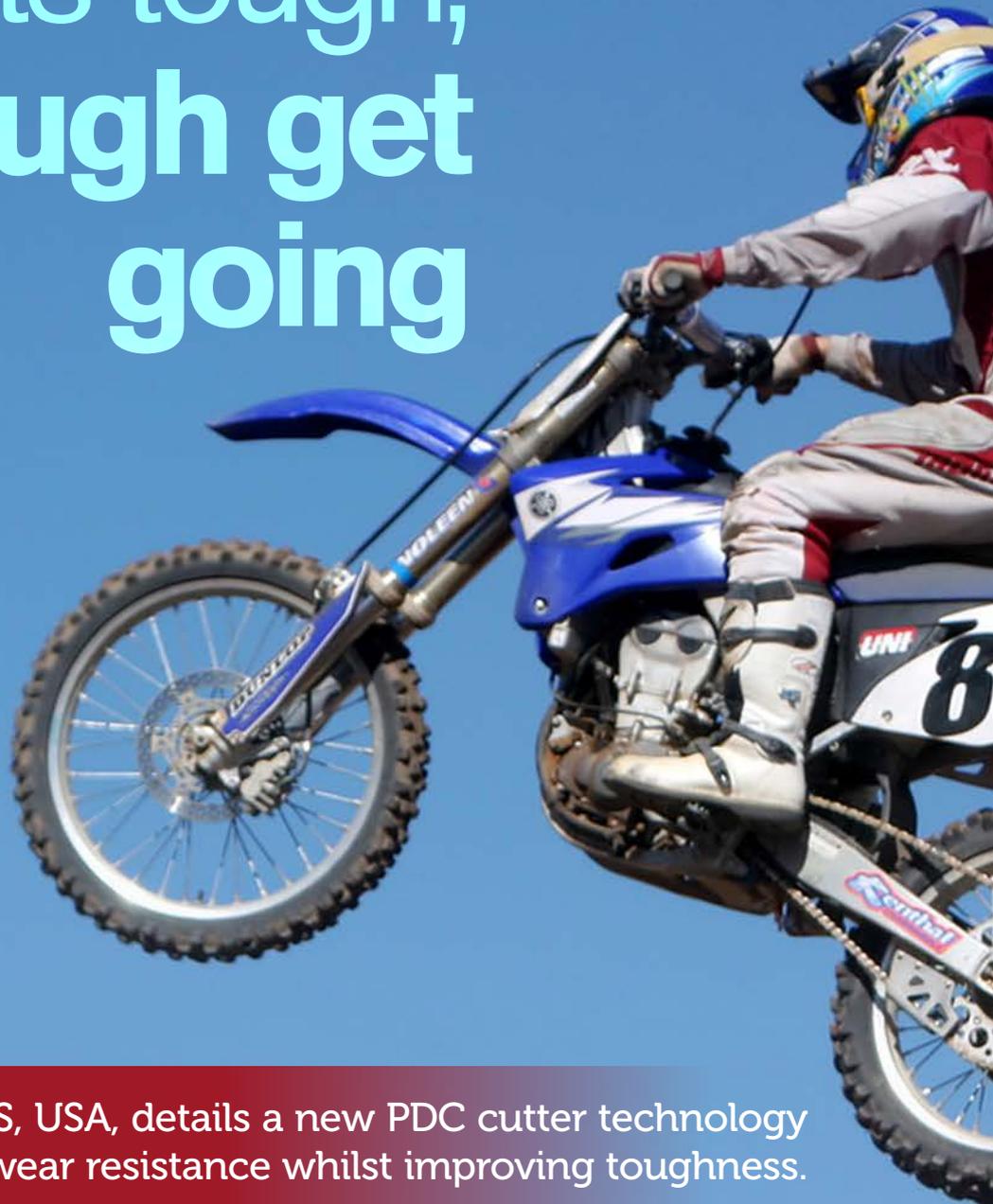


When the going gets tough, the tough get going



Tim Beaton, SHEAR BITS, USA, details a new PDC cutter technology which retains wear resistance whilst improving toughness.

