	Life	Ductility	
Oxides	↓	↓	↓	↓	↓
M2-Steel	0	-	-	↓	↓
LC Astroloy	0	-	-	-	0
Argon >0.2 percent tip	-	-	-	-	↓

↓ Severe degradation.
\- Slight degradation.
0 No significant effect.

ORIGINAL PAGE IS
OF POOR QUALITY

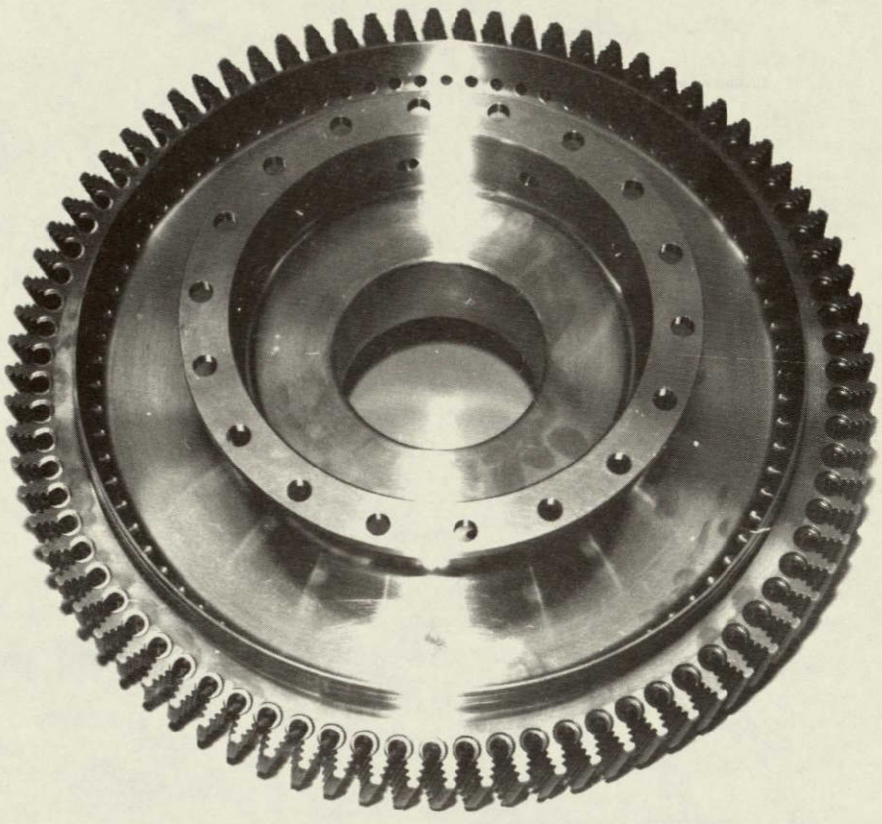


Figure 1. - As-HIP LC Astroloy turbine disk (ref. 1).

