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Effects of Silicone Carbide and Its Additive Amount on Diamond Bit Property

Jialiang Wang[a], Wenjie Wei[b], Shaohe Zhang[b,*], Fenfei Peng[a]

[a]Hunan University of Science and Technology, National Local Joint Engineering Laboratory of Marine Mineral Resources Exploration Equipment and Safety Technology, Xiangtan 411201, China
[b]School of Geosciences and Info-Physics, Central South University, Changsha 410083, China; Key Laboratory of Metallogenic Prediction of Nonferrous Metals and Geological Environment Monitoring (Central South University), Ministry of Education, Changsha 410083, China
zhangshaohe@163.com

To improve the diamond bit property, this paper studies the influencing mechanism of silicon carbide (SiC) and its additive amount on diamond bit; in the study, firstly, the SiC particles in different weight percentage were added in the matrix, then the drilling bit was fabricated, and finally the indoors drilling test was made. The results show that proper concentration of SiC particles can improve the synchronic wear property of diamond bit and matrix; at the additive amount 5.5% (wt%), the drilling efficiency increases by 55% as compared with the conventional bit; besides, compared with the diamond particles, the SiC-impregnated force by matrix is limited, so it can be more easily peeled off to form a pit on the matrix surface, which helps to increase the specific pressure of bit's crown (bit) and further promote the micro-wears morphology of matrix; at last, the free-state SiC residue on hole bottom can on one hand has a sharpening effect on the single-particle diamond in matrix to increase the diamond protrusion height and improve the machinability of single-particle diamond, on the other hand, it can enhance the solid component, promoting the erosive effect of flushing fluid on matrix.

1. Introduction

In recent years, with the environment protection awareness and ecological construction promoted, the exploration operation is gradually oriented to the green exploration by applying the "green and harmony" concept in the whole exploration process; specifically, it means to improve the drilling efficiency, shorten the project cycle, and reduce the interference with the surroundings during the construction process etc. (Wu and Li, 2016) Thus, higher requirements for the overall performance of diamond drill bit, esp. for the drilling efficiency, have been proposed, where the key influencing factor on drill bit property is the fulfilment of synchronic wear between diamond and matrix (Zhao et al., 2010).

Now one of the important research directions is application of the materials such as solid lubricant and chemical pore former etc. into the drill bit matrix in the appropriate form, in order to improve the micro-wear morphology of matrix, create a favourable condition for diamond protrusion and cooling, and finally adjust the synchronic wear of matrix and diamond. Based on thermodynamics and chemical kinetics theory, Duan Longchen and Pang Feng et.al analysed the effects of physical and chemical behaviour of pore forming material on the micro-wear morphology of matric in the reaction process and elaborated on the influence mechanism of such material on the drilling property (Pang, 2014). Per self-lubrication theory, Pan Bingsuo, Duan Longchen, and Xie Lanlan et al. studied the influence mechanism of the solid lubricants such as graphite and MoS2 etc. on the wear property of drill bit matrix in different aspects, including the physical and chemical characteristics of lubricants, design parameters, and drilling technical parameters etc.; then they illuminated the rock fragmentation mechanism self-lubricant diamond-impregnated bit (Duan et al., 2015; Duan et al., 2015). According to bionic coupling theory, Sun Youhong, Liu Baochang, Gaoke, and Wang Zhaozhi et al. adopted the different methods (theoretical analysis, indoor and outdoor test, and numeral simulation etc.) to study the influences of bionics structure unit on the friction and wear behaviour of matrix by taking the columnar graphite as bionic structure unit into the drill bit (Wang et al., 2011 Wang et al., 2016;

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Wang et al., 2016). Tan Songcheng et al. conducted one research on the wear mechanism of composite impregnated bit with columnar graphite, indicating that the composite impregnation structure can improve the matrix wear morphology, so as to enhance the drilling pressure of single-particle diamond and further promote the rock fragmentation efficiency (Tan and Fang, 2014).

