

Faster and Longer Bit Runs With New-Generation PDC Cutter

A new process for manufacturing polycrystalline-diamond compact (PDC) cutters creates a wrapped thermostable region across the face and around the periphery of the PDC cutter. This differs significantly from existing first-generation thermostable product because the treated region has complex geometry in three dimensions. The full-length paper describes the new cutter geometry and shows how the thermostable region supports the cutter as it slowly wears.

Introduction

Historically, there has been a trade-off between abrasion and impact resistance of PDC cutters. Typically, impact resistance was achievable by use of a larger diamond grain size but at the expense of abrasion resistance. The first attempts to extend the envelope of PDC-bit and -cutter performance occurred in the mid-1990s when multimodal polycrystalline diamond was introduced. This used a mixture of grit sizes from 50 to 2 μm in diameter, allowing the smaller grits to fill the voids left between the larger particles, resulting in a much denser polycrystalline-diamond layer that improved abrasion resistance.

Additional improvement was achieved by use of nonplanar interfaces. The move from planar to nonplanar interfaces was driven by a desire to reduce stresses at the interface between the polycrystalline diamond and its tungsten carbide substrate.

This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 102067, "Faster, Longer, and More-Reliable Bit Runs With New-Generation PDC Cutter," by J. Clegg, SPE, ReedHycalog, prepared for the 2006 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 24–27 September.

The introduction of the nonplanar interface combined with the multimodal polycrystalline-diamond mix provided significant improvement in both relative toughness and relative wear life over planar multimodal materials. The thicker diamond edge that resulted improved relative abrasion life.

Thermostable PDC Cutters

Cobalt normally is present in the creation of polycrystalline diamond in the PDC press. It is introduced in the tungsten carbide support, where it acts as a cement. At the elevated temperature and pressure where diamond-to-diamond bonding occurs, the cobalt migrates into the diamond grit and helps to catalyze the bonding process. It also forms a bond with the tungsten carbide substrate and ensures that the PDC is one integral component. However, cobalt significantly reduces the thermal stability of the PDC because it has a greater coefficient of thermal expansion than the surrounding diamond particles. Between 700 and 760°C, the cobalt expands and forces the diamond-to-diamond bonds apart. This results in the rapid breakdown of the compact. What appears to be abrasive wear when a dull PDC bit is analyzed often can be the result of the breakdown of the diamond-to-diamond bonds because of overheating. Therefore, it is important that the temperature of the PDC cutter is maintained below 700°C to avoid thermal breakdown. Unfortunately, the cutting-tip temperature often exceeds this critical limit.

Thermally stable product (TSP) diamond can be manufactured to overcome the temperature limitations of PDC. This can be made either by leaching synthetic diamond with acid to remove all of the cobalt or by adding silicon to form silicon carbide (by reaction with the diamond particles) to act as a

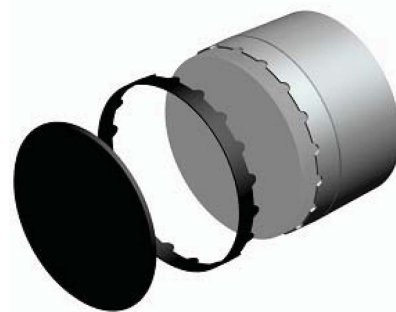


Fig. 1—New-generation thermostable PDC cutter.

binder phase for the diamond in place of the cobalt. The removal of cobalt, or the low thermal-expansion coefficient of the silicon carbide, ensures that these TSP materials are thermally stable to temperatures higher than 1150°C. However, because of the lack of cobalt in the structure, these forms of TSP are not readily "wetted" by braze alloys and must be retained mechanically. In addition, the removal of cobalt significantly weakens the mechanical structure, and the abrasion resistance of TSP is an order of magnitude less than that of PDC because its structure is designed to be more open to allow total leaching. The thickness necessary to provide structural strength precludes an effective self-sharpening action.

It was the partial removal of cobalt, by partial and preferential leaching, that provided the long-awaited breakthrough. Taking a pressed PDC and leaching the cobalt to a predetermined depth created a completely new class of cutter—thermostable PDC cutters.

As the cutter wears, a lip is generated from the preferential wear of nonleached, nonthermostable polycrystalline diamond because of thermal breakdown at temperatures greater than 700°C. The relatively thin, leached layer at the front of the cutter does not

For a limited time, the full-length paper is available free to SPE members at www.spe.org/jpt. The paper has not been peer reviewed.



Fig. 2—Dull 616 bit.

have the same temperature limitation and wears more slowly. This clearly demonstrates that cutting-tip temperatures do exceed 700°C.

When introduced commercially, these new cutters generated significant improvements in abrasive life as a result of thermal stability. Significant improvements in rate of penetration (ROP) also were achieved, partly by delaying the onset of wear and partly as a result of stress concentration in the rock resulting from the formation of the distinctive lip.

As well as improving performance in conventional PDC bit applications, this also allowed PDC bits to drill formations that had been believed to require insert bits. As a result, in 2005, PDC-bit sales exceeded U.S. \$1,000,000 and accounted for more than 50% of footage drilled for the first time.

