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Machining of a novel Alumina/Cyanoacrylate green ceramic compacts

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Research at Nottingham Trent University has led to the invention of a novel Alumina/Cyanoacrylate ceramic compact that can be machined using conventional methods. *Powder Reaction Injection Moulding Engineering (P.R.I.M.E)* is a novel solution to the problems associated with the debinding of conventional polymer or wax carriers since the binder employed in the manufacture of the green compacts de-polymerises to a gas, rather than burns. The study of green machining of a new ceramic material is important for the future development and application of that material, since this is a common manufacturing process in many industries. This paper reports the initial research results demonstrating that cyanoacrylate can be used as an effective reactive binder with aluminium oxide to produce compacts that can be machined using carbide tools to manufacture engineering parts.

1. INTRODUCTION

Advanced or engineering ceramics are used in significant quantities in the production of components such as valves, valve seats, turbine blades, liners, cutting tools, artificial hip joints, dental prosthetics and artificial heart valves [1-4]. This has led to intensive research into alternative forming methods to reduce the generally high costs of these items.

PRIME is a technique that involves mixing a reactive binder with a particulate ceramic powder, moulding, debinding and finally sintering to near net density [5]. This process utilises cyanoacrylate fluid (superglue) as the powder binder or carrier and has proved to be successful for developing conduit articles out of ceramic [1,2,4,5].

Machining before sintering of ceramic (i.e. in their green state) represents an alternative to other shaping processes, and offers a high degree of flexibility and economic efficiency for the machining of ceramic parts. However, the fragility of conventional ceramic green compacts generally provides considerable difficulties when machining. Diamond grinding, which is high cost and limited in the shape complexity that can be produced, is used for more than 80% of all machining performed on advanced ceramics [6]. Although new physical and chemical (P&C) machining techniques have been introduced, the practical limitations to their use are the high initial investment costs and restrictions on the materials that can be shaped.

2. GREEN COMPACT MANUFACTURE

In PRIME, the binder cyanoacrylate is a reactive monomer, which simplifies the moulding process and does not need complex controls [5]. Conventional polymer binders can take a long time to de-bind, and leave harmful residues in the green compact, which are carried through to the final sintering stage. However cyanoacrylates can be removed in minutes from the compact and leave no harmful residues.

This paper is concerned with the manufacture and machining of green compacts using Alumina (Al_2O_3), since it is the most commonly used advanced engineering ceramic, as a result of its combination of reasonable cost and useful properties. Calcined alumina powder were selected for the investigation with purity >99.8%, green density 2.12 g/cm^2, and median particle size <8 µm. Other ceramic powders have also been used successfully.

In the PRIME process, inhibition of the cyanoacrylate polymerisation is one of the most important factors in ensuring that there is enough time for thorough mixing by preventing premature polymerisation. However, if sufficient inhibitor is added to prevent polymerisation during mixing, then the subsequent polymerisation time can be lengthy (>1 week). Thus, the processing route requires a step to promote the initiation of the polymerisation reaction.

In the present studies, the alumina powder was added, up to 48% by volume, to a low-blooming cyanoacrylate liquid. The mixing took approximately 10 minutes, and curing was controlled to start 30 minutes after mixing and to be completed within 2 hours. Cylindrical compacts, of maximum dimensions 30mm diameter and 30mm height, have been successfully prepared for the machining trials.

3. MACHINING OF THE COMPACT

Since the PRIME process is relatively new, there has been very little research into the properties of the green compacts. Thus, given the unusual nature of these compacts, it was considered that their machining might be quite dissimilar to the machining of other ceramic compacts.

In this study, drilling blind holes in the compacts has been used to an initial method to determine the feasibility of machining the compacts, and to form a basic understanding of the green compact behaviour during machining. The parameters that were investigated included tool material, cutting speed and feed rate.

3.1 Tool Material

Drilling of the compacts was performed on a Bridgeford CNC with four 4 mm diameter drill bits of different materials: High Speed Steel (HSS), Tungsten Carbide tipped, HSS TiN coated drill, and solid Tungsten Carbide drill. Each used drill was compared with a new drill of the same make.

3.2 Drilling Conditions

A few preliminary trials were used to identify three cutting speeds: 1000 rpm, 1500 rpm and 2000 rpm, at a feed rate of 100 mm/min, which were selected to drill four 10 mm deep blind holes in the compact for each drill bit. The swarf was collected and examined by SEM.

4. RESULTS

The HSS and HSS TiN coated drills exhibited substantial wear after the operation of drilling 4 holes in the compacts. The surface coating on the Tungsten Carbide tipped drill was deformed after machining and swarf was stuck to the drill. The solid carbide drill was only slightly worn after drilling 23 holes at the highest cutting rate. The wear of the cutting edge is relatively limited, Figure 1, which means that this material is suitable for machining the alumina/cyanoacrylate compacts.

