Final Technical Report A002
Reporting Period: 25 December 1995-25 September 1996
Contract DAAEO7-95-C-R040

COMPOSITE CERAMICS

Submitted By:

Kathryn V. Logan, Ph.D.
School of Materials Science and Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0245

November 20, 1996

COMPOSITE CERAMICS

ABSTRACT

This task encompassed an eighteen month technical effort to determine the effects of processing and resultant microstructural variations on the resistance to penetration exhibited by hot pressed, composite ceramic titanium diboride/alumina (TiB_2/Al_2O_3). During the course of the task, the effect of processing on the product microstructure and the effect of variation in microstructure on the ballistic performance of TiB_2/Al_2O_3 were determined. Processing conditions were studied in depth in order to develop consistent procedures for reproducing a specifically desired microstructure. The main goal of the program was the continued development of a technology to produce low cost (less than $10 per pound) armor material which has a significant resistance to KEW penetration and is reliable and light weight. The technology is dual use providing a low cost material which is suitable for DoD, as well as commercial use in high performance applications. The task included synthesis, forming, ballistic testing, and pre-ballistic materials analysis of hot pressed, composite titanium diboride/alumina formed using the patented Georgia Tech SHS (thermite) technology and conventional processing technology.

OVERHEAD KEY

1. OUTLINE: Outline of the report contents.

2. BACKGROUND: Logan's Ph.D. research produced "one" data point that a test target composed of the SHS produced titanium diboride/alumina had a mass efficiency of 4.

3. UDRI BALLISTIC PENETRATION DATA: A tabulation of the DOP test results showing sample # 1-0225 with a DOP of 1.9mm.

4. SLAP BALLISTIC TEST RESULTS: Graphical representation of SLAP DOP tests with □ = SHS formed composite titanium diboride/alumina at 2,6 and 30 hour ball milling times, ● = SHS formed titanium diboride, and ▲ = carbothermically formed titanium diboride. This shows that the SHS composite TiB_2/Al_2O_3 resistance to SLAP penetration was comparable to that of SHS and carbothermic produced titanium diboride.

LRP BALLISTIC TEST RESULTS: Graphical representation of LRP DOP tests of composite SHS TiB_2/Al_2O_3 after 8 and 30 hour ball milling times.

5. SAMPLE 225 T@A: Low and high magnification scanning electron microscopy (SEM) views showing a microstructural bias for titanium diboride to surround the alumina grain boundaries. The TiB_2 grains are the white areas, and the Al_2O_3 grains are the gray areas. The darker gray "channel" areas are where the TiB_2 grains have pulled out during polishing. The circular black areas are pores. (The density of the samples is > 95% of theoretical.

SAMPLE 227 T in A: Low and high magnification scanning electron microscopy (SEM) views showing a microstructural bias for titanium diboride to be dispersed in the alumina areas. The TiB_2 grains are the white areas, and the Al_2O_3 grains are the gray areas. the darker gray "channel" areas are where the TiB_2 grains have pulled out during polishing. The circular black areas are pores. (The density of the samples is > 95% of theoretical.

Note: Samples # 225 and 227 correspond to samples # 1-0225 and 1-0227 respectively as listed in the UDRI BALLISTIC PENETRATION DATA in overhead #3.

6. SPLIT HOPKINSON BAR TEST RESULTS: Graphical representation of compressive strength at increasing strain rates of SHS composite TiB_2/Al_2O_3 using the "dumbbell" shape test configuration. Six dumbbells were cut from each sample # 758,762 and 766 and tested at each strain rate. The dashed line represents Southwest Research Institute data for pure alumina under the same test conditions. The composite shows an exponential increase in compressive strength with an increase in strain rate loading.

7. PROPERTIES: A comparative listing of mechanical properties documented in the literature for various high performance materials. The carbothermic titanium diboride contains an added metal (e.g. Ni, Fe) as a sintering aid. It is possible that the other reported materials also have added sintering aids. Data reported in the literature (especially before 1990) did not fully document the material compositions and processing conditions.

8. OBJECTIVES: It is thought that the main difference in samples 225 and 227 was the microstructural bias of TiB_2 in Al_2O_3. Conventional technologies for powder preparation and densification was also used as a comparison to the SHS technology.

9. PROGRAM SCHEDULE: The total program contracting period was 18 months.

10. SYNTHESIS AND FORMING: A sub-outline of the immediate information to follow in this presentation.

11. SHS POWDERS: The SHS powders were synthesized using self-propagating high temperature synthesis (SHS) technology. The reaction was initiated using a resistance heated nichrome wire. The resulting porous product was then ball milled to an average particle size of 5-12 microns.

MANUALLY MIXED POWDERS: The manually mixed powders were prepared by mixing 30 weight % TiB_2 in 70 weight % Al_2O_3. The mixed powders were then ball milled to an average particle size of 5-12 microns.

12. HOT PRESS MATRIX: This is the general matrix followed in determining the hot press parameters to obtain the specific microstructures of the titanium diboride surrounding the alumina grains (T@A), or the titanium diboride dispersed in the alumina (T in A). The powder was filled into a graphite die, then heated in the hot press at 500, 3375, 5000psi to 1620°C and held at temperature 30, 90, 150 and 240 minutes. Additional runs were made with hold times of 30, 90, 150 and 240 minutes by applying a minimal pressure of 500psi initially, then rapidly applying 5000psi when the hold temperature of 1620°C was reached.

13. SCHEMATIC OF CTP CURVE: The optimal hot pressing parameters required to achieve maximal densities were determined by using a Climbing Temperature Program. A hot press run was made by applying 5000psi, increasing the temperature by 10°/minute and measuring the ram travel (percent density). The increasing percent density was then plotted against temperature. An example curve is shown in a typical "S" shape. A line constructed parallel to the straight line portion of the curve then intersects the temperature axis at the temperature which will produce the maximum density (in the example 1300°C).

As the sample is hot pressed, it progresses through several stages of densification. Stage 1 represents initial bulk compaction of the powder. Stage 2 represents trapped gasses being eliminated through open porosity. Stage 3 represents trapped gasses being eliminated through diffusion.

14. HOT PRESS RUN OF SAMPLE 225: This is a graphical representation of the hot press cycle for sample 225 (UDRI sample #1-0225) showing the increase in temperature and ram travel over time. Pressure additions are designated on the ram travel curve.

15. HOT PRESS RUN OF SAMPLE 227: This is a graphical representation of the hot press cycle for sample 227 (UDRI sample #1-0227) showing the increase in temperature and ram travel over time. Pressure additions are designated on the ram travel curve.

16. TARGETS: A matrix listing of the deliverable targets: a total of 3 each, 4 inch O.D. X 1-1/2" right circular cylinders, of the 4 microstructures for ballistic testing; and 3 each, 3 inch O.D. X 1/2" right circular cylinders, of the 4 microstructures for mechanical property measurements.

17. X-RAY DIFFRACTION TRACE OF SHS COMPOSITE: X-ray diffraction analysis of the SHS composite TiB_2/Al_2O_3 (top trace) showing the confirmation of the presence of titanium diboride and alumina (corundum) and no other phases, or compounds. The second and third graphs represent the standard data for pure titanium diboride (ref. #35-741) and pure alumina (ref. #10-173).

18. HOT PRESS RESULTS: A tabulation of the hot press results. NA = Not Available.

19. 225 CONFIRM T@A: Low and high magnification scanning electron microscopy (SEM) views of additionally prepared samples to confirm the microstructural bias for titanium diboride to surround the alumina grain boundaries throughout the bulk sample. The TiB_2 grains are the white areas, and the Al_2O_3 grains are the gray areas. The darker gray "channel" areas are where the TiB_2 grains have pulled out during polishing. The circular black areas are pores. (The density of the samples is > 95% of theoretical.

227 CONFIRM T in A: Low and high magnification scanning electron microscopy (SEM) views of additionally prepared samples to confirm the microstructural bias for titanium diboride to be dispersed in the alumina areas. The TiB_2 grains are the white areas, and the Al_2O_3 grains are the gray areas. the darker gray "channel" areas are where the TiB_2 grains have pulled out during polishing. The circular black areas are pores. (The density of the samples is > 95% of theoretical.

Note: Samples # 225 and 227 correspond to samples # 1-0225 and 1-0227 respectively as listed in the UDRI BALLISTIC PENETRATION DATA in overhead #3.

20. HOLD TIME @ 1620^{o}C: A graphical representation of the effect of hold time at temperature on the percent theoretical density achieved during hot pressing of manually mixed and SHS powders.
= HOLD TIME (min.) Gray bar = SHS samples Black bar = manually mixed samples.

The density of both manually mixed and SHS samples increased with an increase in hold time.

21. Micrographs depicting the distribution of titanium diboride in alumina. The TiB_2 is represented by the white areas and the alumina is represented by the gray areas. All micrographs are taken at the same 160X magnification. A 100 micron bar is in each field of view for reference.

SHS T@A: The TiB_2 grains are surrounding the Al_2O_3 grains in a swirled pattern. The large areas of alumina range in size up to approximately 50 microns.

SHS T in A: The TiB_2 grains tend to be uniformly dispersed in the Al_2O_3. Even though there are swirls present, they are very small, less than approximately 20 microns.

MM T@A: The TiB_2 grains are surrounding the Al_2O_3 grains. The large areas of alumina range in size up to 100 microns. The darker gray areas are residual oil film remaining after polishing.

MM Tin A: The TiB_2 grains are uniformly dispersed in the Al_2O_3

22. MM SAMPLES @ 1620C: A graphical representation of the density, modulus of rupture (MOR) and elastic modulus (EMOD) results of the manually mixed samples hot pressed to 1620C at pressures of 500, 3375, 5000 and 500/5000psi with hold time at temperature of 30, 90, 150, 240 minutes.

The density, modulus of rupture and elastic modulus increase with an increase in pressure and hold time.

23. SHS SAMPLES @ 1620C: A graphical representation of the density, modulus of rupture (MOR) and elastic modulus (EMOD) results of the SHS samples hot pressed to 1620C at pressures of 500, 3375, 5000 and 500/5000psi with hold time at temperature of 30, 90, 150, 240 minutes.

The density, modulus of rupture and elastic modulus increase with an increase in pressure and hold time.

24. 1620C @ 500psi: A graphical representation of the density, modulus of rupture (MOR) and elastic modulus (EMOD) results of the SHS and manually mixed samples hot pressed to 1620C at a pressure of 500psi with a hold time at temperature of 30 and 150 minutes.

The density, modulus of rupture and elastic modulus of both the SHS and manually mixed samples hot pressed at 500psi increased with an increase in hold time. The density, MOR and EMOD of the SHS samples hot pressed at 500psi were greater than those of the manually mixed samples hot pressed at 500psi.

