Experiment Study on Parameter Optimization of Diamond Impregnated Bit for Abrasive and Hard Formation

Jun Yuan[1, a] *, Deyong Zou[1, b] and Hongjiao Zhong[2, c]

1: School of Petroleum Engineering, China University of Petroleum (East China), Qingdao, 266580, China

2: Institute of Geology, Dongxin Oil Production Plant, Shengli Oilfield Company, SINOPEC, Dongying, 257000, China

a*: yuanjuncup@sina.com, b: 348729591@qq.com, c: yinfanghao@sina.com

Keywords: Abrasive and hard formation; Diamond impregnated bit; Parameter optimization; Polycrystalline diamond grain size; Polycrystalline diamond concentration; Bit matrix formula.

Abstract: Compared with PDC bit, diamond impregnated bit have advantages in strong abrasive and hard formation according to theoretical research and field pilot experience. But the design and parameter optimization of diamond impregnated bit for different kinds of formations haven't been done until now, and this block its application in oilfield. The influence of bit matrix formula, polycrystalline diamond grain size and concentration on rock-breaking efficiency and bit service life were investigated based on drilling experiments. The optimized matrix formula of diamond impregnated bit for drilling in quartz sandstone formation and granite formation were obtained separately according to the experiment result. It also can be observed that with the increase of the polycrystalline diamond grain size and concentration, the drill speed of the diamond impregnated bit increase and then decrease, while the wear loss keep decrease. 80 is the critical mesh for polycrystalline diamond grain size which can let the bit keep high drill speed and ensure its service life. The optimization result for polycrystalline diamond concentration is 20% for quartz sandstone and granite formations. The influence of diamond impregnated bit parameters on drilling performance was studied and the optimized parameter values were obtained for the two kinds of strong abrasive and hard formations of quartz sandstone and granite. The research result can used to select and design diamond impregnated bits for different kinds of formations, and then improve the drill performance and enhance its application.

Introduction

The rock-breaking efficiency and drill speed are very low when using cone bit drill strong abrasive and hard formations, which mainly composed of siliceous quartz sandstone and feldspar sandstone [1]. PDC bit is suitable for soft and medium hard formations as its main rock-breaking mechanism is scraping [2]. For hard formation, PDC bit also can't wedge into the rock to conduct rock-breaking, and lead to low drill speed [3-5]. Diamond impregnated bit can be used in strong abrasive and hard formation according to theoretical research and field pilot experience [6-8]. At the moment, the design of diamond impregnated bit which include the concentration and grain size of polycrystalline diamond, and the formula of the matrix are depends on experience. For different kinds of formations, the design methods for diamond impregnated bit haven't been researched [9-11]. If the polycrystalline diamond parameters and matrix formula was incompatible, the matrix will worn out, and then the impregnated polycrystalline diamond particles will fall off. Furthermore, the loose of impregnated polycrystalline diamond particles will enhance the wear of matrix. They are the main reasons causing the low drill efficiency and high cost of the diamond impregnated bit drilling in strong abrasive and hard formations [12-14].

In this paper, the influence of polycrystalline diamond grain size, polycrystalline diamond concentration and matrix formula on the diamond impregnated bit service life and rock-breaking efficiency was studied based on laboratory drilling experiments. Then diamond impregnated bit parameters such as polycrystalline diamond grain size, concentration and matrix formula were optimized for drilling strong abrasive and hard formations. The research results are meaningful to the design and optimization of diamond impregnated bit and enhance its application.

Experiment plan design

Experiment scheme

In order to compare the influence on the drilling performance, four kinds of polycrystalline diamond grain sizes, four concentrations of polycrystalline diamond and four matrix formulas are selected to conduct drill experiments (see Table 1). The value selections of those three parameters are based on the literature review results [15-18].

Table 1 Experiment design of polycrystalline diamond parameter optimization

Diamond concentration [%]	Diamond grain size [mesh]	Matrix formula
10	40	1#: Cast tungsten carbide (30%) + Tungsten carbide (20%) + Tungsten (10%) + Copper (20%) + Nickel (10%) + Manganese (10%)
15	60	2#: Cast tungsten carbide (40%) + Tungsten carbide (20%) + Copper (20%) + Nickel (12%) + Manganese (8%)
20	80	3#: Cast tungsten carbide (45%) + Tungsten (10%) + Copper (27%) + Nickel (9%) + Manganese (9%)
25	100	4#: Cast tungsten carbide (55%) + Copper (27%) + Nickel (9%) + Manganese (9%)

Rock sample

Quartz sandstone and granite were selected as the representative samples of strong abrasive and hard formations [19, 20]. The hardness, compressive strength, drillability extremum and abrasiveness index of rock samples as shown in Table 2.

