An all-optical system designed for the heating and temperature measurement of the diamond tool

INTRODUCTION

Diamond tools are used in industry for abrasive applications such as grinding, and drilling. One of its important applications is in drill bits used for drilling through rock in search of oil. The early failure of drill bits used in oil drilling rigs has huge financial implications. Therefore, we have undertaken a study trying to understand this problem and solving it by applying the science of light. In this work we outline how a non-contact optical system was designed for the heating and temperature measurement of the diamond tool. A laser beam was used as the source to raise the temperature of the diamond tool, and the resultant temperature was measured by using the blackbody principle. In this paper, we have successfully demonstrated temperature profiles across the diamond tool surface using two laser beam profiles and two optical setups, thus allowing a study of temperature influences with and without thermal stress. The generation of such temperature profiles on the diamond tool in the laboratory is important in the study of changes that occur in diamond tools, particularly the reduced efficiency of such tools in applications as rock drilling where extreme heating due to friction is expected. The results show that laser heating does not result in graphitization of the diamond tool, but rather cobalt and tungsten oxides form on the diamond tool surface.

1. EXPERIMENTAL SET-UP

2. TEMPERATURE MODEL

In order to find the dynamic temperature distribution on the surface of the sample, the heat diffusion in equation was solved with a non-zero source term:

\[
\frac{\partial T(r,t)}{\partial t} - \alpha \Delta T(r,t) = Q(r)
\]

With diffusivity \( D = \kappa C_A \), \( U \) is the temperature on the surface of the sample, \( p \) is the density of the diamond, \( \kappa \) is the thermal conductivity and \( C_A \) is the heat capacity. The source term of this study was a continuous wave laser beam of Gaussian intensity distribution, which leads to a source term given in equation 2 (a) and in case when the flat-top beam is used, the source term is given in equation 2 (b), respectively.

\[
Q(r) = \frac{2P_0 \exp\left(-2r^2/\omega^2\right)}{\pi \omega^2}
\]

\[
Q(r) = -\frac{\rho \omega^2}{\pi C_A} \quad 2(b)
\]

Where \( P_0 \) is the total power of the laser beam, \( \omega \) is the absorption coefficient of the PCD sample, \( \omega \) is the beam radius at the sample and \( I \) is the laser penetration depth. This problem can be formulated in terms of the Greens function approach, which leads to an integral solution given by:

\[
U(r,t) = \int_0^t \int_0^t \int_0^\infty \int_0^\infty J_0(\alpha \rho_1 \rho_2) \frac{\sin(\omega_2 r)}{\omega_2} e^{-\alpha_1} e^{-(\alpha_3 + \alpha_4)r} \, dr_1 \, dr_2 \, dt_1 \, dt_2
\]

Here we have assumed that \( U(r,0) = 0 \), and that \( \alpha r = 300 \, K \). The \( \alpha r \) terms are positive zeros of the first-order of Bessel function, \( J_0(\alpha r) \). Here \( r \) is the sample radius, \( J_0 \) refers to a Bessel function of order \( x \), \( x \) is the radial coordinate.

3. TEMPERATURE MEASUREMENTS RESULTS

4. STRUCTURAL ANALYSIS RESULTS

5. CONCLUSIONS

We successfully designed an optical system to raise and measure the resultant profile temperature of the diamond tool. The optical system can measure temperature ranges from room temperature to 1273 Kelvin and also this system can be used to any material. The generation of such temperature profile on diamond tool in the laboratory are important to study changes that occur in polycrystalline diamond tools, in particular the reduced efficiency of such tools in applications where extreme heating due to friction is expected.