25. 1620C @ 3375psi: A graphical representation of the density, modulus of rupture (MOR) and elastic modulus (EMOD) results of the SHS and manually mixed samples hot pressed to 1620C at a pressure of 3375psi with a hold time at temperature of 30, 90 and 150 minutes.

The density, modulus of rupture and elastic modulus of both the SHS and manually mixed samples hot pressed at 3375psi increased with an increase in hold time. The density, MOR and EMOD of the SHS samples hot pressed at 3375psi were greater than those of the manually mixed samples hot pressed at 3375psi.

26. ELASTIC MODULUS OF SAMPLES HOT PRESSED @ 1620°C: A graphical representation of the elastic modulus and density of the manually mixed and SHS samples hot pressed to 1620C at pressures of 500, 3375, 5000 and 500/5000psi with hold time at temperature of 30, 90, 150, 240 minutes.

= Bar density Gray bar = SHS samples White bar = manually mixed samples.

The density of both manually mixed and SHS samples increased with an increase in hold time. The elastic modulus increased with an increase in density with the EMOD of the SHS samples being significantly higher than the manually mixed samples when the densities were low.

When the densities increased to the high nineties, the EMOD of the manually mixed samples tended to be slightly higher than the SHS samples.

27. MODULUS OF RUPTURE OF SAMPLES HOT PRESSED @ 1620C: A graphical representation of the modulus of rupture and density of the manually mixed and SHS samples hot pressed to 1620C at pressures of 500, 3375, 5000 and 500/5000psi with hold time at temperature of 30, 90, 150, 240 minutes.
= Bar density Gray bar = SHS samples White bar = manually mixed samples.

The modulus of rupture of the SHS samples was significantly higher in all cases (except at the 500/5000psi, 30 and 240 minute hold time) than the manually mixed samples.

28. COMPRESSIVE STRENGTH: A sub-outline of the immediate information to follow in this presentation.

29. CONCLUSIONS

30. RECOMMENDATIONS

31. ACKNOWLEDGMENTS

COMPOSITE CERAMICS

ABSTRACT

This task encompassed an eighteen month technical effort to determine the effects of processing and resultant microstructural variations on the resistance to penetration exhibited by hot pressed, composite ceramic titanium diboride/alumina (TiB_2/Al_2O_3). During the course of the task, the effect of processing on the product microstructure and the effect of variation in microstructure on the ballistic performance of TiB_2/Al_2O_3 were determined. Processing conditions were studied in depth in order to develop consistent procedures for reproducing a specifically desired microstructure. The main goal of the program was the continued development of a technology to produce low cost (less than $10 per pound) armor material which has a significant resistance to KEW penetration and is reliable and light weight. The technology is dual use providing a low cost material which is suitable for DoD, as well as commercial use in high performance applications. The task included synthesis, forming, ballistic testing, and pre-ballistic materials analysis of hot pressed, composite titanium diboride/alumina formed using the patented Georgia Tech SHS (thermite) technology and conventional processing technology.

OUTLINE

I. INTRODUCTION
   A. BACKGROUND
   B. OBJECTIVES

II. EXPERIMENTAL APPROACH
   A. FORMING PARAMETERS
   B. PROPERTIES

III. RESULTS
   A. FORMING PARAMETERS
   B. PROPERTIES

IV. CONCLUSIONS
   A. FORMING PARAMETERS
   B. PROPERTIES

V. RECOMMENDATIONS
   A. FORMING PARAMETERS
   B. PROPERTIES

VI. ACKNOWLEDGMENTS

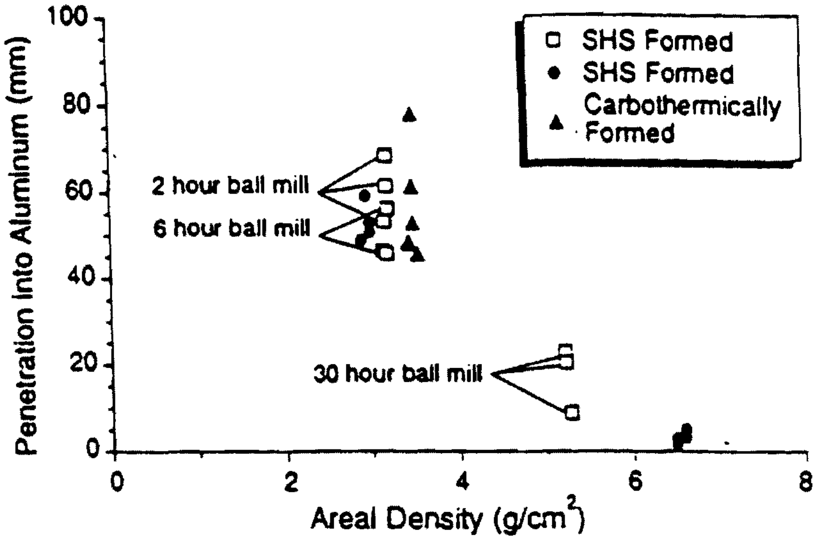
BACKGROUND

PRIOR EXPERIMENTAL RESULTS INDICATED THAT SHS COMPOSITE TIB_2/AL_2O_3 DEMONSTRATED SUPERIOR RESISTANCE TO HIGH STRAIN RATE PENETRATION.

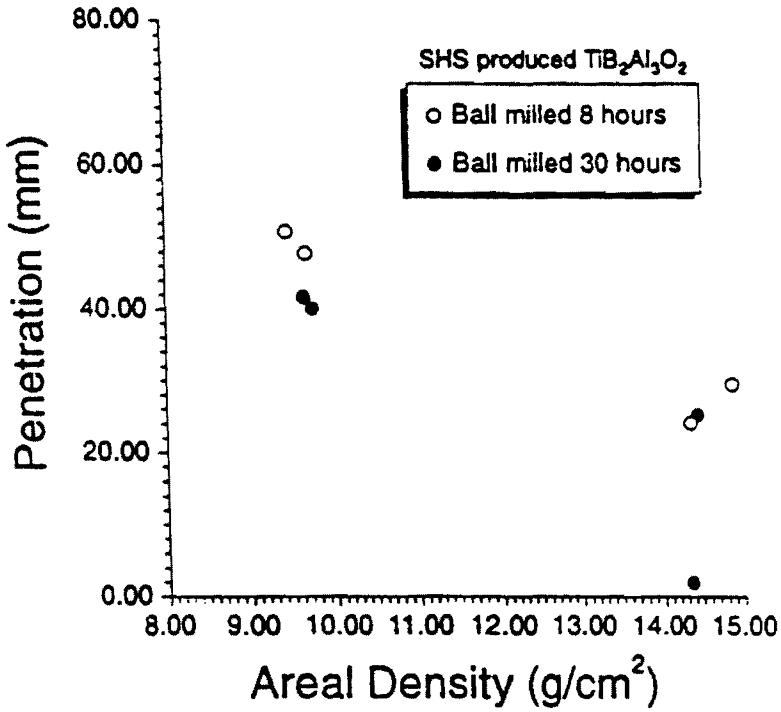
UDRI BALLISTIC PENETRATION DATA

SHOT NUMBER	IMPACT VELOCITY	CERAMIC TARGET IDENTIFICATION	CERAMIC WEIGHT	CERAMIC DIAMETER	CERAMIC THICKNESS	AREAL DENSITY	DEPTH OF PENETRATION	TOTAL YAW	RESIDUAL PEN. WEIGHT
1-0222	1537	764	783.5	10.16	2.42	9.66	47.7	2.1	10.55
1-0223	1537	731-2	1204.0	10.16	3.63	14.85	29.6	2.5	8.32
1-0224	1515	921-1	780.4	10.16	2.43	9.63	41.5	3.0	10.47
1-0225	**1532**	**922-1**	**1163.8**	**10.16**	**3.64**	**14.35**	**1.9**	**1.0**	**2.90**
1-0226	1528	926-1	787.6	10.16	2.43	9.72	40.1	2.9	9.77
1-0227	1529	925-1	1170.2	10.16	3.64	14.43	25.3	0.6	7.74
1-0228	1543	769-2	764.7	10.16	2.42	9.43	50.8	1.0	9.55
1-0229	1541	769-1	1162.5	10.16	3.63	14.34	24.1	1.9	8.72

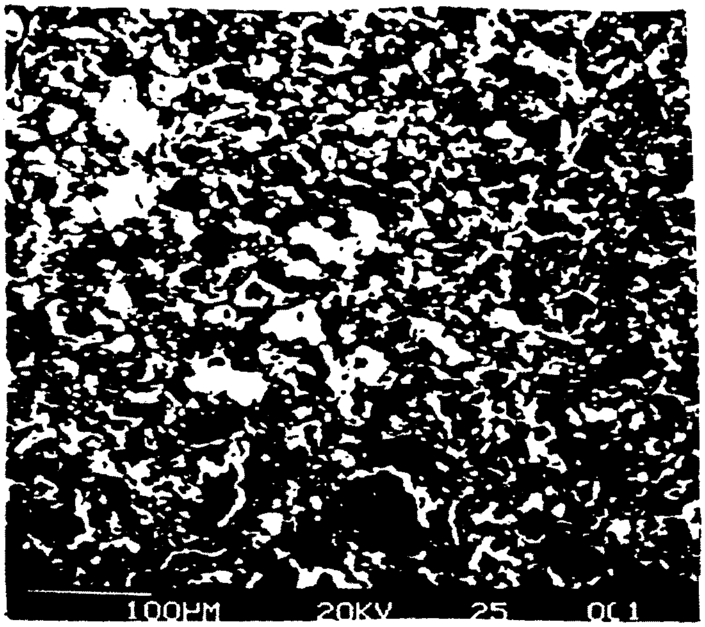
PROJECTILE: BRL STANDARD 65 GM TUNGSTEN ROD, 7.82MM DIA. x 78.74MM LENGTH (L/D 10) WITH HEMISPHERICAL NOSE. TELEDYNE X-21-C TUNGSTEN, 93%, 15% SWAGED & AGED.



