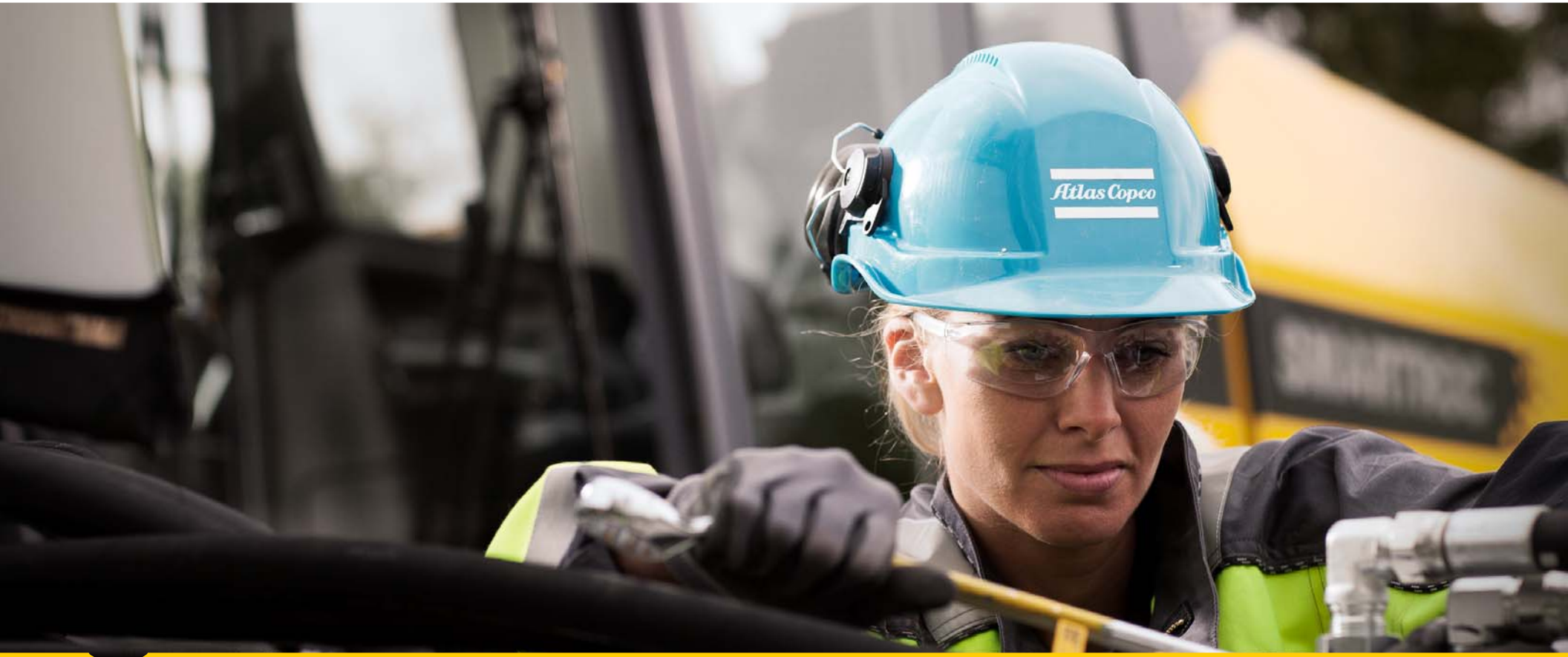


Track VI-B HDD: Operations and Productivity
PDC Cutters and Tooling in HDD Applications

Jason Palmer, Applications Engineer – Bruce Beatty, Product Manager

Epiroc

Objectives

Discuss with conference participants

- What is a Polycrystalline Diamond Compact (PDC)
- History and development of PDC cutters
- PDC tooling history
- PDC tooling selection
- PDC run recommendations
- PDC tooling repair
- PDC developments…the future

PDC Cutters
(Polycrystalline Diamond Compact)

EXTREME PROPERTIES OF DIAMOND

Property	Value
Hardness	100 GPa Knoop scale
Thermal conductivity	2,000 W/m-K (4 times copper)
Melting point	4,000°C (500°C above tungsten)
Sonic velocity	18,000 m/s
Coefficient of thermal expansion	1.1×10^{-6} K^{-1} (< silicon)
Electrical bandgap	5.5 eV
Breakdown voltage	10 MV/cm
Optical index of refraction	2.42
Coefficient of friction	0.03 (< Teflon)
Chemically inert	Resistant to all acids and bases
Biologically compatible	Pure carbon

DIAMOND FORMATION IN NATURE

- **Formed 100 miles (160 km) below the surface or more**
  - **Pressures above 1 million psi (6.9 GPa)**
  - **Temperatures between 2000°F and 3000°F (1100°C – 1650°C)**

