10:14:48 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 08/13/96

Active

Project #: E-18-X23 Cost share #: Rev #: 5
Center # : 10/24-6-R8437-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: DAAE07-95-C-R040 Mod #: P00002 Document : CONT
Prime #: Contract entity: GTRC

Subprojects ? : Y CFDA: NA
Main project #: PE #: P61261

Project unit: MSE Unit code: 02.010.112
Project director(s):
LOGAN K V MSE (404)894-3650

Sponsor/division names: ARMY / TANK AUTOMOTIVE CMD, MI
Sponsor/division codes: 102 / 019

Award period: 950125 to 960925 (performance) 961125 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	99,957.00
Funded	0.00	99,957.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: COMPOSITE CERAMICS

PROJECT ADMINISTRATION DATA

OCA contact: William F. Brown 894-4820

Sponsor technical contact	Sponsor issuing office
THOMAS FURMANIAK	JENNY STERBA
(810)574-6792	(810)574-6792
US ARMY TACOM	US ARMY TACOM
AMSTA-TR-S	AMSTA-AQ-WAA
WARREN, MI 48397-5000	WARREN, MI 48397-5000

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): Y
Defense priority rating : NONE GOVT supplemental sheet
Equipment title vests with: Sponsor X GIT
NONE PROPOSED
Administrative comments -
MOD. P00004 REVISES THE SOW, EXTENDS THE END DATES (9/25/96-PERFORMANCE AND 11/25/96-FINAL REPORT) AND REVISES ADDRESS FOR HARDWARE DELIVERY.

u

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 12/18/96

Project No. E-18-X23 | Center No. 10/24-6-R8437-0A0

Project Director LOGAN K V | School/Lab MSE

Sponsor ARMY/TANK AUTOMOTIVE CMD, MI

Contract/Grant No. DAAE07-95-C-R040 | Contract Entity GTRC

Prime Contract No.

Title COMPOSITE CERAMICS

Effective Completion Date 960925 (Performance) 961125 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	Y	
Classified Material Certificate	N	
Release and Assignment	Y	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

April 19, 1995

Commander
U. S. Army Tank Automotive and Armaments Command
Attn: AMSTA-TR-S, Thomas Furmaniak
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #001
Reporting Period: 25 January-March 31, 1995

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A001
Reporting Period: 25 January-March 31, 1995

Submitted By:

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

April 17, 1995

UNCLASSIFIED

Progress, Status and Management Report A001
Reporting Period: 25 January-March 31, 1995
April 17, 1995

A. Description of progress during reporting period.
   1. Kick-off meeting occurred at Georgia Tech 16 February-17 February, 1995.
   2. Supply purchase initiated.
   3. Climbing Temperature Program (CTP) hot press run on the SHS powder completed to establish maximal parameters.
   4. The optimal soak temperature for SHS powders is 1620°C.

B. Results, conclusions, recommendations related to problem areas.
None.

C. Significant changes in organization, management, milestones.
The #001 Deliverable due date was changed to 20 April since the kick-off meeting was held 16,17 February which would have caused the reporting period to include only seven days of effort. See Attached Milestone Chart.

D. Problem areas affecting technical or scheduling elements with background and recommendations.
Delays occurred in starting the hot press parameter study because of Exam week and the Quarter break. We are still within the schedule since the originally scheduled number of hot press runs per week can be increased from one to two.

E. Problem areas affecting cost elements with background and recommendations.
None.

F. Cost incurred during the reporting period and total to date expenditures.
Actual costs incurred through 31 March were $6535.89 with a $1542.08 Materials and Supply encumbrance. Total to date expenditures are $6535.89 (not including encumbrances). The six months projected expenditures are based on the original full 18 months contract projection with $39,868 allocated for the six month interval (even though $50,000 was contracted).

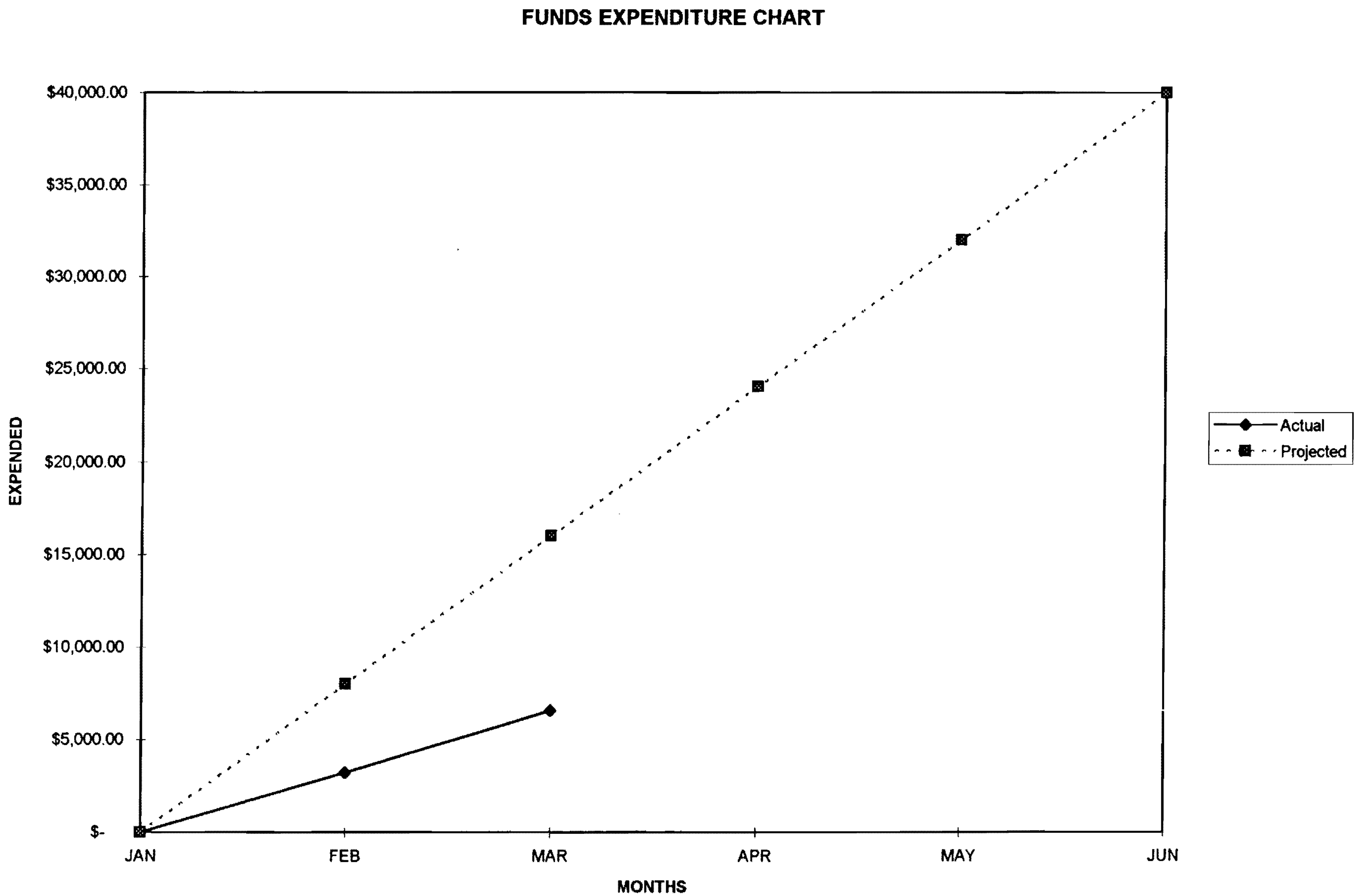
G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

I. Any trips and significant results.
Trip to Monterey, California to attend the 6th Combat Vehicle Survivability Symposium held March 28-30. (The travel expenses were not charged to this contract).

MILESTONE CHART

	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
1.START OF WORK		X																		
2.HOT PRESS STUDY			X	X	X	X	X													
3.MICROSTR. ANAL.			X	X	X	X	X													
4.FORM TARGETS(36)								X	X	X	X	X	X	X						
5.END TECHNICAL																X				
6.DELIVER TARGETS																X				
7.BI-MONTHLY LETTER				X	X		X		X		X		X		X					
8.DRAFT FINAL																	X			
9.DRAFT FIN. APPR.																		X		
10.FINAL REPORT																			X	
11.PROGRAM REVIEWS				X			X			X			X			X				


FUNDS EXPENDITURE CHART
$40,000.00
$35,000.00
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
EXPENDED
JAN
FEB
MAR
APR
MAY
JUN
MONTHS
Actual
Projected

E-18-X25 #2

Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

May 30, 1995

Commander
U. S. Army Tank Automotive and Armaments Command
Attn: AMSTA-TR-S, Thomas Furmaniak
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #002
Reporting Period: 1 April-30 April, 1995

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A002
Reporting Period: 1 April-30 April, 1995

Submitted By:

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

May 20, 1995

UNCLASSIFIED

Progress, Status and Management Report A001
Reporting Period: 1 April-30 April, 1995
May 20, 1995

A. Description of progress during reporting period.

The CTP curve for the SHS material, #1 SHS run, and #1 manually mixed run have been completed. We plan to run again on Tues. and Thurs. (and possibly Wed), but I have not yet decided on the run parameters (am awaiting the density results for #1MM). The CTP run and #1SHS were 96.5% and >97% ("good" runs).

B. Results, conclusions, recommendations related to problem areas.

The hot press pressure has been reduced to 3375psi due to the failing refractory infrastructure. The 3375psi will substitute for the 5000psi until the refractory is replaced. A main issue is to determine the effect of pressure on the microstructure, which can be accomplished by comparing 500psi and 3375psi. It is recommended that the hot press refractory be redesigned in order to accommodate the increased pressure.

C. Significant changes in organization, management, milestones.

There are no significant changes in the organization, or management. The milestone chart has not changed, as we are still within the performance time lines. See Attached Milestone Chart.

D. Problem areas affecting technical or scheduling elements with background and recommendations.

1. The hot press refractory superstructure cracked requiring a redesign of the hot press. The refractory was replaced with steel plates using suitable refractory to insulate the steel from the hot press temperatures. A Pyrex cylinder was used to allow the use of Argon which prevents the graphite from oxidizing.
2. The TiB_2/Al_2O_3 composite is too hard to cut with a laboratory scale diamond saw. 12 hours of continuous cutting only accomplished an 1/8 inch cut. The samples were sent to Chand for cutting and polishing which requires at least a two week wait.

E. Problem areas affecting cost elements with background and recommendations.

1. It is necessary to have at least two people present during the hot press runs. The one graduate student could not accomplish the runs alone. An undergraduate student was hired part-time to assist the graduate student.
2. The samples are too hard for expeditious sample preparation for observation in the microscope. It is necessary to send the samples to a commercial organization for diamond cutting. Chand and Bomas are being contacted for quotes.

F. Cost incurred during the reporting period and total to date expenditures.

Actual costs incurred 1 April through 30 April were $6796.18 which includes a $1732.09 Materials and Supply cost. Total to date expenditures are $13332.07 (not including encumbrances). The six months projected expenditures are based on the original full 18 months contract projection with $39,868 allocated for the six month interval (even though $50,000 was contracted).

G. Actual and projected cost curves.

See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

	April Hours	Total to Date
K. Logan:	29.58	88.74
G. Patel:	17.4	52
A. Carney:	58	58
C. Huthmaker:	~40	~40

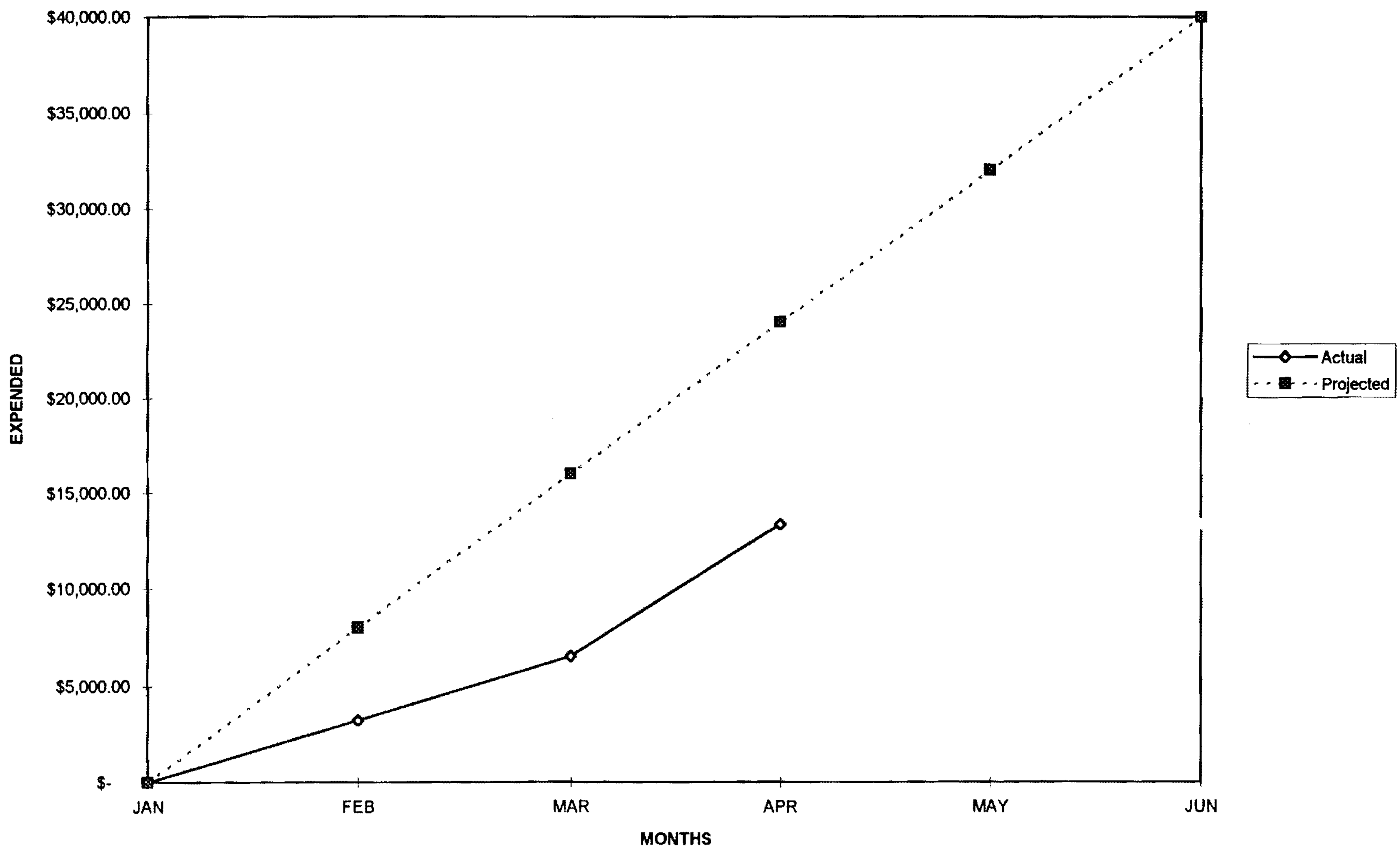
I. Any trips and significant results.

None.

MILESTONE CHART

	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
1.START OF WORK		X																		
2.HOT PRESS STUDY			X	X	X	X	X													
3.MICROSTR. ANAL.			X	X	X	X	X													
4.FORM TARGETS(36)								X	X	X	X	X	X	X						
5.END TECHNICAL																X				
6.DELIVER TARGETS																X				
7.BI-MONTHLY LETTER				X	X		X		X		X		X		X					
8.DRAFT FINAL																	X			
9.DRAFT FIN. APPR.																		X		
10.FINAL REPORT																			X	
11.PROGRAM REVIEWS				X			X			X			X			X				

FUNDS EXPENDITURE CHART



E-18-X23
#3

Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

July 19, 1995

Commander
U. S. Army Tank Automotive and Armaments Command
Attn: AMSTA-TR-S, Thomas Furmaniak
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #003
Reporting Period: 1 May-30 June, 1995

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A003
Reporting Period: 1 May-30 June, 1995

Submitted By:

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

July 19, 1995

UNCLASSIFIED

Progress, Status and Management Report A001
Contract Deliverable #3
Reporting Period: 1 May-30 June, 1995
July 19, 1995

A. Description of progress during reporting period.

May

* Redesigned and rebuilt the hot press.
* Attempted diamond saw at Georgia Tech, but after 24 hours, only obtained a 1/8 inch cut.
* Sent three samples to Chand for diamond cutting.
* Sent three samples to Bomas for diamond cutting.
* Recalibrated the hot press for the new design. Several runs were required to make adjustments in the new design.
* HP SHS, 1620, 3375psi, 30 min successful hot press run.
* HP MM, 1620, 3375psi, 30 min successful hot press run.
* HP SHS, 1620, 3375psi, 150 min
* HP SHS, 1800, 3375psi, no hold (CTP curve)
* HP SHS, 1620, 500psi, 30 min

June

* Review visit, 6/7 with Tom Furmaniak at Georgia Tech
* The following samples were sent to Chand and Bomas for cutting:

SHS @1620°C, 3375psi, 30 min hold
MM @1620°C, 3375psi, 30 min hold
MM @1620°C, 3375psi, 90 min hold
SHS @1620°C, 3375psi, 150 min hold
SHS @1675°C, 6500psi, 0 hold (CTP run)
SHS @1800°C, 3375psi, 0 hold (CTP run)

From the 6 samples, we will be able to see the difference in microstructure caused by
1. A 30 min and 150 min hold on the SHS.
2. A 30 min and 90 min hold for the MM.
3. An "indication" about 1620°C and 1800°C effects.
4. An "indication" about 3375psi and 6500psi effects.
5. A beginning comparison of SHS and MM (30 min hold).
6. Based on comparable density, we can compare the 30 min SHS and 90 min MM.

* All samples in the matrix (Table I) were hot pressed and sent to Chand for cutting. (Total: 18 samples)

B. Results, conclusions, recommendations related to problem areas.
* It is more important to evaluate hold time, than low and moderate temperatures. After evaluating the 18 matrix test samples, we may want to react to the observed microstructural trends by hot pressing additional samples.

C. Significant changes in organization, management, milestones.

The experimental matrix has been redefined (TABLE I.). The milestone chart has not changed, as we are still within the performance time lines with the potential exception of the microstructural analysis. Microstructural analysis is expected to be completed by the end of July. However, a one to two week delay may occur based on timely delivery of the samples which were sent to Chand causing the analysis to be completed the first, or second week of August. See Attached Milestone Chart.

TABLE I.

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

D. Problem areas affecting technical or scheduling elements with background and recommendations.

* Hot press refractory failure: Repeated use of the hot press at high temperatures and pressures caused the refractory ceramic platform to fracture. Consequently, the ceramic had to be replaced after about five runs costing about $3000 in materials.

  The hot press was redesigned to replace the refractory ceramic with steel plates costing about $1000. After 18 hot press runs, the steel plates are showing no signs of failure.

* Delay in sample prep for microstructure: The composite material is too hard (requires diamond grinding) to prepare at Georgia Tech for microstructural examination. After a 24 hour attempt to use a laboratory scale diamond saw, only a 1/8" cut was accomplished.

  The samples were sent to a commercial shop. Initially, one cut with a diamond saw cost $90 with a four week turn-around. However, the standard charge for MOR test bars was $8-10/bar with a two week turn-around.

Subsequently, the samples were sent to a commercial shop for sample preparation.

E. Problem areas affecting cost elements with background and recommendations.

* Cost of diamond cutting: the problem has been resolved by requesting "routine" cutting using automatic and less costly procedures, instead of special cutting requiring continuous operator attention.

F. Cost incurred during the reporting period and total to date expenditures.

Actual costs incurred 1 May through 30 June were $12,887.33 which includes a $1,386.81 Materials and Supply cost. Total to date expenditures are $26,742.86 (not including encumbrances). The six months projected expenditures are based on the original full 18 months contract projection with $39,868.00 allocated for the six month interval (even though $50,000 was contracted). The expenditures are slightly under the projected costs since the program efforts began a month later than expected due to the delay in scheduling the "kick-off" meeting and encumbrances for materials and supplies ($1,440.00 for June) are not included.

G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.
The hours are based on an average 160 working hours/month

	May/June Hours	Total to Date
K. Logan (17%):	54	136
A. George (5%):	16	36
G. Patel (10%):	32	80
A. Carney (33%):	116	121
C. Huthmaker(50%):	160	200

I. Any trips and significant results.

Significant Results: Enclosed are copies of scanning electron micrographs (SEM) obtained from three of the initial Chand and Bomas cut samples showing the distribution of titanium diboride (white areas) in the alumina (dark gray areas):

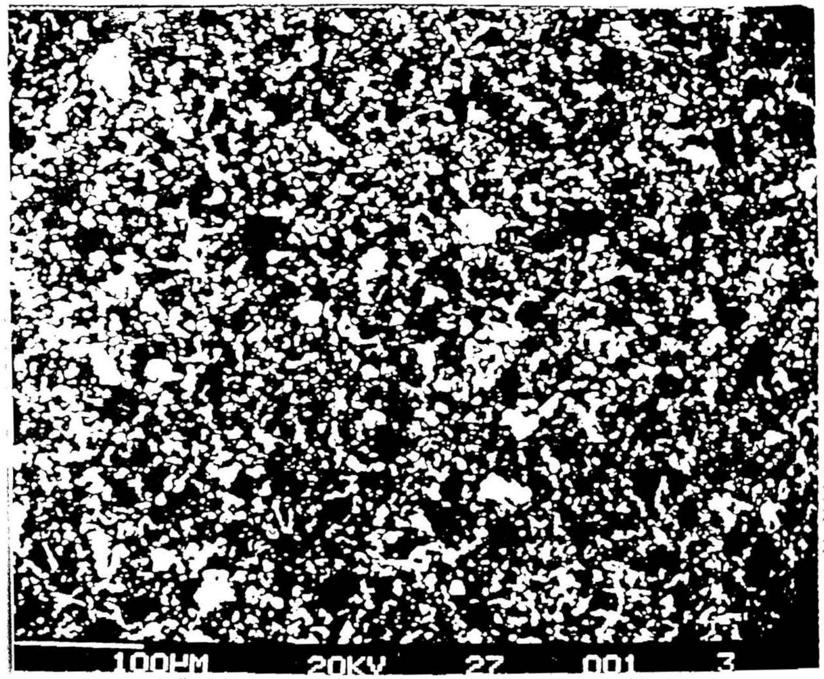
#1,2: Low and high magnification of reference sample #225 showing titanium diboride generally located at the grain boundaries of alumina.

#3,4: Low and high magnification of reference sample #227 showing titanium diboride generally dispersed in the alumina.

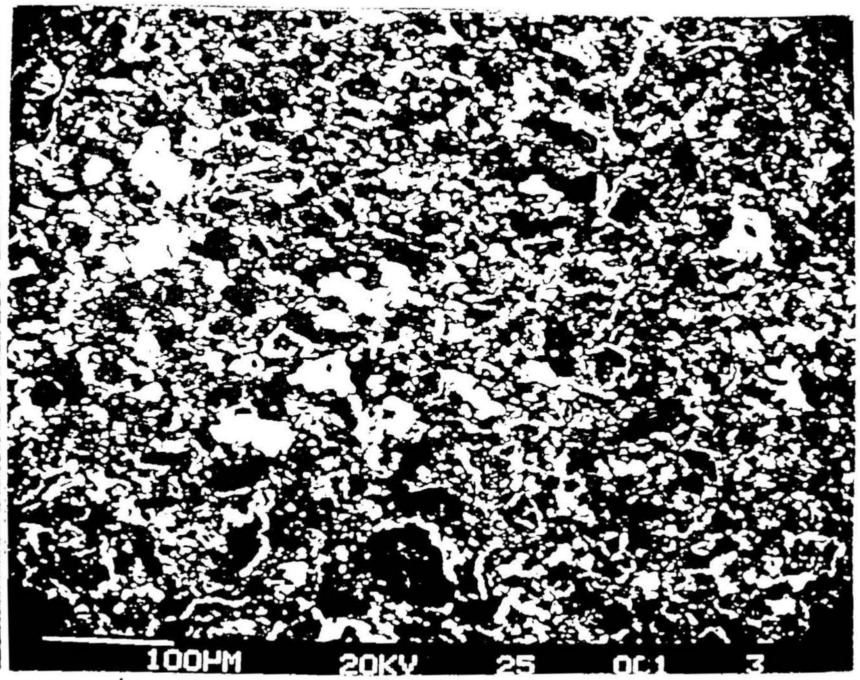
#5,6: Low and high magnification of SHS sample hot pressed at 3375psi with a 30 minute hold at 1620°C showing a tendency for the titanium diboride to be generally dispersed in the alumina.

#7,8: Low and high magnification of SHS sample hot pressed at 3375psi with a 150 minute hold at 1620°C showing an indication of the titanium diboride to localized at the grain boundaries of the alumina.

#9,10: Low and high magnification of manually mixed (MM) sample hot pressed at 3375psi with a 30 minute hold at 1620°C showing titanium diboride to tend to localize around very large grains of alumina. These micrographs are at the same magnifications as the SHS micrographs to show the significant relative size of the manually mixed grains.



REFERENCE 27



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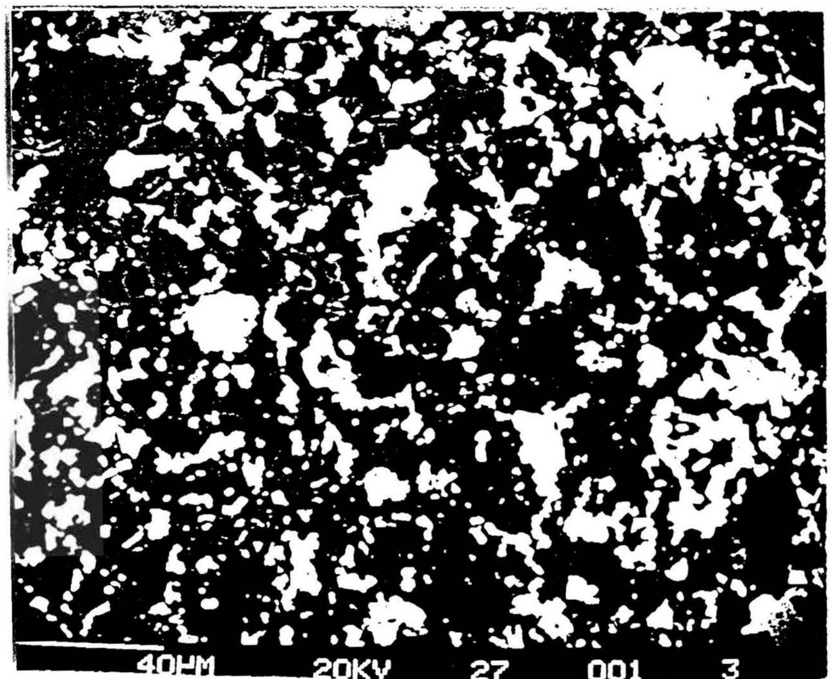

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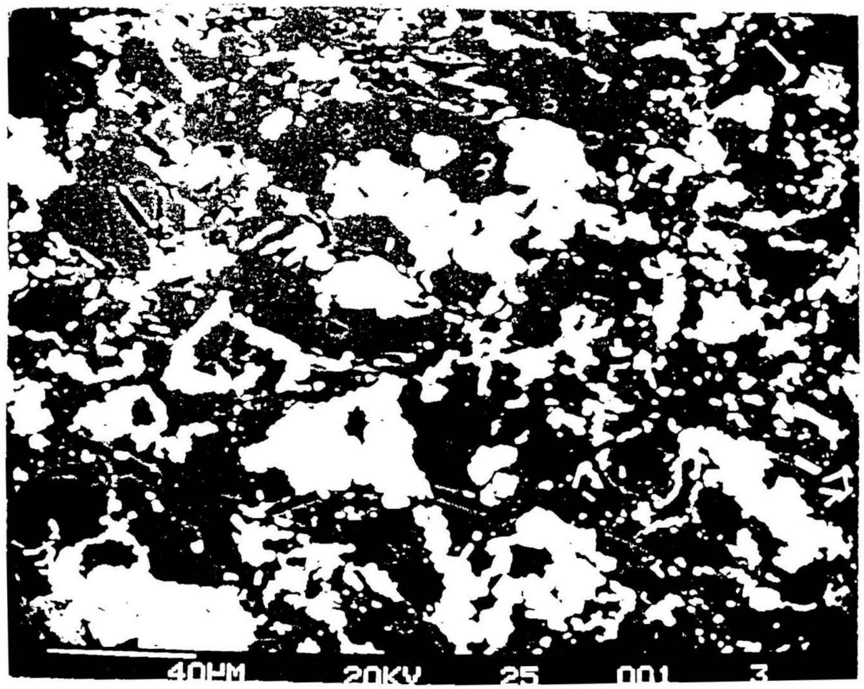
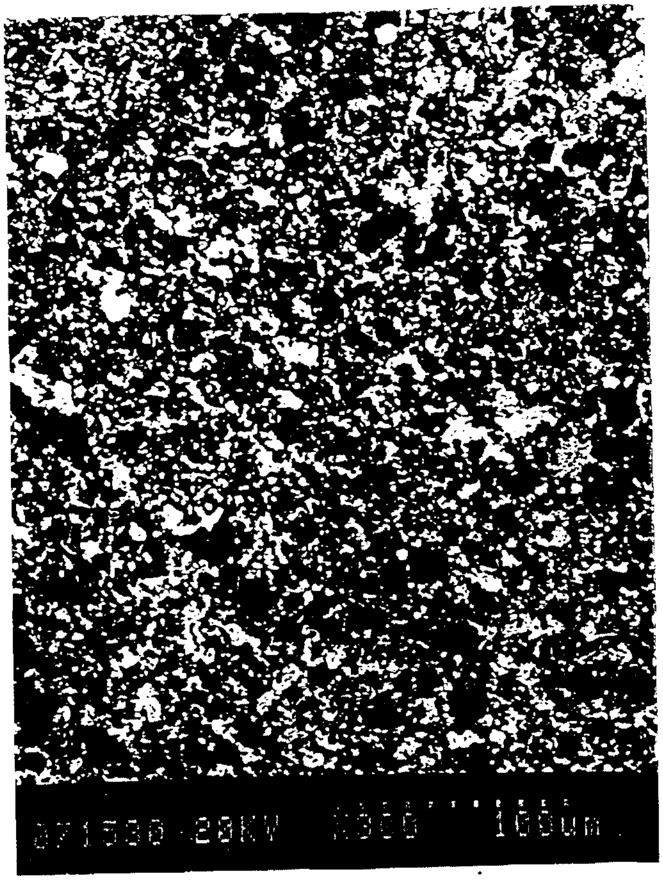
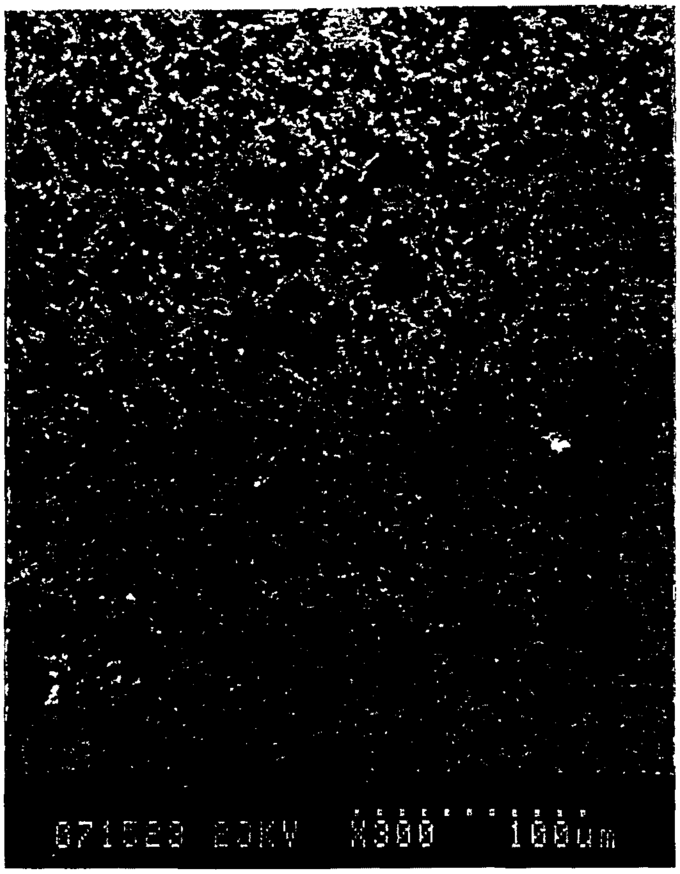
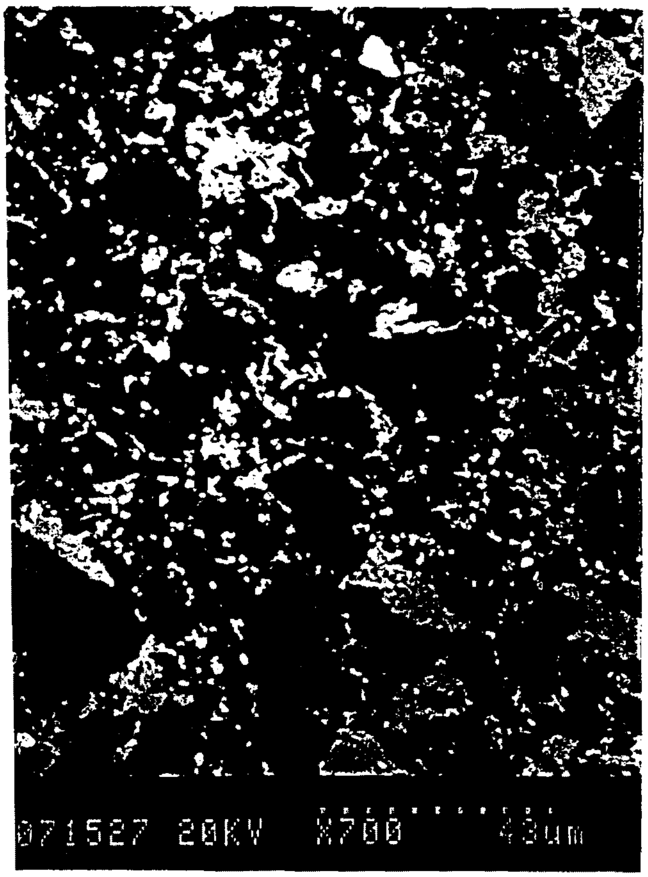