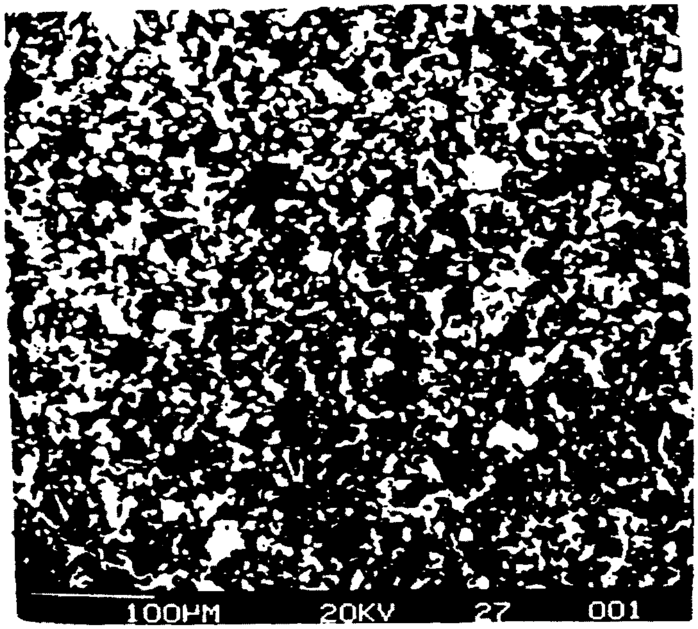
SLAP BALLISTIC TEST RESULTS



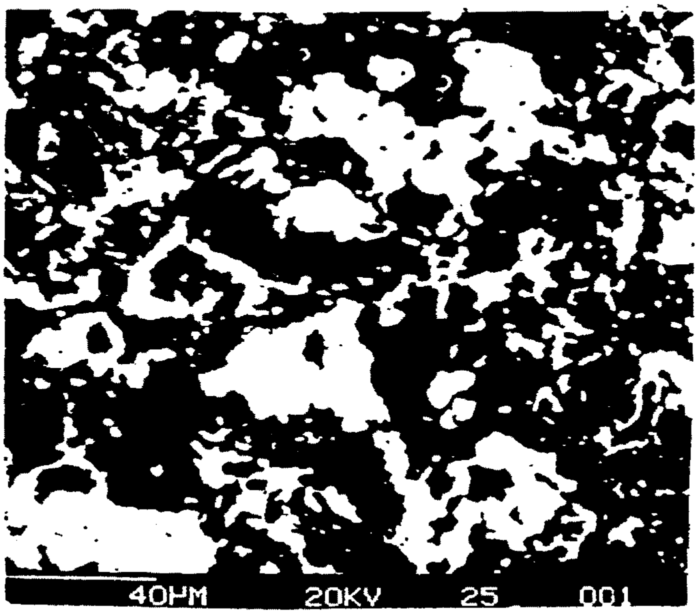
LRP BALLISTIC TEST RESULTS



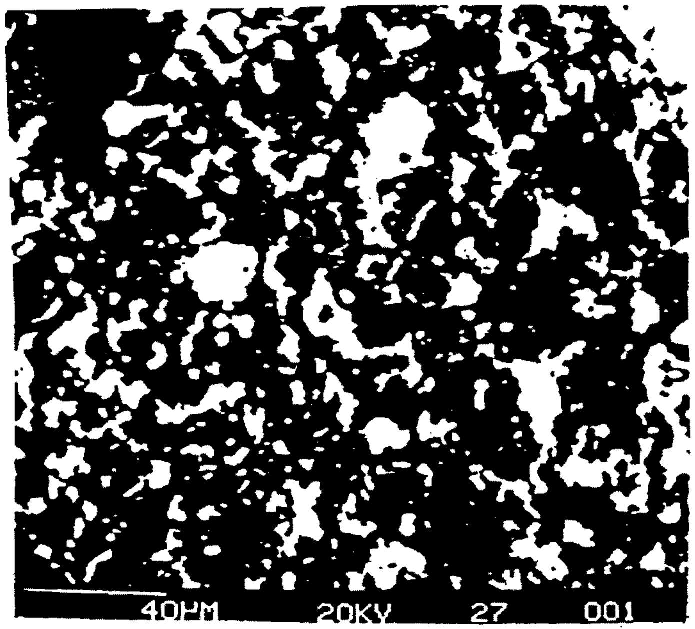
SAMPLE 225 T@A



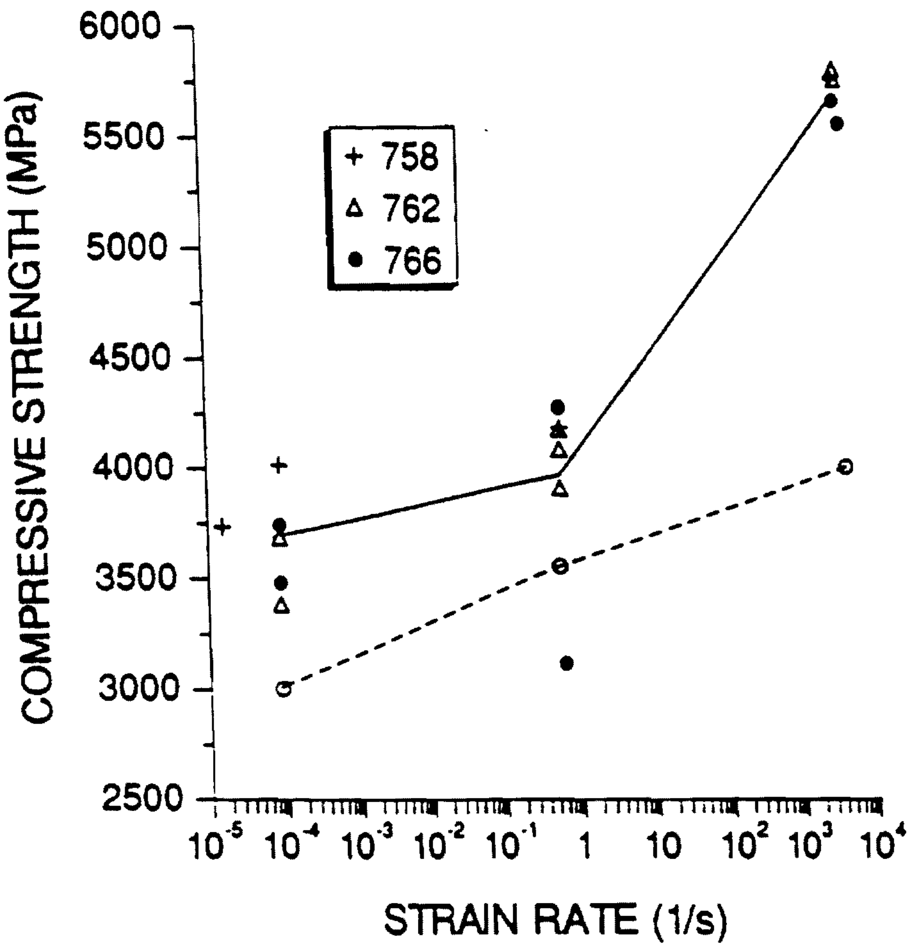
SAMPLE 227 T IN A



SAMPLE 225 T@A



SAMPLE 227 T IN A



SPLIT HOPKINSON BAR TEST RESULTS

+ = SAMPLE # 758 Δ = SAMPLE # 762 ● = SAMPLE # 766
--- = PURE ALUMINA ——— = COMPOSITE

PROPERTIES

Compound	MOR (MPa)	K_{Ic} ($MPa \cdot m^{1/2}$)	Compr.Str. (GPa)	Y. Mod. (GPa)	Poiss. Ratio
Al_2O_3	380-440	3.5-4.0	3.41-3.80	280-390	0.23
TiB_2 (C)	400	6.69-8.00	5.33-5.87	347-570	0.11-0.13
TiB_2/Al_2O_3(MM)	310	3.60	---	415	---
SiC/Al_2O_3	451	7.3	5.62-6.74	392	0.22
SiC (HP)	690-730	3.01-5.23	5.2-6.79	315-445	0.16-0.17
SiC (S)	312	3.0	3.87-5.24	408	0/16
B_4C	400-690	3.70-4.50	3.73-5.43	440-457	0.17-0.19
4340 Steel	792	48 ($ksi \cdot in^{1/2}$)	---	200	0.29

(C): Carbothermic
(MM): Manually-Mixed

(S): Sintered
(HP): Hot Pressed

MOR: Modulus of Rupture
K_{Ic} : Fracture Toughness

OBJECTIVES

To compare the effect of biased microstructures on the resistance to penetration of hot pressed powders formed using

- self-propagating high temperature synthesis, and
- conventional technologies.

PROGRAM SCHEDULE

				PHASE I											PHASE II									
TASK/MONTH	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
1. START OF WORK		X																					
2. HOT PRESS STUDY			X	X	X	X	X	X	X	X	X	X	X	X									
3. MICROSTRUCTURAL ANALYSIS			X	X	X	X	X	X	X	X	X	X	X	X									
4. FORM TARGETS															X	X	X	X	X	X	X		
5. END TECHNICAL EFFORT																					X		
6. DELIVER TARGETS																					X		
7. BI-MONTHLY LETTER				X	X		X		X		X		X		X		X						
8. DRAFT FINAL REPORT																					X		
9. APPROVAL DRAFT FINAL																						X	
10. FINAL TECHNICAL REPORT																							X
11. PROGRAM REVIEWS				X			X			X			X			X							

SYNTHESIS AND FORMING

- POWDERS
- DENSIFICATION

SHS POWDERS

- OXIDATION-REDUCTION REACTIONS

$$3TiO_2 + 3B_2O_3 + 10Al \rightarrow 3TiB_2 + 5Al_2O_3$$

- PARTICLE SIZE REDUCTION:

  BALL MILLED TO AVG. 5-12 MICRONS

MANUALLY MIXED POWDERS

- COMBINATION OF COMPONENTS

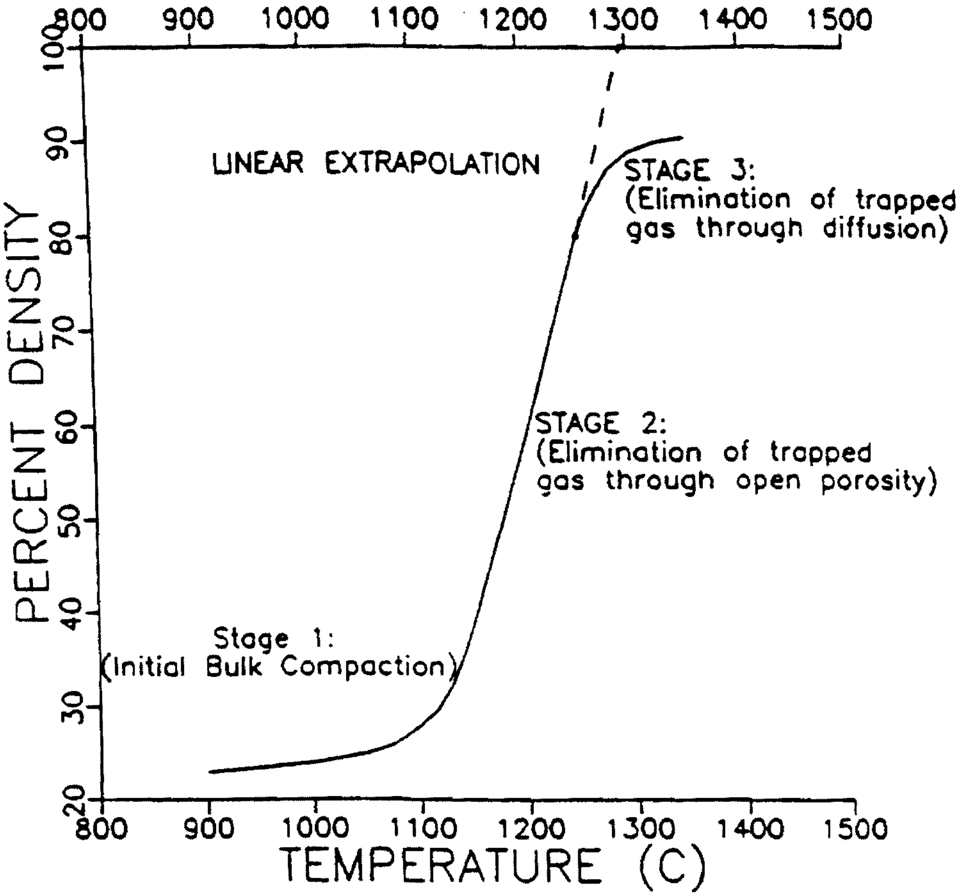
$$3TiB_2 + 5Al_2O_3 \longrightarrow 3TiB_2 / 5Al_2O_3$$