In order to further improve the synchronic wear property of diamond and matrix, by adding proper concentration of hard-brittle abrasive SiC particles into matrix and fabricating the diamond bit, this paper conducts the drilling performance test of the fabricated bit, studies the effect law of SiC abrasive particle parameters on the drilling property, and finally analyses its influence mechanism on matrix micro-wear morphology and single-particle diamond machinability.

2. Test

In the test, the pre-alloy powder FJT-A1 and FJT-A2 was selected as the basic matrix formulation of bit. The formulation system of test bit is shown in Table 1.

Table 1: Basic system of matrix formulation

Metal powder	Co	Ni	Fe	Cu+Sn
Weight fraction wt/ %	8-80	7-30	32-66	Margin

The amounts of SiC particles which at average grain size 175μm in the matrix of bit 1 to bit 4 is 5.5%, 6%, 6.5%, 7% (wt%) respectively. Bit 5 is the common bit for comparison. Besides, the 3D blender was adopted to make powder mixture for 2.5h; KGBS-B energy-saving type medium frequency furnace was used to make hot pressing at the sintering temperature 960℃, sintering pressure 3.5 MPa, and soaking time 5 min. The test bit includes the following parameters: flat-base bit crown Φ36/25 mm, height of working layer 4mm, diamond grade SMD40, average grain size of diamond 425μm, diamond concentration 15%, and number of water gaps 4. In this test, the 200×200×200mm concrete sample with 30MPa compressive strength was taken as object of drilling. The following drilling rule should be followed in the test, including 0.5kN bit pressure, 980r/min revolving speed, 12L/min pump volume, and cooling with clean water.

Five holes were drilled by every bit in test. The drilling efficiency and service life are used as evaluation index to measure the bit property, where the former is represented by the average drilling time for single hole, and the latter is measured by the wear loss of drilling distance per unit.

3. Results and discussion

3.1 Effect of silicon carbide and its additive amount on drilling efficiency

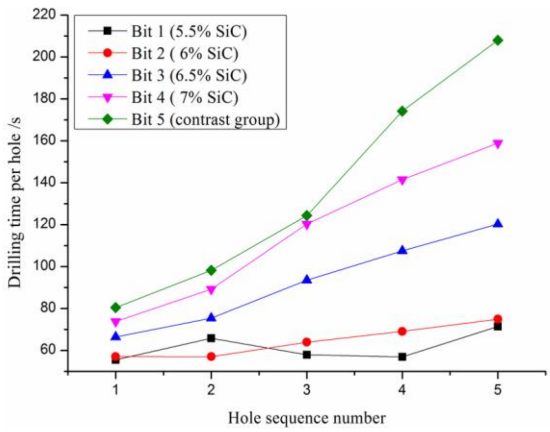

Figure 1: Drilling efficiency of bits

Fig.1 depicts the drilling efficiency of bit, and Fig.2 shows the average drilling time for single hole. It can be found in Fig.1 that the bits 1-4 with added silicon carbide particles have higher drilling efficiency than the ordinary bit 5.

