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High Cycle Fatigue Crack Initiation Study of Case Blade Alloy René 125

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High Cycle Fatigue Crack Initiation Study of Cast Blade Alloy René 125

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Introduction

This study was conducted in order to investigate and document the high cycle fatigue crack initiation characteristics of blade alloy René 125 as cast by three commercially available processes. This alloy is typically used in turbine blade applications. It is currently being considered as a candidate alloy for high T_3 compressor airfoil applications. This effort is part of NASA's Advanced Subsonic Technology (AST) program which aims to develop improved capabilities for the next generation subsonic gas turbine engine for commercial carriers.

Wrought alloys, which are customarily used for airfoils in the compressor, cannot meet the property goals at the higher compressor exit temperatures that would be required for advanced ultra-high bypass engines. As a result cast alloys are currently being considered for such applications. Traditional blade materials such as René 125 have the high temperature capabilities required for such applications. However, the implementation of cast alloys in compressor airfoil applications where airfoils are typically much thinner does raise some issues of concern such as thin wall castability, casting cleanliness, and susceptibility to HCF loading.

Processing and heat treatment

The nominal composition of the Ni-based superalloy, René 125 is given in Table I. This alloy was cast both as bar and sheet by three casting vendors, Howmet, Hitchiner, and PCC. Howmet castings were made using the Microcast-X[®] process (ref. 1). This process relies on a low, well controlled superheat during pouring. Hitchiner castings were performed using the Chandley Low-pressure vacuum melt process. In this process the mold is filled countergravity with the help of a vacuum. PCC used a Thermally Controlled Solidification process which is comparable to a directional solidification slow cool process. All castings were given the same post-cast heat-treatment:

HIP 2165° F/25 ksi/4 hr
Solution 2150°F/15 min/fast cool at 250°F/min (He quench)
Age 1400°F/12 hr/He quench

This heat treatment was based on a Design of Experiments (DOE) optimization by General Electric Aircraft Engines where a variety of heat treatment variables were evaluated based on the 1400° F tensile properties of the alloy. A detailed explanation of this study is included in ref. 2.

In addition to this heat treatment, alternate HIP and heat treatments outside the range of the DOE were investigated at NASA LeRC. Higher HIP and solution treatment temperatures were explored in hopes of producing more homogenization and increasing the amount of γ' dissolved and re-precipitated in finer form during aging. Two different aging temperatures were also explored. The alternate heat treatments were performed only on the Howmet bar castings, (Hitchiner and PCC castings were only subjected to the optimum heat treatment):

Alternate heat treatment 1 (same as the GE optimized heat treatment)

HIP 2165° F/15 ksi/4 hr

Solution 2150° F/15 min/fast cool at 250° F/min (He quench)

Age 1400° F/12 hr/He quench

Alternate heat treatment 2

HIP 2250° F/15 ksi/4 hr

Solution 2200° F/15 min/fast cool at 250° F/min (He quench)

Age 1400° F/12 hr/He quench

Alternate heat treatment 3

HIP 2250° F/15 ksi/4 hr

Solution 2200° F/15 min/fast cool at 250° F/min (He quench)

Age 1600° F/12 hr/He quench

The first alternate heat treatment was intended to duplicate the DOE optimum heat treatment, however, the HIPing for this and all of the alternate heat treatments was erroneously performed at 15 ksi instead of 25 ksi. This difference proved to be costly in terms of HCF life for all the alternate heat treatments.

Microstructures

The microstructures of the various castings were examined using metallographic sections obtained from failed HCF specimens. As shown in Figure 1, orientations both parallel and perpendicular to the specimen loading direction, (designated as (L) and (T) respectively), were examined. The majority of the metallographic sections taken parallel to the loading axis were obtained through the specimen's fracture surface (and at the initiation site) in order to document the presence of various casting defects. Metallographic samples were obtained from both cast sheet and cast bar specimens from each vendor.

General observations for the optimum heat-treatment

A summary of the microstructures obtained by the various vendors are shown in Figures 2-7. These figures are a combination of low and high magnification micrographs and show representative microstructures of both sheet and bar castings. In general, the microstructure varies significantly among the casting processes. The grain structure obtained in the Howmet castings is equiaxed and cellular in appearance (Figure 3) and finer in comparison to the PCC

and Hitchiner castings which typically displayed large dendritic grain structure (Figures 5 and 7). The dendritic structure in the Hitchiner castings (Figure 4) is also much finer in comparison to the PCC castings (Figure 6) which display a coarse microstructure. The grain structure in the Hitchiner castings was also columnar (Figure 4c), whereas the PCC grain structure was primarily equiaxed (Figure 6c).

There also were differences in microstructure between the sheet and bar castings. The Hitchiner material displayed a significantly smaller grain structure in the sheet form (Figure 4a and 4b) in comparison to the bar form (Figure 4c and 4d). In the PCC castings the grain structure in the sheet (Figure 6b) was only slightly smaller than that observed in the bar castings (Figure 6d). In the Howmet castings, the sheet material has retained slightly more of the dendritic structure, however, the grain structure still remains fine and mostly equiaxed (Figures 2a and 2b). The grain structure relative to the plate thickness is shown in Figures 2a, 4a, and 6a. The Howmet casting has the highest number of grains (8-9) through-the-thickness. On the other hand, the PCC and Hitchiner castings have significantly fewer grains (1-3).

In general, all the castings showed a significant amount of retained eutectic primarily at grain boundaries and interdendritic regions. The Howmet and PCC castings displayed large coarse eutectic structure (Figures 3 and 7 respectively). The Hitchiner castings displayed a more refined eutectic structure (Figure 5). The effect of the eutectic regions on the fatigue properties is not clear. Eutectics have on occasion shown up at initiation sites on crystallographic (111) facets, however, it should be noted that local regions associated with eutectics are also likely to include chemical segregation and micro porosity which can also initiate failure. The size and distribution of the retained and cooling γ' was very similar for all the castings (Figure 8). All castings show significant amount of cooling γ' .

Carbides

The carbide morphology for the three castings is shown in detail in Figure 9. EDS analysis suggests that the carbides present were primarily (Ti,Ta)C and HfC. In general, the (Ti,Ta)C are in the script form and within a γ' envelope. The HfC are typically smaller than the (Ti,Ta)C and are not jacketed by γ' and found primarily near the eutectics. In the PCC and Hitchiner castings the (Ti,Ta)C are in script form and typically found at the grain boundaries and interdendritic regions (Figure 9a and 9b). In the Howmet castings the (Ti,Ta)C are more blocky than script and are well dispersed both within the grains and grain boundaries (Figure 9c). In some cases, the (Ti,Ta)C carbides seem to be in the process of degeneration to form the more stable HfC as shown in Figure 9d.

Casting defects

In addition to the defects present in the HCF specimens that resulted in crack initiation and failure some additional defects were found in the metallographic sections. Photomicrographs of typical defects are shown in Figure 10. As determined by EDS analysis, hafnium-rich oxide inclusions were found in the Howmet castings (Figure 10a, and 10b), along with some porosity (Figure 10c). Some small porosity was also found in the PCC castings (Figure 10d). No HfO₂ inclusion were found in the PCC and Hitchiner castings. However, several large hafnium oxide inclusions were found to have initiated failures in the Hitchiner HCF specimens.

Microstructure of Howmet bar castings with the alternate heat treatments

The main goal of the alternate heat treatments was to solution more of the eutectic γ' in hopes of re-precipitating more finer γ' . The microstructure obtained by the alternate heat treatments was comparable to the Howmet cast microstructure obtained with the GE optimum heat treatment. However, quantitative metallography revealed that both the second and third alternate heat treatments reduced the volume fraction of γ/γ' eutectic in the Howmet castings from about 24 v/o for the optimum heat treatment to about 18 v/o. Also, outside the eutectic regions, the amount of γ' that was put into solution increased from about 78 v/o to about 93 v/o for the second and third alternate heat treatments.

Mechanical Testing

Tensile Results

The tensile properties of René 95 at 1400° F are shown in Table II. Among the various casting processes, the Howmet castings display better overall tensile properties. This may in part be attributed to the finer microstructure exhibited by the Howmet castings. The tensile properties obtained by the various alternate heat treatments on the Howmet bar castings are shown in Table III. All three alternate heat treatments, including alternate 1 which is identical to the GE optimum, produced somewhat higher yield and UTS in comparison to the GE optimum heat treatment. The reason for this discrepancy is not clear. However, comparison among the alternate heat treatments shows that only the third alternate heat treatment improved ductility. The second alternate heat treatment, which ages at 1400 °F resulted in slightly higher yield strength but significantly lower ductility.

HCF Results

The HCF testing was conducted on smooth bar specimens and sheet specimens. All specimens were machined from cast specimen blanks. Smooth HCF bar specimens with a 0.200 inch diameter and 0.75 inch gage were machined from bar castings having approximately ½ inch diameter. The HCF sheet specimens having approximately 0.06 inch by 0.250 inch cross-sections and 0.500 inch gage length were machined from sheet material having slightly oversized thickness. The specimen geometries were intended to simulate the dovetail and airfoil dimensions of a high pressure compressor blade.

Testing was conducted in axial load control using a sinusoidal waveform at 59 Hz with an A ratio (alternating stress/mean stress) of 1 and a R ratio (minimum stress/maximum stress) of 0. Testing temperatures were 1000° F and 1400° F. Testing, machining and specimen geometries all conform to ASTM E466. The test matrix for specimens tested from the various vendors that received the same optimum heat treatments is shown in Table IV. Table V. shows the test matrix for the Howmet specimens that were subjected to the alternate heat treatments. The alternate heat treated specimens were all tested at 1400° F.

The HCF life results of the bar specimens are shown in Figure 11. The data obtained from the sheet specimens were not plotted because they were plagued by failures at the loading pins (9 out of 18 test specimens). It is obvious from Figure 11 that HCF lives for the alternate heat treatments were significantly reduced in comparison to the HCF lives for the optimum heat

treatment even though the tensile properties were in general somewhat improved. The 10^7 cycle runout stress was about 35 ksi for the alternate heat treatments in comparison to 45 ksi for the optimized heat treatment. Furthermore, the HCF life among the alternate heat treatments did not seem to be affected by the heat treatments. As it will be shown by the fractography results, failure to HIP at 25 ksi resulted in significant porosity which dominated the initiation of failure and significantly reduced HCF life.

Fractography

Crack initiation

The HCF crack initiation characteristics exhibited by this alloy are typical of cast Ni-based superalloys and can be classified in two general categories: initiation from defects and Stage I crack initiation. An overview of the initiation sites leading to failure is shown in Figure 12.