- PARTICLE SIZE REDUCTION:

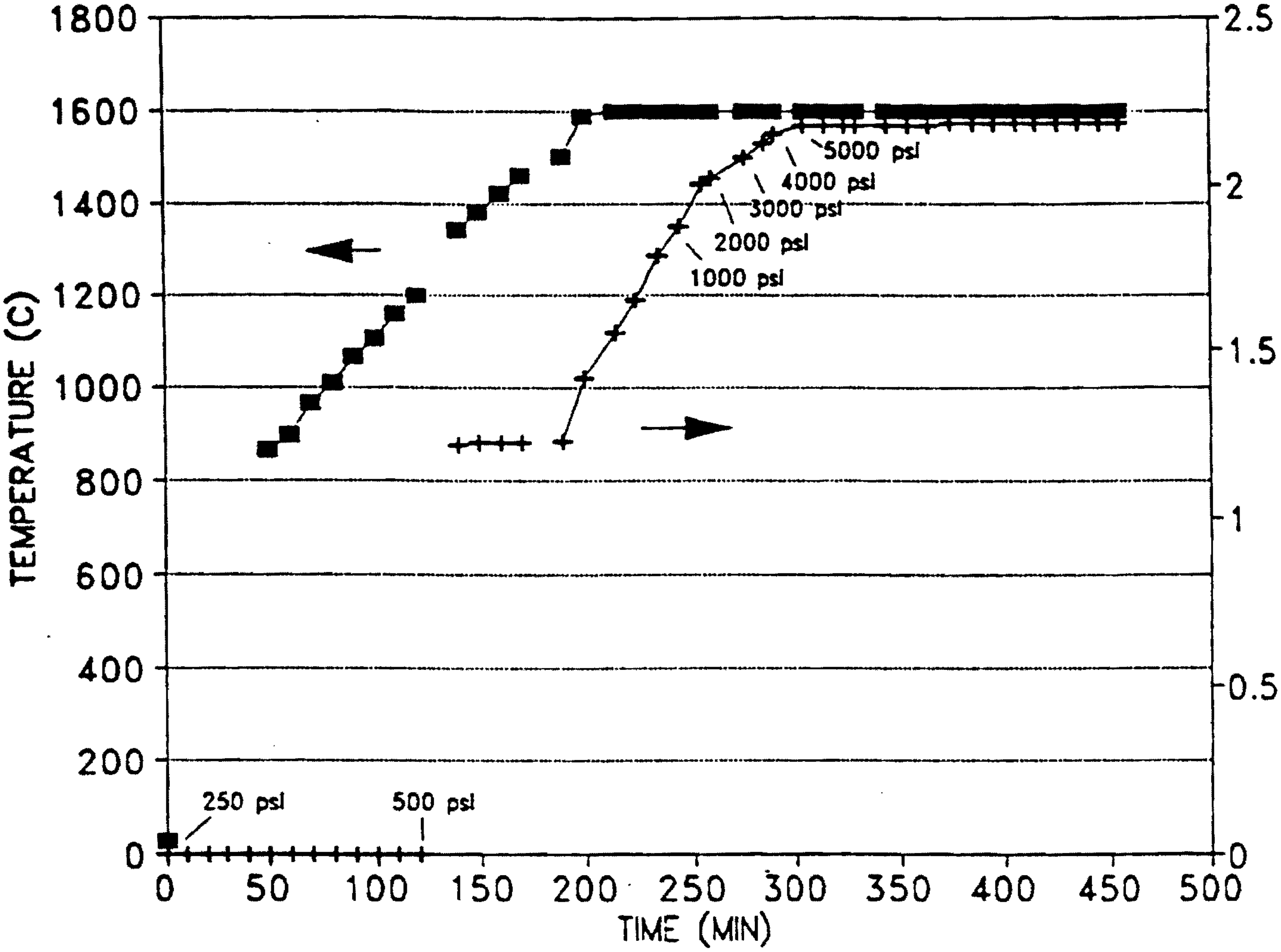
  BALL MILLED TO AVG. 5-12 MICRONS

HOT PRESS MATRIX

HOLD TIME	500psi	3375psi	5000psi	500/5000psi
30 min	MM	MM	MM	MM
30 min	SHS	SHS	SHS	SHS
90 min	-	MM	MM	-
90 min	-	SHS	SHS	-
150 min	MM	MM	MM	MM
150 min	SHS	SHS	SHS	SHS
240 min	MM	-	MM	MM
240 min	SHS	-	SHS	SHS