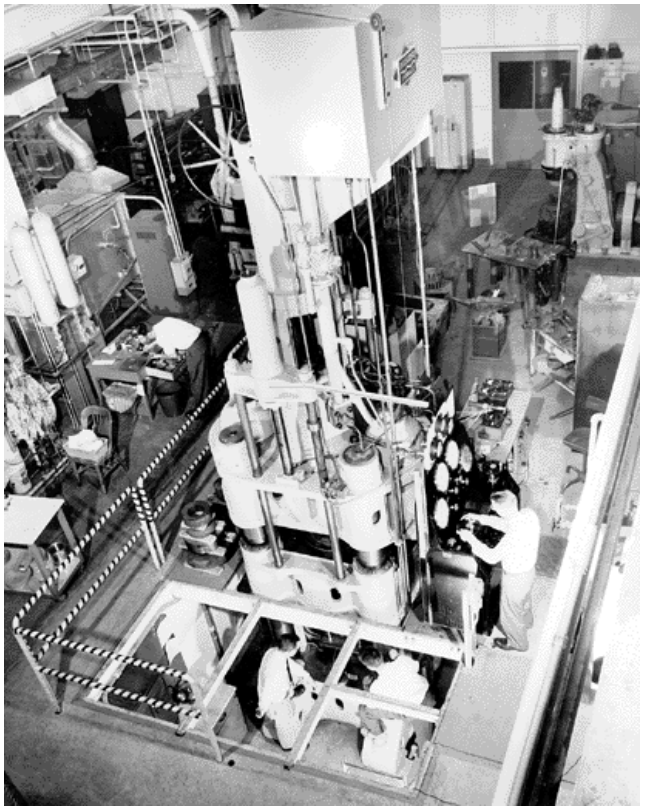
1,000,000 psi =

Eiffel Tower upside down on a 5” plate =

2400 Washington monuments stacked together

PROJECT SUPER PRESSURE

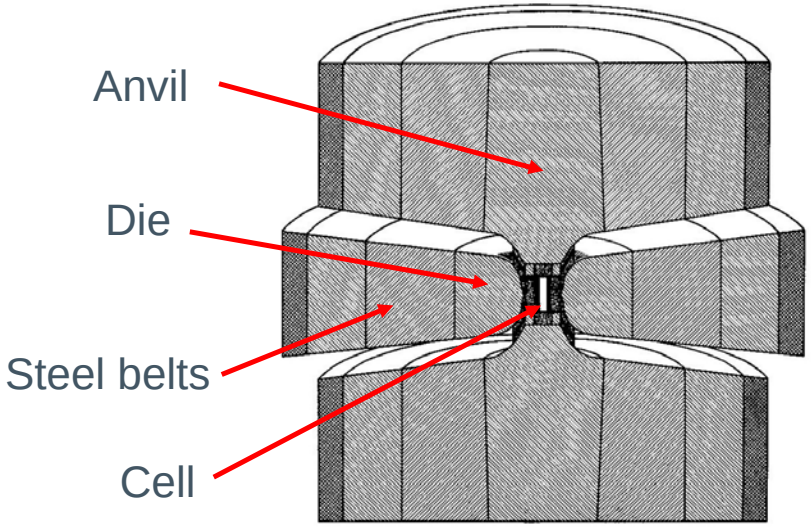
- General Electric (GE) put together a team in 1951 to produce the world's first industrial diamonds:
  - Francis P. Bundy
  - Herbert M. Strong
  - H. Tracy Hall
  - Robert W. Wentorf
  - James E. Cheney
  - Hal Bovenkerk
  - Anthony Nerad



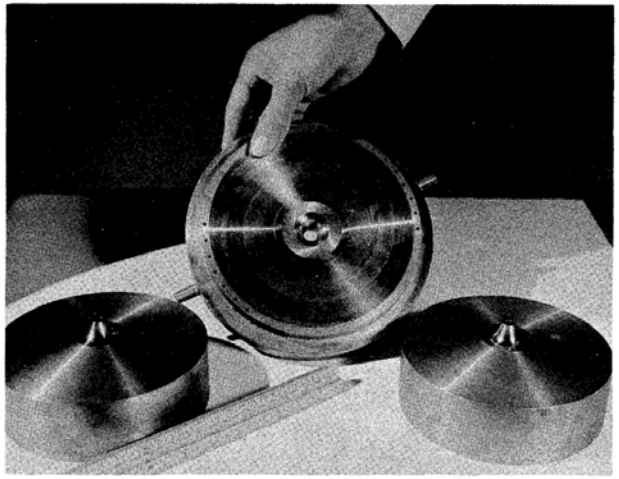
This project was referenced in an episode of Breaking Bad where Walter White mentions that the inventor of the process to make synthetic diamonds (H Tracy Hall), was compensated for his invention with a $10 savings bond….this is actually a true story

PROJECT SUPER PRESSURE

- Belt press
  - Invented by H. Tracy Hall (US Patent 2,941,248)
  - Capable of generating 100,000 atm (1.5 million psi) at 1800°C (3270°F)



