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ENVIRONMENTAL EFFECTS ON ADVANCED COMPOSITES

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INTRODUCTION

This is the final report for NASA-Langley Grant # NSG 1531. This report is divided into four parts:

Part 1 - Mechanical Property Degradation and Chemical Interactions in a Borsic/Titanium Composite.

Part 2 - Interfacial Coatings for SiC/Ti Composites

Part 3 - Solutions for Diffusion in Single-, Two-, and Three-Phase Binary Alloy Systems.

Part 4 - Moisture Effects on Graphite/Polyimide Composites.

The first two parts deal with the development of titanium matrix composites for elevated temperature applications. Part 3 represents progress toward the ultimate goal of treating interactions in multiphase multicomponent systems. Part 4 represents the progress in support of NASA's CASTS program.

The research in this grant resulted in several publications. These are listed in the References Section.

PART 1 - MECHANICAL PROPERTY DEGRADATION AND CHEMICAL INTERACTIONS IN A BORSIC/TITANIUM COMPOSITE

OBJECTIVE

Titanium-alloy matrix composites have the potential for high specific strength and stiffness in high temperature applications. These fiber-reinforced materials have unique properties which make them attractive for such applications as advanced engine components and a variety of aerospace structural components. However, the use of titanium composites has been limited because of poor as-fabricated properties and/or degradation of mechanical properties in high-temperature environments because of fiber/matrix interface interactions. The objective of this study is to identify the mechanisms of mechanical property degradation in a Borsic (boron coated with silicon carbide) fiber reinforced Ti-3Al-2.5V composite exposed to elevated temperatures.

APPROACH

Samples containing 0.45 volume fraction of fibers were exposed, in vacuum, to temperatures from 700 K to 1255 K for times up to 240 hours. Room temperature tensile properties of unidirectional material were determined in both the longitudinal and transverse directions, before and after high-temperature exposure. Electron microprobe analysis, scanning electron microscopy, and X-ray diffraction were used to determine the compounds formed and the extent of interaction between the boron, SiC coating, and matrix materials. The results of this study are summarized below, and the details are presented in reference 1.

RESULTS AND DISCUSSION

High temperature exposure had no effect on the longitudinal modulus of the composite whereas the transverse modulus for the thermally exposed specimens was about 20 percent greater than that for the as-fabricated specimens. The strength of the composite did not depend to any great extent on the exposure time for temperatures of 922 K or less, but was degraded significantly by the longer exposure times at temperatures of 1033 K and greater. For all exposure times, the strength after exposures at 811 K and 922 K was greater than that after 700 K exposures. No quantitative correlation between strength and reaction-zone thickness was found.

Electron microprobe, X-ray diffraction, and reaction-zone thickness data suggest a two-stage reaction process. The first stage consisted of the simultaneous interdiffusion of the Si, C, and Ti resulting in the depletion of the SiC coating and formation of titanium silicides (Ti_5Si_3, TiSi, $TiSi_2$). The second stage resulted in significant titanium boride (TiB, TiB_2; Ti_3B_4) formation as well as a higher rate of formation of $TiSi_2$. The strength of the composite was degraded before the formation of any identifiable boride compounds. The aluminum in the matrix did not take part in the reactions and was rejected from the reaction region, whereas the vanadium remained throughout the reaction zone.

PUBLICATIONS AND TALKS

The research on this study resulted in the following publication: Mechanical Property Degradation and Chemical Interactions in a Borsic/Titanium Composite, Proceedings of the 24th National SAMPE Symposium and Exhibition, San Fransisco, CA., 1979.

PART 2 - INTERFACIAL COATINGS FOR SiC/Ti COMPOSITES

OBJECTIVE

The concept of interfacial coatings, to provide reduced chemical interaction between the SiC fiber and titanium matrix, is the subject of this study. The objectives are: (1) to investigage the effectiveness of interfacial coatings, in reducing the reactivity between fiber and matrix, (2) to identify the intermetallic compounds responsible for the degradation of the as-fabricated and heat-treated composite mechanical properties, (3) to determine any modification of the reaction zone compounds in the composites with interfacial coatings compared to the uncoated titanium alloys, (4) to provide a mechanical and chemical characterization of the SiC fiber for a better understanding of its role in the degradation of the composite mechanical properties.

APPROACH

The interfacial coatings selected for examination were aluminum, molybdenum and vanadium. These coatings were chosen because they were constituents of the alpha-beta alloy, Ti (6Al-4V), and certain beta alloys of titanium, which are known to have reduced reactivity with SiC compared to unalloyed titanium. The interfacial coatings were radio frequency (RF) sputtered onto Ti (A55) sheets and diffusion bonded (by DWA Composite Specialties in Chatsworth, CA) into unidirectional, SiC reinforced composite panels. Additional panels of SiC reinforced Ti(6Al-4V), Ti(3Al-2.5V) and Ti(A55), with no interfacial coatings, were fabricated

(by TRW Incorported in Cleveland, OH) to provide a comparative evaluation of the mechanical properties, reaction compounds and reaction zone thicknesses with the coated composite systems. The results of this study form the basis of Mr. Larry House's M.S. Thesis (ref. 2). The author of this report, Dr. Unnam, worked closely with Mr. House on this study.

RESULTS AND DISCUSSION

An interest in SiC reinforced titanium composites has been generated by the strength loss at elevated temperatures (near 1000^{o}F) of boron and Borsic fibers, and a need for stronger matrices with higher temperature capabilities (up to 1400^{o}F) than can be provided by aluminum and resin matrix composites. Also, the reaction kinetics are reported to be slower for the SiC/Ti system than for B/Ti, thereby reducing the deleterious effects associated with fiber-matrix interaction. However, the poor as-fabricated mechanical properties of the SiC/Ti composites have precluded extensive utilization of this composite system. The best results were achieved with SiC/Ti (6Aℓ-4V) system which yielded only 75% of the rule-of-mixture fracture strength.

The degradation of the tensile strength is largely due to the formation of a brittle phase boundary at the fiber/matrix interface. The strength loss is attributed to the stress intensification caused by defects or cracks that develop because of the low strengths and strain-to-failure of the reaction compounds.

Two, crucial, technical issues determining the utility of the SiC-Ti composites remain to be resolved. These are: (1) whether the fiber-matrix reaction kinetics during fabrication can be sufficiently reduced to prevent forming a reaction zone thickness greater than the critical thickness, and (2) if so, whether the composite degradation at the expected service temperature will be small.

Although the chemical compatibility between SiC and Ti has not proven satisfactory, several approaches to reduce the fiber-matrix reaction have been suggested in the literature. Among these were: (1) optimization of the consolidation process, (2) development of a low-reactivity matrix, (3) development of protective interfacial coatings. The first two approaches have been given considerable attention with only limited success. The development of protective interfacial coatings is the approach taken in this study.

Reaction Zone Thicknesses:

A comparison of reaction zone thicknesses for each composite system, after the 1600 and 1800°F exposures, is shown in figure 1. The reaction zone thicknesses of the SiC-Ti (A55)/Aℓ, SiC-Ti(3Aℓ-2.5V) and SiC-Ti(6Aℓ-4V), after the 1600°F-25 hour exposure, were comparable. However, the composites with molybdenum and vanadium interfacial coatings have reaction thicknesses, after the 1600°F exposure, comparable to the thicknesses in the 1800°F exposed SiC-Ti(3Aℓ-2.5V) and SiC-Ti(6Aℓ-4V) specimens. Indeed, the composites