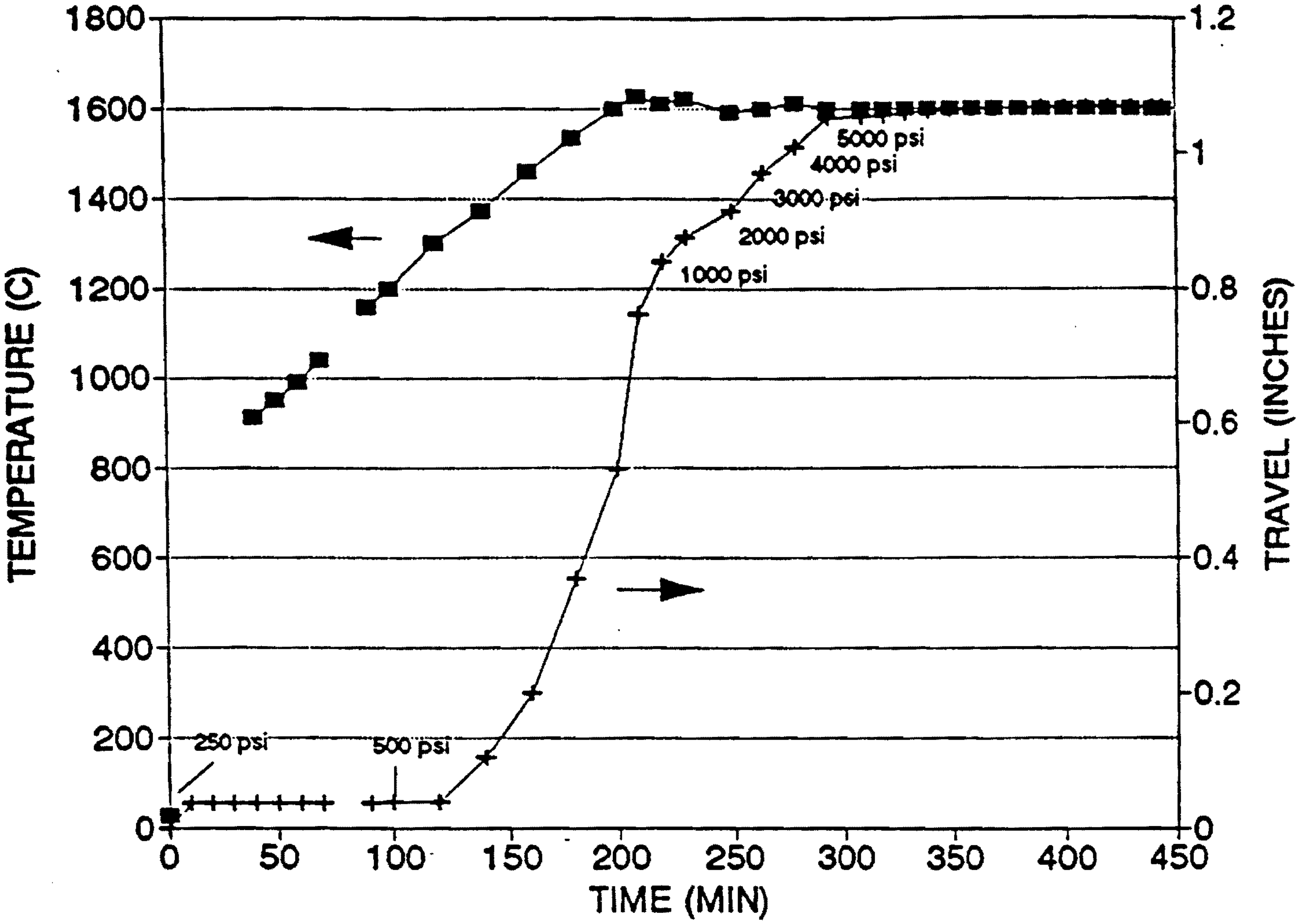


SCHEMATIC OF CTP CURVE



HOT PRESS RUN OF SAMPLE 225

■ = TEMPERATURE + = RAM TRAVEL



HOT PRESS RUN OF SAMPLE 227

■ = TEMPERATURE + = RAM TRAVEL

TARGETS

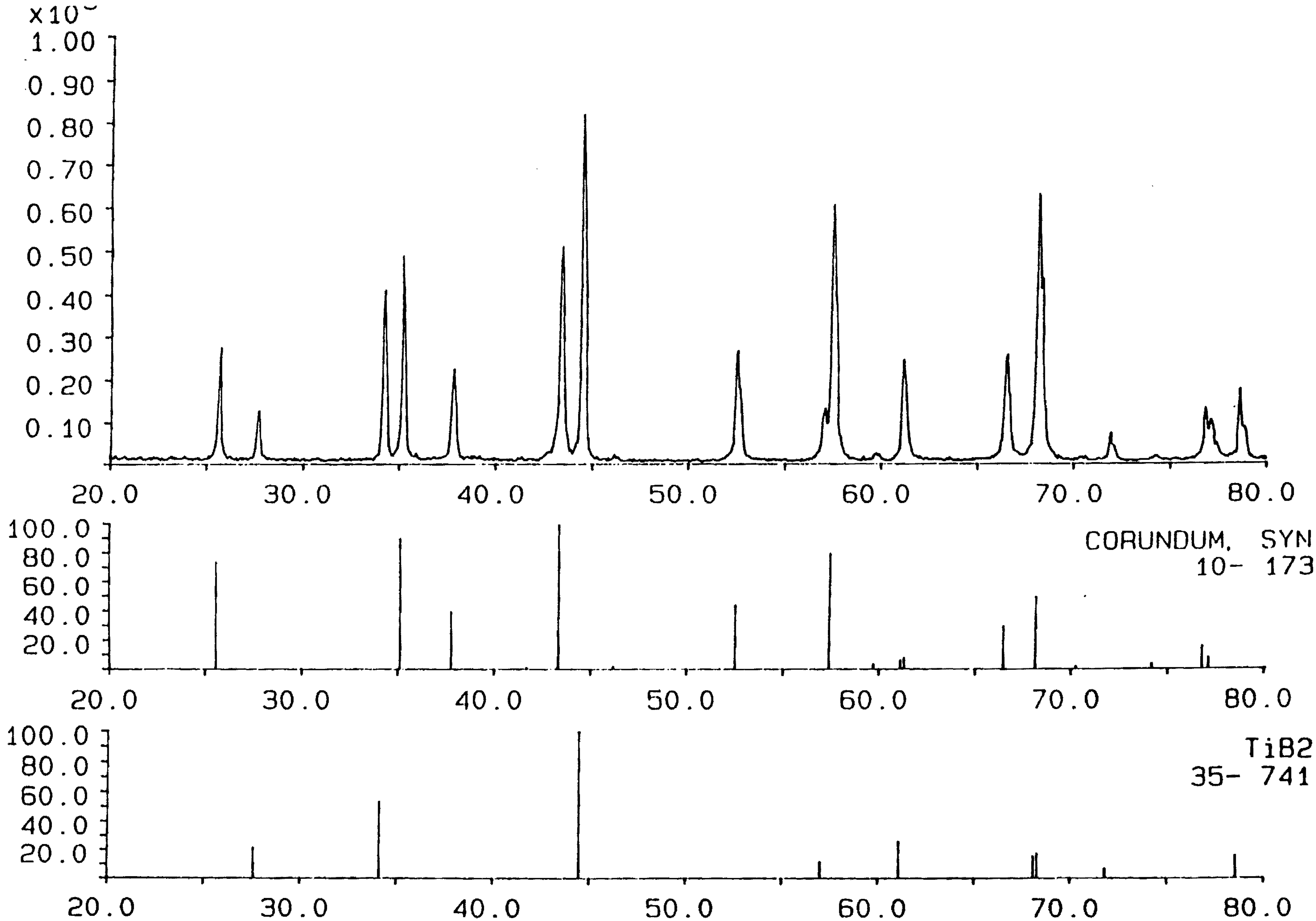
SAMPLE		QUANTITY AND SIZES	
		Ballistic Targets	Mechanical Properties
SHS	T @ A	3 ea. 4"x 1-1/2"	3ea. 3"x 1/2"
	T IN A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"
MIXED	T @ A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"
	T IN A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"

SHS: SELF PROPAGATING HIGH TEMPERATURE

MIXED: MECHANICALLY MIXED DISPERSED SAMPLES

T @ A: TITANIUM DIBORIDE AT THE ALUMINA GRAIN BOUNDARIES

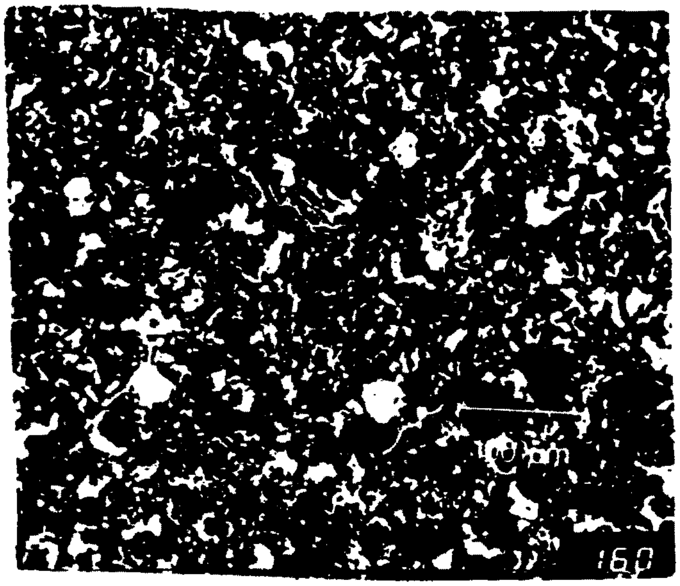
T IN A: TITANIUM DIBORIDE IN THE ALUMINA MATRIX



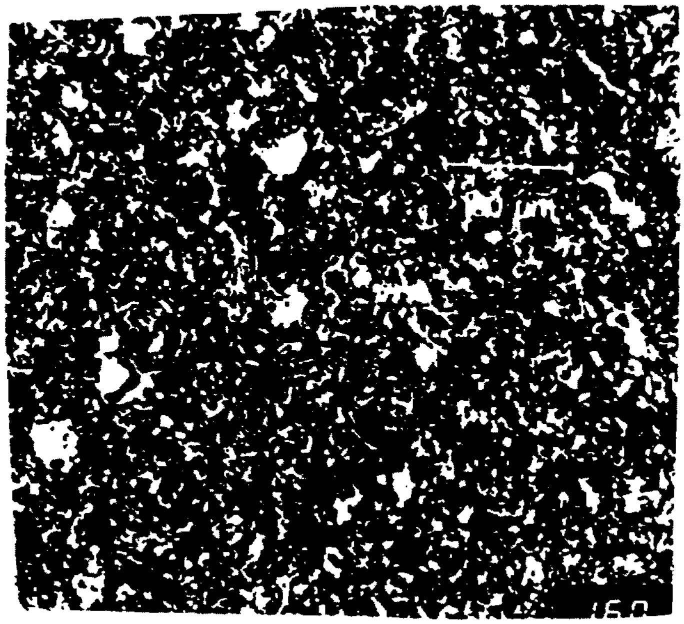
X-RAY DIFFRACTION TRACE OF SHS COMPOSITE

HOT PRESS RESULTS

HOT PRESS MATRIX SAMPLE #	POWDER TYPE (synthesis)	HOLD PRESSURE (psi)	HOLD TIME (min)	HOLD TEMP C	BULK DISK DEN. (% theo.)	TEST BAR DENSITY (% theo.)	MOR MPa (avg. 5)	RESIST. 1 ohm·cm (raw avg.)	RESIST. 1 ohm·cm (stat. avg.)	RESIST. 2 ohm·cm (raw. avg.)	RESIST. 2 ohm·cm (stat. avg.)	EMOD GPa (avg. 5)	Comments
1	MM	500	30	1620	77.4	75.7	49.6	0.23	0.23	0.31	0.31	150.8	Hand Mixed
2	SHS	500	30	1620	90.7	91.9	250.7	54.68	14.62	40.67	13.45	324.4	
3	MM	500	150	1620	79.3	79.2	82.7	0.59	0.42	0.72	0.72	180.2	Hand Mixed
4	SHS	500	150	1620	0	95.4	321.2	15.38	4.36	11.63	11.63	367.4	
5	MM	3375	30	1620	91.0	91.7	109.4	1.36	1.15	1.39	1.11	319.8	Hand Mixed
6	SHS	3375	30	1620	93.0	96.7	479.8	13.90	4.09	10.47	6.26	392.4	
7	MM	3375	90	1620	91.5	94.7	156.2	1.53	1.53	1.39	1.39	361.2	Hand Mixed
8	SHS	3375	90	1620	94.3	98.5	415.5	14.93	14.93	16.80	16.80	413.0	
9	MM	3375	150	1620	96.0	97.7	200.4	0.68	0.68	0.83	0.82	407.2	Hand Mixed
10	SHS	3375	150	1620	94.2	98.7	458.6	13.11	13.11	16.03	10.28	413.8	
15	MM	5000	30	1620	94.4	98.1	414.7	4.14	1.42	6.40	2.33	405.8	Hand Mixed
16	SHS	5000	30	1620	93.9	98.1	510.9	47.79	47.79	35.12	23.52	405.6	
17	MM	5000	150	1620	NA	99.0	288.9	2.18	2.18	2.20	2.20	429.8	Hand Mixed
18	SHS	5000	150	1620	97.3	98.3	498.3	50.74	50.74	69.46	69.46	409.0	
21	MM	5000	240	1620	NA	99.3	311.4	0.21	0.23	0.23	0.23	425.3	Ball Milled to get small grains
22	SHS	5000	240	1620	NA	98.7	353.7	0.34	0.27	0.40	0.26	408.6	
11	MM	500/5000	30	1620	89.9	93.5	166.3	2.23	2.23	2.88	1.54	349.6	Hand Mixed
12	SHS	500/5000	30	1620	90.9	93.4	150.0	53.87	53.87	64.93	64.39	344.2	
13	MM	500/5000	150	1620	94.3	99.1	288.2	3.15	3.15	3.57	3.57	433.6	Hand Mixed
14	SHS	500/5000	150	1620	97.4	98.4	434.3	36.81	36.81	21.07	21.07	412.3	
24	MM	500/5000	240	1620	NA	98.9	277.5	0.27	NA	0.26	NA	421.2	Ball Milled to get small grains
23	SHS	500/5000	240	1620	NA	94.8	300.1	0.23	NA	0.23	NA	356.8	
19	SHS-225M	500/5000	250	1620	93.3	NA	433.7	NA	0.21	NA	0.23	427.2	
20	SHS-227M	5000	250	1620	91.4	NA	448.7	NA	0.34	NA	0.40	427.4	

