Finite Element Analysis of Impregnated Diamond Drilling Bits

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Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Dedication

This work is dedicated to my beloved parents.

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Abstract

Diamond, including its synthesis, is a unique material not just because of its rarity and decorative features. Some of its physical properties are exceptional, which can not easily be matched by other materials. It is the hardest material, measured at 10 Mohs on the Mohs scale of mineral hardness. It has the highest thermal conductivity at room temperature, the highest bulk modulus and the highest tensile strength for cleavage. It has low coefficients of friction and thermal expansion, and is relatively inert to chemical attack by common acids and bases. Due to these exceptional properties, synthetic diamond as an abrasive has been used as an advanced engineering material, in making tools for grinding, cutting and drilling purposes. Synthetic diamond is commonly used in impregnated drills for cutting purposes.

For bit design and manufacturing purposes, it is important to fully understand the complex interactions between rocks and diamond bits, as well as the mechanical behaviour of diamond particles within the impregnated bit during the drilling process. Major current issues of impregnated diamond tools include premature failure of diamonds, the ineffective wear rate of the matrix to continuously expose fresh diamonds and premature diamond fall out. Published researches to date include both experimental studies and numerical modellings for performance assessments and improvement. Some experimental studies have identified different failure mechanisms of the diamond particles and have studied the wear rate of the matrix under different drilling parameters, such as torque, reactive load and penetration rates. Others have tested suitable combinations of metals for the production of different matrix composites for different drilling purposes. It is well understood that in order to achieve optimal cutting efficiency during service, the matrix and diamond must wear simultaneously such that fresh diamonds will expose themselves after worn diamonds have fallen out of the matrix. It has been found that diamonds are mostly held by the matrix through mechanical interlocking, which in general has low interfacial bond strength. Some

research have been conducted to investigate the effects of metal-coating diamonds in an attempt to provide sufficiently high bond strength between diamond particles and the matrix and at the same time to ensure the bonds are weak enough so that the self-dressing capability of the drill bits can be achieved. Numerical models have been used to investigate the effects of the variation of stresses at the interface under different wear conditions. The local plastic deformation and residual stresses due to the sintering process have also been studied through numerical simulations.

In this research, the finite element method (FEM) is employed to investigate the interface failure mechanism of impregnated diamond bits, which is essentially an interface de-bonding process between diamond particles and the matrix, termed the diamond particle fallout. In particular, the cohesive zone modelling (CZM) technique is implemented to simulate the crack initiation and propagation along the interface. The extended finite element method (XFEM) is used to predict fractures in the matrix under certain loading conditions.

The thesis is divided into five chapters, which are described briefly below:

In Chapter 1, the general background together with the objectives and originality of the present research are introduced.

In Chapter 2, a two-dimensional micromechanical finite element model of diamond impregnated bits suitable for the simulation of interfacial failure between diamond particles and the metal matrix are presented. The surface based cohesive zone model (CZM) is an advanced and efficient technique that is able to adequately simulate and predict fracture initiation and propagation of an uncracked interface between two adhesive surfaces. Two numerical examples have been developed to validate the accuracy and adequacy of the presented model. The effects of different modelling parameters on the diamond particle retention capacity have also been thoroughly studied and compared in order to have a better understanding of the failure mechanism.

Chapter 3 describes the extension of the two-dimensional FE model to three-dimensional analysis. Similar to two-dimensional models, a model representing a single diamond particle partially embedded inside the matrix has been developed. A three-dimensional double cantilever beam (DCB) testing model has been created to simulate the crack propagation along the interface, and its results have been compared with the experimental results to validate the precision of the model. The effects of diamond particle shape, orientation, and protrusion, as well as interface properties on the diamond's retention ability, have also been studied.

Chapter 4 presents an efficient two-dimensional FE model incorporating both the cohesive zone method (CZM) and the extended finite element method (XFEM) for the prediction of de-bonding along interfaces and micro-cracking in the matrix. The effects of interface property, as well as the particle shape on failure modes, have also been investigated.

Finally, the conclusions of the present research are summarised in Chapter 5. The limitations of the present study and further research recommendations are also described in this chapter.

Statement of Originality

I, **Jiayi Xu**, hereby declare that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution in my name and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and, where applicable, any partner institution responsible for the joint award of this degree.

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