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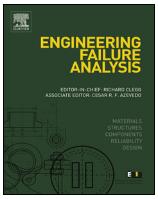

Review

A review on the wear of oil drill bits (conventional and the state of the art approaches for wear reduction and quantification)

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ABSTRACT

Since the first use of oil drill bits to penetrate petroleum and gas wells, the wear of the teeth and bearing (for roller-cone bits) and cutters for (Polycrystalline Diamond Compact (PDC) bits) has been a major dilemma that causes money and time loss, consequently affecting the whole drilling operation. The present study reviews wear mechanisms in both bit types. The review has carried out the previous and the state of the art approaches for improving the drill bits against wear.

Advantages and disadvantages of the conventional technologies for improving the manufacturing of the drill bits are explained. Conventional and emerging approaches of wear testing of drill bits are shown to expand the scope for developing the manufacturing of more reliable drill bits against the wear.

We report a literature survey of the old and current methods of wear quantification in terms of drilling parameters and mechanical properties of the minerals forming the drill bits, and means of increasing the efficiency of oil and gas drill bits. Empirical wear models, as well as wear prediction techniques while drilling are discussed along with the simulation wear models using Finite Element Analysis (FEA) and the Discrete Element Method (DEM).

1. Introduction

Drilling for oil and gas is still very demanding in many areas around the world. Rotary drilling is the most common technique for drilling oil and gas and since the invention of rotary drilling two types of drill bits have been used: roller-cone and polycrystalline diamond compact (PDC) bits. Roller cone bits or tricone bits have three rotating cones with each one rotating on its own axis during drilling, while PDC bits are fixed cutter bits with no moving parts. Drilling occurs due to the compression and rotation of the drill string. Tricone bits are used in general to drill a wide variety of rocks, from soft to extremely hard, while PDC bits can drill various sorts of formations, especially at harsh environments. Since the wear of drill bits is considered an intrinsic cost, significant savings can be achieved by effective control and minimisation of bit wear.

Here we assess wear analysis methods for drill bits, where bit wear mechanisms have been clarified to give a better understanding of the failure modes of both roller-cone and PDC bits. In addition, the current study deals with the state of the art of manufacturing processes of synthesizing oil drill bits to mitigate the increasing challenges resulting from bit wear. Two kinds of laboratory tests have been discussed in the literature to verify the concept of wear mechanisms of roller-cone bits: abrasion and scratch tests, whereas destructive and non-destructive tests are used for PDC bits. Laboratory scratch tests indicate the concept of micro-ploughing and micro-cutting behaviour in roller-cone bits, however further scratch test analysis is needed for PDC bits. Wear in drill bits is influenced by many factors related to drilling and rock properties, as well as the properties of materials that form the bit. The type and intensity of wear is dependent on several complicated factors that need to be considered in anticipating the rates of wear in field and

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Nomenclature

a_1	empirical constant
a_2	empirical constant
d	bit diameter (in)
E	Young's modulus (N/m^2, GPa)
E_D	bit drilling efficiency (dimensionless)
F	applied load (mN, N)
F_D	dimensionless tooth flatness (dimensionless)
H	hardness of the material (N/m^2, GPa)
Ha	hardness of the abrasive material (N/m^2, GPa)
H_w	hardness of the abraded material (N/m^2, GPa)
K_c	fracture toughness of the material ($MPa.m^{1/2}$)
MSE	mechanical specific energy (psi)
N	speed rotation of the bit (rpm)
PR	rate of penetration (ft/hr)
PR_D	dimensionless rate of penetration
SE	specific energy (psi)
T	measured torque (lb.ft)
T_D	dimensionless torque
V_w	volume of wear (μm^3, mm^3)
W	weight on bit (lb)
W_D	dimensionless weight on bit
W_H	wear resistant coefficient (dimensionless)
X	sliding distance (µm)
α	half angle of the abrasive particles (degrees)
β	abrasion angle (degree)
μ	bit coefficient of friction (dimensionless)
θ	abrasion angle (degree)
θ_c	attack angle (degree)

