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MASTER

Development of Boron Carbide-Copper Cermets - Status Report

TRANSPORTATION TECHNOLOGY CENTER

Sandia Laboratories
energy report

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[illegible] Laboratories
Albuquerque, NM [illegible]

[illegible]

Abstract

[illegible] for [illegible] [illegible] [illegible] [illegible]. It is shown that in certain [illegible] [illegible] [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] eliminated these high conductivity materials, e.g., [illegible] with melting point below 1070 K.

Finally, the mechanical behavior of the metal matrix was considered in order to [illegible] materials, e.g., Ir, which are known to [illegible] [illegible] is mechanical [illegible] over the temperature range [illegible] K.

[illegible] criteria [illegible] with metal availability, [illegible] the selection of [illegible], [illegible] the using [illegible] the [illegible] [illegible].

[illegible]

[illegible] the metal matrix, a parametric analysis was performed to establish, [illegible] given a [illegible] of B_4C, what thickness [illegible] would be required to meet [illegible] criteria, [illegible] the effect of varying [illegible] thickness [illegible] what the effect of [illegible] B_4C-[illegible] would have [illegible] required thickness.

[illegible] through the [illegible] Regulatory Commission's [illegible] accident criteria [illegible] measured at 1 m from the accessible [illegible] surface, a level of [illegible] was selected as the maximum allowable [illegible] in this evaluation. [illegible] was [illegible] in [illegible] and neutron [illegible], and the exclusion of [illegible] ground scattering from the calculations. In addition, the [illegible] used for the study is one-dimensional and can therefore not account for the more complex [illegible] pattern actually expected. It was, however, estimated that these exclusions and simplifications should not result in an error of more than 10 pct., well within the selected factor of two safety margin. For example, the gamma radiation contribution to the external dose rate in the post-accident configuration is in all cases expected to be less than 10 pct. of the total, while the ground scattering contribution to the total external dose rate is expected to increase the rate by 30 to 40 pct. The source definitions used for the parametric analysis was that of nine 180-day cooled Alternate Fuel Management Scheme (AFMS) Clinch River Breeder Reactor spent-fuel subassemblies in a 12-assembly cask design (4,5).

[illegible] the minimum shield thickness required to meet the [illegible] [illegible] for [illegible] content. [illegible] values of B_4C the [illegible] [illegible] ~ [illegible] [illegible] content [illegible] values of. Increase [illegible] [illegible] [illegible]. The [illegible] results in [illegible] that, [illegible] within the range [illegible] [illegible] [illegible] very sensitive function [illegible] content.

[illegible] of [illegible] varying [illegible] the [illegible] [illegible] [illegible] [illegible] [illegible] in Fig. [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] with the materials, for example B_4C and TiB_2, are [illegible] that the particle size, the particle size distribution, and the [illegible] are all important variables [illegible]. However, it was [illegible] in the powder [illegible] that of [illegible], [illegible] the [illegible] of the [illegible] [illegible] TiB_2. In the [illegible] was [illegible] with the same size distribution [illegible] with a [illegible] [illegible].

[illegible] experiments were [illegible] [illegible] [illegible]

[illegible] between the Porter, Jenkin, and Y-12 results may [illegible] [illegible] [illegible] [illegible] [illegible] purity.

[illegible] from Y-12 permeate measurements by the [illegible] [illegible] [illegible] [illegible] [illegible]

conductivity. A high volume fraction of the B_4C-Cu cermets will be controlled by that of B_4C and that a minimum level of Cu will be required before the thermal conductivity of B_4C-Cu cermet will be significantly better than the pure B_4C. Measurement results below 0 K indicate this conclusion and indicate that the required level of Cu is [illegible] volume pct.

Hot Isostatic Pressing

The relatively low densities obtained by vacuum hot pressing suggest that hot isostatic pressing may not be amenable to manufacturing the full-scale B_4C-Cu cermets intended for breeder reactor spent-fuel neutron shields. In an attempt to increase the density, a powder consolidation procedure, hot isostatic pressing, was explored. Hot isostatic pressing involves three dimensional pressure application at a constant temperature, rather than the one-dimensional hot pressing operation. The influence of B_4C powder size distribution and content on the microstructure, thermal conductivity and transverse rupture properties of B_4C-Cu cermet has been explored for a single hot isostatic compacting condition (1073 K, 103 MPa, 3 h).

Using as-received powders the density of 80 volume pct. B_4C was 87.7 pct. of the theoretical value. Further attempts to increase the hot pressed density emphasized gap-grading the B_4C powders. Powders were screened into coarse (-150 + 105 μm), medium (-74 + 53 μm) and fine (-44 μm) batches. Five different mixtures of these batches were used for 80 vol. pct. B_4C and two for 70 vol. pct. B_4C, Table 4. An improvement in density for an 80 vol. pct. B_4C from 87.7 pct. to 93.6 pct. was achieved by gap-grading.