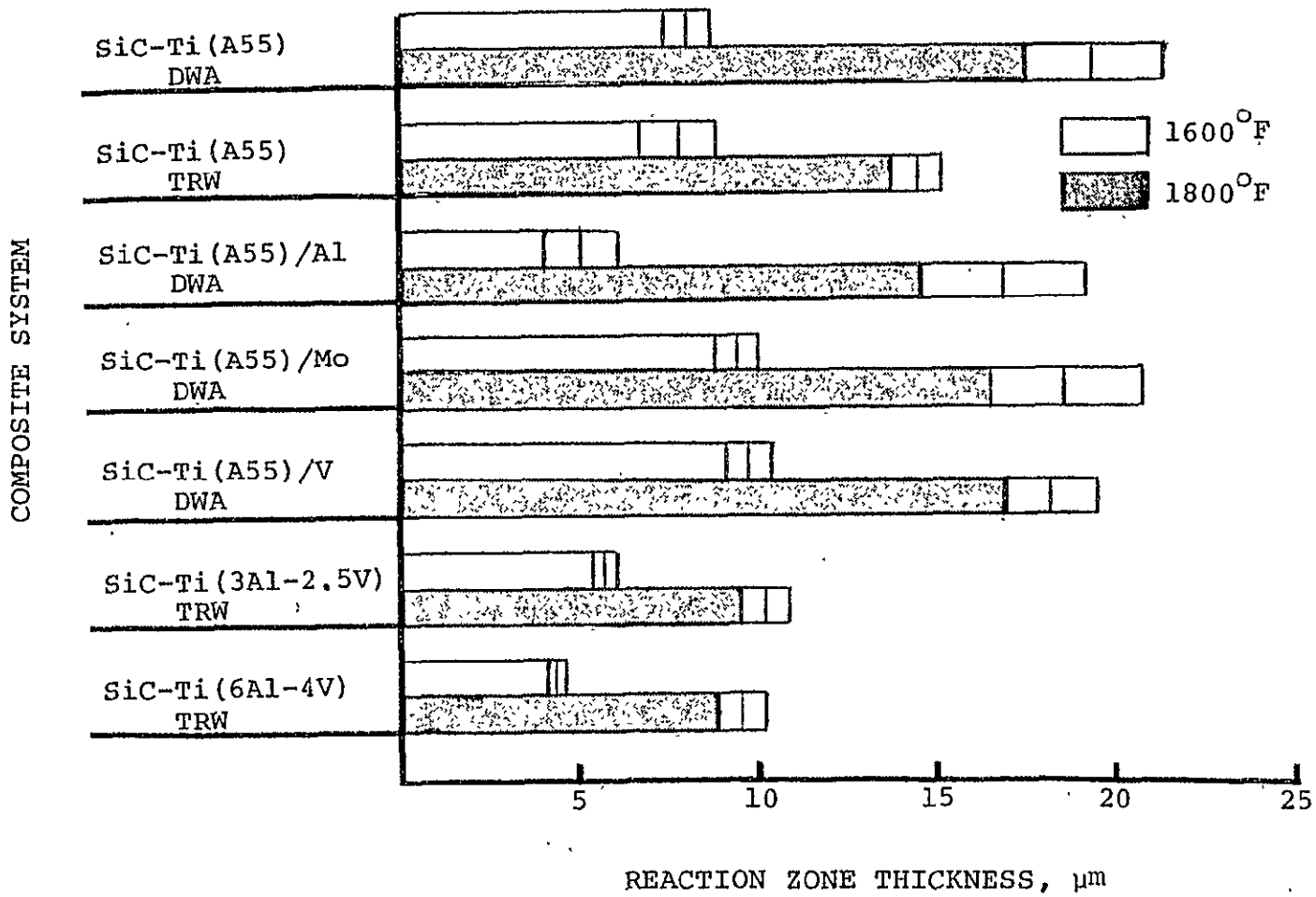

Figure 1. A comparison of the reaction zone thicknesses for the various composite systems after the 25 hour exposure at 1600 and 1800°F.

with molybdenum and vanadium coatings appear to have reacted, at 1600°F, more extensively than the composites with the uncoated Ti (A55) matrix. After the 1800°F exposure, all the DWA composites, with and without interfacial coatings, had similar reaction zone thicknesses. This should be expected because the homogenization of the coatings throughout the matrix leaves an insufficient amount of the coating to affect the fiber-matrix reaction. The larger reaction zone thickness for the 1800°F exposed (DWA) SiC-Ti (A55) specimen, compared to the (TRW) SiC-(A55) composite, was due to larger TiC precipitates in the outer boundary of the reaction zone in the DWA specimen.

The reaction zone thickness data for the 1600°F exposure suggest that a binary Ti-Aℓ alloy matrix may be less reactive than the Ti (3Aℓ-2.5V) and Ti (6Aℓ-4V) matrices. This conclusion is made in view of the enhanced reactivity of the V coated composite, and the considerably reduced reactivity provided by the Aℓ coating.

Identification of Reaction Products:

To identify the compounds formed in the fiber-matrix reaction zone, X-ray diffraction analyses of the as-fabricated and thermally exposed DWA and TRW composites were performed. DWA composite samples were of SiC fiber reinforced Ti (A55) and also composites of Aℓ, Mo and V coated Ti (A55). The TRW composites were of SiC fiber reinforced Ti (A55), Ti (3Aℓ-2.5V) and Ti (6Aℓ-4V). The experimental apparatus consisted of a Siemens diffractometer with a high intensity, fine focus, copper tube. The specimens were

rotated about the ϕ axis to reduce fluctuations in intensity which may result, due to the presence of large grains and texture within the sample. The data were collected using a diffracted beam graphite monochromator. The monochromator improved the peak-to-background ratios by minimizing contributions to the background from continuous radiation as well as fluorescence from the Ti-base substrate. Survey scans of 2θ were made at 1° per minute and slow scans were made at $1/4^{\circ}$ per minute.

The samples were ground using 600 grit paper to uniformly expose the filaments. They were then fine-polished on a lapping wheel using 1 micron and 0.3 micron alumina powder. In order to get a meaningful comparison in a semiquantitative analysis, the samples were ground to expose about 33% area fraction of filament in all cases. This procedure maximized the effective volume of the reaction zone so that small amounts of transformation about the interface could be observed with X-ray diffraction.

DWA composite samples in the as-received condition as well as those exposed to $1600^{\circ}F$ and $1800^{\circ}F$ for 25 hours each were examined to determine the various phases at each temperature. The results are presented in Tables 1 through 12. The 2θ values denoted by an asterisk represent unidentified reflections which were of low intensity. The intensity for each reflection was determined by integrating the area under the corresponding peak, using a small grid technique.

The as-fabricated composite gave diffraction lines from α-Ti, β-SiC and TiC. Although a few weak reflections appeared due to Ti_5Si_3, the presence of Ti_5Si_3 phase, in general, in the

Table 1. - Experimental d-spacings and intensities for phases identified in as-fabricated SiC-Ti(A55)

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.02	2.6330	300	(???)				
35.61	2.5190	9,000		(111)	(010)	(111)	(002)
38.31	2.3474	615			(002)		
40.11	2.2461	830			(011)		
41.06	2.1963	75					(211)
41.46	2.1761	75				(200)	
41.96	2.1513	50		(200)			(300)
52.86	1.7305	325			(012)		
*59.01	1.5639	75					
60.01	1.5403	970		(220)			
60.76	1.5230	124				(220)	
62.86	1.4771	164			(110)		
70.46	1.3352	600			(103)		
71.81	1.3134	856		(311)			
72.61	1.3009	81				(113)	
75.46	1.2587	338		(222)		(222)	
75.98	1.2514	313			(112)		
77.21	1.2344	100			(201)		
82.16	1.1722	36			(004)		
86.56	1.1235	23			(202)		
92.46	1.0666	75			(014)		
100.06	1.0050	20				(331)	
100.81	.99958	162		(331)			
102.21	.98966	150			(203)		
*104.11	.97672	88					
104.71	.97276	81		(420)			
108.96	.94635	75			(211)		
114.01	.91836	188			(114)		
119.61	.89116	198		(422)	(212)		
121.06	.88472	119				(224)	

Table 1. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
121.86	.88126	244			(015)		
126.11	.86404	32			(204)		
133.46	.83845	725		(333, 511)			
138.96	.82243	150			213)		

Table 2. - Experimental d-spacings and intensities for phases identified in 1600°F-25 hour exposed SiC-Ti(A55)

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.06	2.6300	150	(???)				
35.61	2.5190	8,500		(111)	(010)	(111)	(002)
36.91	2.4331	87					(210)
38.18	2.3551	650			(002)		
40.11	2.2461	910			(011)		
40.96	2.2015	164					(211)
41.86	2.1562	145		(200)		(200)	(300)
42.66	2.1190	32					(112)
52.81	1.7320	350			(012)		
60.06	1.5391	660		(220)			
60.66	1.5253	127				(220)	
61.41	1.5084	75					(222)
62.86	1.4771	262			(110)		
70.26	1.3386	600			(103)		
71.81	1.3134	574		(311)			
72.56	1.3017	101				(113)	
75.36	1.2601	191		(222)		(222)	
75.86	1.2531	210			(112)		
77.16	1.2351	117			(201)		
86.62	1.1229	25			(202)		
92.31	1.0680	71			(014)		
100.46	1.0023	68				(331)	
101.42	.99522	50		(331)			
102.01	.99105	252			(203)		
104.32	.97534	86		(420)			
106.00	.96445	20	(???)				
108.81	.94723	75			(211)		
113.56	.92072	125			(114)		
119.61	.89116	172		(422)	(212)		
120.61	.88669	108				(224)	

Table 2. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
121.46	.88298	175			(015)		
*122.51	.87850	20					
133.41	.83861	318		(333, 511)			
138.86	.82270	100			(213)		

Table 3. - Experimental d-spacings and intensities for phases identified in 1800°F - 25 hour exposed SiC-Ti(A55)

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.16	2.6225	160	(???)				
35.61	2.5190	11,250		(111)	(010)	(111)	(002)
36.91	2.4331	163					(210)
37.53	2.3944	79					(102)
38.41	2.3415	810			(002)		
40.11	2.2461	1,557			(011)		
40.93	2.2030	290					(211)
41.93	2.1527	575		(200)		(200)	(300)
42.63	2.1190	215					(112)
53.03	1.7253	188			(012)		
*59.21	1.5591	50					
60.21	1.5356	470		(220)			
60.78	1.5230	302				(220)	
61.41	1.4656	75					(222)
63.01	1.4953	250			(110)		
65.56	1.4227	32					(321)
66.51	1.4046	100					(410) (213)
68.61	1.3666	50					(402)
70.71	1.3312	275			(103)		
71.83	1.3131	450		(311)			
72.76	1.2986	150				(113)	
75.46	1.2587	288		(222)		(222)	
76.26	1.2475	340			(112)		
77.36	1.2325	127			(201)		
82.36	1.1698	20			(004)		
83.86	1.1527	20					(502)
86.81	1.1209	36			(202)		
92.86	1.0631	52			(014)		

Table 3. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
100.22	1.0039	40				(331)	
100.66	1.0007	89		(331)			
102.41	.98827	275			(203)		
104.36	.97507	200		(420)			
106.26	.96281	138	(???)				
109.06	.94576	125			(211)		
114.46	.91604	112			(114)		
119.86	.89003	156		(422)	(212)		
121.06	.88472	100				(224)	
*122.41	.87893	200					
133.36	.83876	325		(333, 511)			
139.56	.82083	110			(213)		

Table 4. - Experimental d-spacings and intensities for phases identified in as-fabricated SiC-Ti(A55)/Al

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.01	2.6337	250	(???)				
35.61	2.5190	11,400		(111)	(010)	(111)	(002)
38.08	2.3611	860			(002)		
40.05	2.2493	2,200			(011)		
40.82	2.2087	50					(211)
41.42	2.1781	100				(200)	
41.86	2.1562	25		(200)			(300)
52.81	1.7320	219			(012)		
*59.21	1.5591	50					
60.06	1.5391	813		(220)			
60.56	1.5276	253				(220)	
62.81	1.4872	210			(110)		
70.41	1.3361	550			(103)		
71.76	1.3142	958		(311)			
72.31	1.3055	171				(113)	
75.68	1.2556	601		(222)		(222)	
76.26	1.2475	108			(112)		
77.16	1.2351	155			(201)		
86.56	1.1235	41			(202)		
92.41	1.0671	47			(014)		
99.61	1.0083	20				(331)	
101.06	.99778	270		(331)			
102.01	.99105	310			(203)		
104.48	.97427	427		(420)			
105.81	.96566	71	(???)				
108.86	.94694	121			(211)		
113.98	.91862	143			(114)		
119.66	.89093	226		(422)	(212)		
120.61	.88669	238				(224)	