Table 2 Mechanical parameters of rock samples

Sample name	Hardness [MPa]	Compressive strength [MPa]	Drillability extremum	Abrasiveness index [mg/10min]	Representative formation
Quartz sandstone	1177.12	306.36	7.735	143.0	Hard and strong abrasive
Granite	1131.60	235.74	7.372	126.4	Strong abrasive

Experimental bit

A type of half circular arc diamond impregnated bit was employed in the experiment. Its structure is shown in Fig. 1.Its outer diameter was 70mm, and the inner diameter is 54mm.

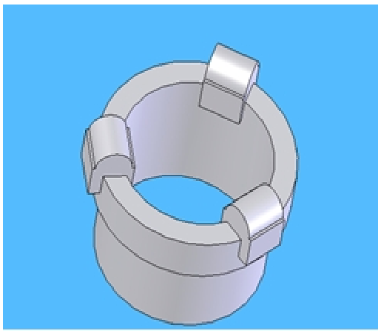
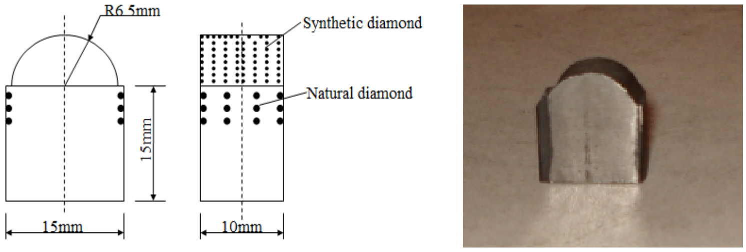


Fig. 1 The structure of diamond impregnated bit

The cutting teeth structure of diamond impregnated bit is shown in Fig. 2(a) ant its material object are shown in Fig. 2(b). The half circular arc part is diamond impregnated layer for rock-breaking and twelve natural diamond particles arranged on the cube part for gauge protection.

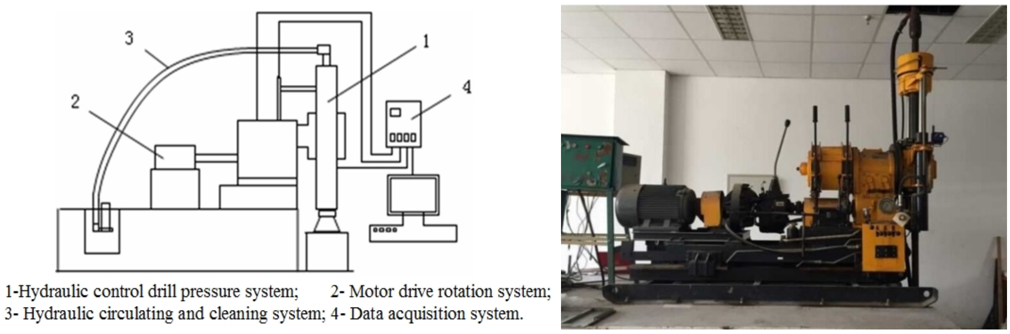


(a) Main view and side view (b) Sample

Fig. 2 Cutting teeth of diamond impregnated bit

Experiment equipment

The experiment was conducted on the bit experimental bench of 3H-650A type as shown in Fig. 3. The rotational speed was fixed to 60rpm, drill pressure was 8kN and water flow rate was 11L/s during drill experiment process.



(a) Structure diagram (b) Real diagram

Fig. 3 The bit experimental bench of 3H-650A type

Experiment result analysis

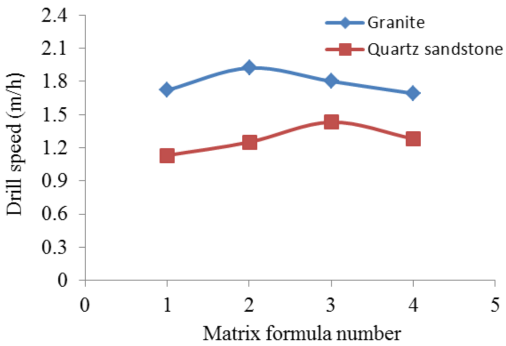
Effect of bit matrix formula on rock-breaking efficiency

Matrixes of diamond impregnated bit were sintered by hot-pressing method according to the four kinds of matrix formula designed in Table 1. The matrix hardness of four kinds of matrix were tested and the results are shown in Table 3.