The variations in density are plotted in Fig. 12 while the microstructures of four different size distributions using 80 volume pct. boron carbide is shown in Fig. 13. Although maximum density is achieved for a 70 coarse/10 medium/20 fine distribution, the -149 + 44 μm classification represents the simplest separation procedure. Since these densities were achieved for a 1073 K hot isostatic pressing temperature and a 103 MPa pressure, it is conceivable that higher densities could be achieved with either higher temperature and/or higher pressure consolidation conditions.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] 19 hours [illegible] [illegible] [illegible]

[illegible]

[illegible]

[illegible]

References

[illegible] Hick, [illegible] of [illegible] Metal Matrix Composites, [illegible] Metal Matrix Composites, [illegible], [illegible], [illegible], [illegible], New York, [illegible].

[illegible] Freeman, [illegible], [illegible], [illegible], [illegible] Metal Matrix Composites, [illegible].

[illegible], [illegible], Linear Thermal Expansion, [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible].

[illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [

L. Memo from J. T. Bushnell to H. J. Beck, March 30, 1976, Subj: Manufacturing Inspection System for K_{α} 2/0x Compacts.

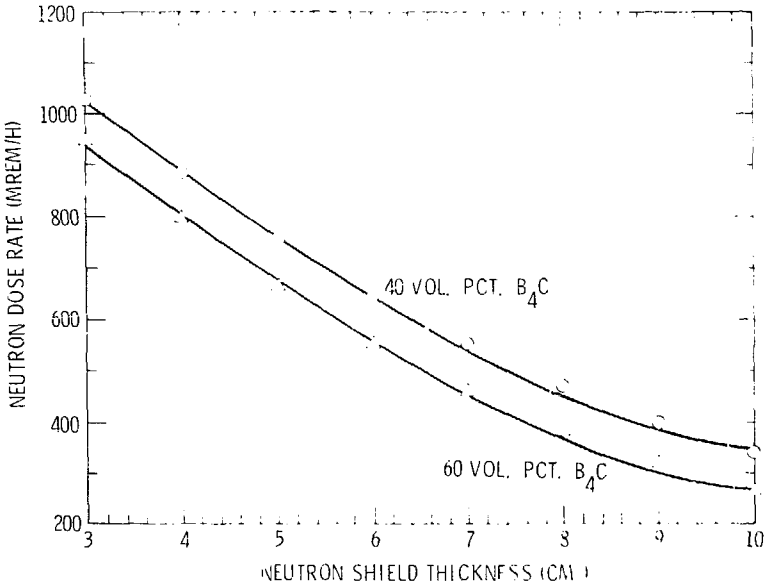


Figure 1. The Influence of B_4C Content and Neutron Shield Thickness on the Neutron Dose Rate Experienced at 1 m from a Possible Cask Surface with a Bricks Neutron Shield

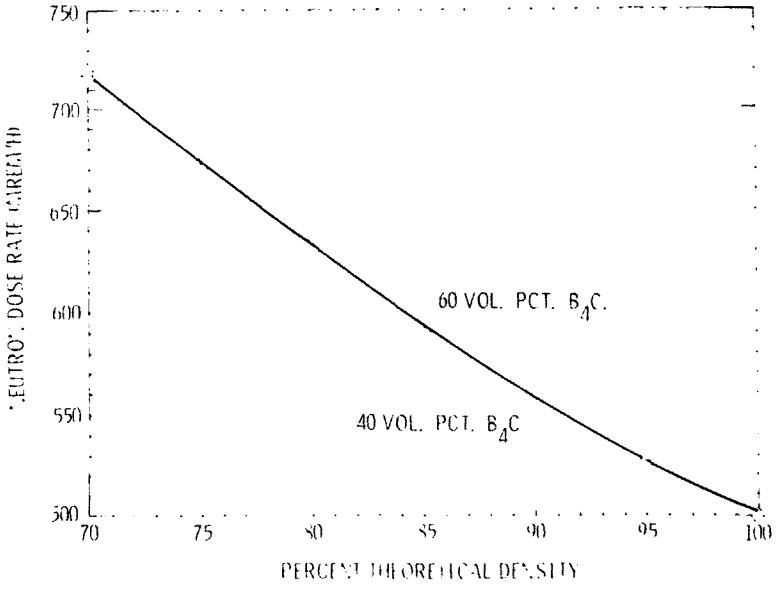


Figure 2. The Influence of Pct. Theoretical Density on the Neutron Dose Rate Expected at 1 m [illegible] Shield