Table 4 . - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
121.81	.88148	246			(015)		
133.47	.83842	608		(333, 511)			
138.81	.82283	156			(213)		

Table 5. - Experimental d-spacings and intensities for phases identified in 1600°F-25 hour exposed SiC-Ti(A55)/Al

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.16	2.6225	150	(???)				
35.58	2.5210	10,950		(111)	(010)	(111)	(002)
36.76	2.4428	172					(210)
38.14	2.3575	972			(002)		
40.00	2.2521	3,435			(011)		
40.88	2.2056	178					(211)
41.88	2.1552	216		(200)		(200)	(300)
42.56	2.1223	82					(112)
52.72	1.7348	470			(012)		
*59.31	1.5567	70					
60.06	1.5391	584		(220)			
60.61	1.5265	187				(220)	
62.85	1.4773	277			(110)		
70.26	1.3386	455			(103)		
71.81	1.3135	545		(311)			
72.41	1.3040	120				(113)	
75.46	1.2587	308		(222)		(222)	
75.91	1.2523	310			(112)		
77.21	1.2345	108			(201)		
86.48	1.1244	71			(202)		
92.21	1.0689	110			(014)		
100.06	1.0050	25				(331)	
101.02	.99807	110		(331)			
101.91	.99175	144			(203)		
104.44	.97454	250		(420)			
106.06	.96408	94	(???)				
108.86	.94694	116			(211)		
113.64	.92029	209			(114)		
119.61	.89116	152		(422)	(212)		

Table 5. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
120.68	.88638	128				(224)	
121.51	.88277	134			(015)		
*122.26	.87956	50					
125.66	.86578	40			(204)		
133.38	.83870	422		(333, 511)			
136.51	.82925	50				(115)	
138.71	.82311	200			(213)		

Table 6. - Experimental d-spacings and intensities for phases identified in 1800°F-25 hour exposed SiC-Ti(A55)/Al

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
33.92	2.6481	302	(???)				
35.72	2.5115	21,750		(111)	(010)	(111)	(002)
36.78	2.4415	414					(210)
37.58	2.3913	226					(102)
38.48	2.3374	230			(002)		
40.18	2.2424	1,800			(011)		
40.92	2.2035	298					(211)
41.98	2.1503	512		(200)		(200)	(300)
42.68	2.1166	190					(112)
53.06	1.7244	322			(012)		
*58.72	1.5710	165					
60.12	1.5377	1,050		(220)			
60.72	1.5239	680				(220)	
61.32	1.5105	120					(222)
*61.72	1.5016	124					
63.02	1.4737	622			(110)		
65.72	1.4196	24					(321)
66.52	1.4044	90					(410) (213)
68.68	1.3654	44					(402)
70.82	1.3293	417			(103)		
71.87	1.3124	1,425		(311)			
72.78	1.2983	120				(113)	
73.22	1.2916	145					(500) (004)
75.52	1.2578	670		(222)		(222)	
76.38	1.2458	245			(112)		
77.42	1.2317	129			(201)		

Table 6. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
83.92	1.1520	40					(502)
86.80	1.1210	40			(202)		
88.82	1.1007	20					(304)
90.20	1.0874	153				(400)	
*91.50	1.0753	153					
*93.02	1.0617	64					
99.32	1.0105	121				(331)	
101.32	.99593	767		(331)			
102.52	.98751	481			(203)		
104.52	.97401	136		(402)			
106.32	.96244	260	(???)				
109.12	.94541	467			(211)		
114.72	.91470	196			(114)		
119.02	.89385	230		(420)	(212)		
120.32	.88798	742				(224)	
*122.42	.87889	336					
125.42	.86672	44			(204)		
133.52	.83826	1,528		(333, 511)			
136.72	.82865	144				(115)	

Table 7. - Experimental d-spacings and intensities for phases identified in as-fabricated SiC-Ti(A55)/Mo

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.06	2.6300	130	(???)				
35.61	2.5190	12,480		(111)	(010)	(111)	(002)
36.86	2.4364	120					(210)
38.31	2.3474	2,210			(002)		
*38.81	2.3183	150					
40.13	2.2450	3,750			(011)		
40.96	2.2015	50					(211)
41.36	2.1811	25				(200)	
41.86	2.1562	25		(200)			(300)
52.86	1.7305	611			(012)		
60.01	1.5402	295		(220)			
60.56	1.5276	125				(220)	
62.86	1.4771	182			(110)		
70.48	1.3349	778			(103)		
71.86	1.3126	454		(311)			
72.46	1.3032	116				(113)	
75.48	1.2584	177		(222)		(222)	
76.01	1.2509	471			(112)		
77.28	1.2335	143			(201)		
81.98	1.1743	113			(004)		
86.56	1.1235	43			(202)		
92.46	1.0666	75			(014)		
100.16	1.0043	25				(331)	
100.86	.99922	92		(331)			
102.18	.98986	269			(203)		
104.43	.97460	154		(420)			
105.16	.96984	46	(???)				
108.96	.94634	116			(211)		
114.01	.91836	278			(114)		
119.36	.89230	132		(422)	(212)		

Table 7. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
120.41	.88758	114				(224)	
121.81	.88148	488			(015)		
133.46	.83845	373		(333, 511)			
139.16	.82190	189			(213)		

Table 8. - Experimental d-spacings and intensities for phases identified in 1600°F-25 hour exposed SiC-Ti(A55)/Mo

2θ	d	Intensity (arbirtrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
33.92	2.6405	400	(???)				
35.61	2.5190	13,140		(111)	(010)	(111)	(002)
36.76	2.4428	416					(210)
38.41	2.3415	647			(002)		
40.16	2.2435	930			(011)		
40.91	2.2040	216					(211)
41.91	2.1537	226		(200)		(200)	(300)
42.61	2.1199	53					(112)
53.01	1.7259	225			(012)		
*59.49	1.5529	50					
60.13	1.5374	2,812		(200)			
60.56	1.5276	750				(220)	
*62.01	1.4953	120					
62.96	1.4750	372			(110)		
70.76	1.3303	540			(103)		
71.91	1.3118	1,425		(311)			
72.51	1.3024	376				(113)	
75.56	1.2573	562		(222)		(222)	
76.11	1.2495	386			(112)		
77.36	1.2325	177			(201)		
82.11	1.1727	60			(004)		
86.81	1.1209	47			(202)		
90.12	1.0882	84				(400)	
*91.21	1.0780	110					
92.96	1.0622	88			(014)		
99.36	1.0102	50				(331)	
101.16	.99707	633		(331)			
102.41	.98827	420			(203)		
104.51	.97407	672		(420)			

Table 8. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
105.56	.96726	238	(???)				
108.91	.94664	184			(211)		
114.28	.91696	119			(114)		
119.06	.89367	100		(422)	(212)		
120.31	.88802	582				(224)	
121.41	.88319	249			(015)		
*122.26	.87956	196					
133.51	.83829	771		(333, 511)			
139.56	.82083	194			(213)		

Table 9 . - Experimental d-spacings and intensities for phases identified in 1800°F-25 hour exposed SiC-Ti(A55)/Mo

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.16	2.6225	375	(???)				
35.61	2.5190	11,430		(111)	(010)	(111)	(002)
36.81	2.4395	418					(210)
37.46	2.3987	167					(102)
38.41	2.3415	786			(002)		
40.16	2.2435	1,605			(011)		
40.93	2.2030	255					(211)
41.93	2.1527	432		(200)		(200)	(300)
42.61	2.1199	398					(112)
53.06	1.7244	226			(012)		
60.16	1.5368	814		(220)			
60.78	1.5230	528				(220)	
61.46	1.5074	161					(222)
63.01	1.4739	236			(110)		
65.71	1.4198	106					(321)
66.48	1.4052	200					(410) (213)
68.66	1.3658	84					(402)
70.81	1.3295	350			(103)		
71.91	1.3118	882		(311)			
72.78	1.2983	326				(113)	
73.21	1.2917	75					(500) (004)
75.63	1.2562	430		(222)		(222)	
76.46	1.2447	405			(112)		
77.46	1.2311	214			(201)		
78.46	1.2179	78					(420)
79.46	1.2051	70					(331)
83.86	1.1527	121					(502)
85.12	1.1388	30					(214)

Table 9. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
86.16	1.1277	50					(511)
87.06	1.1183	125			(202)		
88.36	1.1052	55					(304)
*91.41	1.0761	73					
100.26	1.0036	50				(331)	
101.06	.99778	360		(331)			
102.46	.98792	372			(203)		
104.41	.97674	390		(420)			
106.31	.96250	378	(???)				
108.56	.94872	130			(211)		
*109.46	.94342	118					
114.51	.91578	127			(114)		
119.46	.89184	256		(422)	(212)		
120.71	.88625	434				(224)	
*122.51	.87850	464					
125.41	.86675	88			(204)		
133.51	.83829	394		(333, 511)			
136.61	.82807	140				(115)	

Table 10. - Experimental d-spacings and intensities for phases identified in as-fabricated SiC-Ti(A55)/V

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.06	2.6300	250	(???)				
35.61	2.5190	10,530		(111)	(010)	(111)	(002)
38.11	2.3593	1,350			(002)		
40.01	2.2515	1,521			(011)		
41.06	2.1963	120					(211)
41.56	2.1711	120				(200)	
42.02	2.1483	25		(200)			(300)
52.76	1.7835	307			(012)		
*59.31	1.5567	50					
60.01	1.5403	1,164		(220)			
61.01	1.5174	316				(220)	
62.81	1.4782	283			(110)		
70.51	1.3344	770			(103)		
71.76	1.3142	1,295		(311)			
72.56	1.3017	122				(113)	
75.46	1.2587	423		(222)		(222)	
76.16	1.2489	168			(112)		
*76.91	1.2385	40					
77.56	1.2298	50			(201)		
81.86	1.1757	102			(004)		
90.06	1.0887	50				(400)	
*91.46	1.0757	50					
*93.56	1.0570	50					
99.91	1.0061	20				(331)	
100.86	.99922	160		(331)			
102.01	.99105	131			(203)		
*104.11	.97672	104					
104.71	.97276	106		(420)			
105.91	.96502	75	(???)				