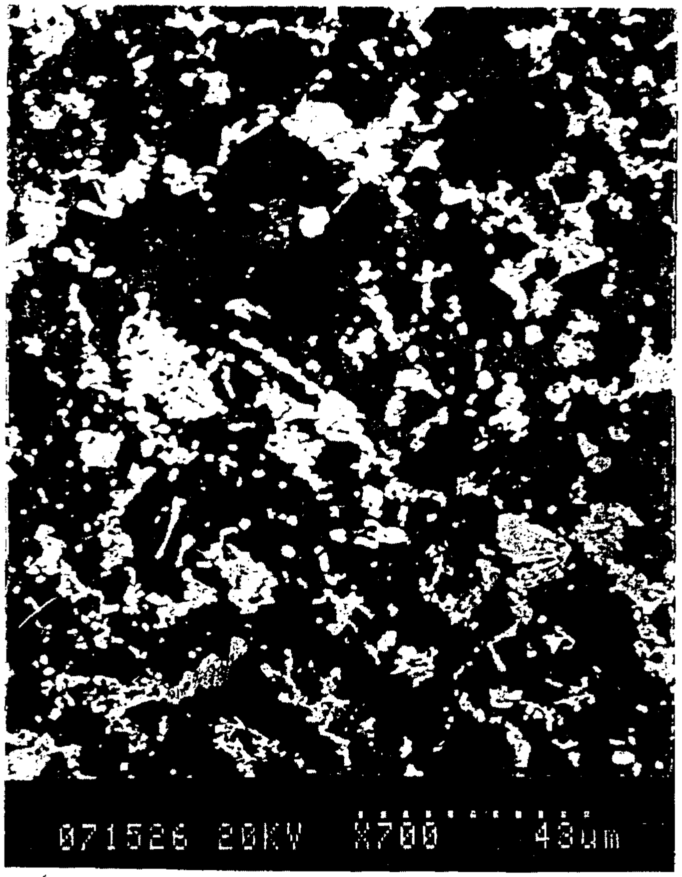
4S, 3375 psi, 150 min, 1620°C



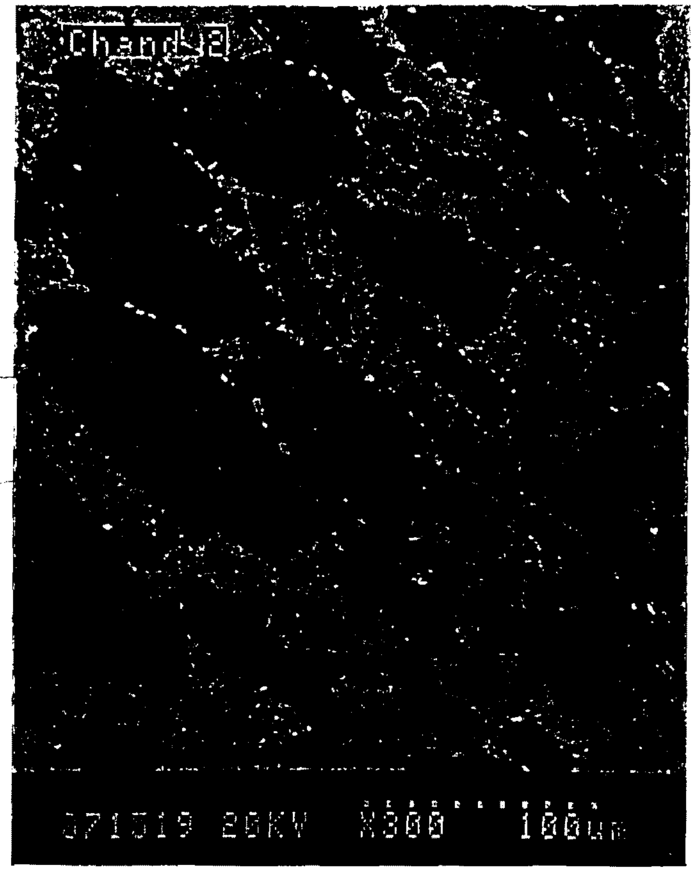
SHS2, 1A, 3375 psi, 30 min, 1620°C



4S, 3375 psi, 150 min, 1620°C



SHS 2, 7A, 3375, 30 min, 1620°C

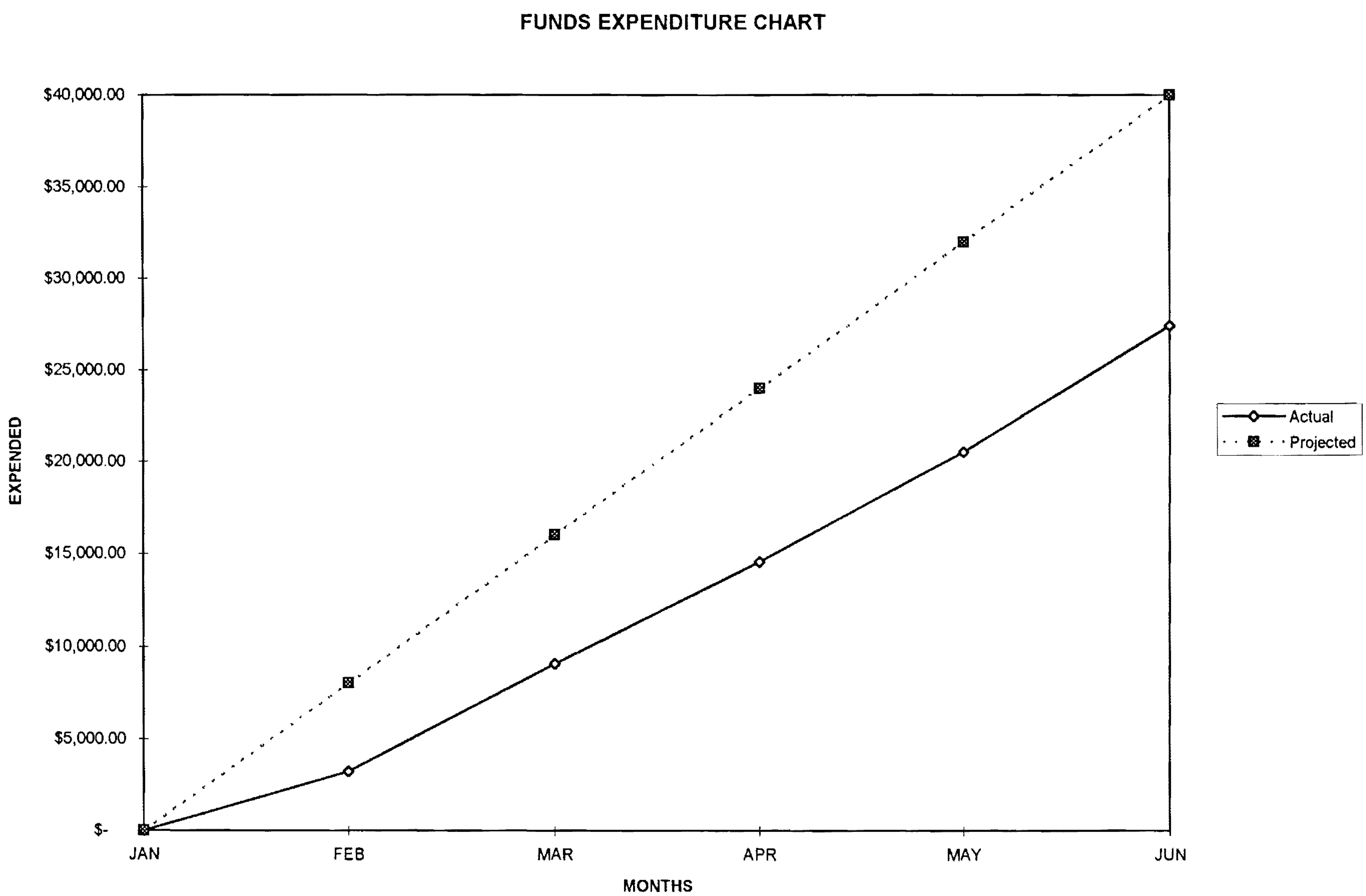


MIM, 3375 psi, 90 min, 1620°C

MIM, 3375 psi, 90 min, 1620°C

MILESTONE CHART

	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
1.START OF WORK		X																		
2.HOT PRESS STUDY			X	X	X	X	X													
3.MICROSTR. ANAL.			X	X	X	X	X													
4.FORM TARGETS(36)								X	X	X	X	X	X	X						
5.END TECHNICAL																X				
6.DELIVER TARGETS																X				
7.BI-MONTHLY LETTER				X	X		X		X		X		X		X					
8.DRAFT FINAL																	X			
9.DRAFT FIN. APPR.																		X		
10.FINAL REPORT																			X	
11.PROGRAM REVIEWS				X			X			X			X			X				


FUNDS EXPENDITURE CHART
$40,000.00
$35,000.00
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
EXPENDED
JAN
FEB
MAR
APR
MAY
JUN
MONTHS
Actual
Projected

Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

September 19, 1995

Commander
U. S. Army Tank Automotive and Armaments Command
Attn: AMSTA-TR-S, Thomas Furmaniak
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #004
Reporting Period: 1 July-31 August, 1995

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A004
Reporting Period: 1 June-31 August, 1995

Submitted By:

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

September 19, 1995

UNCLASSIFIED

Progress, Status and Management Report A001
Contract Deliverable #4
Reporting Period: 1 July-31 August, 1995
September 20, 1995

A. Description of progress during reporting period.

July

* Additional samples were sent to Chand and Bomas for cutting.
* A technique for polishing the samples was begun.
* Scanning electron microscopy (SEM) was attempted, but not successful since the microscructure was not polished enough.
* A new student (a senior undergraduate) student began working on the project.
* Additional (repeats) of two selected hot press runs were made to allow determination if the microstructure was repeatable.
* Preparations were begun to make larger diameter slip cast fused silica (SCFS) refractory sleeves for the four inch diameter disks.

August

* All samples in the matrix (Table I) have been hot pressed, polished and microstructures documented.

* August 23 FAX document discussing microstructure is attached.

B. Results, conclusions, recommendations related to problem areas.

* There was difficulty in polishing the sample surfaces adequately for microscopic examination since the sample are very hard. The problem was resolved by sending samples to Buehler Polishing to advise us on proper polishing techniques. Samples can now be successfully polished in less than one day.

* There was difficulty in observing the TiB_2 and Al_2O_3 areas in the SEM due to scheduling conflicts with other users. The problem was resolved by using the metallograph which was less time consuming and easier to use. The phase contrast is quite good.

C. Significant changes in organization, management, milestones.

The milestone chart has not changed, as we are still within the performance time lines. See Attached Milestone Chart.

TABLE I.

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

D. Problem areas affecting technical or scheduling elements with background and recommendations.

* There are some delays occuring with the scale-up to four inch diameter disks such as: finding a suitable 16 inch O.D. form to shape the copper coil for the hot press. After discussions with T. Furmaniak, reasonable forms were identified (a wooden, glued 2X4 turned cylinder, a wire cable spool).

E. Problem areas affecting cost elements with background and recommendations.

None.

F. Cost incurred during the reporting period and total to date expenditures.

Actual costs incurred 1 July through 31 August were $17,277.36 which includes a $3899.09 Materials and Supply cost. Total to date expenditures are $44930.29 (including encumbrances). The eight months projected expenditures are based on the $50,000 allocation for the first six months. The expenditures are slightly under the projected costs since the program efforts began a month later than expected due to the delay in scheduling the "kick-off" meeting and expected material expenditures for the modification of the hot press to four inch disks.

G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

The hours are based on an average 160 working hours/month

	July/August Hours	Total to Date
K. Logan (17%):	54	190
A. George (5%):	16	52
G. Patel (10%):	32	112
A. Carney (33%):	116	237
C. Huthmaker(50%):	160	360

I. Any trips and significant results.

Significant Results: Enclosed are copies of scanning electron micrographs (SEM) which were FAXed on August 11 and 23, 1995 (FAX texts are attached).

HOT PRESS MICROSTRUCTURE PROGRESS
Originally FAXed on August 23, 1995

The following figures represent data points on the hot press matrix. Also included are additional microstructural representations of LRP debris samples which are comparable to reference samples 225 and 227.

The manually mixed (MM) and SHS sample micrographs represent the most extreme hot press conditions followed in the hot pressing matrix. The reference sample micrographs represent additional LRP debris microstructure. The white areas are TiB_2 and the black areas are Al_2O_3.

Manually Mixed Sample Micrographs: The TiB_2 and Al_2O_3 grains are all larger than the SHS produced grains. Note the micron markers represent 300 microns in Figs 1 and 3; and 50 microns in Figs 2 and 4.

1. Figure 1, MM, 500/5000 psi, 150 min. hold time, 160X magnification (100 micron bar):

   TiB_2 grains are "predominately" at Al_2O_3 grain boundaries,

2. Figure 2, MM, 500/5000 psi, 150 min. hold time, 500X magnification (50 micron bar):

   TiB_2 grains are 5-50 microns in size and the grains are more discrete than those in MM Fig.4.

   The Al_2O_3 grains are generally smaller than those in MM Fig 3 and oval in shape indicating an orientation which is preferential to the direction of applied pressure.

3. Figure 3, MM, 5000 psi, 150 min. hold time, 160X magnification (100 micron bar):

   TiB_2 grains appear to be more concentrated at the Al_2O_3 grain boundaries as compared with MM Fig.1.

4. Figure 4, MM, 5000 psi, 150 min. hold time, 500X magnification (50 micron bar):

   TiB_2 grains are 5-50 microns in size and show a more fused appearance than those in MM Fig.2.

   The Al_2O_3 grains are generally larger than those in MM Fig 1 and more elongated in shape indicating further an orientation which is preferential to the direction of applied pressure.

SHS Sample Micrographs: Note the micron markers represent 100 microns in Figs 1 and 3; and 50 microns in Figs 2 and 4.

5. Figure 5, SHS, 500/5000 psi, 150 min. hold time, 160X magnification (100 micron bar):

   There are numerous relatively large areas of TiB_2 and Al_2O_3 as compared with Figure SHS 7.

6. Figure 6, SHS, 500/5000 psi, 150 min. hold time, 500X magnification (50 micron bar):

   The TiB_2 and Al_2O_3 areas are on the order of 10-25 microns in size with the tendency for the TiB_2 to be more localized at the Al_2O_3 grain boundaries as compared with Figure 8.

7. Figure 7, SHS, 5000 psi, 150 min. hold time, 160X magnification (100 micron bar):

   There are fewer localized areas of TiB_2 and Al_2O_3 as compared with Figure 6. The TiB_2 also appears to be more homogeneously distributed in the Al_2O_3.

8. Figure 8, SHS, 5000 psi, 150 min. hold time, 500X magnification (50 micron bar):

   The TiB_2 appears to be more homogeneously distributed in the Al_2O_3 as compared with Figure 6.

Reference Sample Micrographs: These are additional samples taken from the LRP debris where samples 225 and 227 were taken. Note the micron markers represent 100 microns in Figs 1 and 3; and 50 microns in Figs 2 and 4.

9. Figure 1, Same LRP debris as ref. 225, 160X magnification (100 micron bar):

   There are more relatively large areas of TiB_2 and Al_2O_3 as compared with Ref. Figure 3.

10. Figure 2, Same LRP debris as ref. 225, 500X magnification (50 micron bar):

    The TiB_2 and Al_2O^3 areas are on the order of 25-50 microns in size with the tendency for the TiB_2 to be localized at the Al_2O_3 grain boundaries as compared with Ref. Figure 4.

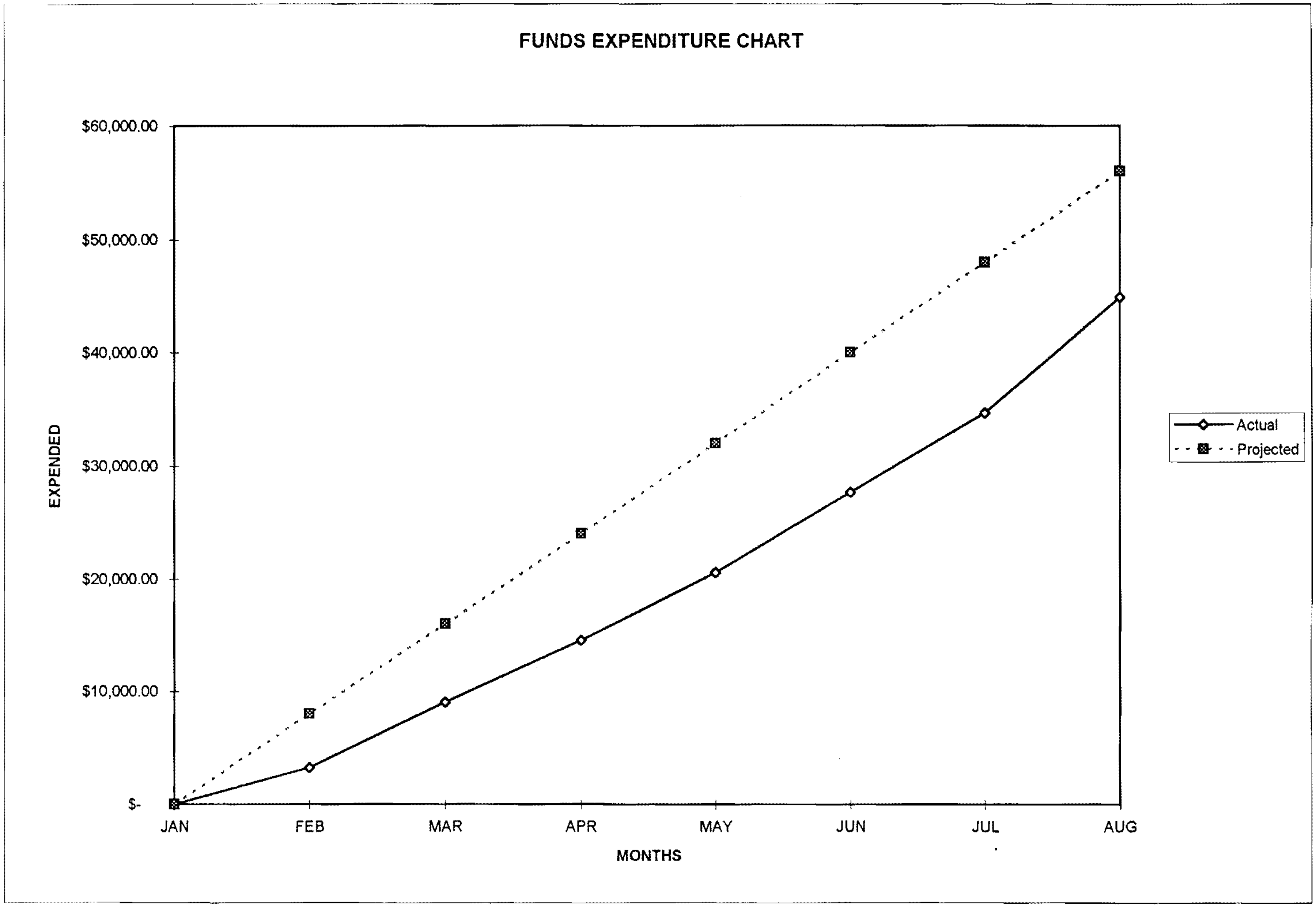
11. Figure 3, Same LRP debris as ref. 227, 160X magnification (100 micron bar):

    There are fewer localized areas of TiB_2 and Al_2O_3 as compared with Ref. Figure 1. The TiB_2 also appears to be more homogeneously distributed in the Al_2O_3.

12. Figure 4, Same LRP debris as ref. 227, 500X magnification (50 micron bar): The TiB_2 also appears to be more homogeneously distributed in the Al_2O_3 as compared with Ref. Figure 2.

The microstructures of the SHS 500/5000 seem to be comparable to the Reference 225 microstructures; and the microstructures of SHS 5000 seem to be comparable to the Reference 227 microstructures. The significant difference is in the Reference microstructure which is twice the relative size of the hot press matrix samples. The size difference can be explained by the longer hot press cycles used in the reference samples causing more grain growth.

We have already reproduced the hot press cycle times used in samples 225 and 227. The disks are presently at Chand being prepared for the microstructural analysis. The ETA of the disks at GIT is expected within two weeks.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MILESTONE CHART

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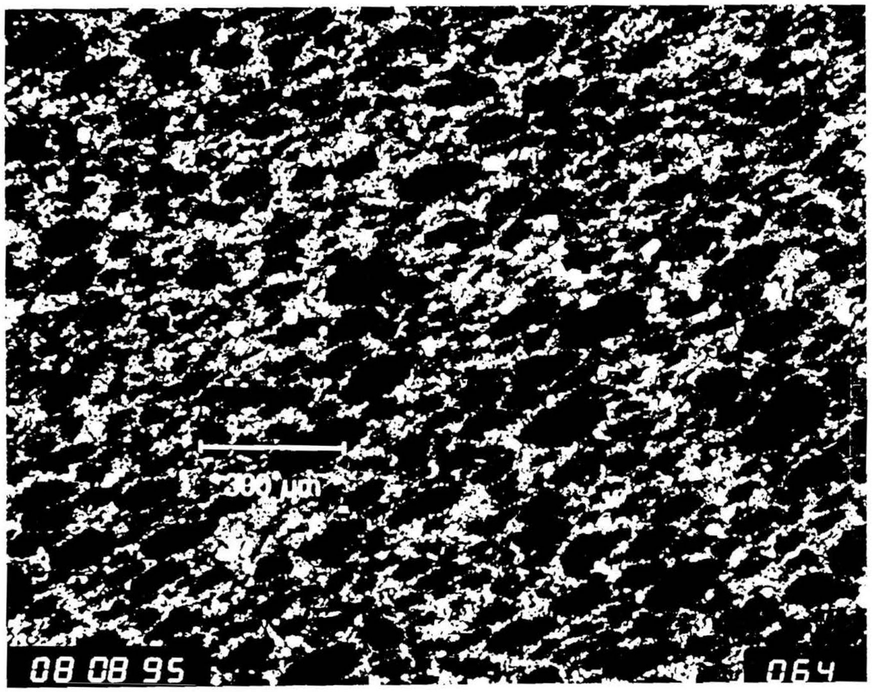
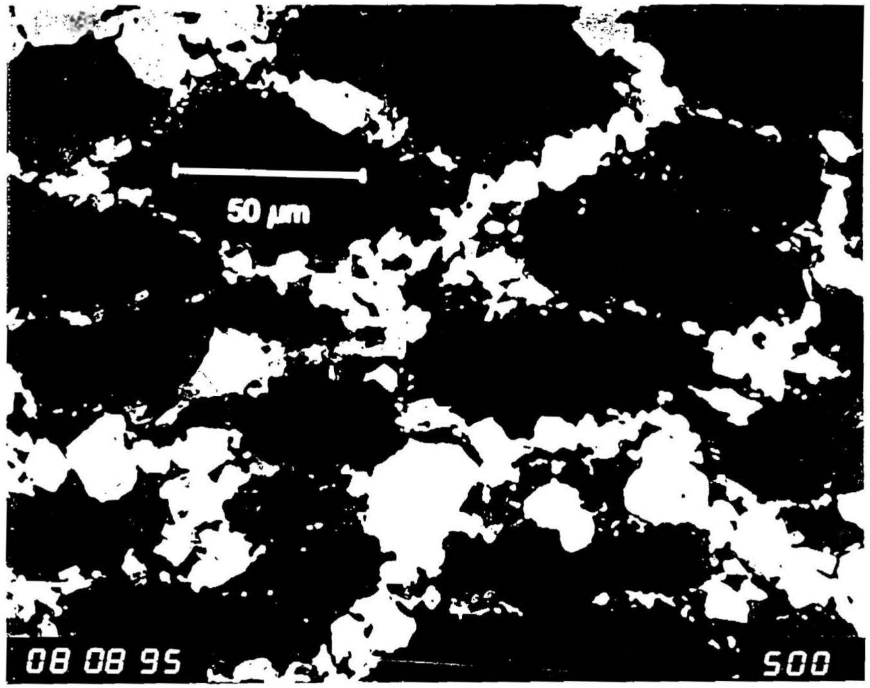
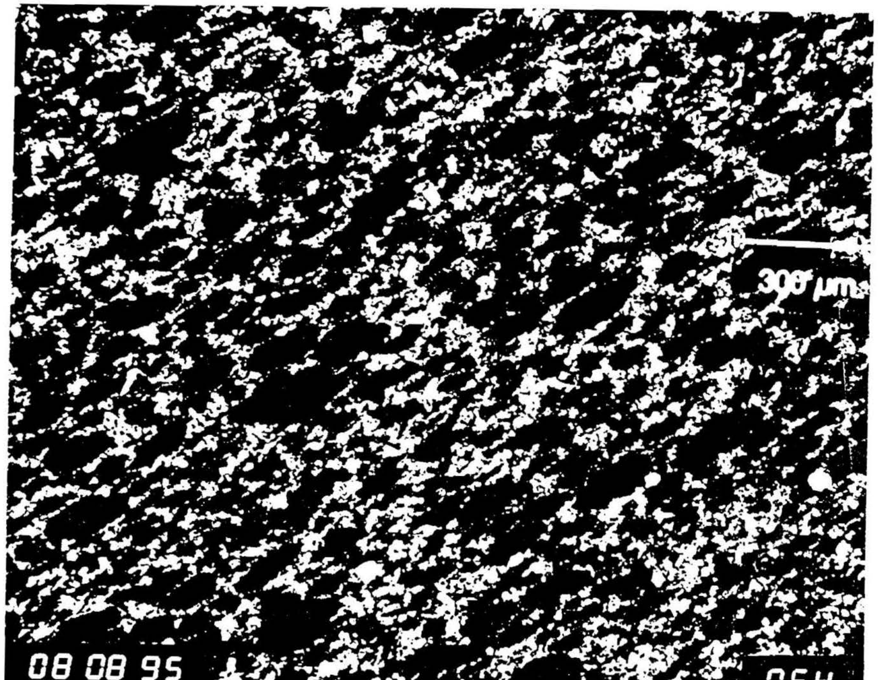
1.START OF WORK		X																		
2.HOT PRESS STUDY			X	X	X	X	X													
3.MICROSTR. ANAL.			X	X	X	X	X													
4.FORM TARGETS(36)								X	X	X	X	X	X	X						
5.END TECHNICAL																X				
6.DELIVER TARGETS																X				
7.BI-MONTHLY LETTER				X	X		X		X		X		X		X					
8.DRAFT FINAL																	X			
9.DRAFT FIN. APPR.																		X		
10.FINAL REPORT																			X	
11.PROGRAM REVIEWS				X			X			X			X			X				



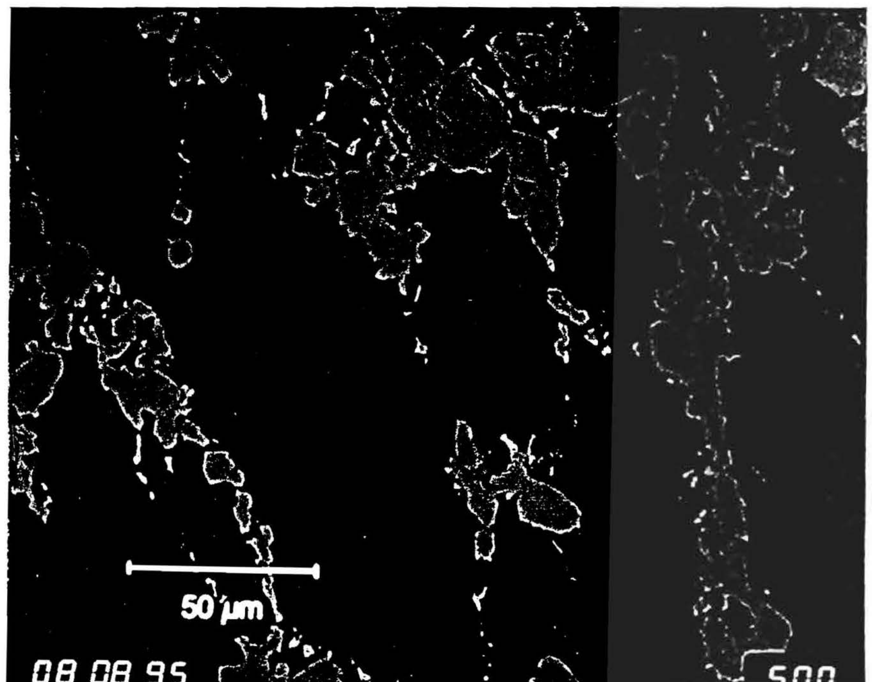
① mm 500/5000 psi 150 min



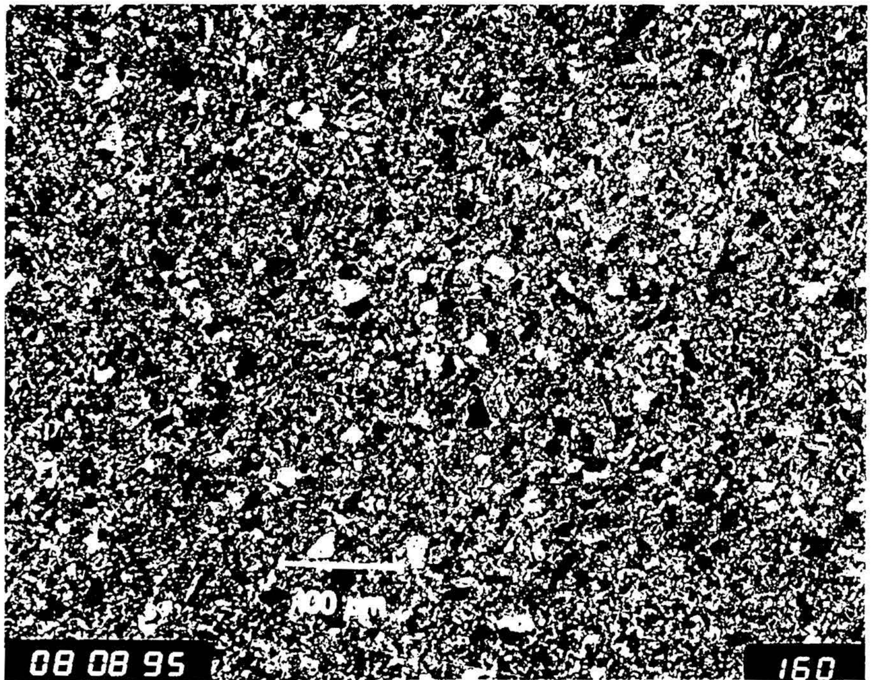
② mm 500/5000 psi 150 min



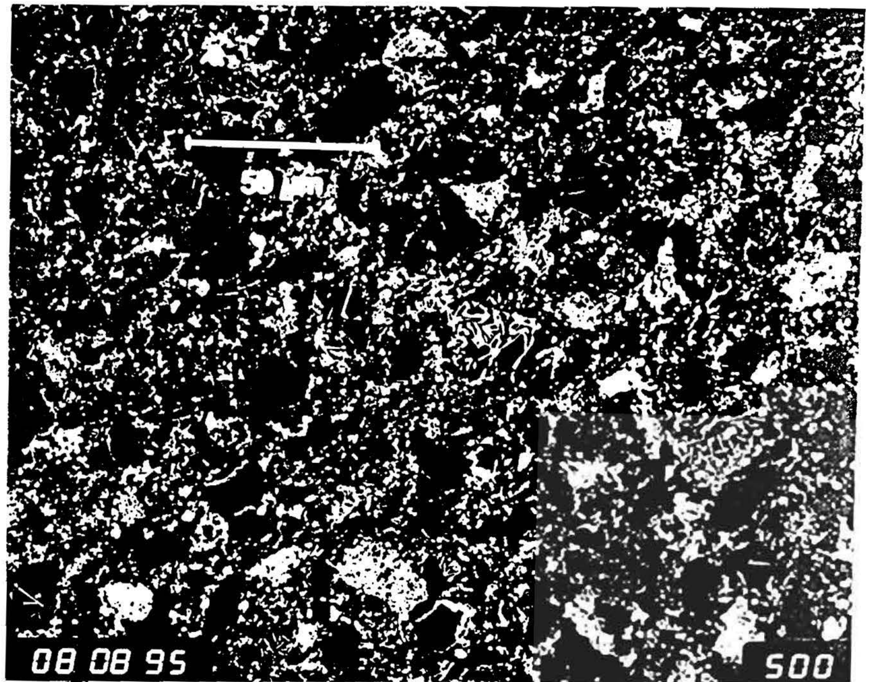
③ mm 500 0psi 150 MIN



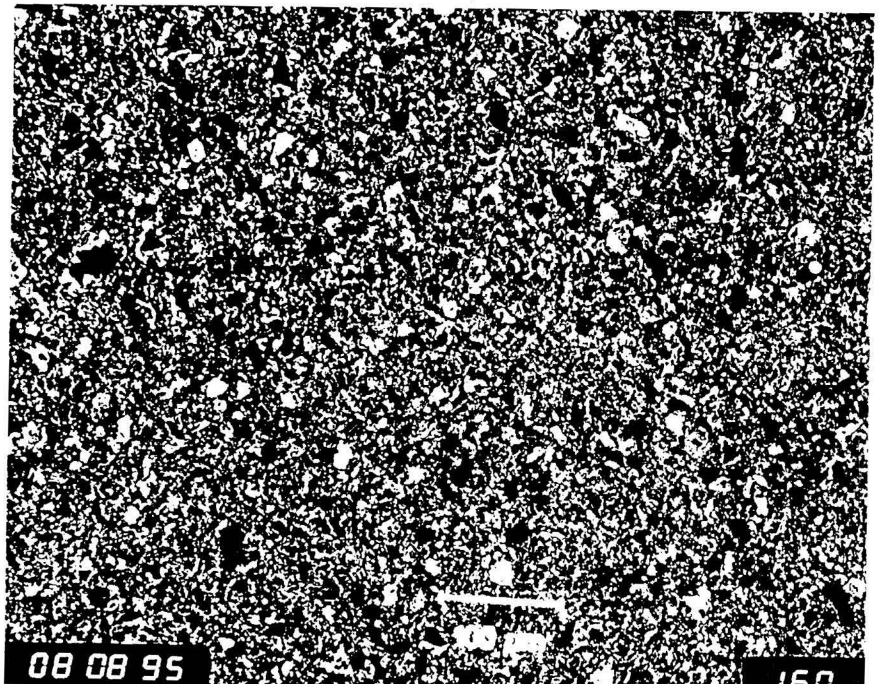
④ mm 500psi/150min



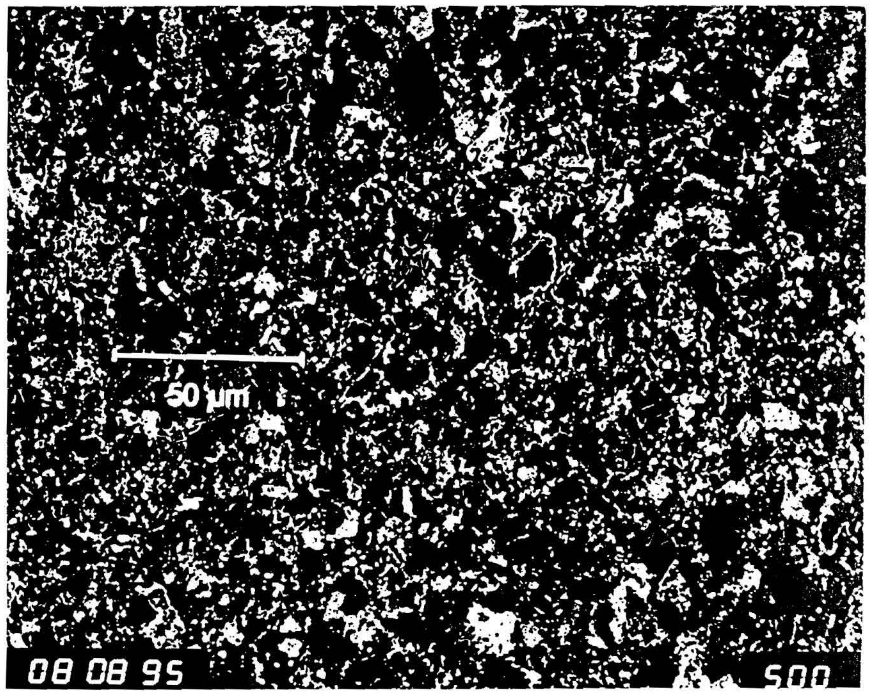
(5) SHS 500/5000 psi 150min



(6) SHS 500/5000 psi 150min



(7) SHS 500p 150min



(8) SHS 500p 150min

Reference 225

8/10/95 227

8/10/95 225

② Reference 225

8/10/95 227

8/10/95 225

Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

November 17, 1995

Commander
U. S. Army Tank Automotive and Armaments Command
Attn: AMSTA-TR-S, Thomas Furmaniak
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #005
Reporting Period: 1 September-31 October, 1995

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A005
Reporting Period: 1 September-31 October, 1995

Submitted By:

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

November 17, 1995

UNCLASSIFIED

Progress, Status and Management Report A001
Contract Deliverable #5
Reporting Period: 1 September-31 October, 1995

November 17, 1995

A. Description of progress during reporting period.

September

* Continued with the four inch part, hot press modification: RF copper coil, riser sleeves, refractory sleeve mold.