Defect related initiations

Defect related failures in this alloy (and for the given casting and heat treating conditions) were exclusively HfO_2 inclusions and porosity. Inclusions consisting of mold material (alumina, silica, zircon ...) were also present but these were typically associated with the HfO_2 inclusions which may indicate a dross problem during casting.

Porosity was the primary initiation site for all the Howmet test specimens that were given the alternate heat treatment. As seen in Table V, 10 out of 14 HCF failures were initiated at porosity.

As indicated previously, the HIPing pressure for the alternate heat treatments was 15 ksi (instead of 25 ksi), and even though the HIPing was performed at a higher temperature (2250°F) than the optimized heat treatment (2165°F) it did not compensate for the lower HIPing pressure. Only one porosity initiated failure was observed for the specimens subjected to the optimized heat treatment. This implies that HIPing at 25 ksi heals most of the porosity.

Initiations from HfO_2 inclusions were found in specimens from Hitchiner and Howmet, but none were observed in the PCC specimens. The Howmet castings had the most failures initiated by HfO_2 inclusions (Figure 12). Furthermore, the remainder of the Howmet HCF specimens from the alternate heat treatments that did not initiate cracks at pores, also initiated cracks from HfO_2 inclusions.

In general, failure from HfO_2 inclusions was more prevalent in the sheet specimens. Failure from inclusions were also more likely to occur at the 1400°F test temperature and the higher stress conditions (55 ksi). Typical morphologies of the observed defects are shown in Figures 13 and 14. The data is inadequate to definitively identify the role of inclusions on HCF life for these castings and testing conditions. However, inclusions in general are detrimental to fatigue life. For example, in the Howmet bar specimens tested at 1400°F, the specimen tested at 50 ksi (in which failure initiated at an HfO_2) inclusion had about half the life of the specimen tested at 55 ksi (which failed from a Stage I crack). Similarly, the presence of unhealed porosity is very damaging to HCF life.

Stage I crack related initiations

Stage I initiations are classified as initiations that occur strictly on (111) crystallographic facets and in the absence of inclusions. This distinction is made because there are occasions where inclusions and porosity initiate failure along (111) planes however these initiations are governed primarily by the presence of the inclusion, (Figure 13c). Three type of Stage I related initiations were observed in this alloy:

- 1) Carbide related
- 2) Micro-porosity/eutectic related
- 3) Classical extrusion-intrusion failure at crystallographic plane

Typical Stage I failure sites are shown in Figure 15. In this alloy, carbide related failures on (111) planes were most common. Both HfC and (Ti,Ta)C were present at initiation sites, and at about the same frequency. Micro-porosity and eutectic related Stage I cracks and strictly (111) planar failures were less common. These failures however, were more difficult to discern because of the abundance of eutectic present in this alloy. In general, Stage I initiations were more common at the 1000°F test temperature and in the bar specimens. For example, all bar specimens tested at 1000°F failed from Stage I initiations. Under these conditions, the Howmet specimens exhibited the best HCF life. This may be partially attributed to the fact that the Howmet castings also exhibited the finest grain structure.

Crack propagation and tensile overload

Slow, stable crack growth in all cases occurred transgranularly. The crack path generally displayed little or no tortuosity (Figure 16). In the Hitchiner and PCC specimens which displayed large grain structure stable crack propagation commonly occurred on (111) crystallographic facets (Figure 17 and 18a and b). Some crack propagation along crystallographic facets was also observed in the Howmet casting, however, these facets were typically smaller (Figure 18c). Fast crack growth and overload typically occurred through interdendritic regions and occasionally intergranularly, with a much more tortuous crack path which followed along eutectics and fragmented carbides (Figure 19).

Conclusions

- 1) Howmet castings displayed the finest microstructure which was equiaxed and cellular in appearance. Howmet castings also displayed large coarse eutectic.
- 2) Based on the limited metallographic sections examined, the Howmet castings displayed the most HfO₂ inclusions.
- 3) Hitchiner castings displayed a fine columnar dendritic structure, and the most refined eutectic.
- 4) In comparison to the Hitchiner castings, the PCC castings had a coarser but more equiaxed dendritic structure and coarser eutectic.

- 5) Some variation in grain structure between the sheet and bar castings was evident especially for the Hitchiner and Howmet castings. This may imply that the grain structure may also differ in the blade castings.
- 6) The alternate HIP and heat treatments that employed higher HIP, solution, and aging temperatures were successful in solutioning and reprecipitating more γ' .
- 7) The most commonly observed defects for the specimens that were subjected to the optimum heat treatment were HfO_2 inclusions.
- 8) The Howmet specimens from the alternate heat treatments failed primarily from unhealed porosity due to the failure to HIP at 25 ksi.
- 9) HfO_2 inclusions were found as initiation sites in both the Hitchiner and Howmet castings. None were observed in the PCC castings. This may be a result of dross and is probably related to the differences in casting processes.
- 10) Defect initiated failures were more common at the higher temperature (1400°F) and higher stress conditions (55 ksi) and in sheet specimens.
- 11) Stage I initiations were more common at the lower test temperature (1000°F), and were most commonly associated with (HfC and (Ti,Ta)C) carbides.
- 12) At 1000°F, the initiation mode for the bar specimens was dominated by Stage I initiations.

References

1. Howmet Technical Bulletin 3101, "Microcast-X® IN-718", 1991.
2. "High T_3 Compressor Material Development Task Order 53 - Final Report", Prepared for NASA Lewis Research Center by General Electric Aircraft Engines under Contract NAS3-26617.

Table I. Composition of René 125 blade alloy

Element	Co	Cr	Mo	W	Al	Ti	Ta	Hf	Zr	B	C	Ni
w/o	10	9	2	7	5	2.5	4	1.5	0.05	0.02	0.1	Balance

Table II. 1400 °F Smooth tensile properties for R125 cast bar with optimum heat treatment

Vendor	Y.S., ksi	U.T.S., ksi	EL, %
Howmet	130	168	8.0
Hitchiner	124	161	7.6
PCC	118	157	8.7

Table IV. 1400°F Tensile Properties of Howmet René 125

Treatment	Y.S., ksi	U.T.S., ksi	EL, %	RA, %
Standard HIP, DOE optimum heat treatment	130	168	8.0	10
*Alternate 1	138	173	8.5	12
	138	174	11	12
Alternate 2	140	160	**2.5	6.5
	140	173	5.5	7.5
Alternate 3	139	169	13	16
	137	169	14	17

*Same as DOE optimum heat treatment w/15 ksi HIP pressure

**Failed at extensometer knife edge

TABLE V. R125 test matrix and fractographic results for specimens with the optimum heat treatment.

Testing Conditions				Inclusion			
Bar HCF	T, °F	σ_{th} , ksi	N ₀ , Cycles	Type**	Size, μ m	Depth, μ m	Facet
HIT-19	1000	50	160,587	---	760X760	400	Stage I
HIT-20	1000	45	283,900	MP	1000X360	1000	Stage I
HIT-21	1000	40	441,767	(Ti,Ta)C	1900X875	1870	Stage I
HIT-22	1400	55	66,773	HfO ₂	400X127	965	Y
HIT-23	1400	50	2,180,000	---	500X600	650	Stage I
HIT-24	1400	45	*runout				
PCC-32	1000	50	72,286	HfC	145X100	270	Stage I
PCC-33	1000	45	114,160	---	750X500	1800	Stage I
PCC-34	1000	30	runout				
PCC-35	1400	55	30,889	P, Hf	63	270	N
PCC-14	1400	50	32,543	C		316	
PCC-15	1400	40	3,029,786	---	260	0	Stage I
HOW-40	1000	50	292,546	(Ti,Ta)C	172X325	0	Stage I
HOW-41	1000	45	383,647	---	200X330	200	Y
HOW-46	1000	30	runout				
HOW-56	1400	55	247,500	E/HfC	200X100	770	Stage I
HOW-57	1400	50	121,600	HfO ₂	254X200	1321	Y
HOW-58	1400	40	runout				
Sheet HCF	T, °F	σ_{th} , ksi	N ₀ , Cycles	Type	Size, μ	Depth, μ	Facet
HIT-18	1000	45	54,837	HfO ₂ ,M	1270X1118	51	N
PCC-28	1000	50	54,059	HfC	(2) 26X15	72	Y
PCC-30	1000	45	104,035	(Ti,Ta)C	31 X 23	38	Stage I
PCC-32	1000	40	466,735	E	260X345	0	Stage I
PCC-35	1400	50	49,967	(Ti,Ta)C	97 X97	196	Stage I
HOW-16	1400	55	41,776	HfO ₂ ,M	775 X 566	580	N
HOW-17	1400	50	3,294,995	HfO ₂	114 X 75	130	Y

*10⁷ cycles for runout

** See table below for explanation of the defect types

CODE	INCLUSION TYPE
HfO ₂	hafnium-rich (oxide)
HfC	hafnium carbide
(Ti,Ta)C	Ti/Ta script carbide
E	eutectic
C	carbide (not identified)
P/MP	porosity/micro porosity
M	mold material (Al-Si-Ca-Mg)

Table VI. 1400°F HCF Behavior of Howmet René 125 having the alternate heat treatments

Treatment-Specimen	σ_{alt} , ksi	N_f , cycles	Inclusion Type*	Inclusion Size, μm	Inclusion Depth, mm
1-6	45	538,866	P,E	160	0.7
1-7	40	724,398	P	120	0.6
1-8	40	3,035,724	P	120	1.4
	35	*runout			
	30	runout			
1-5	37.5	948,647	HfO ₂	900	0.8
1-4	36	runout	-	-	-
2-4	45	326,062	P	200	1.6
2-7	40	706,961	HfO ₂	150	0.3
2-5	40	340,161	P	120	1.5
	35	runout			
	30	runout			
2-3	37.5	2,350,077	P	180	0.3
2-6	36	12,626,384	P	100	0.6
3-3	45	556,870	P	160	0.9
3-1	40	2,031,587	P	210	1.1
3-2	40	401,542	HfO ₂	220	1.2
	35	runout			
	30	runout			
3-6	37.5	848,361	HfO ₂	230	0.5
3-7	36	2,498,529	P	240	1.6

* See table below for explanation of the defect types

CODE	INCLUSION TYPE
HfO ₂	hafnium-rich (oxide)
HfC	hafnium carbide
(Ti,Ta)C	Ti/Ta script carbide
E	eutectic
C	carbide (not identified)
P/MP	porosity/micro porosity
M	mold material (Al-Si-Ca-Mg)