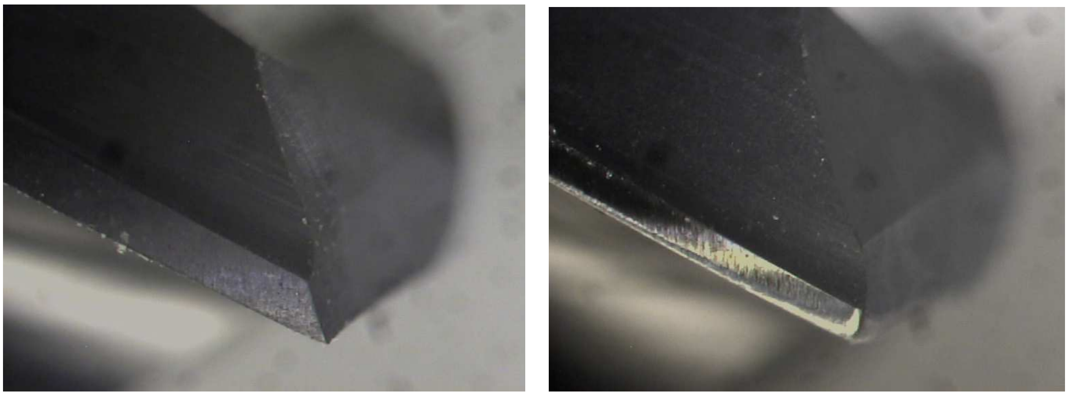

Figure 1: Comparison of new and used solid carbide drills

It was also noted that continuous swarf were formed (Figure 2). This type of swarf is normally present in the machining of a ductile material. The swarf were not discoloured, indicating that there was little friction induced by the process, and the maximum workpiece/swarf temperature was well below the debinding point of cyanoacrylate. Coolant was not required for the machining operation, as the compacts did not show any signs of thermal degradation.

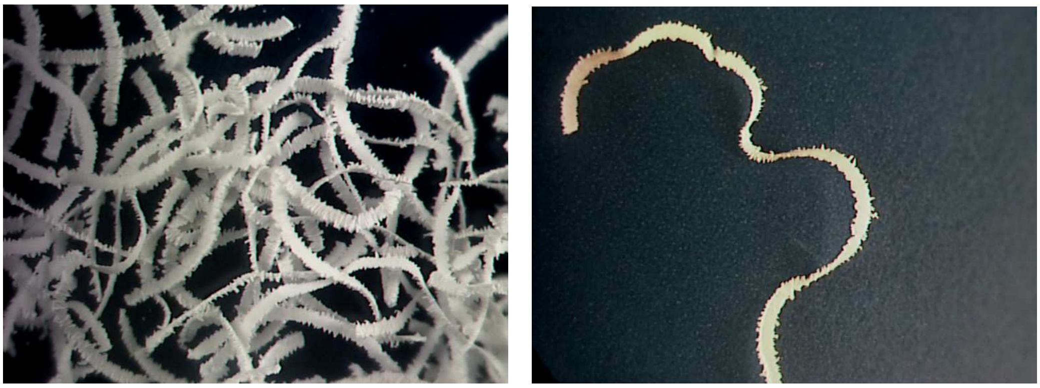

Figure 2: Swarf from the machining of the alumina/cyanoacrylate compact

Figure 3 is an SEM image of the surface of a section of swarf. The ceramic particles are still bonded together and there is no debinding effect due to the temperature generated during machining. The machining speed did not affect the structure of the compact, but it was observed that swarf became stuck to the flute of the drill at a speed of 2000 rpm. Therefore the compact should be machined below 2000 rpm, or a special drill bit that imparts more efficient swarf flow could be used.

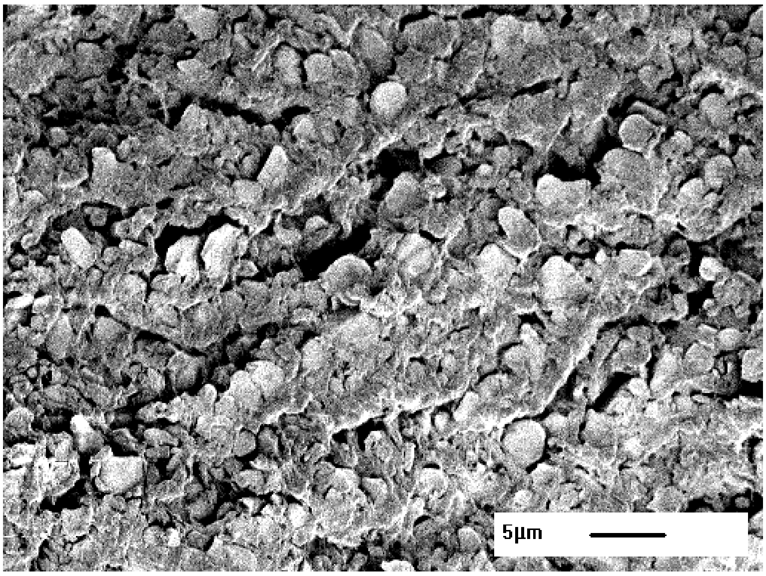

Figure 3: SEM image of the swarf surface.

6. CONCLUSIONS

The aim of this research was to establish the interaction of parameters and conditions to produce high quality ceramic products that are able to be machined by conventional machining methods. This is generally concerned with the preparation processes of the compact, i.e. inhibition, initiation and mixing, and the selection of materials are key aspects. From these observations, the following conclusions are obtained:

1. Alumina powder can be mixed with the cyanoacrylate binder to produce compacts with powder volume fraction as high as 48%V_f
2. Samples were drilled with ease, e.g. no cracking and easy to handle, indicating that the cyanoacrylate binder has suitable mechanical properties for green machining
3. Continuous swarf formation while machining indicates that the compacts behave in an effectively macroscopically ductile manner

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