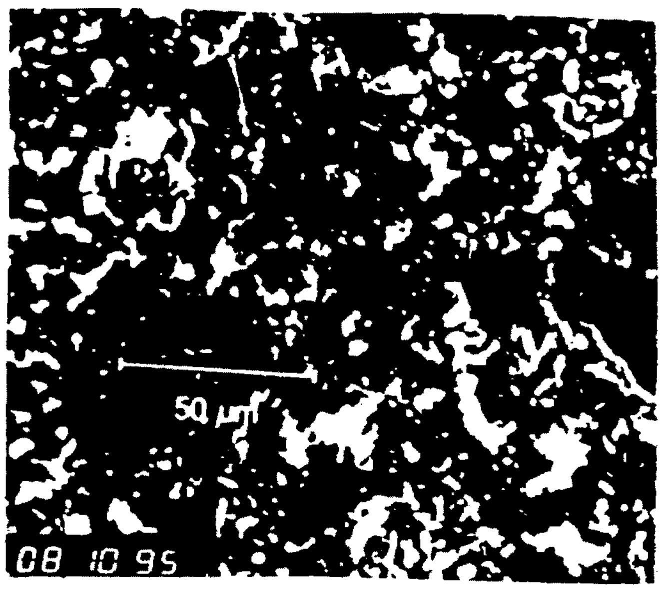


225 CONFIRM T@A

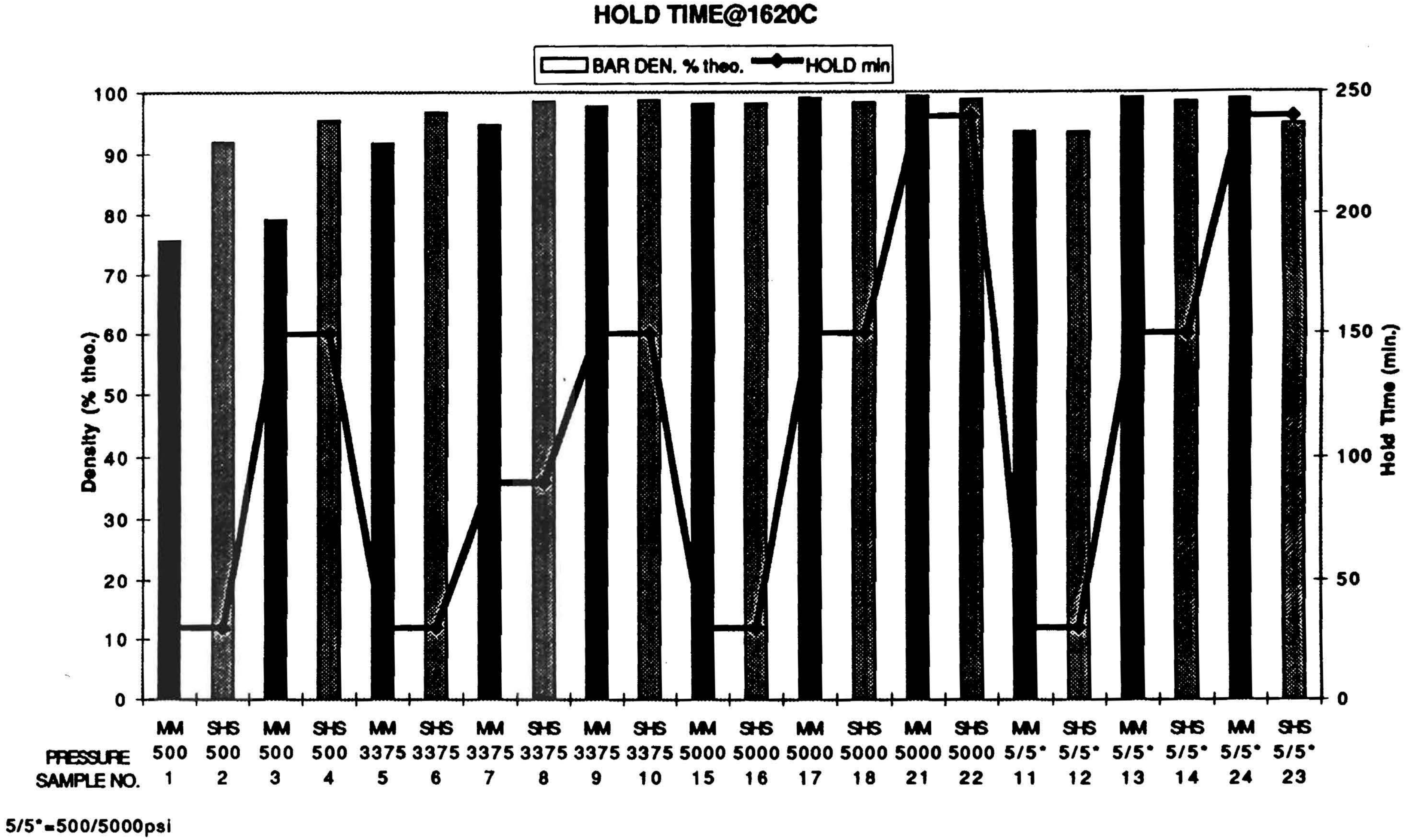


227 CONFIRM T IN A

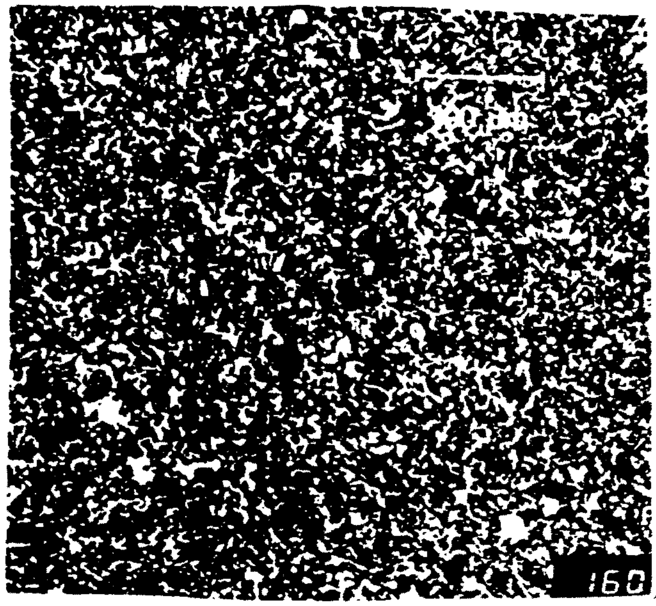
225 CONFIRM T@A



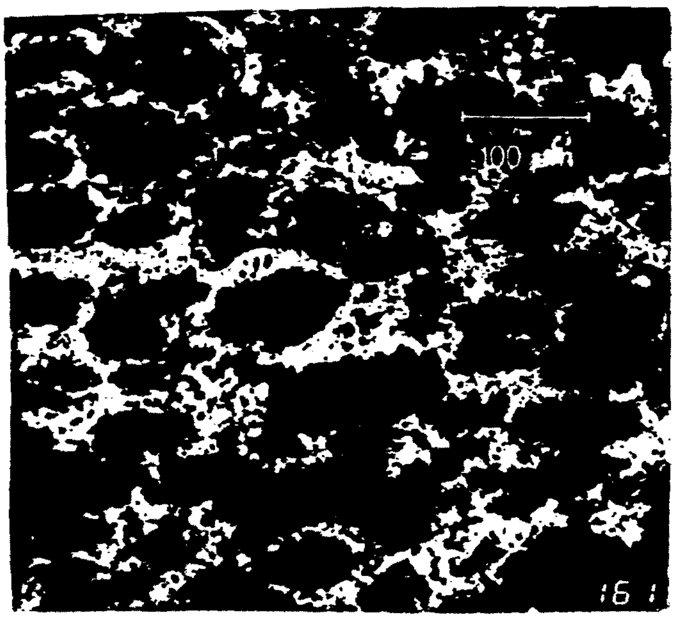
227 CONFIRM T IN A


HOLD TIME@1620C
BAR DEN. % theo.
HOLD min
Density (% theo.)
Hold Time (min.)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
PRESSURE
SAMPLE NO.
MM SHS MM SHS MM SHS MM SHS MM SHS MM SHS MM SHS MM SHS MM SHS MM SHS MM SHS
500 500 500 500 3375 3375 3375 3375 3375 3375 5000 5000 5000 5000 5000 5000 5/5* 5/5* 5/5* 5/5* 5/5* 5/5*
1 2 3 4 5 6 7 8 9 10 15 16 17 18 21 22 11 12 13 14 24 23
5/5*=500/5000psi

