

Chapter 1: Introduction

1.1 Background

This thesis is part of research on nano-composites conducted by the Diamond Research Laboratory of De Beers[‡] from 1996 to 1997.

1.2 Rationale for diamond-alumina composites

The incorporation of diamond particles in an alumina matrix may result in a composite with superior wear properties to pure alumina due the following reasons:

- 1) Intuitively, one might expect that hardness might be additive in some way. Although this may seem simplistic at first hand, this is in fact the case. In fig 1-1, the range of wear resistance of a composite as a function of composition as predicted by Axén and Jacobson (1994) is shown. 'Wear resistance' as defined by Axén and Jacobson is roughly proportional to hardness.

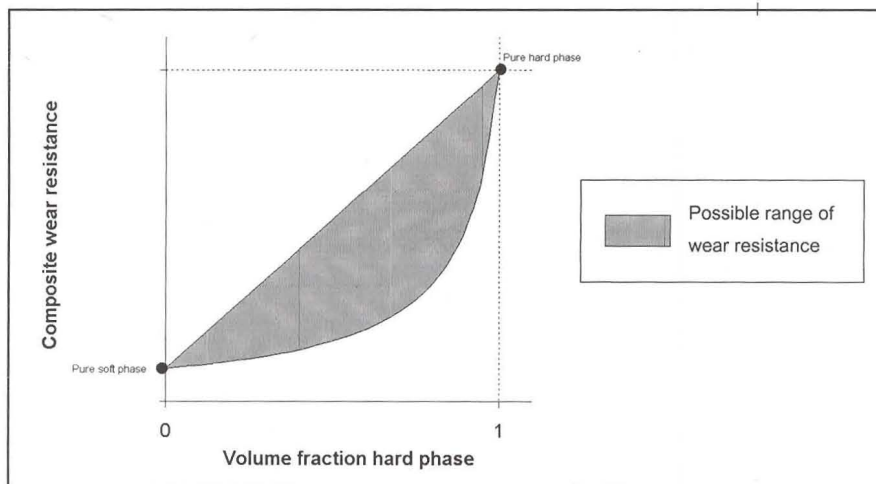


Fig. 1-1: The range of wear resistance for composites as predicted by Axén and Jacobson (1994).

- 2) The presence of the strong diamond particles may reinforce alumina in some way.

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3) Diamond has superior heat conduction properties. Thermal conductivity is additive, ideally,

$$k_{\text{Composite}} = f_{\text{Diamond}} k_{\text{Diamond}} + f_{\text{Alumina}} k_{\text{Alumina}} \quad (1-1)$$

where k is thermal conductivity and f volume fraction. Materials with high thermal conductivity conduct heat away from the friction zone more efficiently, which results in less thermal stressing and less chemical reactions at the friction zone.

4) Empirical evidence from published work of Chu *et al* (1992) and Noma and Sawaoka (1984 and 1985). Chu *et al* showed that diamond-alumina have superior wear qualities to zirconia toughened alumina (see fig. 5-12 on page 43). Noma and Sawaoka showed that diamond-alumina can be tougher than alumina alone, although hardness is sacrificed in their work (see fig. 5-10 to 5-12 on pages 43 to 44).

1.3 Rationale for nano-sized particle powders and filter casting

Although diamond is very inert under normal conditions, it is in fact only metastable. Diamond rapidly converts to graphite at high temperature. If diamond particles are to be incorporated into an alumina matrix, they will experience high temperature when the composite body is fired.

To minimise the temperature and firing time needed for the densification of the composite green body, easily sinterable alumina should be used. An obvious way to achieve this is to use alumina powders consisting of nano-sized particles.

As discussed in chapter 2, a further way to reduce both the firing time and temperature is to start off with green compacts that are as dense as possible. 'Wet' processing e.g. slip casting or filter casting, gives superior green density. As formation rate of filter cake (the wet green body) increases with decreasing particle size, filter casting is the only feasible option of the two 'wet' processing routes.

1.4 The interrelationship between factors

The interrelationship between the processing variables and the properties of a fired alumina compact is complex. For this survey, some of the stronger dependencies between the final properties and the variables for this work may be approximated as in fig. 1-2.

The factors at the extreme left of the diagram in fig. 1-2 can be controlled during processing. These processing variables determine the quality of the final product.

Green body density is shown as a separate branch in fig. 1-2, as it depends on the green microstructure. The green body has other properties that could have been shown on the diagram. Green density, however, is given special significance in the diagram as it is an easily measurable and frequently measured quantity, which gives a good impression of the general quality of the green body.