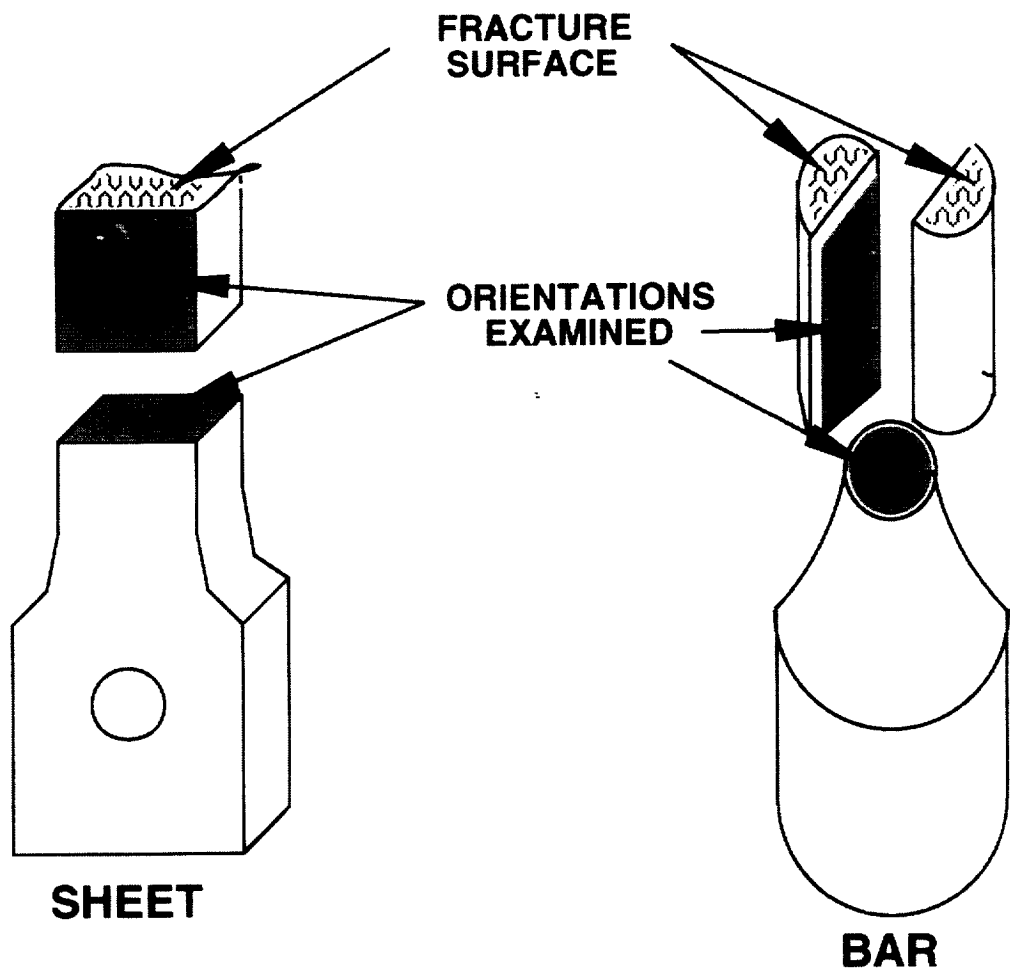


Figure 1. Schematic depicting the location and orientation of metallographic sections. (L) orientation is typically through the fracture surface and parallel to the loading direction. (T) orientation is typically through the specimen thickness and perpendicular to the loading direction.

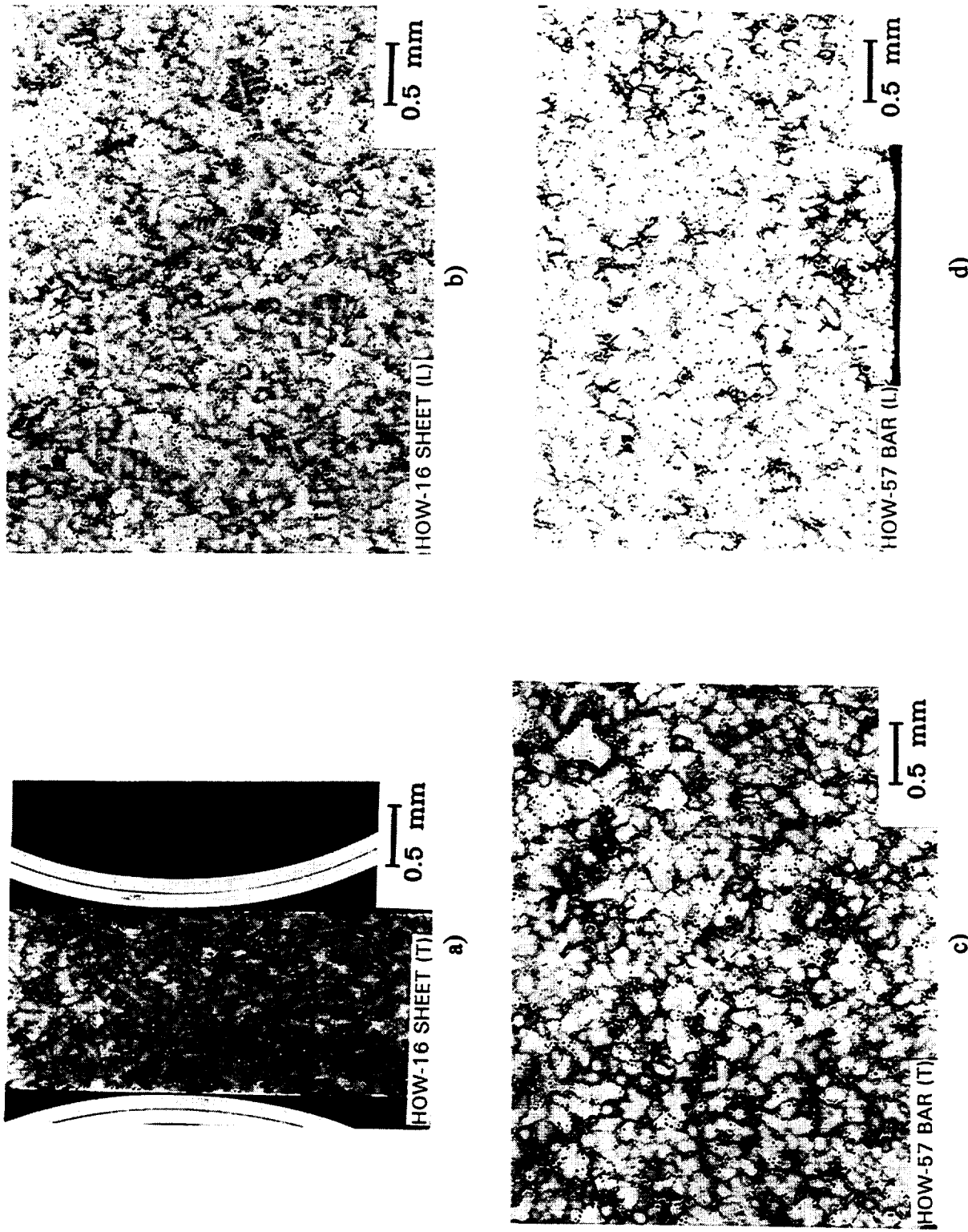
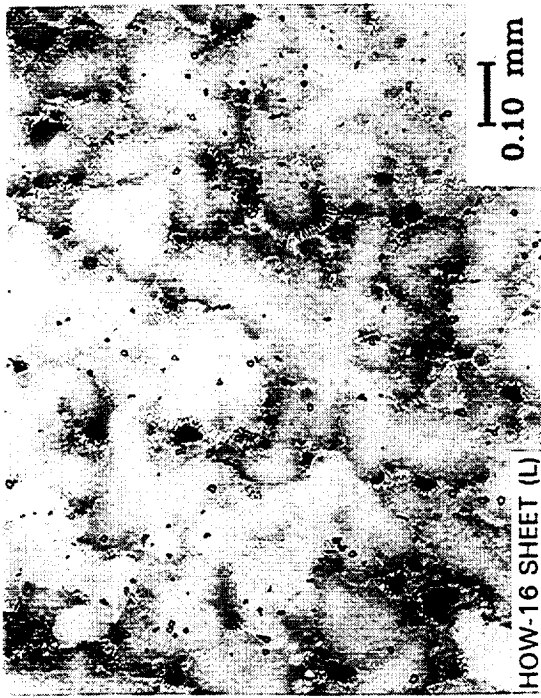


Figure 2. Low magnification view of Howmet cast R125 microstructure, a) HOW-16 sheet (T) orientation, b) HOW-16 sheet (L) orientation, c) HOW-57 bar (T) orientation, and d) HOW-57 bar (L) orientation.



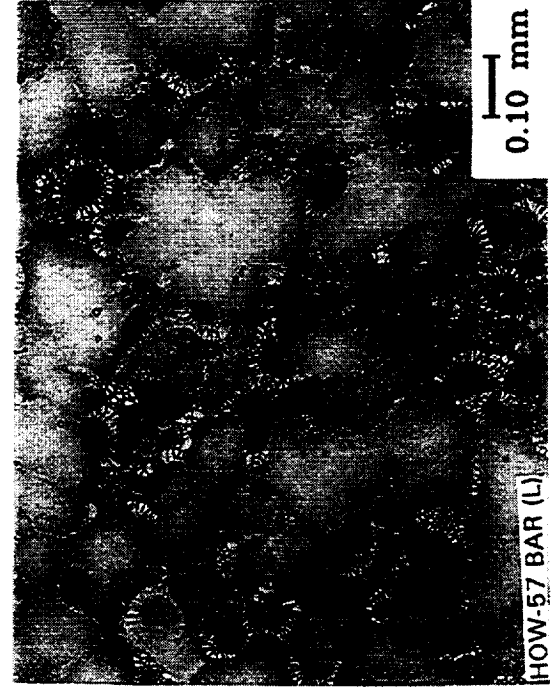
a)



b)



c)



d)

Figure 3. High magnification view of Howmet cast R125 microstructure, a) HOW-16 sheet (T) orientation, b) HOW-16 sheet (L) orientation, c) HOW-57 Bar (T) orientation, and d) HOW-57 bar (L) orientation.