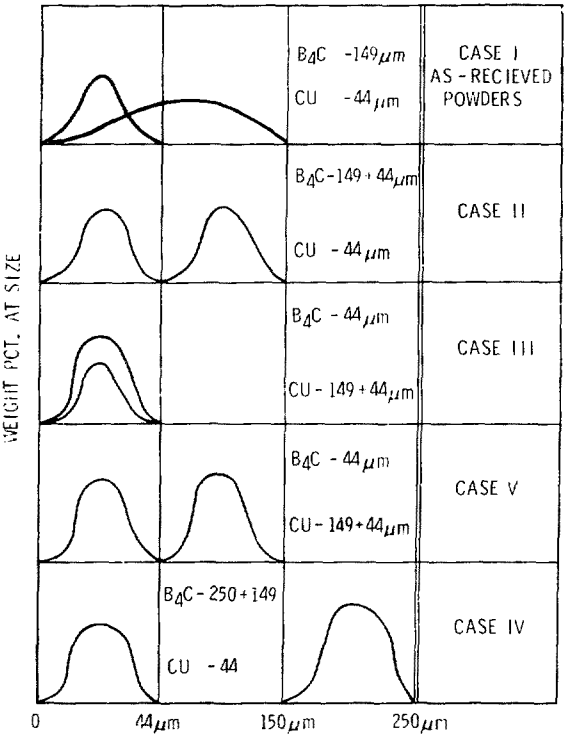


Figure . Schematic Representation of Ideal Powder Size Distributions for Two Component Binder Systems.