J16609-4
R770402

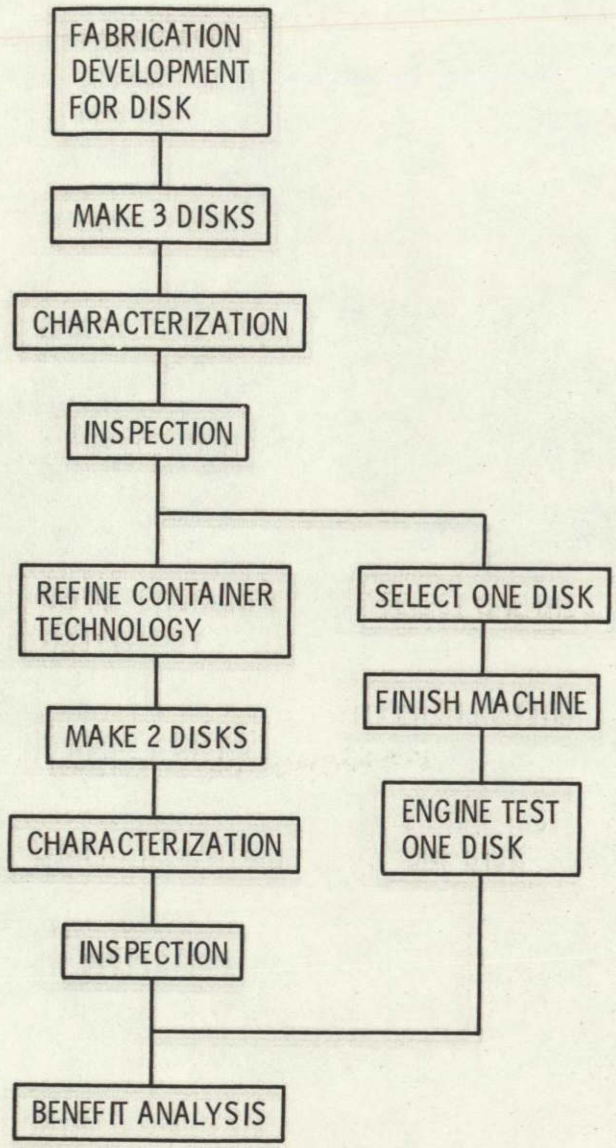


Figure 2. - Development program at Pratt & Whitney Aircraft for As-HIP LC Astroloy turbine disk (ref. 1).

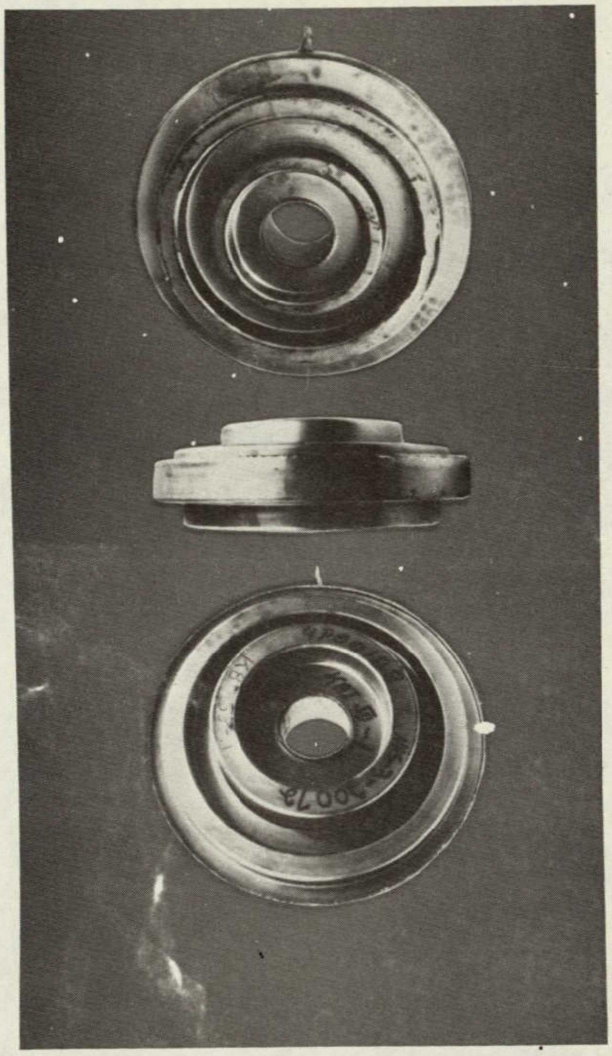


Figure 3. - As-HIP shape of LC Astroloy for JT8D turbine disk (ref. 1).

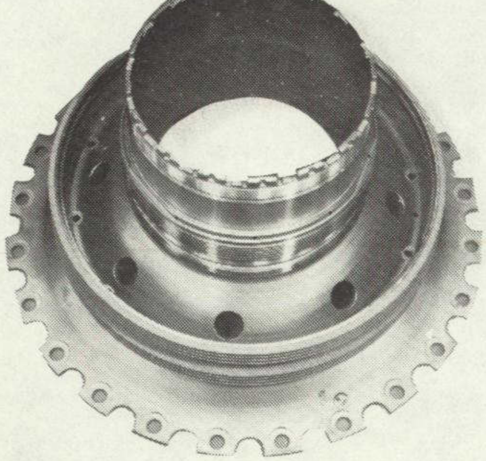


Figure 4. - As-HIP René 95 turbine aft shaft for CF6 engine (ref. 3).