* Continued studying and observing the hot pressed part microstructures corresponding to the hot press matrix.

October

* Continued with the four inch part, hot press modification: RF copper coil, riser sleeves, refractory sleeve mold.

* Continued studying and observing the hot pressed part microstructures corresponding to the hot press matrix.

* Prepared detailed day by day schedule.

* Prepared micrograph matrix corresponding to the hot press schedule.

B. Results, conclusions, recommendations related to problem areas.

1. The objective microstructure is not yet clearly defined.

Results: Hot press parameters have been defined to "bias" the TiB_2 to either preferentially surround, or be distributed in, the Al_2O_3 grains. However, the average grain size is about half that of the objective microstructure.

Conclusions: The results to date are positive and indicate the potential to obtain the objective microstructure. (Note: no one has ever been able to "control" ceramic composite microstructure to the extent we are attempting).

Recommendations: Increase the soak time at 1620°C from 150 minutes to 240 minutes. It is standard hot press practice to increase grain size by increasing the soak time. If the increased soak time does not allow completion of the objective, then decrease the rate of temperature increase to 1620°C (to more closely mimic the original hot press cycles which produced the objective microstructures). See Table I for additional hot press matrix parameters.

2. The manually mixed composite hot pressed grain size is significantly larger than the SHS composite hot press grain size.

Results: The relatively large manually mixed grain size prevents direct comparison of the properties with the SHS composite. However, the manually mixed large grain size is of considerable interest because of the large size.

Conclusions: Produce a manually mixed composite with a grain size similar to the SHS composite.

Recommendations: The original particle sizes of 74 microns (200 mesh) for the Al_2O_3 and 1-10 microns (commercially available size) for the TiB_2 manually mixed powders were chosen based on the estimated original eight hour ball milled SHS TiB_2/Al_2O_3 particle size of 64 microns containing 1-10 micron particles of TiB_2. Since the SHS composite powders were ball milled until the composite particle sizes reached an average of 7 microns, it is recommended that the manually mixed powders be ball milled 24 hours. See Table I for additional hot press matrix parameters.

TABLE I.

HOLD TIME	500/5000psi	5000psi
150 min	MM(fine)	MM(fine)
240 min	MM(fine)	MM(fine)
240 min	SHS	SHS

C. Significant changes in organization, management, milestones.

There are no significant changes in organization, or management. The milestone chart has been changed to reflect the progress to date and required further developmental time to achieve the objective microstructure. See Attached Milestone Chart.

D. Problem areas affecting technical or scheduling elements with background and recommendations.

1. Delay in obtaining the objective microstructure (see B. 1,2 above).

E. Problem areas affecting cost elements with background and recommendations.

1. Delay in obtaining the objective microstructure (see B. 1,2 above).

The complete expenditure of the budgeted materials and supplies category is the main cost element affected. The increased number of hot press runs to accommodate the recommendations in B.1,2 above, and the increased soak times has caused an unexpected decrease in the number of hot press repeats on a specific die set. It is necessary to order additional graphite die sets for the additional three inch hot press runs. (Cost ~$1700) Also, the increased number of samples required to be machined by Chand for the microstructural analyses will require additional machining costs. (Cost: ~$1000) Total additional M&S required ~$3000 (includes ~$300 for polishing supplies).

Recommendation:

1. Rebudget existing funds to allow additional materials and supplies.

F. Cost incurred during the reporting period and total to date expenditures.

Actual costs incurred 1 September through 31 October were $11,637.24. Total to date expenditures are $56,571.69 (not including $362.50 in travel encumbrances). The twelve months projected expenditures are based on the total project allocation.

G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

The hours are based on an average 160 working hours/month

	Sept/Oct Hours	Total to Date
K. Logan (18%):	54	244
A. George (5%):	16	68
G. Patel (10%):	32	144
A. Carney (33%):	106	343
C. Huthmaker(50%):	0	360

I. Any trips and significant results.

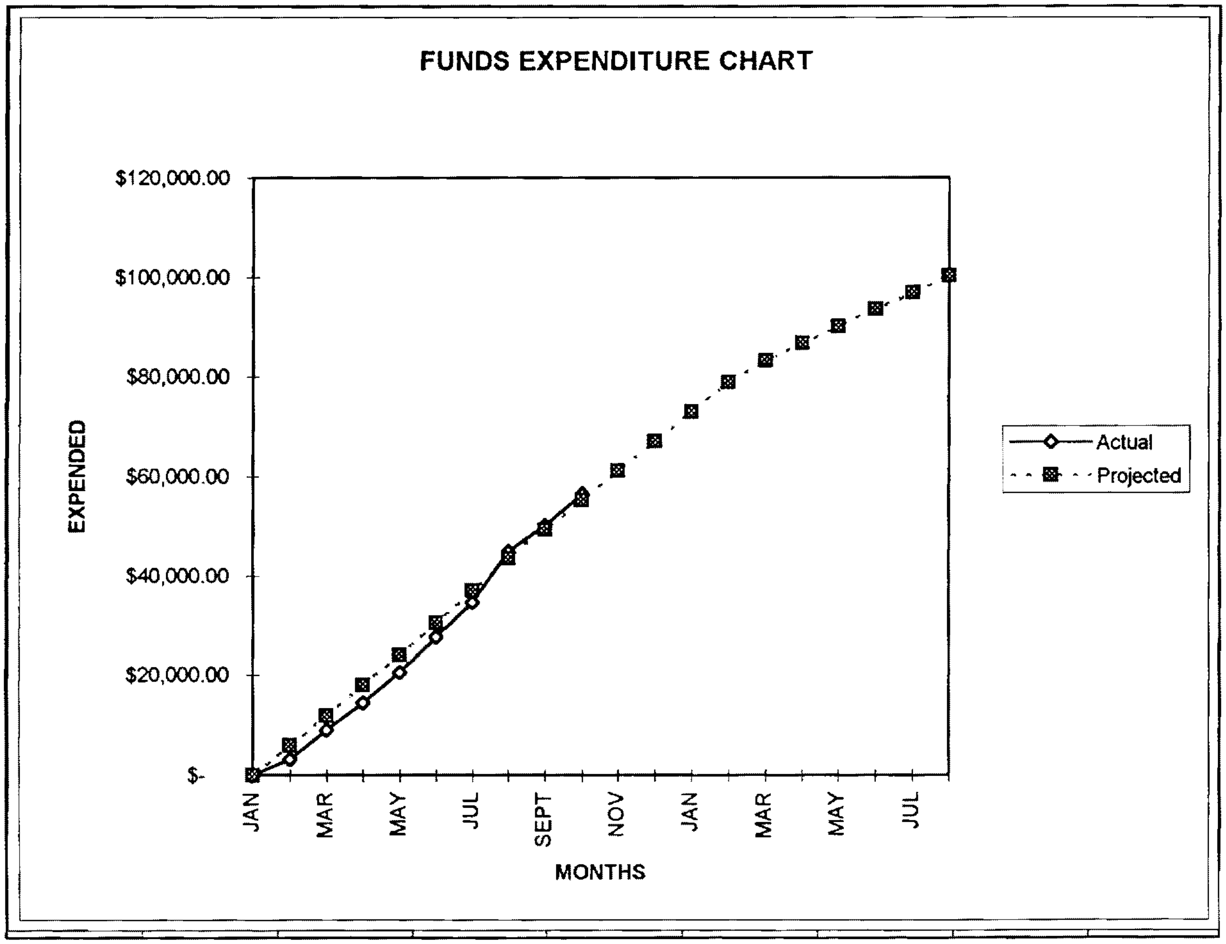
A program review was held at Aberdeen Proving Ground on Thursday, October 12.

Significant results:

1. The hot press parameter study demonstrates the ability to obtain a "bias" in obtaining preferential migration of TiB_2 in, and around, Al_2O_3 grains.

MILESTONE CHART

	I							I I													
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
1.START OF WORK		X																		
2.HOT PRESS STUDY			X	X	X	X	X													
3.MICROSTR. ANAL.			X	X	X	X	X	X	X	X	X									
4.FORM TARGETS(36)											X	X	X	X	X					
5.END TECHNICAL																X				
6.DELIVER TARGETS																X				
7.BI-MONTHLY LETTER				X	X		X		X		X		X		X					
8.DRAFT FINAL																	X			
9.DRAFT FIN. APPR.																		X		
10.FINAL REPORT																			X	
11.PROGRAM REVIEWS				X			X			X			X			X				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Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

January 17, 1996

Mr. T. Furmaniak
MS263
Emerging Technology Team
USATACOM
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #006
Reporting Period: 1 November-31 December, 1996

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A006
Reporting Period: 1 November-31 December, 1996

Submitted By:

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

January 17, 1996

UNCLASSIFIED

Progress, Status and Management Report A001
Contract Deliverable #6
Reporting Period: 1 November-31 December, 1996

January 17, 1996

A. Description of progress during reporting period.

November

* Prepared prints for hot press matrix microstructure.
* Continued studying and observing the hot pressed part microstructures corresponding to the hot press matrix.
* An unanticipated requirement to move the synthesis and ball milling facilities out of its present location slowed progress.

December

* The manually mixed TiB_2/Al_2O_3 was ball milled to reduce the particle size to a size more similar to the SHS TiB_2/Al_2O_3 particle size. The original particle sizes of 74 microns (200 mesh) for the Al_2O_3 and 1-10 microns (commercially available size) for the TiB_2 manually mixed powders were chosen based on the estimated original eight hour ball milled SHS TiB_2/Al_2O_3 particle size of 64 microns containing 1-10 micron particles of TiB_2. Since the SHS composite powders were ball milled until the composite particle sizes reached an average of 7 microns, the manually mixed powders were ball milled 24 hours.
* SHS and the reduced particle size manually mixed powders were hot pressed at 5000psi and 500/5000psi, 1620°C and held for a four hour soak period.
* The resulting four samples were sent to Chand for sample preparation.
* Continued studying and observing the hot pressed part microstructures corresponding to the hot press matrix.
* The student posters were prepared for the 1996 Conference and exposition on Composites, Advanced ceramics, materials and Structures to be held at Cocoa Beach January 7-11, 1996.
* Prepared micrographs corresponding to the hot press schedule matrix.

B. Results, conclusions, recommendations related to problem areas.

1. The objective microstructure is not yet clearly defined.

Results: We are preparing the additional samples for microstructural observation.

Conclusions: The results to date continue to be positive and indicate the potential to obtain the objective microstructure. (Note: no one has ever been able to "control" ceramic composite microstructure to the extent we are attempting).

Recommendations: Observe the microstructures.

TABLE I.

HOLD TIME	500/5000psi	5000psi
240 min	MM(fine)	MM(fine)
240 min	SHS	SHS

C. Significant changes in organization, management, milestones.

There are no significant changes in organization, or management. The milestone chart has been changed to reflect the progress to date and required further developmental time to achieve the objective microstructure. See Attached Milestone Chart.

D. Problem areas affecting technical or scheduling elements with background and recommendations.

1. Delay in obtaining the objective microstructure (see B. 1,2 above).
2. Unanticipated requirement to relocate the synthesis and ball milling facilities.

E. Problem areas affecting cost elements with background and recommendations.

1. Delay in obtaining the objective microstructure (see B. 1,2 above).

The complete expenditure of the budgeted materials and supplies category is the main cost element affected. The increased number of hot press runs to accommodate the recommendations in B.1,2 above, and the increased soak times has caused an unexpected decrease in the number of hot press repeats on a specific die set. It is necessary to order additional graphite die sets for the additional three inch hot press runs. (Cost ~$1700) Also, the increased number of samples required to be machined by Chand for the microstructural analyses will require additional machining costs. (Cost: ~$1000) Total additional M&S required ~$3000 (includes ~$300 for polishing supplies).

Recommendation:
1. Rebudget existing funds to allow additional materials and supplies.

F. Cost incurred during the reporting period and total to date expenditures.

Estimated costs incurred 1 November through 31 December were $10,696.16 (November actual cost: $5,523.28 and December estimated cost: $5,172.88). Total to date expenditures are estimated $67,267.85 (not including $362.50 in travel encumbrances). The twelve months projected expenditures are based on the total project allocation.

G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

The hours are based on an average 160 working hours/month

	Nov/Dec Hours	Total to Date
K. Logan (18%):	54	298
A. George (5%):	16	84
G. Patel (10%):	32	176
A. Carney (33%):	106	449
C. Huthmaker(50%):	0	360

I. Any trips and significant results.

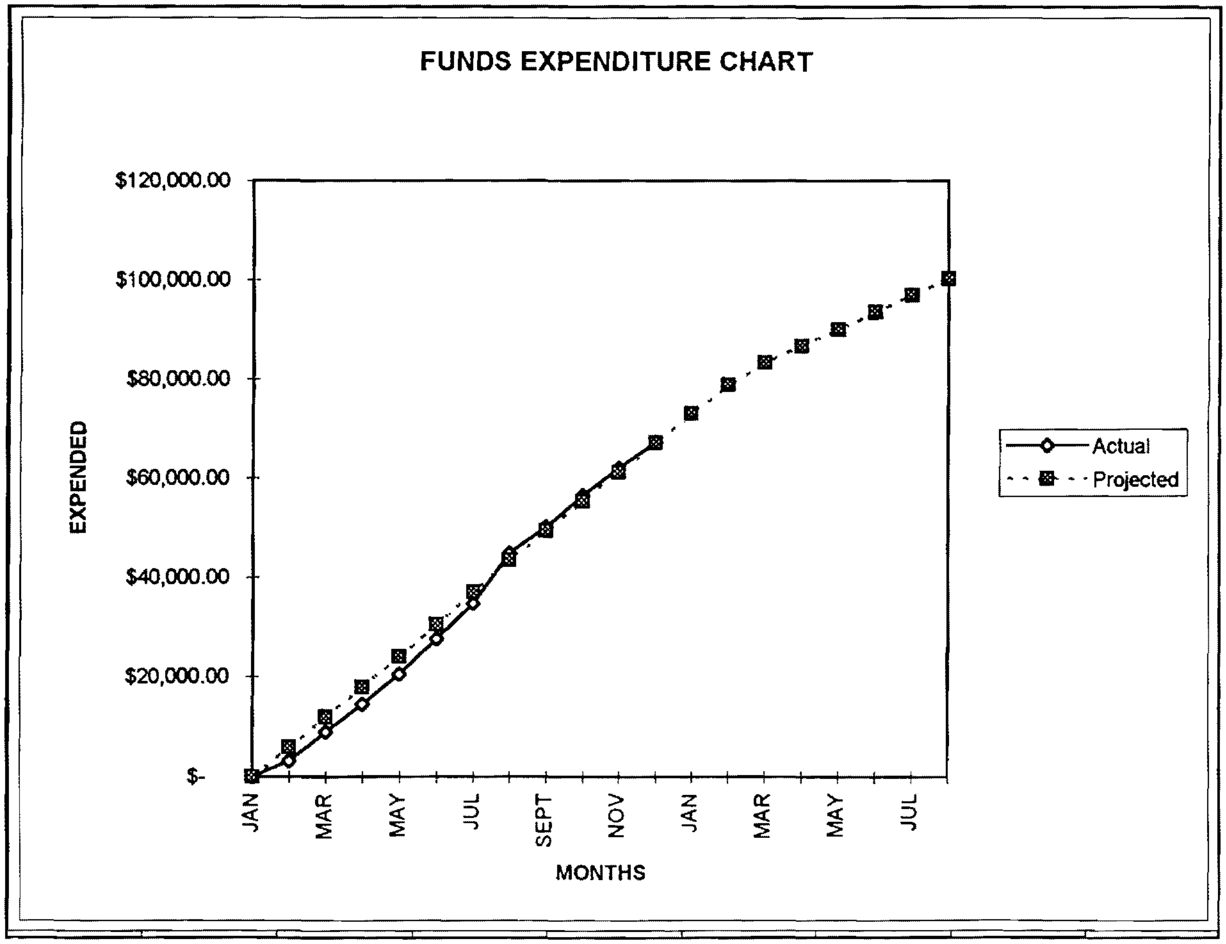
None.

Significant results:

1. The hot press parameter study demonstrates the ability to obtain a "bias" in obtaining preferential migration of TiB_2 in, and around, Al_2O_3 grains.

MILESTONE CHART

	I							II												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
1.START OF WORK		X																		
2.HOT PRESS STUDY			X	X	X	X	X	X	X	X	X	X	X							
3.MICROSTR. ANAL.			X	X	X	X	X	X	X	X	X	X	X							
4.FORM TARGETS(36)														X	X	X				
5.END TECHNICAL																X				
6.DELIVER TARGETS																X				
7.BI-MONTHLY LETTER				X	X		X		X		X		X		X					
8.DRAFT FINAL																	X			
9.DRAFT FIN. APPR.																		X		
10.FINAL REPORT																			X	
11.PROGRAM REVIEWS				X			X			X			X			X				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#7

Georgia Tech

School of Materials Science and Engineering

Georgia Institute of Technology
Atlanta, Georgia 30332-0245
USA
FAX: 404•853•9140

March 19, 1996

Mr. T. Furmaniak
MS263
Emerging Technology Team
USATACOM
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #007
Reporting Period: 1 January-29 February, 1996

Dear Mr. Furmaniak:

Enclosed is the Subject Bi-Monthly Letter Report with the two required copies.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A006
Reporting Period: 1 January-29 February, 1996

Submitted By:

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

March 19, 1996

UNCLASSIFIED

Progress, Status and Management Report A001
Contract Deliverable #7
Reporting Period: 1 January-29 February, 1996

March 19, 1996

A. Description of progress during reporting period.

January

* Completed hot pressing parameter 3" diameter disk runs as shown in Table I. Samples were sent to Chand for shaping.

TABLE I.

HOLD TIME	500/5000psi	5000psi
240 min	MM(fine)	MM(fine)
240 min	SHS	SHS

* Inventoried supplies in preparation for processing of 3" and 4" deliverables.
* Documented microstructure of samples hot pressed according to Table I.

February

* COTR IPR visit on February 2, 1996.
* Chose microstructure for the 3" and 4" deliverables as follows: T@A=TiB_2 at Al_2O_3 grain boundaries; T in A= TiB_2 dispersed in Al_2O_3; SHS=synthesized using SHS technology; MM=manually mixed; Pressure, 5000=continuously held; 500/5000=500psi continuously held, then 5000psi applied manually and immediately when the 1620°C hold temperature was reached; Samp.HPID#=hot press parameter study sample number.

#	Grain Dist.	Process Method	Pressure (psi)	Hold Time	Density (% theo.)	MOR (MPa)	Samp. HPID#
1	T@A	SHS	5000	240min	98.7	354	2
2	TinA	SHS	500/5000	150min	98.4	434	14
3	TinA	SHS	500/5000	240min	94.7	300	3
4	T@A	MM	500/5000	150min	99.0	288	13
5	TinA	MM	500/5000	240min	98.8	277	4

B. Results, conclusions, recommendations related to problem areas.

Results of the microstructural analysis indicated that samples #1,2,4 and 5 all had generally comparable densities and MOR values. However, sample #3 exhibited a more definitive distribution of T in A when compared with sample #2. Sample #3 had a lower density (94.7%).

It was decided to repeat the hot press parameters which produced samples #1-5, send them to Chand, then confirm the microstructures and densities to see if the microstructures are repeatable.

C. Significant changes in organization, management, milestones.

There are no significant changes in organization, or management. The milestone chart has been changed to reflect the progress to date and required further developmental time to achieve the objective microstructure. It will be necessary to obtain a No Cost Extension to the technical effort in order to be able to provide the deliverable disks. See Attached Milestone Chart.

D. Problem areas affecting technical or scheduling elements with background and recommendations.

Scheduling has been changed to reflect the needed additional time to complete hot pressing of the deliverables. Additional hot press parameter runs were necessary to achieve the desired microstructures. The necessary additional runs delayed initiation of the deliverable hot press runs.

E. Problem areas affecting cost elements with background and recommendations.

At the present time, there are sufficient funds available to complete the required deliverables.

F. Cost incurred during the reporting period and total to date expenditures.

Estimated costs incurred 1 January through 29 February were $9,899.38 (January actual cost: $4,726.77 and February estimated cost: $5,172.62). Total to date expenditures are estimated $78,498.14. The twelve months projected expenditures are based on the total project allocation.

G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

The hours are based on an average 160 working hours/month.

	Jan/Feb Hours	Total to Date
K. Logan (18%):	80	378
A. George (5%):	16	100
G. Patel (10%):	32	208
A. Carney (33%):	106	555
C. Huthmaker(50%):	0	360

I. Any trips and significant results.

Trips: Attended the 1996 Conference & Exposition on Composites, Advanced Ceramics, Materials and Structures on Jan. 7-11, 1996, Cocoa Beach, FL and presented two posters (abstracts attached).

Significant results: We have prepared composite titanium diboride/alumina using the GIT patented advanced synthesis process and compared it with conventionally prepared, manually mixed composite with the main goal to be able to predict and control the resulting microstructure. There are two principle types of microstructure which occur in varying relative amounts: titanium diboride grains surrounding alumina grain boundaries, and titanium diboride grains homogeneously dispersed in the alumina. We have learned how to bias the microstructure to achieve predominantly one, or the other microstructure.

The American Ceramic Society Abstract Form

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THE EFFECTS OF HOT PRESS PARAMETERS ON TITANIUM DIBORIDE\ALUMINA COMPOSITE MICROSTRUCTURE, J.K. Phillips*, K.V. Logan, Georgia Institute of Technology, Atlanta, GA. 30332, (404) 894-6902

Toughness and other properties of ceramic composites can be maximized by optimizing the grain structure. Hot press parameters which were studied included the applied pressure, pressure application rate, and hold time. Variation of the parameters affected achieved densities and microstructure of a composite 30 % titanium diboride\70 % alumina powder which was manually mixed or synthesized by using self-propagating high-temperature synthesis (SHS). The resulting grain size was significantly smaller for the SHS produced powder, as compared with the grain size of the manually mixed powder. Two types of titanium diboride and alumina phase distributions were obtained: one with titanium diboride dispersed uniformly in the alumina, and another where the titanium diboride was concentrated at the alumina grain boundaries.

Research supported by U.S. Army Research Office Contract No. P-34517-RT-AAS, Dr. George Neese, COTR and U.S. Army TACOM Contract No. DAAE07-95C-RO40 Mr.Thomas Furmaniak, COTR

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+ See ACerS Roster

EFFECT OF MICROSTRUCTURE ON THE MECHANICAL PROPERTIES OF A TITANIUM DIBORIDE/ ALUMINA COMPOSITE, A.F. Carney* and K.V. Logan, Georgia Institute of Technology, Atlanta, GA 30332, (404) 894-2881

A 30% titanium diboride/ 70% alumina composite material, made using self-propagating, high-temperature synthesis (SHS), has been shown to have superior resistance to high strain rate deformation. The objective of this research was to determine the effect of microstructure on mechanical properties of both SHS produced and manually mixed composites. SHS and manually mixed powders were ground and hot pressed into disks having greater than 95% theoretical density. This investigation studied the distribution of titanium diboride in an alumina matrix, and the effect of microstructure on the mechanical properties. The microstructures consisted of either titanium diboride at alumina grain boundaries, or titanium diboride homogeneously distributed in alumina.

Research supported by U.S. Army TACOM, Contract No. DAAE07-95C-R040, Mr. Thomas Furmaniak, COTR and U.S. Army Research Office, Contract No. P-34517-RT-AAS, Dr. George Neese, COTR.

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- ☑ Poster presentation preferred
- ☑ Student presenter
- ☐ Non-student presenter

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MILESTONE CHART

	I							II														
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
1. START OF WORK		X																				
2. HOT PRESS STUDY			X	X	X	X	X	X	X	X	X	X	X	X								
3. MICROSTR. ANALYSIS			X	X	X	X	X	X	X	X	X	X	X	X								
4. FORM TARGETS (36)															X	X	X	X				
5. END TECHNICAL																		X				
6. DELIVER TARGETS																		X				
7. BI-MONTHLY LETTER				X	X		X		X		X		X		X		X					
8. DRAFT FINAL																						
9. DRAFT FINAL APPROVAL																		X				
10. FINAL REPORT																					X	
11. PROGRAM REVIEWS				X			X			X			X			X						

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N/A
#8

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Progress, Status and Management Report A001
Reporting Period: 1 March-30 April 1996

Submitted By:

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

May 17, 1996

UNCLASSIFIED

Progress, Status and Management Report A001
Contract Deliverable #7A
Reporting Period: 1 March-30 April 1996

May 17, 1996

A. Description of progress during reporting period.

March

* Completed hot pressing parameter 3" diameter disk runs as shown in attached Table I. Samples were sent to Chand for shaping.
* Documented microstructure of samples hot pressed according to Table I. (Copies of micrographs are attached, T. Furmaniak has originals)

April

* Chose microstructure for the 3" and 4" deliverables as follows: T@A=TiB_2 at Al_2O_3 grain boundaries; T in A= TiB_2 dispersed in Al_2O_3; SHS=synthesized using SHS technology; MM=manually mixed; Pressure, 5000=continuously held; 500/5000=500psi continuously held, then 5000psi applied manually and immediately when the 1620°C hold temperature was reached; Samp.HPID#=hot press parameter study sample number. See Table I for parameters.

B. Results, conclusions, recommendations related to problem areas.

Results of the microstructural analysis indicated that samples #22, 24, 13, 14 all had generally comparable densities and MOR values. However, sample #23 exhibited a more definitive distribution of T in A when compared with sample #14. Sample #23 had a lower density (94.7%).

The hot press parameters which produced samples #22, 23, 24, 13 and 14 were used to in an attempt to duplicate the microstructures. The resulting disks were then sent to Chand, polished and the microstructures were observed to see if they microstructures were repeatable.

C. Significant changes in organization, management, milestones.

There are no significant changes in organization, or management. The milestone chart has been changed to reflect the progress to date and required further developmental time to achieve the objective microstructure. It will be necessary to obtain a No Cost Extension to the technical effort in order to be able to provide the deliverable disks. See Attached Milestone Chart.

D. Problem areas affecting technical or scheduling elements with background and recommendations.

Scheduling has been changed to reflect the needed additional time to complete hot pressing of the deliverables. Additional hot press parameter runs were necessary to achieve the desired microstructures.

E. Problem areas affecting cost elements with background and recommendations.

At the present time, there are sufficient funds available to complete the required deliverables.

F. Cost incurred during the reporting period and total to date expenditures.

Estimated costs incurred 1 March through 30 April were $4.673.00 in March and $7,361.15 in April. Total to date expenditures are estimated to be $79,678.05. The twelve months projected expenditures are based on the total project allocation.

G. Actual and projected cost curves.
See Attached (the encumbrances are not included).

H. Person-hours expended during the reporting period and total to date expenditures.

The hours are based on an average 160 working hours/month.

	Mar/Apr Hours	Total to Date
K. Logan (25%):	80	458
A. George (5%):	16	116
G. Patel (10%):	32	240
A. Carney (33%):	106	661
C. Huthmaker(50%):	0	360

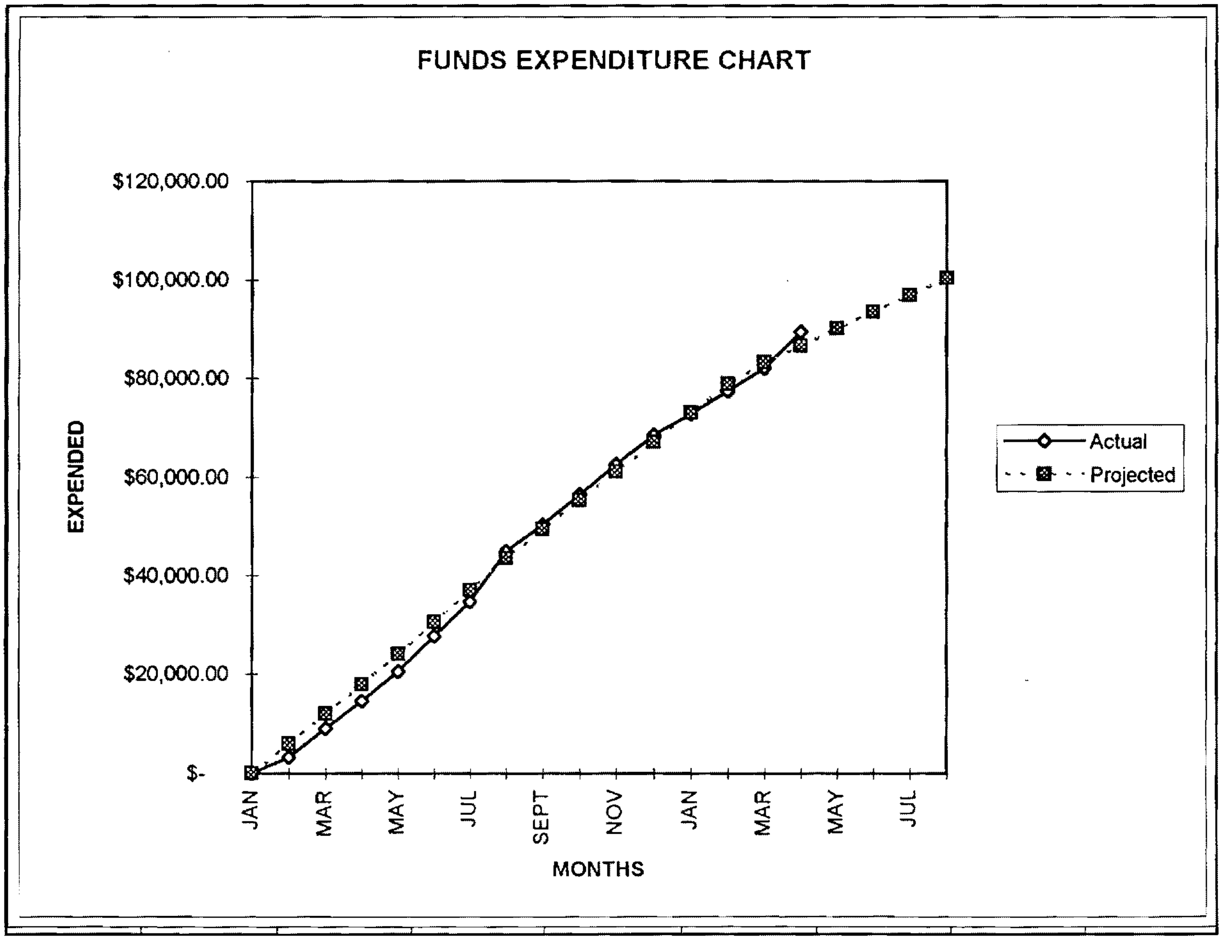
I. Any trips and significant results.

Significant results: We have prepared composite titanium diboride/alumina using the GIT patented advanced synthesis process and compared it with conventionally prepared, manually mixed composite with the main goal to be able to predict and control the resulting microstructure. There are two principle types of microstructure which occur in varying relative amounts: titanium diboride grains surrounding alumina grain boundaries, and titanium diboride grains homogeneously dispersed in the alumina.