Belt press schematic

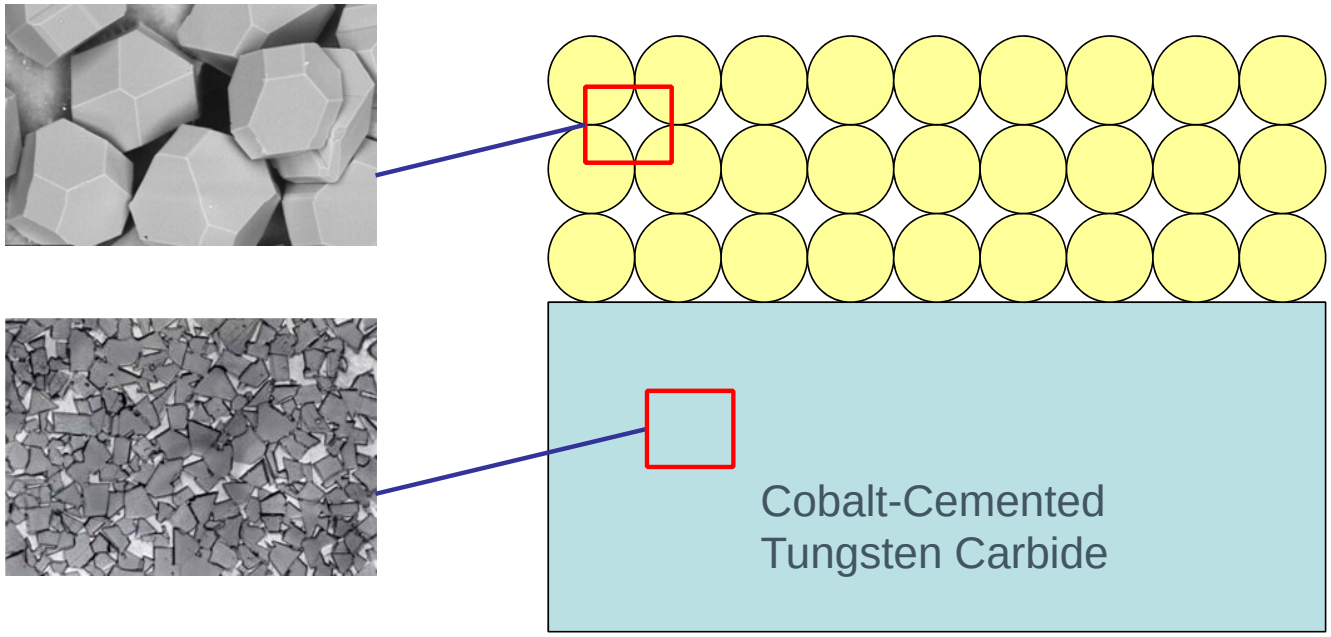


Early belt press tooling

PDC CUTTER MANUFACTURING PROCESS

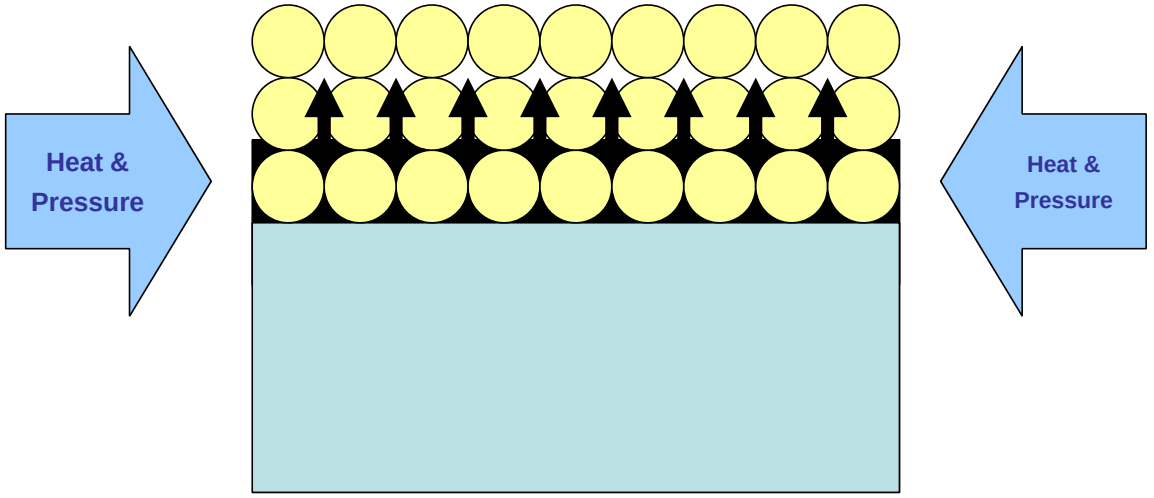
(Polycrystalline Diamond Compact)

1- Diamond powder held in place next to Tungsten Carbide substrate by a refractory metal container.



