Program 7 **Investigation of the Reaction Kinetics Between SiC Fibers and Selectively Alloyed Titanium Matrix Composites and Determination of Their Mechanical Properties**

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Objective

The objective of this study is to investigate fiber-matrix interactions in selected titanium reinforced composites and to define reaction kinetics and influences on the mechanical properties of the composites.

Investigation of the Reaction Kinetics Between SCS-6 Fibers and Ti-1100 and Determination of Their Mechanical Properties

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Abstract

During high temperature exposure, an interfacial reaction occurs between SiC fiber reinforcement and titanium matrices which can be detrimental to the mechanical properties of the composite. The reaction kinetics between SCS-6 fibers and Ti-1100 were determined at 800 to 1000°C and found to be slower than those of other currently used titanium alloys (Ti-15-3, Ti-6-4). The experimentally determined reaction kinetics for Ti-1100 were extrapolated to 700°C and found to accurately predict reaction zone size after 1000 hours of exposure. Predictions of the time to consume the surface layer on the SCS-6 and SCS-9 fibers were made in an effort to estimate the time that the fiber will retain its strength in Ti-1100 during isothermal exposure at high temperatures. Using this approach, the strength of an SCS-6 fiber in Ti-1100 should be retained for over 20,000 hours at isothermal exposures less than 800°C. Strength predictions using the rule of mixtures for a unidirectional Ti-1100/SCS-6 composite are presented for short term exposures up to 700°C. Room temperature tests of an as-fabricated 20 volume percent fiber/Ti-1100 composite yielded a UTS of 226 ksi (1490 MPa) which is close to that predicted by the ROM.

INVESTIGATION OF THE REACTION KINETICS BETWEEN SCS-6 FIBERS AND Ti-1100 AND DETERMINATION OF THEIR MECHANICAL PROPERTIES

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OBJECTIVE: TO INVESTIGATE FIBER-MATRIX INTERACTIONS OF SCS TYPE SiC FIBERS WITH Ti-1100 AND DETERMINE THE EFFECT ON MECHANICAL PROPERTIES OF THE COMPOSITE.

APPROACH:

FABRICATE COMPOSITES USING:

FIBERS - SCS-0 (140 μ), NO SURFACE LAYER
SCS-9 (75 μ), C-RICH SURFACE LAYER, 3.0 μ
SCS-6 (140 μ), C-RICH SURFACE LAYER, 4.5 μ
TiB_2 (1 μ) COATED SCS-6

MATRICES - Ti-1100 NEAR α
(Ti-6Al-2.8Sn-4.0Zr-.4Mo-.45Si-.07O_2-<.03Fe)

For Comparison

UNALLOYED (UA) Ti	
Ti-6Al-4V	$\alpha + \beta$
Ti-15V-3Al-3Cr-3Sn	β
BETA 21S (Ti-15Mo-2.7Nb-3Al-.2Si)	β
Ti-14(wt%)Al-21(wt%)Nb	$\alpha_2 + \beta$

FABRICATION - HAND LAYUP USING FOILS, 10-15 v/o FIBER, VACUUM HOT PRESSING

THERMAL EXPOSURE - VACUUM ENCAPSULATED AND HEATED 800 - 1100^{o}C FOR 5 - 150 HOURS

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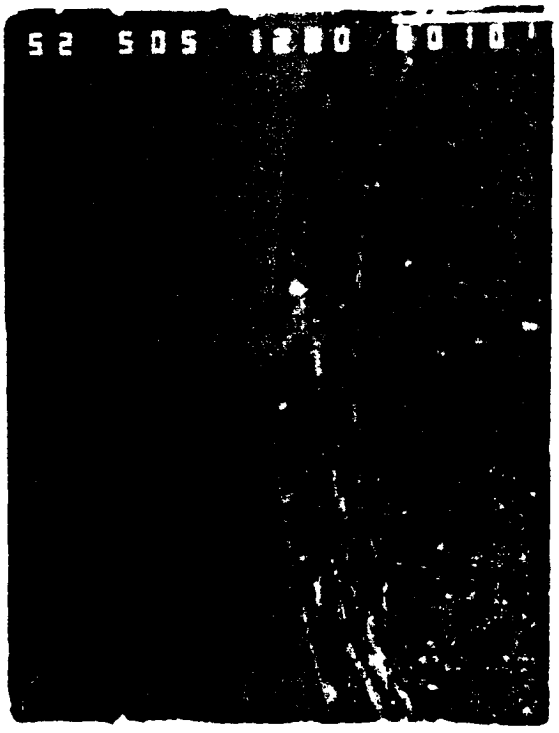
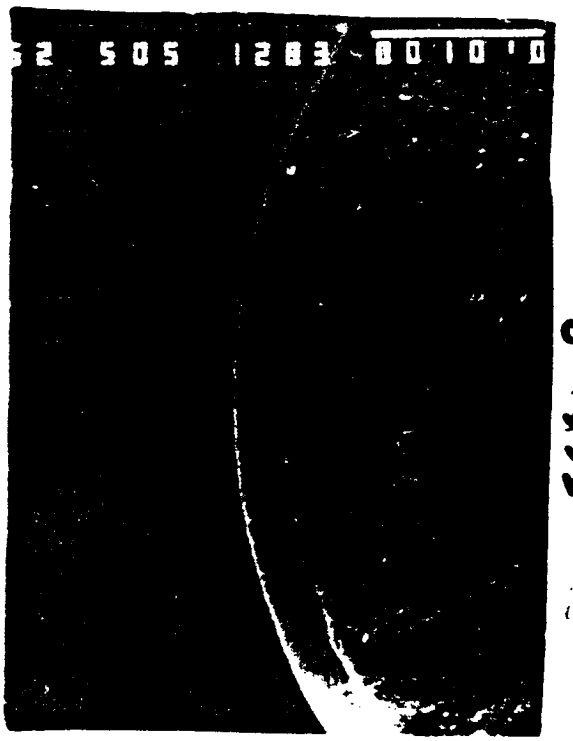
TIR/SCS-6

SCS-0



SCS-6



SCS-9

Matrix	UA Ti	Ti-15-3	Ti-6-4	Ti1100	Ti-14Al-21Nb
Fabrication Temperature(^{o}C)	850	875	950	975	1050
As-Fab. RZ Thickness (μm)	.43	.67	.66	.42	.58

Table 1. Fabrication parameters of the SCS-6 composites used in this study. All samples were fabricated using 15 ksi for 30 minutes.

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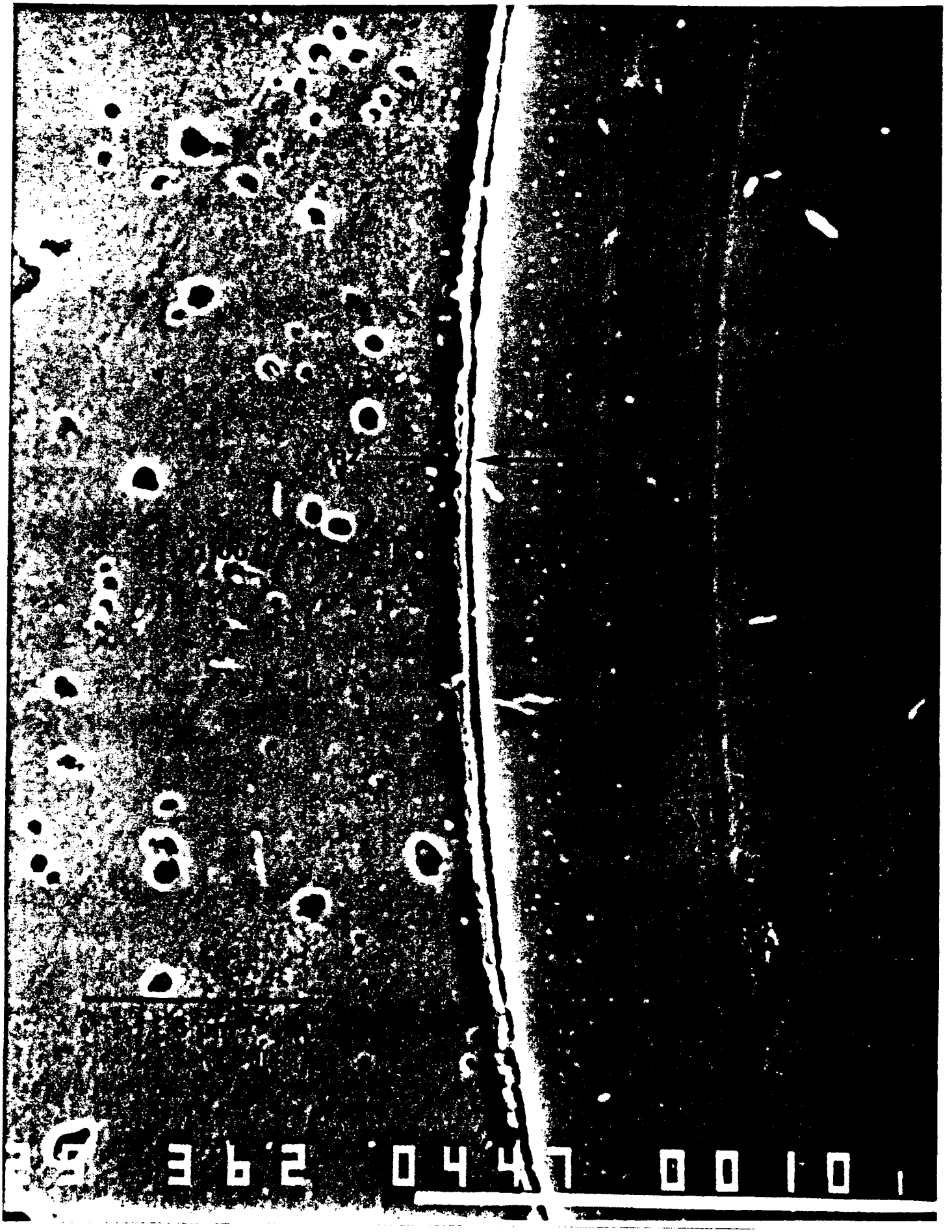


