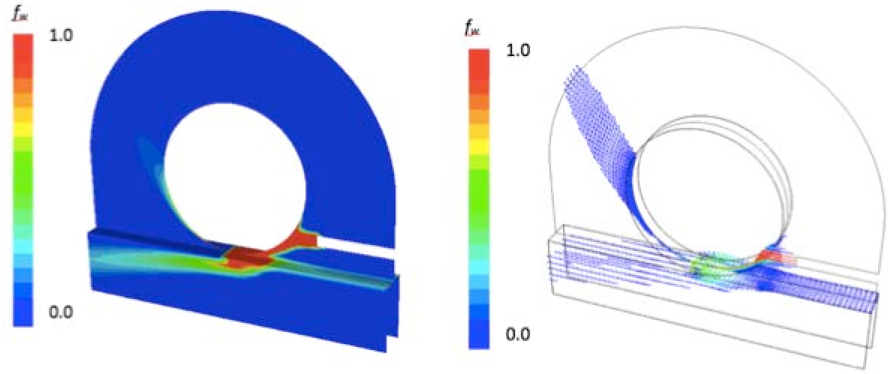
Multiscale modelling of lubrication flow during grinding

Cutting fluid plays a vital role in machining processes such as drilling, grinding, milling and turning. The main purposes of the cutting fluid are: to reduce friction between tool and work piece; to limit and dissipate any heat generated; to flush away chips from the machining process. The cutting fluid is often supplied as a jet through a nozzle, so the position, orientation and geometry of the nozzle, as well as rate of supply of fluid, need to be well optimized to achieve high removal rates and good workpiece quality in machining processes. The use of cutting fluid does, however, have significant negative effects. For example, it usually contains carcinogens that pose serious health risks for machine operators. In addition, the delivery of cutting fluid can account for more than 15% of manufacturing costs. Although many have tried to optimize the delivery of cutting fluids [*1*], either through experimental studies or simplified models [2], these methods cannot provide a detailed picture of the whole machining process, particularly with respect to the dynamic interactions between the workpiece, cutting tool and coolant. CFD can be used to study the process in more detail, and recent preliminary work by *Axinte* and *Hao* has involved the development of a turbulent multiphase 3D model and associated numerical solution algorithms to study the interaction of a jet of coolant with a grinding wheel (Figure 1) while considering grinding wheel porosity and position relative to the workpiece. However, the key region where the model is at its least accurate, but which is probably the most vital for the study of material removal and cooling, is the thin zone between the grinding wheel and the workpiece.



(a) *(b)*

Fig. 1: An example of preliminary work by Axinte and Hao: (a) computed volume fraction of cutting fluid (blue = 100% air, red = 100% liquid); (b) computed velocity vector of cutting fluid (red = 35m/s, blue = 0m/s).

In this PhD project, the student will develop a lubrication model for the flow in the grinding zone. Due to the random position and protrusion of the abrasives from the theoretical wheel geometry, there is a thin zone of varying thickness, typically *<100μm*, across the width of the wheel where fluid is forced into the cutting zone to lubricate and cool the workpiece; this zone will be modelled as a rapidly moving porous medium. Rational approximation methods, such as the method of matched asymptotic expansions, will be used to derive simplified equations that relate the flowrate and composition of the multiphase cutting fluid/air mixture to the parameters of the system. In particular since, on the lengthscale of the jet and the exterior fluid flow, the thickness of the grinding region is negligible, we aim to formulate a boundary condition that can provide a link between the exterior flow and the flow in the grinding zone, thereby allowing costly CFD calculations to be focussed on the lengthscale of the exterior flow, where it can be used effectively.

To validate this work we will perform Laser Doppler Anemometry measurements using a transparent (glass) enclosure and workpiece to enable the visualisation the distribution of the fluid around and within the cutting zone; additionally grinding wheels with different porosities and geometries will be tested to validate the models towards industrial utilisation.

The project will be jointly supervised by three researchers:
- Professor Axinte in the Faculty of Engineering – University Park Campus - who will provide guidance on manufacturing/engineering aspects of the problem and support experimental trials,
- Dr Hao in the Faculty of Science and Engineering – Ningbo Campus - who is an expert in CFD relevant to the project; she has done preliminary CFD studies on this problem to assess the viability of the approach,
- Professor Billingham in the School of Mathematical Sciences – University Park Campus - who will lead on mathematical modelling and asymptotic methods.

References

[1] S Ebbrell, N.H Woolley, Y.D Tridimas, D.R Allanson, W.B Rowe, The effects of cutting fluid application methods on the grinding process, International Journal of Machine Tools and Manufacture, 40/2, 2000, 209-223

[2] S. Mihić; Ss. Cioc; I. D. Marinescu; M. C. Weismiller, Detailed Study of Fluid Flow and Heat Transfer in the Abrasive Grinding Contact Using Computational Fluid Dynamics Methods, J. Manuf. Sci. Eng. 2013, 135/4, 041002-041002-13.