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QUALITY EVALUATION AND CONTROL OF IMPREGNATED DIAMOND BIT

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ABSTRACT

For evaluating and control the quality of impregnated diamond bit used in exploration drilling and improving the microstructure of the final matrix layers to equivalent its working life with the initiative, layers *etc*, the property of load applied on bit crown and the K_{Ic} value and the regulating of the K_{Ic} value as well have been discussed and tested. The results shows that the diamond bit quality can only be correctly and precisively judged by using experimentally measured physical-mechanical properties and K_{Ic} value, controlling the cracking speed and reinforcing the final matrix layers with W fibres can equivalent the service life of the final matrix layers significantly.
Key words: impregnated diamond bit service life K_{Ic} value W fibre reinforced

1 INTRODUCTION

The percentage of impregnated diamond bit used in the exploration drilling increases day by day. In the position of competition, the producer attempt to manufacture high quality bits, to meet the need of user. The users for the benefit of themself have to select high quality bit from many manufacturers to complete his drilling work. The problem of how to further scientifically and accurately judge the quality of impregnated diamond bit be well worth notice. The result of it can be affored to the manfacturer a technology processes, which must be obeyed, while also offered the criterion to user for the selecting and judging of diamond bits.

Based on a series tests in research processes for example the rock fragmentation, the classification of rock drillability, the experiences accumulated in supper hard meterials field, and the experiences of international technique interflow, it is suggest that the judgement of the quality of impregnated diamond bits must be related to the bit working processes at borehole bottom, and the situation of loads acting on the bits, in other word the inherent factors which results in the damaging of the bit crown must be exactly known. Only under the view of microphenomena to study the true cause that can be used to analysis the problems relating to bit failure and guide the correct judgement can be realized.

2 THE PROPERTY OF LOAD APPLIED ON IMPREGNATED DIAMOND BIT CROWN

During drilling the loads applied on bit crown are alternated, which can be proved by the following ways. Vertical loading on bit, created mainly by the weight of drilling string and some times by the incremental or diminishable pressure formed by surface rig, is often incorrectly considered to be relatively static basing on superficial phenomenon. As regards the horizontal shear forces, for the sake of rotational cutting speed of bit in every trip is constant, it is also usually defined as homogenous. But in real rock fragmentation processes owing to the vertical load and the rotational torque of the bit are transmited by the elastic drill string, and the rock being broken is consisted of minerals with different hardness and different cements those are obviously inhomogeneous, the loads on bit crown in spit of vertical or horizontal are all alternative.

The change of vertical loading on bit in real borehole bottom are as following:

Under the vertical loading accompaning with torque the shape of drilling stem in borehole becomes multiple waves spring. The length of waves are determinated by the loading on the bit and the ratio of diameters between drilling rod and borehole. In rotating this elastic system will certainly be existed different vibrations, the origin of vibrations results from following aspects:

In addition to the drilling stem under the condition of lost stability to be rubbed against the borehole wall accompany with randam vibration, the drilling stem itself exists a vibration.

When drilling is carrying out by diamond, because the inhomogeneous property of the rock the bit crown moves downward in a leap form, its detail process is that, whenever the rock stress goes beyond the elastic limit to produre crack propagation and intereaction, it is very fast to create a zone of fragmentation to produce a great shear and then resulting rock volumetric failure. This process is completed at a period accounting for μs.

Every great shear event imposes the bit crown a pulsatile vibration. The vibration frequency of a diamond bit and the drilling stem some times are disturbance each other, but some times may be reinforced, and then compose an obviously dynamic pulsating vibration, which can be measured and even observed in test stand using short drilling rod as shown in Fig. 1.

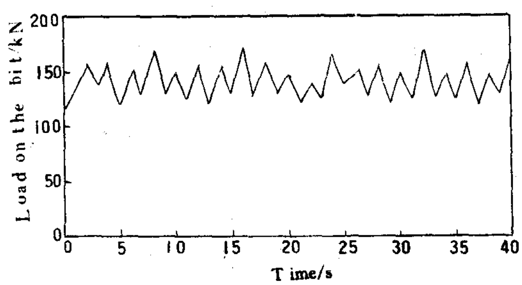

Fig. 1 Vibration load on an impregnated diamond bit

It is necessary to point out that, while the drilling stem be rotated with its own center in borehole, it also be at the meantime rotated with the center of borehole, thus leading the drill stem to contact against the wall and exist transverse vibration. When the diameter ratio between the borehole and drilling stem nearly equals to 1, the transverse vibration be much less than the longitudinal one, so that when analysis the loading situation of bits in working condition as well as to determine the strength of bit crown, it must be consided that the failure moded for small power impact but high frequency, especially drilling into a fissuring rock.