REACTION KINETICS:

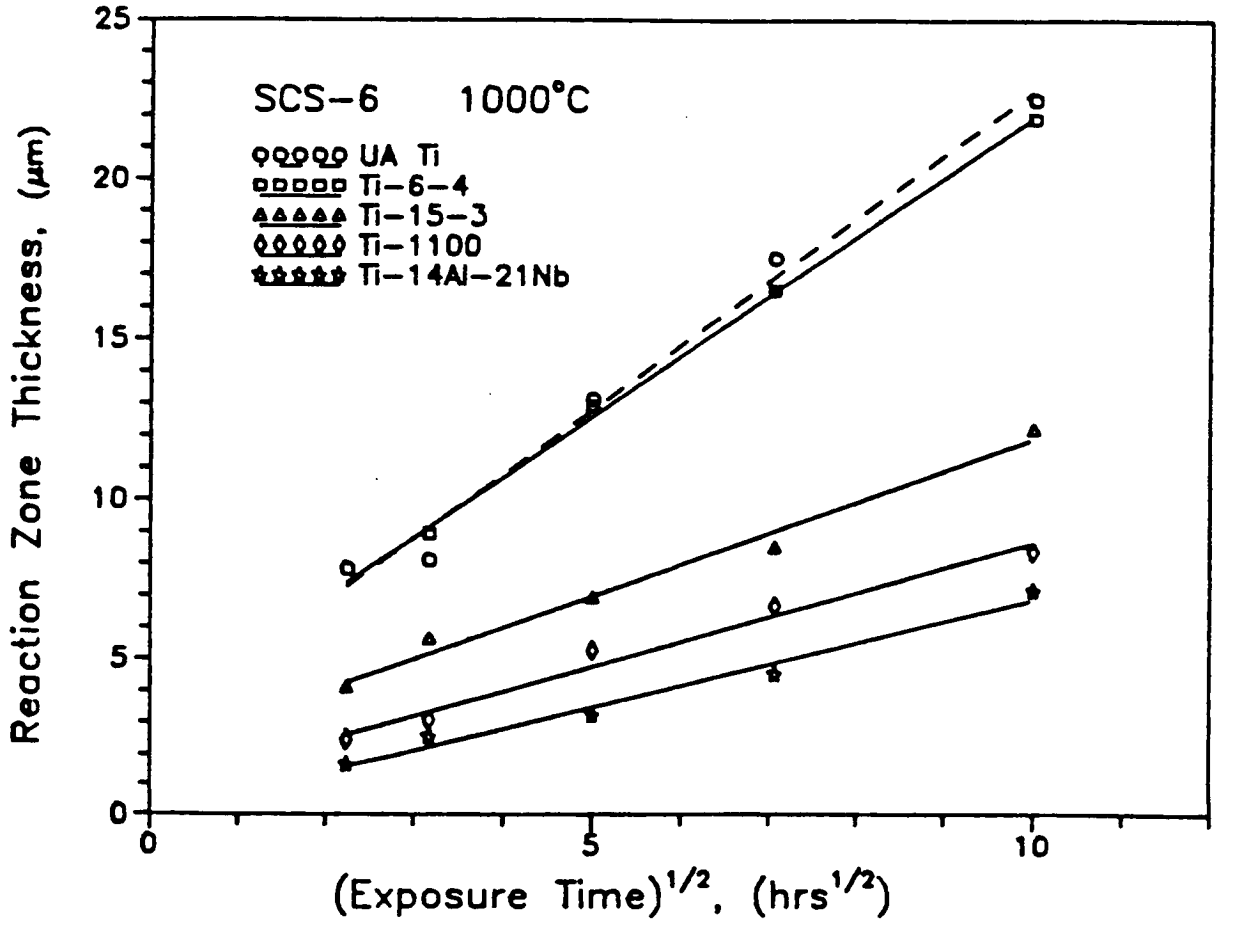
RATE OF REACTION ZONE (RZ) GROWTH HAS BEEN SHOWN TO FOLLOW A PARABOLIC LAW FOR THESE SYSTEMS:

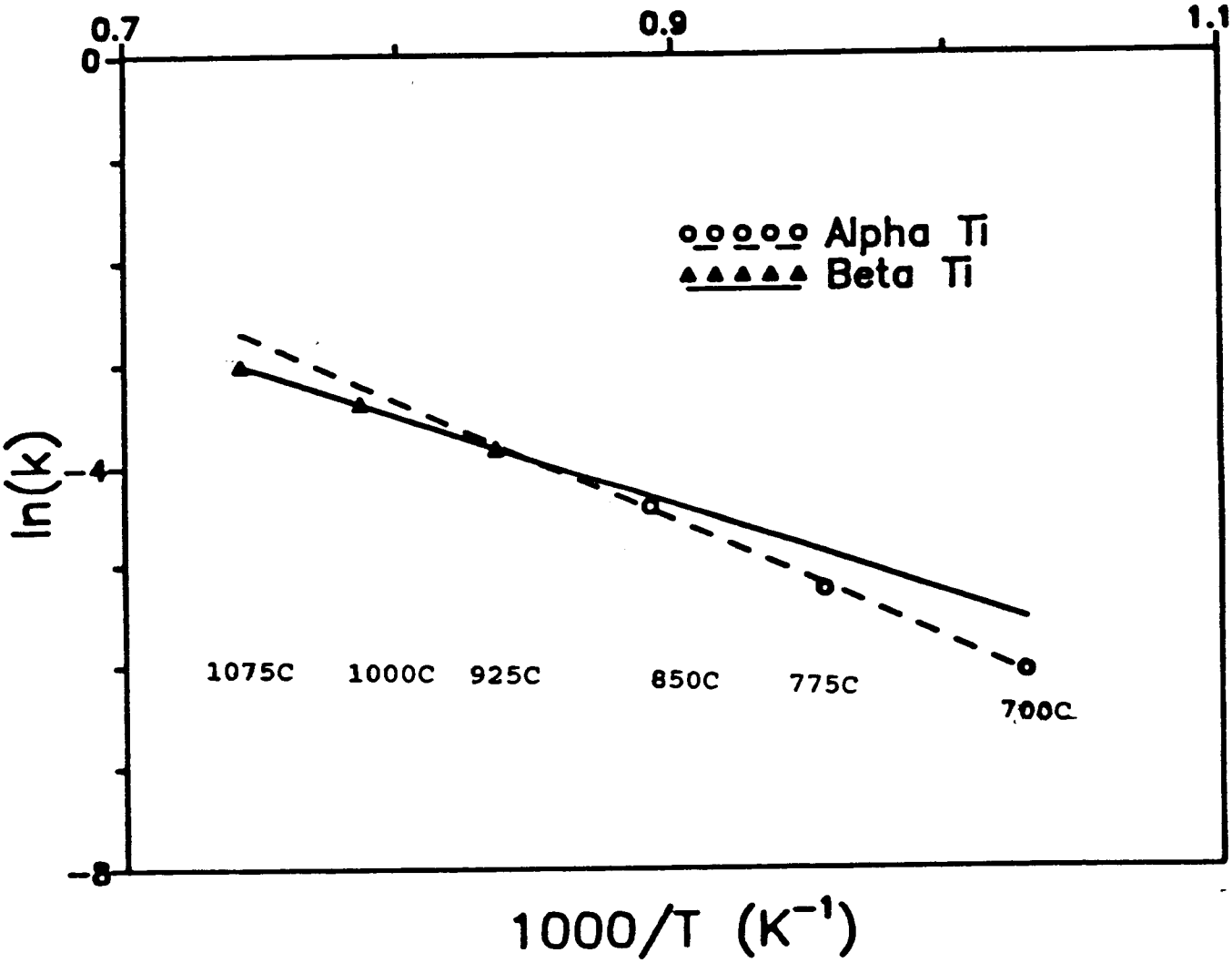
$$Z = k(t)^{1/2} + b$$

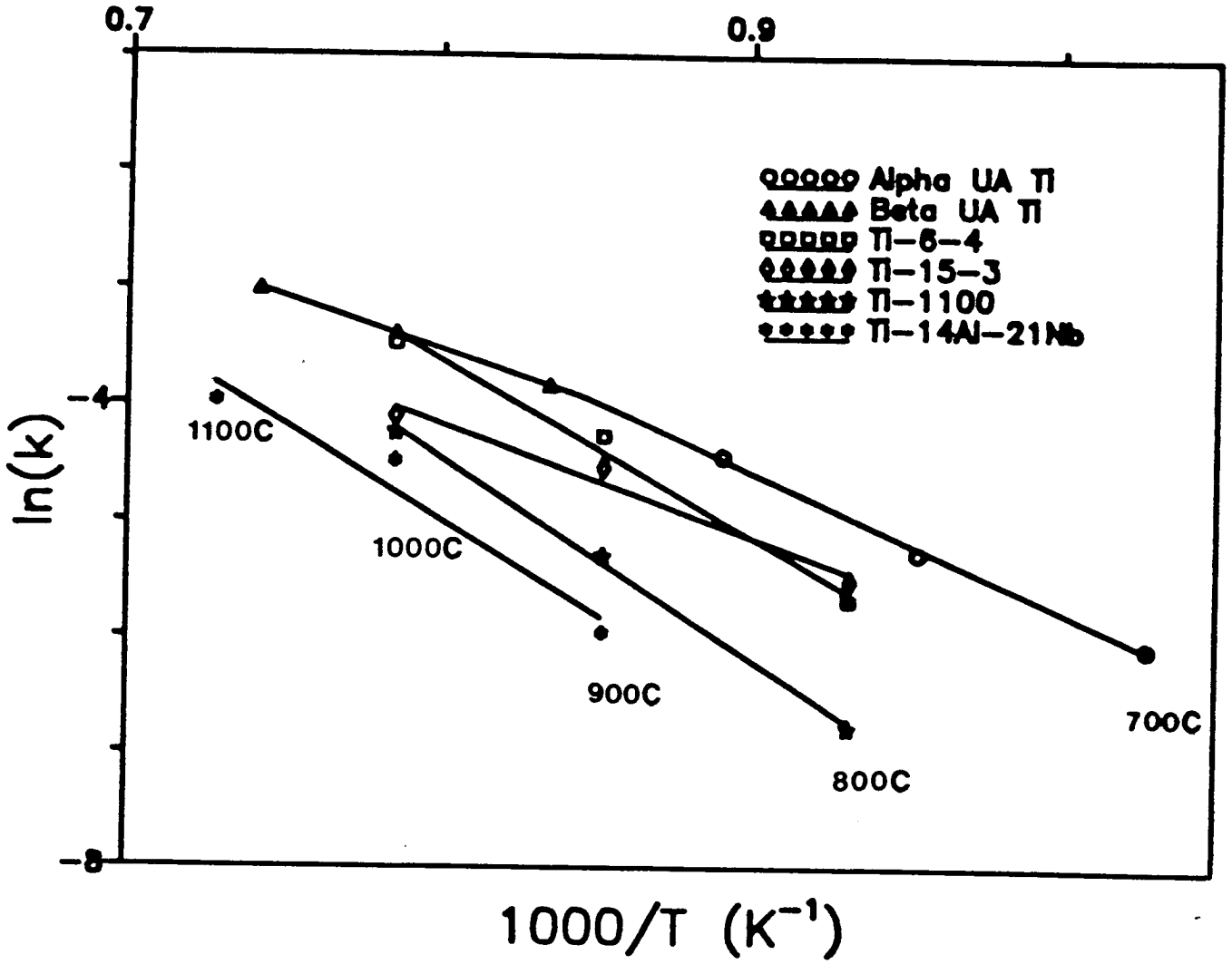
K FOLLOWS THE ARRHENIUS RELATION:

$$k = k_O \exp(-Q/2RT)$$

RZ MEASURED AFTER THERMAL EXPOSURE BY IMAGE ANALYSIS OF SEM MICROGRAPHS


SCS–6 1000°C
UA Ti
Ti–6–4
Ti–15–3
Ti–1100
Ti–14Al–21Nb
Reaction Zone Thickness, (μm)
(Exposure Time)^1/2, (hrs^1/2)
0
5
10
15
20
25

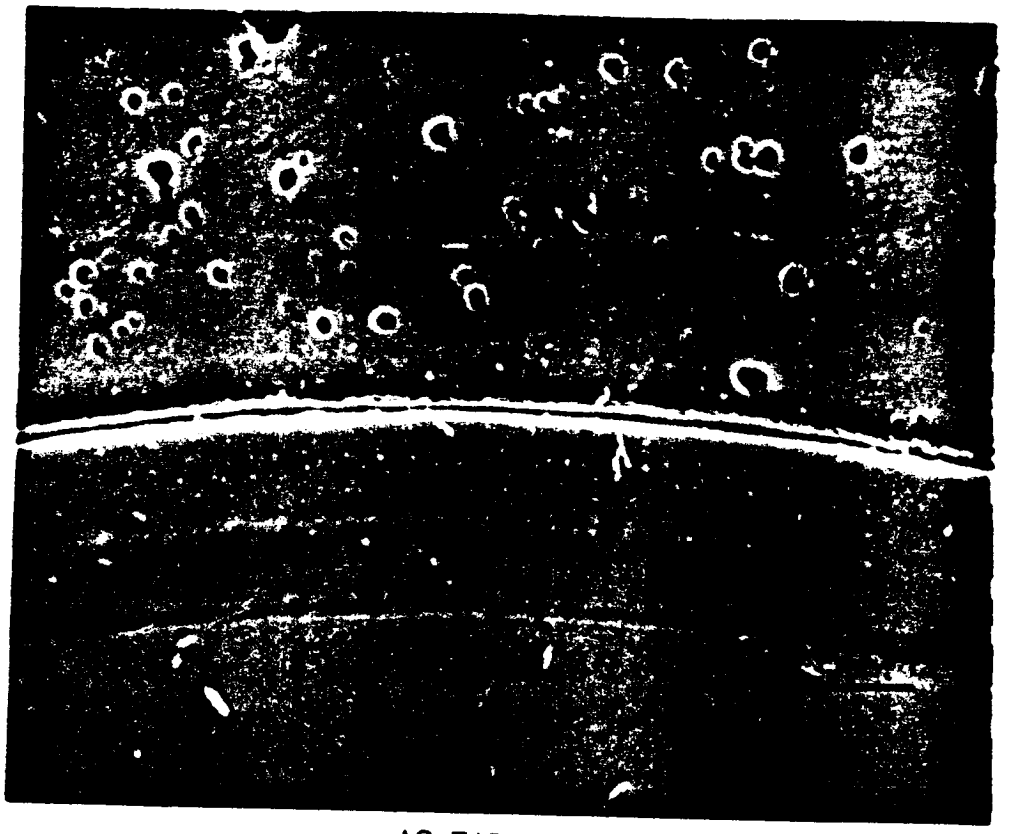

0.7
0.9
1.1
0
-4
-8
ln(k)
Alpha Ti
Beta Ti
1075C
1000C
925C
850C
775C
700C
1000/T (K⁻¹)


0.7
0.9
Alpha UA Ti
Beta UA Ti
Ti-6-4
Ti-15-3
Ti-1100
Ti-14Al-21Nb
-4
-8
ln(k)
1100C
1000C
900C
800C
700C
1000/T (K⁻¹)