3 X1/2 INCH DISKS				**4X1-1/2 INCH DISKS**			
	T @ A	T @ A			T @ A	T @ A	
Sample #	MM	SHS		Sample #	MM	SHS	
1	Test HP13 x	Test HP22 x		1	Test HP"13"	Test HP "22"	
2	x	x		2	CTP	CTP/rerun	
3	x			3			
4				4			
				5			x = completed
	T in A	T in A			T in A	T in A	
	MM	SHS			MM	SHS	
1	Test HP24 x	Test HP14 x		1	Test HP "24"	Test HP "14"	
2		x		2	CTP/rerun	CTP/rerun	
3		x		3			
4				4			
Extra				5			
1	Test HP23 x						
	(May substitute						
	for #14)						
HOT PRESS PARAMETERS (3 ea. + 1 test)				**HOT PRESS PARAMETERS (3 ea. + 2 tests)**			
	Pressure	**Pressure**			**Pressure**	**Pressure**	
Hold Time	500/5000	5000		**Hold Time**	500/5000	5000	
150 min	MM/SHS	MM/SHS		150 min	MM/SHS	MM/SHS	
240 min	MM/SHS	MM/SHS		240 min	MM/SHS	MM/SHS	
			REFERENCE SAMPLE PROPERTIES				
H.P. Matrix #	**H. P. Temp**	**Hold @ Temp**	**Pressure**	**Density**	**MOR**	**T/A Dist.**	**Comments**
22	1620	240 min	5000 psi	98.7	354 MPa	SHS, T @ A	
23	1620	240 min	500/5000 psi	94.7	300 MPa	SHS, T in A	Relatively low density
24	1620	240 min	500/5000 psi	98.8	277 MPa	MM, T in A	Finer particles
13	1620	150 min	500/5000 psi	99.0	288 MPa	MM, T @ A	Coarse particles/large grains
14	1620	150 min	500/5000 psi	98.4	434 MPa	SHS, T in A	Relatively high MOR

HOT PRESS RESULTS

HOT PRES MATRIX #	POWDER TYPE	PRESSURE psi	HOLD min	TEMP C	DISK DEN. % theo.	BAR DEN. % theo.	MOR (avg 5 MPa	RESIST. 1 raw. avg.	RESIST. 1 stat. avg.	RESIST. 2 raw. avg.	RESIST. 2 stat. avg.
1	MM	500	30	1620	77.4	75.7	49.6	0.23	0.23	0.31	0.31
2	SHS	500	30	1620	90.7	91.9	250.7	54.68	14.62	40.67	13.45
3	MM	500	150	1620	79.3	79.2	70.7	0.59	0.42	0.72	0.72
4	SHS	500	150	1620	0	95.4	321.2	15.38	4.36	11.63	11.63
5	MM	3375	30	1620	91.0	91.7	109.4	1.36	1.15	1.39	1.11
6	SHS	3375	30	1620	93.0	96.7	479.8	13.90	4.09	10.47	6.26
7	MM	3375	90	1620	91.5	94.7	156.3	1.53	1.53	1.39	1.39
8	SHS	3375	90	1620	94.3	98.5	415.5	14.93	14.93	16.80	16.80
9	MM	3375	150	1620	96.0	97.7	200.4	0.68	0.68	0.83	0.82
10	SHS	3375	150	1620	94.2	98.7	458.5	13.11	13.11	16.03	10.28
11	MM	500/5000	30	1620	89.9	93.5	166.3	2.23	2.23	2.88	1.54
12	SHS	500/5000	30	1620	90.9	93.4	150.0	53.87	53.87	64.93	64.39
13	MM	500/5000	150	1620	94.3	99.1	288.2	3.15	3.15	3.57	3.57
14	SHS	500/5000	150	1620	97.4	98.4	434.3	36.81	36.81	21.07	21.07
15	MM	5000	30	1620	94.4	95.5	414.7	4.14	1.42	6.40	2.33
16	SHS	5000	30	1620	93.9	98.1	510.9	47.79	47.79	35.12	23.52
17	MM	5000	150	1620	0	99.0	288.9	2.18	2.18	2.20	2.20
18	SHS	5000	150	1620	97.3	98.3	497.1	50.74	50.74	69.46	69.46
19	SHS-225M	500/5000	250	1620	93.3	0	433.7	0.00	0.21	0.00	0.23
20	SHS-227M	5000	250	1620	91.4	0	448.7	0.00	0.34	0.00	0.40
21	MM	5000	240	1620		99.3	311.4	0.21	0.23	0.23	0.23
22	SHS	5000	240	1620		98.7	353.7	0.34	0.27	0.40	0.26
23	SHS	500/5000	240	1620		94.8	300.1	0.23		0.23	
24	MM	500/5000	240	1620		98.9	277.5	0.27		0.26	



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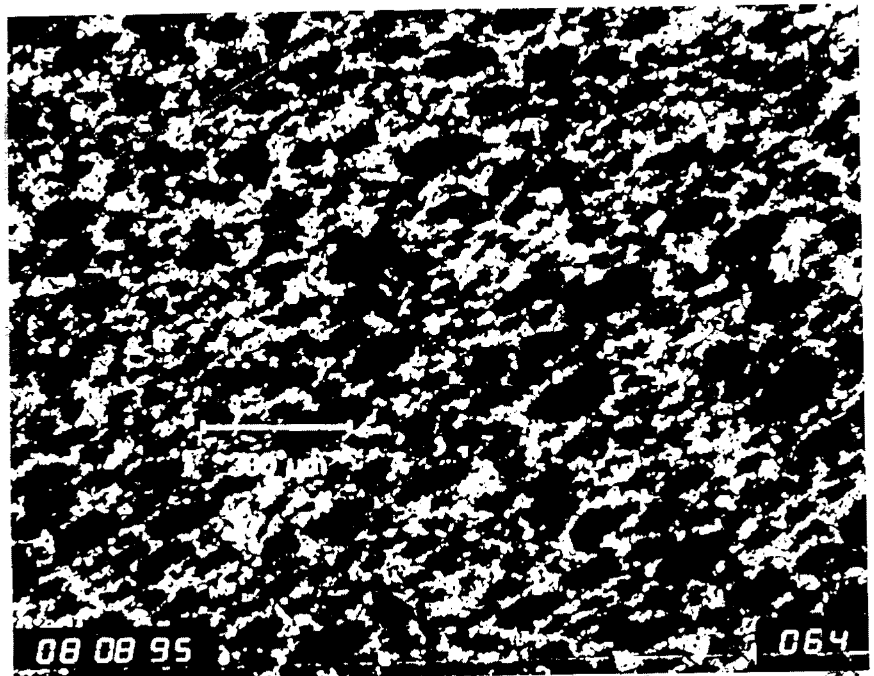
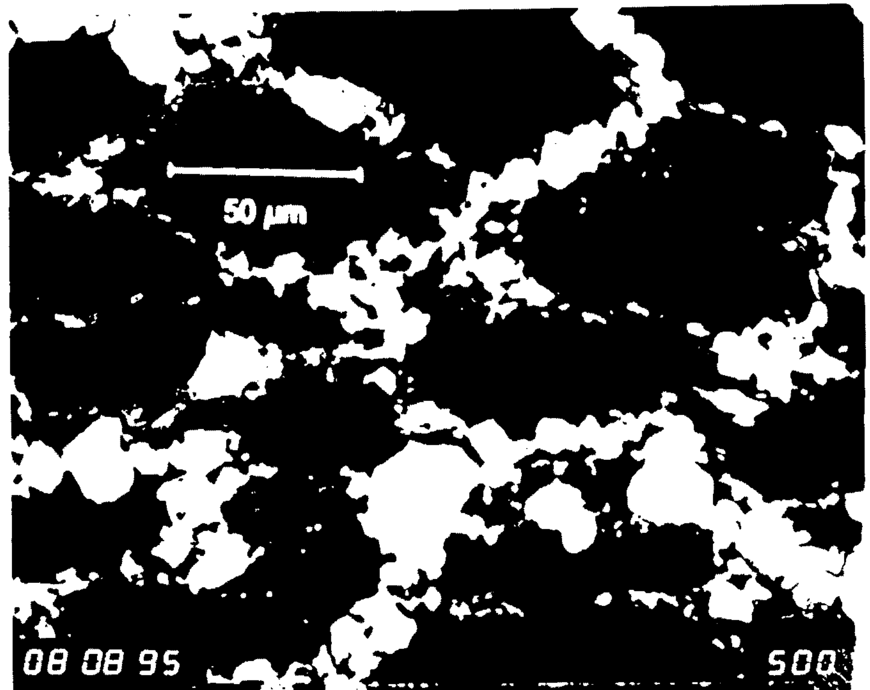
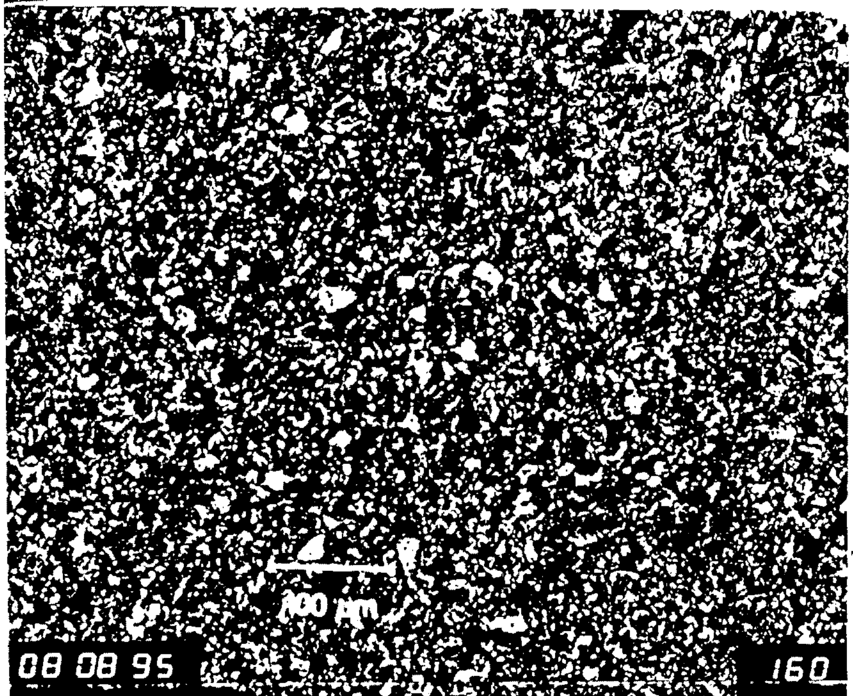
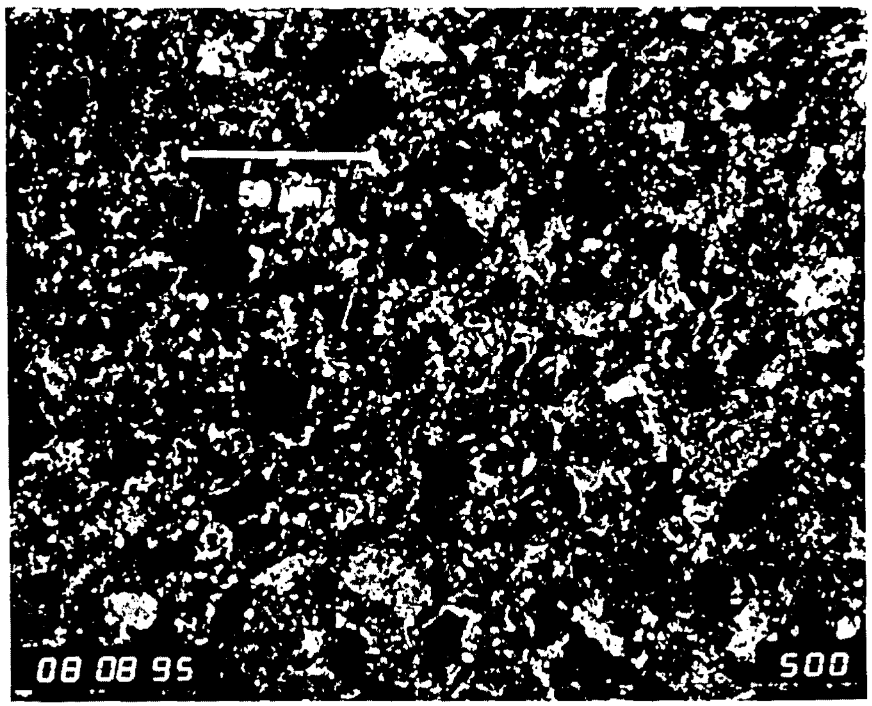




500/5000 288 MPa 13A MM. 150 µm 99.0

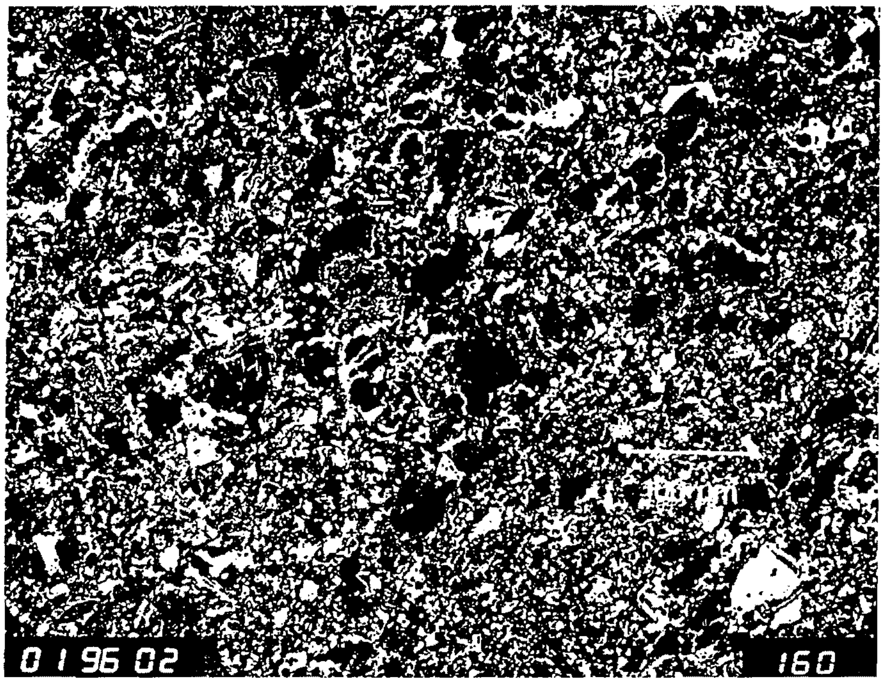
126





500/5000 99.4 14A SHS 430 MPa 150 µm

142



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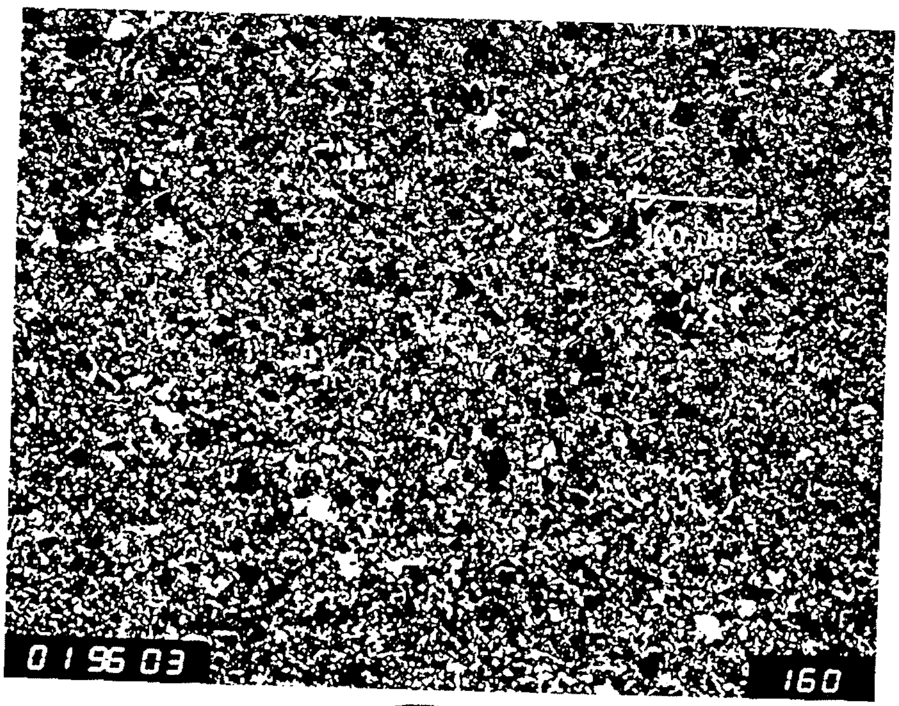

dispersed

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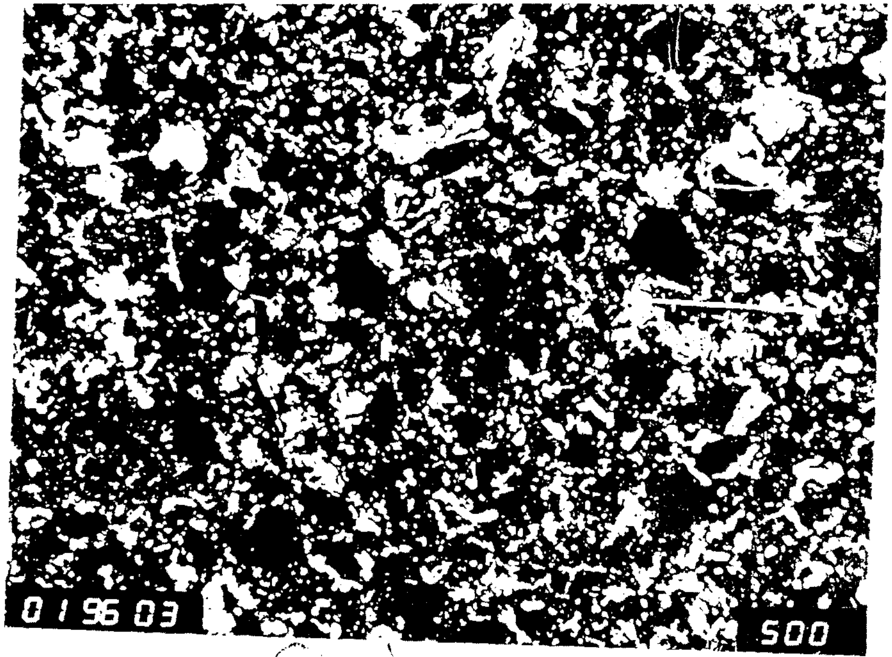
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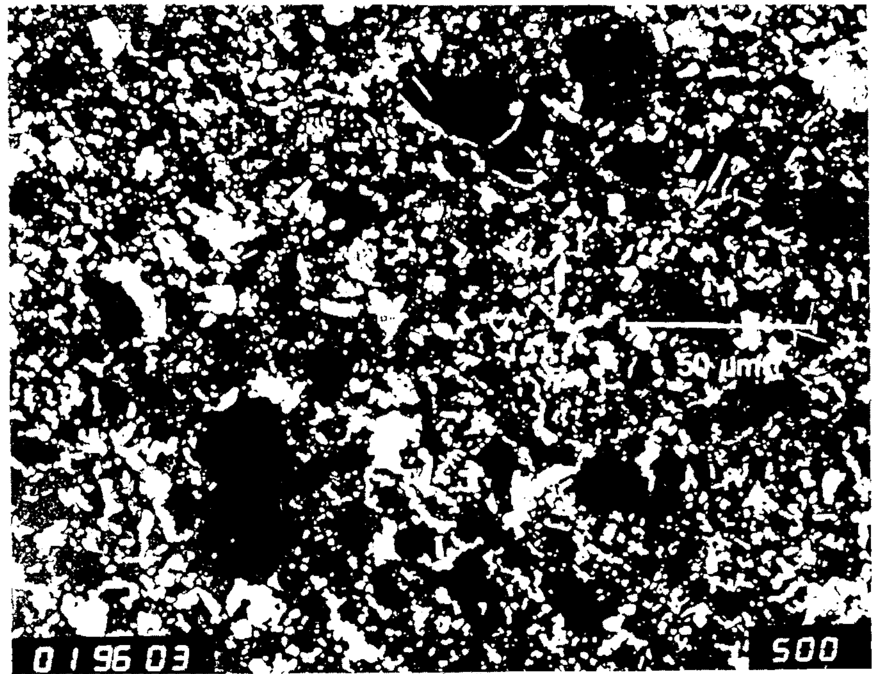
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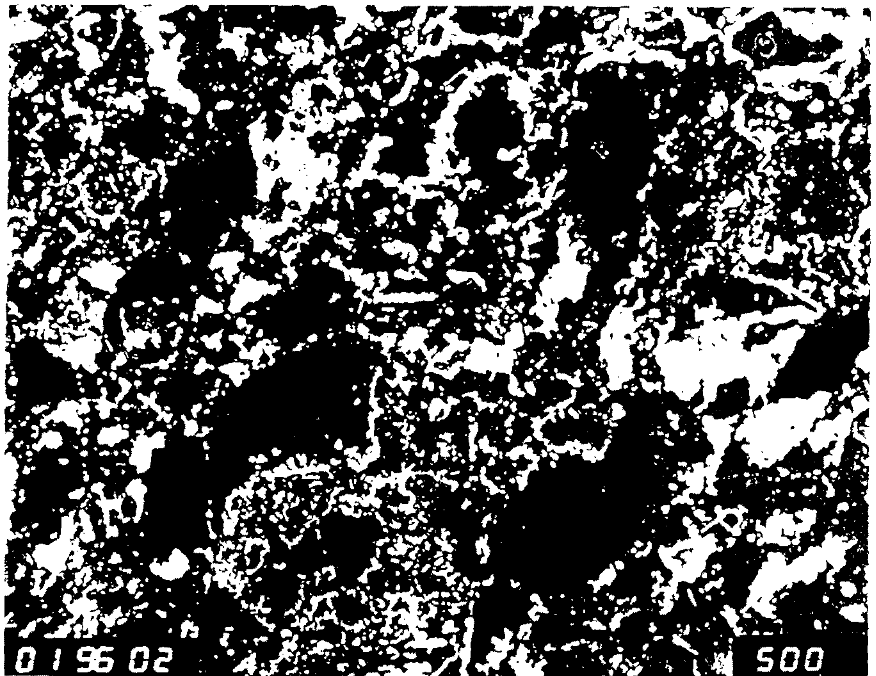
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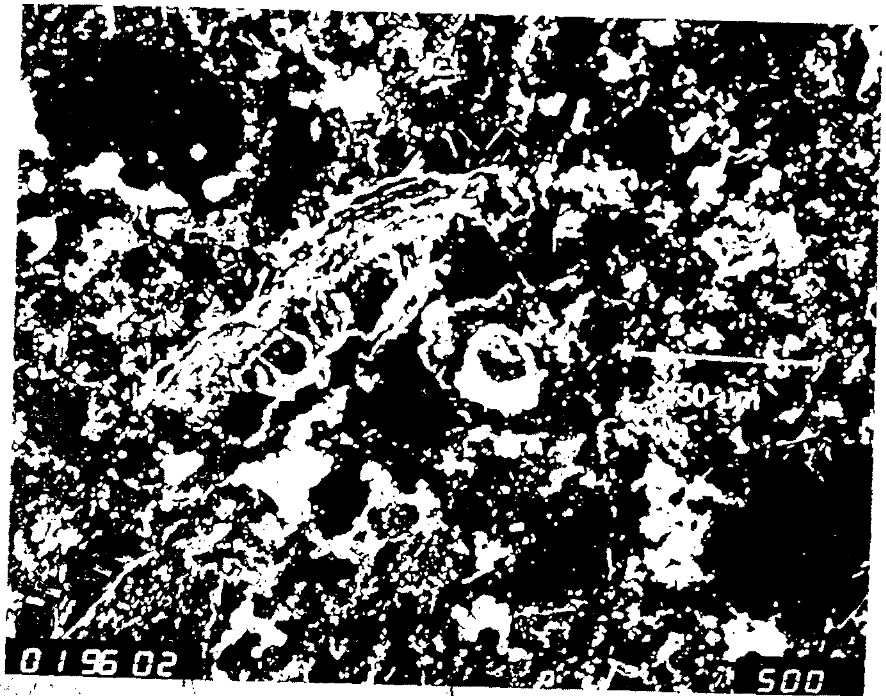
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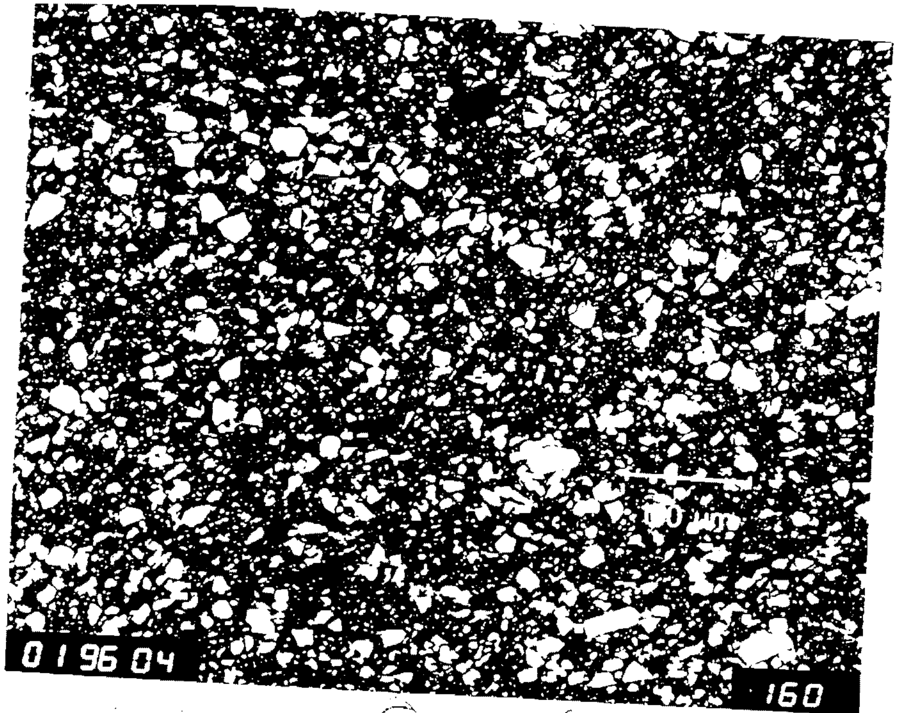
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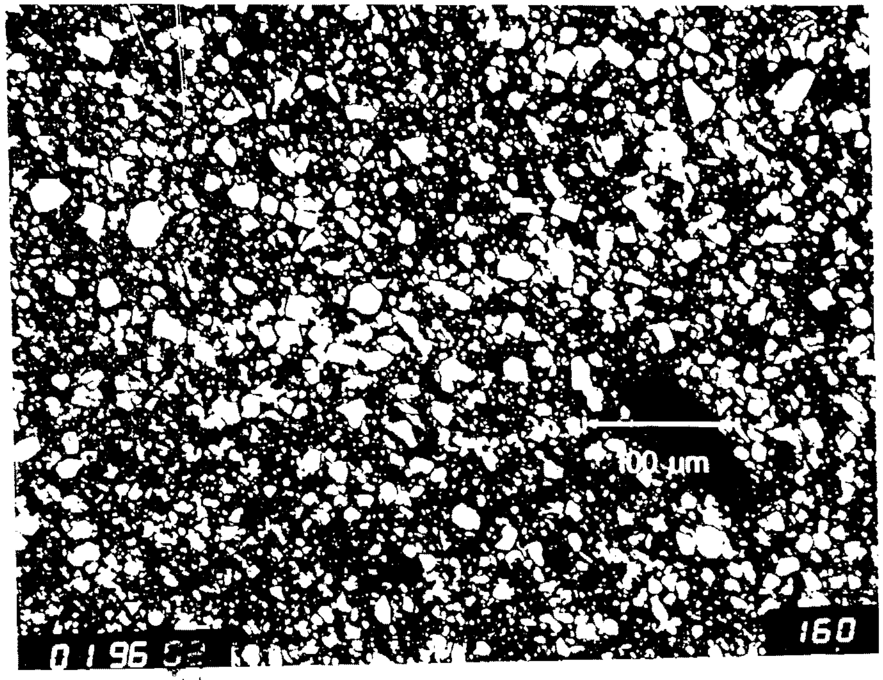
100 µm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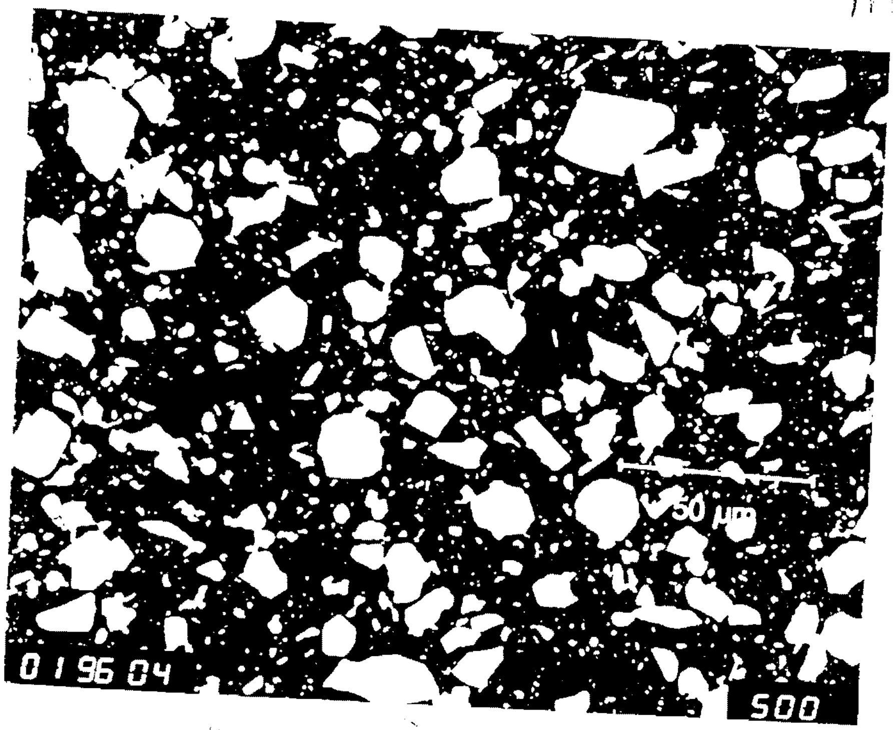
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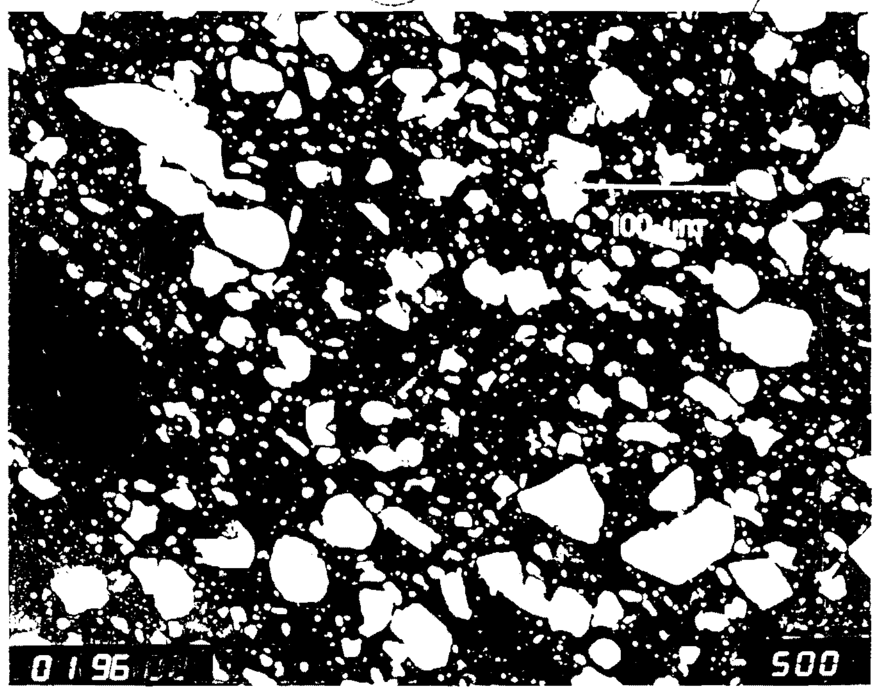

100 µm
500

MILESTONE CHART

	I							I I													
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
1. START OF WORK		X																				
2. HOT PRESS STUDY			X	X	X	X	X	X	X	X	X	X	X	X								
3. MICROSTR. ANALYSIS			X	X	X	X	X	X	X	X	X	X	X	X								
4. FORM TARGETS (36)															X	X	X	X				
5. END TECHNICAL																		X				
6. DELIVER TARGETS																		X				
7. BI-MONTHLY LETTER				X	X		X		X		X		X		X		X					
8. DRAFT FINAL																						
9. DRAFT FINAL APPROVAL																		X				
10. FINAL REPORT																					X	
11. PROGRAM REVIEWS				X			X			X			X			X						

E-18-X23
#9

Georgia Institute of Technology

Office of Graduate Studies and Research

Tuesday, September 24, 1996

Mr. T. Furmaniak
MS263
Emerging Technology Team
USATACOM
Warren, MI 48397-5000

Subject: Contract DAAE07-95-C-R040
Development of Ceramic Ballistic Targets
Progress, Status and Management Report A001
Deliverable #010
Reporting Period: 951225 to 960925

Dear Mr. Furmaniak:

Enclosed is the Subject Draft Final Report with the two required copies. As we discussed, the draft is in the format of overheads on paper with only the Georgia Tech logo. The TACOM logo will be supplied for the final copy.

We have shipped the 12, 4 inch X 1-1/2 inch disks and the 3 inch X 1/2 inch disks to Matt Berkins per the contract.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

Georgia Institute of Technology
Atlanta, Georgia 30332-0265 U.S.A.
PHONE 404-894-3092
FAX 404-894-5657

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

Contract DAAE07-95-C-R040

Draft Final Technical Report A002
Reporting Period: 25 December 1995-25 September 1996

Submitted By:

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

Tuesday, September 24, 1996

UNCLASSIFIED

DEVELOPMENT OF CERAMIC BALLISTIC TARGETS

ABSTRACT

This task encompassed an eighteen month technical effort to determine the effects of processing and resultant microstructural variation on the penetration resistance exhibited by hot pressed, composite 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 composite material was determined. Processing conditions were studied in depth in order to develop consistent procedures for reproducing a desired microstructure. The relationship between process variables and resulting microstructure, and variation in microstructure on the ballistic performance was determined. The main goal of the program was to develop a method to produce low cost (less than $10 per pound) technology to form reliable, light weight, low porosity ceramic, composite shapes 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 GTRI 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

Table 2. UDRI Ballistic Penetration Data

UNIVERSITY OF DAYTON RESEARCH INSTITUTE DAYTON, OH 45469-0182

STEPHEN J. HANCHAK 513-229-3546

SHOT NUMBER	IMPACT VELOCITY (m/sec.)	CERAMIC TARGET IDENTIFICATION (TiB_2/Al_2O_3)	CERAMIC WEIGHT (gm)	CERAMIC DIAMETER (cm)	CERAMIC THICKNESS (cm)	AREAL DENSITY (gm/cm^2)	DEPTH OF PENETRATION (mm)	TOTAL YAW (degrees)	RESIDUAL PEN. WEIGHT (gm)
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	1534	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 65gm TUNGSTEN ROD. 7.82mm DIA. x 78.74mm LENGTH (L/D 10) WITH HEMISPHERICAL NOSE.
TELEDYNE X-21-C TUNGSTEN, 93%, 15% SWAGED & AGED.