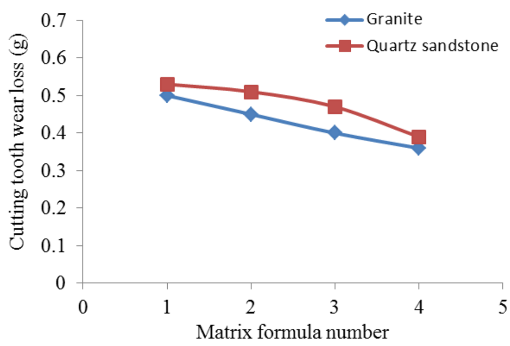
Table 3 the matrix hardness of four kinds of bit matrix

Matrix number	Matrix hardness [HRC]	Matrix performance
1	40	Medium hard
2	43	Hard
3	46	Hard
4	49	Extra hard

The drill experiments were conducted on quartz sandstone and granite with four kinds of matrix separately. The experiment results are shown in Fig. 4. It can be observed that with the increase of matrix hardness, the drill speed gradually increase and then decrease during the process of drill quartz sandstone (see Fig. 4(a)). No. 3 matrix corresponding to the maximum drill speed and this prove that the wear resistance of No. 3 matrix was adaptive best with polycrystalline diamond wear. The hardness of No. 1 matrix was relatively low and the rock abrasiveness of quartz sandstone was very high. This will lead to the matrix worn out before polycrystalline diamond fully exposed. Then the retention capacity of matrix will decrease, the polycrystalline diamond particles will fall off before it make full role. The hardness of No. 3 matrix could ensure a high retention capacity for polycrystalline diamond particles. Polycrystalline diamond will drop off when the polycrystalline diamond wear to a certain degree. Then the under layer polycrystalline diamond particles solely exposed and began to cut rock. This ensures the drill speed keep at a high level. The matrix had not worn and the new polycrystalline diamond particles could not exposed when polycrystalline diamond particles worn completely as the hardness of No. 4 matrix was too high and its wear resistance was strong. This is the reason of low drill speed. The effect of bit matrix on drill in granite is similar to quartz sandstone. The hardness and wear resistance of No. 2 matrix are suit for granite as the abrasiveness of granite are weaker than that of quartz sandstone.



(a)



(b)

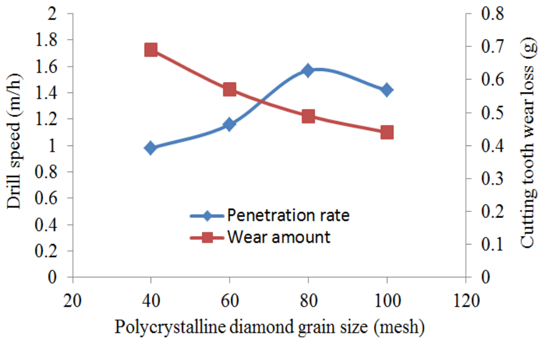
Fig. 4 The influence of bit matrix formula on drill speed and wear loss

It can be seen from Fig. 4(b) that the wear loss of the diamond impregnated cutting teeth decreased with the increase of matrix hardness. The wear loss of the diamond impregnated cutting teeth is very high as strong abrasiveness of the rock.

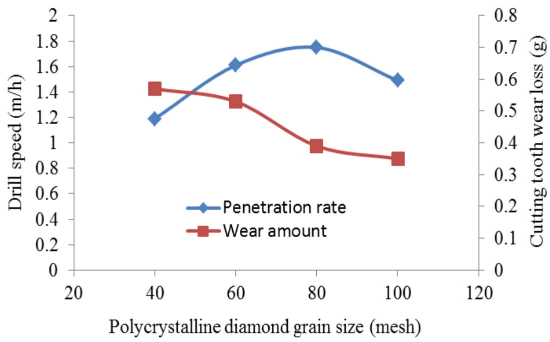
Based on the influence analysis of matrix formula on drill speed and wear loss, it can be obtained that No. 3 matrix formula are suit for drilling in quartz sandstone formation and No. 2 matrix formula are suit for granite formation.