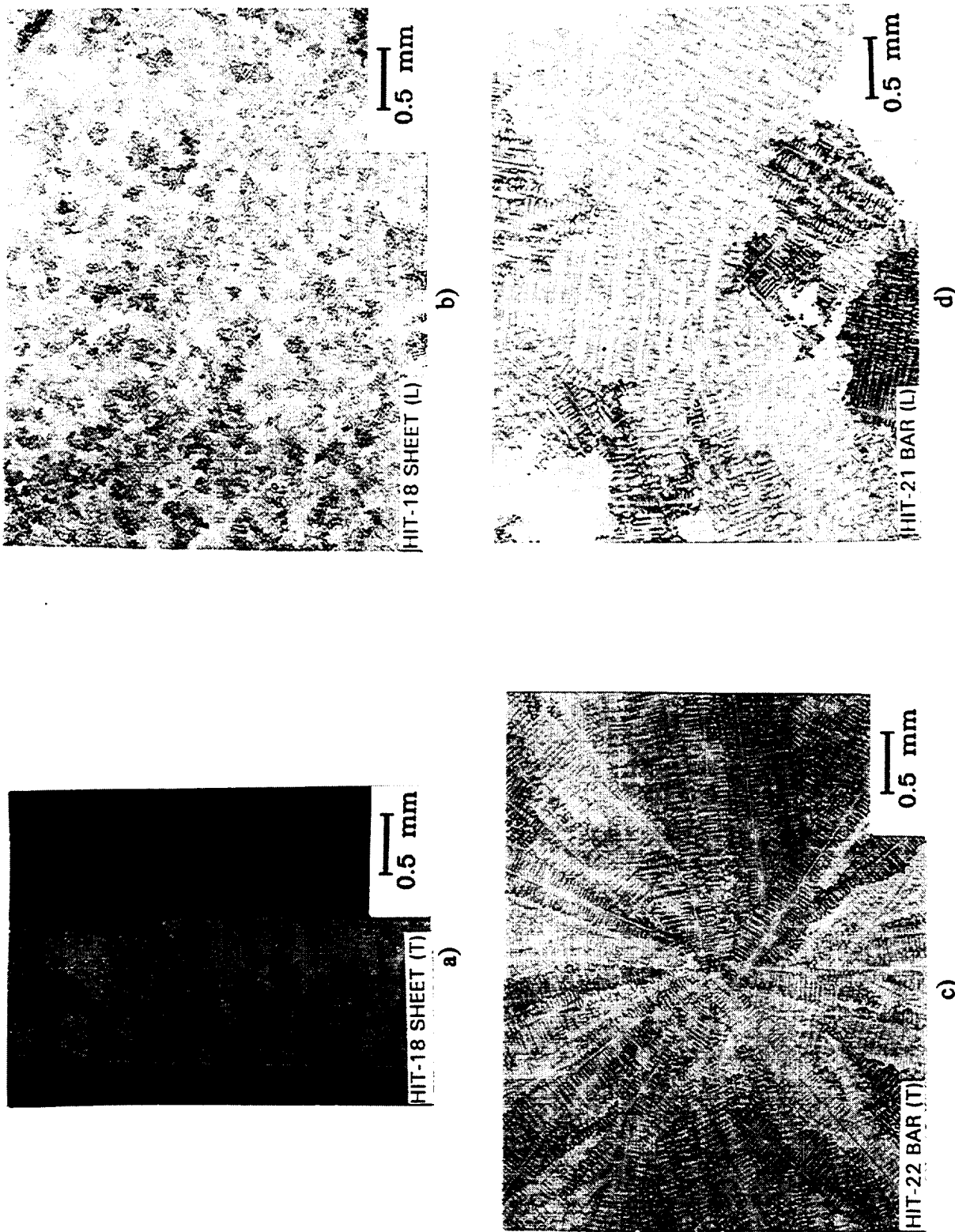


Figure 4. Low magnification view of HITCHER cast R125 microstructure, a) HIT-18 sheet (T) orientation, b) HIT-18 sheet (L) orientation, c) HIT-22 bar (T) orientation, and d) HIT-21 bar (L) orientation.

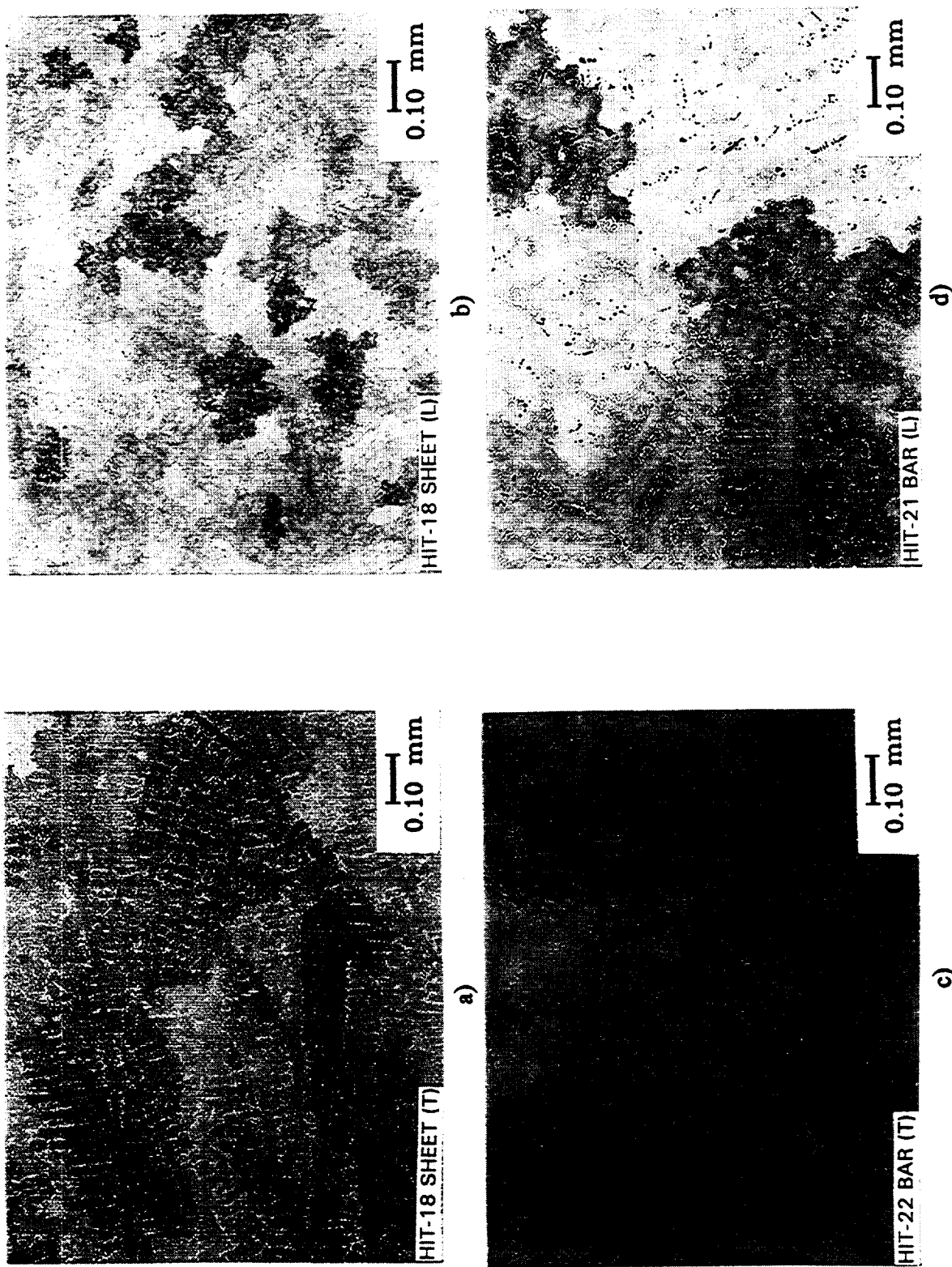


Figure 5. High magnification view of Hitchiner cast R125 microstructure, a) HIT-18 sheet (T) orientation, b) HIT-18 sheet (L) orientation, c) HIT-22 bar (T) orientation, and d) HIT-21 bar (L) orientation.