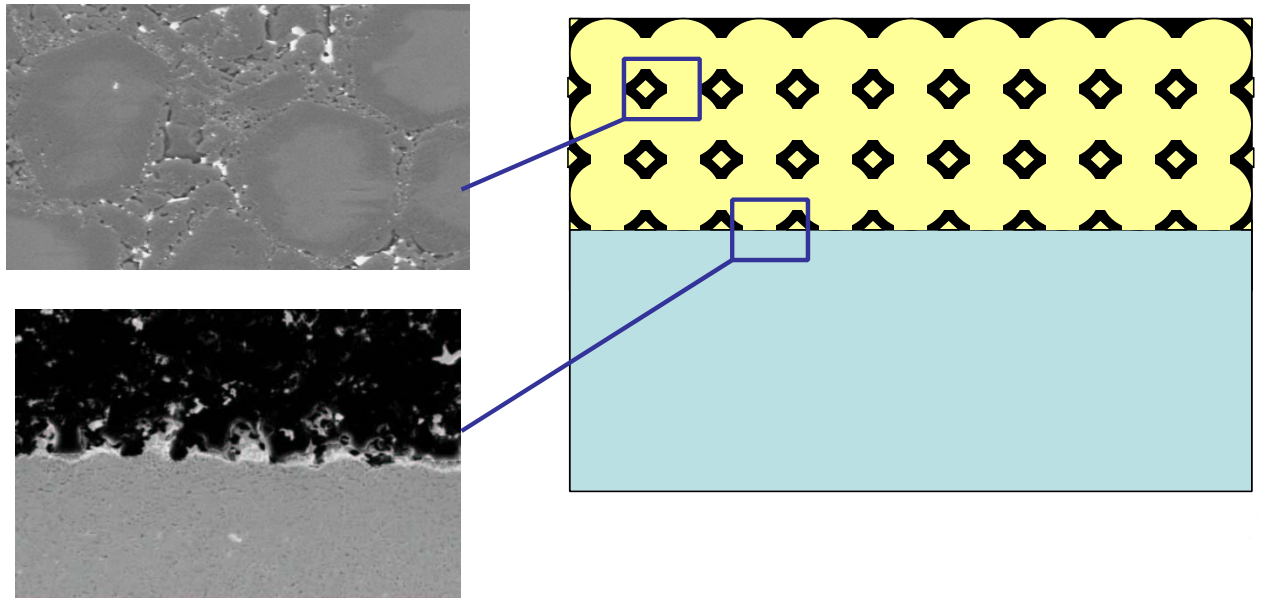
PDC CUTTER MANUFACTURING PROCESS

2- Cobalt in substrate melts and infiltrates the diamond powder upon application of heat and pressure. Heat is supplied by a graphite resistance heater, and pressure is applied by a cubic-type HTHP press.



PDC MANUFACTURING PROCESS

3- Cobalt sinters (bonds) the diamond granules together, as well as bonds the diamond to the Tungsten Carbide substrate.

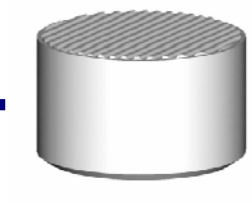


POLYCRYSTALLINE DIAMOND COMPACTS (PDC)

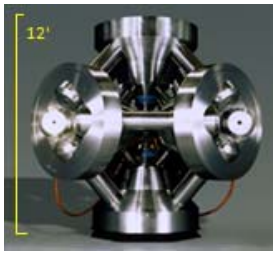
- **The PDC manufacturer combines diamond grit with tungsten-carbide under intense heat and pressure to form PDC cutter.**

Diamond Grit Powder

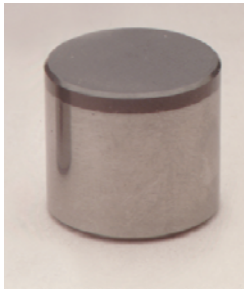
Tungsten-Carbide Substrate



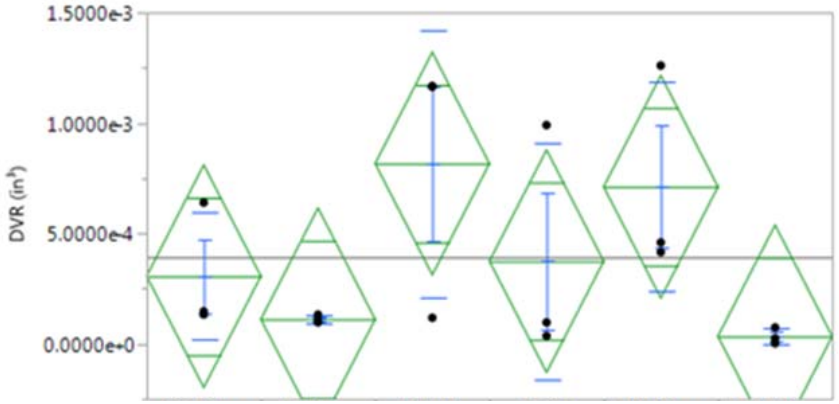
High Pressure High Temperature Cubic Press
1,000,000 psi and 2000°F and 3000°F (1100°C – 1650°C)