Twenty years ago, the vast majority of holes drilled around the globe in the pursuit of oil and gas were drilled with rollercone bits. At that time, PDC bits generally only drilled very soft and homogeneous rock. Since then, the trend has been rapidly changing, with PDC bits taking an ever increasing share of the total footage drilled around the world.

There are many factors that have influenced this change in the industry, but one of the most significant has been the advancement of PDC cutter technology and performance. In the 1990s, the progression of PDC bit usage saw an increase in momentum, largely due to improvements in design that addressed downhole drilling dynamics. However, starting shortly after the turn of the century, PDC bit

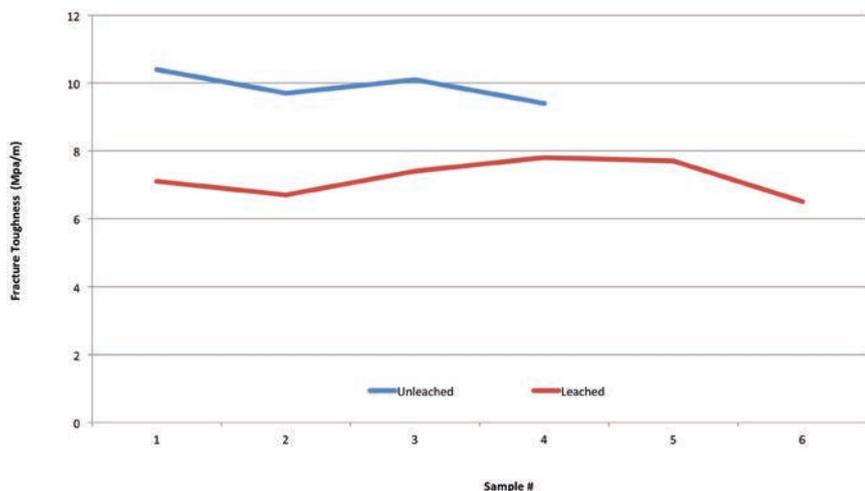


Figure 1. Fracture toughness of leached versus unleached cutters of identical configuration.



Figure 2. Dull condition of first SHEAR BITS 16 in. SV613 run with HD Cutters™.



Figure 3. Dull condition of second 16 in. SV613 with HD Cutters.

performance experienced a step change due to a corresponding step change in the wear resistance of PDC cutters brought upon by the introduction of leaching technology. By the middle of the first decade of the 21st century, most bit manufacturers had adopted the practice of leaching the outermost surface of PDC cutters to enhance wear resistance, and while not a new concept to the world of polycrystalline diamond (PCD), the adoption of this technology in the field of PDC bits yielded exceptional results. The overall wear resistance of PDC bits increased by an extraordinary margin, catapulting them into new applications where they were previously unsuitable.

Today, it is estimated that up to 80% of the footage drilled in the oil and gas industry is performed with PDC bits, and wear resistance is generally no longer a limiting factor for bit performance. The leaching process has dramatically reduced wear issues for nearly all applications, leaving chipping and breakage as the primary mode of PDC cutter failure. A new PDC cutter technology, however, has recently become available that addresses the impact damage issue by increasing cutter toughness while retaining good wear resistance.

Technology outperforming itself

There has been a shift change in the industry – until very recently, there were many applications where PDC bits could not effectively drill the formation, and that was the main reason that rollercones drilled a large percentage of the wells in the world.

Today, however, PDC bits are capable of drilling in almost any application encountered in the industry. The few remaining applications dominated by rollercones are in very specific formations such as gravel or conglomerates, but those formations comprise little of the 20% of remaining rollercone applications. Rather, the majority of rollercone usage in the world is now due to economic reasons instead of performance reasons. The decline of rollercones not only represents a major change in the industry, but also exemplifies the current state of PDC bit technology. In nearly all applications, the challenge for PDC bits is no longer to outperform rollercone bits, as it has been for the last 30 years, but rather to outperform themselves in an effort to continually improve drilling performance and reduce drilling costs.