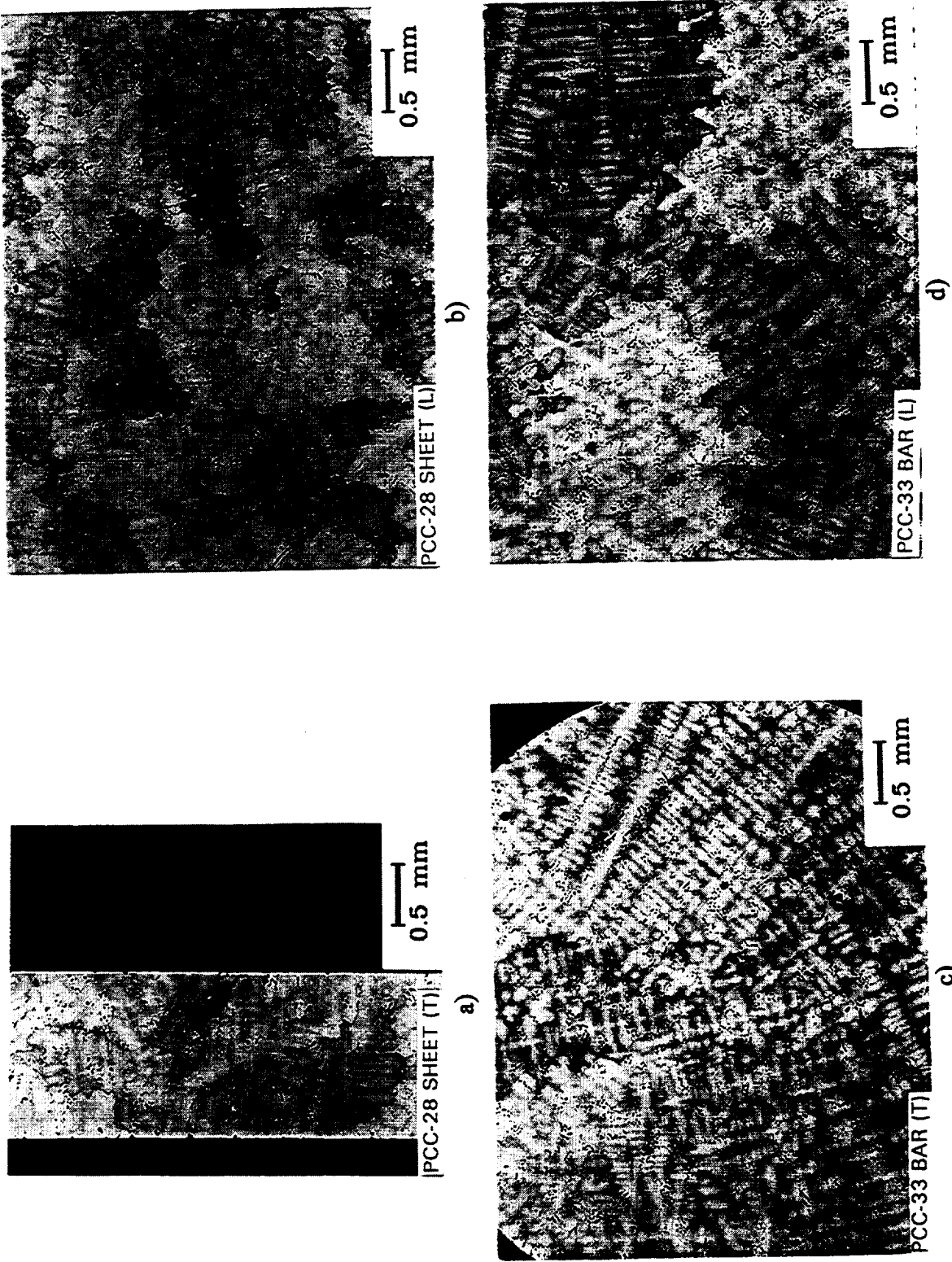


Figure 6. Low magnification view of PCC cast R125 microstructure, a) PCC-28 sheet (T) orientation, b) PCC-28 sheet (L) orientation, c) PCC-33 bar (T) orientation, and d) PCC-33 bar (L) orientation.

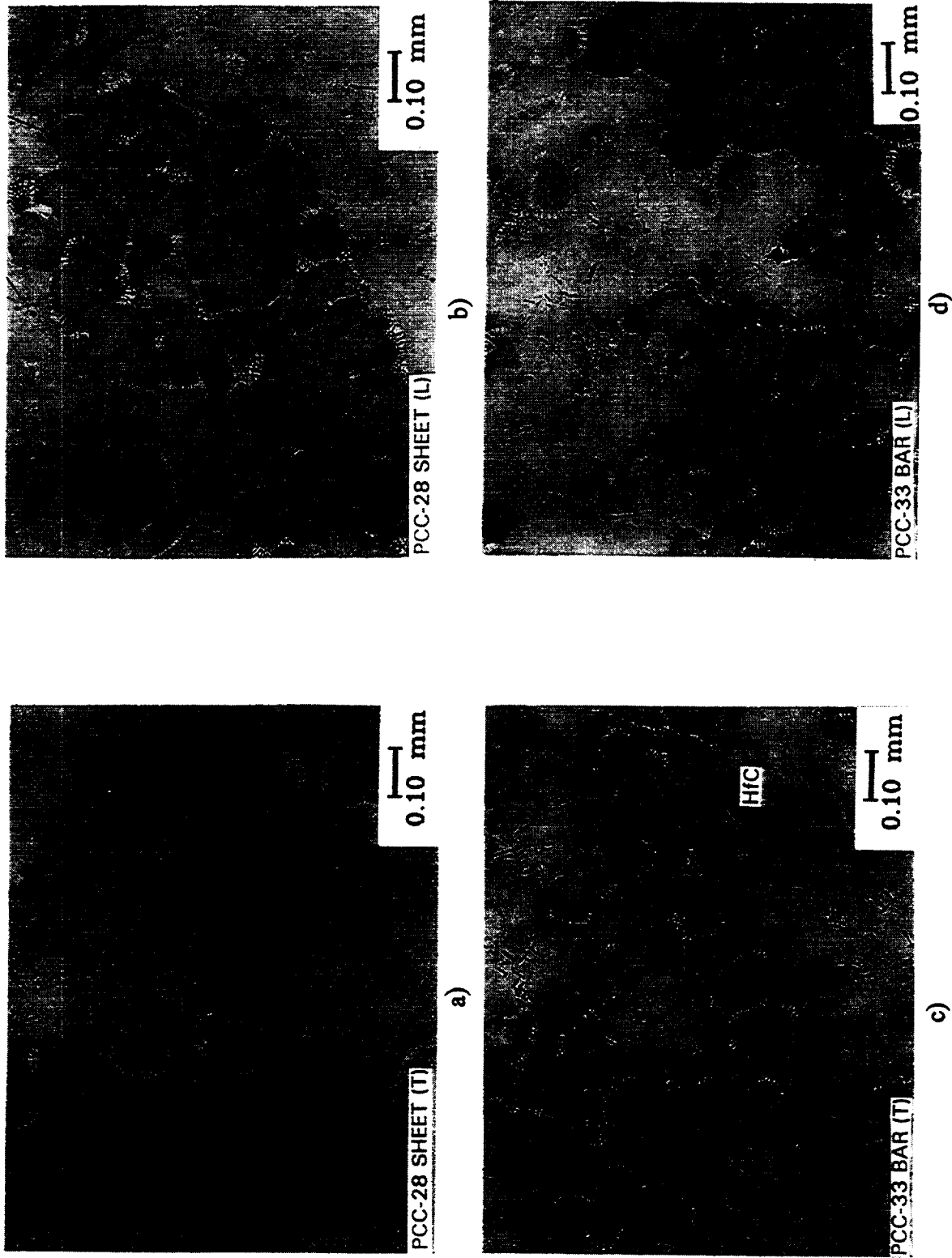
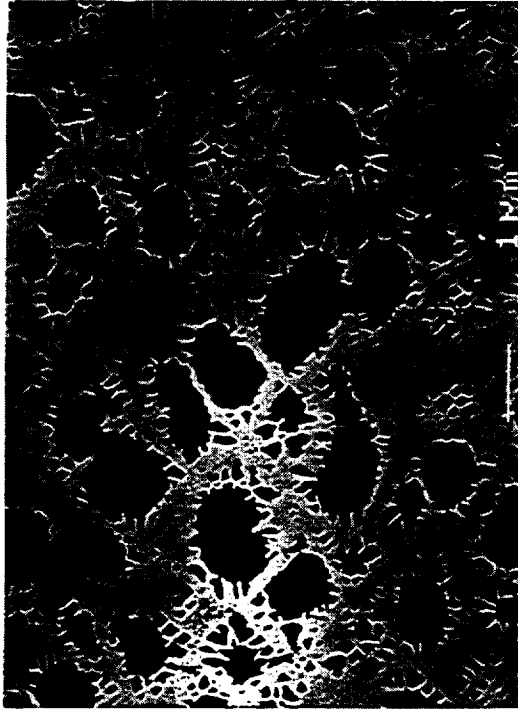
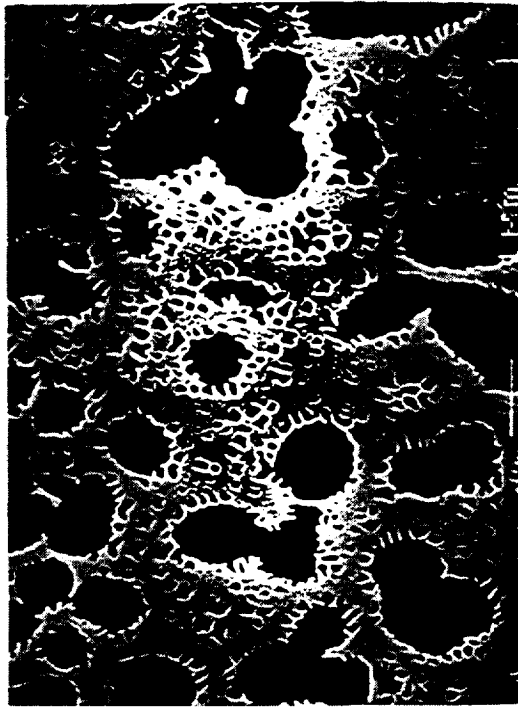


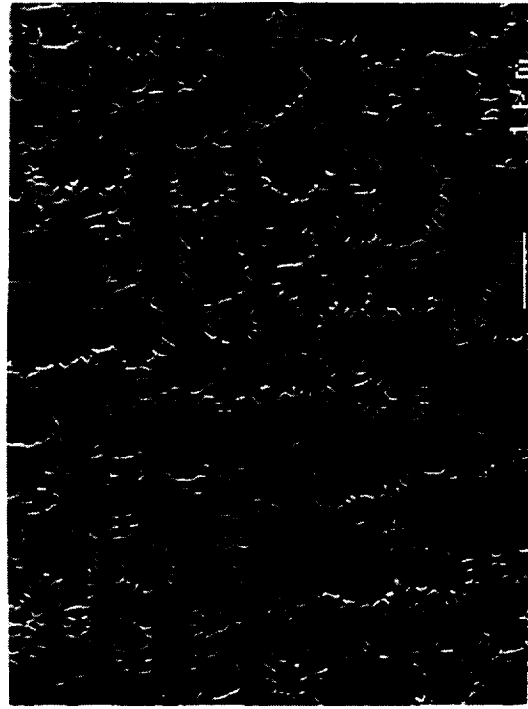
Figure 7. High magnification view of PCC cast R125 microstructure, a) PCC-28 sheet (T) orientation, b) PCC-28 sheet (L) orientation, c) PCC-33 bar (T) orientation, and d) PCC-33 bar (L) orientation.



a)



b)



c)

Figure 8. Precipitate morphology of retained and cooling γ' for various bar castings, a) HIT-22 bar, b) PCC-33 bar, and c) HOW-16 sheet, having the optimum heat treatment.

