



# **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

School of Civil, Environmental and Mining Engineering  
Faculty of Engineering, Computer and Mathematical Sciences  
The University of Adelaide

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## **Dedication**

This work is dedicated to my beloved parents.

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# Finite Element Analysis of Impregnated Diamond Drilling Bits

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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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# Table of Contents

<b>Abstract</b> .....	<b>v</b>
<b>Statement of Originality</b> .....	<b>ix</b>
<b>Acknowledgments</b> .....	<b>xi</b>
<b>Table of Contents</b> .....	<b>xiii</b>
<b>List of Tables</b> .....	<b>xvi</b>
<b>List of Figures</b> .....	<b>xvii</b>
<b>Chapter 1</b> .....	<b>1</b>
<b>Introduction</b> .....	<b>1</b>
1.1 Background.....	1
1.2 Research objectives.....	7
1.3 Thesis overview .....	8
References for Chapter 1 .....	11
<b>Chapter 2</b> .....	<b>15</b>
<b>Interfacial failure modelling of diamond bits made of particulate composites</b> .....	<b>15</b>
2.1 Introduction.....	18
2.2 Numerical Model .....	23
2.2.1 Geometry of the model and its finite element meshing.....	23
2.2.2 Material model of the matrix and diamonds and their properties	26
2.2.3 Failure model for the diamond-matrix interface .....	27
2.3 Validation of the numerical examples .....	33
2.3.1 Validation of the model with perfect diamond-matrix interface considering different levels of matrix and diamond wear.....	34
2.3.2 Validation of the interfacial damage model with a double cantilever beam .....	39
2.4 Parametric study .....	42
2.4.1 Effect of diamond shapes .....	42

---

2.4.2	Effect of diamond orientations.....	49
2.4.3	Effect of diamond protrusion (particle wear and matrix wear)...	53
2.4.4	Multiple diamond particles and their interactions .....	55
2.4.5	Effect of interface properties .....	56
2.5	Conclusions .....	57
	Acknowledgement .....	59
	References for Chapter 2.....	60
<b>Chapter 3</b>	.....	<b>65</b>
<b>Modelling of interfacial debonding and diamond pull-out failure in diamond bits</b>	.....Error! Bookmark not defined.	
3.1	Introduction .....	68
3.2	Finite element model .....	71
3.2.1	Failure model for the diamond-matrix interface .....	71
3.2.2	Material model of the matrix, diamond and interface.....	76
3.2.3	Material model of the matrix, diamond and interface.....	77
3.3	Validation of the numerical examples.....	79
3.3.1	Validation with available numerical researches .....	79
3.3.2	Validation of the interfacial damage model with a DCB test .....	82
3.3.3	Validation of the interfacial damage model with an MMB test..	84
3.4	Results and discussions of parametric study .....	86
3.4.1	Effect of diamond shapes with different load directions .....	86
3.4.2	Effect of diamond orientations.....	90
3.4.3	Effect of interfacial properties .....	92
3.5	Conclusions .....	95
	Acknowledgement .....	97
	References for Chapter 3.....	98
<b>Chapter 4</b>	.....	<b>103</b>
<b>Numerical modelling of the failure mechanisms of diamond impregnated bits</b>	.....	<b>103</b>
4.1	Introduction .....	106
4.2	Model formulation and material properties.....	108
4.2.1	Geometry of the model and its finite element meshing .....	108



4.2.2	Material model of the matrix and diamonds and their properties .....	110
4.2.3	Cohesive zone model for the diamond-matrix interface .....	111
4.2.4	Extended finite element model for the metal matrix .....	116
4.3	Validations .....	119
4.3.1	Validation of the interfacial damage model .....	119
4.3.2	Validation of the extended finite element model .....	120
4.4	Results of the parametric study.....	122
4.4.1	Effect of interfacial material properties – 2D.....	122
4.4.2	Effect of matrix fracture properties – 3D .....	126
4.4.3	Effect of diamond shapes .....	129
4.5	Conclusions.....	134
	Acknowledgement.....	136
	References for Chapter 4 .....	137
<b>Chapter 5</b>	.....	<b>141</b>
<b>Conclusions</b>	.....	<b>141</b>
5.1	Research contributions .....	143
5.2	Limitations and future perspectives.....	146
<b>Appendix</b>	.....	<b>149</b>

# List of Tables

Table 2.1 Dimension and properties for MMB test specimen. ....	41
Table 2.2 Numerical and experimental comparison of maximum loads of MMB Test. ....	42
Table 2.3 Critical forces for the onset of interfacial failure. ....	52
Table 2.4 Variation of critical load with respect to spacing between diamonds. .....	55
Table 2.5 Four case studies of different interfacial parameters. ....	56
Table 3.1 Mechanical properties of diamond, matrix and interface. ....	77
Table 3.2 Mechanical properties of diamond, matrix and interface. ....	85
Table 3.3 Force to initiate interfacial failure for different case studies. ....	89
Table 3.4 Critical forces to initiate interface debonding of different diamond shapes with various orientations and loading directions.....	92
Table 3.5 Twelve case studies of different interfacial parameters.....	94
Table 4.1 Seven case studies of different interfacial parameters. ....	123
Table 4.2 Six case studies of different matrix material properties. ....	128