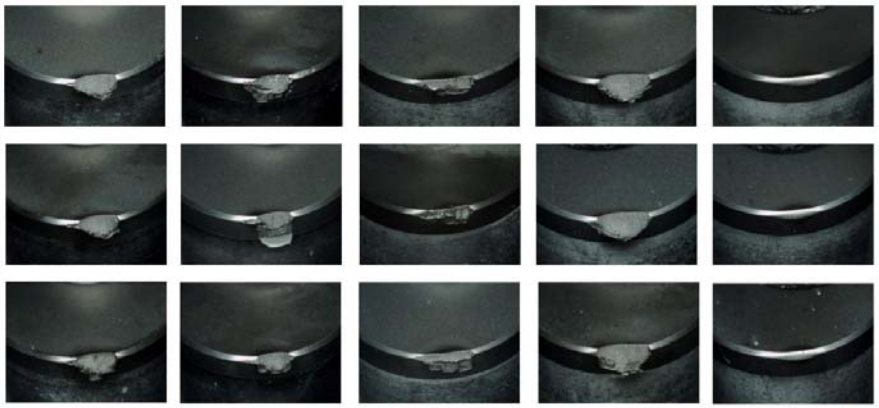


PDC Cutter



All PDC'S ARE NOT CREATED EQUALLY





Vertical Turret Lathes are used to test diamond wear characteristics

- Lathe is loaded with a granite slab which rotates while the PDC is held in a fixture against the granite slab
- PDC cutters are tested by measuring how much diamond is removed after a fixed number of rotations of the lathe

PDC BITS AND TOOLING HISTORY

- PDC Bits

1954 – GE first to synthesize diamond.

1971 – GE – invented Polycrystalline Diamond Cutter (PDC) on carbide substrate

1973 – Christensen – first PDC bit test

1981 – Introduction of thermally stable TSP cutters.

- PDC Drilling Economics

- PDC bits are more expensive

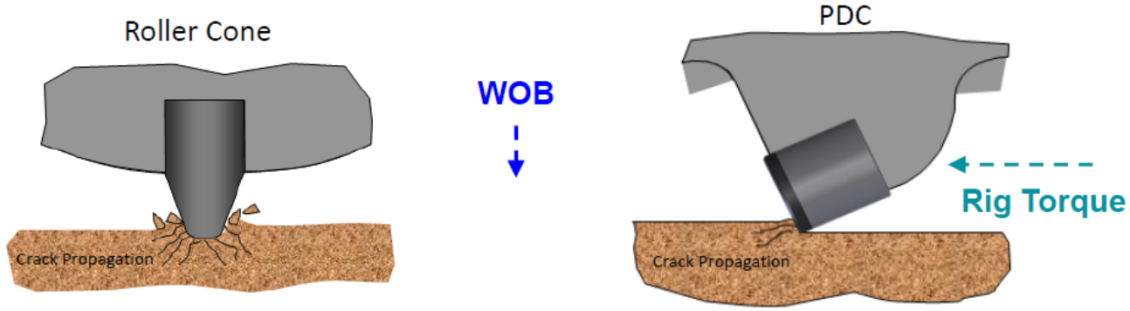
- PDC bits penetrate faster

- PDC bits drill farther

- PDC bits are repairable

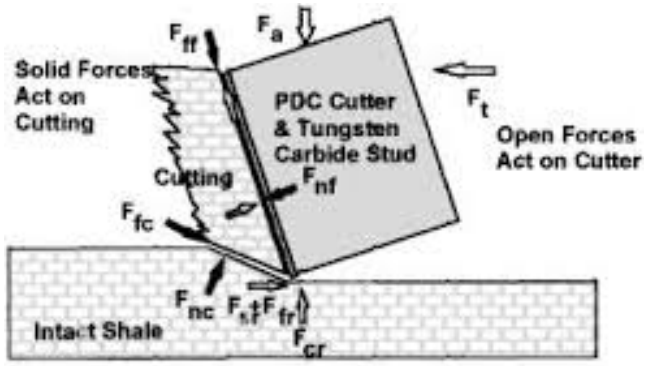
- PDC bits result in less total drilling cost

PDC CUTTER ROCK FAILURE



Gouging/Scraping (Soft Formations)
Chipping/Crushing (Hard Formations)
Requires high WOB (Less Efficient)

Shearing (Soft & Hard Formations)
Requires less WOB (More Efficient)

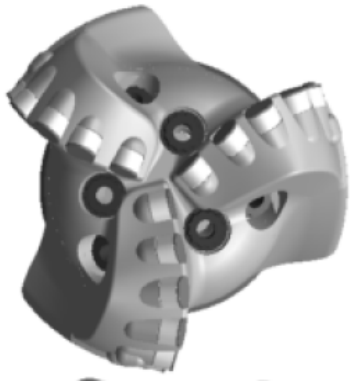


Note: F_{sr} is force to shear rock, and F_{fr} is friction on wear flat due to force F_{cr} between rock and wear flat

Consolidated Formations

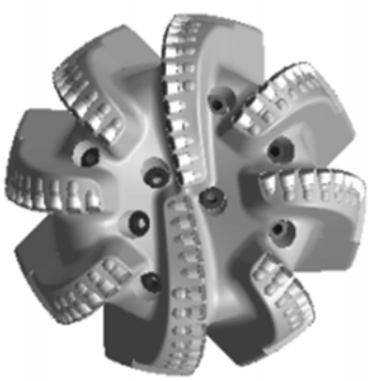
Depth of Cut dependent upon WOB (Weight on Bit), Cutter Size & Density, Formation, and Back Rake Angle