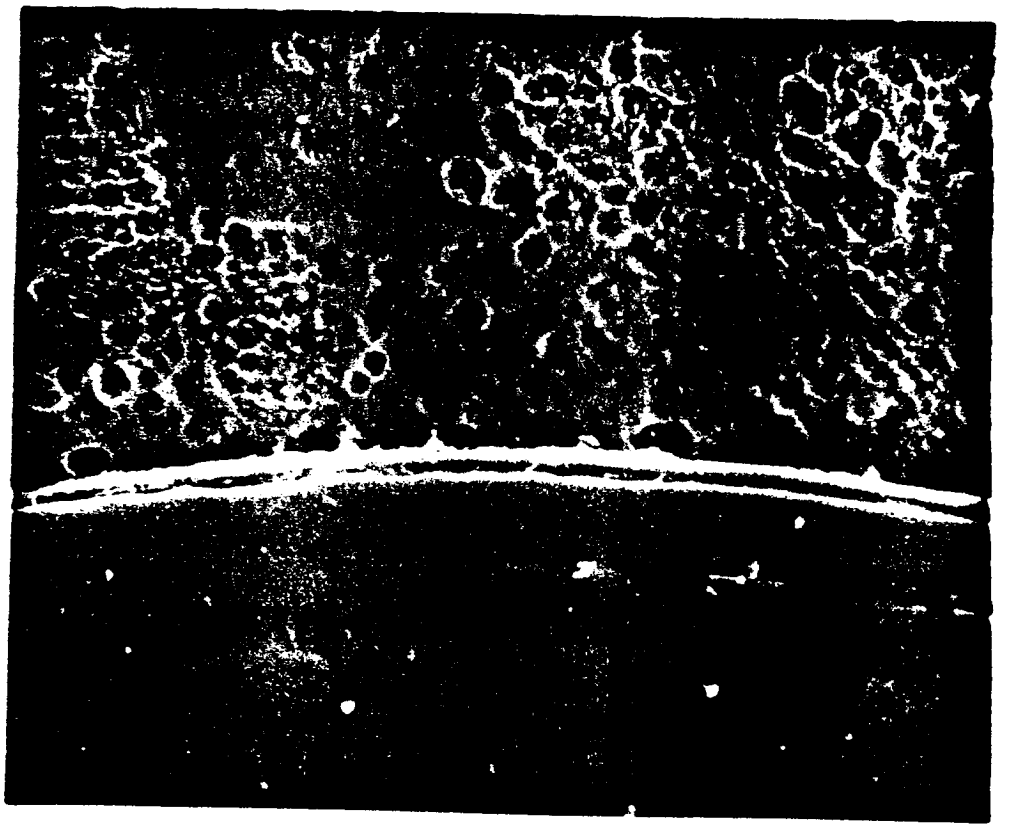
RZ SIZE (μ) AFTER EXPOSURE AT 700^{O}C FOR 1000 HOURS

	CALCULATED	MEASURED
UA Ti	4.7	5.2 ± .5
Ti-6-4	2.1	2.1 ± .3
Ti-1100	0.8	0.7 ± .1
Ti-14Al-21Nb	0.8	0.8 ± .1
Ti-15-3	3.8	1.5 ± .1