To a certain extent, the property of the load applied on bit is related to a certain borehole interval or in a certain interval of time, the number of impact experienced by the bit crown may be calculated using the followig formula:

$$M = Lnkc/v = knTc \quad (1)$$

where M—numbers of impact experienced by the bit in a certain time interval t (second) or a certain borehole interval L (m); n—rotating speed, (r/min); v—penetration rate, (m/h); c—index of rock cracks, which represents the average number of cracks met by the bit when it rotates one revolution in certain borehole interval; T—drilling time, (min); k—correction coefficient of calculating, taking it here as 1.5 ~2.

In an intermediate cracking formation and drilling under normal parameters the numbers of impact experienced by the bit per one metre penetration is about 20×10^3. With the increasing of rotating speed and the number of cracks, the penetration rate be decreased, but the impact number of each metre of penetration be increased.

3 JUDGING THE QUALITY OF DIAMOND BIT MATRIX USING K_{Ic}[1]

The users of impregnated diamond bit have a common experience that the working life and penetrating effect of the final layer of diamond impregnated matrix can't be compared with that of its initiative layers. This phenomenon existed in the diamond bit made by various kinds of method, such as sintering, electroplated and the others.

Various explanations for this phenomenon such as the compacting density at final layer is not sufficient or the total area of water flow be changed, *etc*, but in a concret diamond bit such as electroplated diamond bit with changable ways also exists the same phenomenon, thus those explenations are failured. However the real reason may be that the diamond bit matrix is destroyed by fatigue, and in spite of diamond bit drillig is carried out in integral formation or in fisscering formation its loading property is dynamic high frequncy pulsating impact, in highly fissuring formation this loading is more intensive.

Therefore the failure mechanism of the diamond bit matrix is brittle one under low stress conditions. Although in the initiative period the matrix has macroscopically high strength, but after it works in boreholes for a long time and experiences repeatly dynamic pulsating impact, the cracks existed in matrix and diamond crystallite be propagated and spreaded out gradually until intersecting each other thus resulting in the strength of matrix decreases fastly and abrases rapidly.

In fact there are many inavoidable microcracks, microporosities, soft bonding interfaces and other weak faults existed in the impregnated layer of the diamond bit, because the impregnated layer is sintered under high temperature with a compressed aggregate mixed with matrix WC, bonding phase Co, diamond, and other additions such as Cu, Mn, Ni, *etc*.

Therefore it is feasible to use the fracture toughness K_{Ic} of the fracture mechanics to study the working life of impregnated layer of the bit crown. However in order to determinate the value of K_{Ic} of impregnated diamond layer crack must be preestablished in it. It's well known that this is a hardly work.

Some graduates in the Department of Exploration Engineering of China University of Geosciences preestablished cracks in pure matrix (without diamond particles) to get some experimental data, of course those only can be referred.

It is well know that, the shear strength and impact tougness are usually used instead of fracture strength. The impact toughness indicates essentially the maxmum impact energy absorbed by unit area of fractured plane under once impact, it can be expressed by the area under the stress-strain curve before fracturing of the matrix sample. The total impacting energy before fracturing consists of three parts:

$$A = A_1 + A_2 + A_3$$

where A—total energy; A_1—the energy spent on elastic strain of the sample; A_2— the energy spent on plastic deformation of cracking; A_3— the energy spent on crack propagation and fracture.

It is known from the mechanism of fracturing that the more fraction of energy are spent on A_2 and A_3 in special, therefore for a material having high plastic property and intermediate strength the impact toughness may be used instead of the ability of anti-fracturing.

But for the material having obvious brittleness, e. g. diamond bit matrix, the plastic energy A_2 occupies on more than 10%, the elastic strain energy A_1 occupies nearly 85%, and once the cracks be appeared the broken limit value will soon be reached. Obviously the impact toughness of different matrix samples is the same, but the consisting proportions of A_1, A_2, A_3 are different, it indicates that the resistance abilities to dynamically crack propagation are different, namely the impact toughness can't be used instead of fracture-toughness. It also can't be real reflects the ability of resistance to the high frequency but small energy impact.