New-Generation Thermostable Geometry

Where the existing thermostable designs had a 2D leached layer, the new-generation cutters extended it into 3D space. The leached layer across the face of the cutters was supplemented with a “ring” of leached material around their periphery (**Fig. 1**). This was expected to improve performance in three ways. First, the presence of additional thermostable material in the region of the cutting tip further delays the onset of wear compared with the first-generation thermostable cutters. This, in turn, delays both the development of wear flats and the point at which the tungsten carbide substrate begins to rub on the formation. Once the carbide begins to rub, heat dissipa-

tion from the cutting region is compromised and cutter wear is accelerated. Second, once the thermostable material eventually wears, a “dual-lip” cutting structure develops. This enhances ROP because both edges cut the rock. Third, a crescent-shaped lip is formed that supports and supplements the lip observed in first-generation thermostable cutters. This may make the overall cutter tougher—through improved geometry—and, in particular, more resistant to reverse cutter motion and to axial impact loads.

Laboratory Tests

Laboratory tests were conducted to evaluate potential impact and wear resistance. Impact testing showed no significant difference in material properties from the previous generation of thermostable cutters or from the multimodal, nonplanar-interface cutters that preceded them.

One wear test required that the cutter be plunged into a premachined quartzite block and traversed across it as the block was rotated, to simulate the cutting action downhole in a full-scale drill bit. The onset of wear and thermally induced damage was accelerated because the cutter was run with no cutting fluid. The test terminated when the cutter burned out and a black line appeared on the rock, indicating gross graphitization of the base polycrystalline-diamond material. The new-generation thermostable material showed a 75% improvement in wear resistance over existing thermostable cutters and an even more impressive 270% improvement over base material. All tests were conducted on chamfered

13-mm-diameter×13-mm-long PDC cutters. The results were consistent and repeatable and promised sufficiently dramatic improvement to move to controlled field tests.

Field Tests

Forty bits were built for controlled field testing. The tests were designed so that the only change was to the cutter type, so that any overall change in performance could be attributed to the new cutters. Second, the performance improvement observed would be with reference to the existing first-generation thermostable cutters, which had already established significant performance improvements over premium-quality nonleached PDC cutters.

The field results with the new cutters showed very significant improvements in performance over the existing first-generation thermostable-cutter-equipped bits in hard, abrasive formations. The best improvement in footage drilled in an individual case was 349%. In terms of ROP, the best individual improvement achieved was 144%. Mean improvements were 43% mean improvement in footage drilled and 26% mean improvement in ROP.

The improvement in footage drilled clearly results from the superior abrasion resistance of the cutters, as evidenced in laboratory testing. The improvement in mean ROP arises from delaying the onset of significant wear to the cutter and maintaining the cutter in a sharper, more-efficient form for a longer time.

Recent Field Results

Since commercialization, many bits with the new-generation thermostable

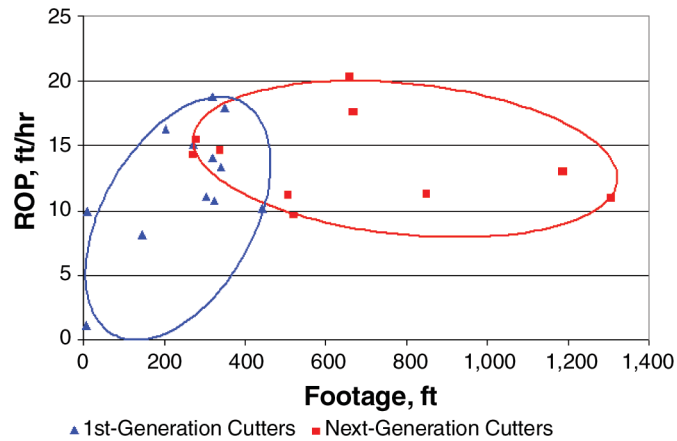


Fig. 3—Scatter plot of ROP vs. footage drilled.



Fig. 4—Bit used in Case 2.

cutters have been run successfully. The full-length paper presents six case studies to illustrate performance benefits.

Case 1. An 8¹/₂-in.-diameter, 6-bladed, 16-mm-cutter (616) bit was run on a point-the-bit rotary-steerable system in the Cretaceous and Jurassic formations of the U.K. sector of the North Sea. Typically, drilling the section required two or three bits. This bit drilled it in a single run. ROP was limited by equivalent-circulating-density considerations, but the bit broke the field record for footage drilled. The field record of 1380 m had been set by the same bit design equipped with first-generation thermostable cutters. The second-generation bit drilled 2408 m, shattering the field record by 75%. The dull condition after this run was very good (**Fig. 2**).

Case 2. A 6¹/₈-in.-diameter, 8-bladed, 13-mm-cutter (813) bit is regularly used to drill the very hard and abrasive Cotton Valley formations in Jackson Parish, Louisiana. This bit is equipped with a full-ring gauge design successfully used in the area with first-generation thermostable cutters. In this location, six bits of this design have been used with first-generation thermostable PDC cutters and nine bits with the new-generation thermostable PDC cutters. The bits have been run through similar formations, average depth in for the two sets of runs differs by only 18 ft. **Fig. 3** shows a scatter plot of ROP vs. footage drilled for the two sets of runs. On average, the new-generation thermostable-cutter-equipped bits have drilled with a 6% improvement in ROP and a 91% improvement in footage. **Fig. 4** shows the bit. JPT