Today, there is another step change underway in the world of drilling performance, and it is coming as a result of a new PDC cutter technology that produces equivalent wear resistance to leaching, but without a corresponding decrease in toughness. HD Cutters™ (high-density cutters) from SHEAR BITS are manufactured in a novel process, using much higher pressure than conventional PDC cutters, and the result is a highly dense diamond structure that combines enhanced wear resistance with enhanced toughness.

Wear resistance and toughness

Wear resistance in PDC cutters is a function of both abrasion resistance and thermal stability. Generally speaking, abrasion resistance improves with smaller diamond grain size and thermal stability improves with larger diamond grain size, so increasing overall wear resistance is a significant challenge. This is due to the effect of the catalyst metal, cobalt, in the diamond structure – when PCD is sintered in a high pressure, high temperature manufacturing process, the cobalt in the carbide substrate sweeps through the diamond grains and helps to form the diamond-to-diamond bonds that make up the PCD. However, it is the cobalt that causes the PCD to wear while drilling, mainly due to its higher rate of thermal expansion relative to diamond, such that when the cutter gets hot, the cobalt expands and breaks apart the diamond bonds that it helped to form in the first place. This is why the leaching process had such a huge effect on wear resistance in PDC compact cutters – it removes the interstitial cobalt from the working surface of the PCD through acid leaching, which dramatically improves the thermal stability of the cutter on that surface. However, it is the cobalt between the diamond grains that gives the PCD its toughness, and so by removing that cobalt, the overall toughness of the cutter is dramatically reduced.

There are many tests conducted in the industry to measure the toughness of a cutter, i.e., its resistance to chipping, spalling or breaking



Figure 4. 6 1/8 in. Horizontal Series - SH513DE dull bit with SD cutters.



Figure 5. 6 1/8 in. Horizontal Series - SH513DE dull bit with HD Cutters.

while drilling. It is, however, generally accepted that none of the laboratory tests in practice today are directly indicative of the actual toughness of a cutter, as it is extremely difficult to accurately replicate the downhole conditions that cause PDC cutters to chip, spall or break. So while these tests have proven to suggest which cutters are more likely to resist breakage than others, none are an absolute measure of toughness. Interestingly, in all of the tests currently conducted in the industry, every one shows a very large decrease in toughness due to the leaching process – when comparing identical cutters in the unleached and leached condition, the toughness values for leached cutters generally decrease by 20 - 50%. As reported by J.D. Belnap, fracture toughness was found to decrease by almost 30% due to the leaching process (Figure 1).¹ This is the primary reason why the predominant dull condition for PDC cutters is now breakage and not wear.

Less cobalt, still tough

Unlike leached cutters, HD Cutters achieve enhanced wear resistance due to a dramatic overall reduction in cobalt content – throughout the entire PCD as opposed to only at the outer surface. The new higher pressure sintering process allows stronger diamond-to-diamond bonds, while requiring less cobalt to catalyse the sintering process, thus producing a PCD with a much larger percentage of diamond than a conventional cutter. The resulting PCD has up to 50% less cobalt than a deep-leached cutter, but also retains cobalt throughout the entire PCD to maximise toughness. In fact, the new structure is so dense that it is no longer conducive to the leaching process. In order for a PCD to be leached, the microstructure must be porous enough to allow the acid to reach the cobalt. However, HD Cutters are so densely packed with diamond that the acid cannot penetrate to a significant depth. In comparison to conventional deep leached cutters, HD Cutters have more diamond, which equates to better abrasion resistance, less cobalt throughout the PCD, which equates to better overall thermal stability, and stronger diamond bonds and cobalt throughout the microstructure, which results in high toughness. Hundreds of field tests have been completed to date that have conclusively proven the performance benefits realised through this new technology, and a few of these will be reviewed in this article.