Because the fracture toughness K_{Ic} indicates the ability of resistance of stability failure by crack propagation. The more value the K_{Ic} is the more difficut the crack propagation will be.

The matrix of diamond bit crown is a typical brittle material. The load resulted in crack initiation and propagation is usually closed to the load of fracture. As mentioned above the working diamond bit crown experiences over a long term of time the high frequency but small energy impact, its inherent faults, such as the interfaces of WC particles, of diamond particles of diamond and bonding material, *etc*, are easy to be the origin of stress concentration and crack initiation. And the longer the working time of the diamond bit is, the easier the propagation of the crack initiated will be. This is why the working life of the impregnated layer located at near the crown tail is usually less than those of the initiative layers, as a matter of fact it is a result of fatigue time effect.

To determinate the K_{Ic} value a stnadard matrix sample with the following dimensions must be prepared:

$$s = 4W$$
$$W = 2B \qquad (3)$$
$$a/W = 0.5$$

where W—sample width; B—sample thickness; s—sample length; a—length of crack preestablished.

The prepared sample was then polished using a buffing lathe to a mirror finish and cut a standard crack using 0. 2 mm Mo silk by an electrosparking lathe. Finally the K_{Ic} value was determined using a standard test method.

4 REGULATING THE K_{Ic} OF DIAMOND BIT MATRIX

4. 1 *The Matrix Composition Basically Effect the* K_{Ic} *Value*

In this aspect the problem should be considered complexly, because the high value of

K_{Ic} must be co-existed with other main properties. According to literature[2, 3], B added in matrix can improve the interface condition of bonding metal and increase the strength of crystalloid interface, a suitable quantity of W added in matrix can increase the ability of resistance to the solution and separating out processes of WC particle. If the processes of WC solution and separating out are too heavy, the middle and small particle of WC ean be solved and separated out and attached to the large particle of WC; and then the fine particles of WC are eliminated, the remainder particle of WC becomes more large, thus leading to the value of K_{Ic} be decreased. Meanwhile metallic W powder added in matrix can depress the crystalloid shape change of the W-Co solid solution to keep the α-Co phase under high temperature in the structure of face-centered cube, and has 12 slide system increasing plasticity, absorbing more strain energy and relaxing stress, in addition it can also improve the value of K_{Ic}. Under the condition of consisting of Ni, adding in a little Mn can not only decrease the melt point of Ni but also can make the Mn to be a solid solution with Ni for increasing the point-lattice constant of Ni and approximating it to diamond's. The point-lattice constant of $Ni_{77}Mn_{23}$ is 3.5 Å, of the diamond's face-centered cubi-structure isalso 3.5 Å, According the theory of crystal growth, this alloy will be twinned with diamond particle to improve the bonding forces between the matrix and diamond. Changing the component of matrix for regulating the value of K_{Ic} must attention to whether the increased melt point of matrix metal is beyond the temperature limit of thermally damage of the diamond particle.

4.2 *The Relationship Between Crack propagation Speed and Bit Weight*

As mentioned above, when the bit crown working in borehole, the alternatively dynamic pulsating load causes the impregnated layer fatigue failure. It is also well known that the crack propagation speed is a main factor resulting in fatigue. If the min, alternative stress at bit crown is not equal to zero, the quantity of crack propagation can be expressed by following formula:

$$\frac{da}{dN} = f[\Delta(K_1)] \tag{4}$$

where N—number of alterative stress circulation; a—length of crack; $\Delta(K_1)$—strength factor of the stress field at crack tip.

The N is related to the properties of formation being drilled, if the formation is inhomogeneous and fissured the value of N is greater, if the rotation speed of drilling stem is larger the N is greater.