The "1.9" is a valid data point

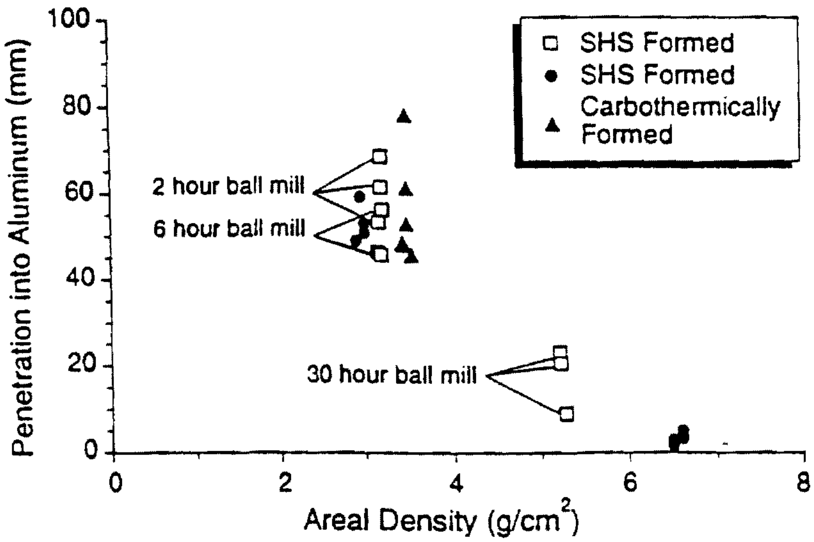
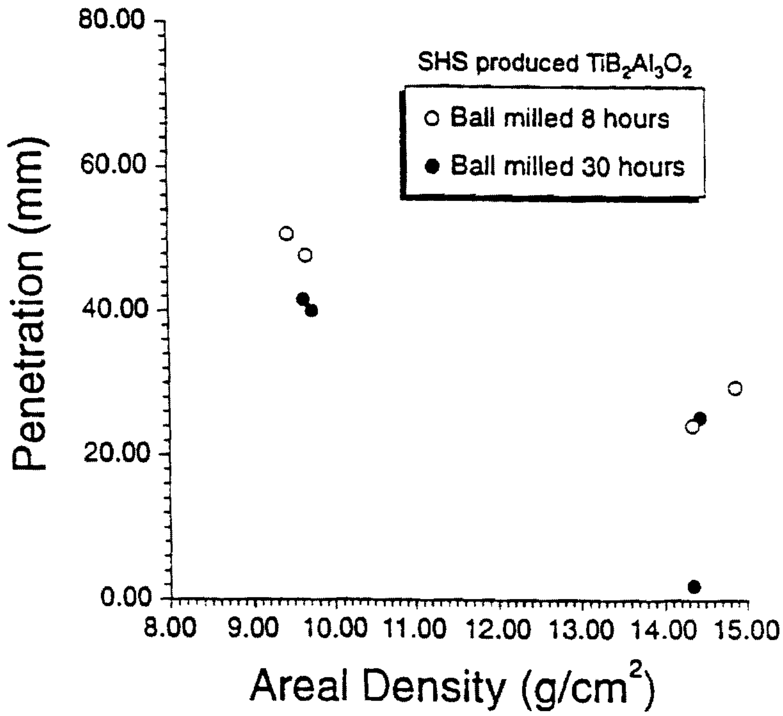
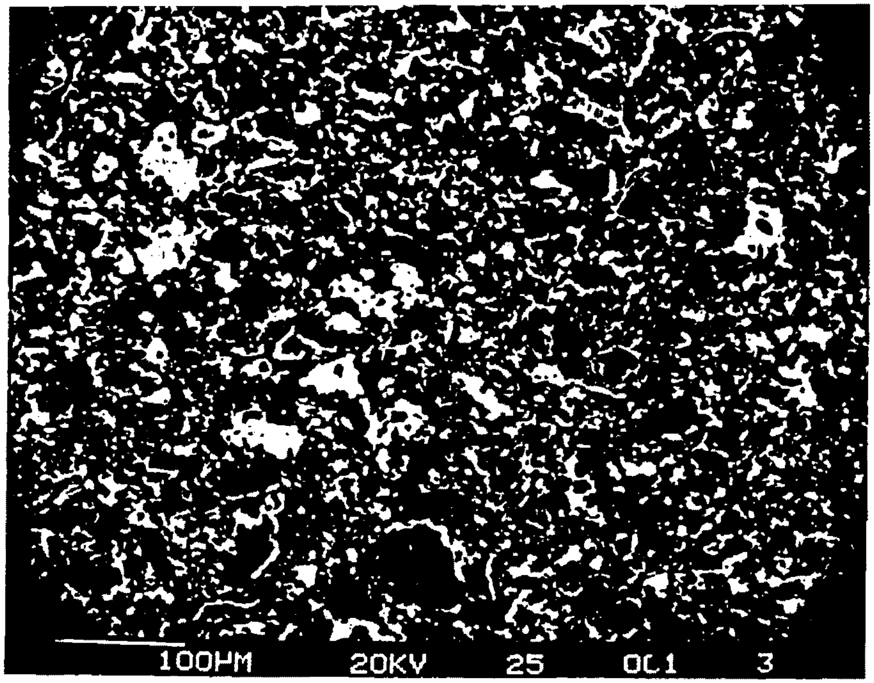


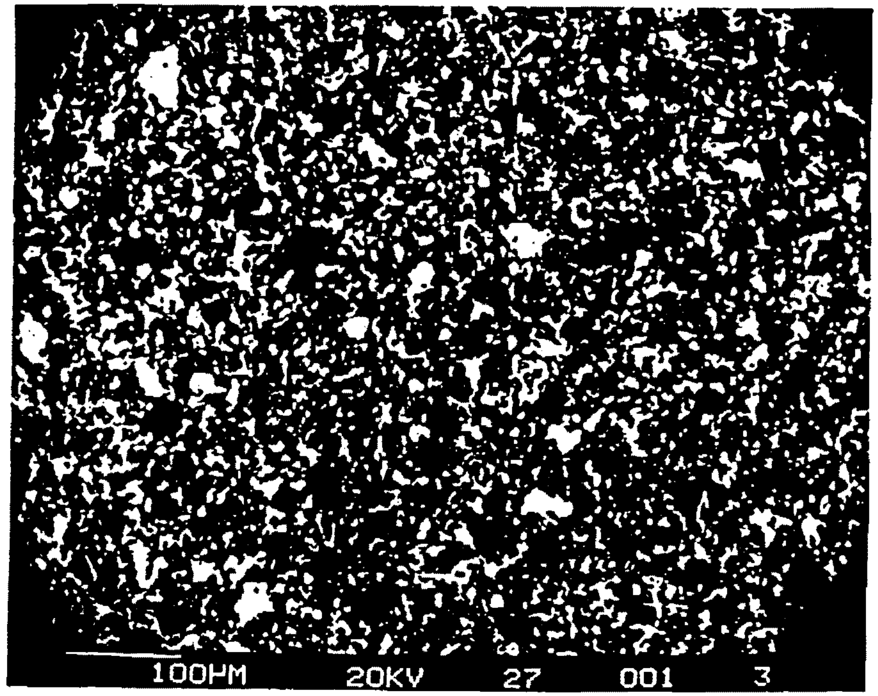
Figure 1. SLAP Ballistic Test results.



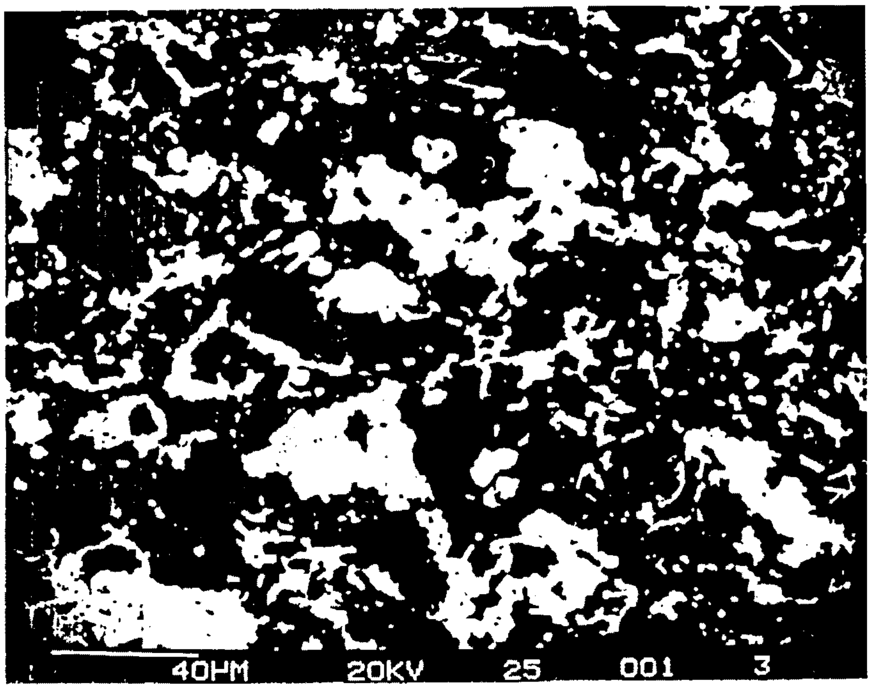
LRP Ballistic Test Results.



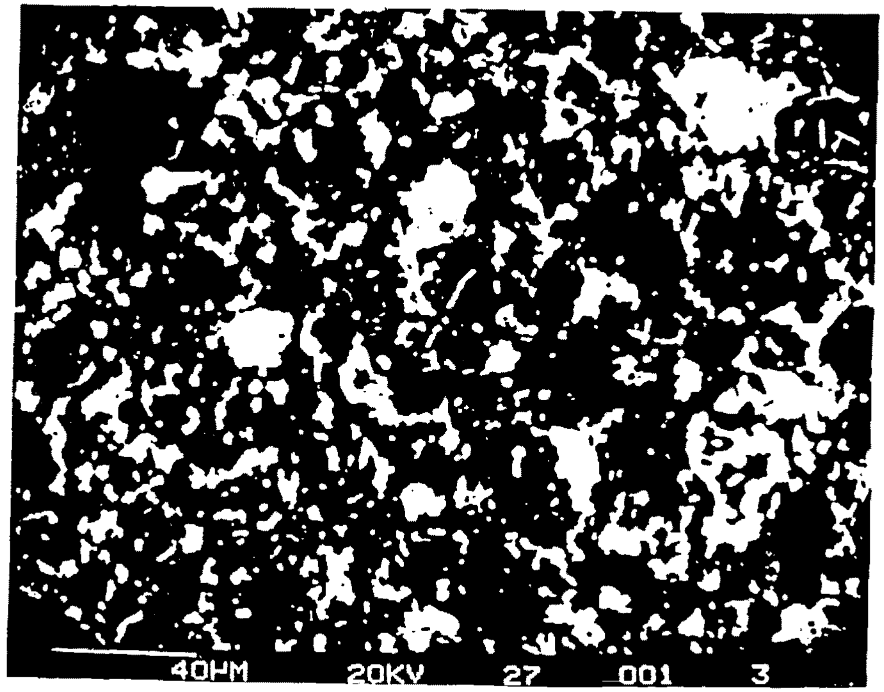
T@A



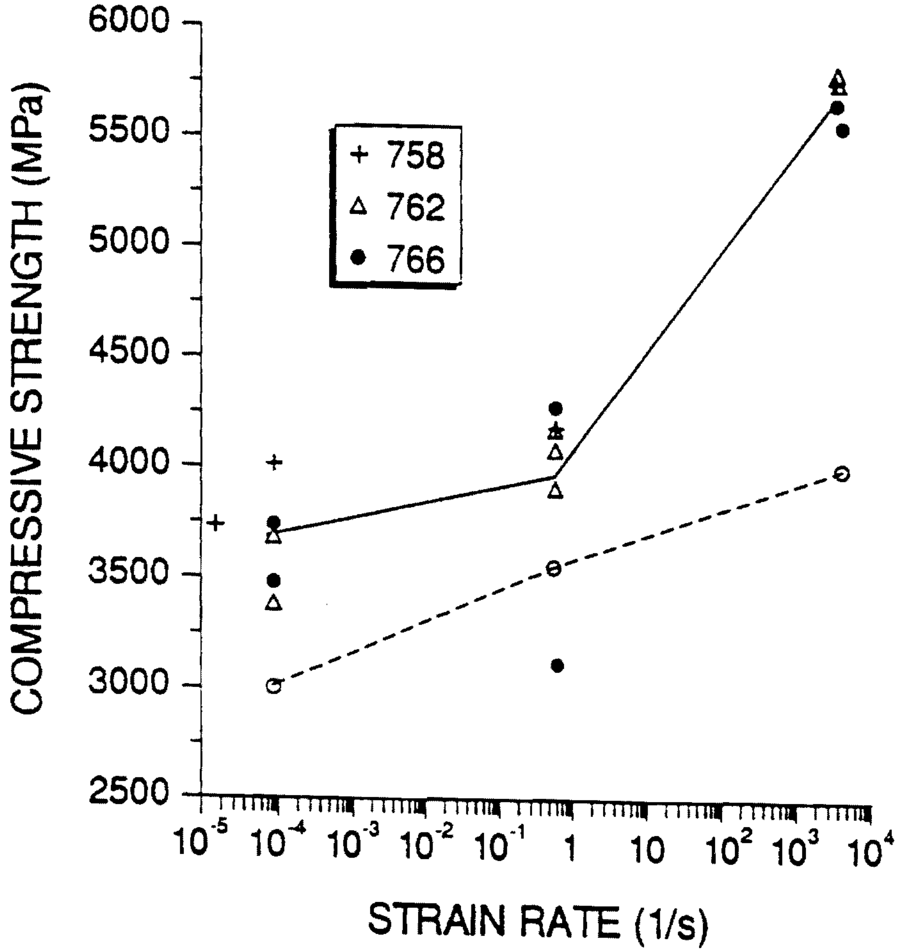
T in A



T@A



T in A



Compression Test Results.

Table I. Properties.

Compound	MOR (MPa)	K_{Ic} (MPa·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·in$^{1/2}$)	—	200	0.29

(C): Carbothermic(MM): Manually-Mixed(S): Sintered(HP): Hot Pressed

OBJECTIVES

To compare the effect of microstructure on high performance properties of hot pressed powders formed using

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

MILESTONE CHART

	I							II														
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
1. START OF WORK		X																				
2. HOT PRESS STUDY			X	X	X	X	X	X	X	X	X	X	X	X								
3. MICROSTR. ANALYSIS			X	X	X	X	X	X	X	X	X	X	X	X								
4. FORM TARGETS (36)															X	X	X	X				
5. END TECHNICAL																		X				
6. DELIVER TARGETS																		X				
7. BI-MONTHLY LETTER				X	X		X		X		X		X		X		X					
8. DRAFT FINAL																						
9. DRAFT FINAL APPROVAL																		X				
10. FINAL REPORT																					X	
11. PROGRAM REVIEWS				X			X			X			X			X						

SYNTHESIS AND FORMING

- POWDERS
- DENSIFICATION

SHS POWDERS

- OXIDATION-REDUCTION REACTIONS

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

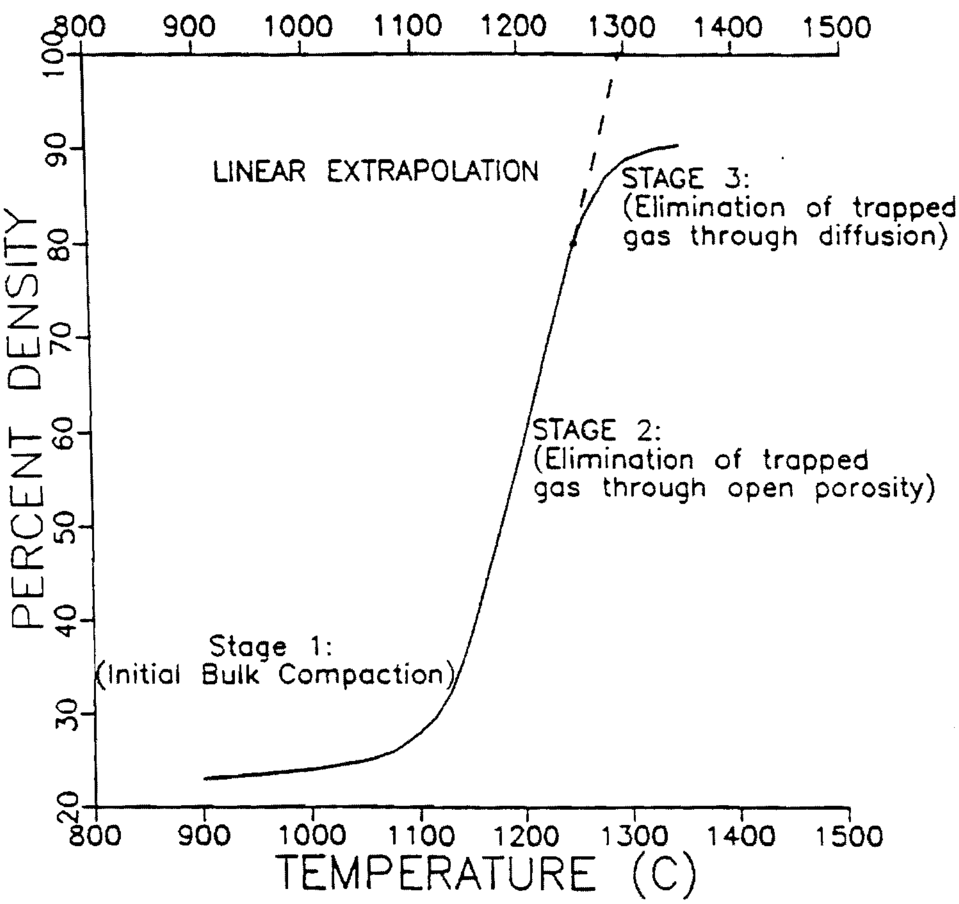
MANUALLY MIXED POWDERS

- COMBINATION OF COMPONENTS

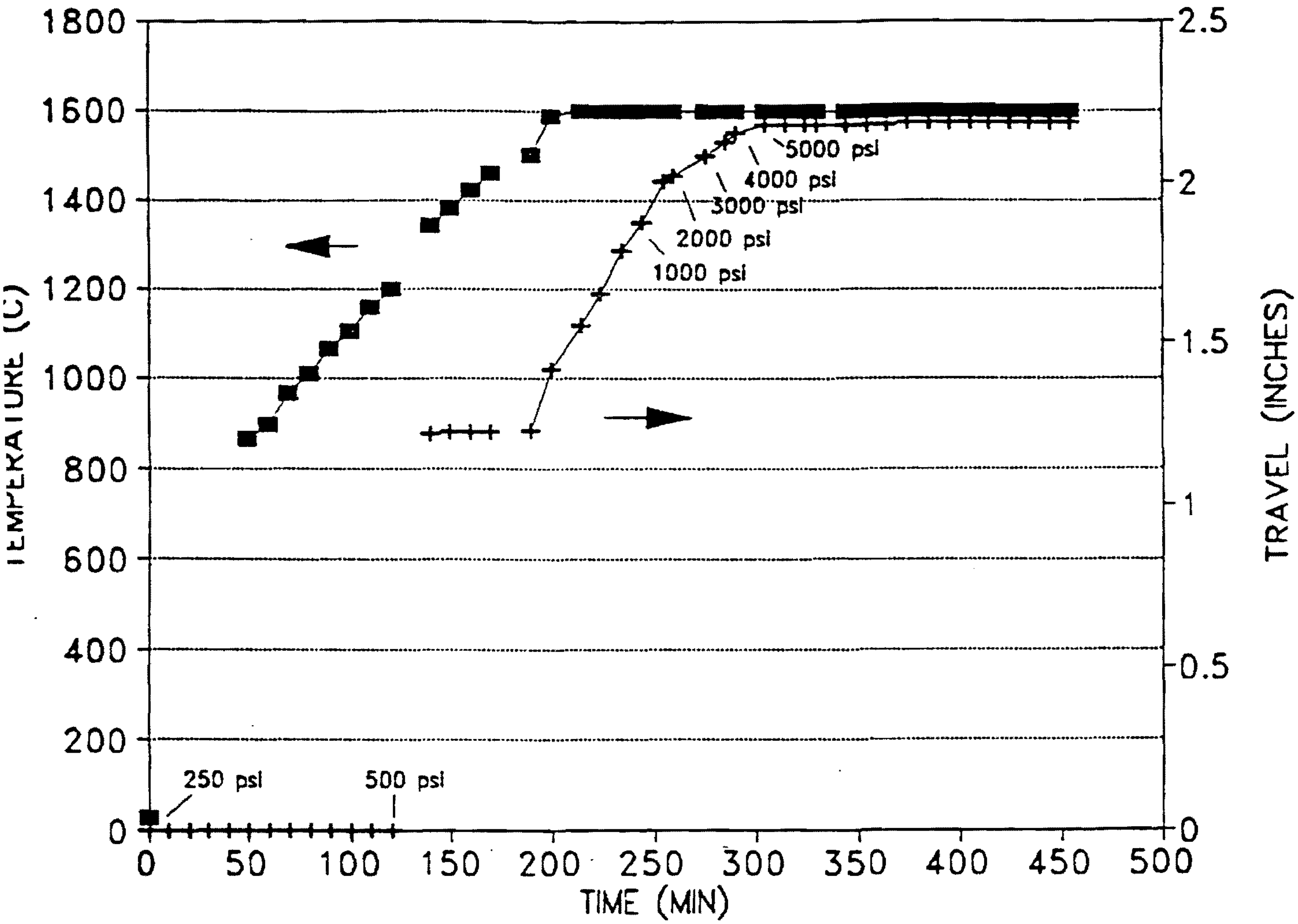
$$TIB_2 + Al_2O_3 \rightarrow TiB_2 / Al_2O_3$$

HOT PRESS MATRIX

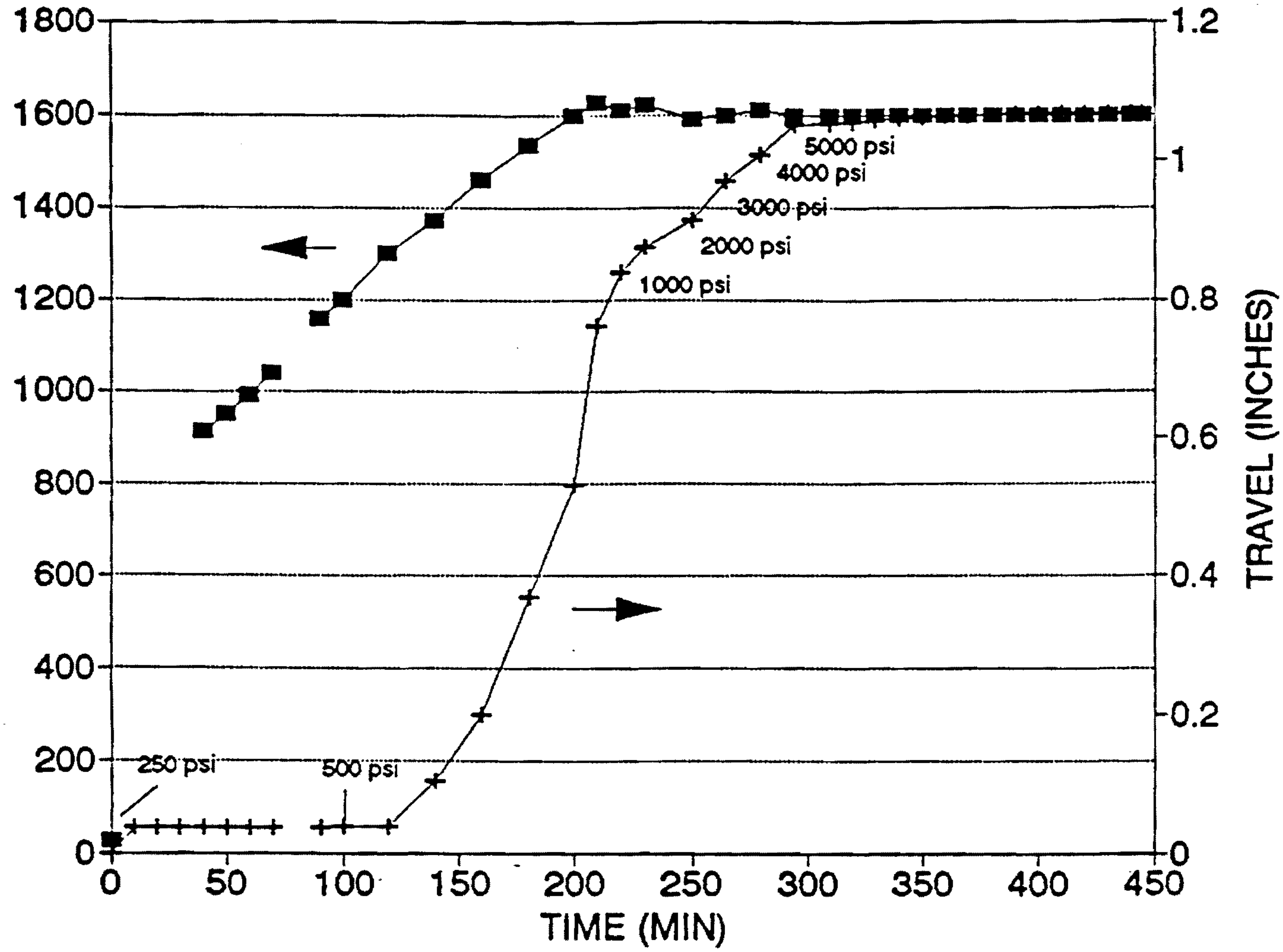
HOLD TIME	500psi	3375psi	5000psi	500/5000psi
30 min	MM	MM	MM	MM
30 min	SHS	SHS	SHS	SHS
90 min	-	MM	MM	-
90 min	-	SHS	SHS	-
150 min	MM	MM	MM	MM
150 min	SHS	SHS	SHS	SHS
240 min	MM	-	MM	MM
240 min	SHS	-	SHS	SHS



Schematic of CTP Curve.



Hot press run of sample 225.



Hot press run of sample 227.

TARGETS

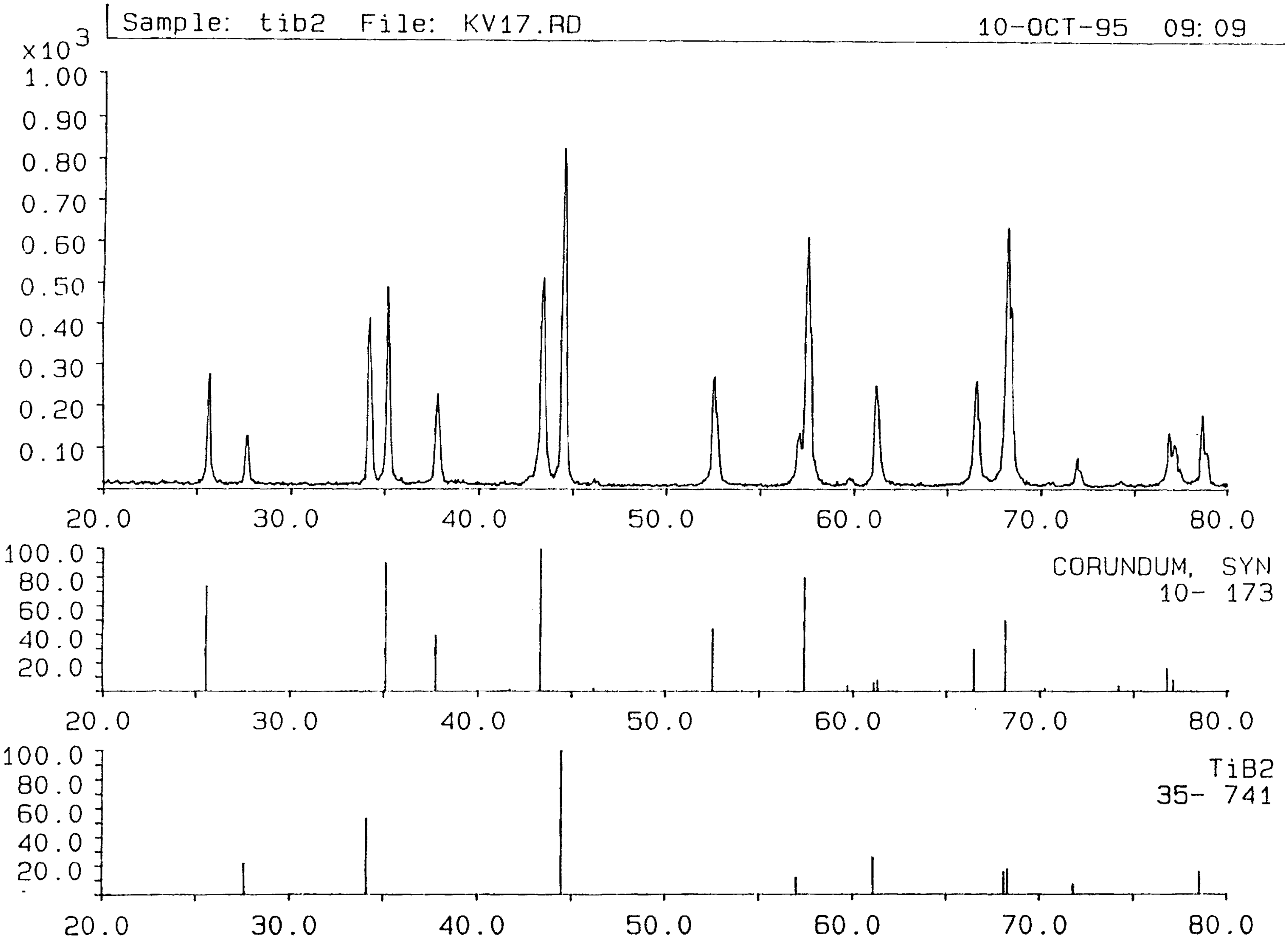
SAMPLE		QUANTITY AND SIZES	
		Ballistic Targets	**Mechanical Properties Targets**
SHS	**T @ A**	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"
	T IN A	3 ea. 4"x 1-1.2"	3 ea. 3"x 1/2"
MIXED	**T @ A**	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"
	T IN A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"

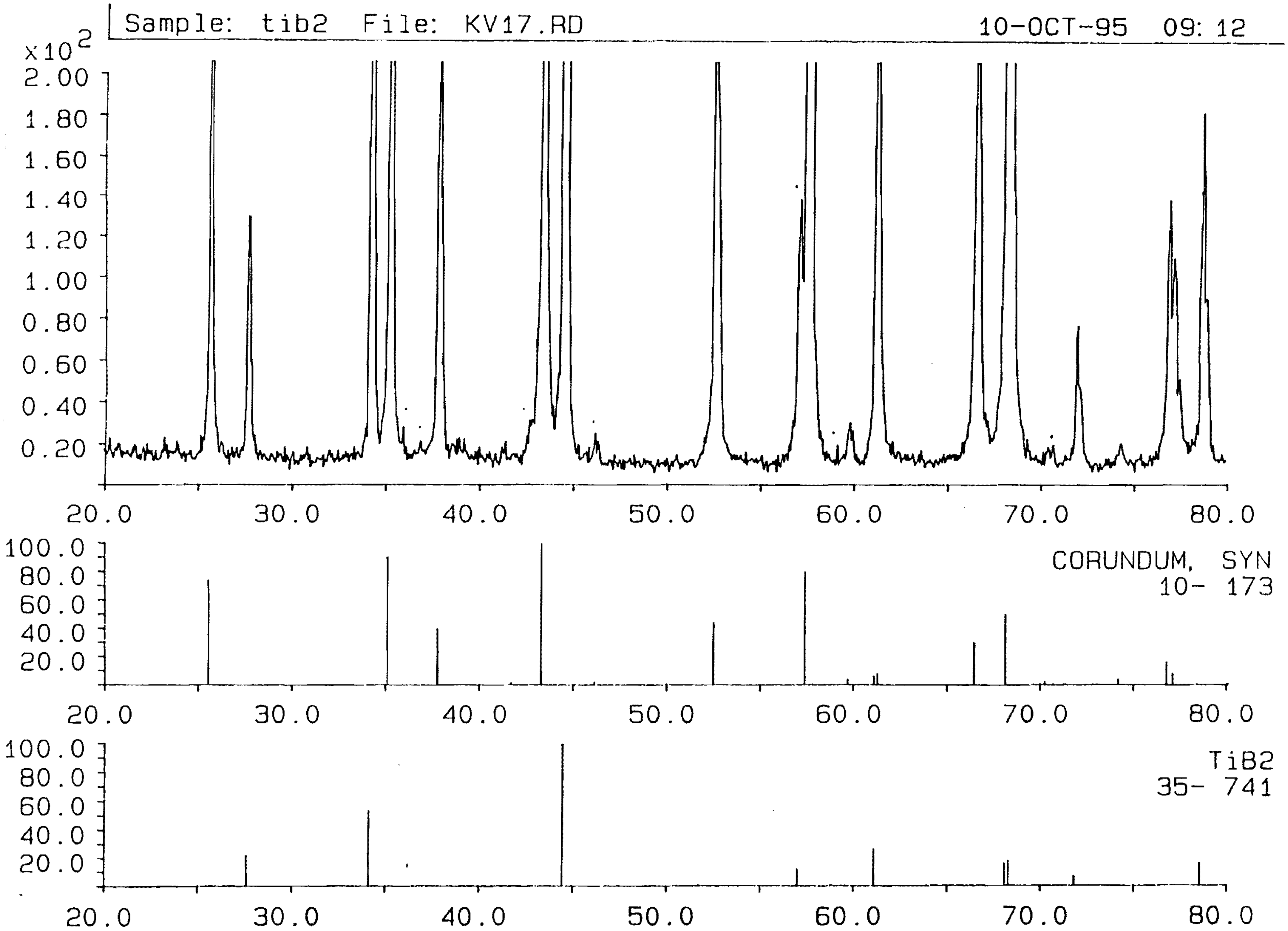
SHS -- SELF PROPAGATING HIGH TEMPERATURE

MIXED --MECHANICALLY MIXED DISPERSED SAMPLES

T @ A -- TITANIUM DIBORIDE AT THE ALUMINA GRAIN BOUNDARIES

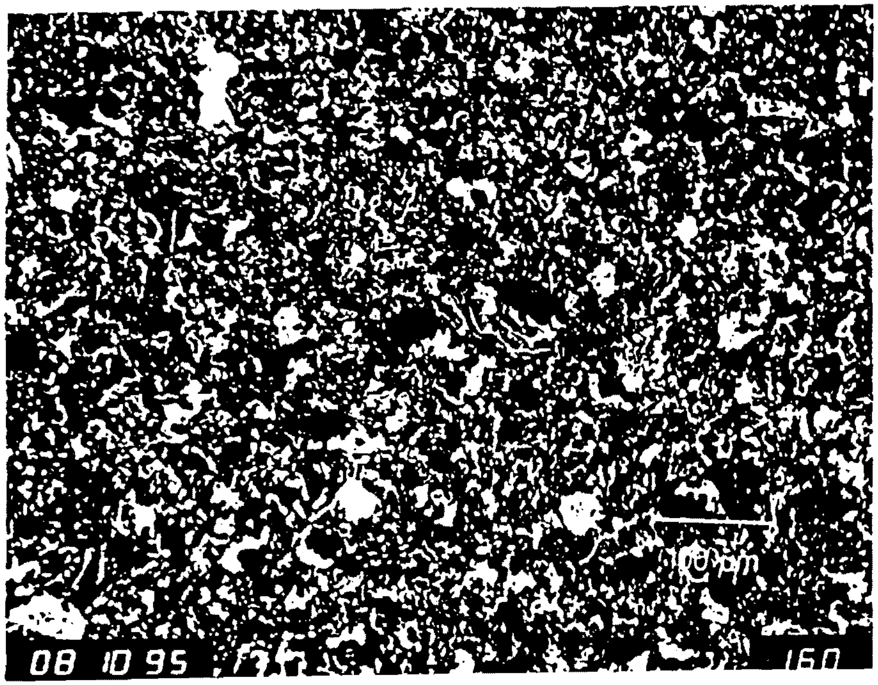
T IN A -- TITANIUM DIBORIDE IN THE ALUMINA MATRIX


Sample: tib2 File: KV17.RD
10-OCT-95 09:09
x10^3
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
20.0
30.0
40.0
50.0
60.0
70.0
80.0
100.0
80.0
60.0
40.0
20.0
CORUNDUM, SYN
10- 173
TiB2
35- 741