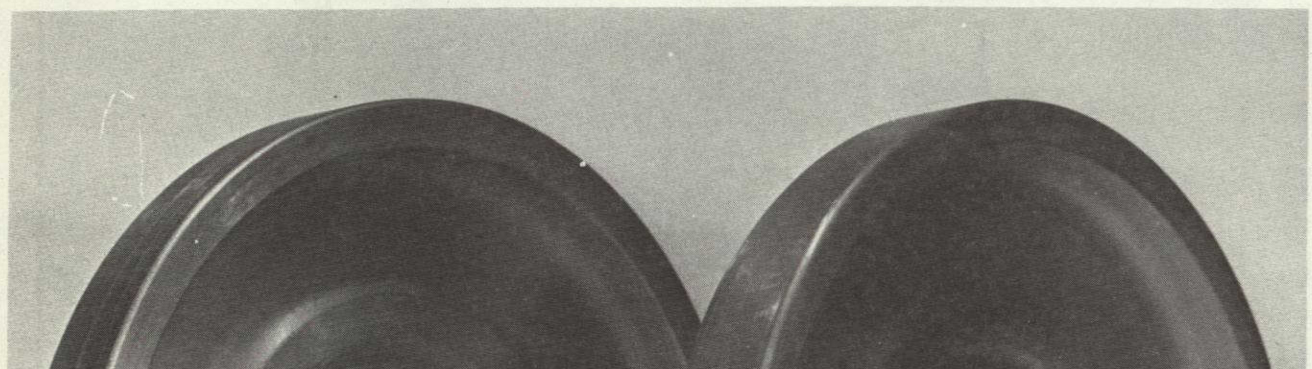


Figure 5. - René 95 hot die forgings for CFM 56 compressor disks (ref. 3).