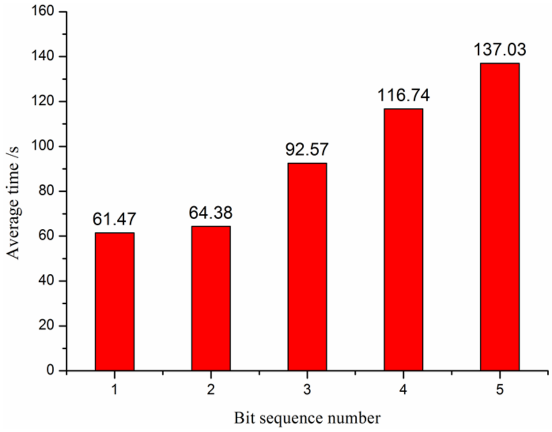

Figure 2: Average drilling time for single hole of every bit

In Fig.2, it is found that the average single-hole drilling time of bits 1-4 is lower that of the ordinary drill bit 5, e.g. the drilling efficiency of bit 1 at the minimum single-hole drilling time increases by 55% by comparison with the ordinary bit 5, indicating that the proper concentration of silicon carbine could enhance the drilling property of diamond bit, and at the additive amount 5.5% SiC, the drilling property can be improved at the most extent. Besides, with the drilled holes increased, the single-hole drilling time is lengthened accordingly, because during the drilling process, the protruded diamond in matrix can gradually be dulled, peeled off, or disabled, but the new protruded diamonds are so insufficient that the rock erosion efficiency of drill bit is decreased and the single-hole drilling time is increased. Drill bits 1-4 with SiC particles have a milder drilling efficiency than bit 5, where the drilling efficiency curve of bits 1 and 2 tend to be on the straight line, indicating that at 5.5%-6% (wt%) SiC, the drill bit exhibits the best drilling performance.

3.2 Effect of silicon carbide and its additive amount on service life

Fig. 3 depicts the average single-hole drilling time and the wear weight loss of bits. It can be found in Fig.3 that bit 5 has the longest average time for single hole and the minimum weight loss by wear, i.e. bit 5 has the lowest drilling efficiency, but with the longest service life. Comparatively, drill bits 1-4 with SiC particles take less drilling time for single hole than bit 5, whereas the wear weight loss of bits 1-4 is higher than that of bit 5, so their theoretical service life is less than bit 5. Besides, it should be noted that the proper concentration of SiC particles in the matrix can enhance the drilling efficiency as well as its service life. Among the test bits 1-4 with SiC particles, the bit 2 takes less drilling time for single hole at the minimum wear weight loss; it can be seen in Fig.3 that compared with the ordinary bit, the drilling efficiency of bit 1 has increased by 55% while the service life only reduces by 14.29%, at the maximum performance ratio, indicating that with the 5.5% (wt%) additive amount of SiC, it can be ensured to improve the drilling efficiency as well as keep its lifetime in some degree.

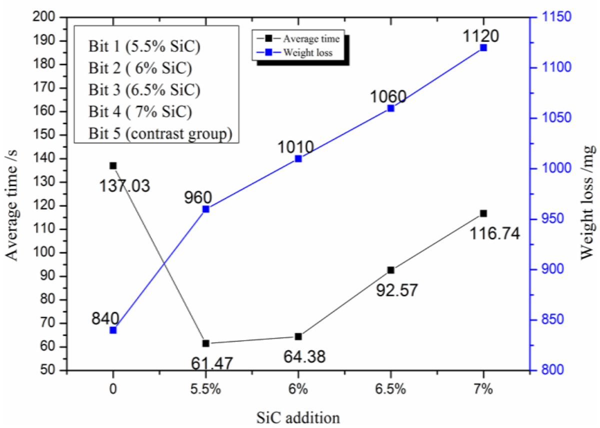

Figure 3: Average single-hole drilling time and wear weight loss

3.3 Influence mechanism of silicon carbide and its additive amount on drill bit property

3.3.1 Pit effect

Compared with diamond particles, SiC particles has the similar drilling process in matrix, but the main difference is that SiC is more easily peeled off. This test focused on the surrounding areas of extruded diamond: when the bit is turned, the existence of single-particle diamond can ensure the surrounding matrix to be not easily grinded or erosively crushed by hydraulic power seriously, maintaining the better primitive morphology of pit.