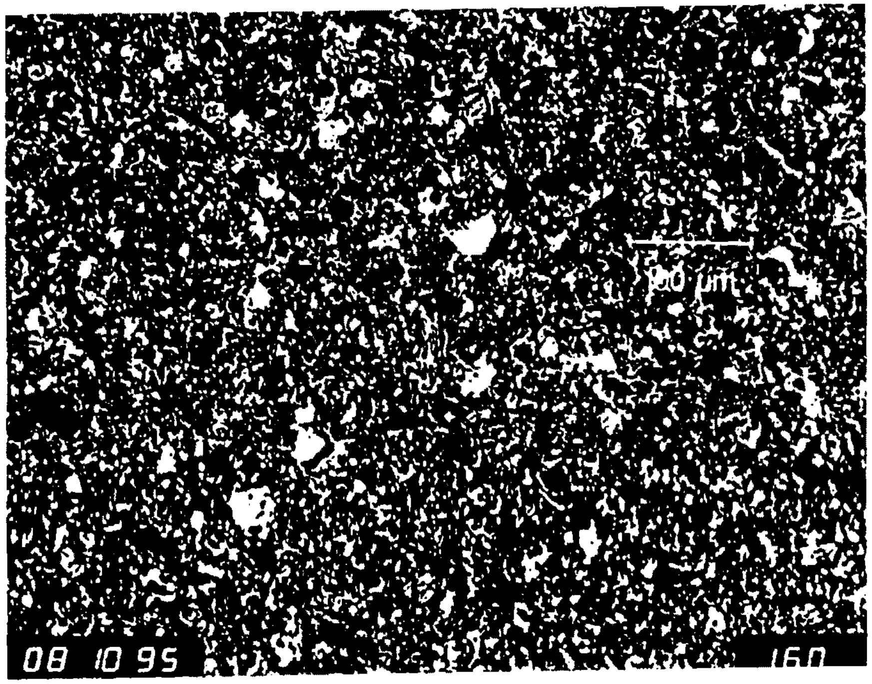

Sample: tib2 File: KV17.RD
10-OCT-95 09:12
x10^2
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
20.0
30.0
40.0
50.0
60.0
70.0
80.0
100.0
80.0
60.0
40.0
20.0
CORUNDUM, SYN
10- 173
TiB2
35- 741

HOT PRESS RESULTS

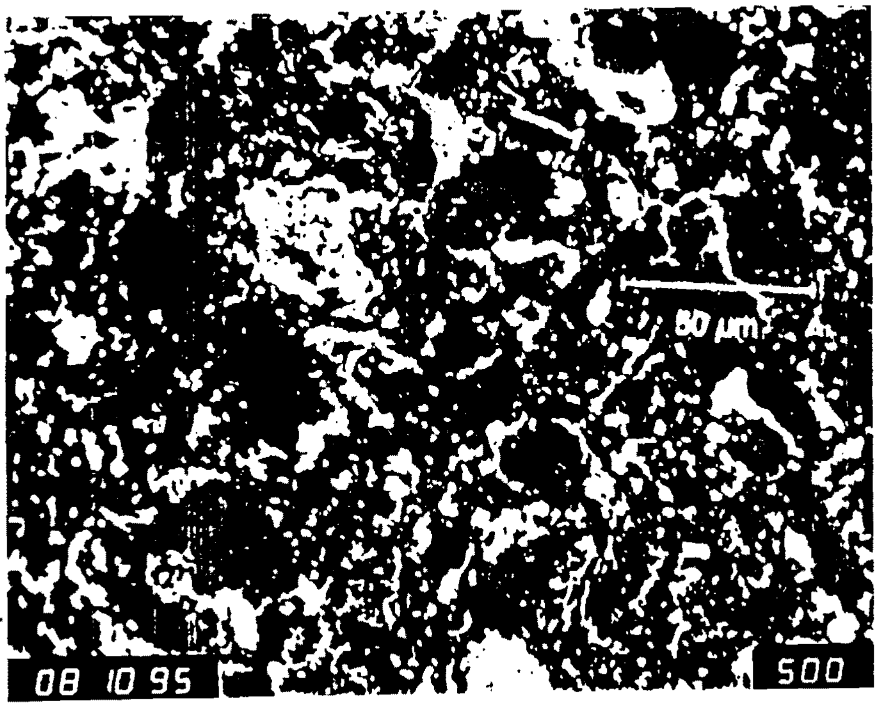
HOT PRES MATRIX #	POWDER TYPE	PRESSURE psi	HOLD min	TEMP C	DISK DEN. % theo.	BAR DEN. % theo.	MOR (avg 5 MPa	RESIST. 1 raw. avg.	RESIST. 1 stat. avg.	RESIST. 2 raw. avg.	RESIST. 2 stat. avg.
1	MM	500	30	1620	77.4	75.7	49.6	0.23	0.23	0.31	0.31
2	SHS	500	30	1620	90.7	91.9	250.7	54.68	14.62	40.67	13.45
3	MM	500	150	1620	79.3	79.2	70.7	0.59	0.42	0.72	0.72
4	SHS	500	150	1620	0	95.4	321.2	15.38	4.36	11.63	11.63
5	MM	3375	30	1620	91.0	91.7	109.4	1.36	1.15	1.39	1.11
6	SHS	3375	30	1620	93.0	96.7	479.8	13.90	4.09	10.47	6.26
7	MM	3375	90	1620	91.5	94.7	156.3	1.53	1.53	1.39	1.39
8	SHS	3375	90	1620	94.3	98.5	415.5	14.93	14.93	16.80	16.80
9	MM	3375	150	1620	96.0	97.7	200.4	0.68	0.68	0.83	0.82
10	SHS	3375	150	1620	94.2	98.7	458.5	13.11	13.11	16.03	10.28
11	MM	500/5000	30	1620	89.9	93.5	166.3	2.23	2.23	2.88	1.54
12	SHS	500/5000	30	1620	90.9	93.4	150.0	53.87	53.87	64.93	64.39
13	MM	500/5000	150	1620	94.3	99.1	288.2	3.15	3.15	3.57	3.57
14	SHS	500/5000	150	1620	97.4	98.4	434.3	36.81	36.81	21.07	21.07
15	MM	5000	30	1620	94.4	95.5	414.7	4.14	1.42	6.40	2.33
16	SHS	5000	30	1620	93.9	98.1	510.9	47.79	47.79	35.12	23.52
17	MM	5000	150	1620	0	99.0	288.9	2.18	2.18	2.20	2.20
18	SHS	5000	150	1620	97.3	98.3	497.1	50.74	50.74	69.46	69.46
19	SHS-225M	500/5000	250	1620	93.3	0	433.7	0.00	0.21	0.00	0.23
20	SHS-227M	5000	250	1620	91.4	0	448.7	0.00	0.34	0.00	0.40
21	MM	5000	240	1620		99.3	311.4	0.21	0.23	0.23	0.23
22	SHS	5000	240	1620		98.7	353.7	0.34	0.27	0.40	0.26
23	SHS	500/5000	240	1620		94.8	300.1	0.23		0.23	
24	MM	500/5000	240	1620		98.9	277.5	0.27		0.26	

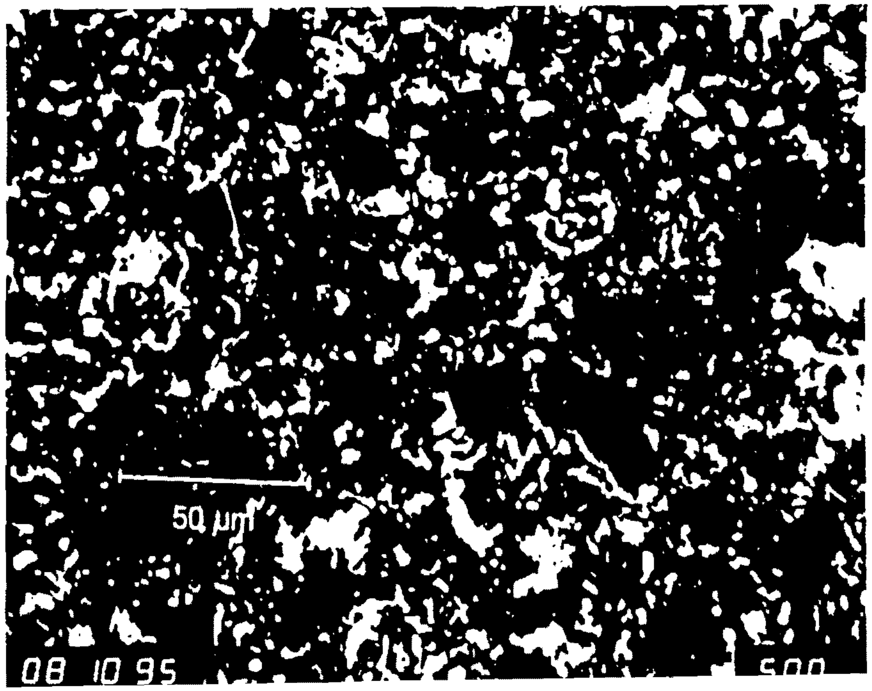


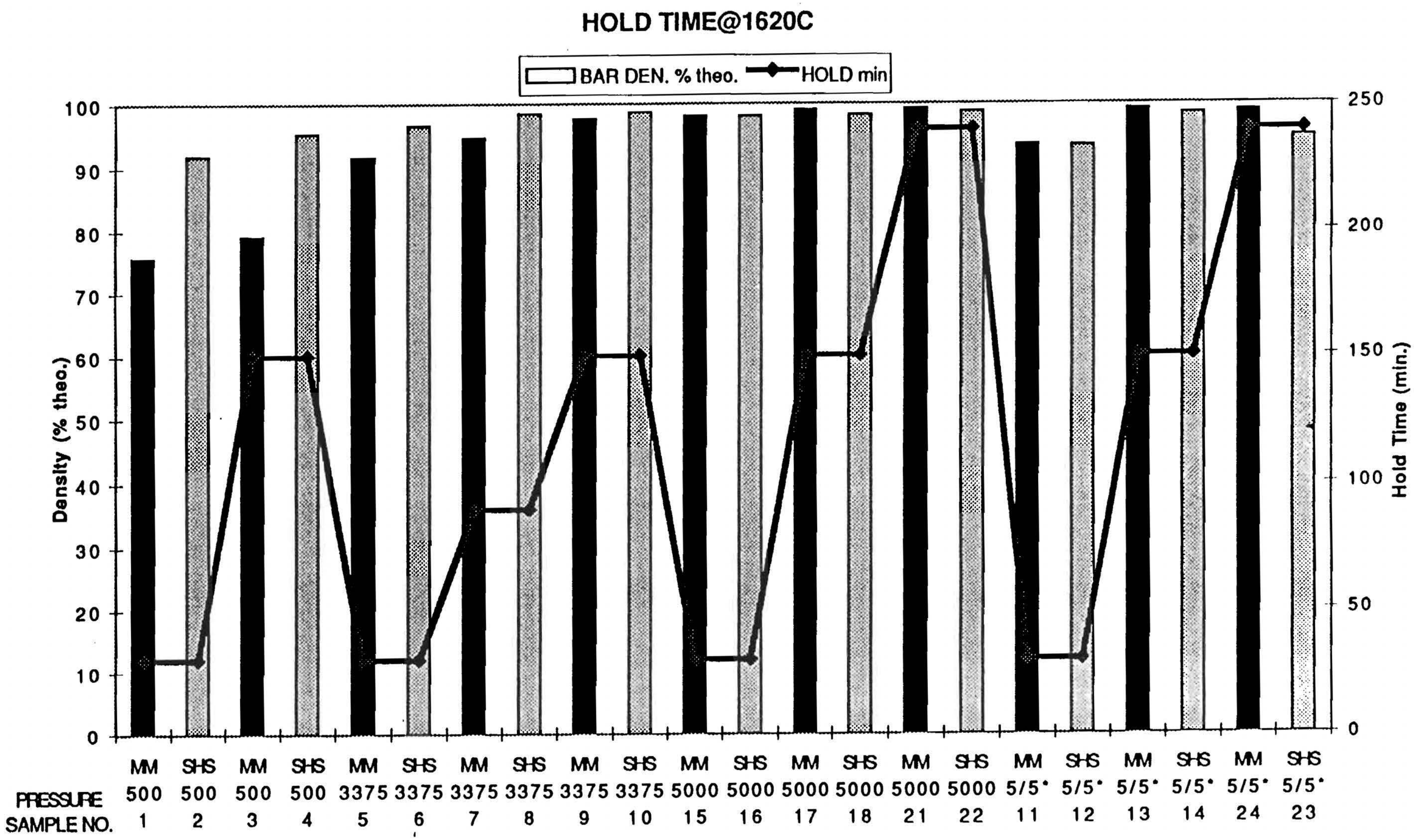
225 T@A confirmation



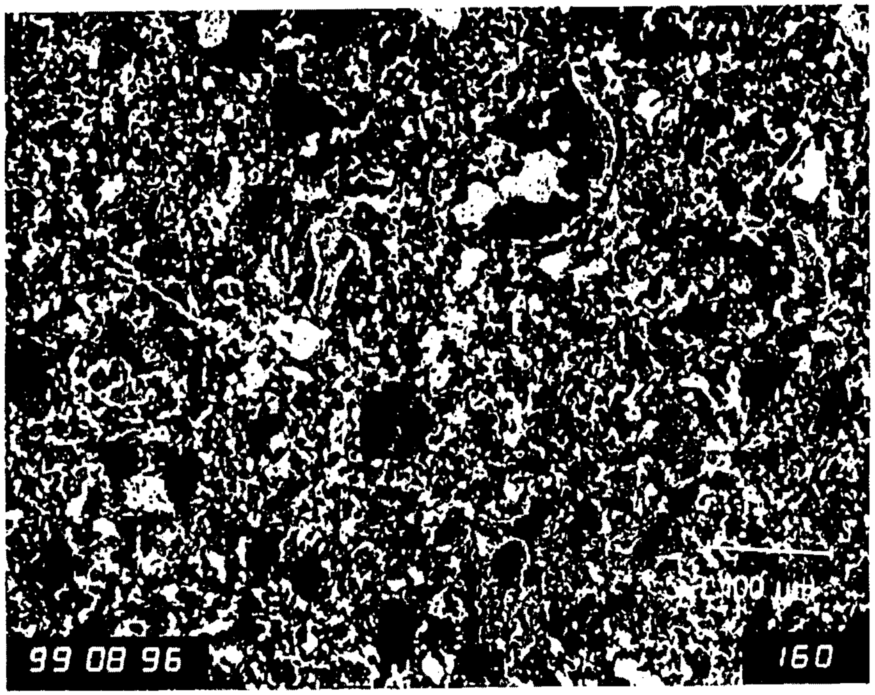
227 T in A



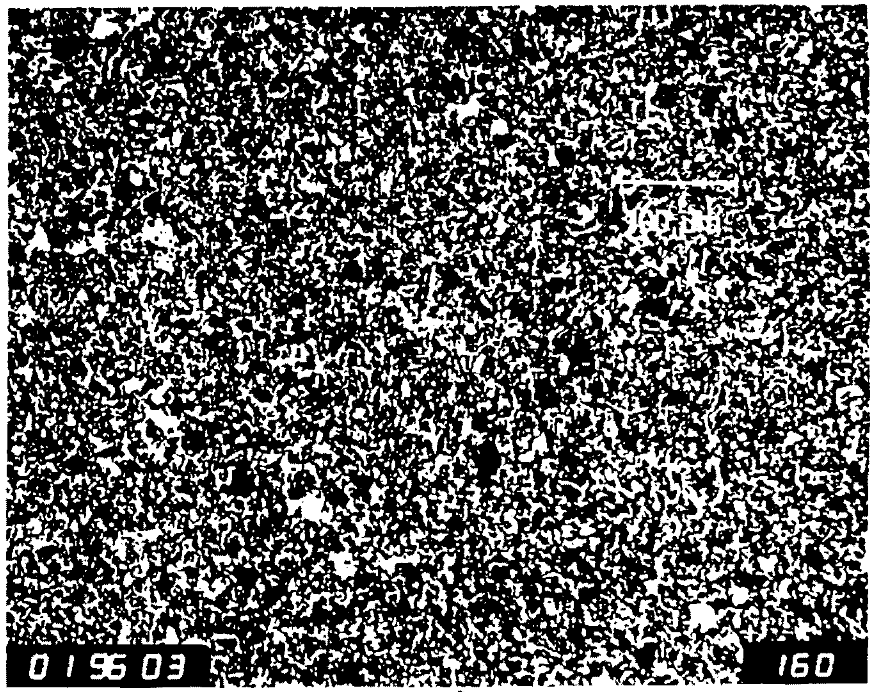




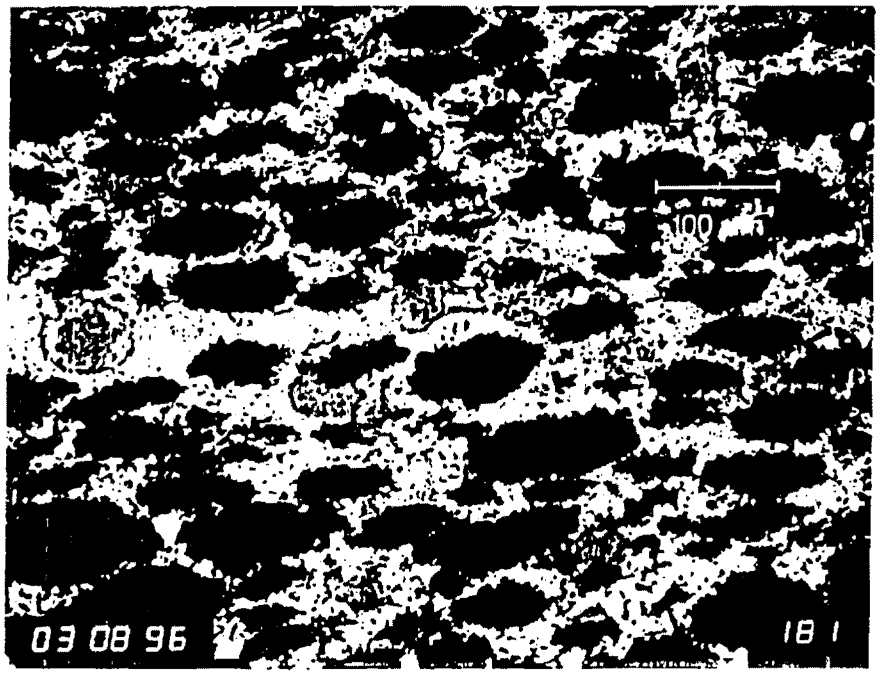
5/5*=500/5000psi



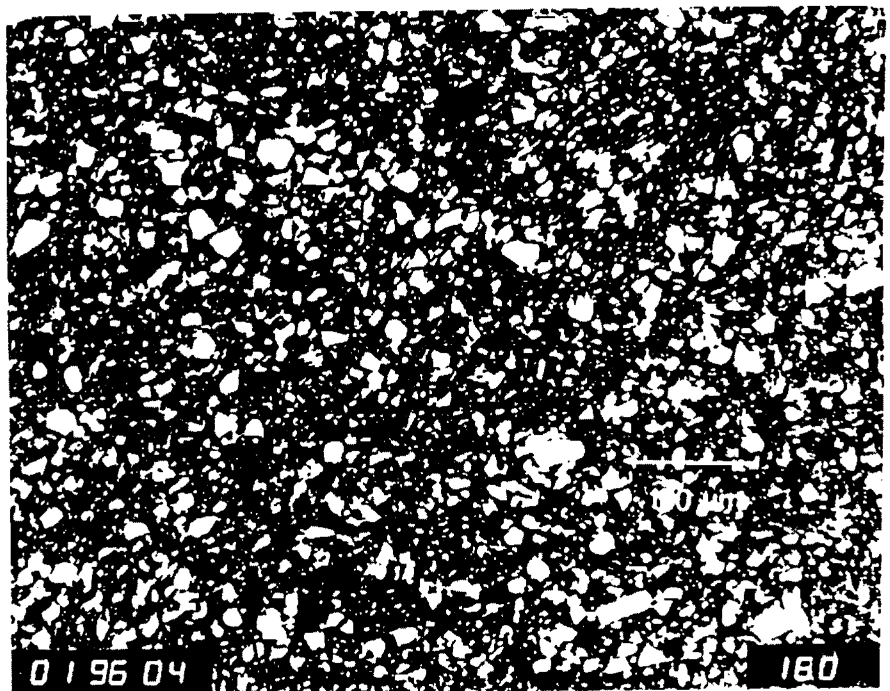
SHS TeA



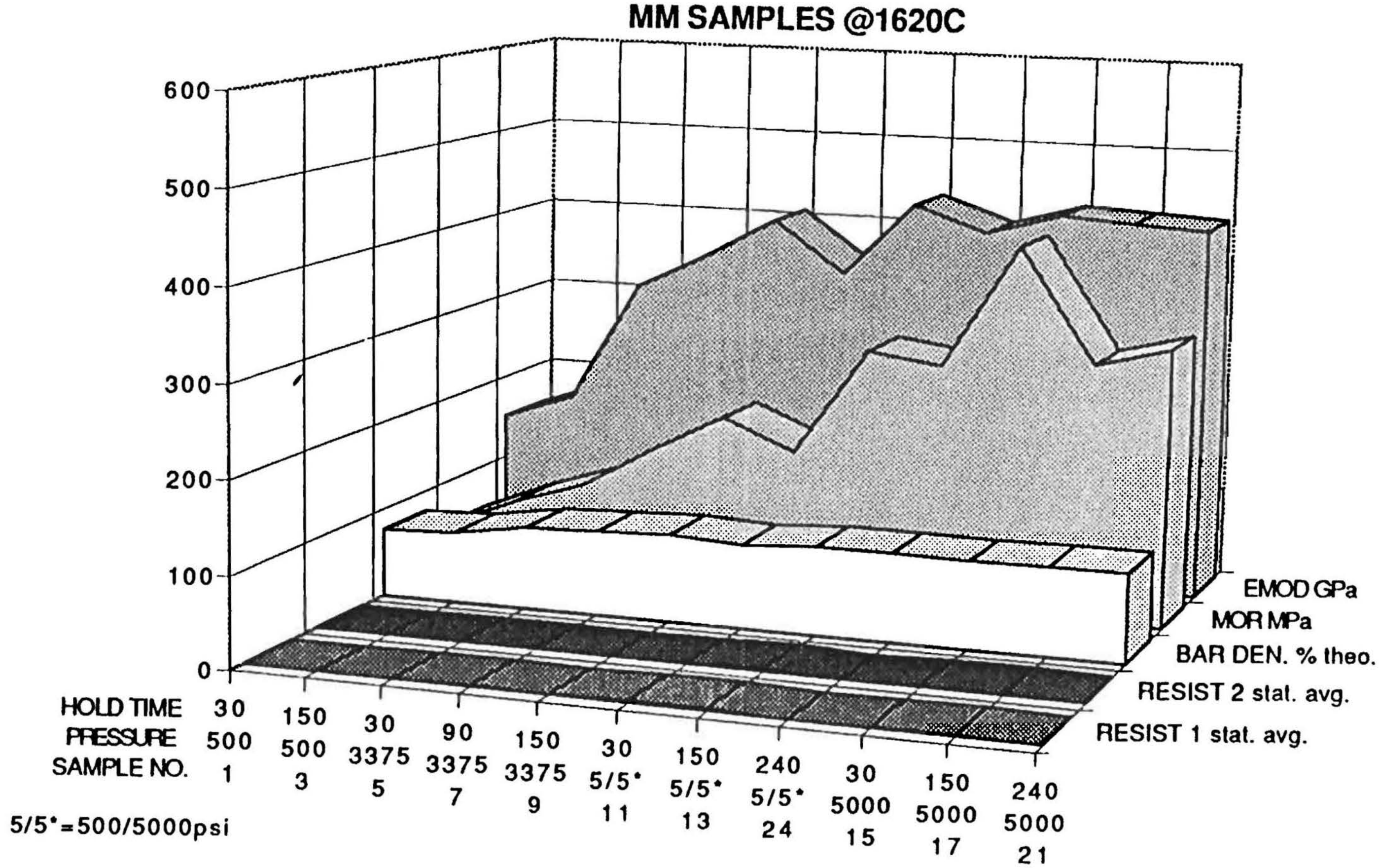
SHS TmA



MM TeA

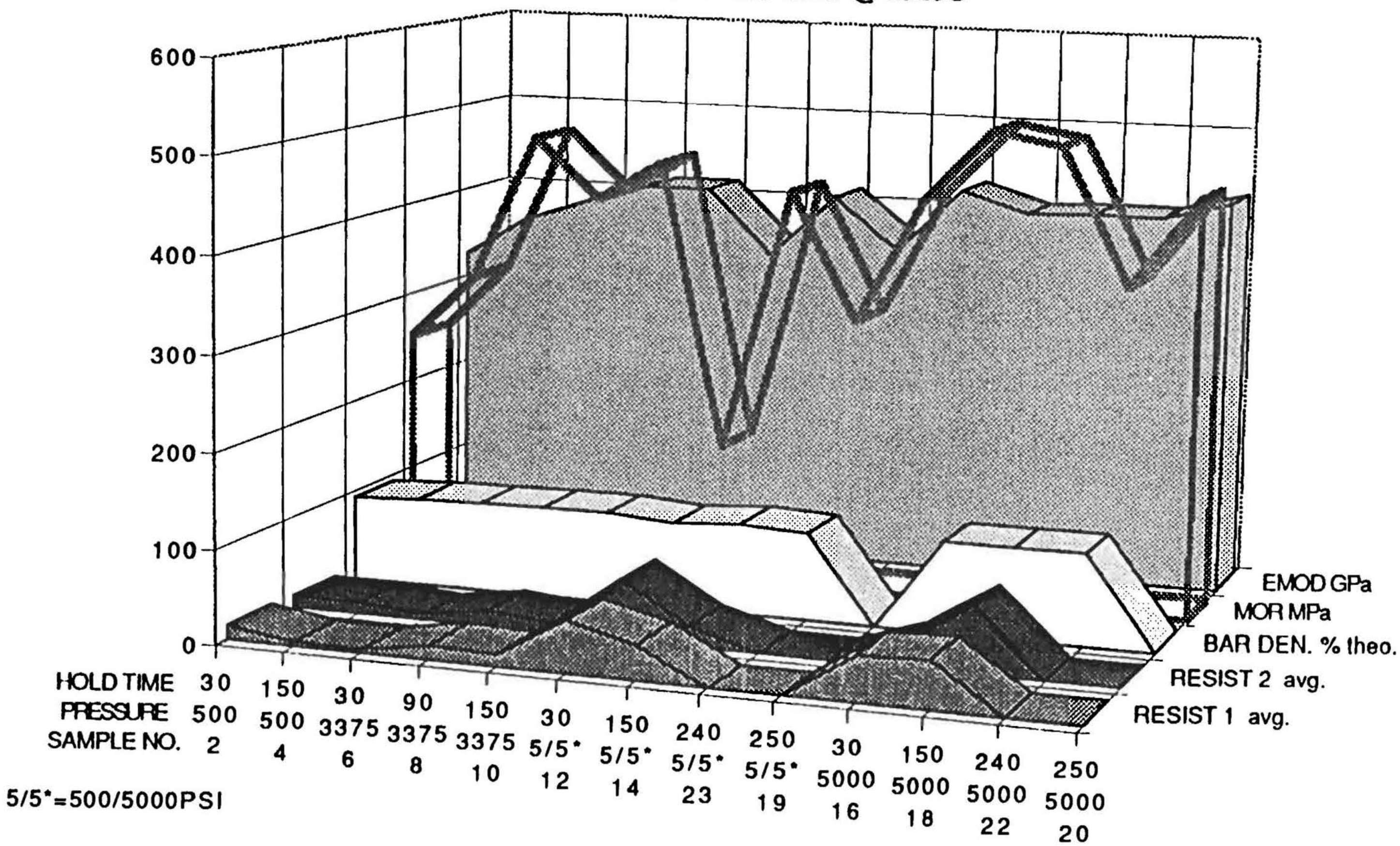


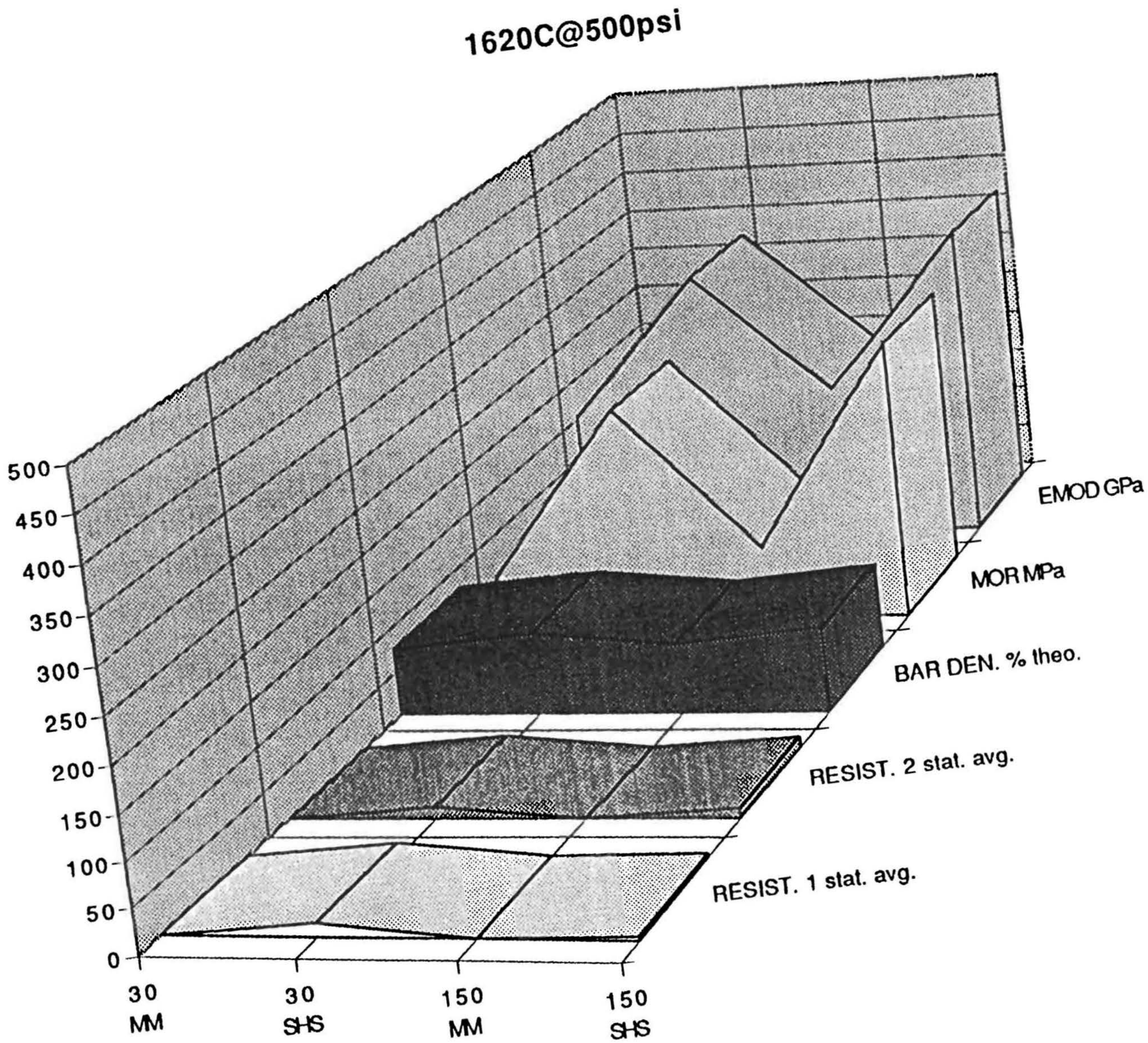
MM TmA



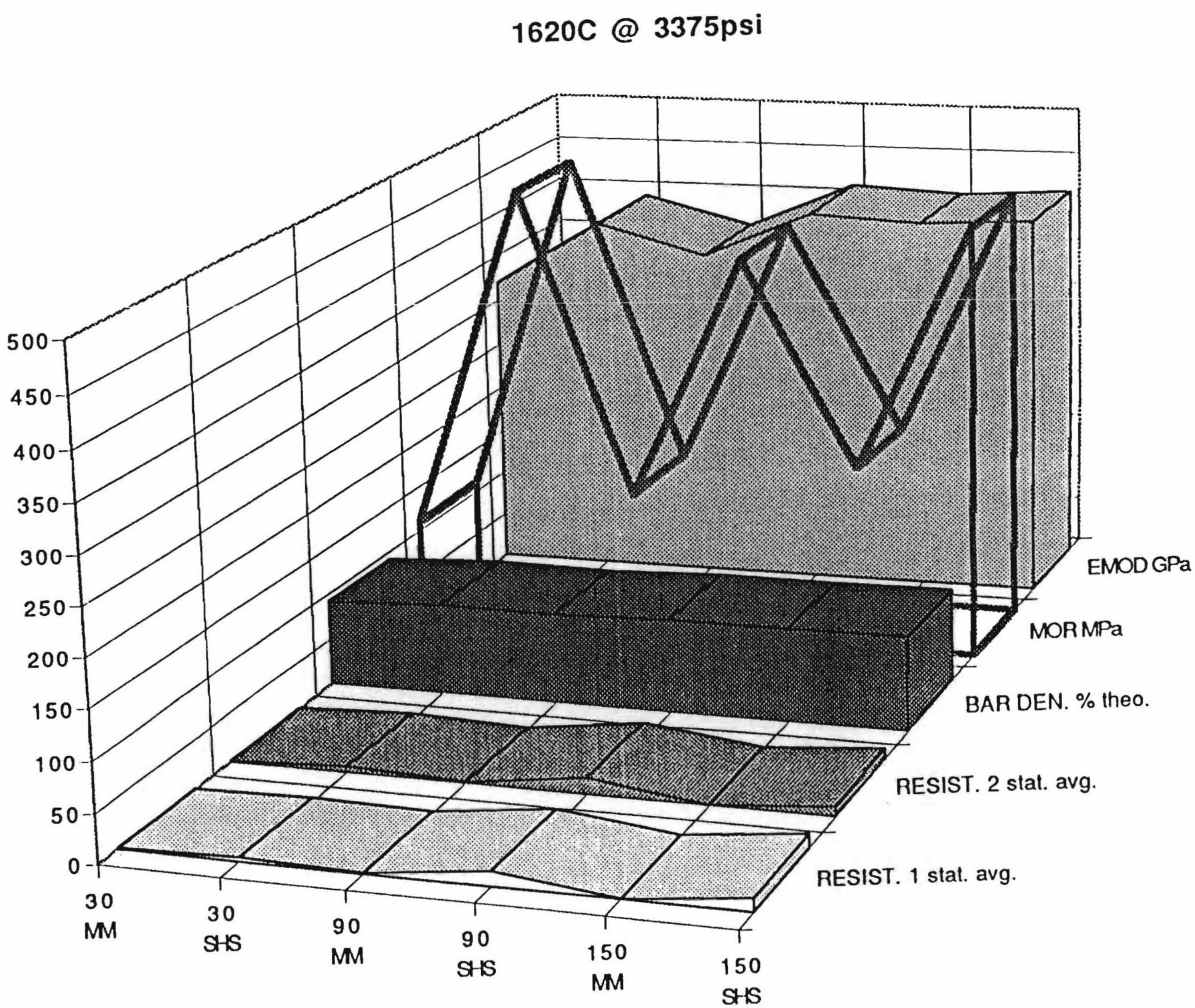
MM SAMPLES @1620C
600
500
400
300
200
100
0
EMOD GPa
MOR MPa
BAR DEN. % theo.
RESIST 2 stat. avg.
RESIST 1 stat. avg.
HOLD TIME 30 150 30 90 150 30 150 240 30 150 240
PRESSURE 500 500 3375 3375 3375 5/5* 5/5* 5/5* 5000 5000 5000
SAMPLE NO. 1 3 5 7 9 11 13 24 15 17 21
5/5*=500/5000psi