Effect of diamond grain size on rock-breaking efficiency

Diamond impregnated cutting teeth were sintered using four kinds of polycrystalline diamond grain sizes (see Table 1). Drill experiments were conducted and the results are shown in Fig. 5. The drill speed of the diamond impregnated bit increase and then decrease with the increase of diamond grain size, while the critical size is 80 mesh. The wear loss significant decreases with the increase of diamond grain size. When polycrystalline diamond concentration is fixed, large diamond grain size means less diamond numbers. Then the cutting force of single diamond particle on the rock will become larger under the same drill pressure, and the rock-breaking efficiency increase. However, the fracture and crack of polycrystalline diamond particles will more frequently due to the high hardness and abrasiveness of quartz sandstone and granite. This means that with the increase of diamond grain size, the rock-breaking efficiency and the wear loss will increase at the same time. The cutting efficiency of single diamond particle will decrease along with diamond grain size reduces, but the number of exposed diamond particles increase. The best combined effect can be achieved when the grain size was 80mesh. The diamond particles will expose more and the wear resistance will increase if continue to reduce the grain size of the polycrystalline diamond particles. In this case, the wear loss are small, the life of diamond impregnated bit are long. But if the diamond particles too small, the cutting force of single diamond particle are small under the same concentration, the rock-breaking efficiency will be affected and lead to the drill speed decrease. According to the analysis above, 80 is the critical mesh for diamond grain size which can achieve the best drill performance.



(a) Quartz sandstone



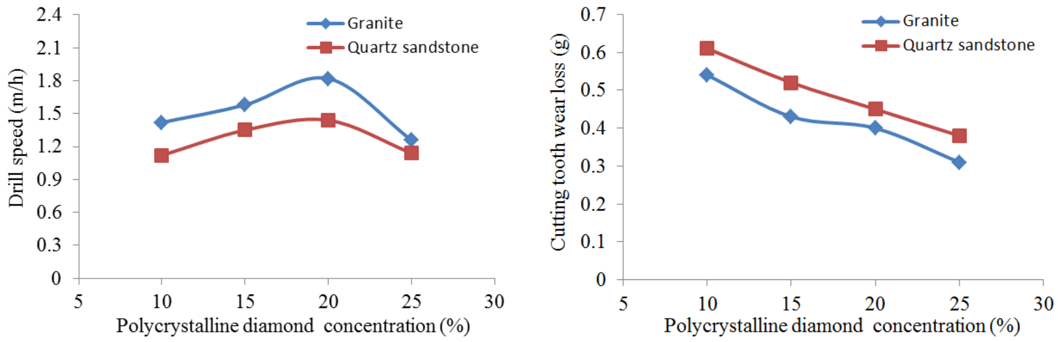
(b) Granite

Fig. 5 The influence of diamond grain size on drill speed and wear loss

Effect of diamond concentration on rock-breaking efficiency

The drill experiment used four kinds of diamond concentrations were conducted (see Table 1) and the results are shown in Fig. 6. The drill speed increase and then decrease with the increase of polycrystalline diamond concentration and the critical point are 20%. This because when polycrystalline diamond grain size is fixed, the cutting force of single diamond particle decreases with the increase of polycrystalline diamond concentration. At low diamond concentration, the excessive cutting force cannot enhance the drill speed as the wear of the diamond particles and matrix are very quick in strong abrasive formations. Polycrystalline diamond particles did not play the role of grinding and prematurely ruptured or threshed. When polycrystalline diamond concentration increased to 20%, the force of single diamond particle on the rock could be adapted to the rock abrasiveness, the drill speed significantly increases. The cutting force of single diamond particle decrease sharply and lead to the drill speed reduces if continue to increase the diamond concentration.

It also can be observed that the trends of wear loss in quartz sandstone and granite decrease at the same time with the increase of polycrystalline diamond concentration (See Fig. 6(b)). This because under the same diamond grain size, the exposed diamond particles is much more because of the increase of diamond concentration, and the wear resistance increase. The wear loss tended to be linear in quartz sandstone with the increase of polycrystalline diamond concentration. The wear loss in granite had a slight fluctuate. This trends determined by the properties of the rocks. The maximum drill speed can be achieved at the critical diamond concentration of 20%, while the wear loss are low enough to ensure the bit service life. Therefore, 20% is the optimized concentration for diamond impregnated bit.



(a) (b)

Fig. 6 The influence of diamond concentration on drill speed and wear loss

Conclusion

(1) The optimized matrix formula of diamond impregnated bit for drilling in quartz sandstone formation was 45% cast tungsten carbide + 10% tungsten + 27% copper + 9% nickel + 9% manganese, and the optimized matrix formula for granite formation was 40% cast tungsten carbide + 20% tungsten carbide + 20% copper + 12% nickel + 8% manganese based on laboratory experiment results.

(2) With the increase of the polycrystalline diamond grain size, the drill speed of the diamond impregnated bit increase and then decrease, while the wear loss keep decrease. 80 is the critical mesh for polycrystalline diamond grain which can keep high drill speed and ensure its service life.

(3) The drill speed and wear loss vary behavior with polycrystalline diamond concentration are similar with polycrystalline diamond grain size. The optimization result for polycrystalline diamond concentration is 20 %.

