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6. AUTHOR(S)

M. A. Meyers, J. C. LaSalvia, and D. Hoke

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of AMES
University of California, San Diego
La Jolla, CA 92093
Mail Code 0411DTIC
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13. ABSTRACT (Maximum 200 words)

The objectives of this research program were to apply combustion synthesis and dynamic forging in order to produce fully dense ceramics. The program was successfully carried out but was unfortunately terminated. TiC and TiB₂ ceramics, TiC-Ni cermets, and Al₂O₃-TiB₂ and TiB₂-SiC ceramic-ceramic composites were successfully produced and characterized. The research effort carried out from October 1988 to the present yielded eleven technical publications, of which seven were (or will be) published in archival journals and four in conference proceedings. The work has been presented at eight technical meetings and has been very well received by the community. Three students were supported by this research program. Three M.S. degrees were awarded and two Ph.D. theses are in progress, with projected completion in August 1992 and January 1993. Collaboration with BRL and CERACON was active during this period.

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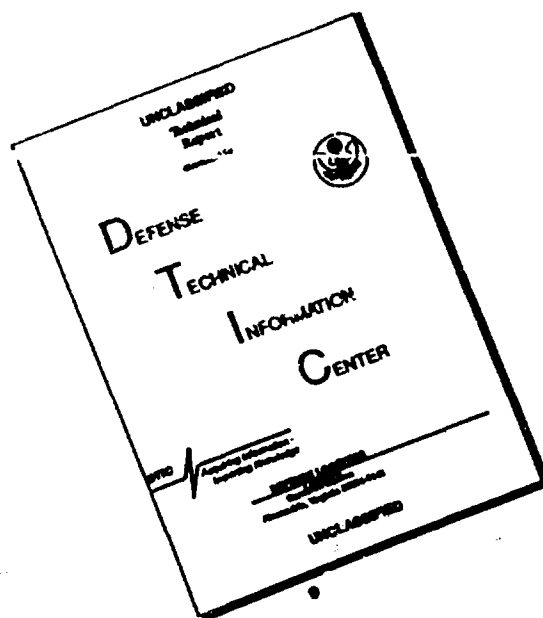
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PRODUCTION AND EVALUATION OF DENSE CERAMIC COMPOUNDS
BY COMBUSTION SYNTHESIS AND DYNAMIC COMPACTION

FINAL REPORT

M. A. MEYERS, J. C. LaSALVIA, and D. HOKE

APRIL 15, 1993

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A. STATEMENT OF THE PROBLEM

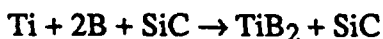
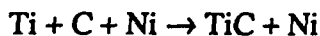
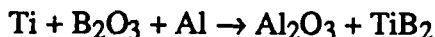
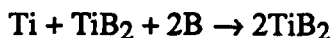
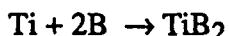
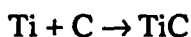
The objective of this research program was to synthesize, by combustion reactions, ceramics, and to densify them dynamically. Two dynamic densification methods were proposed: explosive compaction and high-speed forging. This research is a direct outgrowth of the work conducted at the Ballistic Research Laboratory by Niiler and co-workers [1-3]. These researchers demonstrated the fully dense TiC and TiB₂ disks could be produced by combustion synthesis followed by explosive compaction. The second objective of the program was to assess the mechanical performance and to characterize the microstructure of these ceramics.

Unfortunately, the research program was interrupted in its second year, and it is only due to additional, but limited funds supplied by the U. S. Army Research Office, that the research program is reaching its conclusion. The objectives of the program were not only met, but considerably exceeded, through the enthusiastic activity of the graduate students and visiting scientists. Two new directions taken by the research program were the synthesis/densification of ceramic-ceramic composites and cermets.

B. SUMMARY OF THE MOST IMPORTANT RESULTS

The principal results obtained in this investigation will only be summarized here. The reader is referred to the publications list in Section C for detailed presentation of results.

1. Computer simulations conducted by Dr. M. L. Wilkins showed that the pressures generated in the shock compaction setup developed at BRL by Niiler and co-workers did not produce very high pressures. The calculated pressures were of the order of 350 MPa. This rendered the use of high-speed forging a viable method.
2. A DYNAPAK high-speed forging machine was acquired and modified to produce dense compacts from combustion synthesis products.
3. During the period 1988-1993, different materials were produced by the combined combustion synthesis/dynamic densification technique.



4. These materials were characterized by optical, scanning, and transmission electron microscopy and their quasi-static and dynamic strength was determined.

5. Quasi-static densification experiments were performed in an instrumented compression machine to establish the mechanisms for densification of the combustion synthesis products and the effect of different metallic additives.
6. A temperature measuring apparatus was constructed to establish the combustion-wave propagation velocities and the cooling of compacts.
7. In collaboration with CERACON, a novel specimen confinement configuration was used. The use of a powder as a pressure transmitting medium resulted in the improvement of compact integrity for some compositions.
8. A collaboration was developed with Los Alamos National Laboratory through the extended visit of Mr. D. Hoke. This visit is being funded by Associated Western Universities and should have a minimum duration of six months.

C. PUBLICATIONS

A total of eleven publications resulted from this research. Of these, seven are in archival journals (two pending acceptance) and four in conference proceedings.