Blade Layout



Light Set

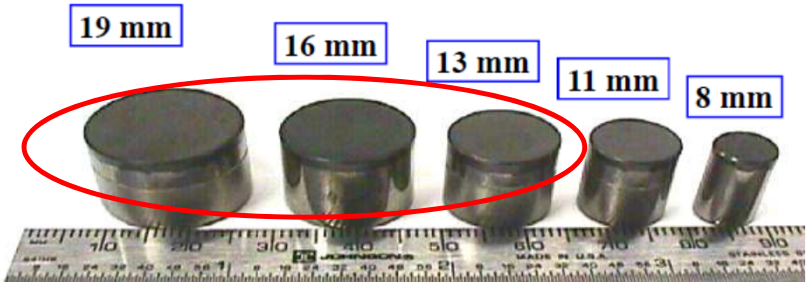
Medium Set



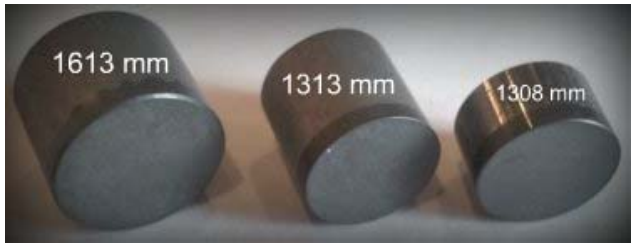
Heavy Set

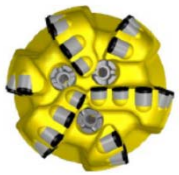
Heavy Set

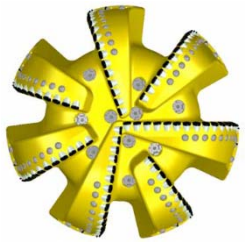
Cutter Size



First 2 numbers = Diameter
Second 2 numbers = Length





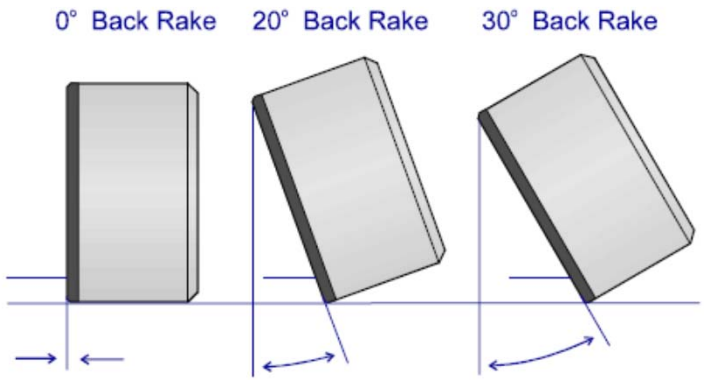


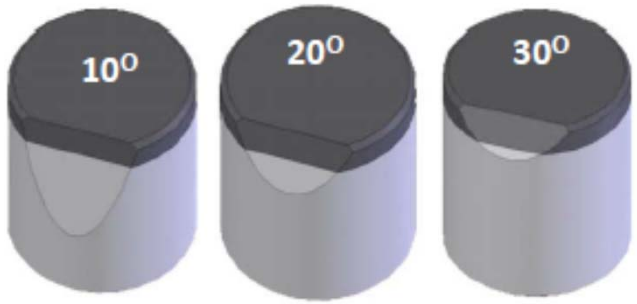
BASIC RULE OF THUMB:

Soft Formation = Larger Cutter
Harder Formation = Small Cutters

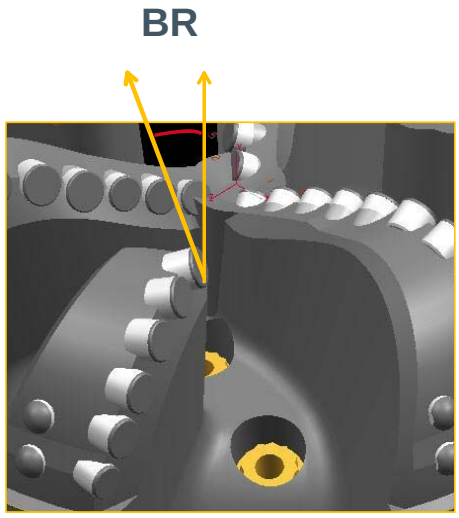
Cutter size is also relative to bit size

CUTTER BACK RAKE





CUTTER BACK RAKE



Typical Back Rake Angle Relative to Formation Hardness

Back Rake Angle	Formation Hardness
5° - 10°	Soft shale. Low angle produces high ROP
15°	All formations. Best in shale.
20°	All formations. Improves cutter life. Best in abrasive, sandy formations.
30°	Gage: Typical for GeoDiamond gage. Decreases aggressivity and improves cooling.