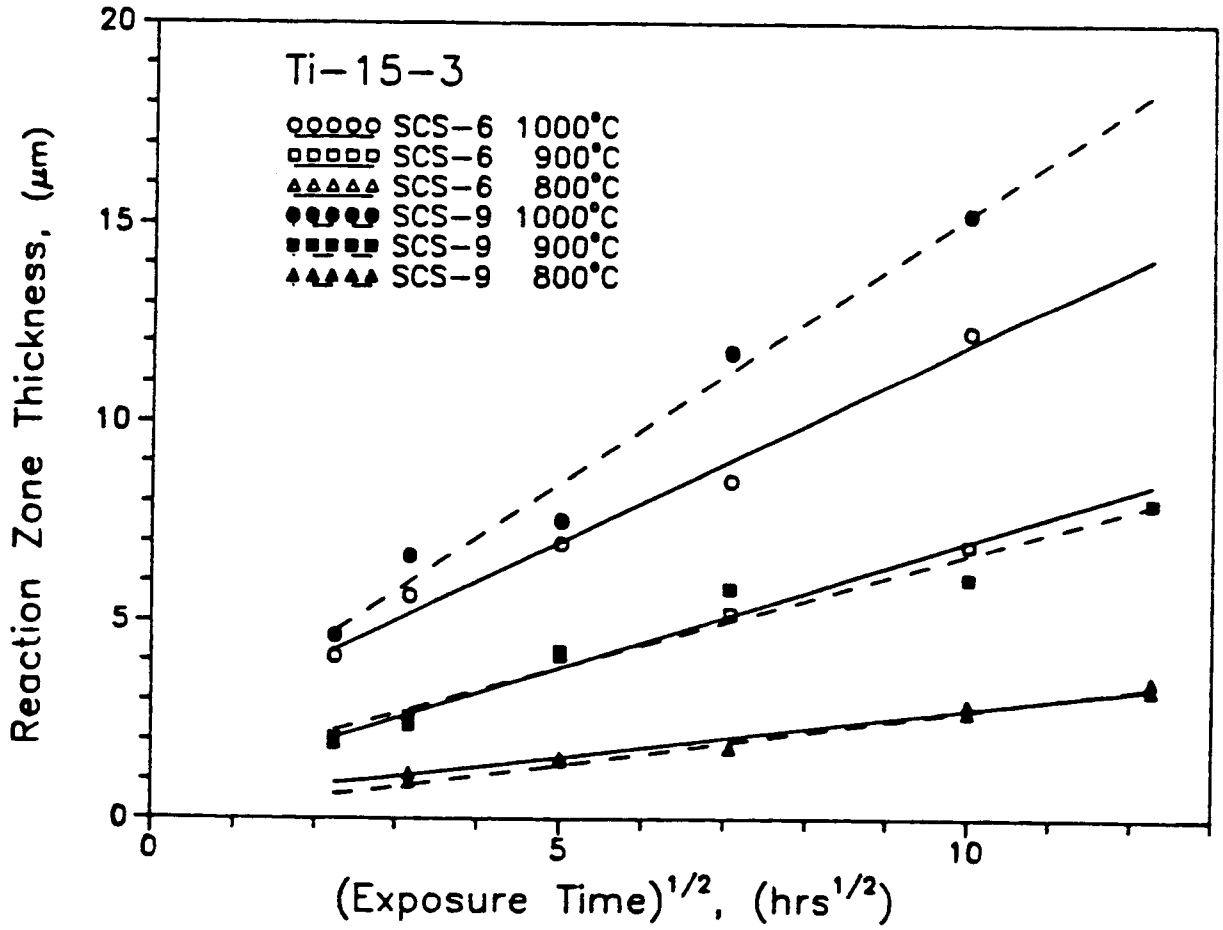
Ti-1100/SCS-6 INTERFACE

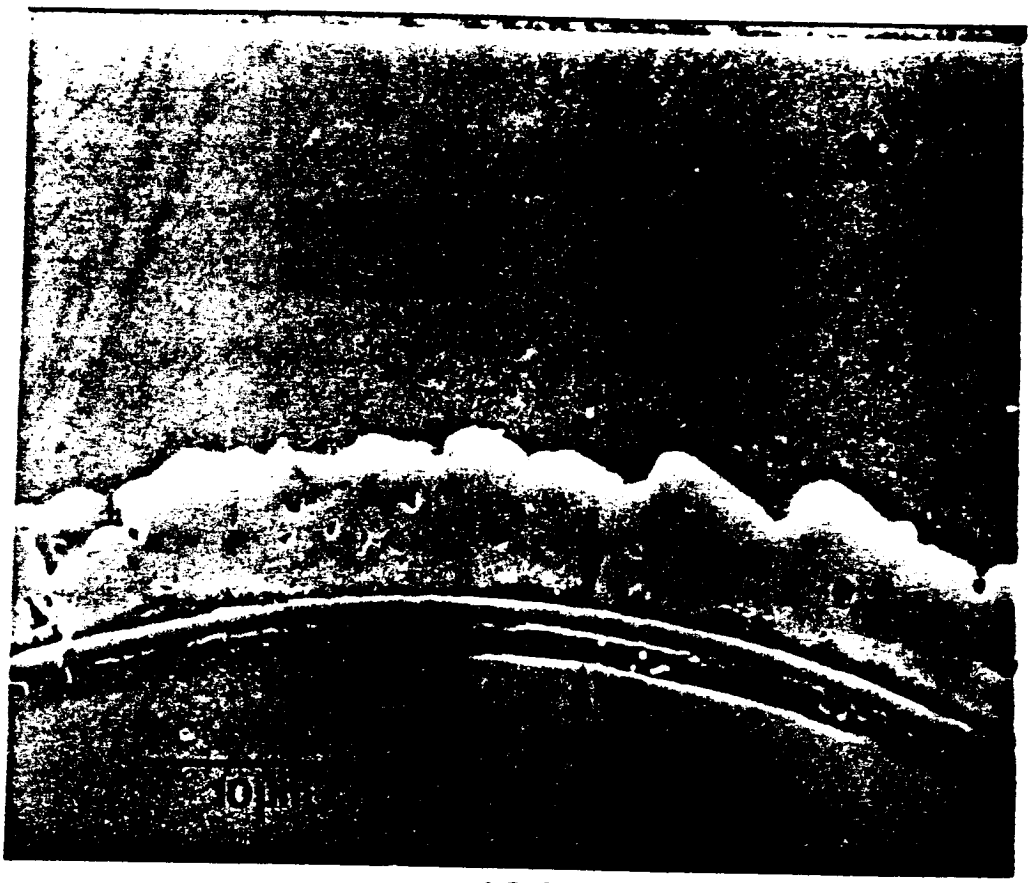


AS-FABRICATED

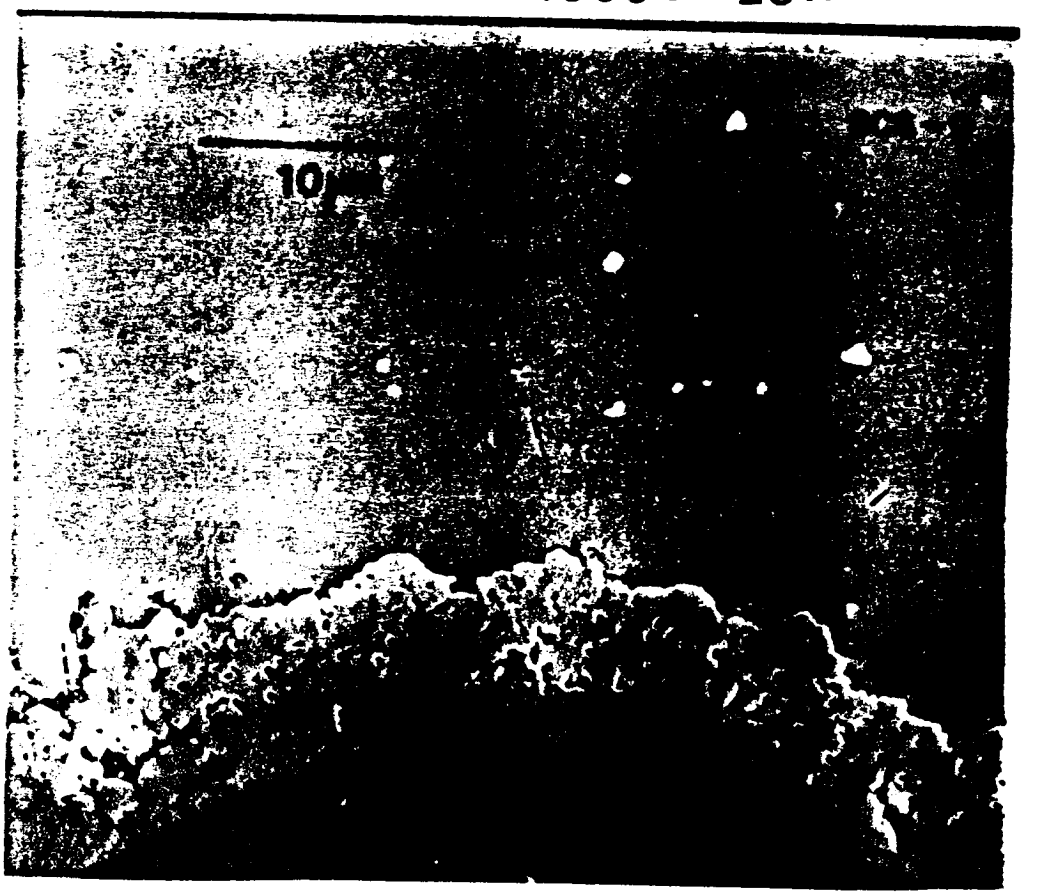


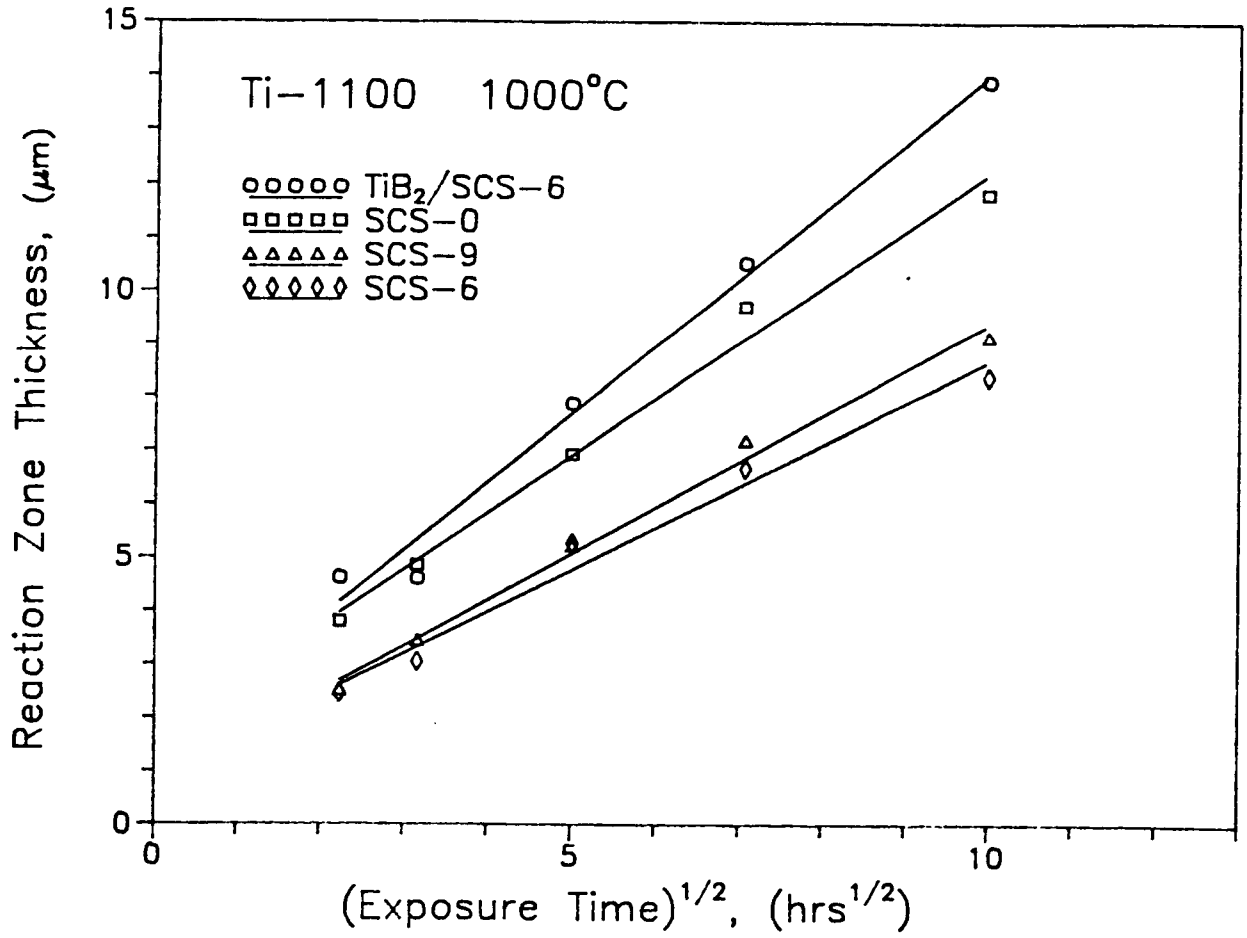
700°C 1000 HOURS



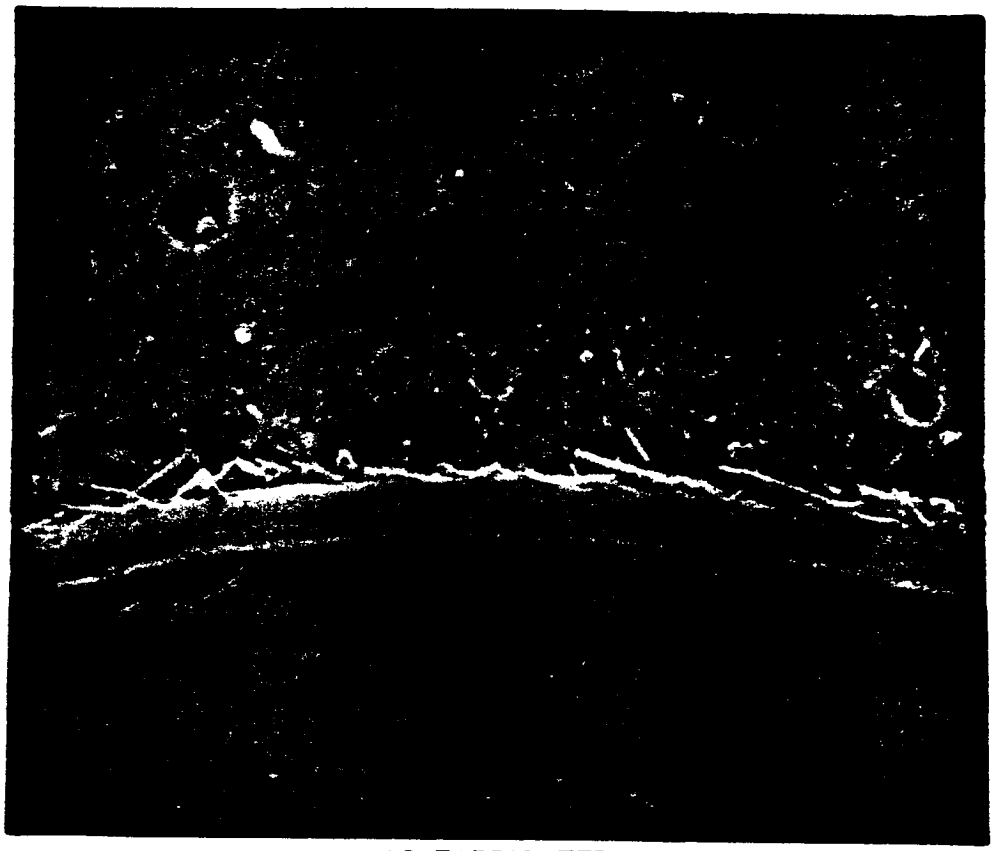


Ti 15 3 1000C 25H




Ti–1100 1000°C
TiB2/SCS–6
SCS–0
SCS–9
SCS–6
Reaction Zone Thickness, (μm)
(Exposure Time)1/2, (hrs1/2)
0
5
10
15