Table 10. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
109.06	.94576	20			(211)		
114.06	.91810	131			(114)		
119.11	.89343	125		(422)	(212)		
120.51	.88713	389				(224)	
121.91	.88104	210			(015)		
133.41	.83861	668		(333, 511)			

Table 11. - Experimental d-spacings and intensities for phases identified in 1600°F-25 hour exposed SiC-Ti(A55)/V

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.06	2.6300	575	(???)				
35.66	2.5156	19,350		(111)	(010)	(111)	(002)
36.81	2.4395	300					(210)
38.51	2.3357	525			(002)		
40.26	2.2381	1,587			(011)		
40.96	2.2015	75					(211)
41.41	2.1786	120				(200)	
41.96	2.1513	150		(200)			(300)
42.62	2.1195	100					(112)
53.16	1.7214	230			(012)		
*59.11	1.5615	250					
60.16	1.5368	1,350		(220)			
60.71	1.5241	597				(220)	
*61.91	1.4975	120					
63.16	1.4708	386			(110)		
71.06	1.3238	918			(103)		
71.88	1.3123	1,350		(311)			
72.66	1.3001	210				(113)	
75.56	1.2573	615		(222)		(222)	
76.36	1.2461	433			(112)		
77.66	1.2284	175			(201)		
87.11	1.1178	100			(202)		
90.32	1.0863	70				(400)	
*91.50	1.0753	70					
92.96	1.0622	70			(014)		
99.96	1.0058	120				(331)	
101.01	.99814	696		(331)			
102.31	.98901	604			(203)		
104.61	.97342	786		(420)			

Table 11. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
106.26	.96281	186	(???)				
109.12	.94541	125			(211)		
*109.86	.94111	125					
114.61	.91526	109			(114)		
119.16	.89321	216		(422)	(212)		
120.16	.88869	777				(224)	
*122.31	.87935	524					
131.46	.84492	120			(300)		
133.51	.83829	1,411		(333, 511)			
136.46	.82940	142				(115)	
140.51	.81836	176			(213)		

Table 12. - Experimental d-spacings and intensities for phases identified in 1800°F-25 hour exposed SiC-Ti(A55)/V

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
34.02	2.6330	350	(???)				
35.71	2.5121	11,250		(111)	(010)	(111)	(002)
36.91	2.4331	320					(210)
37.58	2.3913	184					(102)
38.51	2.3357	525			(002)		
40.26	2.2381	1,473			(011)		
40.98	2.2004	300					(211)
41.98	2.1503	350		(200)		(200)	(300)
42.66	2.1176	318					(112)
53.16	1.7214	303			(012)		
*54.36	1.6862	84					
*59.31	1.5567	125					
60.13	1.5374	625		(220)			
60.78	1.5230	552				(220)	
61.41	1.5084	222					(222)
63.16	1.4708	380			(110)		
65.71	1.4198	77					(321)
66.56	1.4037	423					(410) (213)
68.76	1.3640	75					(402)
71.06	1.3238	386			(103)		
71.91	1.3118	1,113		(311)			
72.71	1.2993	335				(113)	
73.50	1.2873	60					(500) (004)
75.56	1.2573	506		(222)		(222)	
76.51	1.2440	456			(112)		
77.61	1.2291	155			(201)		
78.56	1.2166	32					(420)

Table 12. - Continued

2θ	d	Intensity (arbitrary units)	α-SiC	β-SiC	α-Ti	TiC	Ti_5Si_3
79.46	1.2051	45					(331)
82.51	1.1681	61			(004)		
83.91	1.1521	90					(502)
85.11	1.1389	35					(214)
86.06	1.1288	39					(511)
87.06	1.1183	110			(202)		
88.46	1.1042	81					(304)
*91.31	1.0770	52					
100.02	1.0053	60				(331)	
100.71	1.0003	294		(331)			
102.36	.99862	522			(203)		
104.56	.97375	433		(420)			
106.26	.96281	312	(???)				
*108.22	.95075	55					
109.01	.94605	39			(211)		
*109.66	.94226	50					
114.81	.91424	157			(114)		
119.96	.88958	198		(422)	(212)		
120.56	.88691	496				(224)	
*122.51	.87850	552					
*123.16	.87580	125					
125.56	.86617	135			(204)		
133.41	.83861	1,008		(333, 511)			
136.81	.82839	292				(115)	
140.56	.81824	188			(213)		

as-fabricated specimens is doubtful. The Ti_5Si_3 phase started appearing more clearly in all samples after an exposure of 1600°F for 25 hours. With further thermal exposure, the total intensity from Ti_5Si_3 was found to increase. A quantitative analysis of the phases found in DWA samples was not attempted at the present time.

Some moderate line shifts were observed in the α-Ti diffraction patterns after the thermal exposure. This would be expected due to lattice expansion or contraction as C and/or Si goes into solution. Residual stresses in the composite, introduced during thermal exposure, may have also contributed to the α-Ti shifts.

No lines from the interfacial coatings could be detected in the diffraction patterns of the coated composites. This was probably because the various coatings went into solution with the matrix during composite fabrication cycle.

Composites of SiC reinforced Ti (A55), Ti (3Aℓ-2.5V) and Ti (6Aℓ-4V) fabricated by TRW were found to be well bonded compared to those of DWA. These composites were thermally exposed to 1200°F, 1600°F and 1800°F for 25 hours each. The most obvious difference in the TRW composites of Ti (A55) compared to DWA composites of Ti (A55) was that lines due to TiSi and $TiSi_2$ were present in the TRW composites for 1600°F and 1800°F exposures, whereas, in the DWA composite, these lines were absent. In addition, reflections due to β-Ti were identified in the as-fabricated and thermally exposed composites of Ti (3Aℓ-2.5V) and Ti (6Aℓ-4V).

Quantitative Study of Reaction Products:

For the TRW composites, the study of reaction at the fiber-matrix interface is under study on a quantitative basis. One might expect that the interface reaction can be followed by studying the decrease in the integrated intensity of SiC reflections. However, with an increase in the thermal exposure, SiC reflections were found to overlap with the reflections of reaction products. In order to follow the intensity variation of SiC reflections, it is essential to separate the SiC reflections from other overlapping reflections. The Pearson VII function can be used in the separation of overlapping reflections, and this is given by

$$Y = Y_o \left[1 + \frac{(X-X_o)^2}{ma^2} \right]^{-m}$$

where X_o is the 2θ value corresponding to the peak height Y_o, "a" is related to peak half-width and m is the shape factor. For $m = 1$, the variation is Cauchy, and for $m = \infty$, the variation is Gaussian.

A modified IBM nonlinear least squares program was obtained from Purdue University. This was originally written to separate two overlapping peaks. We have modified it so that it is now capable of separating 12 overlapping reflections from the $K\alpha_1$-$K\alpha_2$ doublet. The program has been used for investigating the Ti (A55) composite samples of TRW. A typical curve is shown in Fig. 2 where individual reflections are separated using the program.