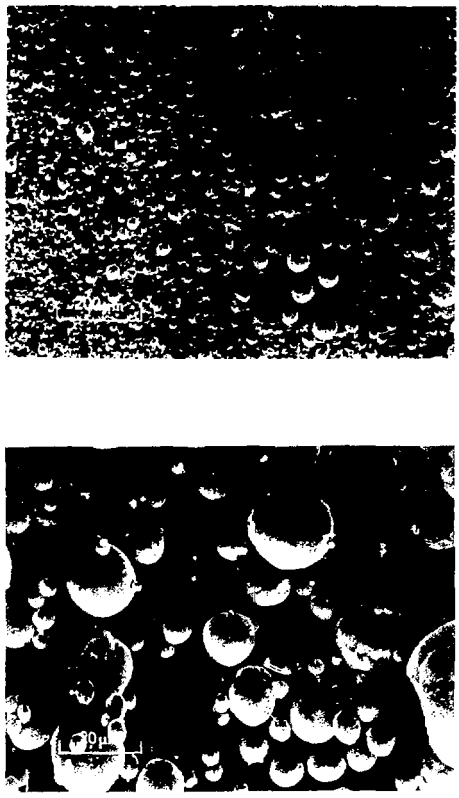


Figure 4. Scanning Electron Micrograph of Cu Powder

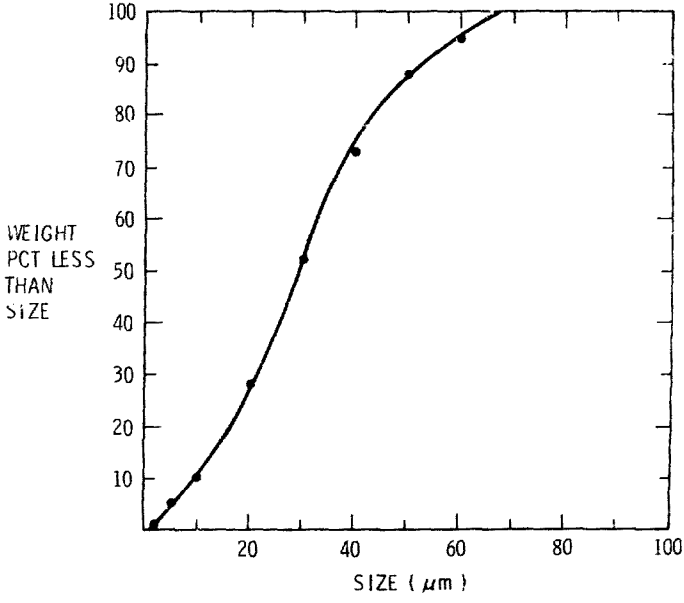


Figure 5. C' Powder Size Distribution

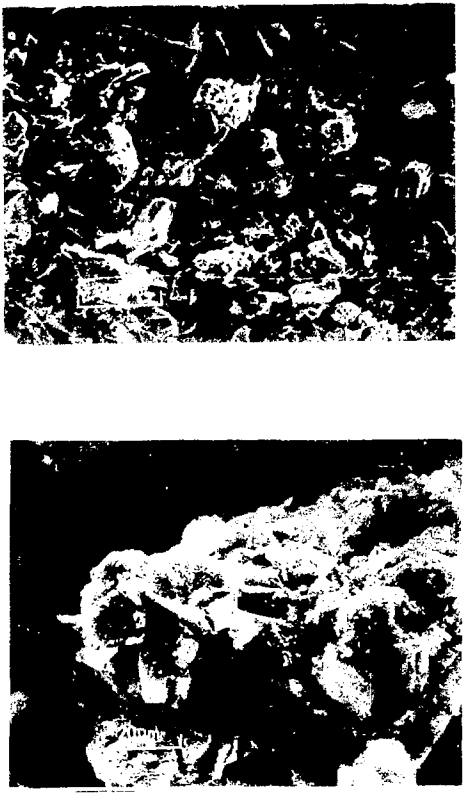


Figure 6. Scanning Electron Micrograph of B_4C Powder

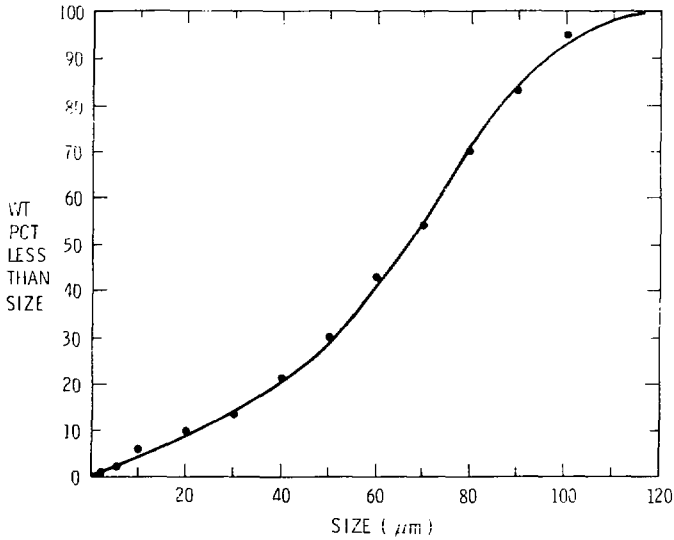


Figure 7. B_4C Powder Size Distribution

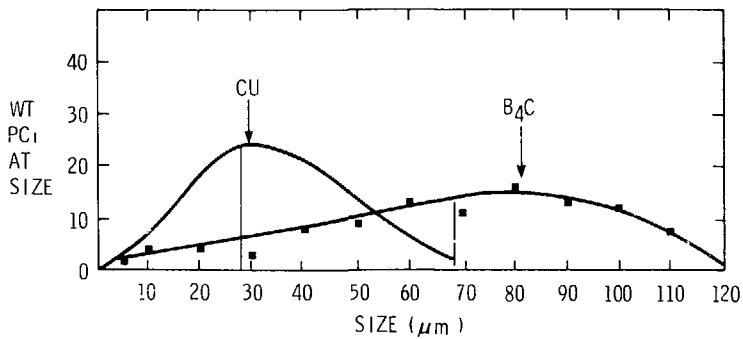


Figure 8. Overlap in Size Distribution of Cu and B_4C Powders

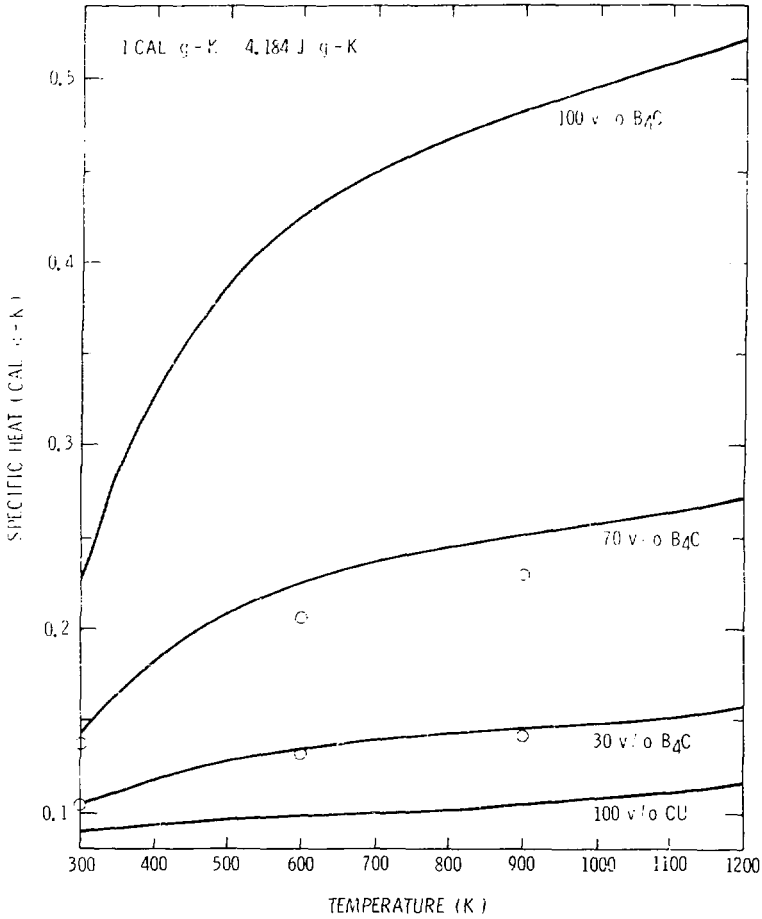


Figure 9. The Influence of Temperature and B_4C Content on the Specific Heat of Selected B_4C-Cu Cermets