TiB_2/SCS-6 IN Ti-1100



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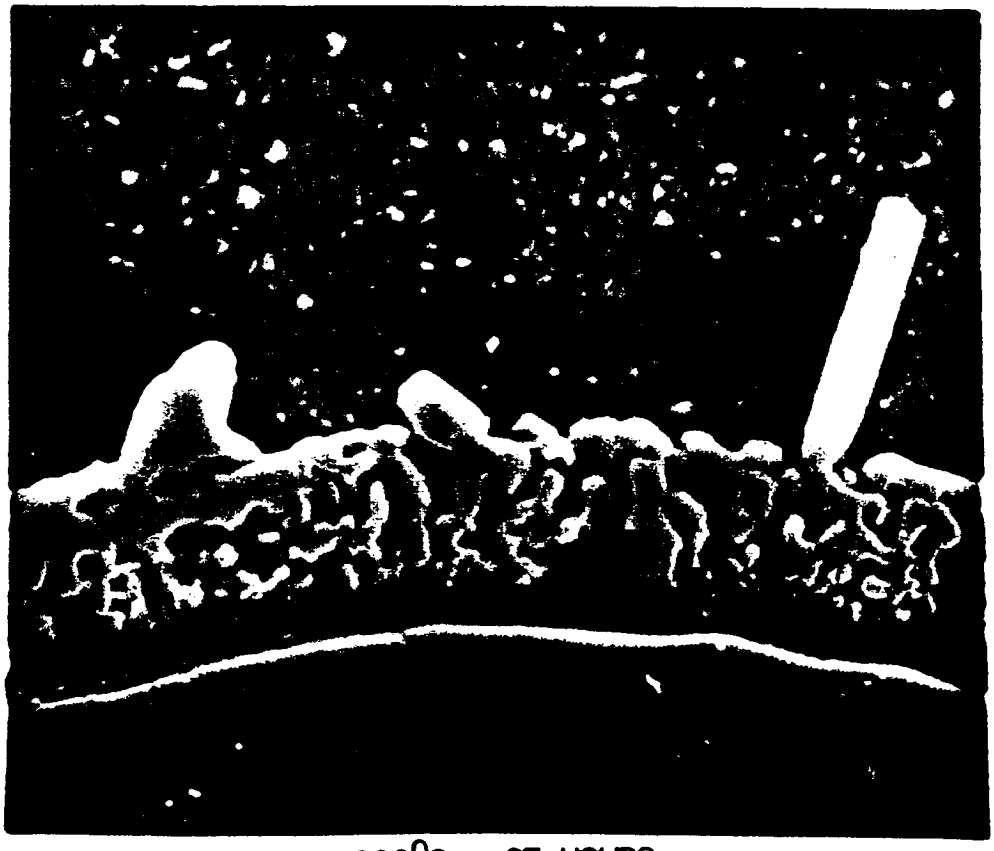
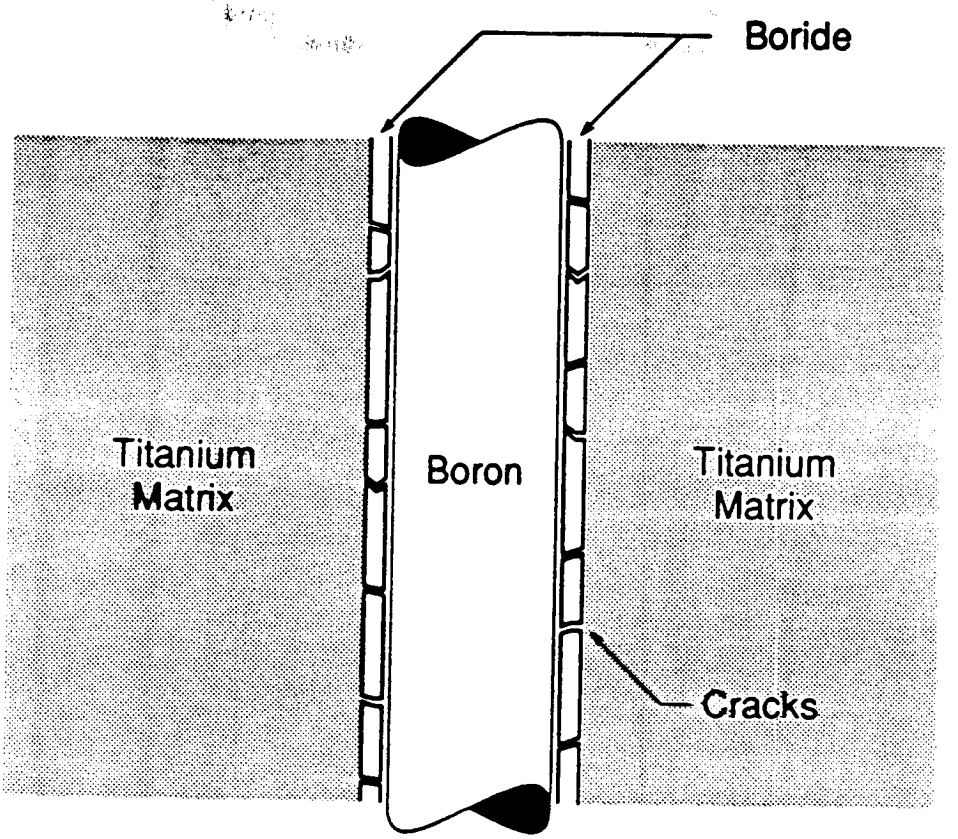
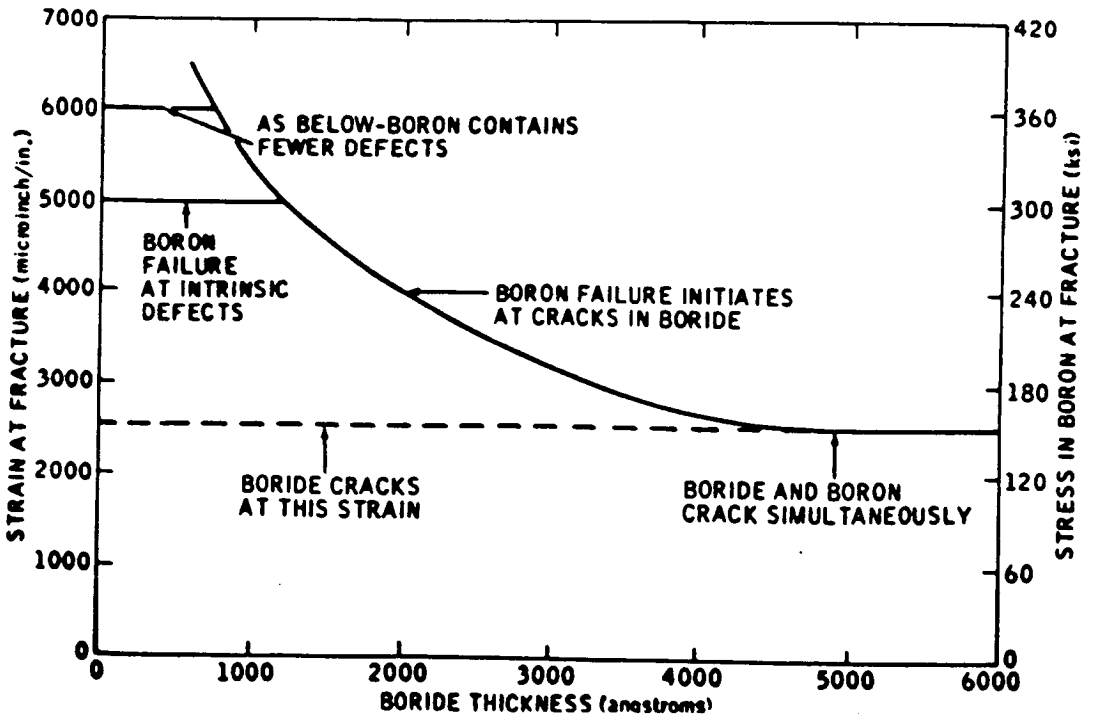
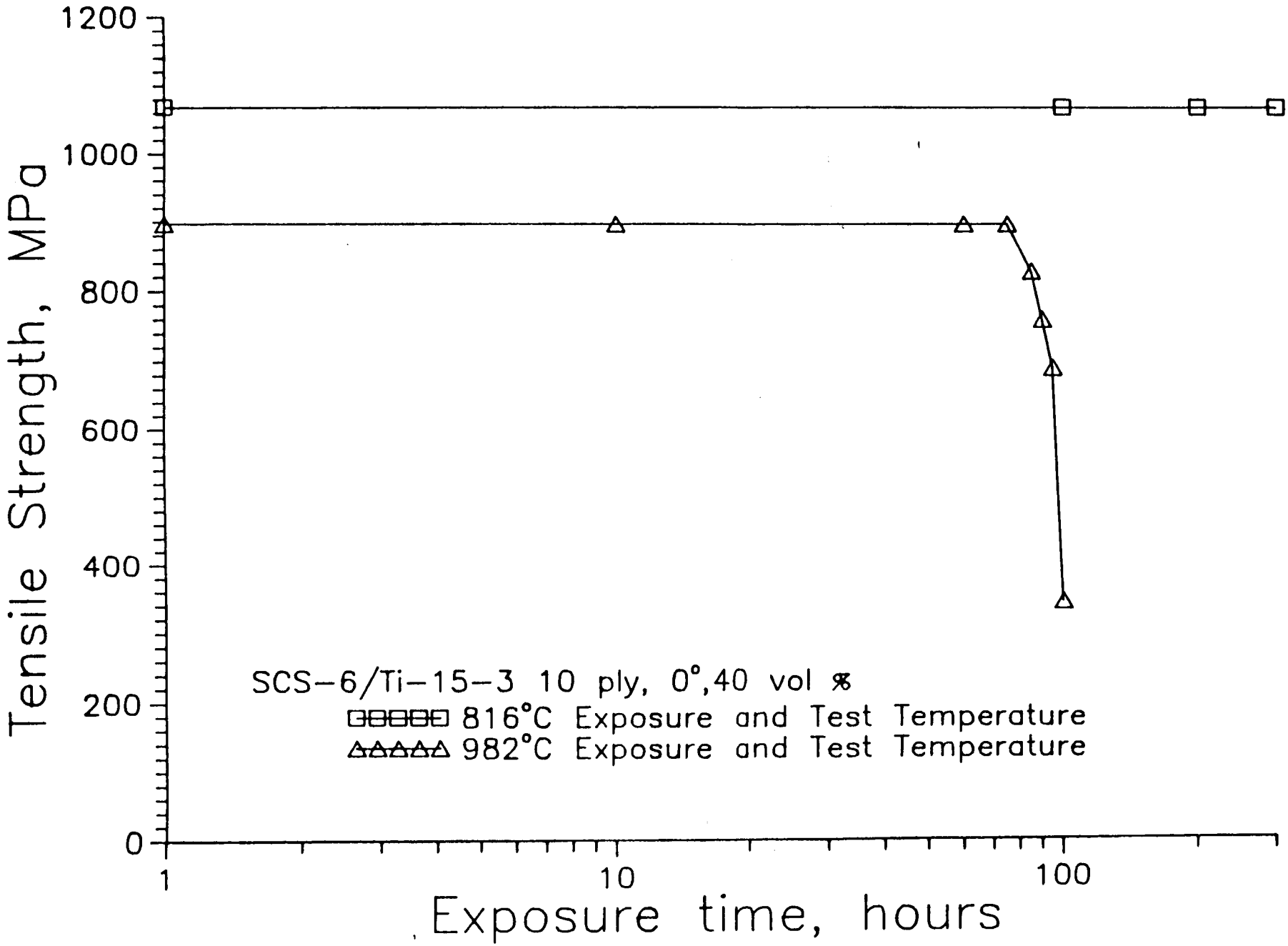