Because there are so many additional variables associated with directional drilling, the case studies included here will focus only on vertical sections and horizontal sections. In directional applications, the bit performance characteristics of the run, (ROP, footage drilled and dull condition), are typically overshadowed by the directional requirements of the interval, and therefore the relative performance of a given cutter compared to another can be more difficult to determine. So although many dramatic performance increases have been achieved in directional applications, it is difficult to demonstrate that improvement accurately in the data. However, in both vertical and horizontal applications, the directional requirements are typically less significant, which allows better focus on bit performance characteristics.

Case study 1: A large diameter vertical interval drilled in northeast British Columbia, Canada

The first application that will be reviewed is a large diameter vertical interval drilled in northeast British Columbia, Canada. This is a 16 in. diameter hole size through quite competent formations, including abrasive sands and severe transitions. Historically, the application required one rollercone bit to drill the first ~150 m (~500 ft) and then 1 - 2 PDC bits to complete the interval to a depth of around 600 m (1970 ft). In an effort to complete this surface application in much less time, a new bit was custom-designed for this application. The first SHEAR BITS 16 in.

SV613, with six blades and 13 mm cutters, using HD Cutters, successfully completed the interval in one run at an ROP of 24.5 m/hr (80.4 ft/hr).

This was the first time that this interval was completed in one run in this area in this hole size. This result is a testament to the superior toughness of HD Cutters – not only was this bit able to drill the lower section of the interval, which is more commonly drilled with PDC bits, it successfully drilled the entire surface interval, including the top section that is always drilled with rollercone bits due to the fact that PDC bits typically take too much damage in this section. Further, in order to manage the inherent torque fluctuations encountered when operating large diameter PDC bits, the bit was run with quite high RPM – between 190 - 220. With a bit this large in diameter, high RPM results in very high tangential velocity on the cutters in the outer portion of the profile of the bit, and typically puts them into a wear condition that is mostly related to the thermal stability of the cutters (as the frictional heating is very high when high tangential velocities are combined with abrasive sand formations). The fact that the bit was able to drill through formations typically only drilled by rollercone bits, and then finish the interval at a very high RPM, is proof positive of the combination of toughness and wear resistance achieved with HD Cutters.

However, despite the positive results of the first run, it was desired to further improve performance for the next well. Therefore, a thorough review of the first dull was performed in order to effectively categorise the wear condition to identify opportunities for further improvement. As seen in Figure 2, the cutters on the outer section of the profile were worn flat with the top of the blade. This wear condition began as pure wear to the cutters, then when a sharp wear flat edge was exposed to the formation, chipping at that edge accelerated diamond loss, which led to further wear to the cutters and ultimately to the dull condition shown in Figure 2. It was therefore decided to change the cutter type to a different HD Cutter with even more abrasion resistance.

The second run also completed the entire interval in one run, and at a very similar ROP to the first run, but resulted in a much improved dull condition. While the cutters still experienced a substantial amount of wear, with associated minor chipping at the cutter edge, the improvement in wear resistance was dramatic compared to the first run (Figure 3). This is an important result as it demonstrates the range of performance that can be achieved with HD Cutters – this new technology can be applied to various different cutter configurations to maximise performance in a very wide range of applications.

Case study 2: A horizontal interval through the Cardium sandstone in Alberta, Canada

The second case study is a 6 1/8 in. horizontal interval through a competent sandstone formation called the Cardium sandstone in Alberta, Canada. As with the first case study, the runs to be compared are on the same rig, are close offsets to another, used the same BHA, same mud system, etc.