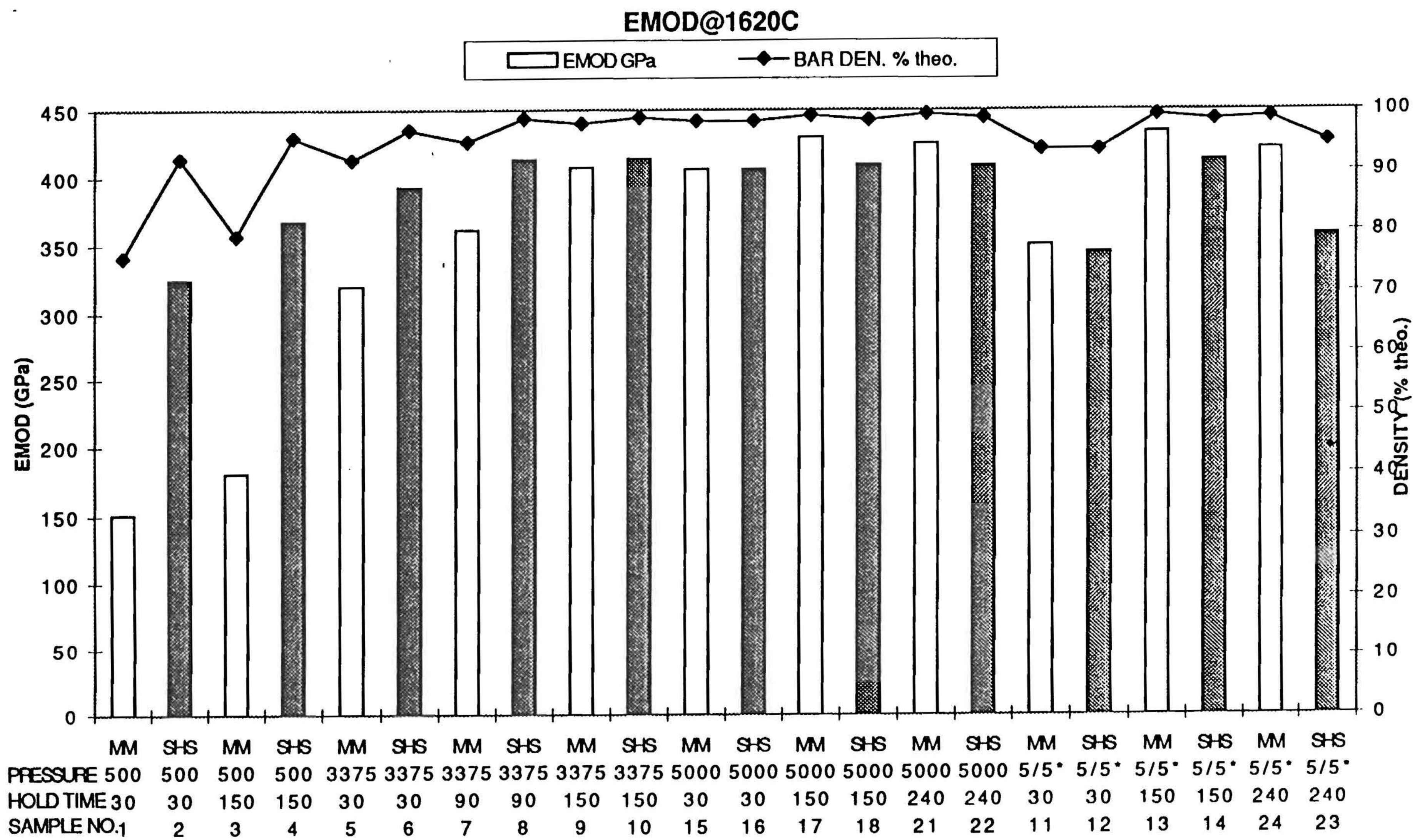
SHS SAMPLES @1620C



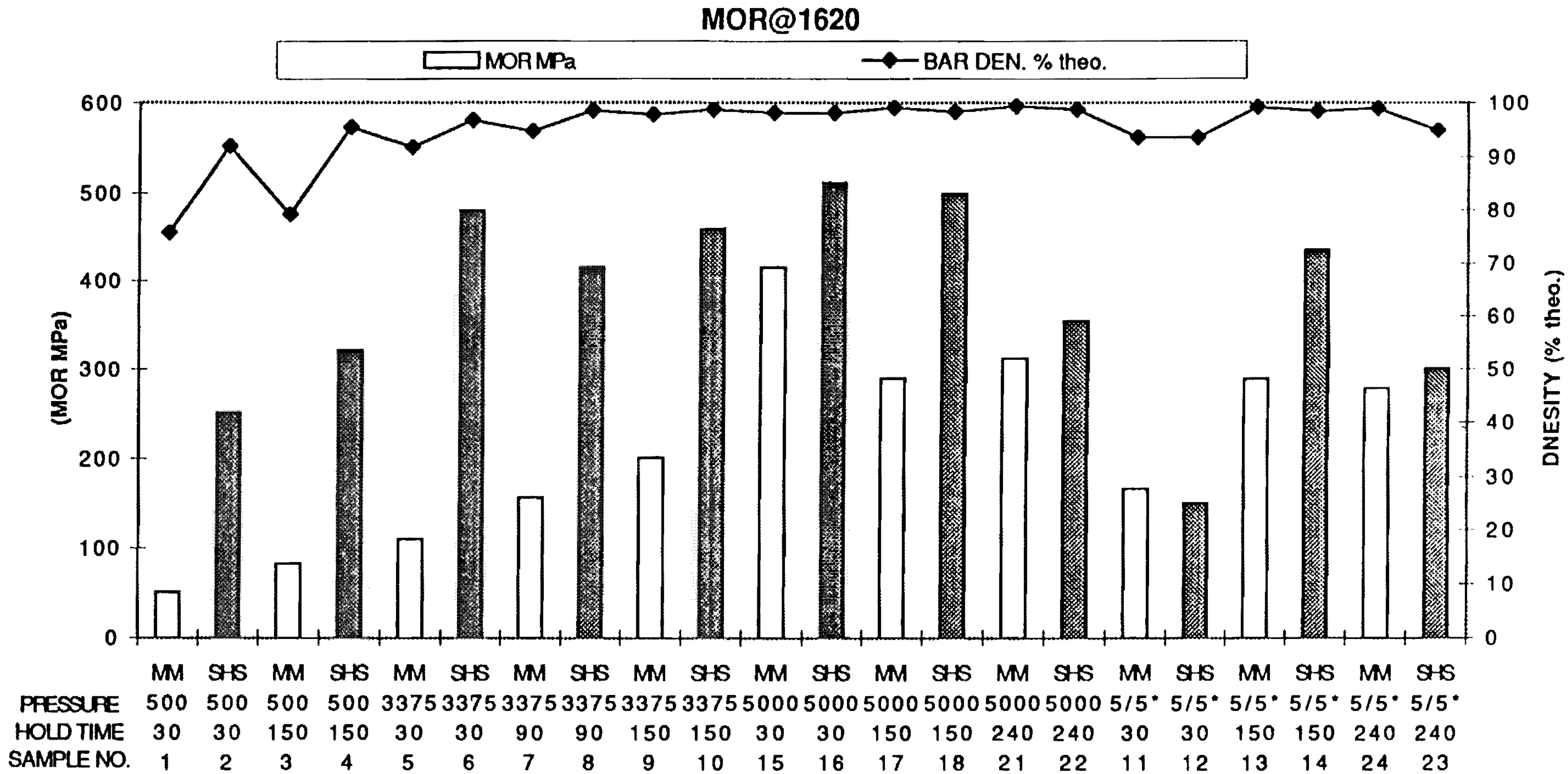


1620C@500psi
500
450
400
350
300
250
200
150
100
50
0
30 MM
30 SHS
150 MM
150 SHS
EMOD GPa
MOR MPa
BAR DEN. % theo.
RESIST. 2 stat. avg.
RESIST. 1 stat. avg.


1620C @ 3375psi
500
450
400
350
300
250
200
150
100
50
0
30 MM
30 SHS
90 MM
90 SHS
150 MM
150 SHS
EMOD GPa
MOR MPa
BAR DEN. % theo.
RESIST. 2 stat. avg.
RESIST. 1 stat. avg.

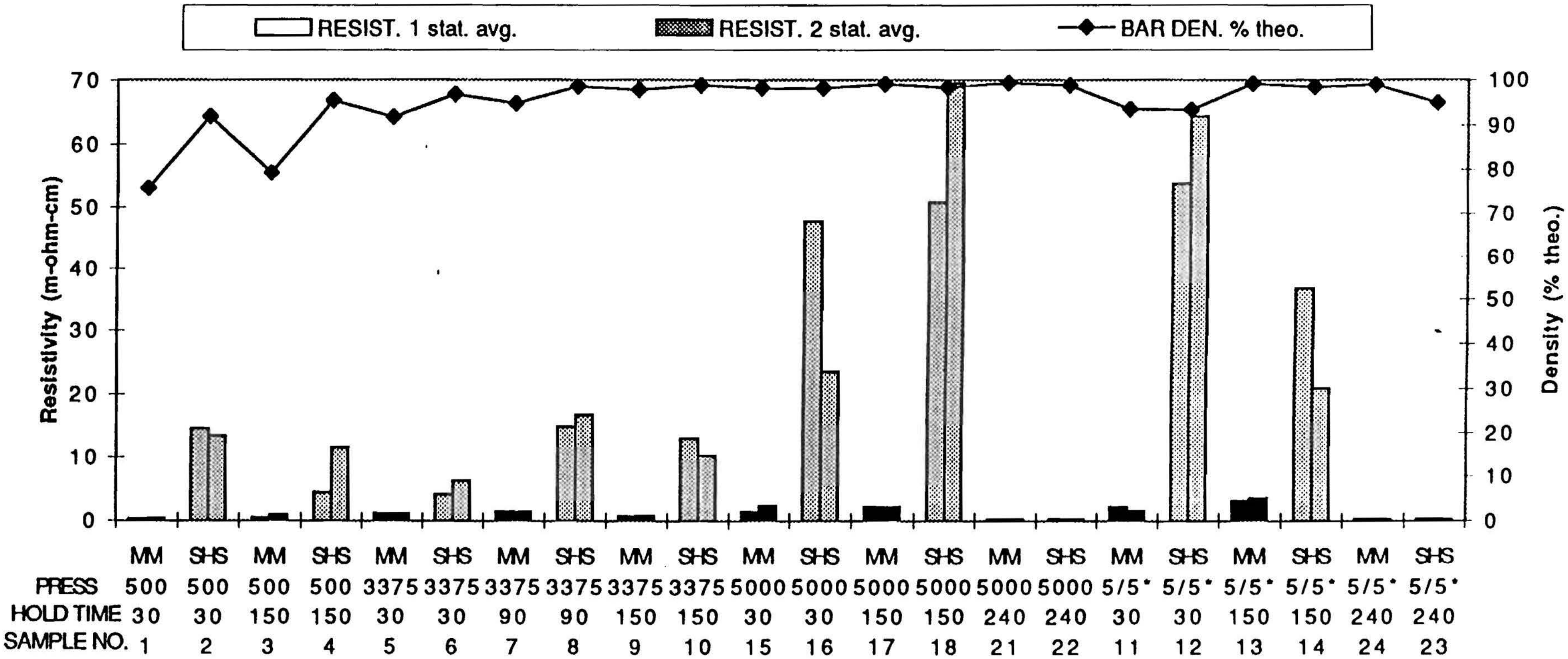


5/5*=500/5000psi



5/5*=500/5000psi

ELECTRICAL RESISTIVITY



5/5*=500/5000psi

CONCLUSIONS

- MICROSTRUCTURE AFFECTS MECHANICAL PROPERTIES
- COMPOSITE T@A MECHANICAL PROPERTIES ARE SIMILAR TO THE PROPERTIES OF PURE TIB_2

RECOMMENDATIONS

- 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)

ACKNOWLEDGMENTS

- TACOM/ARL
  - T. FURMANIAK
  - M.BURKINS
- GIT STUDENTS
  - A. CARNEY
  - K. PHILLIPS
  - G. VILLALOBOS
  - S. ALAFIFI

Georgia Institute of Technology
Office of Graduate Studies and Research

E-18X23
#10

November 20, 1996

Mr. T. Furmaniak
MS263
Emerging Technology Team
USATACOM
Warren, MI 48397-5000

Subject: Contract DAAEO7-95-C-R040
Composite Ceramics
Final Technical Report/A002
Georgia Tech Contract Deliverable #010
Reporting Period: 951225 to 960925

Dear Mr. Furmaniak:

Enclosed is the Subject Final Technical Report with the requested four originals and computer disk with the Power Point file. As we discussed, the final report is in the format of overheads on paper with only the Georgia Tech logo.

Sincerely,

Kathryn V. Logan, Ph.D.,
Principal Investigator
School of Materials Science
and Engineering

Enclosures

Georgia Institute of Technology
Atlanta, Georgia 30332-0265 U.S.A.
PHONE 404-894-3092
FAX 404-894-5657

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°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^{O}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

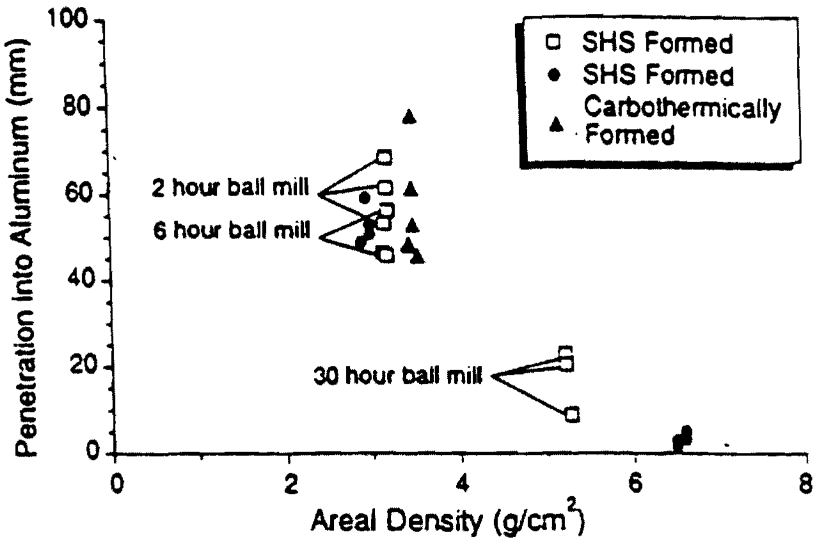
BACKGROUND

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

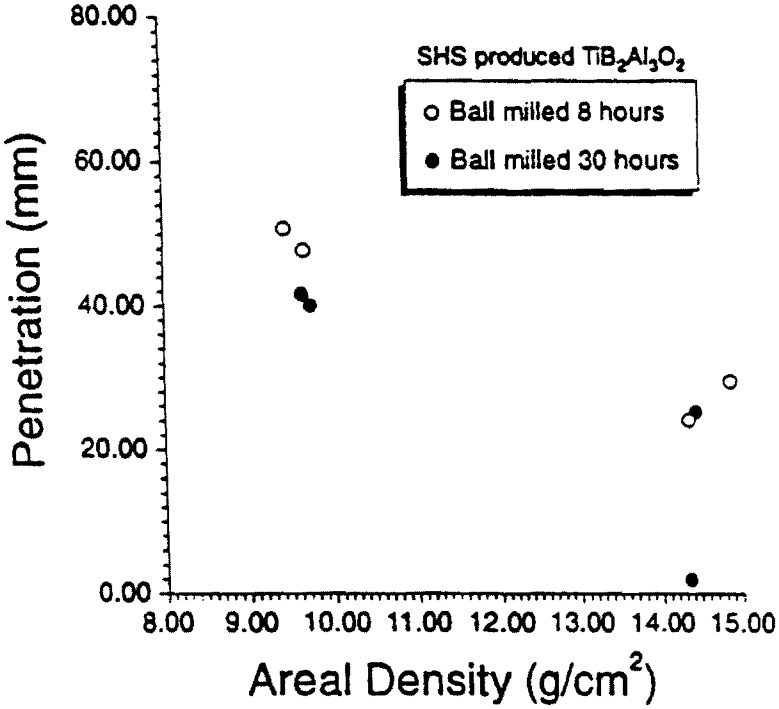
UDRI BALLISTIC PENETRATION DATA

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

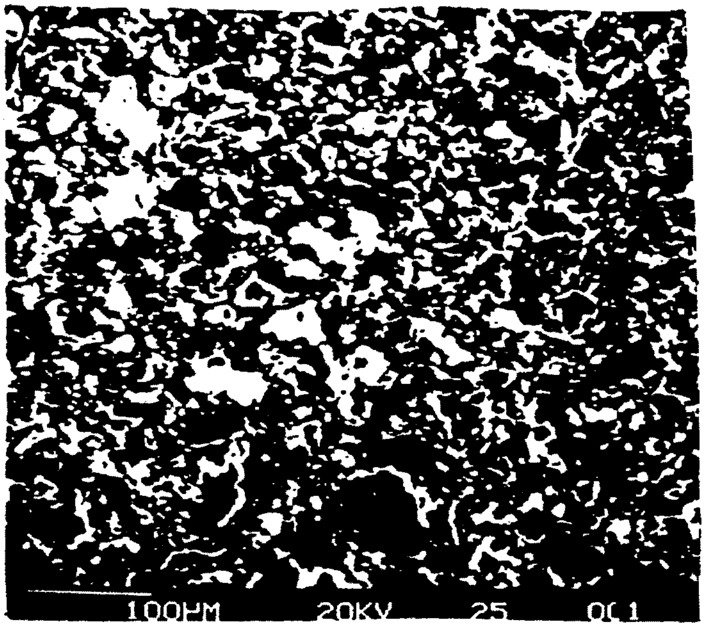
PROJECTILE: BRL STANDARD 65 GM TUNGSTEN ROD, 7.82MM DIA. x 78.74MM LENGTH (L/D 10) WITH HEMISPHERICAL NOSE. TELEDYNE X-21-C TUNGSTEN, 93%, 15% SWAGED & AGED.



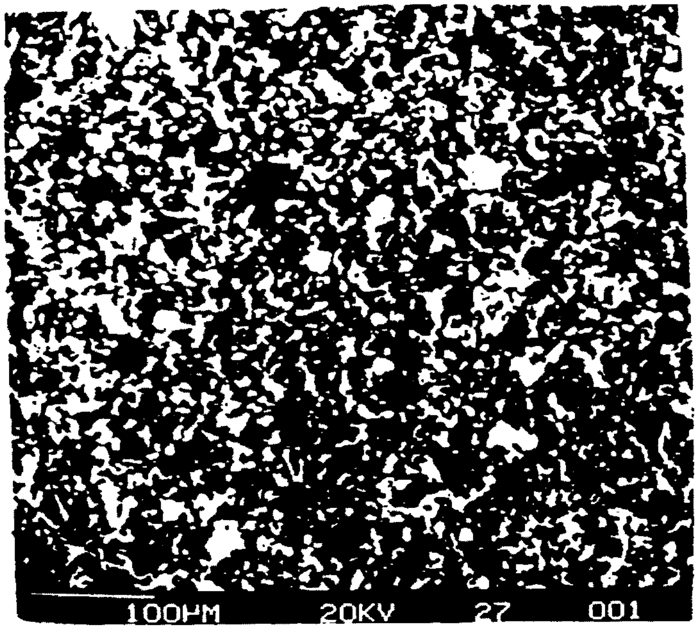
SLAP BALLISTIC TEST RESULTS



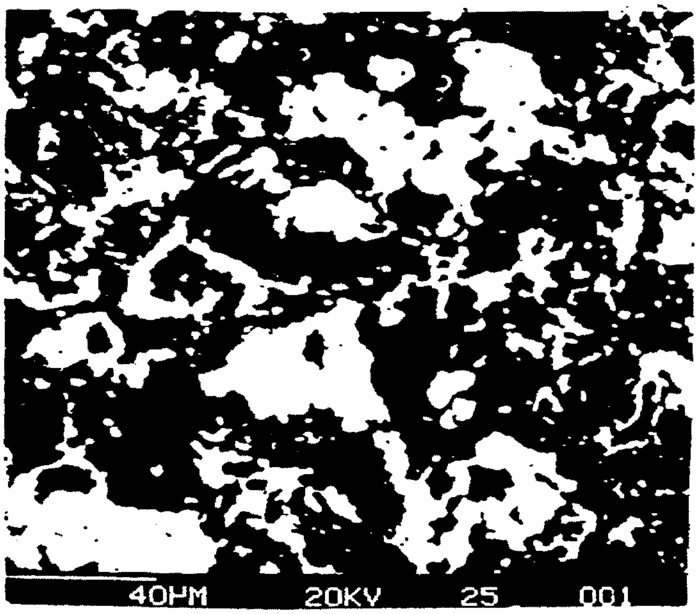
LRP BALLISTIC TEST RESULTS



SAMPLE 225 T@A



SAMPLE 227 T IN A



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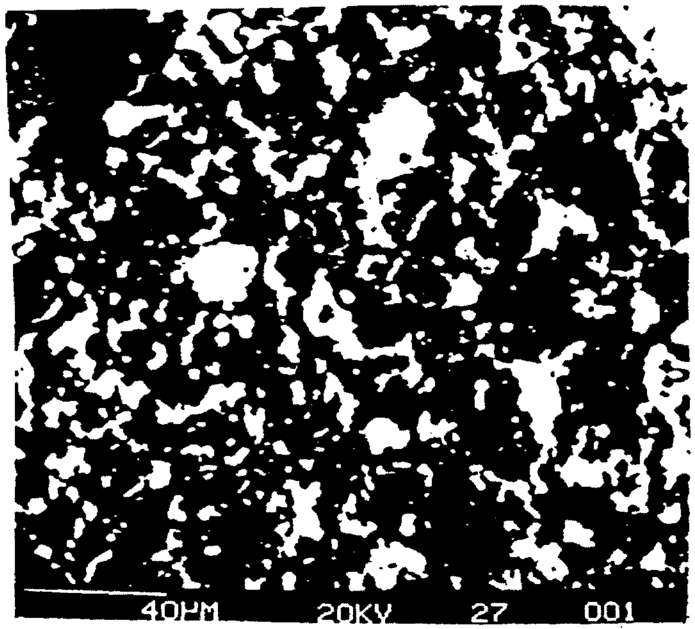
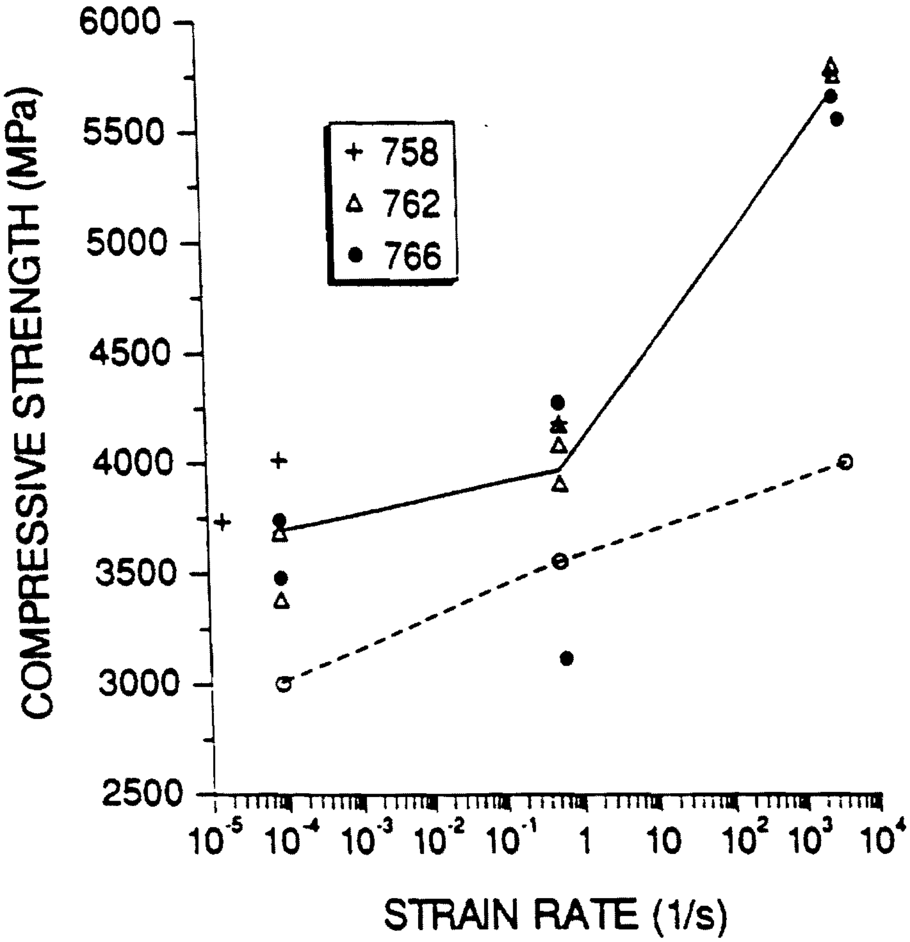


SAMPLE 227 T IN A



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

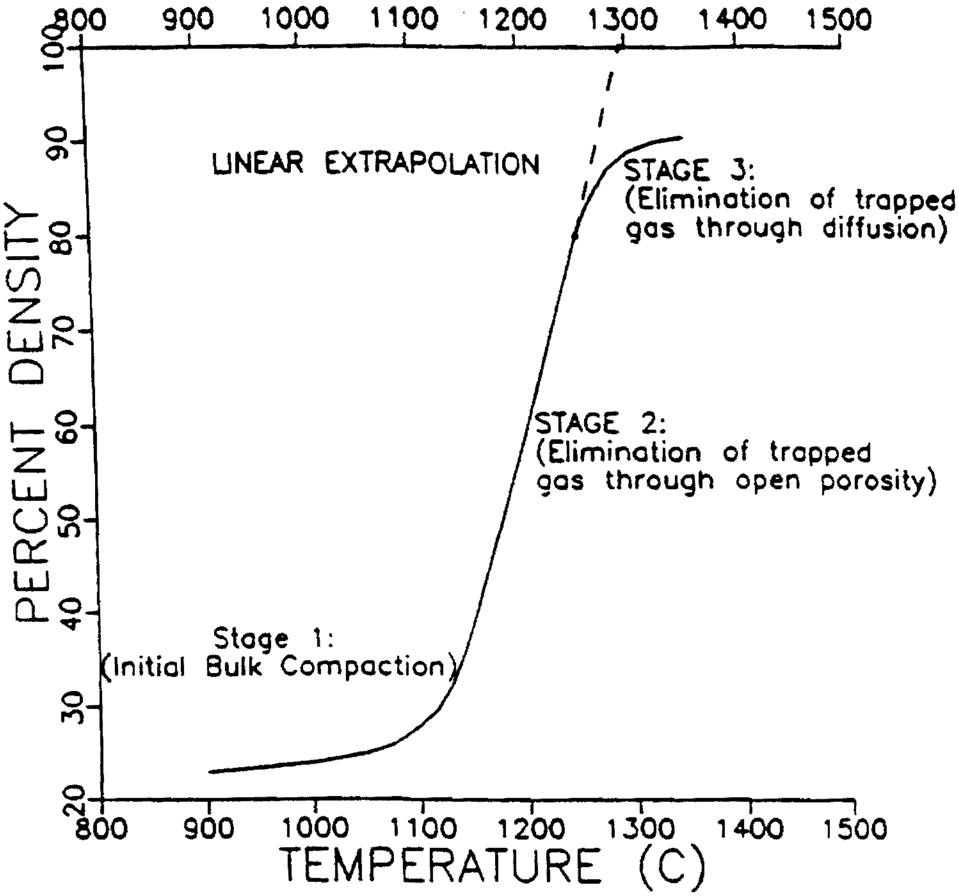
$$3TiB_2 + 5Al_2O_3 \rightarrow 3TiB_2 / 5Al_2O_3$$

- PARTICLE SIZE REDUCTION:

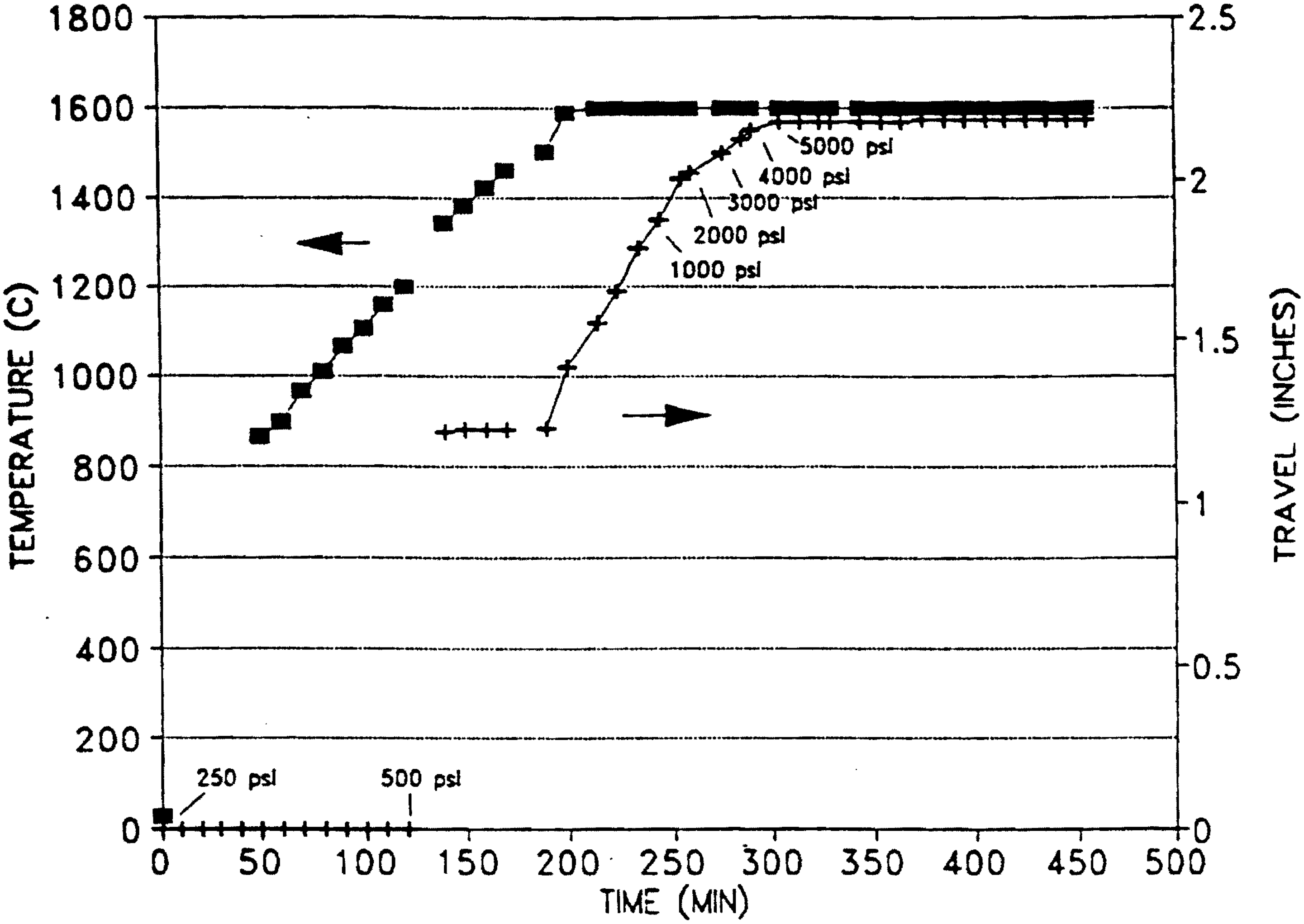
  BALL MILLED TO AVG. 5-12 MICRONS

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

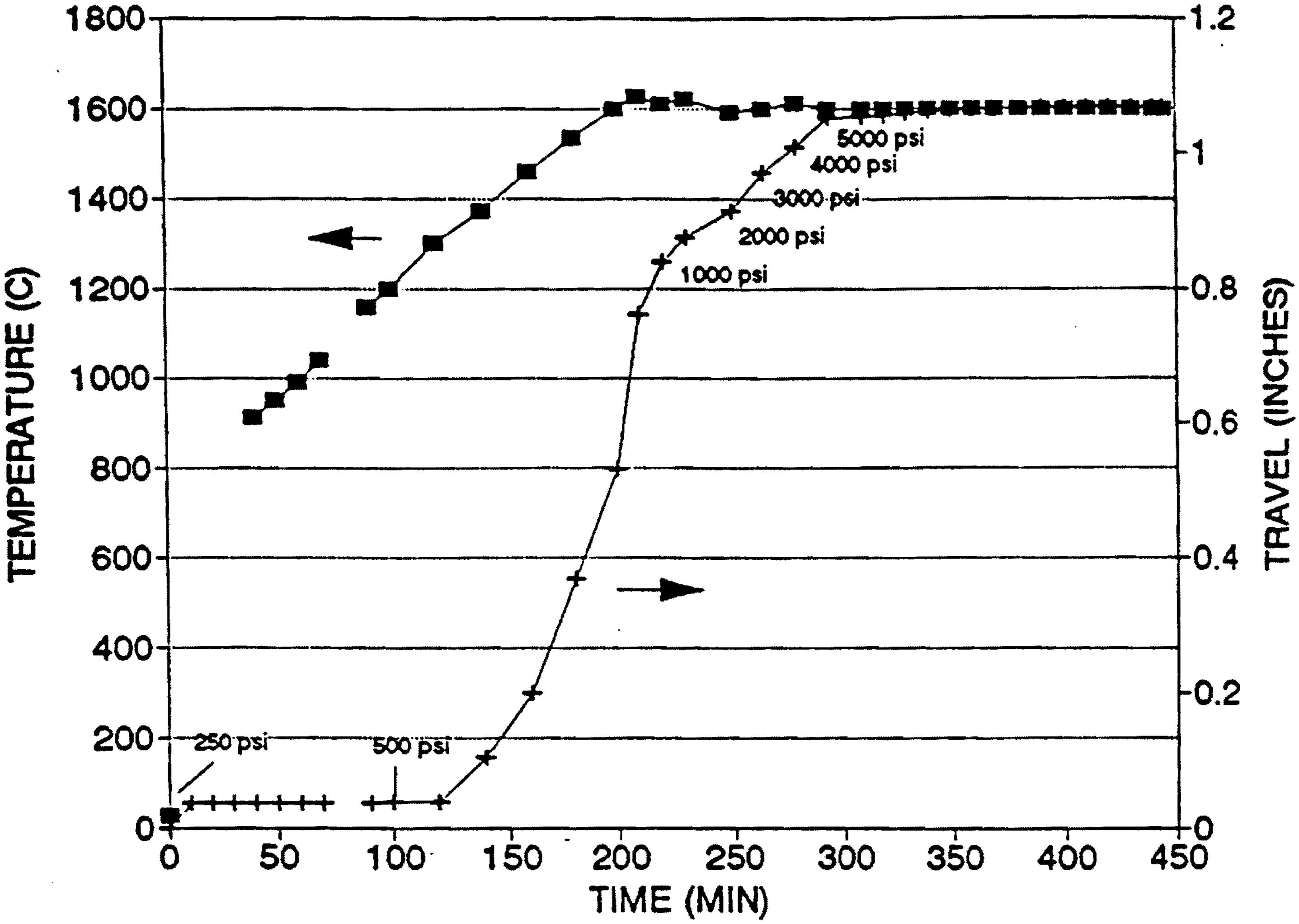


SCHEMATIC OF CTP CURVE



HOT PRESS RUN OF SAMPLE 225

■ = TEMPERATURE + = RAM TRAVEL



HOT PRESS RUN OF SAMPLE 227

■ = TEMPERATURE   + = RAM TRAVEL

TARGETS

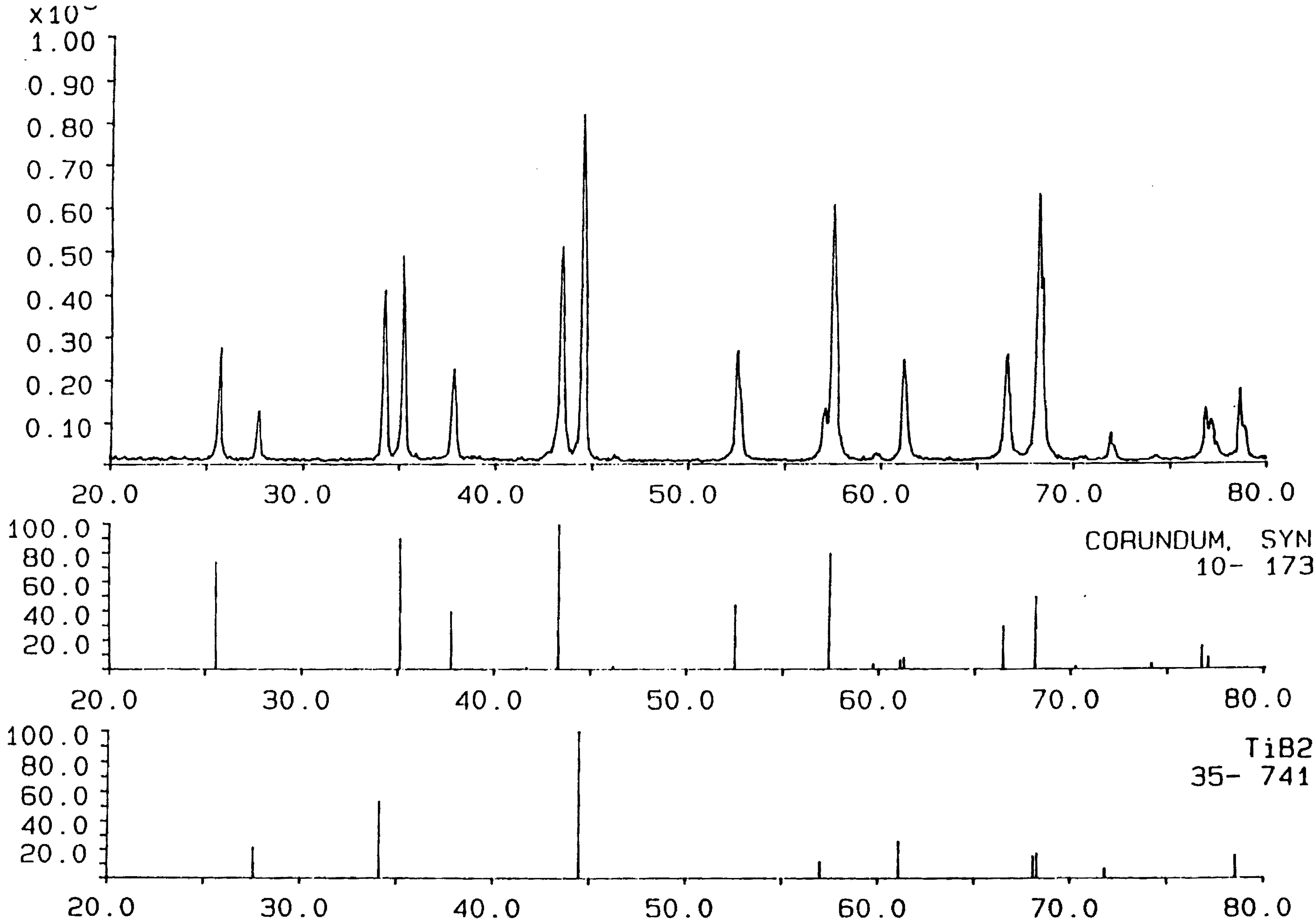
SAMPLE		QUANTITY AND SIZES	
		Ballistic Targets	Mechanical Properties
SHS	T @ A	3 ea. 4"x 1-1/2"	3ea. 3"x 1/2"
	T IN A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"
MIXED	T @ A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"
	T IN A	3 ea. 4"x 1-1/2"	3 ea. 3"x 1/2"