1000°C 25 HOURS


Boride
Titanium Matrix
Boron
Titanium Matrix
Cracks

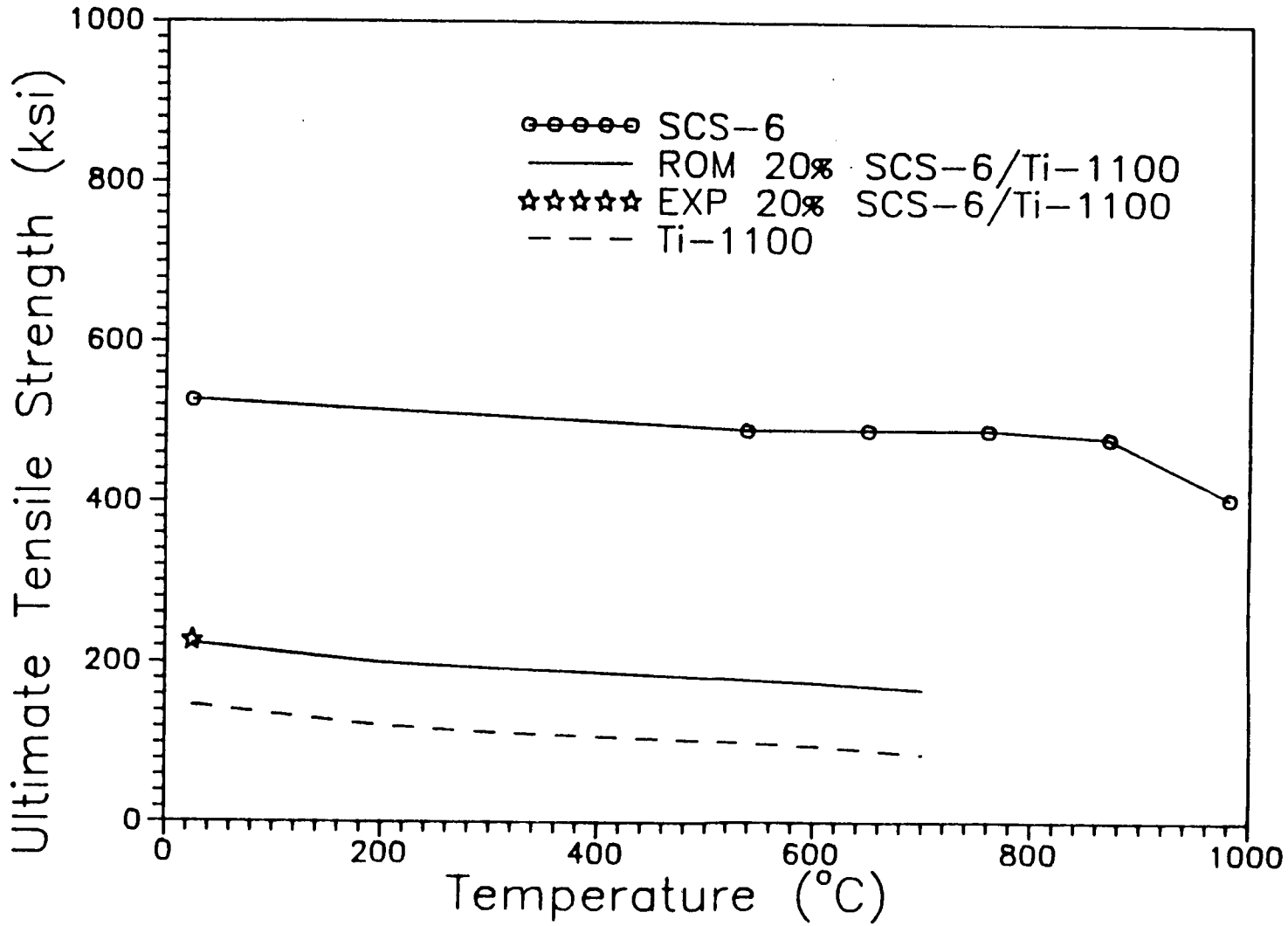

STRAIN AT FRACTURE (microinch/in.)
STRESS IN BORON AT FRACTURE (ksi)
BORIDE THICKNESS (angstroms)
AS BELOW-BORON CONTAINS FEWER DEFECTS
BORON FAILURE AT INTRINSIC DEFECTS
BORON FAILURE INITIATES AT CRACKS IN BORIDE
BORIDE CRACKS AT THIS STRAIN
BORIDE AND BORON CRACK SIMULTANEOUSLY
7000
6000
5000
4000
3000
2000
1000
0
420
360
300
240
180
120
60
0
1000
2000
3000
4000
5000
6000