The $\Delta(K_1)$ is obviously affected by the load and the material property. In addition, because the bit crown being for a long time worked in mud, stress-orrosion may be happened provided that the mud is treated by various alkali, and the original microcracks can be propagated. It is also possible that in original matrix there are not macroscopic faults, but at the combine action of alternatively dynamic loading and corrosion medium crack or cracks may be produced, and then propagated to a critical dimension and made the matrix to be quickly failured or the diamond particles fell down. Under the condition of certain corrosion medium and the working stress of the crown material is below the stress of its yield point, with the passage of time the structure may be suddenly brittle fractured, which is called "delay failure" phenomenon in fracture mechanics. No doubtfully it can be existed in the working conditions of diamond bit.

5 MAKING THE IMPREGNATED DIAMOND LAYERS EQUIVALENTLY

As mentioned above the unequivalent in working life of impregnated diamond layers is caused by the effecting of fatigue. To compensate the damage of final impregnated layers resulted from high frequency but small energy impact the following two methods can be used:

5.1 Change the matrix composition of the final layer to increase its K_{Ic} or reasonablely decrease the concentration of diamond to increase the bonding quality.

In case of changing the matrix composition it is necessary to have the transitional layer between the initiative and final layers in order to provide a good bonding quality between them. Decreasing the concentration of diamond, it needs to use the higher quality diamond than that for initiative layers.

5.2 Add some metallic fibres into the matrix to reinforce the final impregated diamond layers.

It is based upon the general method used in industry to increase the strength of brittle material. The metallic fibre added in matrix must has finely chemical and physical compatibility with the matrix.

A successful test concerning the adding of metallic fibre in matrix has been completed by the author, the metallic W fibre 150~200 μm in diameter was added to matrix metal powder and sintered together. The metallographic structure of this compound was investigated by electron microscope, from the micrograph shown in Fig. 2 it is clearly observed that, at the interface between W fibre and matrix basis, the fibre and the matrix have been obviously sintered together. This phenomenon indicates that a chemical reaction between metallic W fibre and matrix basis has been occurred, but from the edge of the fibre to its inner the metallographic structure is the same as the core of W, and the thickness of reaction zone is about 5 μm.

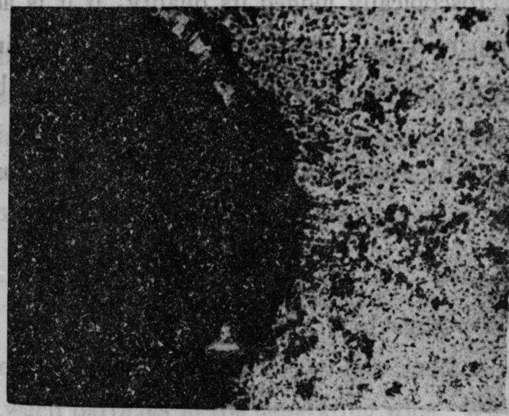

Fig. 2 Interface between the metallic W and the matrix × 1300

The method of adding W fibre to matrix basis has two ways: one is random way, the W fibres arranged in matrix are unregular, another is regular arrangement in matrix.

The change of K_{Ic} value of the matrix sample reinforced by regular arranged W fibre is shown in Fig. 3.

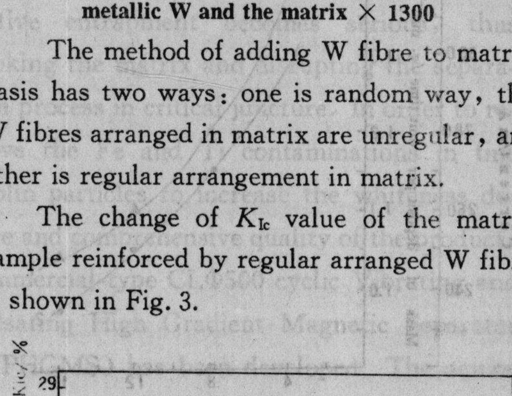

Fig. 3 Relation between WC percentage in matrix and the increasing ratio of K_{Ic}

The curve in Fig. 3 indicates that, with the WC% increasing the K_{Ic} value of the matrix reinforced by W fibre has been obviously improved comparing to the unreinforced matrix.

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Using the strength, hardness and impact toughness of diamond bit matrix can only be macroscopically judged its quality, if it is accompanied with the value of KIc then the inherent quality of diamond bit matrix can be judged.

The problem of unequivalent in working life of the initiative and final impregnation layers is due to the fatigue effect. To control the speed of crack propagation and to reinforce the final impregnation layer is the method to decrease the difference of unequivalent.

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