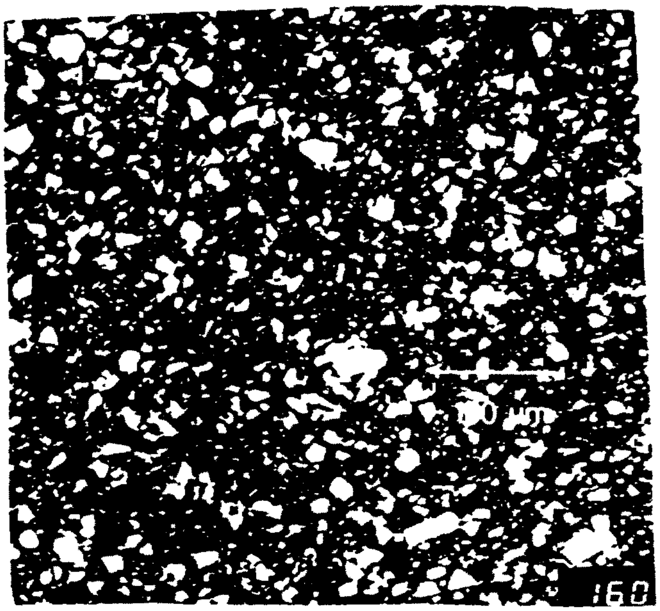
SHS T@ A



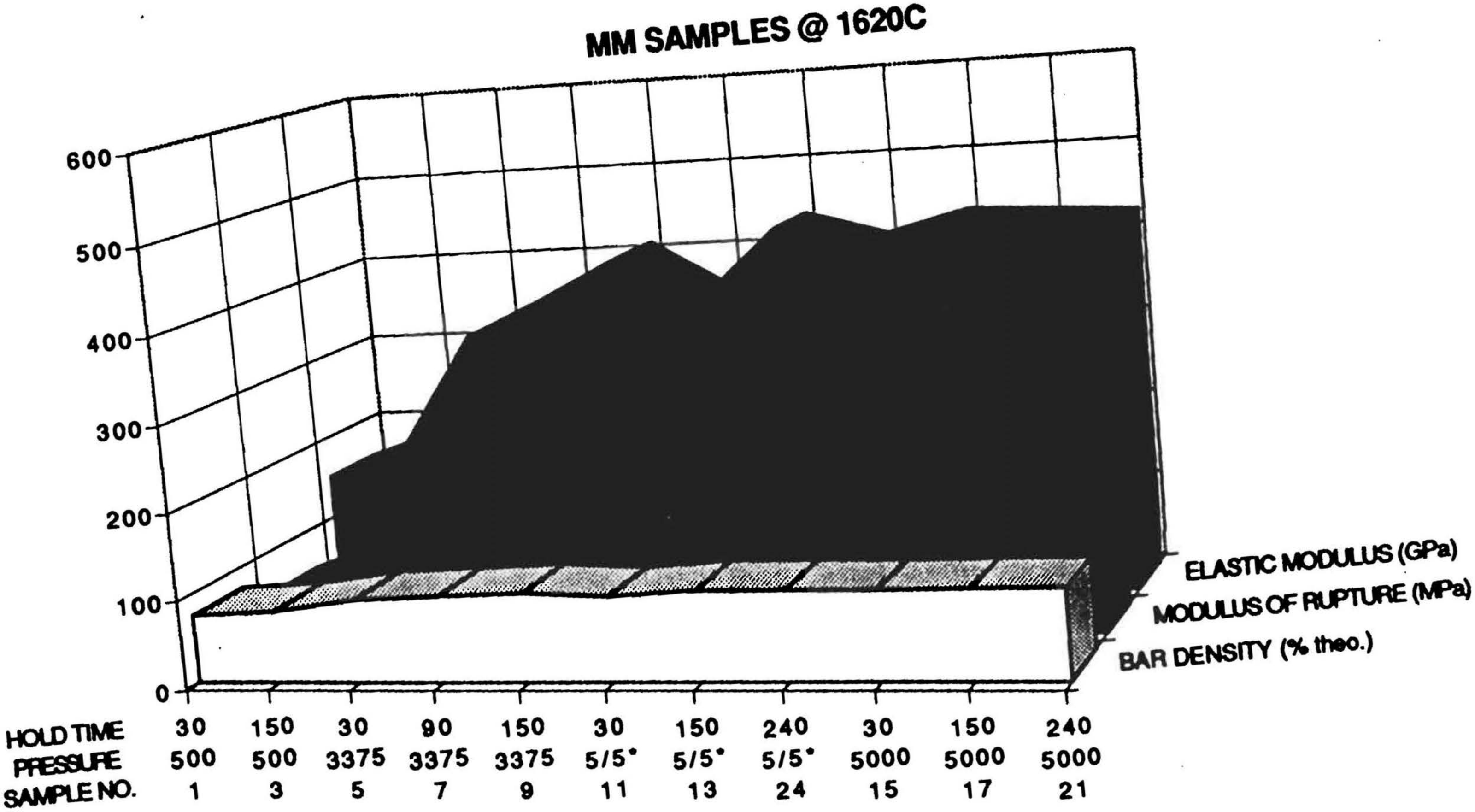
SHS T IN A



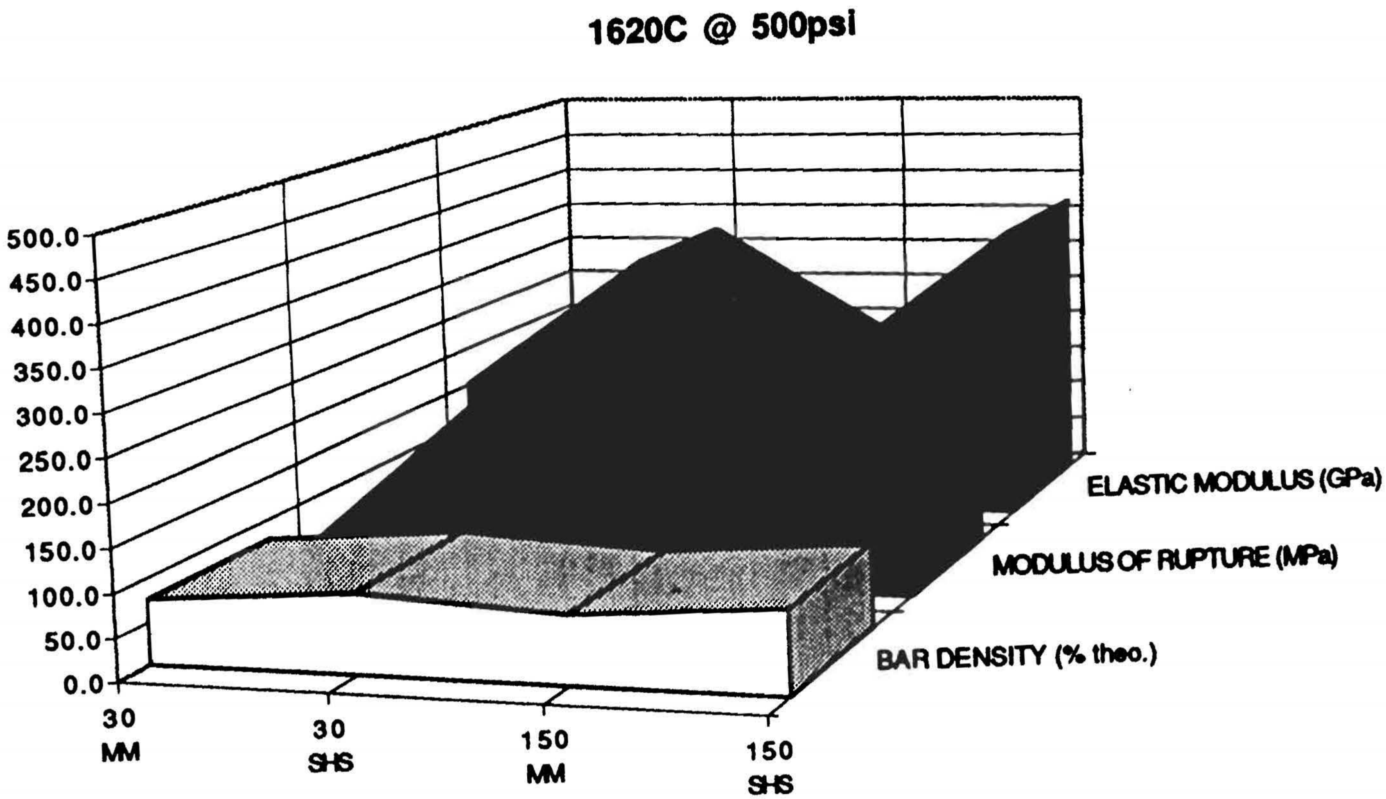
MM T @ A

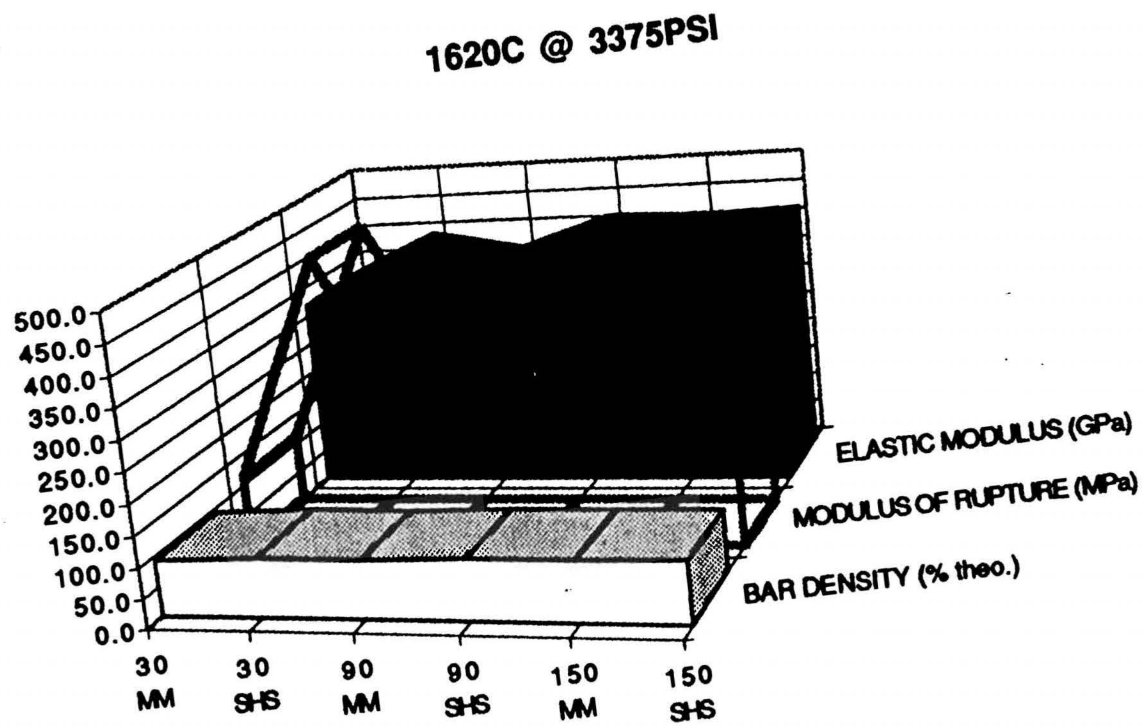


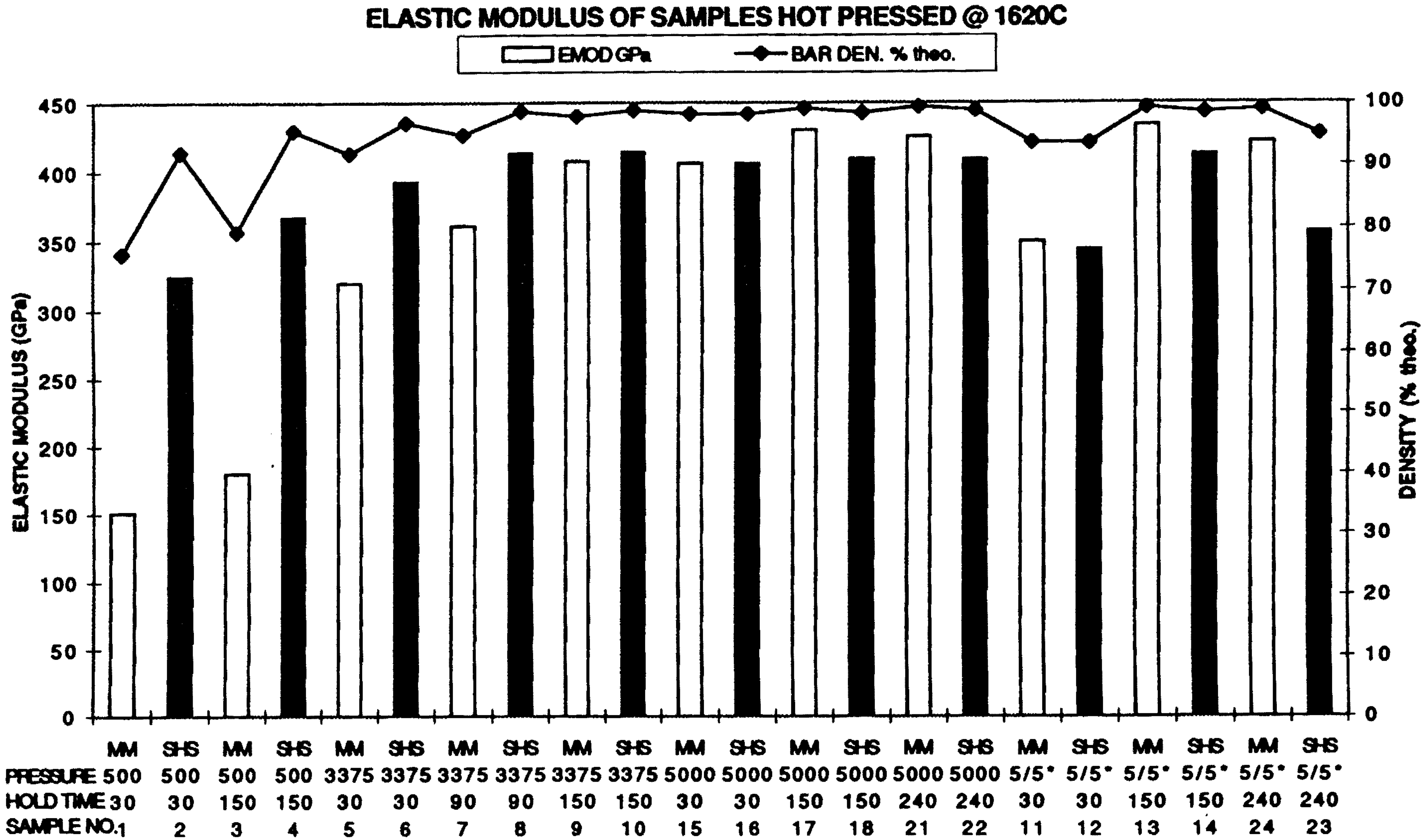
MM T IN A



5/5*=500/5000psi

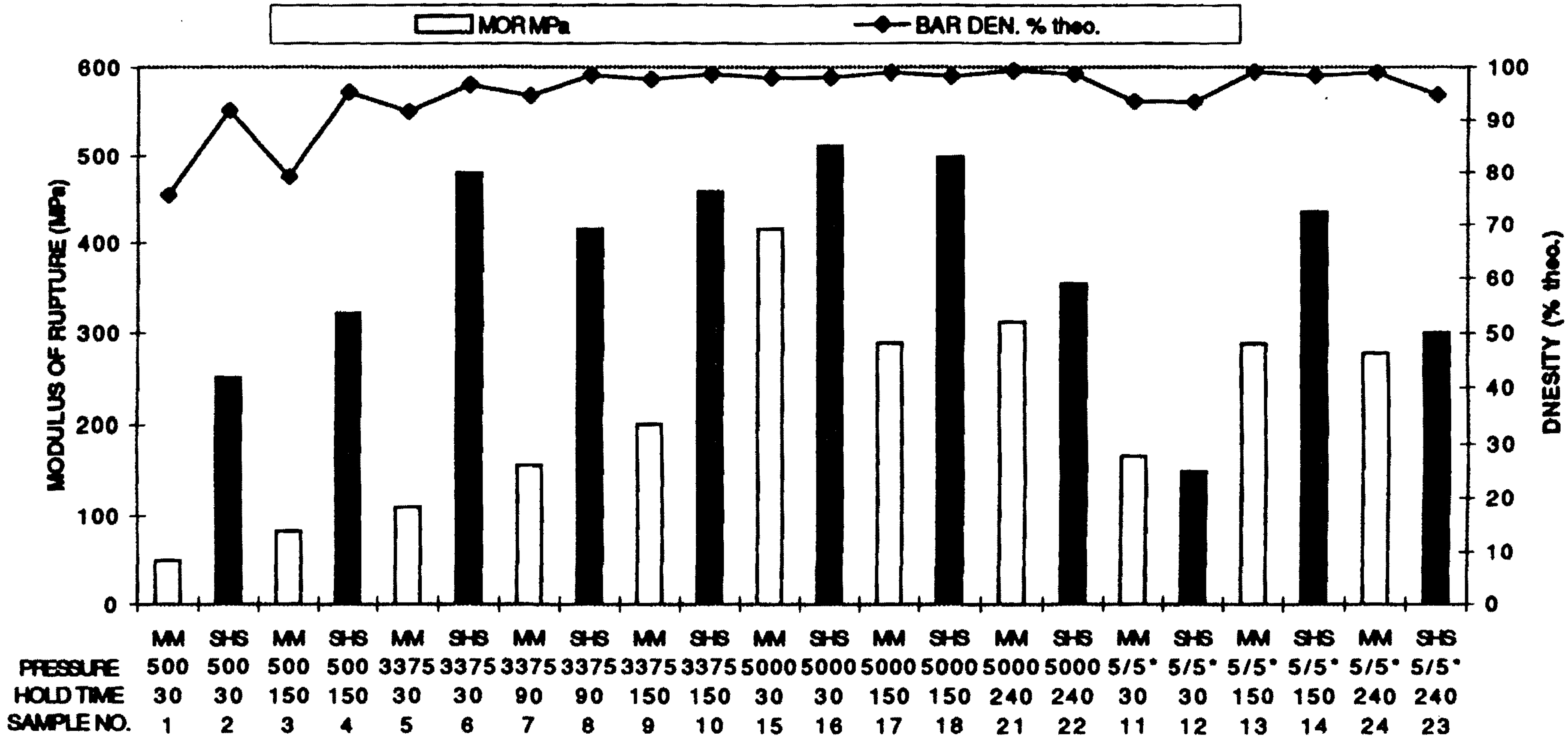

1620C @ 500psi
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
30 MM
30 SHS
150 MM
150 SHS
ELASTIC MODULUS (GPa)
MODULUS OF RUPTURE (MPa)
BAR DENSITY (% theo.)


1620C @ 3375PSI
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
30 MM
30 SHS
90 MM
90 SHS
150 MM
150 SHS
ELASTIC MODULUS (GPa)
MODULUS OF RUPTURE (MPa)
BAR DENSITY (% theo.)



5/5*=500/5000psi

MODULUS OF RUPTURE OF SAMPLES HOT PRESSED @ 1620



5/5*=500/5000psi

COMPRESSIVE STRENGTH

- QUASI-STATIC
- DYNAMIC

CONCLUSIONS

FORMING PARAMETERS

- THE OPTIMAL HOT PRESSING TEMPERATURE TO ACHIEVE MAXIMUM DENSIFICATION DID NOT CHANGE APPRECIABLY WITH AN INCREASE IN SAMPLE SIZE FROM 3 X 0.5 INCHES TO 4 X 1.5 INCHES.

- CONTINUOUS APPLICATION OF PRESSURE TENDED TO CAUSE THE TiB_2 TO MIGRATE AROUND THE Al_2O_3 GRAIN BOUNDARIES.

- RAPID APPLICATION OF PRESSURE TENDED TO CAUSE THE TiB_2 TO DISPERSE WITHIN THE Al_2O_3.

- POWDER PARTICLE SIZE AFFECTED THE DISTRIBUTION OF TiB_2 WITHIN THE Al_2O_3: FINER PARTICLES TENDED TO CAUSE THE TiB_2 TO DISPERSE WITHIN THE Al_2O_3 AND COARSER TiB_2 PARTICLES TENDED TO SURROUND THE Al_2O_3 GRAIN BOUNDARIES.

PROPERTIES

- MANUALLY MIXED AND SHS COMPOSITE TiB_2/ Al_2O_3 EXHIBITED A SIGNIFICANT RESISTANCE TO HIGH STRAIN RATE PENETRATION.

- THE COMPOSITE TiB_2/ Al_2O_3 TECHNOLOGY CONTINUES TO BE POTENTIALLY LOW COST ROUTE TO LESS THAN $10 POUND ARMOR.

- THE CONSISTENCY OF SAMPLES 225 AND 227 MICROSTRUCTURES WERE CONFIRMED THROUGHOUT THE SAMPLES: SAMPLE 225 MICROSTRUCTURE WAS BIASED TO THE T@A DISTRIBUTION, AND SAMPLE 227 WAS BIASED TO THE T IN A DISTRIBUTION.

- THE THEORETICAL DENSITY OF ALL SAMPLES (MM AND SHS) INCREASED WITH THE HOT PRESS HOLD TIME.