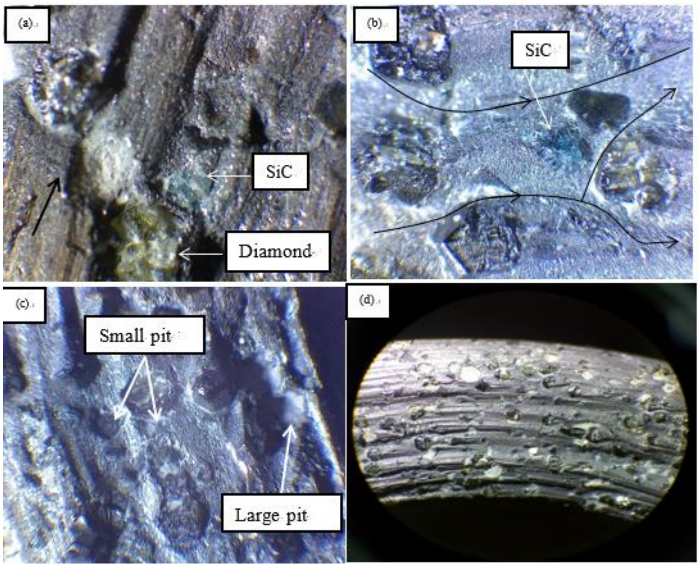

Figure 4: Morphology of bit 1

Fig.4 depicts the matrix surface morphology of bit 1. In Fig.4 (a), the black arrow means the fluid flow direction, and white arrow shows that the SiC particles are in the back of diamond; it is found in Fig.4 (a) that the obvious cracks occur in the binding part of SiC and matrix as one weak bond, so the SiC is easily micro-crushed or peeled off earlier. In Fig.4 (b), the black arrow means the fluid flow direction, and white arrow shows that the silicon carbide particles are in the front of diamond; it can be found that for SiC particles, the brittle micro-cracks mainly happen, without large-volume peeling off. In Fig.4 (c), the pits in various sizes exist in the surrounding areas of diamond, where the large-volume pits in the good form with obvious corner angle are filled with rock powder, as diamond pit; the small-volume pit, as SiC pit, can directly improve the extrusion height of single-particle diamond, promoting the machinability of single-particle diamond. Besides, it is found that on both sides of single-particle diamond exists the groove formed by flushing liquid, and at the tail part of single-particle diamond occurs the obvious tadpole-shaped prop/support In Fig.4 (d). These tadpole-shaped props and grooves help to generate and leave the thicker powder, improving the fragmentation efficiency of drill bits (Wang and Zhang, 2017; Flegnera et al., 2016).

3.3.2 Effect of additive amount of silicon carbide on drill bit property

To sum up, the influences of SiC particles on drilling property can be down to pit effect, which mainly works in three aspects: diamond protrusion effect ($E_{diamond}$), lifting effect on specific pressure of bit crown ($E_{bit\ crown}$), and erosive wear effect of flushing fluid on matrix ($E_{Flushing\ fluid}$). It is given as:

$$E_{pit}=E_{diamond}+E_{bit\ crown}+E_{Flushing\ fluid} \quad (1)$$

As the SiC concentration increases in the matrix, the three effects above takes the trend of firstly increasing, then decreasing. This section analyses these three effects in the following:
Firstly, in terms of $E_{diamond}$, the proper concentration of SiC particles can promote the micro-wear morphology of matrix, besides, the increased pits in matrix improve the protrusion height and quantity of diamond, and further booster its drilling property. But, if too high concentration SiC particles are added, the SiC volume in matrix will be increased to reduce the effective holding force of the remaining matrix for the diamond, so the diamond shall be easily peeled off earlier, decreasing the drilling property of bit.

Then, for $E_{bit\ crown}$, with the increased SiC and pits, the roughness of bit's crown is also enhanced, which can improve the specific pressure of bit crown. Fig.5 shows the lifting effect of pit on its pressure:

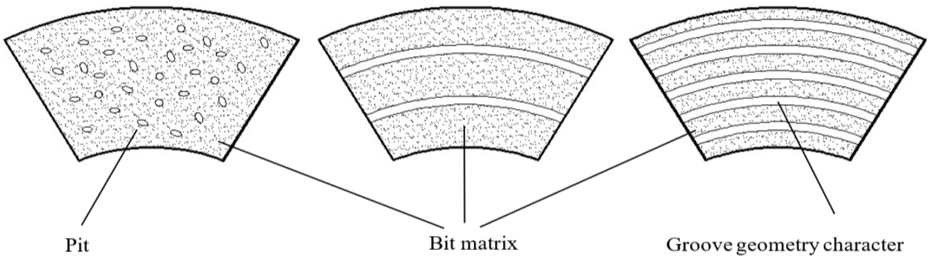

Figure 5: Sharpening effect of pits

Due to the pit, the grooves are easily formed on bit crown. Suppose that the randomly distributed pits are arranged linearly in order, and the linearly organized pits are regarded as one groove; with the more pits, the grooves shall be increased accordingly. Therefore, the lifting effect of pits on the bit pressure comes down to the sharpening effect on surface. However, with the SiC concentration further added, such sharpening effect present the trend of firstly increasing and then decreasing, because too many SiC particles can easily reduce the diamond impregnation in matrix. Besides, at excessive surface pressure, on one hand, the diamond is easily grinded and crushed; one the other hand, the unhealth phenomena such as pressing, large-volume peeling off, or fracture may easily occur to the matrix, so that the groove geometry character cannot be effectively formed and further the drilling efficiency is reduced.

Finally, in terms of $E_{flushing\ fluid}$, with the proper concentration of SiC particles added, the free-state residue can increase the solid fraction/components in the flushing fluid so as to create the pre-condition for the synchronic wear of matrix and diamond in favour to the normal protrusion of diamond. But, at higher SiC concentration, on one hand, the erosive action of flushing fluid on the matrix shall be so strong that the probability of over-wear matrix may increase, and on the other hand, the diamond impregnation/holding force in matrix is weakened, resulting in the earlier peeling off of diamond, and reduction of bit lifetime.

Fig.6 depicts the micro-morphology of matrix. It is clearly shown in Fig.6 (a) that bit 1 (5.5% SiC) has the pits in various forms and dimensions, and the pits are filled with powder, with more protruded diamonds. In Fig.6 (b), it can be found that for the bit 4 with excessive concentration of SiC (7%), its diamond protrusion quantity and effect are worse than bit 1, indicating that for $E_{diamond}$, the more SiC doesn't take better effect, because too high SiC can reduce the quantity of effectively-protruded diamonds. Also, in Fig.6 (a), more deep grooves are found, while Fig.6 (b) depicts less and shallower grooves, without pits filled with more rock powder in matrix, but with the matrix peeling-off area instead, so the grooves form is damaged and bit crown is dulled. It indicates that for $E_{diamond}$, the lifting effect of SiC on bit crown pressure doesn't always increase with the SiC additive amount, because the excessive amount shall lead to earlier fracture of groove geometry character on matrix surface, decreasing the bit crown pressure. At the same time, the reasons that the wear weight loss increases with the additive amount SiC in Fig.3 are revealed: the volumetric damage in matrix leads to greater wear weight loss of bit.

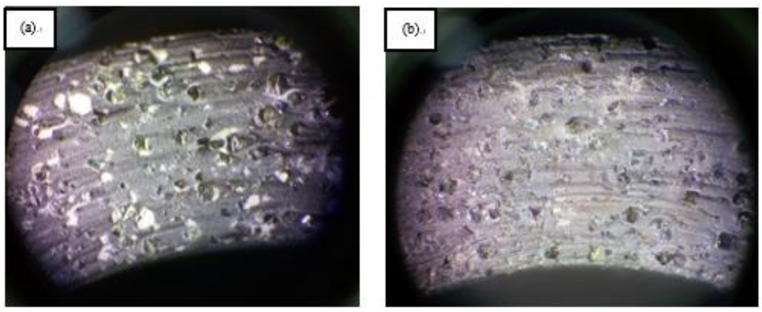

Figure 6: Morphologies of bit 1 and bit 4

4. Conclusion

The SiC particle in proper percentage can improve the synchronic wear property of diamond and matrix; at the additive amount 5.5% (wt%), the drilling efficiency increases by 55% as compared with the ordinary bit.

Compared with the diamond particles, the SiC-impregnated force by matrix is limited, so it can be more easily peeled off to form a pit on the matrix surface, which helps to increase the specific pressure of bit's crown and further promote the micro-wears morphology of matrix;

The free-state SiC residue on hole bottom can on one hand has a sharpening effect on the single-particle diamond in matrix to increase the diamond protrusion height and improve the machinability of single-particle diamond, on the other hand, it can enhance the solid component, promoting the erosive effect of flushing fluid on matrix.

Acknowledgments

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