laboratory conditions such as the geometry of the bit as well as the drilling parameters along with the mechanical properties of the materials forming the drill bit. Numerous quantification technologies of bit wear have been described. Each method depends on the available measured data and on the wise interpretation to estimate the bit wear condition. Furthermore, each approach has assumptions that limit its applicability. However, despite the diverse quantification techniques that have been applied and the better understanding of the bit performance and when to pull out the bit due to the wear, such analysis should be done in conjunction with the conventional techniques of wear detection like bit records and well logging methods. Modelling and simulation are advanced approaches to give a better understanding of the bit behaviour and its design, which consequently leads to the optimum bit performance as well as predicting the wear rate of drill bits. The main objective of this review is to investigate the wear mechanisms of the oil drill bits in both roller-cone and PDC bits. Furthermore, we discuss previous methods for wear quantification and also apply a suggested approach for estimating the torque of the bit which consequently can be used for calculating dimensionless drilling parameters, to be used as indications for monitoring bit wear.

2. Literature review of the wear mechanism of drill bits

2.1. Introduction

For > 4 decades various methods have been implemented in the petroleum industry to meet the need to drill oil and gas wells efficiently, by using various drill bits to gain the paramount increase in drilling performance and to lower drilling costs associated with the drilling operation. Numerous attempts have been made to improve the manufacturing of drill bits by using optimum materials and design methods. Since the common bits used in drilling oil and gas wells are the roller-cone and PDC bits, the majority of the research relates to the particular bit types. Roller-cone bits have been widely used since one hundred years ago and have a undergone series of developments throughout their synthesizing processes and design. The development started from two cone milled tooth bits in 1908 [52] and continues work with the latest technology of diamond enhanced materials and diamond heel inserts, as well as improved bearings and seals. PDC bits use a special kind of cutters from diamond to improve the bit performance by obtaining a high rate of penetration. PDC bits also have improved significantly since they were manufactured in 1970. Roller-cone and PDC bits are used widely in drilling operations, depending on the rock formations and the present drilling conditions required (Figs. 2.3, 2.4, 2.9, 2.26, 2.27, 2.29, 3.4, 3.5).

2.2. An overview of wear mechanism of oil and gas drill bits

2.2.1. Wear mechanisms of roller-cone bits

Wear of drill bits is defined as macroscopic or microscopic removal or fracture of material, particularly at the cutter surface, or more general as, any degradation that reduces bit life. Mouritz and Hutchings [31] investigated the wear rates of the materials used in the teeth of rotary drill bits, and the abrasive wear mechanisms of these materials. The teeth of the rotary drill bits contain three layers. The external layer consists of a WC-Co hardfacing layer, the second layer is made from high-carbon martensitic steel and the third layer is the core of the tooth that consists of low-carbon martensitic steel. Small cylindrical specimens manufactured from materials similar to those used in the teeth of rotary drill bits were used in the investigation by Mouritz and Hutchings [31]. The abrasive rocks like sandstones and non-abrasive rocks such as limestone, representing the most common rock formations encountered in oil drilling were used in the tests.

Two types of tests were performed within the studying of the wear mechanisms by Mouritz and Hutchings [31]:-

1. Abrasion testing: the specimens of the teeth materials were abraded against sandstone and limestone disks for a total period time of 300 s. Mass loss measurements illustrated that the materials used in the cutting teeth of roller-cone bits suffered wear rates almost 140 times or more greater when abraded against sandstone as compared to limestone. Figs. 2.1 and 2.2 demonstrate the

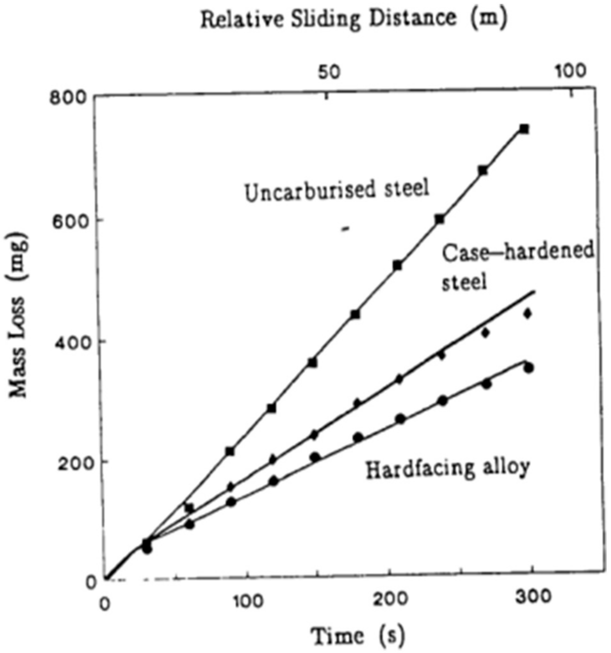


Fig. 2.1. Mass loss of bit materials when abraded against sandstone (after [31]).

difference in the mass loss of the bit materials with time, or sliding distance when abraded with sandstone and limestone respectively.