Like green density, fired density and strength are shown as separate, dead ending branches. Again, as is the case with green density and green body quality, the fired density is a function of the general quality of the fired compact. Like green density, fired density is an easily measurable property of the fired compact, and it gives a good indication of the general quality of the fired compact. Strength, although important in most other applications, is of lesser importance in the wear performance of a material (personal communication, Hickman). For these reasons, the diagram does not indicate any relationship between wear resistance and fired density or strength (which is not strictly true).

Wear resistance depends strongly on hardness and toughness. Hardness and toughness are indicated in fig. 1-2 as the only two properties that would determine wear resistance (which, again, is not strictly true).

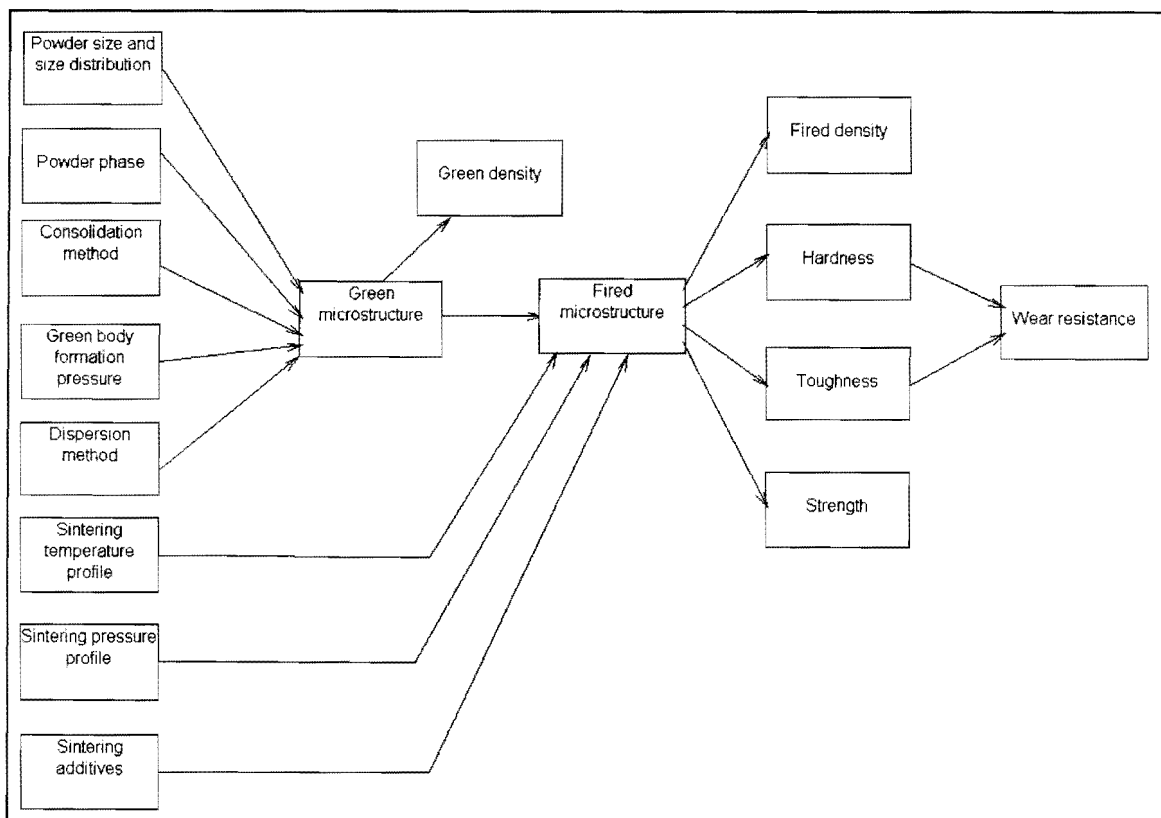


Fig. 1-2: The factors influencing the quality of the final fired product.

1.5 Organisation of thesis

This thesis follows the following structure:

Introduction	Chapter 1
Literature review. Experimental principles.	Chapter 2: Green processing
	Chapter 3: Firing
	Chapter 4: Graphitisation
	Chapter 5: Wear
Preparation of samples	Chapter 6
Characterisation of samples	Chapter 7: Routine characterisation
	Chapter 8: Microstructure
	Chapter 9: Hardness and toughness
	Chapter 10: Wear testing
Discussion	Chapter 11:

1.6 Related document

As part of the requirements of the degree, for which this thesis is a partial fulfilment, a review of literature ('Aspects of the processing of diamond-alumina composites'[§]) relevant to the processing of nano-composites, was also completed. It essentially includes the same material covered in chapters 2 to 5 of this thesis, but it also includes some material that is not covered in this thesis. Excluded material was judged not be relevant enough to the experimental work reported here, but may nonetheless be useful in future evaluation of nano-composites.

[§] Copies with R. Fries of the Diamond Research Laboratory of De Beers and F. K. Bader of the Department of Materials Science of the University of Pretoria.