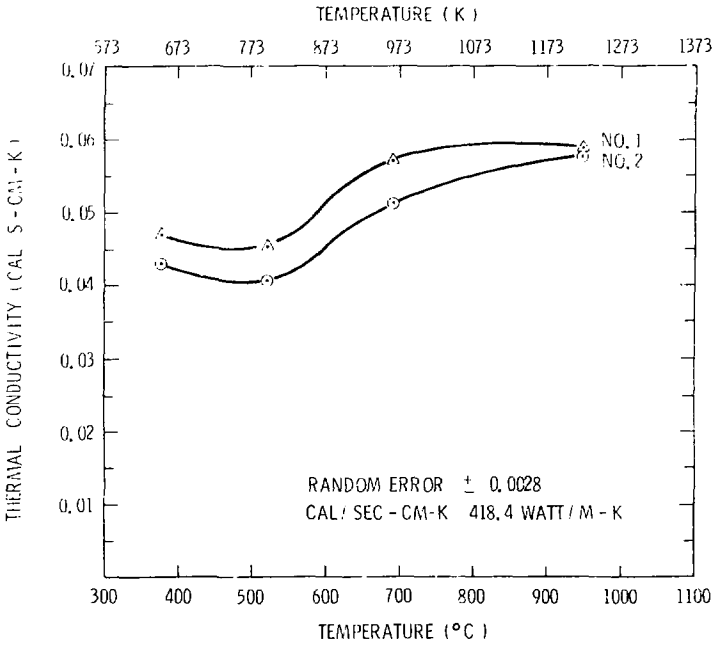


Figure 10. Thermal Conductivity of 70 Volume Pct. B_4C-30 Volume Pct. Cu Cermet

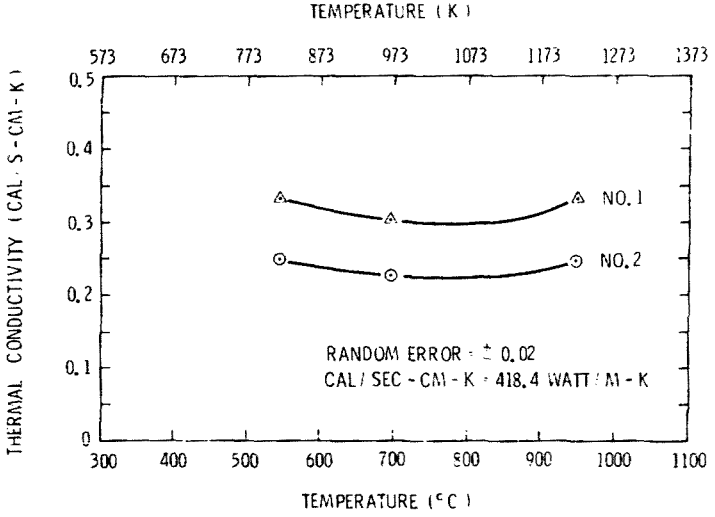


Figure 11. Thermal Conductivity of 30 Volume Pct. B_4C-70 Volume Pct. Cu Cermet

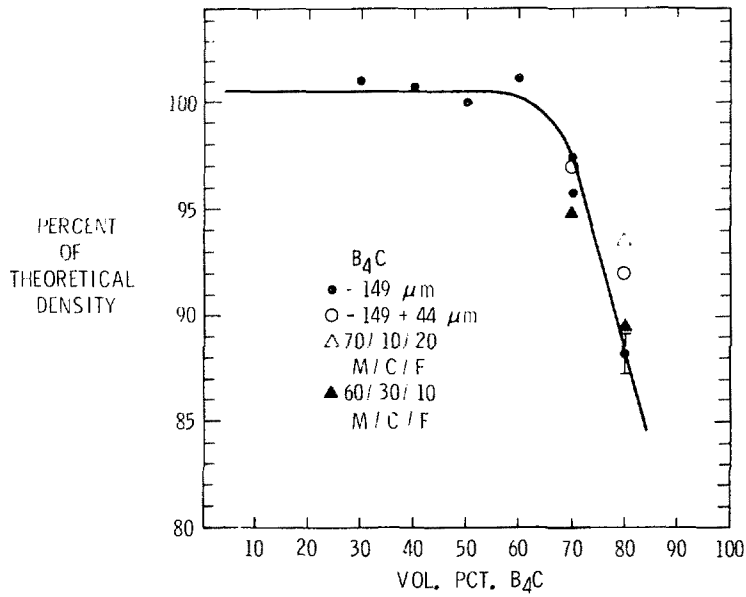
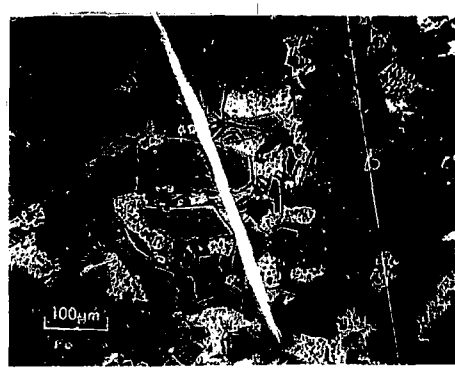


Figure 12. The Influence of B_4C Gap-Grading and B_4C Content on the Pct. Theoretical Density Obtainable in B_4C-Cu Cermets

Figure 13. Microstructures of Gap-Graded and Hot Isostatically Pressed B_4C-Cu Cermets. Sample Identification as Given in Table 4.