DRILL BIT PARAMETERS – RULES OF THUMB

- **Softer Formation:**
  - Lower WOB (Weight on Bit)
  - Higher RPM
- **Harder Formation:**
  - Higher WOB
  - Lower RPM
  - **WOB Minimum and Maximum will vary depending on bit size and formation:** 2,000 lbs to 30,000 lbs (1 ton to 15 ton)
  - **RPM Minimum and Maximum will vary depending on bit size and formation:** 60 to 200 (can be in excess of 500 RPM with motor)

DRILL BIT PARAMETERS – RULES OF THUMB

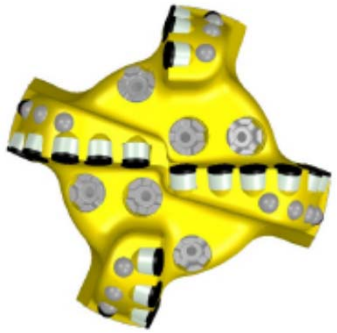
Drill Off Test

1. **Select Minimum recommended WOB and moderate RPM**
2. **Maintain initially selected WOB and record average ROP**
3. **Increase WOB in increments of 2000 lbs, continuing to record average ROP with each increase**
4. **Continue until ROP no longer increases as additional WOB is applied or ROP exceeds cleaning capacity.**
5. **The increase in ROP should be linear with the increase in WOB.**
   a. **In other words: IF your first increase of 2000 lbs WOB raises ROP by 25 ft per hour, and a second increase of 2000 lbs WOB raises ROP by another 25 ft per hour, but a third increase of 2000 lbs WOB raises ROP by only 15 ft per hour the relationship is no longer linear…and you can stop adding weight**
   b. **This is called the founder point.**
   c. **Optimal WOB will be between the second to last WOB increment used and the founder point**
6. **Repeat steps 1-4 using RPM that is incrementally increased or decreased from starting RPM**
7. **Plot data WOB vs. ROP and select the weight and rpm combination which provides the highest ROP. This will correspond to the highest feet rate (ROP/RPM) for the selected rotary speed**

BIT SELECTION BY LITHOLOGY

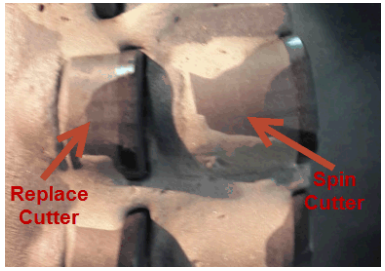
Very Low Strength	Low Strength	Medium Strength
< 4,000 psi	4,000 - 8,000 psi	8,000 - 16,000 psi
gumbo shales	chalk	conglomerates
soft shales	argillaceous sandstones	sandy and chalky limestones
claystones	claystones	marls
loose sands	soft shales	medium to medium hard sandstones
	evaporites	hard shales
	soft siltstones	evaporites
		soft siltstones

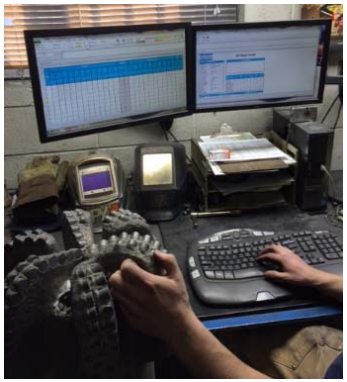
High Strength	Very High
16,000 - 32,000 psi	>32,000 psi
hard stringers	very fine, tight sandstones
hard dolomites	chert
crystalline limestones	quartzite
hard (brittle) shales	igneous rocks
hard sandstones	metamorphic rocks
soft siltstones	



REPAIR OF STEEL AND MATRIX BODY BITS

- Steel and Matrix bits are repairable for reuse.
  - Steel easier to repair body damage.
- Typically for premium oil & gas bits, and potentially Premium Dirt Diggers. Not Dirt Diggers.
- Cutters can be turned and used again based on condition. If cutter is too worn it is replaced.
- Can be repaired to like new condition.
- Depending on application, bit can have 1 to multiple runs before needing repair.
- Depending on applications, can get 5 to 12 repairs on a single bit.





Shaped PDC Cutters

PDC pick offers 40X wear compared to carbide

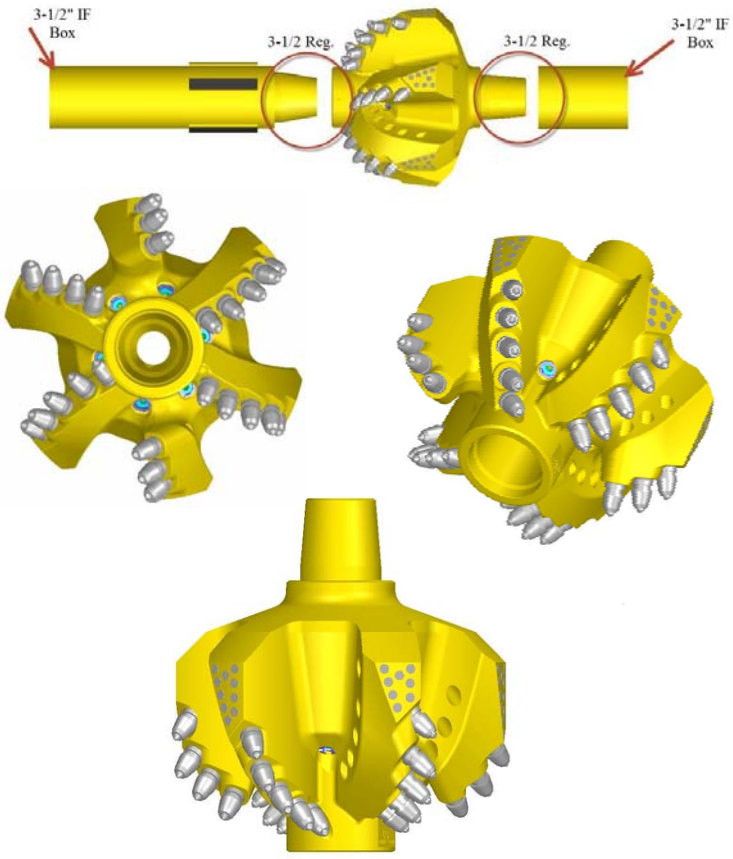
Ridged PDC for use in slippery substrates (clay and mud)