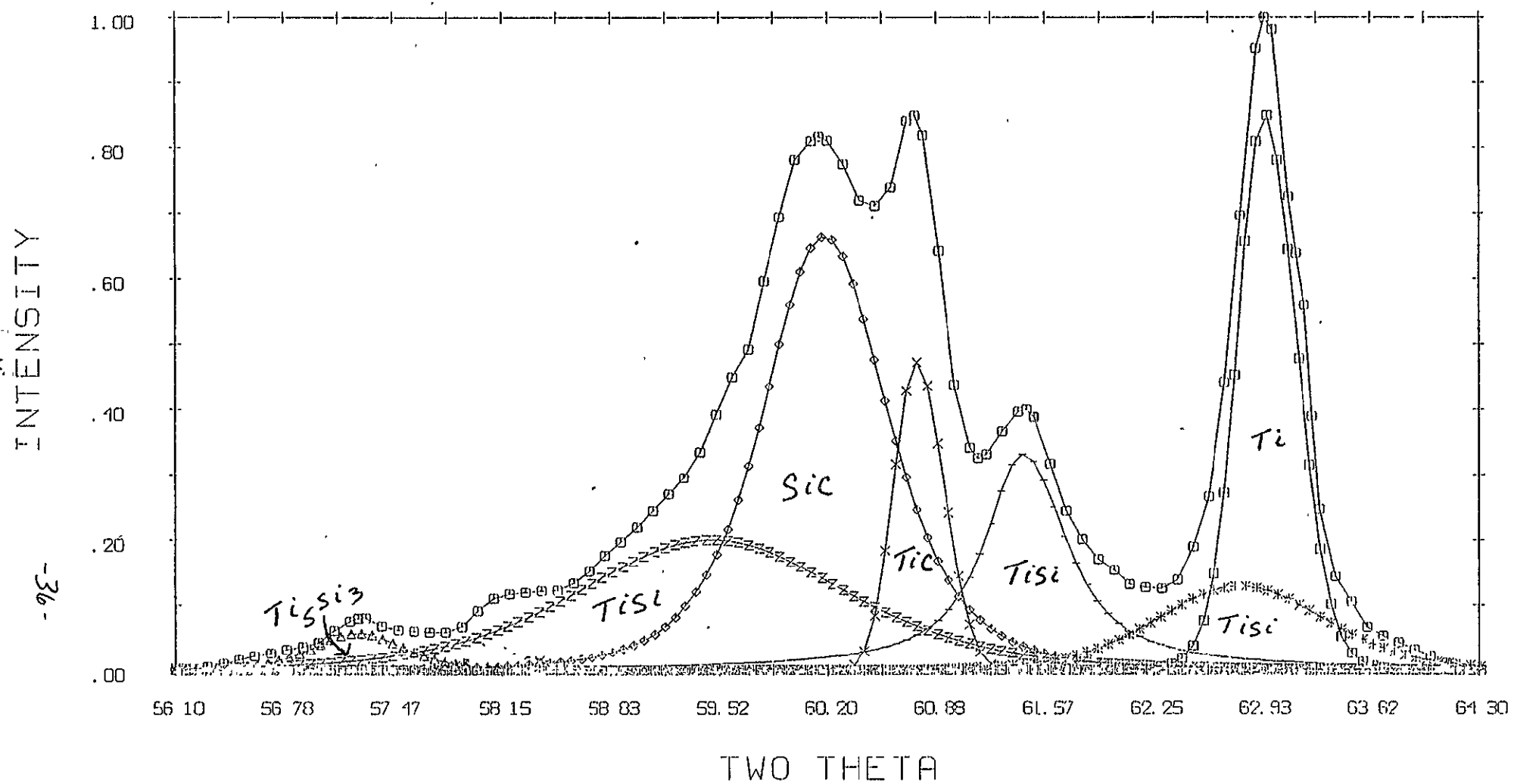

Fig. 2 SiC (220) reflection overlapped with reaction products in Ti (A55) composite exposed at 1600°F for 25 hours.

The half-widths and integrated intensity results are scattered when the same line is examined after the various thermal exposures. This effect may be due to the development of a preferred orientation. More accurate data are being collected at this time. This is required before any conclusions can be made at this time.

Publications and Talks:

The research on this study resulted in the X-ray data listed in Tables 1 through 12, and the following Master's Thesis: A Study of Interfacial Reactions in Silicon Carbide Reinforced Titanium, George Washington University, 1979. These results will be included in future publications.

PART 3 - SOLUTIONS FOR DIFFUSION IN SINGLE-, TWO-, AND THREE-PHASE BINARY ALLOY SYSTEMS

OBJECTIVE

In the analysis of diffusion controlled processes (e.g., the diffusion of planar protective coatings into substrate materials, the filament-matrix interaction in metal matrix composites, or the homogenization of powder compacts), the ability to predict the degree of interaction between different components, given some exposure conditions, is needed. Solutions of the diffusion equation have been reported for several different initial and boundary conditions. Most of these, however, are restricted to one geometry, applicable only for infinite or semi-infinite systems, or require that the diffusion coefficient be independent of concentration. The objective of this study is to develop general solutions for treating diffusion in single-, two-, and three-phase binary alloy systems.

APPROACH

Finite-difference solutions were developed in this study for treating one-dimensional transient diffusion in single-, two-, and three-phase binary alloy systems. These solutions are applicable for planar, cylindrical, or spherical geometries with any diffusion-zone size and any continuous (within each phase) variation of the diffusion coefficient with concentration. Special techniques were included to account for differences in molal volumes, initiation and growth of an intermediate phase (three-phase system, disappearance of a phase (two-, and three-phase systems), and the presence of

an initial composition profile in the specimen. In each analysis, an effort was made to achieve good accuracy while minimizing computation time.

RESULTS AND DISCUSSION

Diffusion calculations were performed (ref. 3) to establish the conditions under which concentration dependence of the diffusion coefficient was important in single-, two-, and three-phase binary alloy systems. Finite-difference solutions for each type of system were obtained using diffusion coefficient variations typical of those observed in real alloy systems. Solutions were also obtained using average diffusion coefficients determined by taking a logarithmic average of each diffusion coefficient variation considered. The solutions for constant diffusion coefficients were used as references in assessing the effects of diffusion coefficient variations. Calculations were performed for planar, cylindrical, and spherical geometries in order to compare the effect of diffusion coefficient variations with the effect of interface geometries.

Diffusion coefficient variations in single-phase systems and in the major-alloy phase of two-phase systems were found to effect the kinetics of diffusion as strongly as the interfacial geometry of the diffusion couple. Concentration dependence of the diffusion coefficient in the minor-alloy phase of a two-phase system was found to have only an initial transient effect on the diffusion kinetics. In three-phase systems, the intermediate phase did not increase in thickness if the diffusion coefficient of the inter-

mediate phase was smaller than the diffusion coefficient of the major-alloy phase. Under these conditions, the three-phase diffusion problem could be treated as a two-phase problem. However, if the diffusion coefficient of the intermediate phase was larger than the diffusion coefficient of the major-alloy phase, the intermediate phase grew rapidly at the expense of the major and minor phases. In most of the cases considered, the diffusion coefficient of the major-alloy phase was the key parameter that controlled the kinetics of interdiffusion.

A semiempirical relationship was developed (refs. 4,5) which describes the extent of interaction between constituents in single-phase binary alloy systems having planar, cylindrical, or spherical interfaces. This relationship makes possible a quick estimate of the extent of interaction without lengthy numerical calculations. It includes two parameters which are functions of mean concentration and interface geometry. Experimental data for the copper-nickel system are included to demonstrate the usefulness of this relationship.

PUBLICATIONS AND TALKS

The research on this study resulted in three publications: Effect of Concentration Dependence of the Diffusion Coefficient on Homogenization Kinetics in Multiphase Binary Alloy Systems, NASA TP 1281, 1978; Geometric Relationships for Homogenization in Single-Phase Binary Alloy Systems, NASA TP 1349, 1978; and An Empirical Relationship for Homogenization in Single-Phase Binary Alloy Systems, Met. Trans., Vol. 10A, No. 3, 1979.

PART 4 - MOISTURE EFFECTS ON GRAPHITE/POLYIMIDE COMPOSITES

OBJECTIVE

Composite materials consisting of graphite fibers in a polyimide resin matrix offer potential for considerable weight savings in structural applications requiring high temperature service. The space shuttle orbiter vehicle aft body flap is a prime candidate for possible application, where operating temperatures will be too high for graphite epoxy consideration and considerable weight savings may be possible compared to conventional aluminum structure. However, the characterization of graphite polyimide materials with respect to mechanical property degradation by environmental effects has not yet been adequately accomplished. The objective of this study was to do such a characterization.

APPROACH

The Materials Research Branch undertook this problem in support of NASA's CASTS program. The experimental program included a large matrix of both material and environmental variables.

Material	HTS2/PMR 15, Celion/PMR 15
Orientation	$(0,\pm45,90)_2$, $(0)_8$
Moisture Condition	As processed, vacuum dried, saturated, saturated and thermally cycled
Temperature	117, 294, 589K (-250, 70, 600°F)
Property	Tension, compression, interlaminar shear, rail shear, flexure

The grant's main contribution to this program was to develop software for a Hewlett-Packard Data Acquisition System to permit extensive

mechanical property data collection on the graphite/polyimide composites.

RESULTS AND DISCUSSION

Software Development:

Three computer programs were developed for an HP-9845 system to facilitate real-time data collection. A listing of these programs is given in Appendix A. Program 1 utilizes a digital voltmeter for data collection during static tests. Program 2 utilizes a fast response system voltmeter and is used for fatique tests. Two amplifiers are used with the system voltmeter to improve accuracy. Programs 1 and 2 store the data on magnetic tape cartridge. This data can subsequently be read using program 3 which gives stress-strain and modulus-strain plots, as required. The programs were written to accommodate more than one test machine at the Langley Research Center. Either a Tinus-Olsen testing machine or an MTS machine could be used with the data acquisition system. All the programs are documented to facilitate usage by other researchers.

Mechanical Properties:

The general conclusions resulting from the on-going study on graphite/polyimide composites are as follows (ref. 6): Moisture conditioning produced moderate to severe reduction in compressive and interlaminar shear properties at 589 K (600°F). No reduction was observed in tests at room temperature or at 117 K (-250°F). The compressive property appeared to be affected more than the interlaminar shear property. Vacuum drying, on the other hand, appeared to improve both properties at elevated temperatures and

might be considered for final processing if it can be shown that increases would not be lost by environmental degradation in service. The degradation by moisture conditioning appears to be associated with the lowering of the glass transition temperature, and this can occur after only a few weeks exposure to condensing humidity conditions at 355 K (180°F).

PUBLICATIONS AND TALKS

The research on this study resulted in the three computer programs listed in Appendix A, and the following technical paper: Mechanical Property Degradation of Graphite/Polyimide Composites after Exposure to Moisture or Shuttle Orbiter Fluids, NASA CP 2079, 1979.

SUMMARY

Good progress has been made in several areas. Mechanical property degradation and chemical interactions were studied in titanium matrix composites. The results suggest that an interfacial coating of aluminum considerably reduces the reaction between SiC fiber ad titanium matrix. General finite difference solutions were developed to treat diffusion in multiphase binary alloy systems with planar, cylindrical or spherical interface. Software was developed for the Hewlett-Packard data acquision system to facilitate real-time stress-strain data collection on graphite/polyimide composites. The research on this grant resulted in six publications.

REFERENCES

1. W. D. Brewer, J. Unnam and D. R. Tenney: Mechanical Property Degradation and Chemical Interactions in a Borsic/Titanium Composite, Proceedings of the 24th National SAMPE Symposium and Exhibition, San Fransisco, CA., 1979.

2. L. J. House: A Study of Interfacial Reactions in Silicon Carbide Reinforced Titanium, M.S. Thesis, George Washington University, 1979.

