

FINAL TECHNICAL REPORT  
January 1, 2005, through September 30, 2005

Project Title: **INTERMETALLIC-BONDED DIAMOND TOOLS FOR COAL MINING– PHASE II**

ICCI Project Number: DEV04-2  
Principal Investigator: Peter Filip, CAFS SIUC  
Other Investigators: Dale E. Wittmer, SIUC  
Project Manager: Francois Botha, ICCI

ABSTRACT

For over 50 years researchers and industries involved in development of wear resistant materials have been searching for a way to produce materials containing diamonds because of their high hardness and wear resistance. Most of these processes use resin or ductile metal binders with pressure or low temperature processes to achieve compaction and usable strength. Higher temperature metals as binders have not been successful until this work, because the diamonds either react with the metal and oxidize or are converted to graphite. If converted to graphite they are no longer strong and hard, and they cannot be used in wear applications. In Phase I of this project the feasibility of producing intermetallic bonded diamond (IBD) composites was proven. The resulting IBD composites were tested by Robert Bosch Tool Co. and found to be an astonishing 800 times more wear resistance compared to their most wear resistant WC. Although the IBD composites demonstrated this superior wear performance, additional work was required to further optimize the processing and production of this new class of hard materials.

The goals of this Phase II research were to: optimize the processing and formulations, investigate alternative densification mechanisms, investigate methods of bonding IBDs to other materials, and to continue wear and performance testing.

IBD processing and formulations were optimized, resulting in the identification of two modified IBD formulations that appear to have promise for mining applications. While hydrogen-vacuum sintering was not successful in improving densification, densification by hot isostatic pressing (HIP) was successful. Bonding of IBD to intermetallics, other IBDs and to standard tool steel was investigated with success in all categories. Wear and wear performance in standard screening tests were found to be exceptional. Based on these results, additional funding was requested from and approved by ICCI for IBD prototype development and demonstration for FY06.

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## EXECUTIVE SUMMARY

### BACKGROUND

Coal mining can benefit from improvements in the technology used to mine and handle coal. As the price of oil continues to increase, the benefits derived from coal as a source of energy increase. The development and production of a mining tool bit that maintains its cutting edge longer than current materials and is strong and tough enough to withstand the forces involved in coal mining operations would be of great benefit to the mining industry. This new tool is expected to also produce less dust, which has obvious health and safety advantages. Advances in recent years in intermetallic matrix materials that contain diamonds have spawned a potentially new generation of hard materials, intermetallic bonded diamond (IBD) composites. Development and production of a new IBD mining tool could also lead to additional manufacturing jobs in Southern Illinois.

Current coal mining bits and drills contain tungsten carbide (WC) bonded with cobalt (Co). These tools have been used for many years and over the years these cutting bits have been redesigned to take advantage of the hardness and toughness of these cutting tools. The major problem with the current bits is related to failure of the tip itself or the wear of the steel body, allowing the tip to be undercut and pulled out. W and Co are both strategic materials which must be imported and the US would benefit from reduced dependence. For many years, researchers have been looking for a way to embed diamonds into metals to improve their wear resistance and sharpness of tools. The major problem with embedding diamonds is the poor oxidation resistance and thermal stability of the diamonds during the processing of the metal binder. This was proven in numerous experimental and theoretical works where attempts were made to embed diamonds in a Co matrix.

In Phase I of this project, supported by ICCI, the feasibility of embedding diamonds in an intermetallic matrix was proven. Over 50 IBD composite formulations were made, densified and tested. Hot pressing was found to be the best method for densification. One of our industrial partners, Robert Bosch Tool Co., reported that some of the IBDs selected had **800 times greater wear resistance** when compared with their most wear resistant WC. Based on the apparent success of Phase I, a proposal was made to and accepted by ICCI for Phase II funding.

### EXPERIMENTAL AND TESTING

One of the experimental goals was to optimize the IBD formulations with respect to volume fraction of intermetallic and size of diamond. As part of the optimization, metal coated diamonds were also investigated. Modification of the intermetallic by alloying elements was continued with support from differential scanning calorimeter (DSC) results. Alternate means of densification were also investigated, including: hot isostatic pressing (HIP) and hydrogen-vacuum sintering (by Robert Bosch Tool Co.). The

investigation of bonding of IBD to other materials was explored in Phase II with the assistance of Robert Bosch Tool Co. Wear testing and investigation of the wear were continued as previously reported in Phase I. Wear was also investigated by the fabrication and testing of an IBD drill bit.