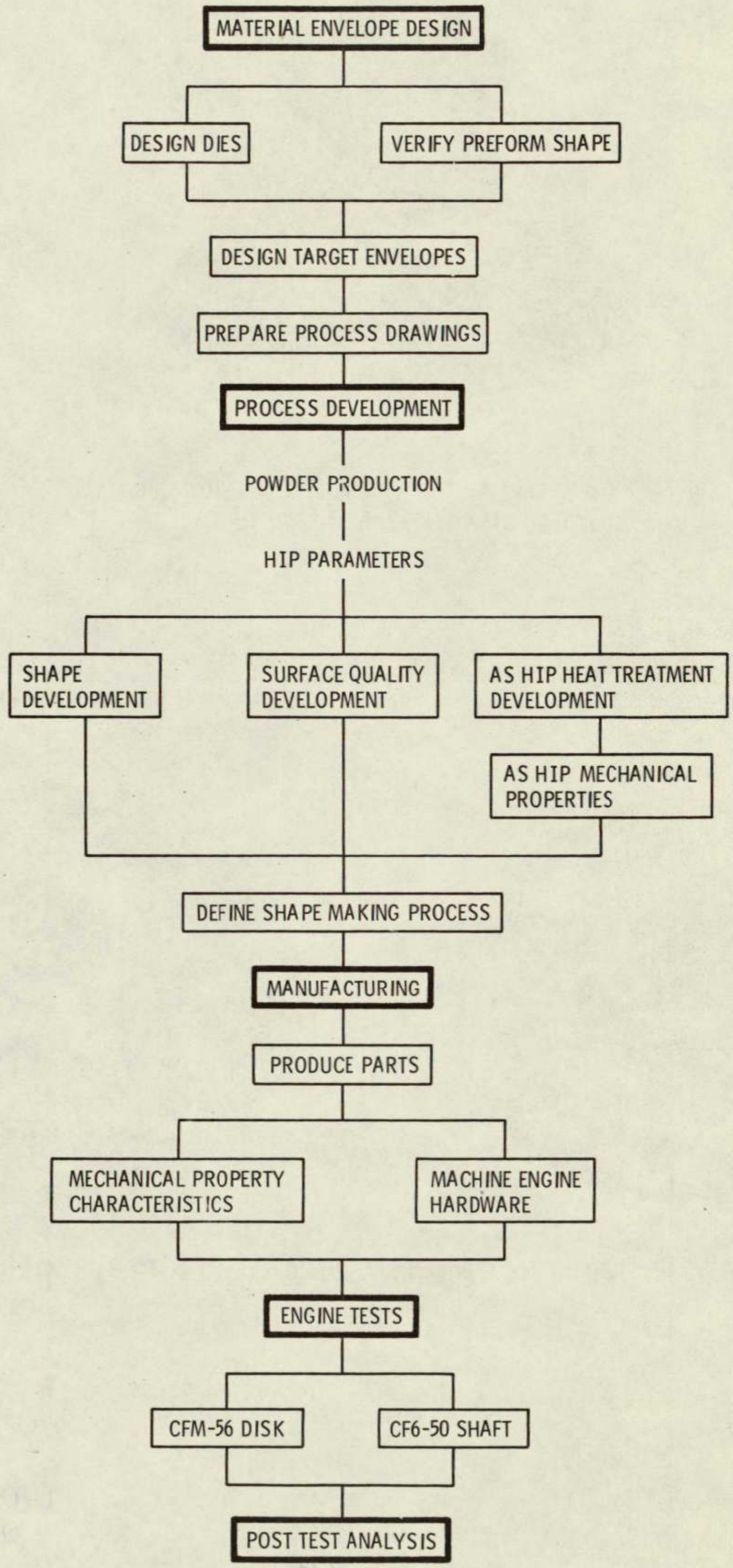


Figure 6. - Development program at General Electric for René 95 powder metallurgy disk and shaft.

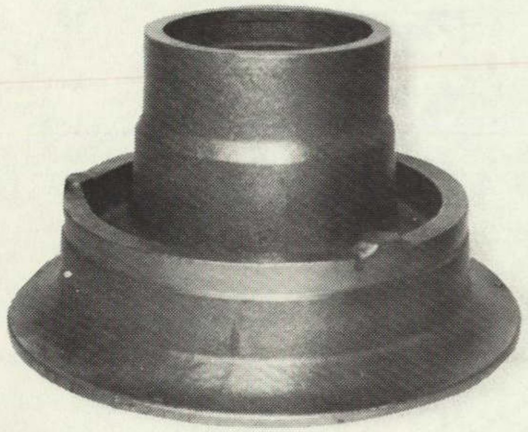


Figure 7. - René 95 as-HIP shape for CF6 turbine aft shaft (ref. 3).

