Dry wire grinding of steel with sintered CBN tools

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1 Introduction

454 nuclear power plants with an average age of 31 years were in operation worldwide in January 2019, according to the International Atomic Energy Agency (IAEA). These nuclear facilities must be decommissioned in an orderly manner after the end of their operational use. Thus, the decommissioning industry will face a large number of costly decommissioning projects in the near future [1, 2].

The dismantling of a nuclear facility imposes high requirements for production engineering. Many different, complex steel and reinforced concrete structures are used in the facilities, which are difficult to access due to contamination and complex design of the reactor. Since the 1990s, in addition to conventional mechanical cutting processes such as sawing processes and thermal cutting processes, wire grinding has also been increasingly used [3]. Wire grinding is characterised by high flexibility in terms of workpiece geometry and achievable depth of cut, as well as low space requirements which is favourable for decommissioning components that are difficult to access. In order to avoid the contamination of coolants when dismantling nuclear facilities, the focus is on the further development of the compressed air-cooled wire grinding process. The resulting contaminated dusts can be controlled more easily and extracted directly from the process [4].

Conventional wire grinding tools used for cutting steel consist of segments made of diamond grains within a sintered or brazed bond strung on a steel wire. The productivity of these tools for machining steel structures is limited by the low thermal stability of diamond combined with its chemical affinity to iron. Furthermore, the use of a single layer bond is limiting the lifetime of the wire grinding tool. Thus, the aim of this paper is to qualify a new type of wire grinding segment meeting the requirements for efficient dry cutting of steel components. This includes the substitution of the diamond grains with polycrystalline cubic boron nitride (CBN) due to its high thermal stability and a multilayer bond to increase the lifetime of the tool.

2 Wire grinding technology

The general assembly of wire grinding tools is shown in Figure 1. Ring-shaped grinding segments strung onto a flexible carrier wire made of steel consisting of several individual strands. The segments are regularly spaced by steel springs. A rubber coating protects the springs and the carrier wire and fixes the grinding segments [5].

The grinding segments consist of diamond grains embedded in a metallic bond matrix. Three bond types are used (Figure 1, bottom). Sintered grinding segments offer a long service life due to their multi-layer structure, but are not suitable for cutting pure steel structures. The ductile material behaviour of steel does not cause a self-sharpening effect by abrasive resetting of the bond, resulting in irreversible loss of cutting ability of the tool during the process due to blunting and chipping of the diamonds. These sintered multilayer tools are primarily used for cutting materials like concrete or natural stone due to their abrasive material behaviour. Single-layer bonding systems are used for processing steel. Vacuum-brazed grinding segments offer a slightly increased grain protrusion and very high grain retention forces compared to galvanically bonded segments. Vacuum-brazed wire grinding tools have therefore become established in steel processing [3].

Prior investigations have shown that one of the most important wear criteria of vacuum-brazed tools is thermal decomposition of the rubber coating above a tool temperature of 100 °C. The tool temperature continuously increases during the wire grinding process due to microscopic tool wear [6, 7]. The diamond grains flatten or chip. The grain protrusion decreases with dulling and chipping of the diamonds, increasing friction in the cutting area and thereby increasing temperature development. To overcome this disadvantage this paper presents a feasibility study regarding a multilayer sintered bond for wire grinding of steel. The sintered segments are made of newly developed bond compositions in contrast to commercial sintered grinding segments.

To cover a wide range of multilayer bond types this work investigates the most common bond types adapted to the wire grinding process. A vitrified bonded tool is excluded due to its high brittleness, which is not suitable to the high impulse load of a wire grinding process. A sintered metallic bond is not suitable to the wire grinding process according to the state of the art. Nevertheless, a new bond composition was developed in cooperation with a partner. This bond specification is modified with soft components to reduce the wear resistance of the bond and to enable a self-sharpening effect for machining of steel. Furthermore, a resin bond will be investigated. This bond type is resistant against impulse load and allows high material removal rates [8]. Thereby, this bond type will be investigated even
though its thermal stability is low. Lastly, a hybrid bond is developed using a combination of vitrified a metallic components. The result is a porous bond combining the advantages of both bond types.

![Diagram of grinding tool composition](image)

**Figure 1:** Composition of a wire grinding tool

### 3 Experimental Setup

In order to investigate the influence of the bond specification on the wear behaviour of the tool, grinding experiments were conducted. The experiments were performed on a high precision surface grinding machine by Geibel & Hotz. An analogy tool was developed to reduce the experimental effort and eliminate the influence of the rubber coating and the vibration behaviour of the wire grinding tool on the process. The analogy tool and the experimental setup is shown in Figure 2. Sintered grinding segments are distributed around the circumference of a solid steel body. The dimensions of the segments are equal to common wire grinding tools with a segment diameter of $d_s = 11$ mm and a segment length of 5.5 mm. The reference value to compare wire grinding and flat grinding is the single grain chip thickness $h_{cu}$ according to Apmann [5]. This value describes the load on an individual grain. A typical single grain chip thickness used in wire grinding of steel is 6.79 µm. At this value, there is a balance between tool life and productivity. Based on this value, the grinding parameters are set to a feed rate of $v_f = 51$ mm/min, a cutting speed of $v_c = 25$ m/s and a depth of cut of $a_e = 35$ µm. A total cutting time of around 340 s was reached for each experiment. Three types of bond specifications have been investigated. A sintered metallic bond, a resin bond and a vitrified-metallic hybrid bond with a CBN grain size of 601 µm were used for the grinding experiments. To evaluate the process and wear behaviour the process forces are measured with a dynamometer 9257-B by Kistler. A laser measurement system was used to investigate the grinding tool topography in the course of the experiment. In addition, the change of the grain protrusion is evaluated by investigation the reduced peak height of the measured topographies.
4 Results

Two aspects have to be taken into account in order to evaluate the ability of multilayer CBN grinding segments to cut steel. The first is the wear mechanism of the CBN grains. Even though the thermal stability of CBN is very high, the hardness is lower than that of diamond. The grains have to resist the high impulse load caused by multiple tool engagements and the tool’s vibrations during the grinding process. The second aspect is the ability of the bond material to be reset by the cutting process. After the surface layer of the grains is worn out, this layer has to be released from the bond matrix in order to engage the layer below.