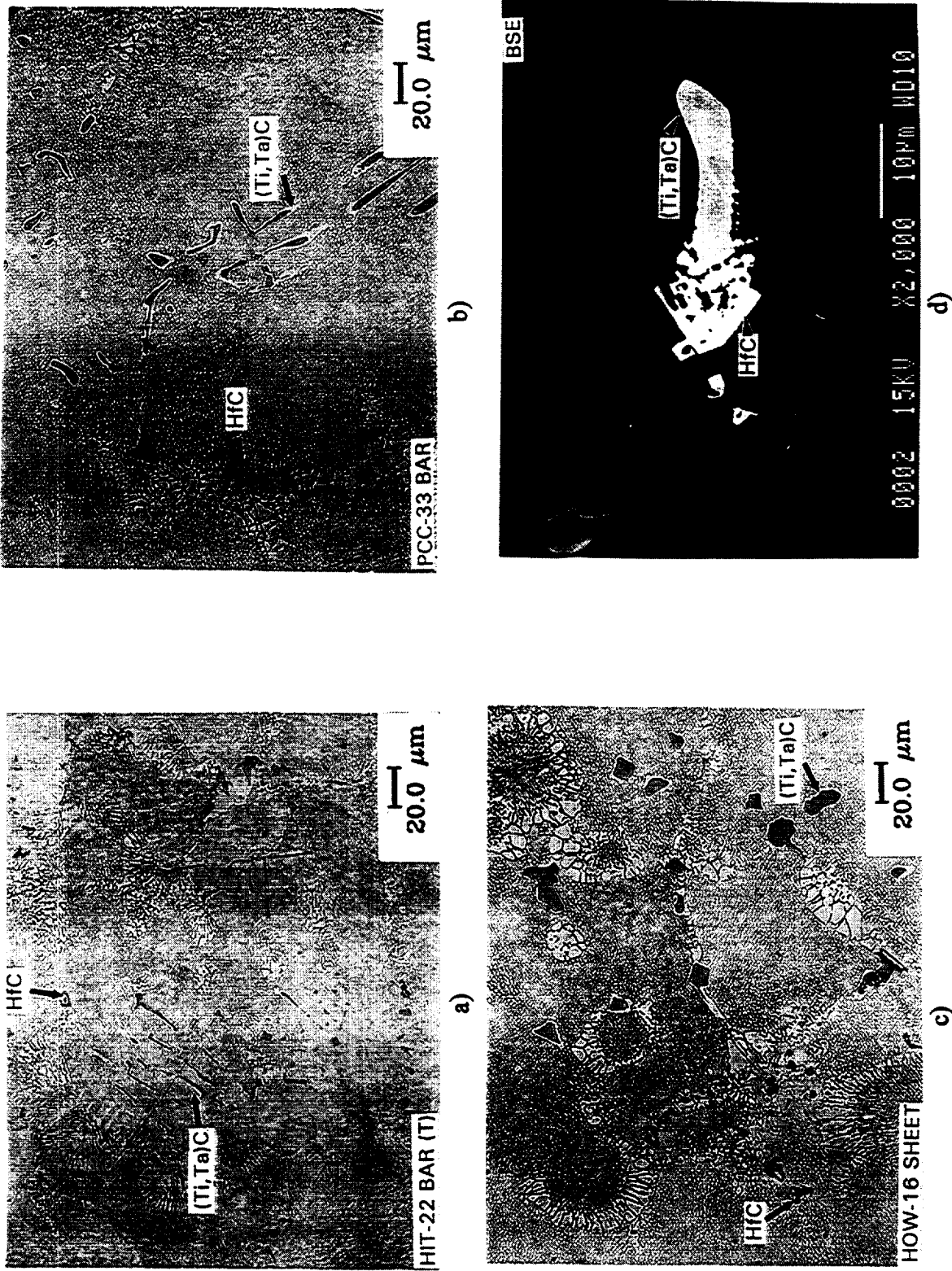


Figure 9. Typical carbide morphology, a) HIT-22 bar, b) PCC-33 bar, c) HOW-16 sheet, and d) high magnification micrograph of (Ti,Ta)C to HfC transformation.

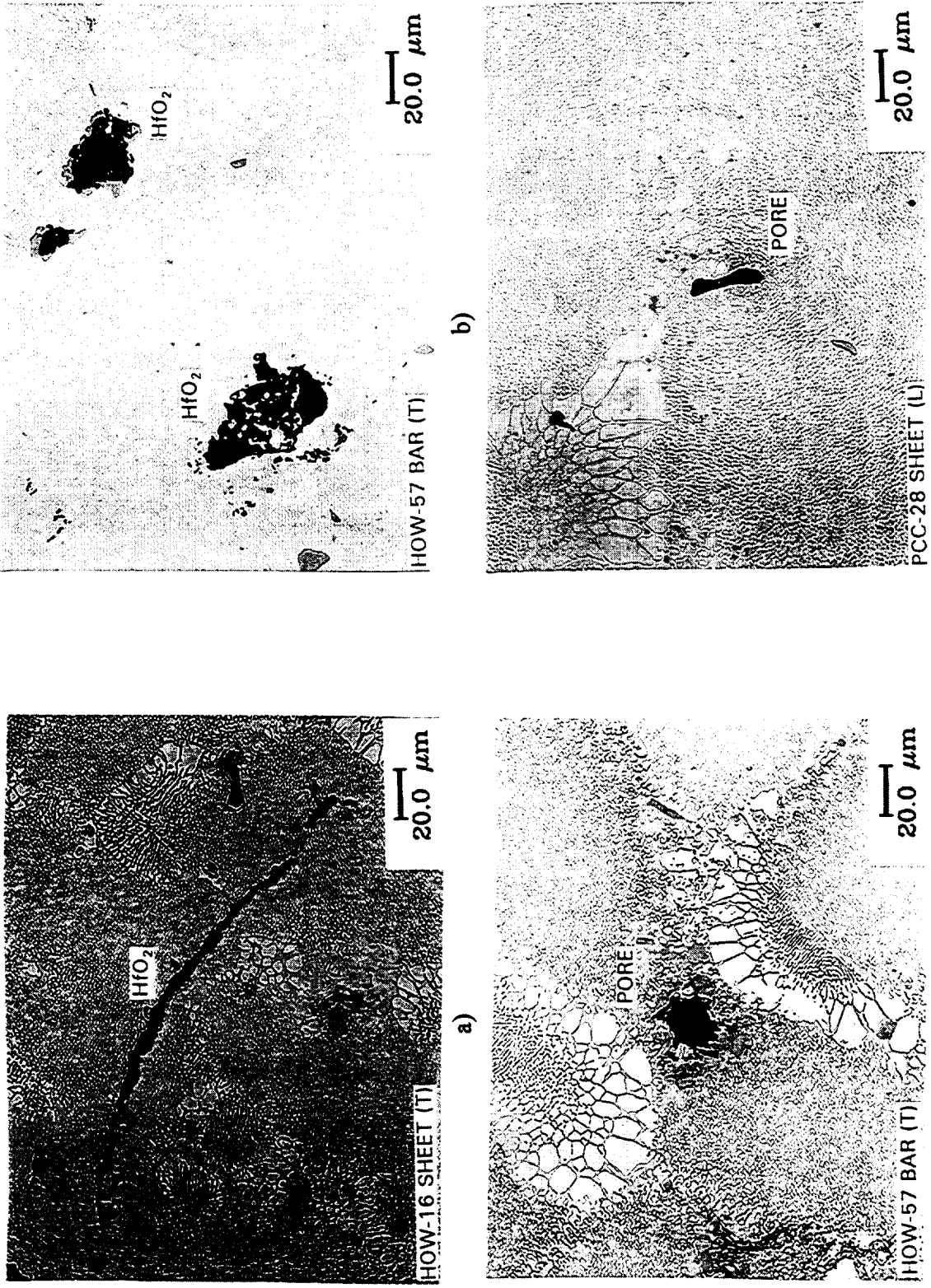


Figure 10. Typical casting defects in cast R125, a), and b), typical HfO_2 inclusions in Howmet castings, c) typical micro porosity in Howmet castings, and d) typical porosity in PCC castings.

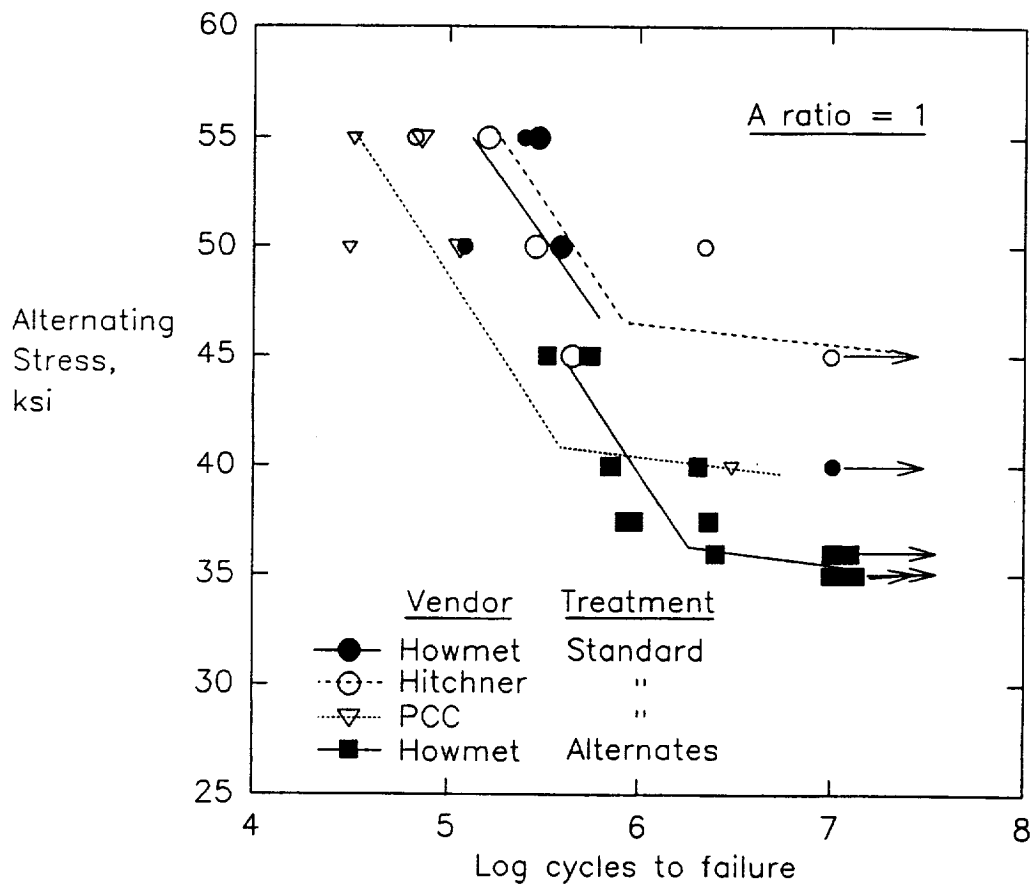


Figure 11. HCF life of cast alloy R125. Data shown is from bar castings manufactured by three different vendors, Howmet, Hitchner, and PCC. Large symbols represent 1400°F, small represent 1000° F. Also shown (solid square) is the HCF life for the alternate heat treatments.