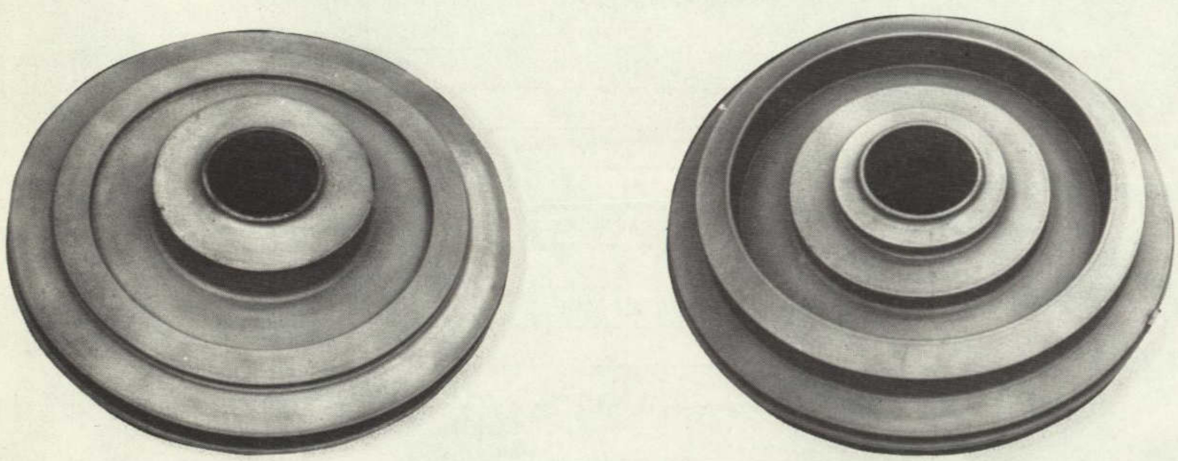
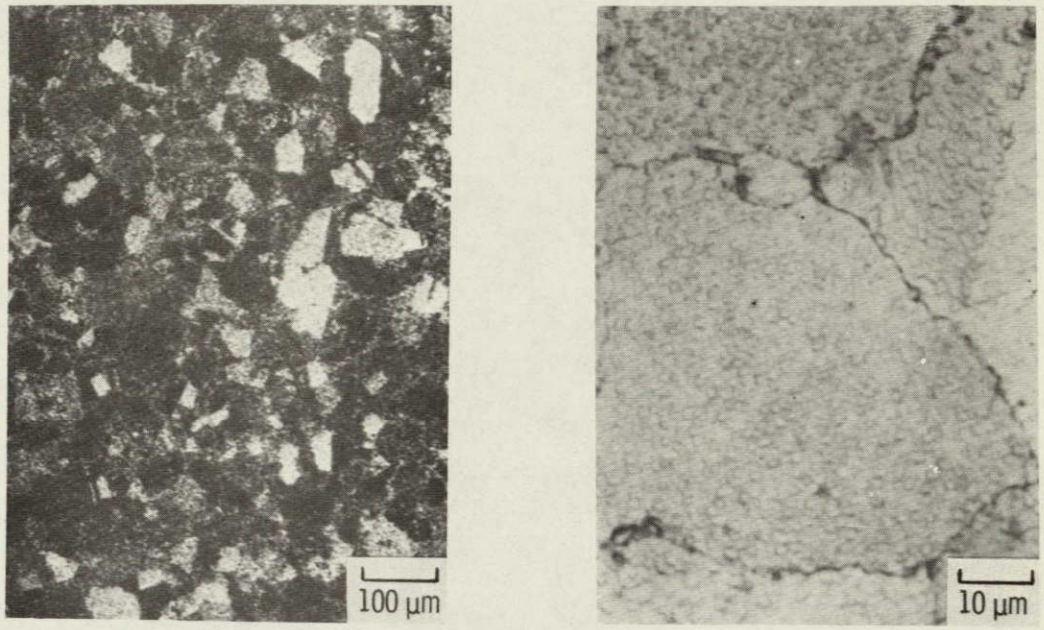
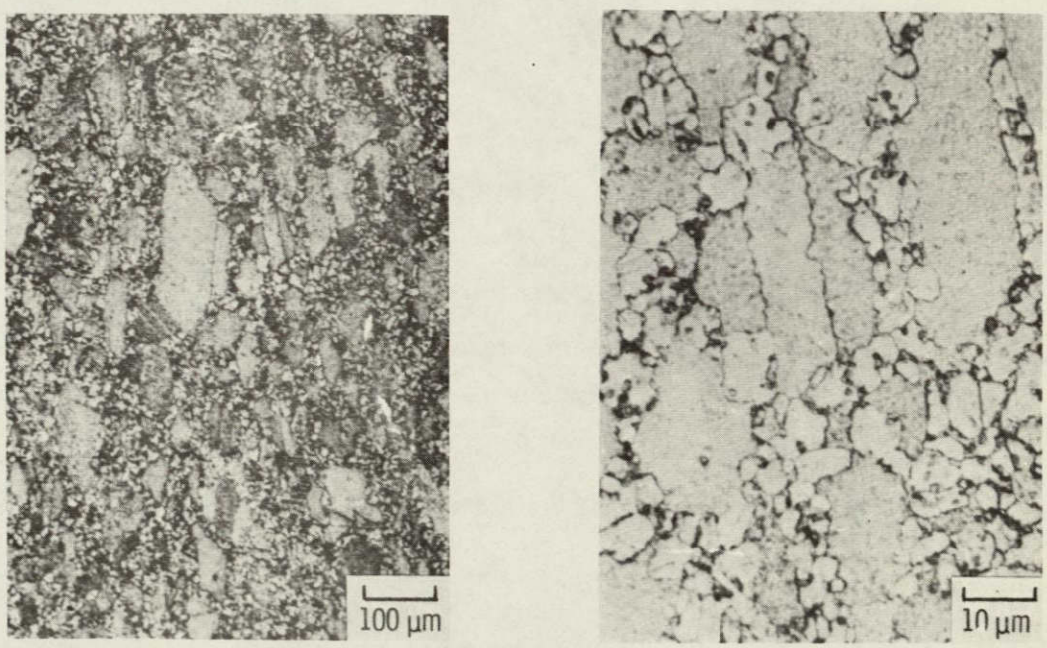


Figure 8. - As-HIP shape made from PM MERL 76 (courtesy Pratt & Whitney Aircraft).