SHS: SELF PROPAGATING HIGH TEMPERATURE

MIXED: MECHANICALLY MIXED DISPERSED SAMPLES

T @ A: TITANIUM DIBORIDE AT THE ALUMINA GRAIN BOUNDARIES

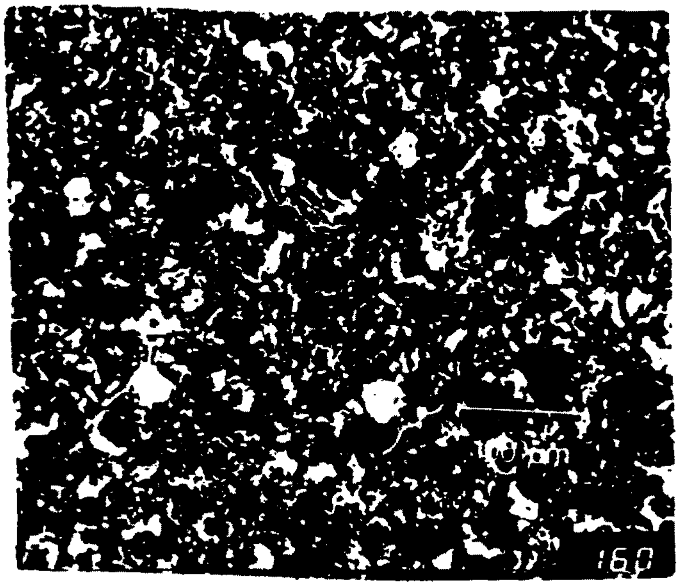
T IN A: TITANIUM DIBORIDE IN THE ALUMINA MATRIX



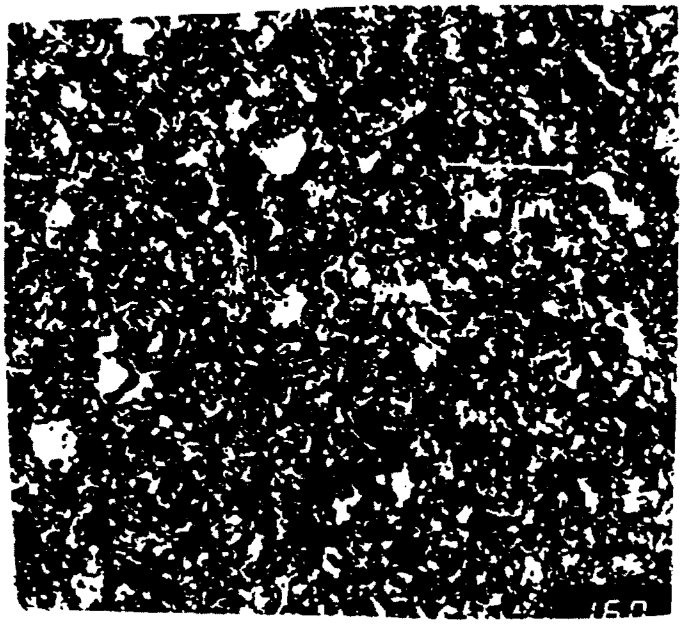
X-RAY DIFFRACTION TRACE OF SHS COMPOSITE

HOT PRESS RESULTS

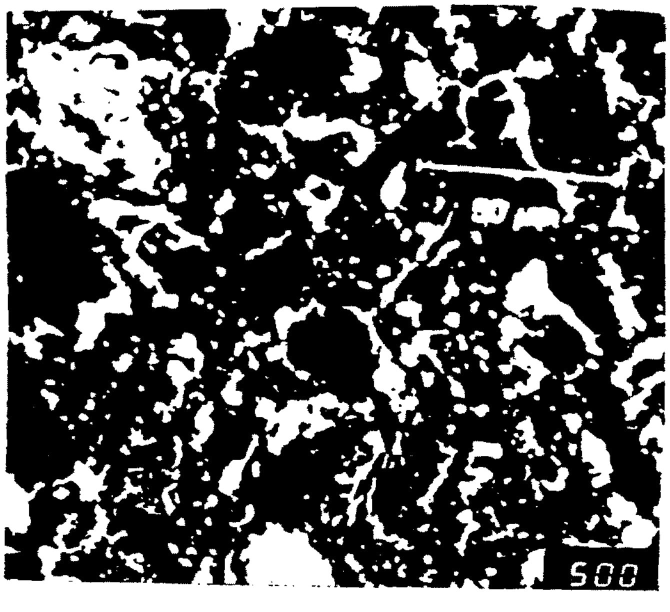
HOT PRESS MATRIX SAMPLE #	POWDER TYPE (synthesis)	HOLD PRESSURE (psi)	HOLD TIME (min)	HOLD TEMP C	BULK DISK DEN. (% theo.)	TEST BAR DENSITY (% theo.)	MOR MPa (avg. 5)	RESIST. 1 ohm·cm (raw avg.)	RESIST. 1 ohm·cm (stat. avg.)	RESIST. 2 ohm·cm (raw. avg.)	RESIST. 2 ohm·cm (stat. avg.)	EMOD GPa (avg. 5)	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	



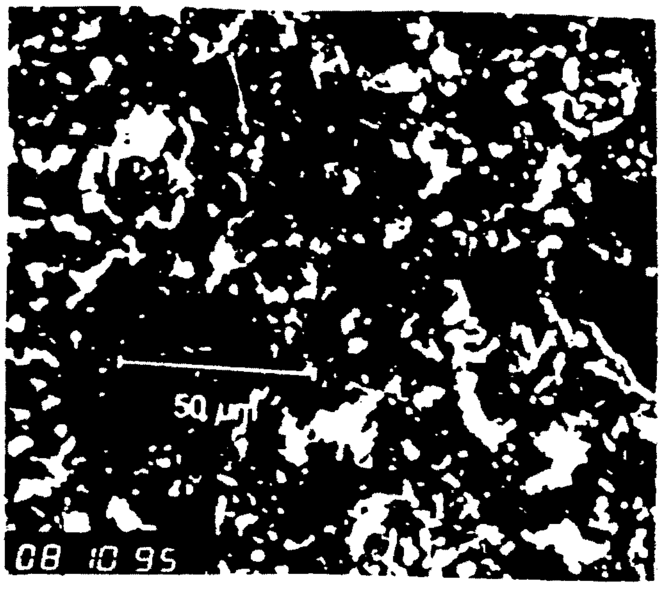
225 CONFIRM T@A



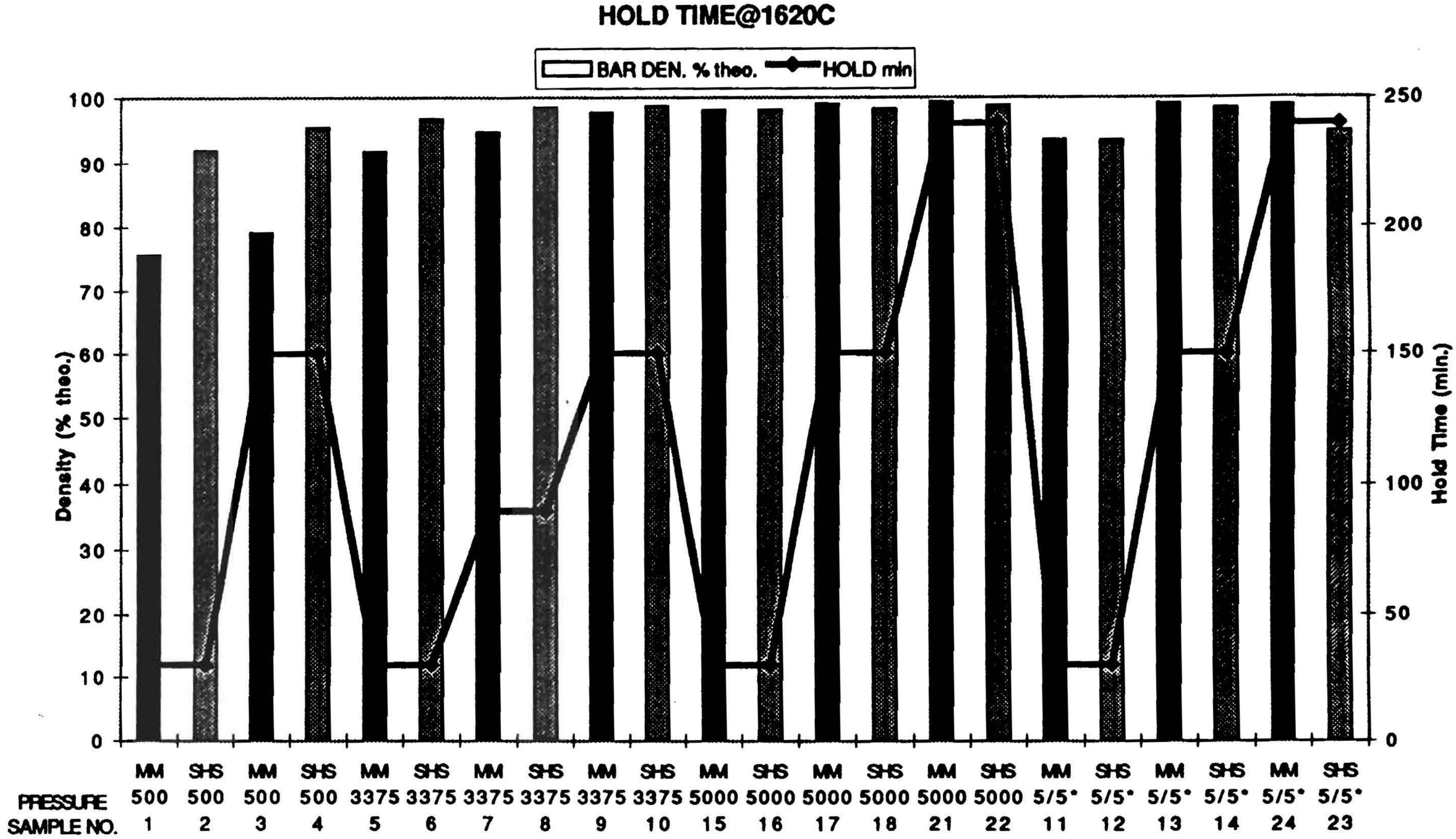
227 CONFIRM T IN A



225 CONFIRM T@A

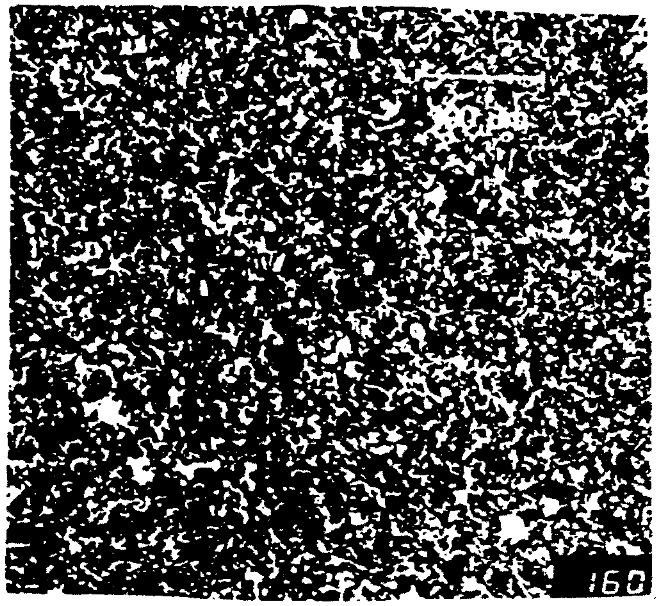


227 CONFIRM T IN A

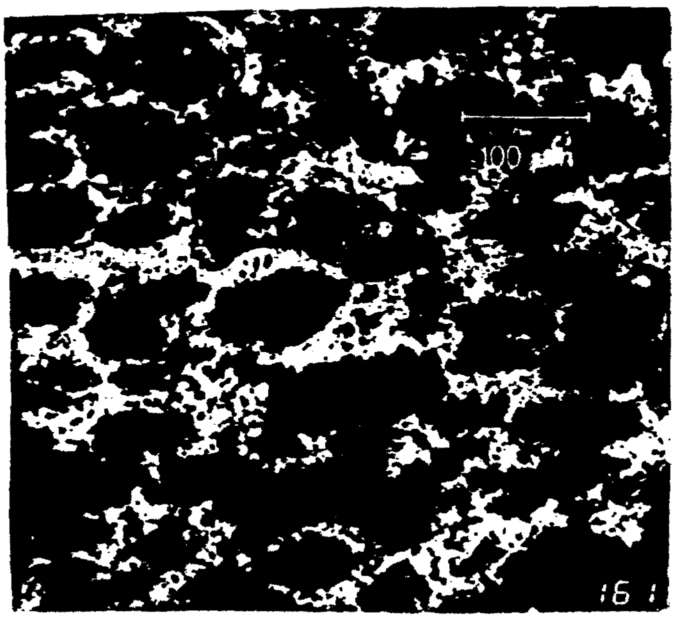


5/5*=500/5000psi

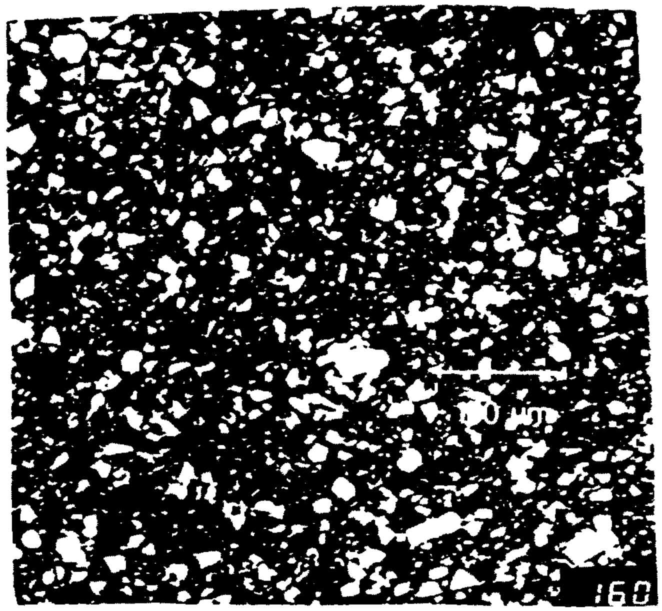
SHS T@ A



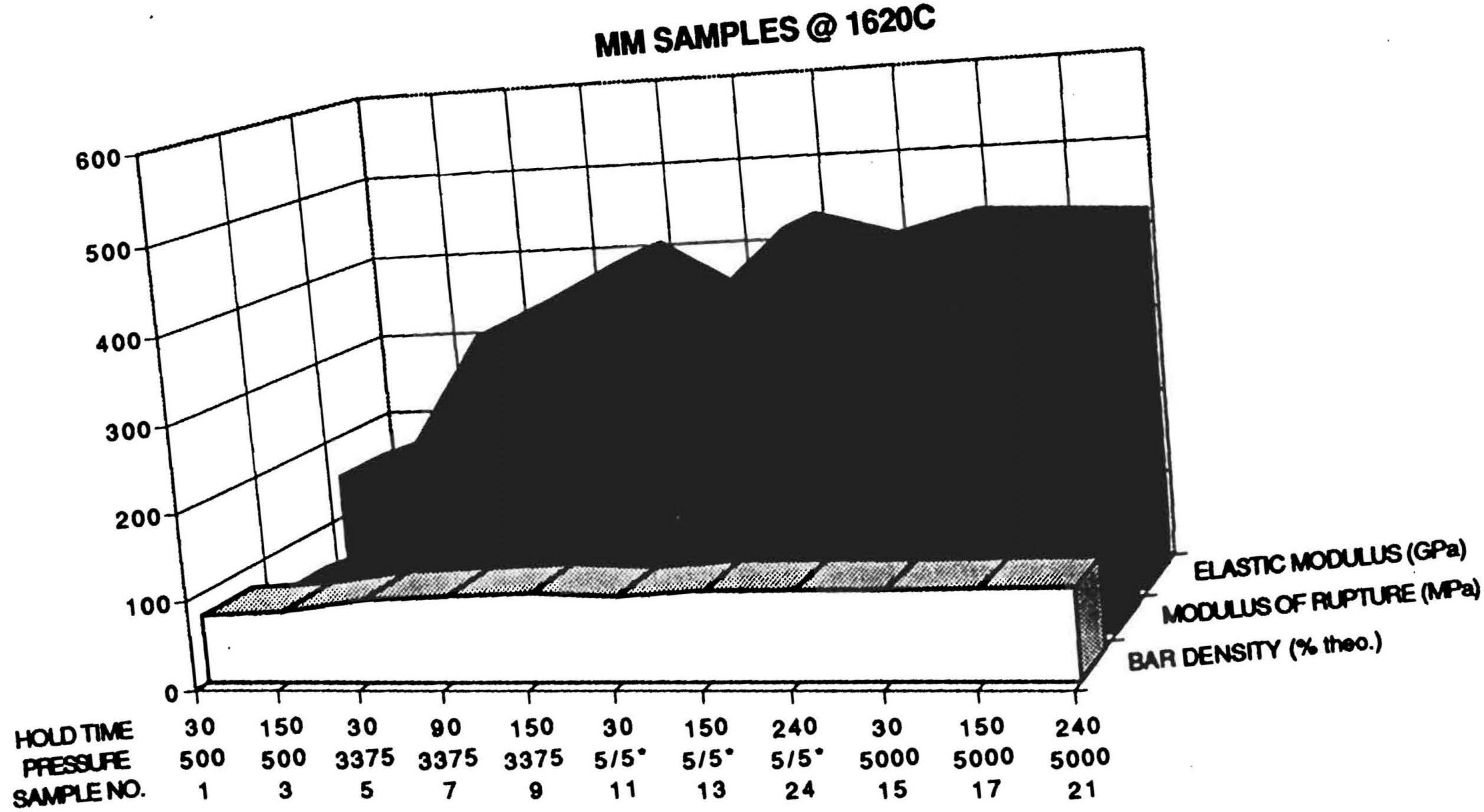
SHS T IN A



MM T @ A

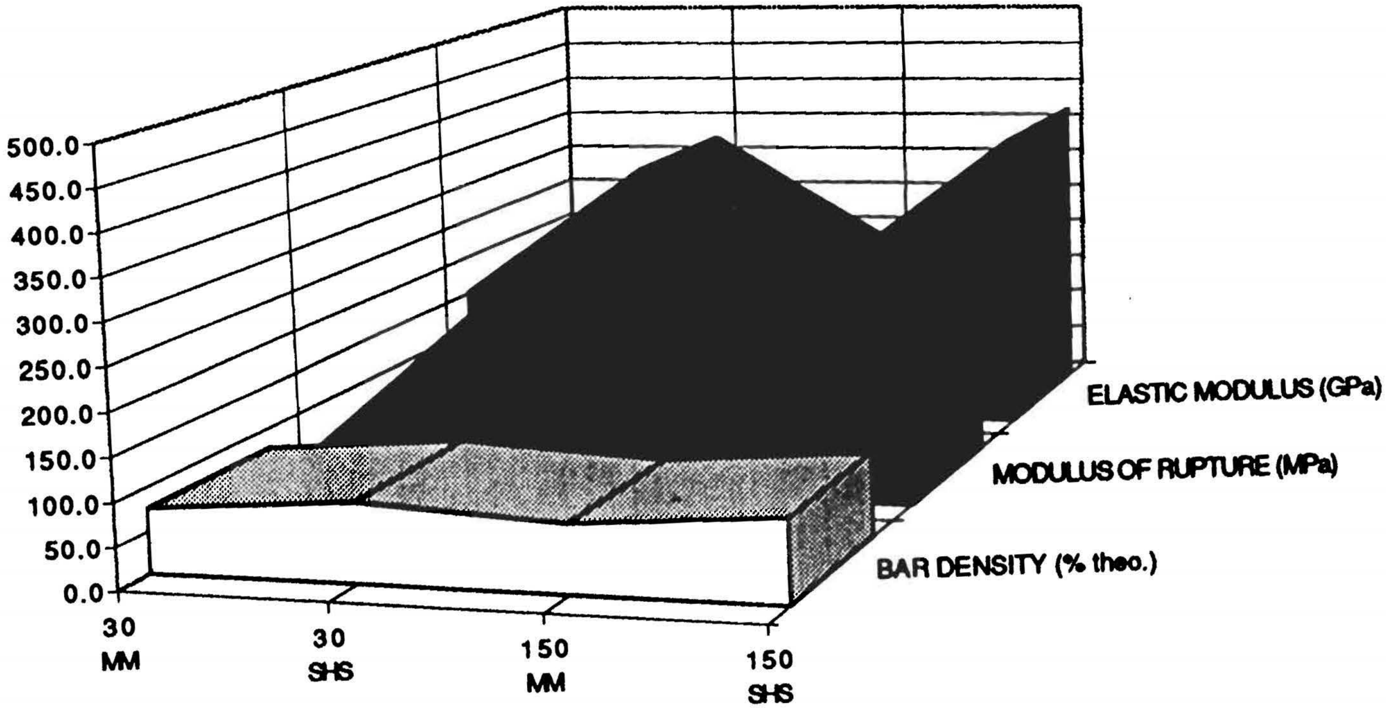


MM T IN A

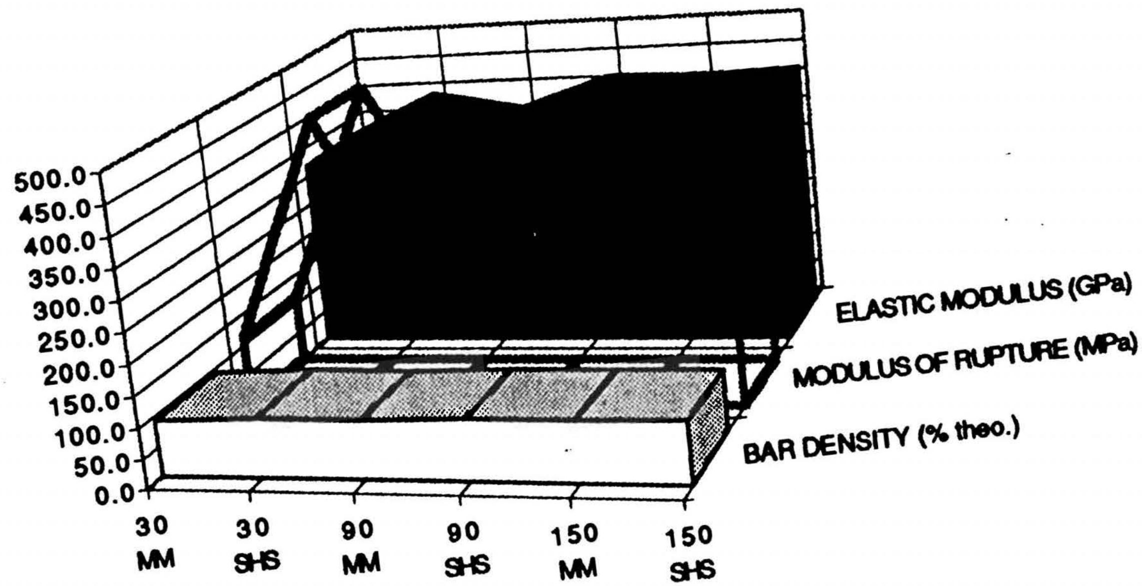


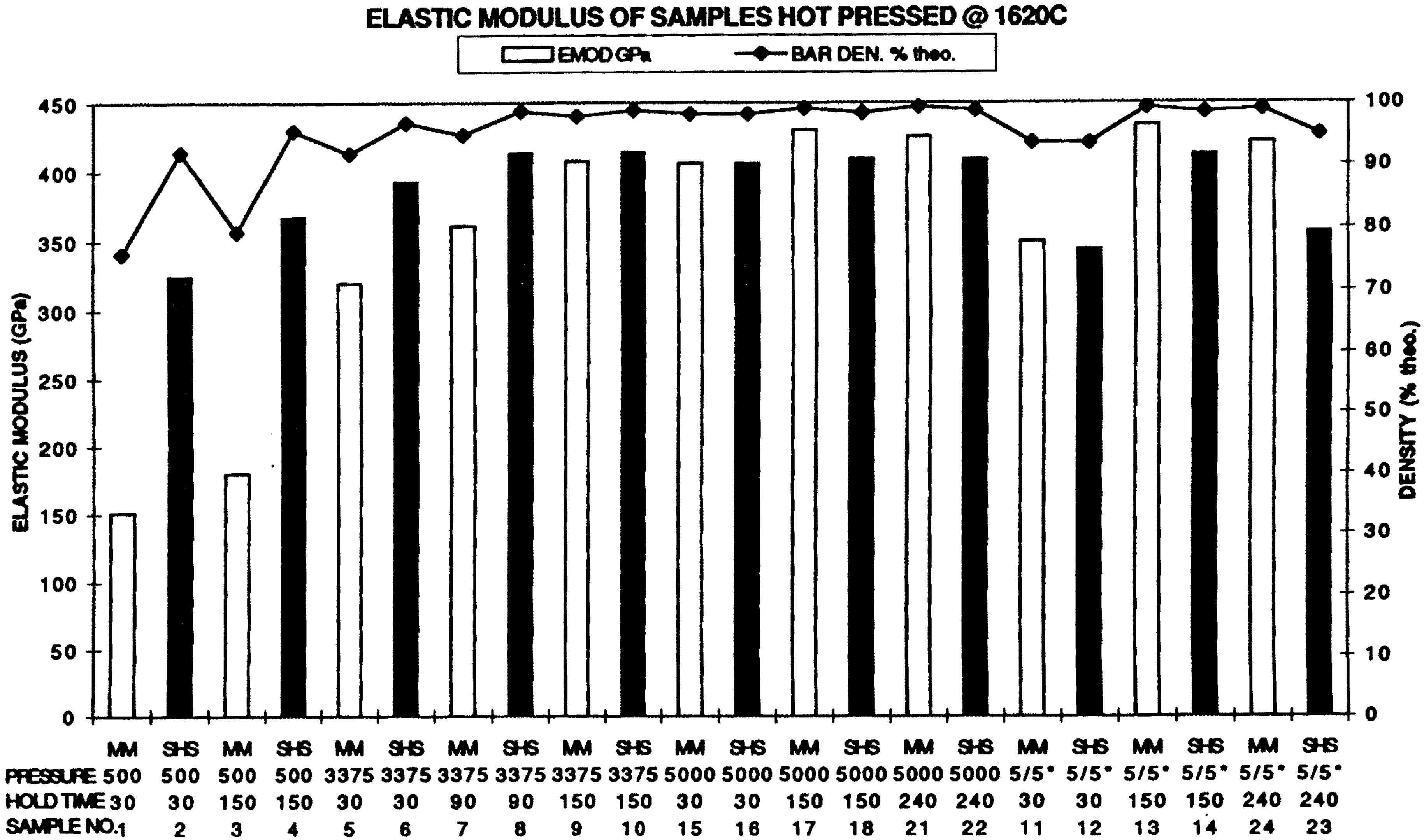
5/5*=500/5000psi

1620C @ 500psi



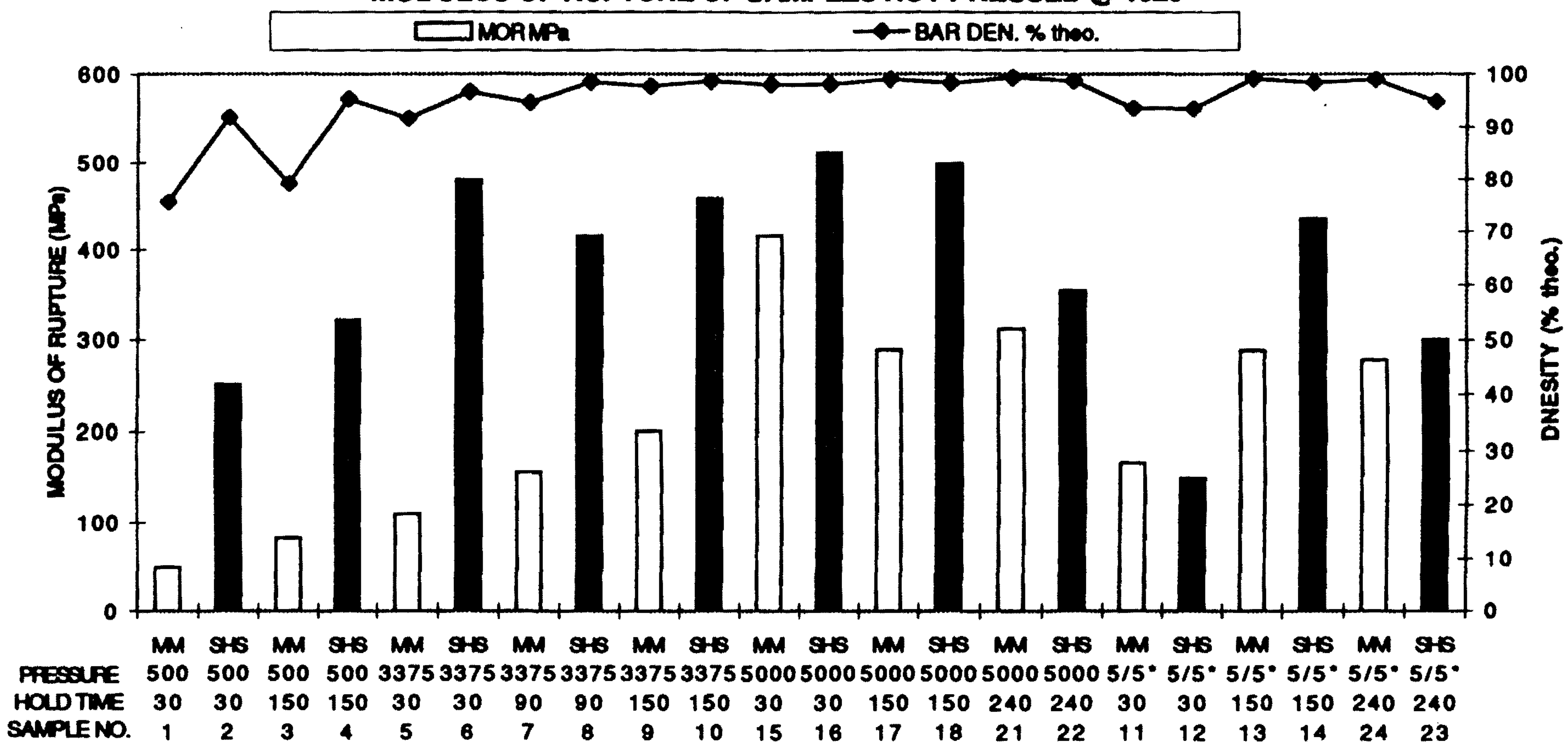
1620C @ 3375PSI





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.

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