Mouritz and Hutchings [31] concluded that the hardness of the metal samples increased as the following order: Low-carbon steel $<$ high-carbon steel $<$ WC-Co alloy. The above conclusion comes from the principle that abrasive wear rate of any material depends on the ratio of its hardness (H_m) to the hardness of the abrasive (H_a). When $H_a/H_m < 1$, this means that the abrasive cannot easily scratch the material and the wear rate is extremely low. However, when $(H_a/H_m) > 1.2$, the abrasive is much more capable of scratching the material and hence causes high wear rates [45]. The hardness values of the three materials used in the test were: -460 HV, 700 HV and 1320 HV for low-carbon steel, high-carbon steel and WC-Co alloy, respectively.

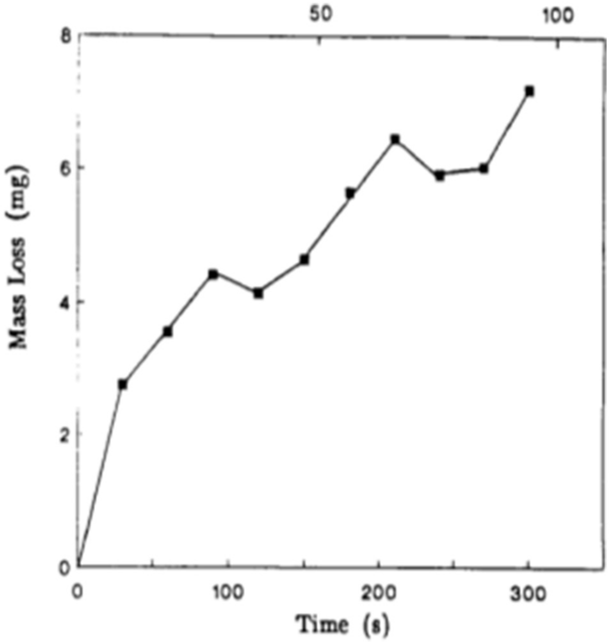


Fig. 2.2. Mass loss of bit materials when abraded against limestone (after [31]).

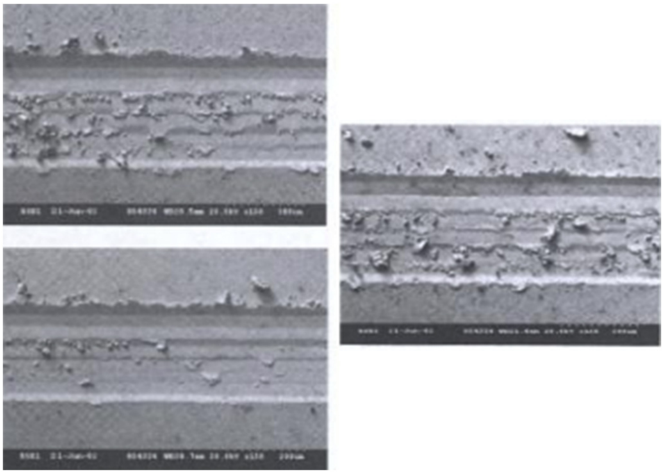


Fig. 2.3. SEM images of low carbon steel scratched by sandstone illustrating wear scars formed by the process of micro -ploughing (after [48]).