ORIGINAL PAGE IS
OF POOR QUALITY



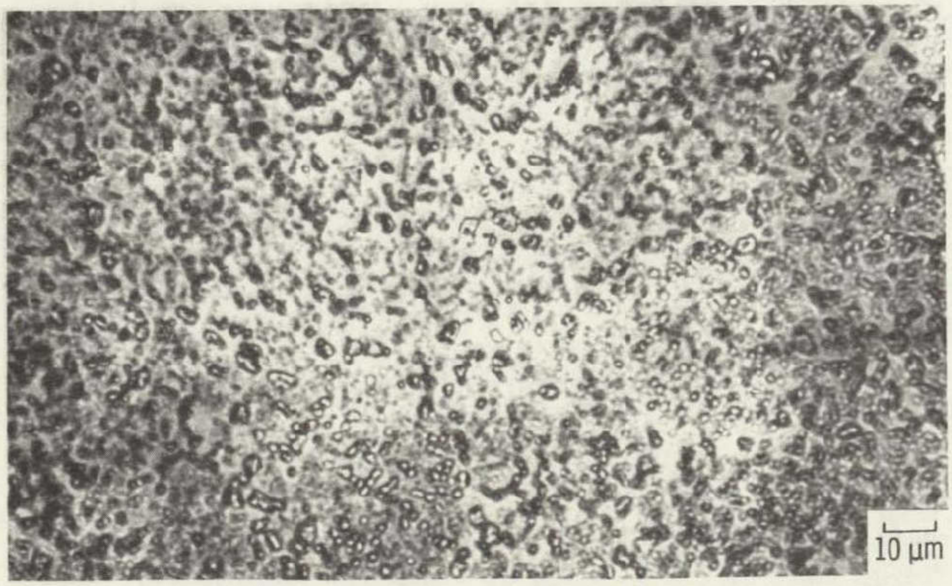
(a) AS-HIP ASTROLOY.



(b) HIP AND FORGED LC ASTROLOY.

Figure 9. - Photomicrographs of PM superalloys.

(c) AS-HIP RENÉ 95.



(d) HIP AND FORGE RENÉ 95.

Figure 9. - Concluded.

