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SYNTHESIS AND PROCESSING OF INCONEL INFILTRATED B_6O/B_4C ROCK CUTTERS

FINAL REPORT

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For development of ultra-deepwater petroleum resources through deep, hard rock formations to be economically viable, costs associated with drilling hard rock under high-temperature, high-pressure conditions must be significantly reduced. Cheaper drag-bit cutters with improved high-temperature properties compared to polycrystalline diamond compact (PDC) would be significant enabling technology for the economical development of these resources. Novel composites composed of boron suboxide (B_6O) and boron carbide (B_4C) demonstrate good hardness and cutting performance compared to PDC cutters of the same design, but are limited by their reactivity with the metal binder at elevated temperatures. We have applied a coating of TiB_2 to these powders through a DOE optimized sol-gel process to reduce reactivity during processing with Inconel 718 and Udimet 720 binders. Coated powders were processed by both hot pressing and isostatic pressing followed by pressureless metal infiltration. Samples were characterized by X-ray diffraction, metallography, and hardness testing. This has resulted in samples with average hardness values between 987 and 1461 VHN comparable in structure and properties to tungsten carbide/ cobalt composites.

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Introduction and Literature Review

PDC Failure Mechanisms

The use of PDC drag-cutting drill bits has become common practice in the oil and gas drilling industry over the last three decades. In soft and medium hard formations, these bits exhibit at least twice the penetration rate of a traditional roller bit [1]. Currently, PDC drill bits hold records for drilling rate, footage drilled in a single run, and net durability. These advantages in drilling performance over rotary bits can easily result in drilling savings of up to $100,000 for a single bit run, and has generated a market for these bits in excess of $200 million per year [2].

One significant disadvantage of PDC bits is the high principal cost of the individual PDC cutters. Production of traditional PDC cutters requires multiple, ultra-high-pressure hot pressing steps carried out at 1600-1800°C and 6-7 GPa. These pressures and temperatures are only attainable in anvil style hot presses used for diamond synthesis. This places severe limitations on the production volume and the cycle rate of the production apparatus. Small sample volumes, long cycle times, and the steeply exponential nature of the cost/processing pressure relationship cumulatively result in individual cutter costs in excess of $100.

When these bits are used to drill hard formations in ultra-deep, hot holes, the drilling rate and lifetime of commercially available PDC bits are dramatically reduced. Failure in individual PDC cutters is due principally to increased impact loading and the higher drilling temperatures associated with an increased wear flat between the bit and the hard rock surface being cut. Above 350°C, the tungsten carbide-cobalt (WC/Co) backing disk softens to the same relative hardness as quartz particles in the drilling surface [3]. This causes a dramatic increase in abrasive wear in the backing disk which, in conjunction with the increased impact loading, reduces or eliminates the self-sharpening effect of the cutter [3]. These same temperature conditions also cause large tensile stresses in the diamond overlay due to thermal expansion mismatch between the WC/Co backing disk and the overlay material. Differential thermal expansion of the entire cutter also causes compressive stresses in the wear-flat region of the WC/Co backing disk that can surpass the compressive strength of the material [3]. These effects accelerate with increasing temperature up to the stability limit of the diamond face at 750°C.

The poor temperature stability of traditional PDC cutters has been partly addressed with the current generation of TSP cutters which are stable up to 1200°C and show decreased wear above 350°C. However, this additional thermal stability comes at the price of reduced fracture toughness in the diamond overlay as a result of using a silica binding phase instead of the cobalt that is used in traditional PDC cutters. Furthermore, the TSP overlay is difficult to attach to the WC/Co backing disk, requiring preferential heating of the overlay to avoid a disadvantageous residual stress profile in the attached cutter.

B_6O/ B_4C Mechanical Properties

Boron suboxide (B_6O) and boron carbide (B_4C) are covalent ceramics which are notable for their high hardness which is reported between 30 and 38 GPa [4-7] . The only materials which are known to be harder are diamond and cubic boron nitride, both of which cannot be synthesized except under ultra high pressures. Recently, B_6O/B_4C composites have been characterized in the literature with hardness values as high as 46 GPa, but exhibit very low fracture toughness (0.5-1.0 MPa√m) in this condition [8]. These results are interesting because the composite hardness values reported in [8] are within 4 GPa of the 50 GPa hardness that is commonly reported for PDC.

Sol-Gel Formation of TiB_2 on B_4C

Based on previous work [9], we have found B_6O and B_4C powders to be highly reactive in most molten metals, and are accordingly difficult to form into metal containing composites without changing the morphology of the precursors. Lee and Kang [10] demonstrated an interesting solution to this problem as encountered in the formation of B_4C-Al composites. In this work, Lee and Kang demonstrated that sol-gel solutions based on titanium isopropoxide could be used to form TiO_2 films on the outer surfaces of B_4C powder particles. During subsequent thermal processing, the sol-gel derived TiO_2 film reacts with the underlying powder surface to form TiB_2 above 1000°C according to Equation 1.

$$\boxed{Equation\ 1:\quad B_4C + TiO_2 \quad \Rightarrow \quad TiB_2 + CO_2}$$

During infiltration with aluminum metal at temperatures up to 1200°C, the TiB_2 coating generated through this reaction was able to suppress reactions between the B_4C precursor powder and the aluminum melt. Initial thermodynamic calculations indicate that this protection should also extend to nickel and chrome based alloys at temperatures up to 1600°C.