MR JAKOB KÜBLER

A **cut** above

Industrial wood cutting can be a difficult process, and **Mr Jakob Kübler** and collaborators have been looking at ways of making it more efficient. Here, he discusses their research in this field, progress so far, and how his studies are expected to directly influence industry practice

Could you begin by outlining the objectives of your current research?

Our research interests are, though widespread, clearly focused on ceramic composites. We design and process ceramic based composites for innovative and challenging structural and functional applications. The projects at the centre of our attention involve ceramic-ceramic composites, micro- and macro-layered structures, coatings, graded materials, joining ceramics to metals and even ceramic-metal composites.

We also develop and optimise state-of-the-art methods of production, and work on applying our expertise and technologies to industry. Applications we have recently been working on include bio-compatible electrodes, sensors for harsh environments and high temperatures, microelectromechanical systems components with specific electrical and optical properties and tools with superior mechanical and wear behaviour. We work closely with industrial partners, often SMEs, and with specialised research groups from national and international universities.

How does this project build upon your previous work on wood-cutting materials?

This project is based on two previous projects. In the first, we looked at the feasibility of machining wood – a naturally inhomogeneous material – with cutting tips made out of ceramic composites. In the second, we focused on more economical ways to produce such tips. Tungsten carbide has long been used for industrial machining of wood, and it has also been very important in machining of metals, although advanced ceramics have also been used for machining of metals for many years but not for wood. This is because machining wood is considerably more demanding than machining metals. Given that cutting tips made out of tungsten carbide might reach their technical limits in the next few years, and as the price of the raw materials soars, it is easy to see why the wood machining industry is looking for alternatives.

What are sintering additives and how are they applied in your research?

Traditional ceramics are densified by firing. For advanced ceramics, produced from micron- down to nanometre-sized powders, that process is called sintering. Sintering is based on the diffusion of atoms over the boundaries between powder particles, which can be done below the melting point of a solid material. Unfortunately, this process is very slow and often full density is not reached. Various strategies can be used to overcome these problems, such as applying a high external pressure to force grains into close contact to each other, or alternatively one can use sintering additives. These foster densification via two mechanisms. Firstly, they enable sintering to take place completely in the solid phase. Secondly,

which is relevant for the silicon-nitride and silicon-carbide composite we have developed, the additives react with the basic ceramic compound to give a liquid phase at a melting point lower than that of the sintering temperature. The additive reacts with the silica layer that covers the nitride grains to form a liquid which wets the grain boundaries and fills up empty pockets at triple points.

Has your work revealed any promising results to date?

The most important result is showing that for industrial machining of wood, ceramic composites can be used. We also now know many of the factors responsible for this success, and how they can be influenced. A surprising finding was that probably the most important advantage of using ceramic cutting tips is not a superior lifetime, but rather a very low weight compared to tungsten carbide. Reducing the weight of cutting tips by about 70 per cent opens interesting new ways to design tools and wood cutting machines. It is interesting to note that the cutting speeds used for machining wood are already about five to 20 times higher than for metal.

Are you confident your new cutting tool will be welcomed on a wide scale? Do you have plans to make it commercially available?

We are very confident that the new cutting tips will be welcomed on a wide scale, as they will not only increase productivity of industrial wood machining but also have a high potential to trigger a new generation of industrial machines for wood cutting. Therefore, it is clear that the tips will be made commercially available by our industrial partners.

An **innovation** in industrial wood cutting

As traditional tungsten carbide cutting tips are expected to be challenged by new materials in the near future, a new study based at the **Swiss Federal Laboratories for Materials Science and Technology** is looking at what might come next in the industrial manufacture of wood

INDUSTRIAL WOOD CUTTING presents many challenges. Wood is, by its very nature, inhomogeneous, and contains a variety of obstructive elements. Knots, sand and acidic tannins which attack the cutting material all affect attempts to cut wood with industrial machinery. Add to this the fact that temperatures at the wood cutting tip can reach 800 °C – and no coolant can be used without damaging the surface of the wood – it becomes easy to see why improving industrial wood cutting provides an area of fascinating research.

Traditionally, the cutting tips used in the industrial processing of wood have been made out of tungsten carbide, whereas in the industrial cutting of metals, ceramic tips have been more successfully employed. A new study – PerWoodCut – led by Mr Jakob Kübler, Group Leader of 'Ceramic based Composites' at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in Dübendorf, Switzerland, is looking into some of the issues surrounding wood cutting tips. Along with his collaborators, Kübler has been investigating the application of ceramic-composite tips in the industrial cutting of wood.

THE STUDY'S FOUNDATIONS

The foundations for Kübler's research were laid in 2007, when he headed a study in which he worked with Fernando Eblagon, Thomas Graule and Bruno Ehrle. The team made a good deal of headway, according to Kübler: "We showed the feasibility of machining hard wood, laminated wood, glued chip-wood-boards and even soft wood such as pine, which from a cutting point of view is the very challenging for any type of cutting material, with ceramic composite cutting tips".