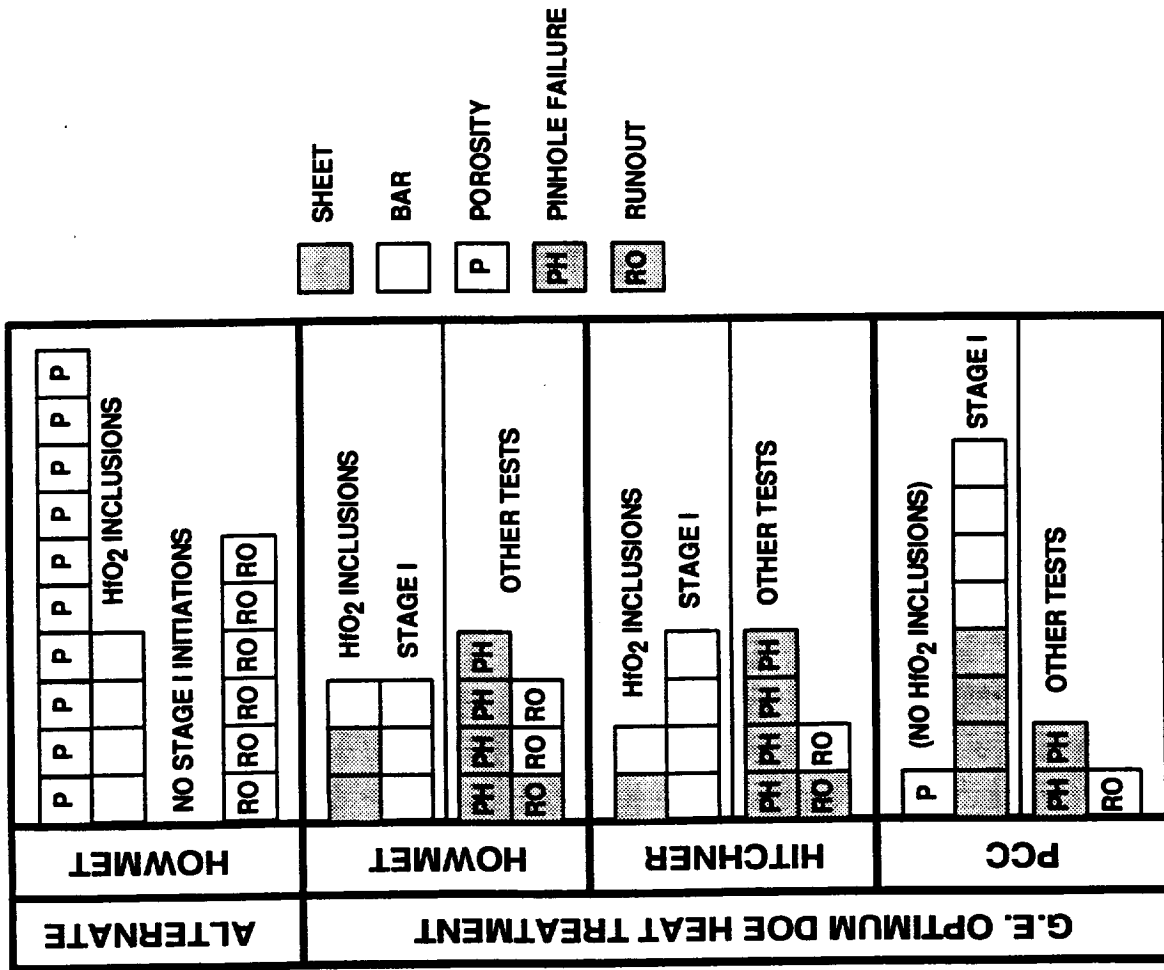


Figure 12. Comparison of the type of HCF initiation sites observed in R125 bar and sheet castings based on the manufacturer and regardless of testing conditions. Note each block represents one specimen, and also no distinction is made between the alternate heat treatments.



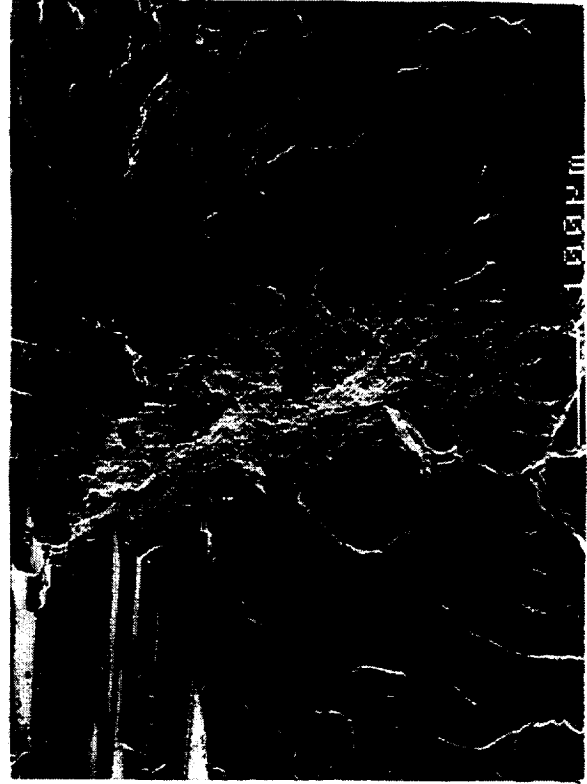
a)



c)



b)



d)

Figure 13. Typical defects found in cast R125 which resulted in HCF initiation and failure, a) HfO_2 inclusion in Howmet sheet specimen, b) large HfO_2 inclusion in Hitchiner sheet specimen, c) HfO_2 inclusion in Howmet bar specimen, d) HfO_2 inclusion in Hitchiner bar specimen.



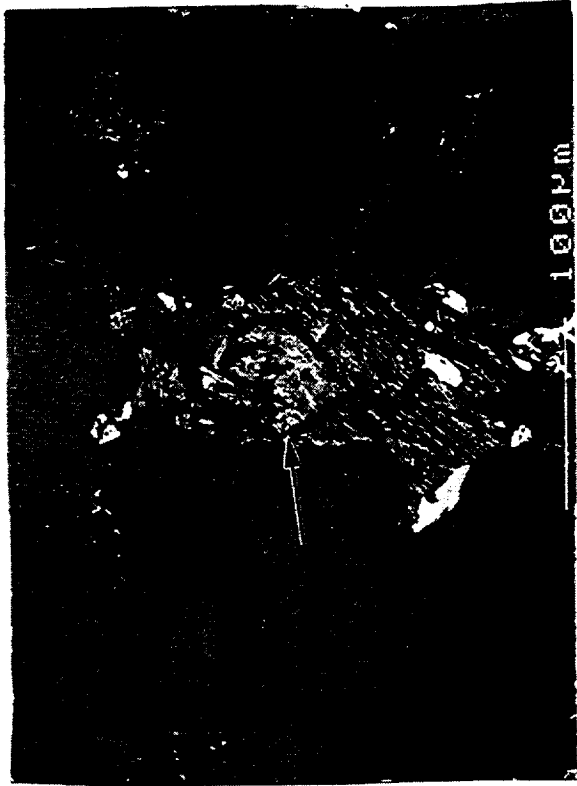
a)



b)



c)



d)

Figure 14. Typical porosity initiations, a) ,b) , and c) as a result of lower HIPping pressure in the alternate heat treated material, and d) the only pore failure observed in the optimum heat treated.

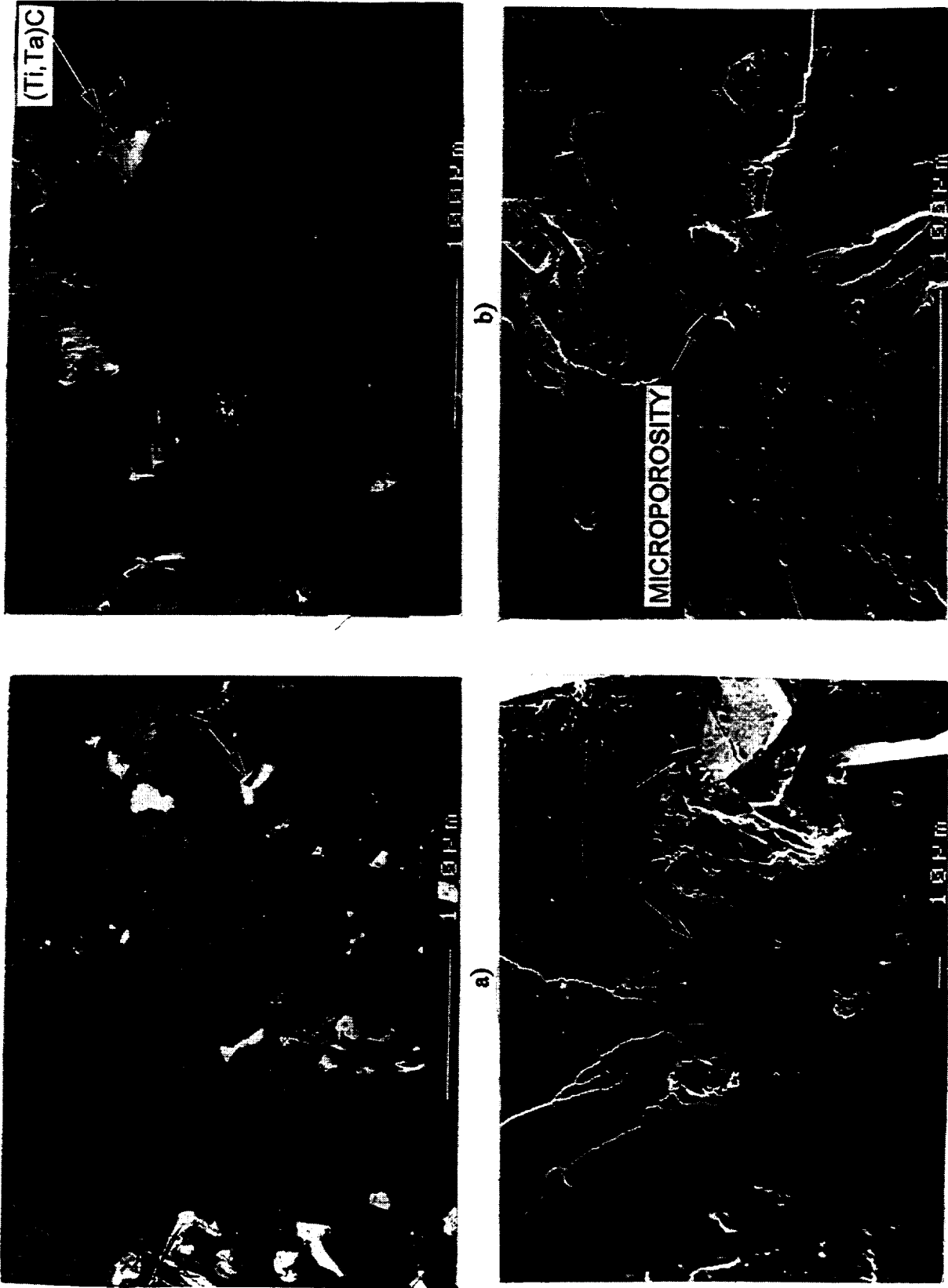
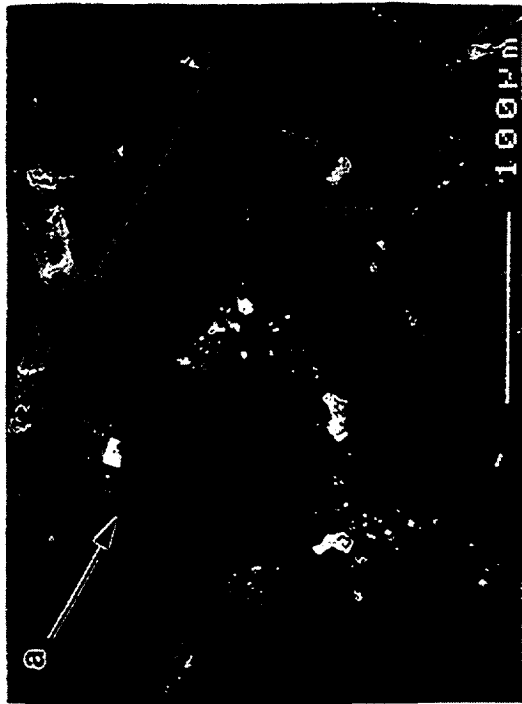
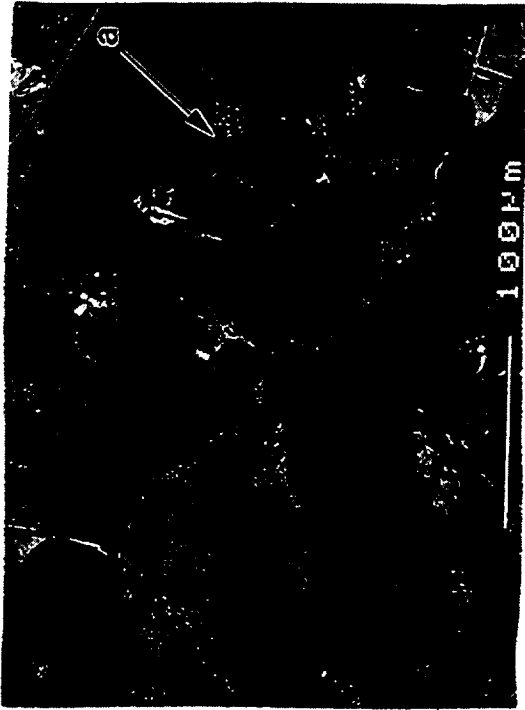