- THE TiB_2 PARTICLES COULD BE BIASED IN BOTH MM AND SHS SAMPLES TO EITHER MIGRATE TO THE Al_2O_3 GRAIN BOUNDARIES, OR DISPERSE WITHIN THE Al_2O_3 BY CHOOSING APPROPRIATE FORMING PARAMETERS.

- COMPOSITE SHS T@A MECHANICAL PROPERTIES ARE SIMILAR TO THOSE OF PURE TIB_2.

- MECHANICAL PROPERTIES IN BOTH MM AND SHS SAMPLES IMPROVED WITH INCREASES IN HOT PRESS TEMPERATURE, PRESSURE AND HOLD TIMES.

- THE ELASTIC MODULUS TENDED TO BE SLIGHTLY HIGHER IN MM SAMPLES AS COMPARED WITH SHS SAMPLES.

- THE MODULUS OF RUPTURE TENDED TO BE SIGNIFICANTLY HIGHER IN SHS SAMPLES THAN IN MM SAMPLES.

- THE ELECTRICAL RESISTIVITY TENDED TO BE COMPARABLE IN THE HIGHER DENSITY MM AND SHS SAMPLES.

- THE ELECTRICAL RESISTIVITY WAS SIGNIFICANTLY HIGHER IN THE SHS SAMPLES AS COMPARED WITH THE MM SAMPLES IN LOWER DENSITY SAMPLES

RECOMMENDATIONS

FORMING PARAMETERS

- DETERMINE EFFECTS OF VARIATION IN RELATIVE AMOUNTS OF TIB_2 IN Al_2O_3 (10, 20, 30, 40 50%...).

- DETERMINE EFFECTS OF DIFFERENT COMPONENTS WITH ALUMINA (SiC, B_4C, TiC, Si_3N_4).

- DETERMINE THE EFFECTS OF DIFFERING SPECIFIC GRAVITIES OF THE COMPOSITE COMPONENTS ON RESISTANCE TO PENETRATION.

- CONDUCT ECONOMIC ANALYSIS OF APPLICABLE FORMING TECHNOLOGIES.

- DEVELOP COST EFFECTIVE FORMING TECHNOLOGY.

PROPERTIES

- CONDUCT KEW AND CEW V-50 TESTS.

- CONDUCT MICROSTRUCTURAL ANALYSIS OF THE LRP TEST SAMPLES TO CONFIRM MICROSTRUCTURAL BIAS.

- CONFIRM ABILITY TO CONTROL MICROSTRUCTURAL BIAS IN MM AND SHS SAMPLES.

- DETERMINE ELECTRICAL AND MECHANICAL PROPERTY RELATIONSHIPS OF THE BIASED MICROSTRUCTURES IN THE MM AND SHS SAMPLES AS A MEANS OF NON-DESTRUCTIVE QUALITY CONTROL (NDE).

- CONTINUE RESEARCH TO DETERMINE THE EFFECTS OF SECOND PHASE MICROSTRUCTURAL BIASING ON RESULTING PHYSICAL PROPERTIES.

- CONTINUE RESEARCH TO DETERMINE THE EFFECTS OF COMPOSITE COMPOSITION ON RESULTING PHYSICAL PROPERTIES.

ACKNOWLEDGMENTS

- U. S. ARMY TANK & AUTOMOTIVE RESEARCH & DEVELOPMENT COMMAND

  U. S. ARMY RESEARCH LABORATORY

  T. FURMANIAK

  M. BURKINS

- GEORGIA INSTITUTE OF TECHNOLOGY

  R. BROWN

  A. CARNEY

  G. PATEL

  K. PHILLIPS

  T. ROYAL

  V. SUNDARAM

  G. VILLALOBOS

  S. ALAFIFI