## RESULTS AND CONCLUSIONS

The processing methods used previously to process the IBD formulations were continued in Phase II. To date approximately 80 formulations have been processed and investigated with respect to densification, microstructure and wear performance. To this end, IBD formulations containing 30 and 50 vol% intermetallic were identified as having the most promise for mining related applications. The diamond size was optimized around a mean size of 100  $\mu\text{m}$ . The incorporation of metal coated diamonds did not produce any enhancement of densification or performance for the IBDs investigated. DSC results were used to identify problems with early liquid formation during reaction sintering of the Ni and NiAl when B was present. As a result B was removed as one of the alloying elements and densification by hot pressing was improved. Higher temperatures and pressures could be used during hot pressing with the absence of B, resulting in higher density and lower apparent porosity.

Alternative sintering by using a hydrogen pre-sinter step followed by vacuum sintering was investigated as a means of improving pressureless sintering of the IBDs. Two trials containing 25 IBD formulations were made by Robert Bosch Tool Co. None of the formulations were successfully sintered to high density by this method. HIP processing using Ti and Fe cans was successful in producing higher density IBD parts than had previously been observed by hot pressing. This process adds considerable cost that may not be warranted, based on the need to keep production costs as low as possible.

Bonding of IBDs to alternate materials was investigated. IBDs were bonded by self-diffusion to the base intermetallic and to other IBD formulations containing lower amounts of diamond. The interfaces were strong and show promise for the production of tools where only part of the volume contains diamonds. Brazing was also investigated at SIU and with the assistance of Robert Bosch Tool Co. Vacuum brazing using a Wesgo Cu-Sil braze was found to be successful for a wide range of IBD formulations (Figure 1). Likewise, active metal brazing was found to be successful for brazing IBDs to steel (Figure 2) and bronze welding braze (found in all welding shops) was used to braze a prototype IBD tip into a steel drill body (Figure 3).

High wear resistance was improved by the addition of alternate metal carbide to the original IBD formulation. This increased the coefficient of friction and increased the wear of the cast iron during friction assessment and screening tests (FAST). Wear of the cast iron disk is shown in Figure 4. Wear performance was also demonstrated by using the prototype IBD drill bit to drill through concrete and brick (Figure 5).



Figure 1. Vacuum Cu-Sil braze between IBD and carbon steel bolt head.

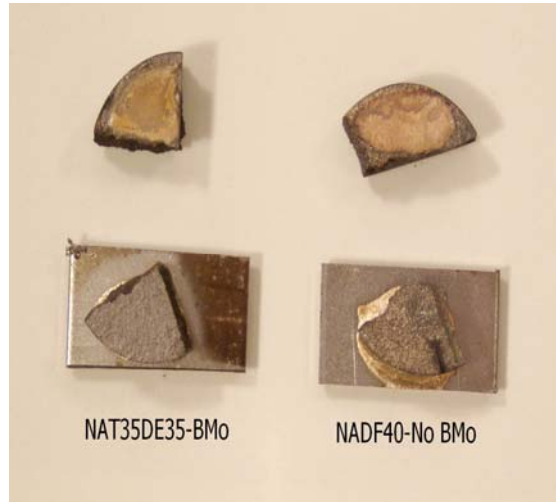


Figure 2. Active metal braze for two IBD formulations, alone and attached to steel.



Figure 3. Standard bronze wire braze used to attach IBD tip to steel drill bit body.



Figure 4. IBD wear on cast iron after FAST testing for 9 hours.

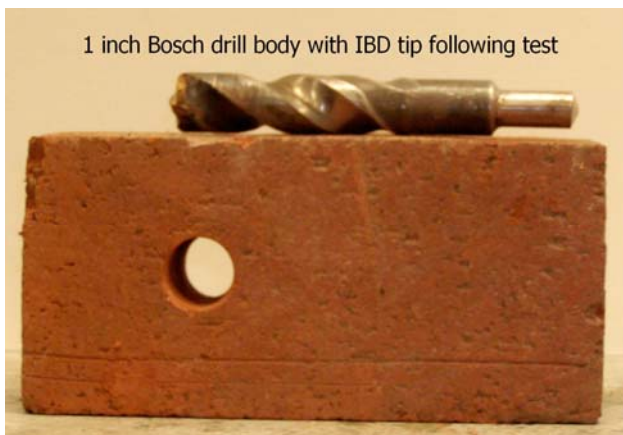


Figure 5. IBD drill and brick after drilling tests.

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