The results of the study revealed that cutting inserts made from ceramic matrix composites (CMCs) have a predicted lifetime which is three times that of tungsten carbide (WC); CMC inserts are estimated to cut 5,000 m under rough wood-machining conditions whilst providing a similar result to standard WC tips in terms of wood surface quality and defect sizes; and that, using CMC tips, cutting edges were not affected by cutting wood with knots or which had been glued. Since these early studies, Kübler and his various collaborators have looked to further develop the

INTELLIGENCE

PERWOODCUT

OBJECTIVES

To open a new, challenging application field for ceramics and ceramic composites. The project showed the feasibility to industrially machine wood with cutting tips made from ceramic composites. New production routes were developed to enable near-net-shape production. At present, the project is looking at alternative ceramics with lower raw material costs and simpler production routes.

KEY COLLABORATORS

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JAKOB KÜBLER is Head of the Ceramic-based Composite group in the Laboratory for High Performance Ceramics at Empa, a research institute of the Swiss ETH domain. He studied at HTL (today HSR) in Rapperswil, Switzerland, and received his degree in Mechanical Engineering in 1982. His work focuses on the development, design, processing and characterisation of ceramic composite materials. He is a Co-lecturer at ETH-Zurich and has supervised many PhD and MSc students in collaboration with national and international universities.

Materials Science & Technology

use of CMC-based tips for use in the industry, and have found that ceramic composites made out of silicon nitrate (Si_3N_4) and silicon carbide (SiC) are potentially a very good replacement for traditional WC cutting tips.

A CHALLENGING PROCESS

These advances, however, have not come without their own set of obstacles. The team has found that the lifetime of Si_3N_4 - SiC cutting tips is limited by initial chipping. "There are three main reasons for this: firstly, the very high hardness of ceramic; secondly, its inherently brittle nature; and finally the very sharp tip geometry needed for cutting individual wood fibres," Kübler explains. Ceramic's combination of hardness and brittleness results in small cracks when diamond-grinding and polishing techniques are used in the manufacture of the tips, or when the tips are being sharpened. These micron-sized cracks are unavoidable and, along with other defects which are typically created during the manufacture of ceramics, such as small pores, coupled with the very high stress peaks caused by the geometry of the tips, lead to this initial chipping.

To address these problems, a combination of measures has to be taken. Firstly, it is very important for Kübler and his team to give the ceramic an optimal microstructure, for example a small grain size, and to reduce both the size and number of micro-pores. They can also use a sintering additive mix which leads to a high micro-toughness, and design the cutting tip in such a way as to reduce stress peaks without lowering the tip sharpness. In addition to this, they have been working to optimise the sharpening process so that related micro-cracks can be minimised and finally, if necessary, using a post-treatment to heal damage and to reduce process-related residual stresses at the crack tip.

Kübler and his collaborators have also been faced with economic-related scientific and technical challenges. In the 2007 feasibility study mentioned, in which the Si_3N_4 -SiC composite with a superior performance compared to standard WC, was developed, they used hot pressing to reach a maximum density and tough microstructure. By the end of this study, the composite they were working with had such a high hardness and good wear resistance that the necessary diamond machining was so challenging, and therefore expensive, that the price of manufacturing the tips prohibited their widespread use in the industry. Given this, the researchers set their sights on developing a different sintering route which allowed a near-net-shape production, reducing the machining costs significantly. However, the relevant mix of sintering additives lowered the performance of the cutting tips. Studies continue into making ceramic tips more economically viable.

A GROUP EFFORT

At the heart of Kübler's studies is a commitment to working with commercial and industrial partners, in order that the technologies being created can match their needs as closely as possible. Their first, and even now their key partner in this field is an innovative and dynamic Swiss company which produces highly specialised tools for machining wood in an industrial setting. Their customers include SMEs who manufacture, amongst other things, wooden profiles for use in the most energy efficient windows and doors available today. "This particular company has an in-depth knowledge of designing and producing individual tools for almost any customer. In addition to this, it has a lot of experience in creating customised cutting tips for very specific profiles," Kübler highlights. As part of their collaboration, the company is going to expand its manufacturing expertise from WC to CMC cutting tips.

> Collaborating with businesses has allowed Kübler to carry out work which has a direct application to industry

On top of this, Kübler cooperates with partners who are skilled at mass-production of semi-finished, high-quality parts made of ceramic composites. Over the years, he has worked with a variety of companies, each of which is a specialist in its field, particularly very skilled ceramic producers. All in all, these collaborations have allowed Kübler to carry out work which has a direct application to the industry.

PLANS FOR THE FUTURE

Moving forward, Kübler envisions his team's efforts being put towards making CMC cutting tips more economically viable: "We are going to work with alternative ceramics whose raw material price is lower than that of silicon nitride and which allow simpler and therefore cheaper production routes". He also expects the team to succeed in developing gentler manufacturing techniques which cause less damage to the cutting tips than the current diamond machining. "My hope," Kübler concludes, "is that our work opens a new application field for ceramics and ceramic composites."