These runs were completed on conventional directional assemblies with a total RPM between 160 and 200. It is critically important when comparing bit runs to ensure that as many variables as possible are left unchanged so the actual results of the variables that have changed can be confidently verified. In this case, there are many runs to analyse using standard density cutters (SD cutters) and HD Cutters, which better confirm the improvements realised with this new technology.

Historically, this application typically required two 513-type PDC bits (5 blades, 13 mm cutters) to complete the interval. However, using a customised SHEAR BITS Horizontal Series PDC design (SH613DE), the best of the SD cutter runs were able to drill the entire interval in one run. The best run in the data set with SD cutters drilled 1367 m (4485 ft) of horizontal interval through the Cardium sandstone at an ROP of 21.7 m/hr (71.2 ft/hr). However, the best two HD Cutter runs drilled 1380 m (4528 ft) and 1395 m (4577 ft) for respective ROP of 39.4 m/hr (129.3 ft/hr) and 37.5 m/hr (123.0 ft/hr). This represents an ROP increase of approximately 80% over the best runs in the field, primarily due to the



Figure 6. 6 1/4 in. Horizontal Series - SH613DE dull bit with HD Cutters.

ability



of the

Figure 7. SHEAR BITS 6 1/8 in. SH513DE Horizontal Series PDC bit.

cutters to stay sharper, longer, through an abrasive formation. The best SD cutter run yielded a dull with a '3' grade on the shoulder of the bit (Figure 4), but the two HD Cutter runs yielded dulls of no worse than a '1' grade on the shoulder of the bit (Figure 5).

Case study 3: Extended length horizontal interval through the Cardium sandstone in Alberta, Canada

The third application is perhaps the most impressive of the three, but is not as perfect of a comparison between SD and HD Cutters as the previous case study. In this situation, again drilling a horizontal interval through the Cardium sandstone in Alberta, Canada, the length of the horizontal interval was increased from a maximum of approximately 1700 m (5580 ft) to around 2900 m (9500 ft).

The BHA for these runs included a rotary steerable system to aid in the transition of weight to the bit in the extended lateral interval. As a result, in addition to moving up from SD cutters to HD Cutters, a new custom Horizontal Series PDC bit design was developed for the new well plan. The bits used in the standard length intervals were an SH513D-type with a double-row of cutters on five blades, fitted with 13 mm cutters. The design created for the extended length intervals was a 6 1/4 in. SH613DE – using a double-row of cutters on six blades with 13 mm cutters.

When drilling the standard interval, the best run that the customer achieved in the field drilled 1395 m (4577 ft) at 31.7 m/hr (104 ft/hr) and was graded a 3:3. In the best run, the SHEAR BITS SH613DE with HD Cutters drilled 2895 m (9500 ft) at an ROP of 34.3 m/hr (131 ft/hr) and was graded a 0:1 (Figure 6). This performance has since been repeated many times to prove the viability of this technology. In this application, the use of HD Cutters has allowed the company to become the only bit manufacturer in the industry to drill an interval of over 2000 m (6500 ft) in the Cardium sandstone in this region. Additionally, the run mentioned above represents the fastest average ROP recorded in this region drilling horizontally through the Cardium sandstone for an interval over 1600 m (5250 ft).

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Conclusion

The rate of change for technology in the oil and gas drill bit industry has remained high since PDC bits were introduced in the 1970s. It is very rare for any given technology to last as long as 10 years as a leading technology in the industry, but leaching achieved that lofty goal over the last decade. However, HD Cutters from SHEAR BITS have raised the bar for performance in many challenging applications due to a step change in the combined properties of toughness and wear resistance. Historically, it was possible to achieve exceptional toughness or exceptional wear resistance in a given PDC cutter, but it is now possible to have both due to new manufacturing processes and materials that produce high-density PCD. When used in conjunction with customised PDC bit designs created specifically for HD Cutters, record performance can be realised. ■

Reference

1. Belnap, J. D., 'Effect of Cobalt on PCD Fracture Toughness', *Materials Science and Technology* (2010).