3. D. R. Tenney and J. Unnam: Effect of Concentration Dependence of the Diffusion Coefficient on Homogenization Kinetics in Multiphase Binary Alloy Systems, NASA TP 1281, 1978.

4. J. Unnam, D. R. Tenney and B. A. Stein: Geometric Relationships for Homogenization in Single-Phase Binary Alloy Systems, NASA TP 1349, 1978.

5. J. Unnam, D. R. Tenney, and B. A Stein: An Empirical Relationship for Homogenization in Single-Phase Binary Alloy Systems, Met. Trans., Vol. 10A, No. 3, 1979.

6. W. B. Lisagor: Mechanical Property Degradation of Graphite/Polyimide Composites after Exposure to Moisture or Shuttle Orbiter Fluids, NASA CP 2079, 1979.

APPENDIX A

HP-9845 Computer Programs

Program 1

```
10 ! Program#1:Static Test with Tinius-Olsen or MTS machine.
20   OPTION BASE 1
30   DEG
40   DIM C(20),G(100,20),A$[50],I(20),N(20),P(20),F$(8),R(20)
50   COM Ru(0:8)
60     INPUT "1 for CPT output, 2 for PAPER output: Select.",Prt
70     IF Prt=1 THEN PRINTER IS 16
80     IF Prt=2 THEN PRINTER IS 0
90     C(1)=1
100    C(14)=60000
110    Ru(7)=1
120    Ru(8)=3
130    INPUT "Total # of Channels(2,3,.....20)?",Ru(1)
140    IF (Ru(1)<2) OR (Ru(1)>20) THEN GOTO 130
150    Ru(2)=INT(2000/Ru(1))
160    REDIM G(Ru(2),Ru(1))
170    INPUT "# of Strain Gages(0,1,...18)?",C(12)
180    INPUT "# of Extensometers(0,1,2)?",C(11)
190    IF C(11)+C(12)+2>Ru(1) THEN GOTO 170
200    INPUT "Type of Test, Sp.#, Date, etc. (50cha.) ?",A$
210    PRINT LIN(2)
220    PRINT "Progrm 1 Output."
230    PRINT LIN(1)
240    PRINT A$
250    PRINT LIN(1)
260    FIXED 0
270    PRINT "----------------"
280    PRINT "channels    =";Ru(1)
290    PRINT "points/cha.=";Ru(2)
300    GOSUB Init
310    C(6)=Ru(1)
320    C(7)=Ru(2)
330    Ru(4)=INT((Ru(1)-2)/2)
340    IF Ru(4)<1 THEN Ru(4)=1
350    INPUT "1 for Tinius-Olsen, 2 for MTS : Select.",C(13)
360    IF C(13)=2 THEN INPUT "How many lbs does the full scale (10V) correspond
to ? (5K,10K,20K,25K,50K,100K)",C(14)
370    INPUT "What is the maximum load (lbs) you expect to use?",Ru(0)
380    Ru(8)=10*C(14)/Ru(0)
390    IF Ru(8)<1 THEN Ru(8)=2
400    IF Ru(8)>.1 THEN Ru(8)=1
410    Ru(0)=20
430    R(Ru(4)+1)=Ru(8)
440    N(Ru(4)+1)=Ru(0)
450    P(Ru(4)+1)=1
460    FOR I=1 TO Ru(4)
470    R(I)=Ru(7)
480    N(I)=Ru(0)+I
490    P(I)=I+1
500    NEXT I
510    IF Ru(1)=2 THEN GOTO 570
520    FOR I=Ru(4)+2 TO Ru(1)
530    R(I)=Ru(7)
540    N(I)=Ru(0)+I-1
550    P(I)=I
560    NEXT I
```

```
570     Rv(0)=-1
580     Rv(5)=Rv(7)
590     INPUT "Channel # to be Balanced(20,21,22,....39)?",Rv(0)
610     IF Rv(0)=-1 THEN GOTO 670
620     IF Rv(0)=20 THEN Rv(5)=Rv(8)
630     OUTPUT 722 USING 1390;INT(R(5))
640     OUTPUT 709 USING "#,K";"C"
650     OUTPUT 709 USING 1380;Rv(0)
660     GOTO 570
670     INPUT "Specimen Thickness in inches ?",C(2)
680     INPUT "Specimen Width in inches ?",C(3)
690     INPUT "Strain Gage Factor ?",C(4)
700     INPUT "Total Test Time (4 to 30 mins)?",C(5)
710     INPUT "Tape Cartridge # ?",Rv(0)
720     INPUT "Specify 2-digit file# (10,11,....99)?",File
730     IF (File<10) OR (File>99) THEN GOTO 710
740     File=INT(File)
750     F$="FILE"&VAL$(File)
760     PRINT "Cartridge# =";Rv(0)
770     PRINT "Data File# =";File
780     PRINT "Strain Gages=";C(12)
790     PRINT "Extensometers=";C(11)
800     PRINT "----------------"
810     PRINT LIN(1)
820     PRINT "To Stop: PAUSE , S=1 , EXECUTE , CONTINUE."
840     S=0
850     Rv(6)=C(5)*60000-C(7)-C(6)*120
860     IF Rv(6)<0 THEN Rv(6)=0
870     OUTPUT 722;"T3"
880     INPUT "Press CONTINUE to Collect Data",Rv(0)
890     BEEP
900     FOR I=1 TO Rv(1)
910     OUTPUT 722 USING 1390;INT(R(I))
920     OUTPUT 709 USING "#,K";"C"
930     OUTPUT 709 USING 1380;N(I)
940     TRIGGER 722
950     ENTER 722 USING 1400;I(P(I))
960     NEXT I
970     FOR J=1 TO Rv(2)
980     IF S=1 THEN GOTO Stop
990     FOR I=1 TO Rv(1)
1000    OUTPUT 722 USING 1390;INT(R(I))
1010    OUTPUT 709 USING "#,K";"C"
1020    OUTPUT 709 USING 1380;N(I)
1030    TRIGGER 722
1040    ENTER 722 USING 1400;G(J,P(I))
1050    NEXT I
1060    WAIT Rv(6)
1070    NEXT J
1080 Stop:BEEP
1090    C(8)=J-1
1100    INPUT "Press CONTINUE to Store",Rv(0)
1110    C(9)=I(Rv(1))
1120    IF NOT ((C(9)<.0115) OR (C(9)>.0125)) THEN GOTO 1150
1130    FIXED 1
1140    PRINT "Bridge Volt.=";C(9)*500
1150    FIXED 0
1160    PRINT "# of Data Points Collected = ";C(8)
1170    FOR J=1 TO C(8)
1180    FOR I=1 TO Rv(1)-1
1190    G(J,I)=G(J,I)-I(I)
1200    NEXT I
1210    NEXT J
1220    INPUT "Insert Cartridge in RECORD mode for data storage.",R(0)
1230    R(0)=(C(6)+C(5)-70-8+300) 256
1240    CREATE F$,Rv(0)
```

```
1250    REDIM G(C\6),C(8)
1255    ASSIGN #9 TO F$
1260    CHECK READ #9
1280    PRINT #9;C(*),G(*),A$
1290    ASSIGN #9 TO *
1300    Rv(0)=-1
1310    INPUT "More data collection(1 yes,0 no)?",Rv(0)
1320    IF Rv(0)<1 THEN GET "PROG3"
1330    GOTO 130
1340    END
1350 Init: !
1360    REMOTE 7
1370    RESET 7
1380    IMAGE #,2Z,"E"
1390    IMAGE "R",1D
1400    IMAGE F
1410    OUTPUT 722;"F1T1"
1420    RETURN
```