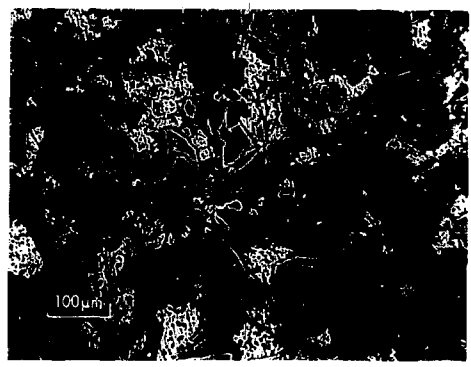
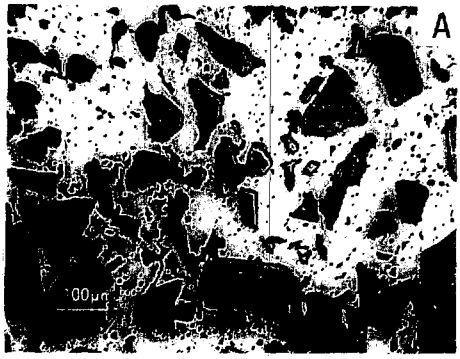


Figure 13

[illegible]

Figure 13



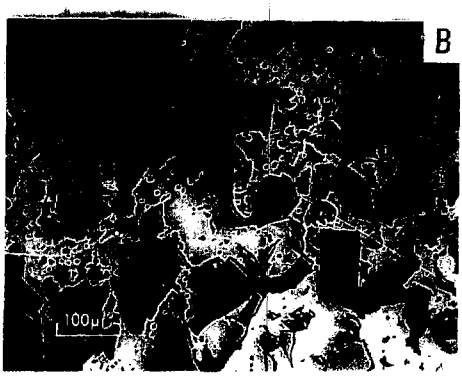


Figure 14: Microstructures of Hot Isostatically Pressed B_4C-Cu Cermets. (a) 30, (b) 40, (c) 50, (d) 60, (e) 70 and (f) 80 Volume Pct. B_4C.

Figure 14

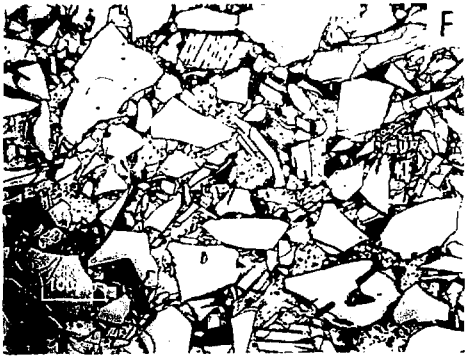


Figure 14

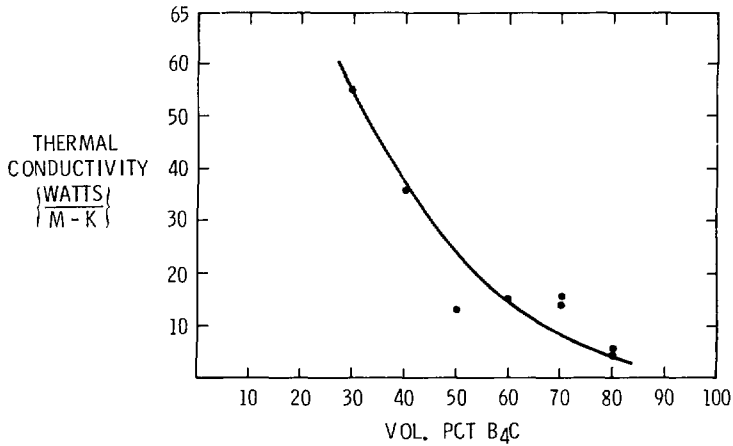


Figure 15. The Influence of B_4C Content on the Thermal Conductivity of Hot Isostatically Pressed B_4C-Cu Cermets