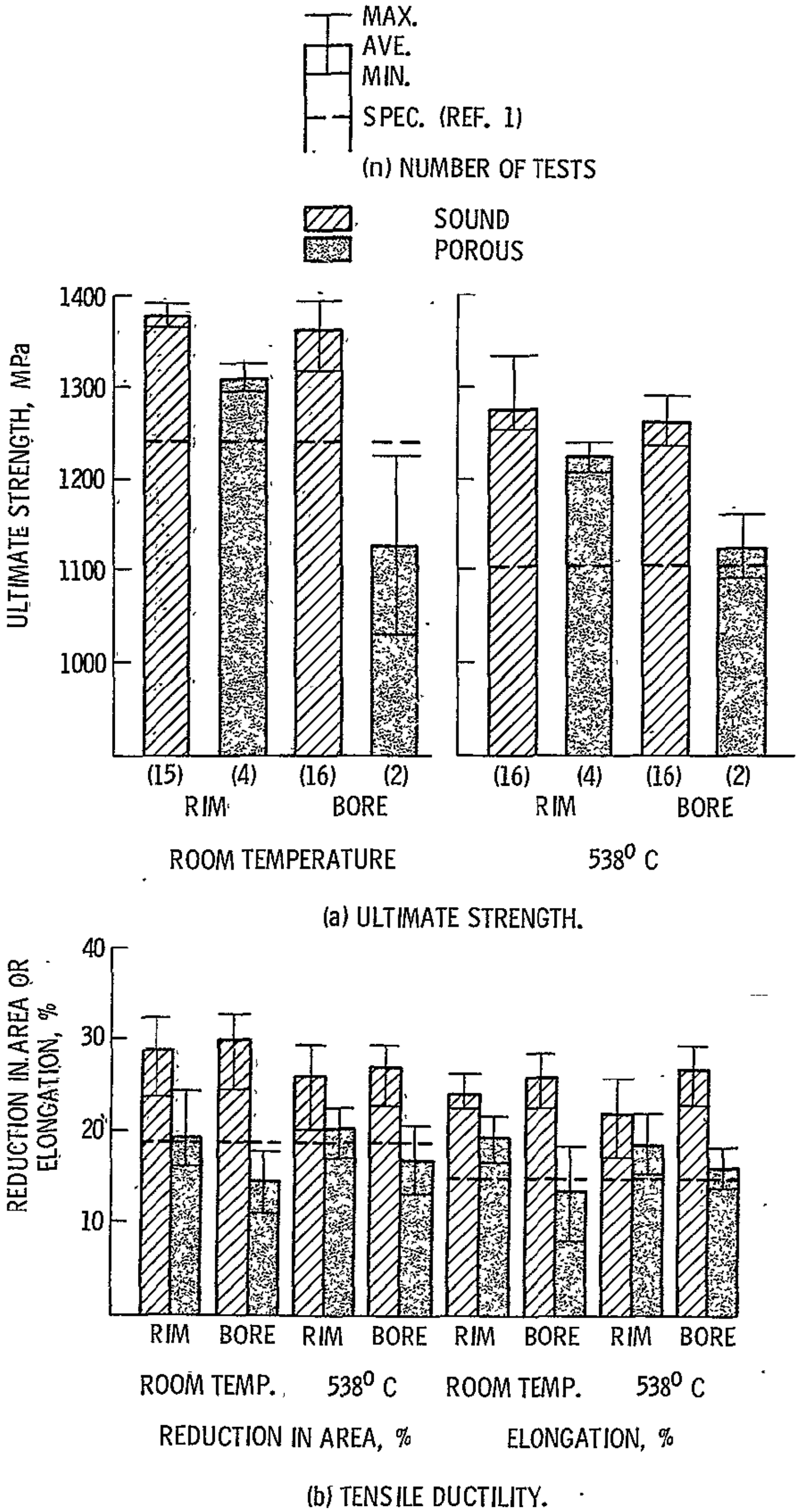
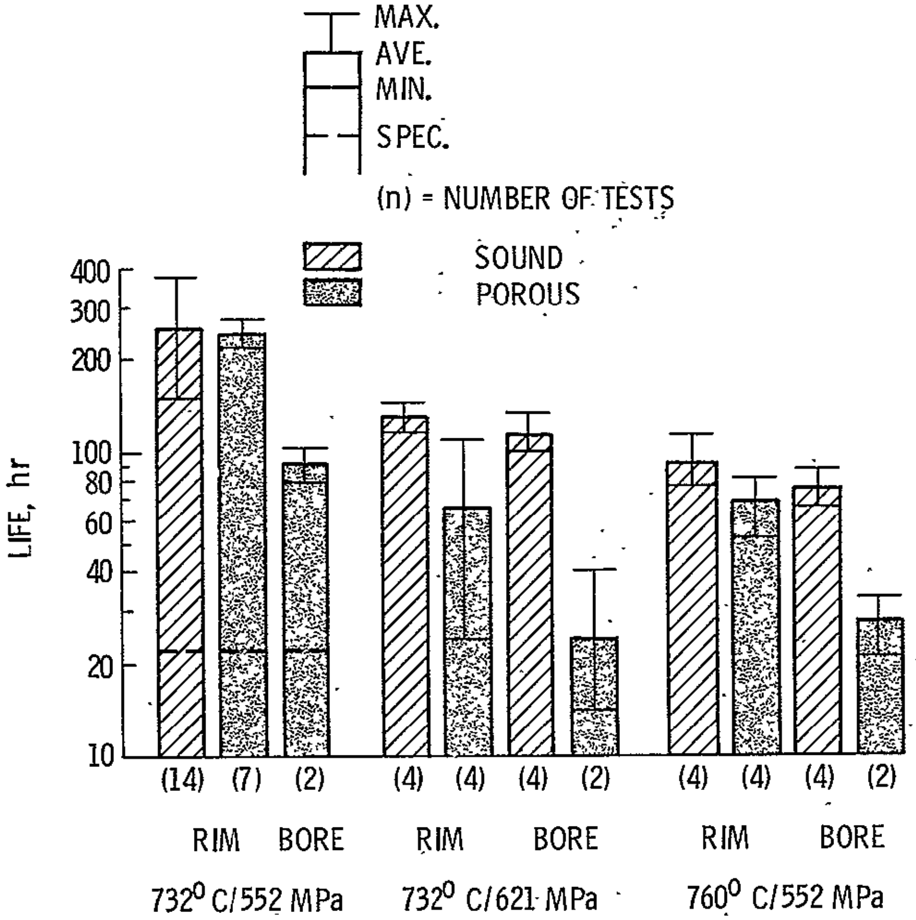
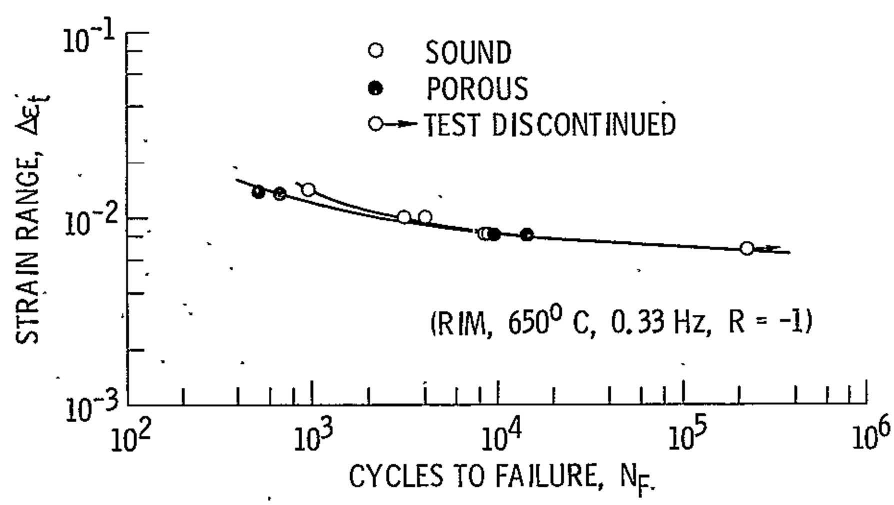