Program 2

```
10  ! Program#2:Fatigue Test with Tinius-Olsen or MTS machine.
20    OPTION BASE 1
30    DEG
40    DIM C(20),G(100,2),A$[50],P(50),F$(6),Z$[50],Buffer$[1401]
50    COM Rv(0:21)
60      INPUT "1 for CRT output, 2 for PAPER output: Select.",Prt
70      IF Prt=1 THEN PRINTER IS 16
80      IF Prt=2 THEN PRINTER IS 0
90      FIXED 0
100     C(1)=2
110     Rv(1)=2
120     Rv(2)=100
130     Rv(3)=50
140     INPUT "Type of Test, Sp.#, Date, etc. (50cha.) ?",A$
150     PRINT LIN(2)
160     PRINT "Program 2 Output."
170     PRINT A$
180     PRINT "----------------------------"
190     PRINT "2 channels."
200     PRINT "100 points/chan."
210     PRINT "50 intervals."
220     INPUT "Cycles/second ?",C(10)
230     PRINT "Cycles. second= ";C(10)
240     INPUT "GAIN for LOAD channel ?",Rv(10)
250     INPUT "GAIN for STRAIN channel ?",Rv(11)
260     PRINT "GAIN for LOAD channel  =";Rv(10)
270     PRINT "GAIN for STRAIN channel=";Rv(11)
280     PRINT "----------------------------"
290     C(12)=1
300     C(11)=0
310     INPUT "1 for Tinius-Olsen, 2 for MTS: Select.",C(13)
320     C(14)=50000
330     IF C(13)=2 THEN INPUT "To how many lbs does the full scale(10V) correspon
d to?(5K,10K,20K,25K,50K,100K)",C(14)
340     OUTPUT 9;"U2H,U2=I2"
350     IMAGE "P",12
360     IMAGE #,22,"E"
370     INPUT "SVM Range (1 for 0.1V, 2 for 1V, 3 for 10V) ?",Rv(9)
380     REMOTE 7
390     RESET 7
400     OUTPUT 726 USING "#,K";"D.01S,N99995,F1T1"
410     OUTPUT 726 USING 350;INT(Rv(9))
420     C(6)=Rv(1)
430     C(8)=C(7)=Rv(2)
440     C(9)=.012
450     P(1)=30
460     P(2)=60
470     P(3)=100
480     P(4)=1000
490     P(5)=10000
500     FOR I=6 TO Rv(3)
510     P(I)=10000+P(I-1)
520     NEXT I
530     Rv(0)=-1
540     INPUT "Channel # to be Balanced (0,1) ?",Rv(0)
560     IF Rv(0)=-1 THEN GOTO 600
570     OUTPUT 709 USING 360;Rv(0)
```

```
580     TRIGGER 726
590     GOTO 530
600     INPUT "Specimen Thickness in inches ?",C(2)
610     INPUT "Specimen Width in inches ?",C(3)
620     INPUT "Strain Gage Factor ?",C(4)
630     INPUT "Tape Cartridge# ?",Rv(19)
640     INPUT "Specify 2-Digit File# for Storing Data (10,11,...80) ?",File
650     IF (File<10) OR (File>80) THEN GOTO 640
670     PRINT "To Store: PAUSE, S=1, EXECUTE, CONTINUE."
680     PRINT LIN(1)
690     PRINT "To Stop : PAUSE, S=2, EXECUTE, CONTINUE."
700     PRINT LIN(1)
710     S=0
720     OUTPUT 726;"T3"
730     FIXED 0
740     INPUT "Press CONTINUE to Collect Data",Rv(0)
750     OUTPUT 9;"U2G"
760     OUTPUT 9;"U2V"
770     ENTER 9;V
780     V=V*C(10)*1000
790     FOR K=1 TO Rv(3)
800     OUTPUT 709;"L01F00I1"
820     OUTPUT 726 USING "#,K";"F1, T1,D.0010SN200S"
830     Buffer$=""
840     BEEP
850     ENTER 726 BFHS 1401;Buffer$
860     BEEP
870     OUTPUT 726;"T3"
880     Rv(18)=Rv(16)=-1E99
890     Rv(17)=Rv(15)=1E99
900     Buffer$[1400]=","
910     J=15
920     FOR I=2 TO Rv(2)
930     G(I,1)=VAL(Buffer$[J])
940     G(I,1)=ABS(G(I,1)*Rv(10))
950     J=J+7
960     G(I,2)=VAL(Buffer$[J])
970     G(I,2)=ABS(G(I,2)*Rv(11))
980     J=J+7
990     IF Rv(18)<G(I,2) THEN Rv(18)=G(I,2)
1000    IF Rv(16)<G(I,1) THEN Rv(16)=G(I,1)
1010    IF Rv(17)>G(I,2) THEN Rv(17)=G(I,2)
1020    IF Rv(15)>G(I,1) THEN Rv(15)=G(I,1)
1030    NEXT I
1040    G(1,1)=G(2,1)
1050    G(1,2)=G(2,2)
1060    Rv(21)=Rv(18)-Rv(17)
1070    Rv(20)=Rv(16)-Rv(15)
1080    Rv(20)=Rv(20)/10*C(14)
1090    Rv(20)=Rv(20)/(C(2)*C(3))*1000
1100    Rv(21)=4*Rv(21)/(C(4)*500*C(9))
1110    Rv(20)=ABS(Rv(20)/Rv(21))
1120    PRINT "Cycle# =";INT(V)
1130    PRINT "Modulus=";Rv(20);"lbf."
1140    IF S=2 THEN GOTO Stop
1150    IF S=1 THEN GOSUB Store
1160    OUTPUT 9;"U2V"
1170    ENTER 9;V
1180    V=V*C(10)*1000
1190    IF V<P(K) THEN GOTO 1140
1200    NEXT K
1210 Stop:GET "PROG3"
1220    END
1230 Store:INPUT "Insert Cartrige in RECORD mode for data storage.",Rv(0)
1240    File=INT(File)
1250    F$="FILE"&VAL$(File)
```

```
1260   Z$="Cartridge"&VAL$(Rv(19))&";   "&F$
1270   CREATE F$,10
1290   ASSIGN #9 TO F$
1295   CHECK READ #9
1300   PRINT #9;C(*),G(*),A$
1310   ASSIGN #9 TO *
1320   PRINT "----------------"
1330   PRINT Z$
1340   PRINT "----------------"
1350   File=File+1
1360   S=0
1370   RETURN
```

