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Probabilistic modelling of tool unbalance during cutting of hard-heterogeneous materials: a case study in Ceramic Matrix Composites (CMCs)

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Abstract

Compared to other materials, CMCs display a unique high hardness and heterogeneous nature which are critically reflected during the drilling process where asymmetrical high forces are suffered by the tool, resulting in an unbalance of the drill bit. Hence, this study proposes a mechanistic approach where the hard nature resulting in high radial forces is analytically studied and coupled with a probabilistic model where the heterogeneous nature of CMCs is taken into consideration. This theoretical study results in an in-depth understanding of the loading unbalance occurring on different tool sizes during drilling of CMCs which can lead to a premature tool breakage. The nature of this unique force that is assumed in the theoretical approach to influence the cutting of hard-heterogeneous materials is experimentally validated by drilling a homogeneous and a heterogeneous hard ceramics, i.e. a monolithic SiC and a SiC/SiC CMC. Moreover, the model developed together the with drilling experiments with different tool diameters result in an understanding of why small tool diameters suffer a premature tool breakage when drilling difficult-to-machine CMCs.

Keywords: Machining, Ceramic Matrix Composites, Instabilities, Heterogeneous materials, Hard materials
2015 MSC: 00-01, 99-00

1. Introduction

Ceramic Matrix Composites (CMCs) are a material choice as replacement to selected high temperature metallic alloys in the aerospace industry [1] and are under consideration for nuclear application [2]. This success in high-value components is due to its high mechanical and chemical performance in severe environments, especially at high temperatures. Non-oxide CMCs are normally formed by ceramic fibres (e.g. SiC or C fibres) embedded in a ceramic matrix (e.g. SiC, C or Si_3N_4), producing a ceramic reinforced ceramic which results in an improved fracture toughness compared to monolithic ceramics [3]. The increase in demand of these materials in high-value sectors has developed the need of understanding and optimising the machining process. Nevertheless, due to its heterogeneous and hard nature, the mechanical machining can be challenging, in particular when small tools need to withstand high cutting forces. Several authors reported short tool life when mechanically machining CMCs [4]; as such, it was concluded that micro-holes could not be machined in hard CMCs probably due to the poor surface quality achieved and the premature tool breakage [5]. Nevertheless, an in-depth analysis of the phenomena occurring when machining hard-heterogeneous CMCs and how the tool size can be affected by the material heterogeneous structure has not yet been reported in the literature.

Several non-conventional machining techniques have been experimentally tested in hard CMCs [6]. Pulsed Laser Ab-

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