Figure 15. Typical Stage I initiation sites, a) HfC initiated facet in PCC sheet specimen, b) (Ti,Ta)C initiated facet in PCC sheet specimen, c) eutectic and/or micro-pore initiated facet in PCC bar specimen, d) micro-pore initiated facet in Hirschner bar specimen.



a)



b)

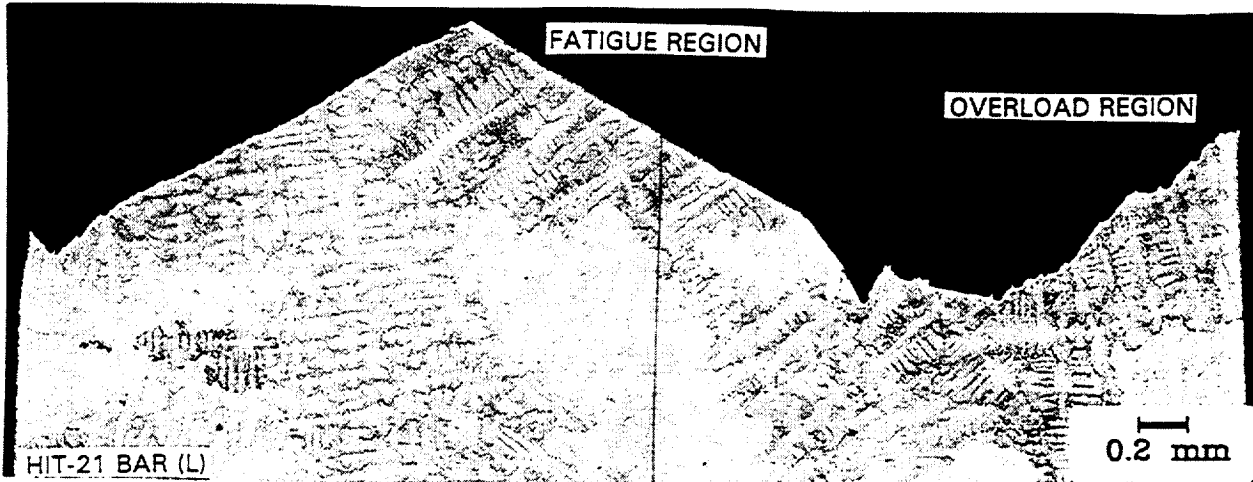


c)

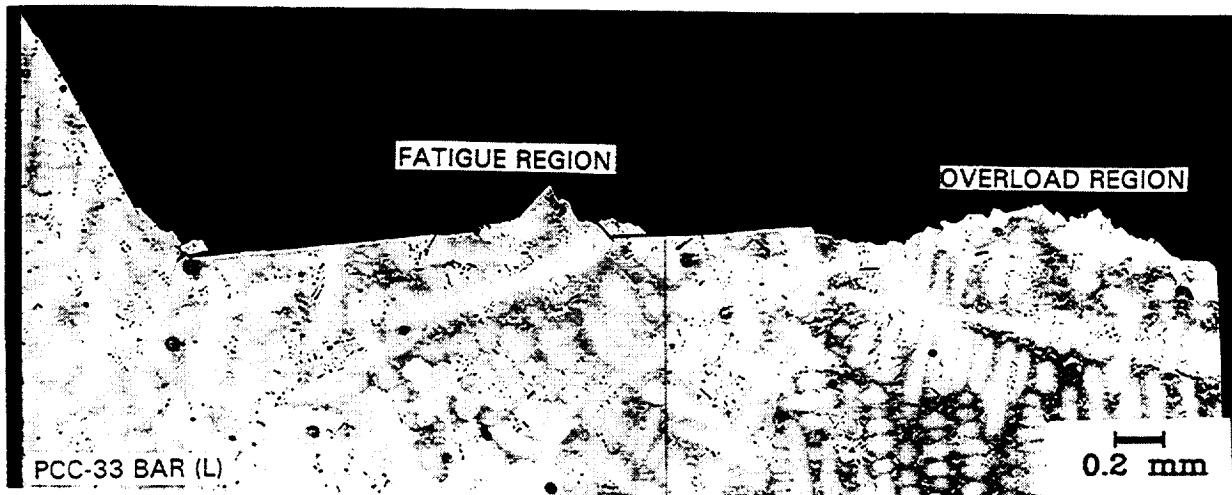
Figure 16. Typical slow crack growth fracture morphology, a) Howmet specimen, b) Hitchiner specimen and c) PCC specimen.



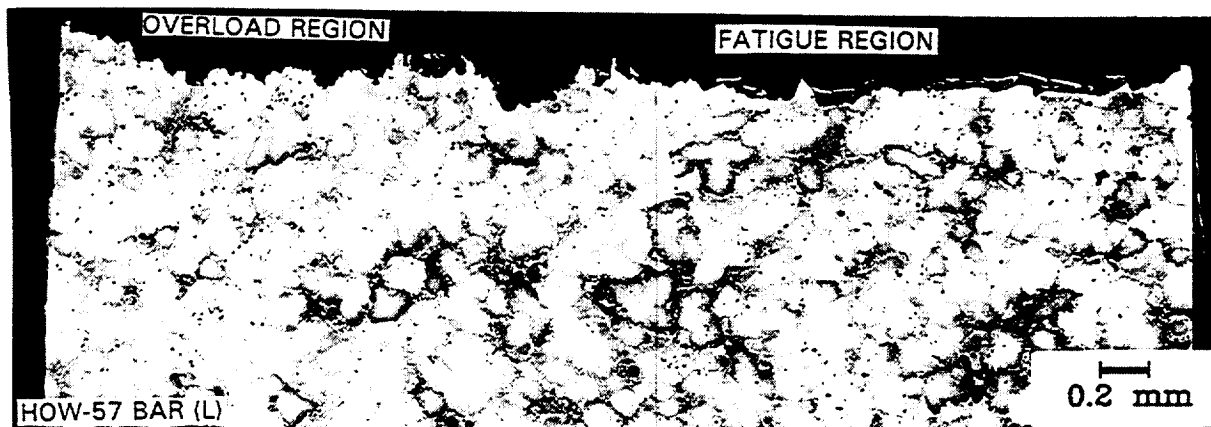
Figure 17. Extensive Stage I stable crack propagation, typically found in Hitchiner and PCC specimens with large grain structures.



a)



b)



c)

Figure 18. Metallographic sections through the fracture surface of a) Hitchiner, b) PCC, and c) Howmet bar specimens.



a)



b)



c)

Figure 19. Typical fast crack growth and overload fracture surface morphology, a) Howmet specimen, b) Hitchiner specimen and c) PCC specimen.

REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words) This study was conducted in order to investigate and document the high cycle fatigue crack initiation characteristics of blade alloy René 125 as cast by three commercially available processes. This alloy is typically used in turbine blade applications. It is currently being considered as a candidate alloy for high T ₃ compressor airfoil applications. This effort is part of NASA's Advanced Subsonic Technology (AST) program which aims to develop improved capabilities for the next generation subsonic gas turbine engine for commercial carriers. Wrought alloys, which are customarily used for airfoils in the compressor, cannot meet the property goals at the higher compressor exit temperatures that would be required for advanced ultra-high bypass engines. As a result cast alloys are currently being considered for such applications. Traditional blade materials such as René 125 have the high temperature capabilities required for such applications. However, the implementation of cast alloys in compressor airfoil applications where airfoils are typically much thinner does raise some issues of concern such as thin wall castability, casting cleanliness, and susceptibility to HCF loading.			
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