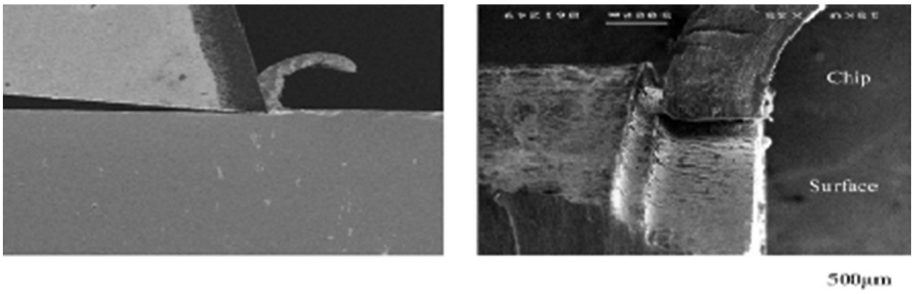
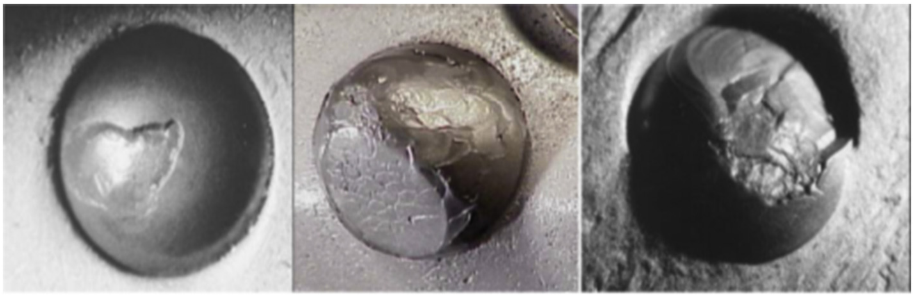


Fig. 2.4. SEM images of sulfurized free-machining steel scratched by cemented carbide tool illustrating large wear particle formed by micro-cutting (after [21]).



Spalling Chipping and heat checking Breakage

Fig. 2.5. Typical failure modes of PDC inserts for rock drill bit (after [18]).

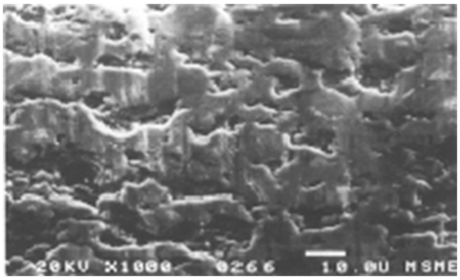


Fig. 2.6. Smooth wear on the diamond layer (after [53]).

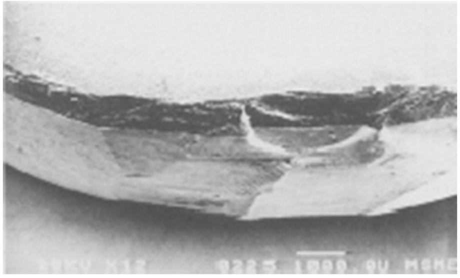


Fig. 2.7. Microchipping damage at the edge (after [53]).

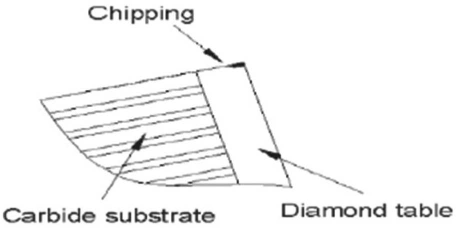


Fig. 2.8. Microchipping failure (after [60]).

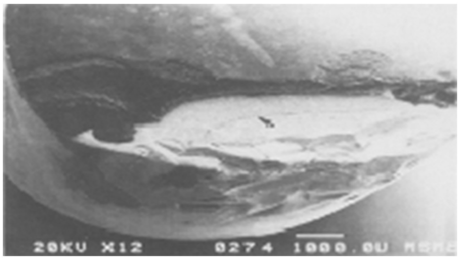


Fig. 2.9. Delamination failure mode of PDC cutter (after [53]).

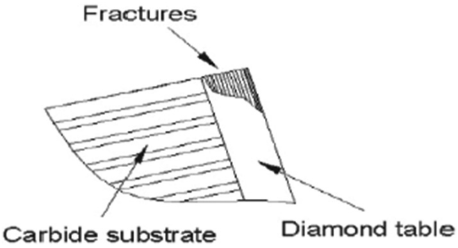


Fig. 2.10. Microfracturing failure (after [60]).

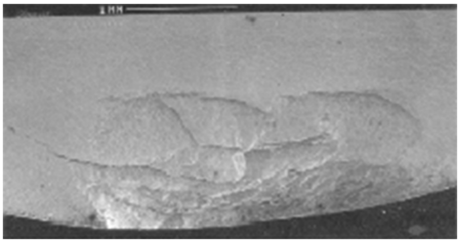


Fig. 2.11. An example of microfracturing failure (after [60]).