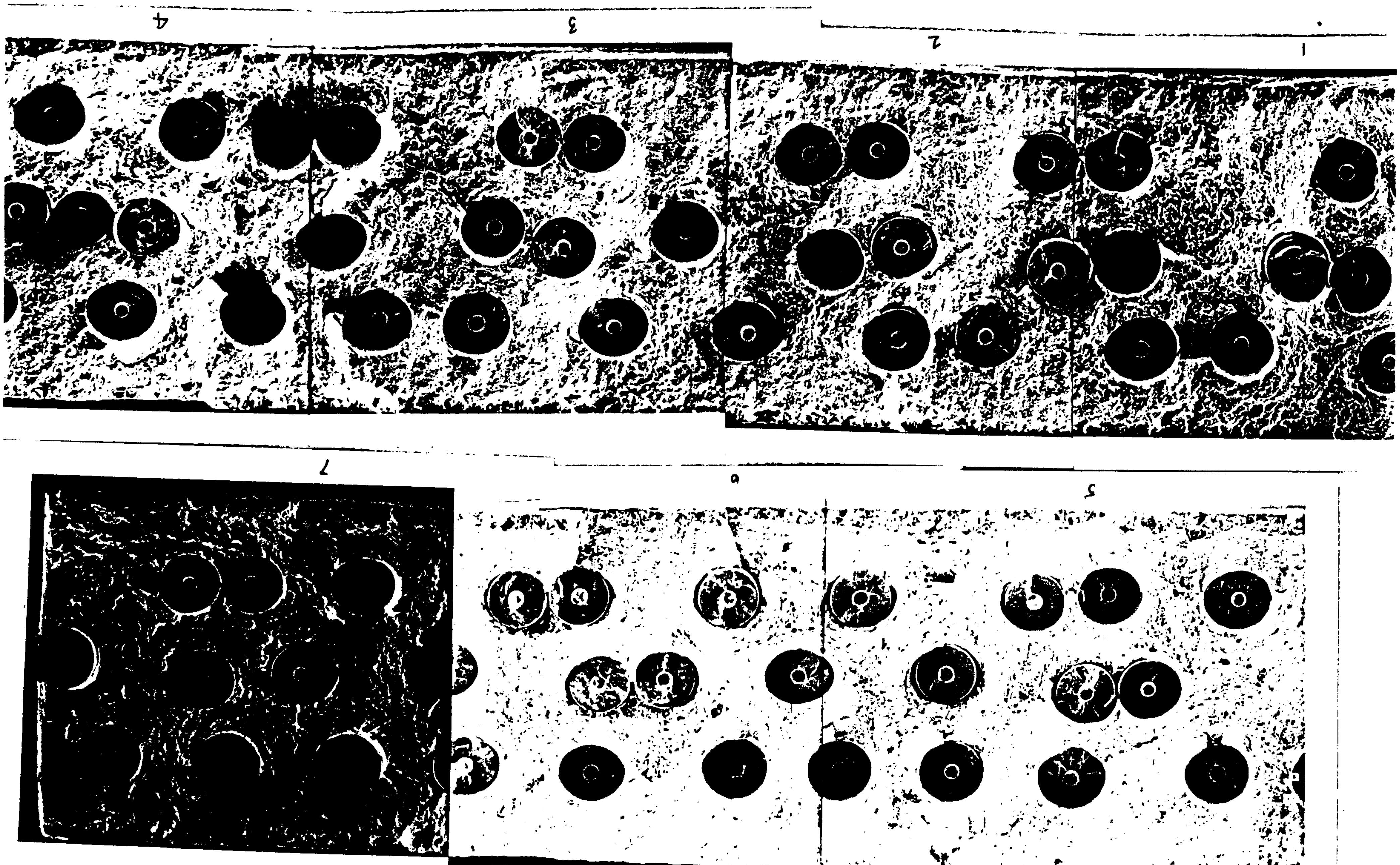

Tensile Strength, MPa
1200
1000
800
600
400
200
0
1
10
100
Exposure time, hours
SCS-6/Ti-15-3 10 ply, 0°,40 vol %
816°C Exposure and Test Temperature
982°C Exposure and Test Temperature

TIME TO CONSUME SURFACE LAYER (hours)

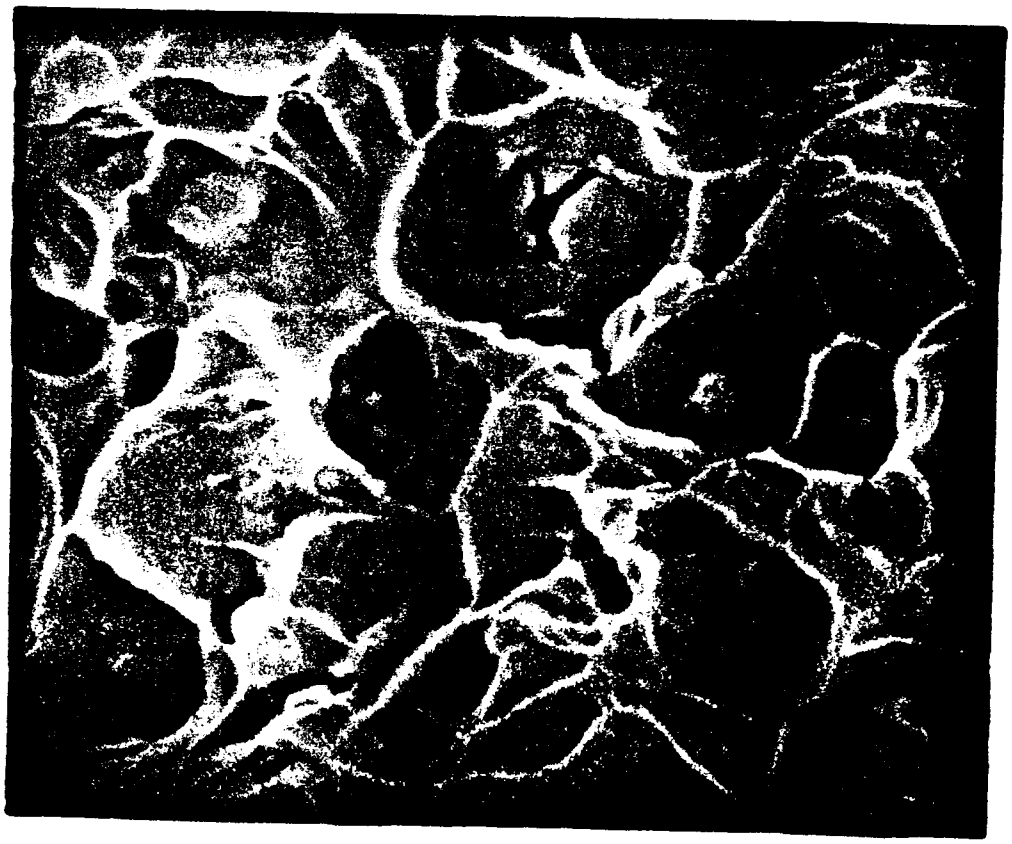
			SCS-6		
	UA Ti	Ti-6-4	Ti-15-3	Ti-1100	Ti-14Al-21Nb
700°C	7,100	51,000		750,000	1,000,000
800°C	590	2,900	2,000	28,000	58,000
900°C	87	280	420	1,800	4,500
1000°C	21	19	89	160	540
1100°C	<10				82
			SCS-9		
700°C	1,600	12,000		170,000	290,000
800°C	91	640	430	6,200	13,000
900°C	14	58	97	390	1,000
1000°C	<10	<10	14	35	110

These values are the calculated exposure times for the RZ to reach 12μ for the SCS-6 fiber, and 6μ for the SCS-9 fiber.


SCS-6
ROM 20% SCS-6/Ti-1100
EXP 20% SCS-6/Ti-1100
Ti-1100
Ultimate Tensile Strength (ksi)
Temperature (°C)
0
200
400
600
800
1000



FRACTURE SURFACE OF Ti-1100/SCS-6



CONCLUSIONS

- THE SCS SURFACE LAYER ON THE SCS-6 AND SCS-9 FIBER REACT AT THE SAME RATE WITH A GIVEN TITANIUM MATRIX.

- ALLOY ADDITIONS TO TITANIUM SLOWED THE RATE OF REACTION IN ALL OF THE CASES STUDIED.

- BELOW 1000°C Ti-1100 REACTS MORE SLOWLY WITH THE SCS COATING THAN UA Ti, Ti-15-3, AND Ti-6-4 -- AND SLIGHTLY FASTER THAN Ti-14Al-21Nb.

- THE KINETIC PARAMETERS DETERMINED IN THIS STUDY CAN BE EXTRAPOLATED TO 700°C FOR Ti-6-4, Ti-1100, AND Ti-14Al-21Nb, BUT NOT FOR Ti-15-3.

- REACTION ZONE GROWTH IN THE Ti-14Al-21Nb SYSTEM WAS ACCOMPANIED BY THE GROWTH OF A BETA-DEPLETED ZONE IN THE MATRIX AROUND THE FIBER.

FUTURE RESEARCH

- TENSILE TEST SAMPLES OF Ti-1100/SCS-6 AT ELEVATED TEMPERATURES.

- EXPOSE SAMPLES TO HIGH TEMPERATURES FOR VARYING LENGTHS OF TIME TO DETERMINE HOW LONG STRENGTH IS MAINTAINED.

- THERMALLY CYCLE Ti-1100/SCS-6 COMPOSITE SAMPLES.