# List of Figures

Fig. 2.1 Finite element model of a diamond impregnated drill bit.....	25
Fig. 2.2 A typical bilinear traction-separation relationship.....	27
Fig. 2.3 Detail of an interface for cohesive zone modelling. ....	28
Fig. 2.4 Finite element analysis for a different level of matrix wear. ....	35
Fig. 2.5 Variation of normal stress along the interface as element centre stress in the diamond. ....	37
Fig. 2.6 Finite element analysis for different level of diamond wear. ....	38
Fig. 2.7 Variation of Von-Mises stresses along the interface node as a function of particle wear. ....	39
Fig. 2.8 Schematic draw of double-cantilever beam test. ....	40
Fig. 2.9 Load-deflection curve of the double cantilever beam with delamination. ....	40
Fig. 2.10 Illustration of mixed-mode bending test. ....	41
Fig. 2.11 Models for different diamond particle shapes with same radius and protrusion height.....	44
Fig. 2.12 Force-displacement variation at the tip of diamond particles. ....	45
Fig. 2.13 Effect of diamond shape on its retention capacity with the same circumcircle radius. ....	46
Fig. 2.14 Results of displacement jump with respect to the cutting force for square shaped diamond particle at point B.....	47
Fig. 2.15 Distributed load applied on the diamond of the model.....	48

Fig. 2.16 Effect of diamond shape on its retention capacity with the same volume fraction. ....	49
Fig. 2.17 Diamond particles with different orientations. ....	50
Fig. 2.18 Effect of orientations and shapes of diamonds on their retention capacity. ....	52
Fig. 2.19 Interface failure influenced by (a) diamond wear and (b) matrix wear. ....	53
Fig. 2.20 Effect of diamond/matrix wear on critical load for interface failure. ....	54
Fig. 2.21 Multiple diamond particles with equal spacing (S). ....	55
Fig. 2.22 Effect of interface properties on the critical load for interface failure. ....	57
Fig. 3.1 Cohesive fracture separation (a) undeformed configuration and (b) deformed configuration. ....	72
Fig. 3.2 A typical bilinear traction-separation relationship. ....	73
Fig. 3.3 Impregnated diamond core bit and its variables: (a) Top view, (b) SEM view of exposed diamond, (c) side view and (d) bit-rock interface view (2-D). ....	78
Fig. 3.4 3-D finite element model of the representative part of the IDC bit: (a) Diamond & Matrix parts and (b) mesh configuration of the model. ....	79
Fig. 3.5 Finite element model for different level of matrix wear: (a) Finite element meshing of the model geometry, (b) Distribution of the Von-Mises stress over the entire body. ....	80
Fig. 3.6 Variation of normal stress along the interface as element centre stress in the diamond. ....	82

Fig. 3.7 Finite element model of DCB test: (a) Illustration of DCB test specimen and (b) 3-D model DCB. ....83

Fig. 3.8 Experimental and numerical results comparison for the three-dimensional DCB debonding. ....83

Fig. 3.9 Finite element model of MMB test: (a) Illustration of MMB apparatus and (b) 3-D model of MMB specimen. ....84

Fig. 3.10 Numerical and experimental comparison of the load-displacement response of MMB test. ....85

Fig. 3.11 Models for diamond particles with vertex-face toward upward: (a) different diamond shapes, (b) different horizontal loads from a top view, (c) finite element meshing and (d) Von-Mises stress distributions. ....87

Fig. 3.12 Force-displacement variation at the tip of diamond particles with different load directions: (a) cube, (b) octahedron and (c) dodecahedron.....88

Fig. 3.13 Cut-out views of Von-Mises stress distribution of different diamond shapes: (a) Cube, (b) Octahedron and (c) Dodecahedron. ....89

Fig. 3.14 Models for diamond particles with edge face toward upward: (a) different diamond shapes and (b) different horizontal loads from top view. ....90

Fig. 3.15 Models for diamond particles with flat surface face toward upward: (a) Different diamond shapes and (b) Different horizontal loads from the top view. ....91

Fig. 4.1 Micromechanical model of diamond impregnated bit: (a) SEM micrograph of ID bit and (b) skeleton draw of ID bit and finite element model of a single diamond particle embedded in the matrix. ....109

Fig. 4.2 Detail of an interface for cohesive zone method..... 111

Fig. 4.3 A typical bilinear traction-separation relationship. .... 112

Fig. 4.4 Heaviside jump function..... 117

Fig. 4.5 The crack tip from a polar coordinate system. .... 117

Fig. 4.6 Schematic draw of double-cantilever beam test. .... 120

Fig. 4.7 Load-deflection curve of the double cantilever beam with delamination..... 120

Fig. 4.8 Geometry of the plate specimen. .... 121

Fig. 4.9 Experimental and numerical results comparison for the plate specimen. .... 122

Fig. 4.10 CZM traction-separation laws of assumed strong and weak interfaces. .... 124

Fig. 4.11 Force-displacement variations at the tip of diamond particles for 4 cases with different interfacial parameters. .... 125

Fig. 4.12 Maximum principle stress contours and failure mechanisms illustration for the square shape ID bit with two cases: (a) weak interface (b) strong interface..... 126

Fig. 4.13 3-D finite element model of the representative part of the ID bit: (a) Diamond & Matrix parts and (b) mesh configuration of the model. .... 127

Fig. 4.14 3-D finite element model of the representative part of the ID bit: (a) Diamond & Matrix parts and (b) mesh configuration of the model. .... 128

Fig. 4.15 3-D finite element model of the representative part of the ID bit: (a) Diamond & Matrix parts and (b) mesh configuration of the model. .... 129

Fig. 4.16 Shape illustration of natural and synthetic diamonds: (a) natural diamond and (b) synthetic diamond. .... 130

Fig. 4.17 Study of different diamond shapes: (a) square, (b) pentagon, (c) hexagon, (d) octagon, (e) decagon and (f) dodecagon. .... 130

Fig. 4.18 Maximum principle stress distributions of different diamond shapes with different interface properties: (a) weak interface and (b) strong interface. .... 132

Fig. 4.19 Effect of diamond particle shape and interfacial strength on its retention capacity. .... 133