(4) The polycrystalline diamond concentration, diamond grain size and bit matrix formula of diamond impregnated bit were optimized during drill in quartz sandstone and granite formations based on drill experiment. It can help the design and selection of diamond impregnated bit when it apply in different kinds of formations.

Acknowledgements

The subject source was 2010 Doctoral fund project “The study on the method of quantitative evaluation of rock abrasiveness in petroleum drilling” (No.: 20100133110002).

Reference

[1] Chen Ting-gen, Guan Zhichuan. Theory and Technology of Drilling Engineering[M]. Dong Ying: Petroleum University Press, 2006, pp.39-45.

[2] Tim Beaton, GeoDiamond, Keith Johnson. New Technology in Diamond Drill Bits Improves Performance in Variable Formations [J]. SPE59113, (2000)

[3] Yang Jun-de, Yang Hongwu, Peng Zhen-bin. Testal Study on the Wear of Diamond Bit during Drilling[J]. Demand and Abrasive Tool Engineering, 137(2003):43-45.

[4] Pan Bingsuo, Shi Dongmei, Yang Kaihua. Effect of Diamond Size on the Performance of Impregnated Diamond Bit[J]. Coal Geology and Exploration, 30(2002) 62-64.

[5] Ghose R, Yoshioka S, Oike K.Cutting Action of a Single Diamond Under Simulated Borehole

Condition[J]. Petroleum Transaction, 181(1987) 937-942.
[6] Carl W. Keith, Spring, Graham Mensa-Wilmot. Stability Enhanced Drill Bit and Cutting Structure Having Zones of Varying Wear Resistance [P]. United States Patent: 5607024, 1997-3-4.
[7] H.Santos, J.C.R.Placide, J.E.Oliveira. Overcoming Hard Rock Drilling Challenges[J]. SPE59182 (2000).
[8] Tim Beaton, GeoDiamond, Keith Johnson. New Technology in Diamond Drill Bits Improves Performance in Variable Formations [J]. SPE59113 (2000)
[9] Wang Chuan-liu, Sun You-hong, Liu Bao-chang. Test and rock fragmentation mechanism of bionic coupling impregnated diamond bit [J]. Journal of Central South University (Science and Technology), 42(2011)1321-1325.
[10] Wang Chuan-liu, Li Jian-jun, Sun Rong-jun. Development of High Matrix Drill Bit with Impregnated Diamond Block[J]. Journal of Central South University (Earth Science Edition), 44(2014)1276-1281.
[11] Tian X, Tian S. The wear mechanisms of impregnated diamond bits [J]. Wear, 177(1994)81–91.
[12] Mostofi M, Franca L F P, Richard T. Drilling Response of Impregnated Diamond Bits: A Testal Investigation [J]. U.s.rock Mechanics/geomechanics Symposium(2013).
[13] Abtahi A, Butt S, Molgaard J, et al. Wear Analysis And Optimization On Impregnated Diamond Bits In Vibration Assisted Rotary Drilling (VARD)[J]. 45th U.S. Rock Mechanics / Geomechanics Symposium(2011).
[14] Sun You-hong, Gao Ke, Zhang Li-jun. High Drilling Efficiency and Wear-Resistant Mechanism of Coupling Bionics Impregnated Diamond Bit [J]. Journal of Central South University (Earth Science Edition), 42(2012)220-225.
[15] Franca L F P, Lamine E. Cutting Action of Impregnated Diamond Segments: Modelling And Testal Validation [J]. American Rock Mechanics Association(2010).
[16] Yang Z A, Duan L C B, Lan Q C. A New Type of Drill Bit with Impregnated Diamond and Tungsten Carbide Bar[J]. Geological Science & Technology Information, 25(2006)101-104.
[17] Lockwood, Gregory T, Oldham, Thomas W, Griffo, Anthony, et al. Method of forming impregnated diamond cutting structures: US, doi:US7845059 B2[P](2010).
[18] Cao Y, Liu B C, Sheng Li J I, et al. Application of Bionic Impregnated Diamond Bit for Natural Gas Hydrate Drilling in Mohe Frozen Soil Region [J]. Exploration Engineering(2012).
[19] Chik-Hotkin V F, Gao S Y, Jiang G S, et al. Research on Some Problems about Optimization of Diamond Drilling Technology with Impregnated Bits[J]. Exploration Engineering(2014).
[20] Li Z T, Ma Y Z, Itakura K. Development of a Rotary Drilling Mechanism for Impregnated Diamond Bits[J]. Advanced Materials Research. (2014) 989-994.