Figure 12. - Effect of TIP on mechanical properties of PM LC Astroloy.



(c) STRESS RUPTURE LIFE.



(d) LOW CYCLE FATIGUE.

Figure 12. - Concluded.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-81466		

4. Title and Subtitle	5. Report Date
APPLICATION OF SUPERALLOY POWDER METALLURGY FOR AIRCRAFT ENGINES	6. Performing Organization Code
7. Author(s) R. L. Dreshfield and R. V. Miner, Jr.	8. Performing Organization Report No. E-395
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	10. Work Unit No 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the International Powder Metallurgy Conference, Washington, D.C., June 22-27, 1980.

16. Abstract

Aircraft engine producers were attracted toward superalloy powder metallurgy for two reasons. First, it was thought that the improved homogeniety of consolidated powder billets would offer more uniformity in the final product than a cast billet. Second, it was recognized that powder metallurgy offerd a potential for low-cost near-net-shape manufacture of components such as disks. In the last decade, Government/Industry programs have advanced powder metallurgy-near-net-shape technology to permit the use of as-HIP turbine disks in the commercial aircraft fleet. These disks offer a 30% savings of input weight and an 8% savings in cost compared to cast-and-wrought disks. Similar savings have been demonstrated for other rotating engine components. A compressor rotor fabricated from hot-die-forged-HIP superalloy billets has demonstrated input weight savings of 54% and cost savings of 35% compared to cast-and-wrought parts. Engine components can be produced from compositions such as René 95 and Astroloy by conventional casting and forging, by forging of HIP powder billets, or by direct consolidation of powder by HIP. However, each process produces differences in microstructure or introduces different defects in the parts. As a result, their mechanical properties are not necessarily identical. Acceptance methods should be developed which recognize and account for the differences.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Powder metallurgy Hot isostatic pressing Superalloys	Unclassified - unlimited STAR Category 26

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return