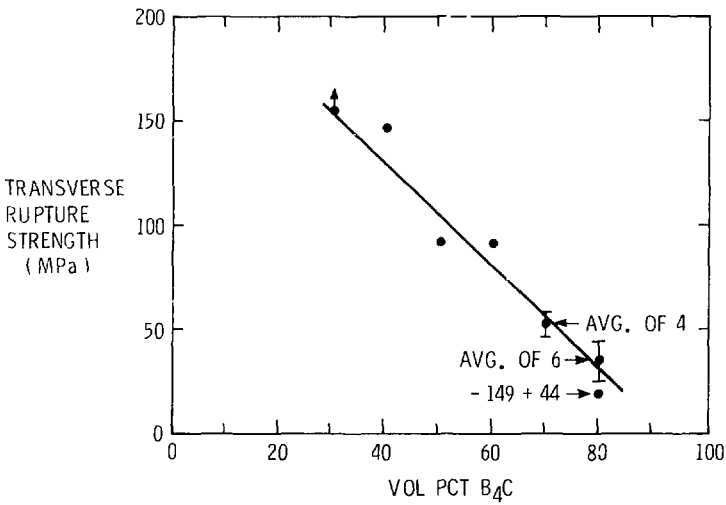


Figure 16. The Influence of B_4C Content on the Transverse Rupture Strength of Hot Isostatically Pressed B_4C-Cu Cermets

Figure 17. Equipment Used for Rheocasting 40 Volume Pct. B_4C-60 Volume Pct. Al-3 w/o Mg Cermet

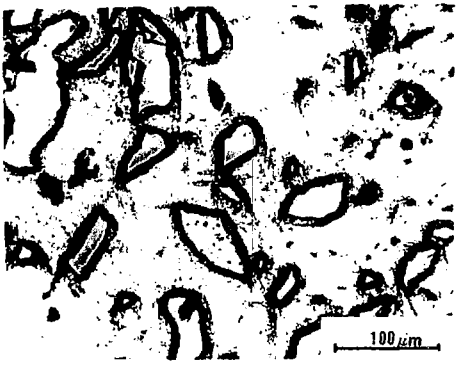


Figure 18. Microstructure of Rheocast 40 Volume Pct. B_4C-60 Volume Pct. Al-3 w/o Mg Cermet

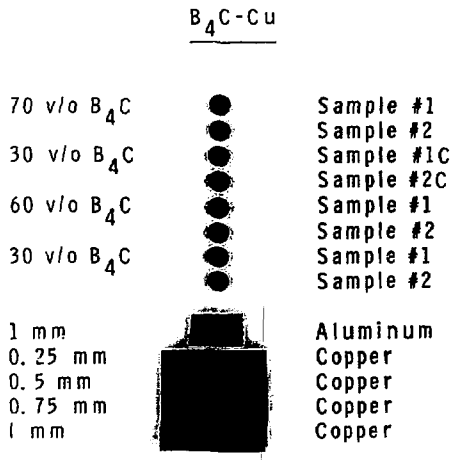
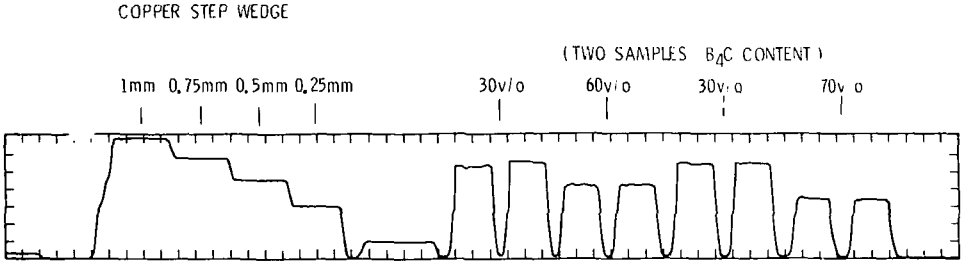


Figure 19. Experimental Set-up for Establishing Radiation Absorption of B_4C-Cu Cermets



EQUIVALENT THICKNESS OF COPPER = T_E =	.66mm	.71mm	.43mm	.68mm	.31mm
ACTUAL THICKNESS = T	ALL SAMPLES = 0.97mm				
VOL. PCT COPPER = TE/T	68	73	44	70	32

Figure 20. Results of X-ray Inspection of B_4C-Cu Cermets

Table 1

Results of Preliminary Experiments Using Vacuum Hot Pressing

	Item+	Vol Pct B_4C	Vol Pct Cu	Temp (K)	Time (H)	Press (MPa)	Pct Theor. Density
HP-1	01	78	22	1173	1	26.9	64
HP-2	01	78	22	1223	1	26.9	60
HP-3	01	78	22	1323	1	26.9	64
HP-4	01	78	22	1428	1	26.9	64
HP-7	03*	78	22	1213	1	26.9	65
NORTON		70	30	1323	0.25	21.0	90
Y-12	04	80	20	1073-1273	?	13.8	72
HP-5	02	60	40	1223	1	26.9	68
HP-6	02	60	40	1178	1	26.9	74

*Copper reduced in H_2 prior to VHP run.

+See Table 2 for chemical composition of Cu powders.