Figure 2: Setup and procedure of the grinding experiments

Figure 3: Wear behaviour of different bond types
The diagram on Figure 3 shows the diameter reduction of the three bond types after 340 minutes of machining time. The highest diameter reduction of 125 µm can be observed when using the hybrid bonded tool. The diameter reduction of the resin bonded and the sintered metallic bonded tool is noticeably lower and on a similar level of 48 µm and 60 µm respectively.

The sintered metallic bond is non-porous. Thereby, the grain retention force of this bond is high even though a new bond composition is chosen. As shown in Figure 3 on the right hand side, the CBN grains are worn at the end of the experiment but they are not released from the bond. This results in a flattened segment surface. The retention force of the metallic bond is too high for the purpose of cutting steel. The wear resistance of this sintered metallic bond is reduced by using a new bond composition but the self-sharpening effect is still too low to reset the bond matrix and the end of tool life is reached before the second grain layer gets into engagement. This bond specification is inappropriate for machining of steel.

The resin bond shows a similar behaviour regarding the self-sharpening ability during the grinding process. The diameter reduction is slightly lower than of the metallic bond, which is explained by the adapted composition of the sintered metallic bond. Figure 3 shows the surface of the resin bonded tool after the experiment. The grains are flattened but still inside the bond matrix. This reduces the grain protrusion significantly. The bond matrix does not release the grains after they are worn out and the end of tool life is reached at this point. In addition, the manufacturing of resin bonded segments with a high grain size is highly challenging. Common resin bonded grinding tools are including a grain size up to 181 µm. During the manufacturing process, the grains agglomerate, which causes an uneven grain distribution within the bond-cutting grain-matrix.

The vitrified-metallic bond shows promising results. This bond combines important properties of both combined bond types. It has a high impact resistance and thermal conductivity due to the metallic share. The vitrified share leads to a porous matrix. The high diameter reduction of the hybrid bond shows that this bond has a self-sharpening effect when cutting steel. The slight abrasiveness of steel is sufficient to reset the bond and thus to sharpen the grinding tool during the process. With progressing wear of the CBN grains the process forces increase due to increasing friction between the grinding tool and the workpiece until the load is high enough to initiate microscopic cracks within the bond because of the brittleness of the vitrified share. If this effect is too pronounced, the diameter reduction of the segment will take place too fast. The grains would release from the bond before they are worn out. This resetting behaviour of the hybrid bond will be further investigated in the following by evaluating the surface topography of the segments and the process forces.

Figure 4: Reduced peak height of the hybrid bonded tool

The porous bond matrix complicates the characterisation of the grinding tools surface topography, as the pores make it difficult to measure the grain protrusion accurately. In this case, the evaluation is simplified by using the re-
duced peak height Spk of the topography. This characteristic value describes the average height of peaks of a surface. Regarding a grinding tool topography, the reduced peak height allows a qualitative evaluation of the grain protrusion.

According to Figure 4, the reduced peak height of the hybrid bonded tool is 17 µm when delivered. After the first engagement with the workpiece, the reduced peak height increases to 40 µm. This is caused by a low grain protrusion when delivered and thus a low chip space. This leads to a lot of friction between bond surface and workpiece and overloaded the bond bridges. The result is initial bond break even though the grains are sharp. After an initial machining time of about 30 min, the reduced peak height and the grain protrusion is increased. The chip space is sufficient and the collective load is constant. Following this initial wear phenomenon, the self-sharpening process begins. The cutting grains wear and flatten over time. This increases the collective load due to increased friction and decreased grain protrusion until a critical load is reached. The bond bridges start to collapse until the chip space is sufficient again or new grains engage. This effect is shown by the fluctuating of the Spk between 32 µm and 44 µm with a linear trend. This trend of the Spk until the end of the experiment indicates a constant self-sharpening effect and thus a continuously resetting of the bond surface.

![Graph showing grinding force ratio](image)

**Figure 5:** Grinding force ratio of the hybrid bonded tool

The consideration of the process forces validates the self-sharpening effect. Figure 5 shows the grinding force ratio μ that is defined as the ratio between tangential force $F_t$ and the normal force $F_n$. The grinding force ratio is constant during the grinding process. Finally, the constant reduced peak height as well as the constant grinding force ratio shows that the hybrid bonded tool is able to reset the bond during the grinding process and to keep the engagement conditions constant. The feasibility of dry cutting of steel with multilayer grinding tools is proved by using vitrified-metallic hybrid bonded CBN grinding segments.

### 5 Summary & Outlook

In this paper, a new type of grinding segments for wire cutting of steel was investigated. The purpose of the shown approach was to eliminate the main disadvantages of commercial single layer diamond tools. By using an analogy tool, the process behaviour of three different multilayer CBN tools was evaluated. The investigations have proven that the vitrified-metallic hybrid bonded tool is able to cut steel with a continuous resetting of the bond. This is shown by a constant fluctuating of the grain protrusion and cutting conditions during the experiment. It is a promising approach for further investigations. A wire grinding tool using these hybrid bonded CBN segments will be manufactured and compared with commercial wire grinding tools.
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7 References