Program 3

```
10    ! Program#3: Retrieving & Plotting Data. May 11,1979.
20    OPTION BASE 1
30    DEG
40    DIM C(20),F$(6)
50    COM Rv(0:37)
60      INPUT "1 for CRT plot, 2 for 9872 plot: Select.",Crt
70      INPUT "1 for CRT output, 2 for PAPER output: Select.",Prt
80      IF Crt=1 THEN PLOTTER IS 13,"GRAPHICS"
90      IF Crt=1 THEN GRAPHICS
100     Savep=0
110     IF Crt=1 THEN GOTO 140
120     OUTPUT 705;"IP 0,0,10500,8300"
130     PLOTTER IS 7,5,"9872A"
140     IF Prt=2 THEN PRINTER IS 0
150     IF Prt=1 THEN PRINTER IS 16
160     INPUT "Tape Cartridge #",Rv(0)
170     FIXED 0
180 Pread:INPUT "Specify 2-digit file# (10,11,...,39)",File
190     IF (File<10) OR (File>99) THEN GOTO Pread
200     File=INT(File)
210     F$="FILE"&VAL$(File)
220   ASSIGN #9 TO F$
230   READ #9;C(*)
240   DIM G(40,60),X(0:39),Y(0:39),F(0:39),W(0:39),Wp(0:39)
250   DIM A$[50],X$[30],Y$[30],Z$[50]
260     Rv(1)=C(6)
270     Rv(2)=C(8)
280   REDIM G(Rv(2),0:Rv(1)-1)
290     FIXED 0
300     PRINT LIN(2)
310     Rv(0)=INT(Rv(0))
320     Z$="Cartridge"&VAL$(Rv(0))&"; "&F$
330     PRINT "Program 3 Output: ",Z$
340     PRINT "# of channels=";Rv(1);"; points/cha.=";Rv(2)
350     PRINT LIN(1)
360     Rv(3)=0
370     Rv(33)=0
380     Rv(34)=0
390 Read: ASSIGN #9 TO F$
400     X$="STRAIN, in/in"
410     READ #9;C(*),G(*),A$
420     FIXED 5
430     C(9)=C(9)+500
440     IF Rv(33)=4 THEN GOTO Plot2
450     Y$="STRESS, ksi"
460     IF Rv(3)=1 THEN GOTO 790
470     Rv(20)=0
480     INPUT "Is Data to be Printed (1 yes, 0 no) ?",Rv(20)
490     IF Rv(20) =0 THEN GOTO 590
500     FOR J=1 TO C(8)
510     FIXED 0
520     PRINT J;
530     FOR I=0 TO Rv(1)-1
540     FIXED 5
550     PRINT G(J,I);
```

```
560     NEXT I
570     PRINT LIN(0)
580     NEXT J
590     IF Rv(3)=1 THEN GOTO 790
600     Rv(3)=1
610     FIXED 0
620     PRINT "-----------------"
630     PRINT "Load Channel = 0"
640     F(0)=1
650     IF C(12)=0 THEN GOTO 700
660     FOR I=1 TO C(12)
670     PRINT "Strain  Gage =";I
680     F(I)=2
690     NEXT I
700     K=3
710     IF C(11)=0 THEN GOTO 770
720     FOR I=C(6)-C(11)-1 TO C(6)-2
730     PPINT "Extensometer =";I
740     F(I)=K
750     K=K+1
760     NEXT I
770     IF C(6)>C(11)+C(12)-1 THEN PRINT "Bridge Volt. =";C(6)-1
780     PRINT "-----------------"
790     FIXED 2
800     PRINT LIN(1)
810     PRINT "-------------------------------------------------------------------"
820     PRINT LIN(1)
830     PRINT "          Channel#    Wt. Fr."
840     PRINT LIN(1)
850     FOR I=0 TO Rv(1)-2
860     Y(I)=-1
870     INPUT "Chan.# & Weighting Factor for Y-axis",Y(I)
880     IF Y(I)=-1 THEN GOTO 940
890     INPUT "Wy(I) ?",Wy(I)
900     PRINT "Y-axis:     ";Y(I);"     ";Wy(I)
910     Rv(4)=I+1
920     NEXT I
930     PRINT LIN(1)
940     FOR I=0 TO Rv(1)-2
950     X(I)=-1
960     INPUT "Chan.# & Weighting Factor for X-axis",X(I)
970     IF X(I)=-1 THEN GOTO 1030
980     INPUT "Wx(I) ?",Wx(I)
990     PRINT "X-axis:     ";X(I);"     ";Wx(I)
1000    Rv(6)=I+1
1010    NEXT I
1020    PRINT LIN(1)
1030    INPUT "Are axes to be plotted(0,1)?",Rv(28)
1040    INPUT "pen # to use(1,4)?",Rv(11)
1050    PEN Rv(11)
1060 Plot2:FOR J=1 TO C(8)
1070    Rv(35)=0
1080    FOR I=0 TO Rv(4)-1
1090    Rv(8)=G(J,Y(I))
1100    Rv(21)=F(Y(I))
1110    GOSUB Function
1120    Rv(35)=Rv(35)+Rv(8)*Wy(I)
1130    NEXT I
1140    Rv(8)=G(J,Y(0))=Rv(35)/Rv(4)
1150    Rv(35)=0
1160    FOR I=0 TO Rv(6)-1
1170    Rv(8)=G(J,X(I))
1180    Rv(21)=F(X(I))
1190    GOSUB Function
1200    Rv(35)=Rv(35)+Rv(8)*Wx(I)
1210    NEXT I
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1220    Ru(8)=G(J,X(0))=Ru(35)
1230    NEXT J
1240   IF Ru(33)=4 THEN GOTO Modulus
1250   IF Ru(28)<1 THEN GOTO Plot
1260 Plot1:IF Crt=2 THEN INPUT "Place 8.5x11 paper (horizontally) touching lower
-left-corner of plotter",Ru(0)
1270    FIXED 5
1280    GOSUB Maxmin
1290    PRINT "Xmin=";Ru(13)
1300    PRINT "Xmax=";Ru(12)
1310    PRINT "ymin=";Ru(15)
1320    PRINT "Ymax=";Ru(14)
1330    INPUT "Xmin?",Ru(25)
1340    INPUT "Xmax?",Ru(24)
1350    INPUT "Ymin?",Ru(27)
1360    INPUT "Ymax?",Ru(26)
1370    INPUT "X-tic Interval?",Ru(9)
1380    INPUT "# of tics per X-unit label?",Ru(18)
1390    INPUT "X-axis label(30 Characters)?",X$
1400    INPUT "Y-tic Interval?",Ru(10)
1410    INPUT "# of tics per Y-unit label?",Ru(19)
1420    INPUT "Y-axis label(30 Characters)?",Y$
1430    Ru(16)=(Ru(24)-Ru(25))/6.5*10
1440    Ru(17)=(Ru(26)-Ru(27))/6.5*10
1450    IF Crt=2 THEN INPUT "P1,P2: 1 you set, 0 program selects, 2 old values re
tained.",Savep
1460    IF Savep=0 THEN LOCATE 15,115,15,85
1470    IF Savep<>1 THEN GOTO 1500
1480    DISP "Set P1, Press ENTER on plotter. Set P2, Press ENTER."
1490    LOCATE
1495    DISP ""
1500    SCALE Ru(25),Ru(24),Ru(27),Ru(26)
1510    AXES Ru(9),Ru(10),Ru(25),Ru(27),Ru(18),Ru(19),.4
1520    Savep=2
1530    CSIZE 3,1/1.5
1540    LORG 5
1550    LDIR 0
1560    FIXED 3
1570    Xtics=INT((Ru(24)-Ru(25))/Ru(9)+.1)
1580    Ytics=INT((Ru(26)-Ru(27))/Ru(10)+.1)
1590    FOR I=0 TO Xtics STEP Ru(18)
1600    Xval=Ru(25)+I*Ru(9)
1610    MOVE Xval,Ru(27)-Ru(17)*3
1620    LABEL USING "K";Xval
1630    NEXT I
1640    MOVE (Ru(24)-Ru(25))/2,Ru(27)-7*Ru(17)
1650    LABEL USING "K";X$
1660    FIXED 0
1670    LORG 8
1680    FOR I=0 TO Ytics STEP Ru(19)
1690    Yval=Ru(27)+I*Ru(10)
1700    MOVE Ru(25)-Ru(16),Yval
1710    LABEL USING "K";Yval
1720    NEXT I
1730    LORG 5
1740    LDIR 90
1750    MOVE Ru(25)-9*Ru(16),(Ru(26)-Ru(27))/2
1760    LABEL USING "K";Y$
1770    PLOT Ru(25),Ru(26),-2
1780    PLOT Ru(24),Ru(26),-1
1790    PLOT Ru(24),Ru(27),-1
1800    PLOT Ru(25),Ru(26),-2
1810    LDIR 0
1820    MOVE (Ru(24)-Ru(25))/2,6-Ru(17)*Ru(26)
1830    LABEL USING "K";A$
1840    MOVE (Ru(24)-Ru(25))/2,3*Ru(17)*Ru(26)
```

```
1850    LABEL USING "K";Z#
1860 Plot:PLOT G(1,X(0)),G(1,Y(0)),-2
1870    FOR J=1 TO C(8)
1880    Rv(0)=-1
1890    IF (G(J,Y(0))<1E-9) OR (G(J,X(0))<1E-9) THEN Rv(0)=-2
1900    PLOT G(J,X(0)),G(J,Y(0)),Rv(0)
1910    NEXT J
1920    IF Crt=1 THEN DUMP GRAPHICS
1930    IF Crt=1 THEN GCLEAR
1940    PEN 0
1950    IF Rv(34)>=1 THEN GOTO Read
1960    IF Rv(33)=0 THEN GOTO 2040
1970    IF NOT ((Rv(33)=1) OR (Rv(33)=2) OR (Rv(33)=4)) THEN GOTO 2000
1980    Rv(33)=0
1990 GOTO Read
2000    IF NOT (Rv(33)=3) THEN GOTO 2040
2010    Rv(31)=2
2020    Rv(33)=4
2030 GOTO Read
2040    IF Y(0)=0 THEN INPUT "Modulus(0No,1Tan,2Sec,3Tan&Sec)?",Rv(33)
2050    IF Y(0)<>0 THEN INPUT "Poisson's Ratio(0No, 1Yes-long.strain on Y, 2Yes-t
rans.strain on X)?",Rv(34)
2060 IF ((Rv(33)<=0) AND (Rv(34)<=0)) THEN GOTO Read
2070    Rv(31)=Rv(33)
2080    IF Rv(33)=3 THEN Rv(31)=1
2090 Modulus:Rv(37)=.0002
2100    Rv(36)=2
2110    FOR J=1 TO C(8)-1
2120    IF (Rv(37)<=G(J+1,X(0))) AND (Rv(37)>=G(J,X(0))) THEN GOTO 2140
2130    NEXT J
2140    Rv(37)=J
2150    IF C(1)=2 THEN Rv(37)=1
2160    PRINT "----------------"
2170    IF Rv(34)>=1 THEN GOTO Poisson
2180    IF NOT (Rv(31)=2) THEN GOTO 2220
2190    PRINT "Secant Modulus."
2200    Y$="SECANT MODULUS, ksi"
2210    GOTO 2320
2220    PRINT "Tangent Modulus."
2230    Y$="TANGENT MODULUS, ksi"
2240    FOR J=Rv(36)+Rv(37) TO C(8)-Rv(36)
2250    Rv(29)=G(J+Rv(36),Y(0))-G(J-Rv(36),Y(0))
2260    Rv(30)=G(J+Rv(36),X(0))-G(J-Rv(36),X(0))
2270    Rv(8)=G(J-Rv(36)-Rv(37)+1,X(0))=G(J,X(0))
2280    Rv(8)=G(J-Rv(36)-Rv(37)+1,Y(0))=Rv(29)/Rv(30)
2290    NEXT J
2300    C(8)=C(8)-2*Rv(36)-Rv(37)+1
2310    GOTO 2410
2320    Rv(22)=G(Rv(37),X(0))
2330    Rv(23)=G(Rv(37),Y(0))
2340    FOR J=Rv(37)+1 TO C(8)
2350    Rv(29)=G(J,Y(0))-Rv(23)
2360    Rv(30)=G(J,X(0))-Rv(22)
2370    Rv(8)=G(J-Rv(37),X(0))=ABS(G(J,X(0)))
2380    Rv(8)=G(J-Rv(37),Y(0))=ABS(Rv(29)/Rv(30))
2390    NEXT J
2400    C(8)=C(8)-Rv(37)
2410    INPUT "Are area to be plotted(0-1)?",Rv(28)
2420    INPUT "pen# to use(1-4)?",Rv(11)
2430    PEN Rv(11)
2440    PRINT "----------------"
2450 IF Rv(28)<1 THEN GOTO Plot
2460 GOTO Plot1
2470    END
2480 Function:IF Rv(31)=0 THEN RETURN
2490    IF Rv(31)=1 THEN R(8)=Rv(8)*10*C(14)
```

```
2500    IF Rv(21)=1 THEN Rv(8)=ABS(Rv(8)*(C(2)-C(3))/1000
2510    IF Rv(21)=2 THEN Rv(8)=ABS(4*Rv(8)/(C(4)*C(9)))
2520    IF Rv(21)=3 THEN Rv(8)=ABS((-1.352994493E-5+1.352994493E1*Rv(8)) 1.017)
2530    IF Rv(21)=4 THEN Rv(8)=ABS((-1.030318028E-4+1.386966577E1*Rv(8))/1.015)
2540    RETURN
2550 Maxmin:  Rv(14)=Rv(12)=-1E99
2560 Rv(15)=Rv(13)=1E99
2570    FOR I=1 TO C(8)
2580    IF G(I,X(0))<Rv(13) THEN Rv(13)=G(I,X(0))
2590    IF G(I,X(0))>Rv(12) THEN Rv(12)=G(I,X(0))
2600    IF G(I,Y(0))<Rv(15) THEN Rv(15)=G(I,Y(0))
2610    IF G(I,Y(0))>Rv(14) THEN Rv(14)=G(I,Y(0))
2620    IF G(I,Y(0))=Rv(14) THEN Rv(32)=I
2630    NEXT I
2640    IF (C(1)=1) AND (Rv(33)=0) THEN C(8)=Rv(32)
2650    RETURN
2660 Poisson: PRINT "Poisson's Ratio."
2670    INPUT "X-axis(1 long.strain, 2 trans.strain, 3 average of long.&trans.)?"
,Rv(36)
2680    Y$="POISSON'S  RATIO"
2690    FOR J=Rv(37) TO C(8)
2700    I=J-Rv(37)+1
2710    Rv(22)=G(J,X(0))
2720    Rv(23)=G(J,Y(0))
2730    IF Rv(34)=2 THEN Rv(22)=Rv(23)
2740    IF Rv(34)=2 THEN Rv(23)=G(J,X(0))
2750    G(I,Y(0))=Rv(23)/Rv(22)
2760    G(I,X(0))=Rv(22)
2770    IF Rv(36)=2 THEN G(I,X(0))=Rv(23)
2780    IF Rv(36)=3 THEN G(I,X(0))=(Rv(22)+Rv(23))/2
2790    NEXT J
2800    C(8)=I
2810    X$="LONGITUDINAL STRAIN, in/in."
2820    IF Rv(36)=2 THEN X$="TRANSVERSE STRAIN, in/in."
2830    IF Rv(36)=3 THEN X$="AVERAGE STRAIN(long.&trans.), in/in."
2840    GOTO 2410
```