Many different shapes of PDC now available, allowing for lots of product development

HDD Tooling

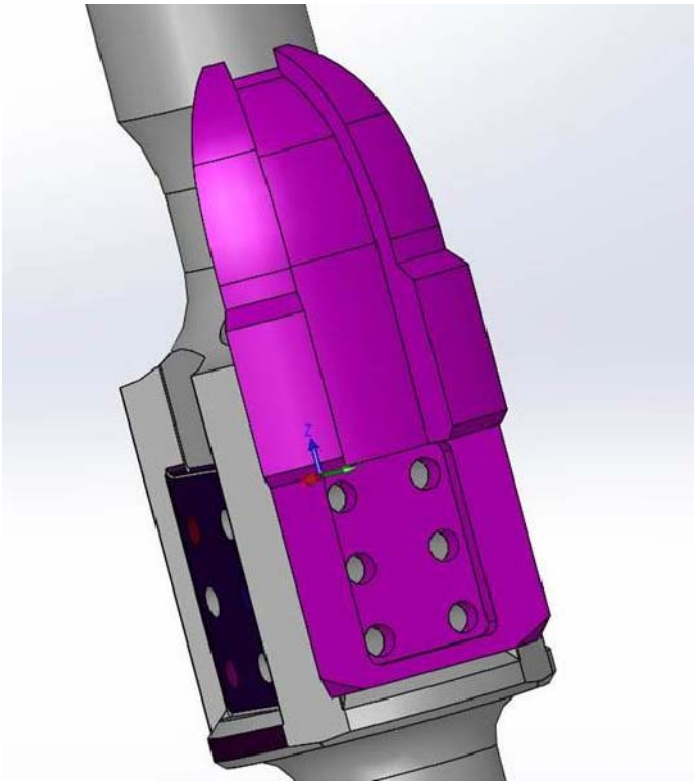
Pilot Bits

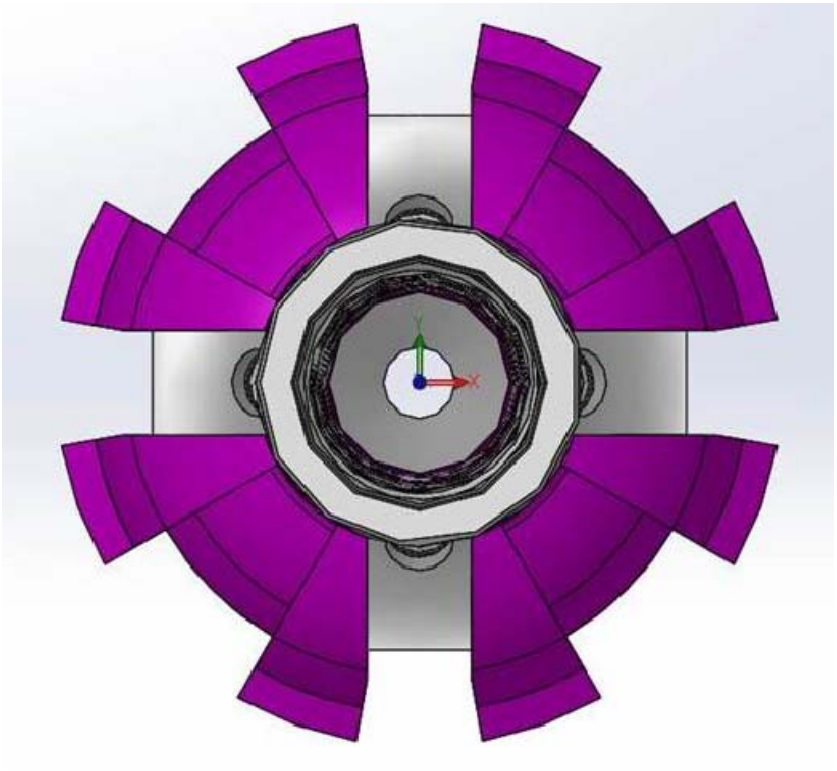
Hole Openers



Klaw or pick style Hole Openers
with PDC picks

PDC HOLE OPENERS WITH MODULAR BLADES





QUESTIONS???

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