1. J. LaSalvia, L. W. Meyer, D. Hoke, A. Niiler, and M. A. Meyers, "Reaction Synthesis/ Dynamic Compaction of Titanium Carbide and Titanium Diboride", in "Shock Waves and High-Strain-Rate Phenomena in Materials", eds., M. A. Meyers, L. E. Murr, and K. P. Staudhammer, M. Dekker, 1992, p. 261-270.
2. L. W. Meyer, J. C. LaSalvia, and M. A. Meyers, "Densification of Reaction Synthesized Titanium Carbide by High-Velocity Forging", *J. Am. Cer. Soc.*, **75**, 1992, 592-602.
3. D. A. Hoke, M. A. Meyers, L. W. Meyer, and G. T. Gray III, "Reaction synthesis/Dynamic Compaction of Titanium Diboride", *Metallurgical Transactions A*, **23A**, p. 77-86 (1992).
4. M. A. Meyers, L. W. Meyer, K. S. Vecchio, and U. Andrade, "High Strain, High Strain-Rate Deformation of Copper", *Proceedings of Third International Conference on Mechanical and Physical Behavior of Materials under Dynamic Loading*, (DYMAT 91), Strasbourg, France, October 14-18, 1991. *Journal de Physique*, IV, C3-11-18 (1991).
5. M. A. Meyers, J. C. LaSalvia, L. W. Meyer, D. Hoke, and A. Niiler, "Reaction Synthesis/Dynamic Compaction of Titanium Carbide and Titanium Diboride", *Proceedings of Third International Conference on Mechanical and Physical Behavior of Materials under Dynamic Loading*, (DYMAT 91), Strasbourg, France, October 14-18, 1991. *Journal de Physique*, IV, C3-123-130 (1991).
6. K. S. Vecchio, J. C. LaSalvia, M. A. Meyers, G. T. Gray III, "Microstructural Characterization of Self-Propagating High-Temperature Synthesis/Dynamically Compacted and Hot Pressed Titanium Carbides", *Met. Trans. A*, **23A**, p. 87-97.
7. J.-M. Jamet and M. A. Meyers, "Combustion Synthesis/ Densification of an $\text{Al}_2\text{O}_3\text{-TiB}_2$ Composite," *Met. Trans.*, accepted.

8. M. A. Meyers, J. C. LaSalvia, D. Hoke, J.-M. Jamet, and D. K. Kim, "Combustion Synthesis/Densification of Ceramics and Ceramic Composites," *Proceedings of International Conference on Advanced Synthesis of Engineered Structural Materials*, September, 1992, ASM International, Ohio, 1993, 43-50.
9. D. K. Kim, J. C. LaSalvia, D. A. Hoke, and M. A. Meyers, "Combustion Synthesis/Dynamic Compaction of TiB₂-SiC Composite", *J. Am. Cer. Soc.*, submitted.
10. D. A. Hoke, D. K. Kim, and M. A. Meyers, "Densification of Combustion Synthesized Titanium Diboride," *J. Am. Cer. Soc.*, submitted (1993).
11. J. C. LaSalvia and M. A. Meyers, "A Novel Processing Method for the Fabrication of Dense TiC-Based Cermets," in preparation (1993).

D. PARTICIPATING SCIENTIFIC PERSONNEL

During the period in which this program was funded, three graduate students, one undergraduate student, two visiting scientists participated in the research.

The three graduate students are:

J. C. LaSalvia, M.S., 1990	Ph.D. in progress
D. Hoke, M.S., 1991	Ph.D. in progress
J. M. Jamet, M.S., 1992	Returned to France.

Of these three students, two are still actively engaged in combustion synthesis research at UCSD. Mr. J. C. LaSalvia is funded currently by a Fellowship from the U. S. Army Research Office made possible by Professor S. Nemat-Nasser. However, his support ends on April 30, 1993. He is expected to complete his Ph.D. by September 1993. Mr. J. C. LaSalvia has been supported by the current program since September 1988.

Mr. D. Hoke joined UCSD in 1990 and is currently at Los Alamos National Laboratory working in collaboration with Dr. G. T. Gray. He is carrying out a testing and characterization program on TiB₂ and TiB₂ + SiC compacts produced by SHS, comparing their properties with TiB₂ processed by hot pressing at CERCOM. He is expected to complete his Ph.D. by January 1994.

Dr. L. W. Meyer was involved with the program from August 1989 to August 1990 and contributed greatly to it. He was instrumental in rendering the DYNAPAC operational and in carrying out quasi-static and dynamic mechanical tests on TiC.

Dr. D. K. Kim, a scientist from Taejon, South Korea, spent the period February 1992 - February 1993 as a visiting scholar at UCSD. He was supported by his host institution and did not require support from ARO. He was responsible for modifying the DYNAPAK and for developing the temperature-measurement and compression-test systems.

Both Dr. D. K. Kim and Mr. J. M. Jamet plan to continue actively in this area at their home institutions.

One graduate student was supported by this program for six months. Mr. R. Kanemoto was extremely helpful in the program and learned a great deal.

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1. A. Niller, T. Kottke, and L. Kecskes, "Shock Consolidation of Combustion Synthesized Ceramics," in *Proc. First Workshop on Industrial Applications of Shock Processing of Powders*, New Mexico Tech., Socorro, NM (1988) 901.
2. A. Niiler, L. J. Kecskes, T. Kottke, P. H. Netherwood, Jr., and R. F. Benck, "Explosive Consolidation of Combustion Synthesized Ceramics: TiC and TiB₂, Ballistic Research Laboratory Report BRL-TR-2951, Aberdeen Proving Ground, MD, December 1988.
3. A. Niiler, L. J. Kecskes, T. Kottke, in *Shock-wave and High-Strain-Rate Phenomena in Materials*, eds. M. A. Meyers, L. E. Murr, and K. P. Staudhammer, M. Dekker, NY, 1992, p. 293.