Table 2

Description of B_4C and Cu Powders

Copper	Description	$\bar{d}$* (μ)	Largest $\bar{d}$ (μ)
Item I	lot #022073 Alpha Ventron Stock #00584 (probably 200 mesh)	45	75
Item II	Spherical Copper (-324 mesh)	29	70
Boron Carbide			
Item I	Fisher #B-377 (-325 mesh)	10	44
Item II	High Purity (-100 mesh)	N/A	N/A
Item III	Carborundum Technical Grade (100 P) Lot #585-8-3	65	120
Item IV	Carborundum Nuclear Grade (200 P) Lot #635-32-7	58	125

*Median particle size as determined by Fisher Sieve Analysis

Table 3

Specific Heat of B_4C-Cu Cermets[+]

Temperature, K	Specific Heat (cal/g-K)[*]	
	70 v/o B_4C-30 v/o Cu	30 v/o B_4C-70 v/o Cu
298	0.137	0.104
600	0.205	0.132
900	0.229	0.137

[+]Errors ± 5 pct.

[*]cal/g-K = 418.4 watt/m-K

Table 4

Effect of Gap-Grading B_4C Powders on the

Theoretical Density of B_4C-Cu Cermets[+]

Volume Pct. B_4C	Sample No.	Mixture I.D.	Pct Coarse	Pct Medium	Pct Fine	Pct of Theor. Density	≠ Density g/cc
	1	SB	50	20	30	90.3	3.37
80	2	SD	60	30	10	89.5	3.34
	3	SC	70	10	20	93.6	3.49
	5	SA	0	70	30	83.7	3.12
	6	U	As-Received			87.7	3.27
	4	SD	60	30	10	94.9	4.12
70	7	U	As-Received			95.6	4.15
100	8	OU	As-Received			71.4	1.80
80	A	Hi Purity	As-Received[*]			91.1	3.4
			-149 +105μm	-74 +53μm	-44μm		

[+]Hot Isostatically Pressed: 1073K, 103 MPa

[*]Item II Table II, all others Item III (Table 2)

≠Based on B_4C = 2.52 g/cc; Cu = 8.6 g/cc.

Table 5*

Effect of B_4C Content on the Pct. Theoretical Density of B_4C-Cu Cermets

Sample I.D.	Vol Pct B_4C	Pct Theor. Density**	Density (g/cc)
11	80	88.2	3.29
12	70	97.5	4.23
13	60	101.2	5.01
14	50	100.0	5.56
15	40	100.8	6.22
16	30	101.0	6.85

+Hot Isostatic Pressing: 1073K, 103 MPa, 3h.

*All B_4C was -149 μm TECH GRADE Lot # 585-8-3 (100 F)

**Based on B_4C = 2.52 g/cc; Cu = 8.60 g/cc.

Table 6

*Variation in Density with B_4C Powder Particle Size**

Vol Pct B_4C	Sample No.	Powder Size (μm)	Pct Theoretical Density≠	Density (g/cc)
	11	-149	88.2	3.29
	6	-149	87.7	3.27
80	2	60/30/10	89.5	3.34
	17	-149 + 44	92.0	3.43
	3	70C/10M/20F	93.6	3.49
	12	-149	97.5	4.23
	7	-149	95.6	4.15
90	18	-149 + 44	97.0	4.21
	4	60C/30M/10F*	94.9	4.12

*Hot Isostatic Pressing:
*C = -149 + 105 μm
M = -74 + 53 μm
F = -44 μm
≠Copper powder size is -44 μm in all cases

Table 7

Thermal Conductivity of Boron Carbide-Copper Cermets Hot Isostatically Pressed at 1073K, 103 MPa for Three Hours

Sample I.D.	Vol Pct B_4C	Density g/cc	Pct Theoretical Density	Transverse Conductivity (watts/m-K) at 298
16	30	6.85	100+	55
15	40	6.22	100+	36
14	50	5.56	100	13
13	60	5.01	100+	15
12	70	4.23	97.5	14
18	70*	4.21	97.0	15
11	80	3.29	88.2	4
17	80*	3.43	92.0	5

*Used -149 + 44 μm B_4C, all others used - 149 μm B_4C.

Table 2

Transverse Rupture Data for Boron Carbide-Copper Cermets

Hot Isostatically Pressed at 1073K/103 MPa/3 H*

Sample I.D.	Vol Pct B_4C	Density g/cc	Pct T.D.	Transverse Rupture Strength (MPa)	
1	80	3.37	90.4	30.4	
2	80	3.34	89.5	28.5	
3	80	3.49	93.6	36.7	35.3 avg.
5	80	3.12	83.7	35.0	
6	80	3.27	87.7	37.7	
11	80	3.29	88.2	4[illegible].7	
17	80	3.43	92.0	17.9	
4	70	4.12	86.0	47.6	
12	70	4.23	97.5	59.4	51.7 avg.
7	7[illegible]	4.15	95.6	47.0	
18	70	4.21	97.0	52.7	
13	60	5.01	100+	91.8	
14	50	5.56	100	92.8	
15	40	6.22	100+	146.3	
16	30	6.85	100+	>152	

*Samples machined from billets as per ASTM B-528-70