Electro-Contact Discharge Dressing of Cut-off Grinding Disks for Natural Stone Machining

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Abstract. In cut-off grinding of natural stone the tool performance and stability mainly depends on the self-sharpening behaviour of the cutting segments. Therefore, it is essential to adjust the bonding composition and the process parameters according to the specific separation mechanisms of the work piece material. Different tool wear mechanisms resulting from the different natural stone categories currently avoid the continuous use of one bonding specification. To overcome this limitation an electro-contact discharge dressing (ECDD) process was implemented in the cut-off grinding process. In this way, the backspacing of the bonding can be controlled in-process. The research presented in this paper focuses on the introduction of this technology in the field of stone machining. The demands for applying ECDD in the environment of a stone saw as well as the main influences and interdependencies of ECDD onto the segment topography are discussed.

Introduction

Since the introduction of stone machining tools based on metallic bonded diamond grains, a close adaption of the cutting segment specification to the properties of the stone material is necessary. This includes the configuration of the diamond concentration and size distribution but also the properties of the metallic bonding.

By a variation of the metallurgical composition of the bonding the abrasive resistance and grit retention forces can be influenced. The aim is to guarantee a continuously alternating wear of the diamond grains and the bonding matrix while processing of the stone material. The key factor for a stable machining process is a bonding topography showing a sufficient grain protrusion of the diamonds (Fig. 1). A mechanical dressing process is only used after the tool manufacturing in order to avoid mechanical and thermal damage due to insufficient grain protrusion. Additionally, dressing increases the concentric and axial runout precision [1].

Currently, the bonding material has to be adapted depending on whether to machine hard or soft stone. Principally, two different cases can be distinguished. Abrasive soft stone like sandstone does not significantly influence the diamond wear. In contrast the bonding wears down rapidly due to the high amount of slurry consisting of stone particles and cooling water. Therefore, the bonding has to provide a high abrasive resistance in order to generate an economic tool life. On the opposite hard stone like granite causes a high mechanical load on the diamonds leading to high quantities of grain micro fractures and pull outs. In order to assure a sufficient grain protrusion, which enables the segment to lead away the slurry, a softer bonding composition is required. In this way, the wear ratio of the diamonds and the bonding level can be kept constant.
Both types of segment configuration need to be operated in a specific field of machining parameters, given by the tool manufacturer. Here, already minor deviations from the ideal parameter set or variations of the workpiece properties can cause severe tool damage. Many stone processing factories are forced to machine different natural stone workpieces. For each category the slab producer has to change the tool specification in order to guarantee a stable cut-off grinding process. This procedure is time and cost consuming. Therefore, a technology is needed to overcome these disadvantages of traditional stone cut-off grinding.

A possibility for a higher operating efficiency and process safety of the cutting disk is dressing. Takubo et al. examined the effects of periodical dressing of cut-off grinding disks with a corundum wheel [2]. They showed that by means of dressing the wear can be reduced by 20 % and the normal forces by 50 %. However, the system cannot be used in the productive time. The change between hard and soft stone machining with one tool in order to have more flexibility was not discussed in this work. Therefore, especially this property is focused with the approach presented in the following.

**Electro-Contact Discharge Dressing**

Electro-contact discharge dressing (ECDD) is a numerically controlled process using the power of an electric circuit for a thermal bond removal. It offers the possibility to create the geometry and the topography of the grinding wheel simultaneously at negligibly low dressing forces. Most of the investigations performed by different researchers focused on the sharpening of the grinding wheel [3-7]. Furthermore, electro-contact discharge dressing of grinding wheels was investigated under dry conditions and under the aspect of profiling, but also at low grain sizes below 10 µm [8]. Moreover, electro-contact discharge dressing is used as an assisting process for the dressing of diamond wheels with a diamond dresser [9]. The investigations show that the material removal rate of the grinding layer is higher under the influence of a coolant.
The principle of ECDD is shown in Fig. 2. An infeed device moves an electrode slightly in radial direction towards the cutting segments rotating with cutting speed. The direct current power supply induces an electric field between the face of the electrode and the metal bonding, utilizing the fact that diamond is the best isolator. The dressing process starts with a chip formation and a resulting field distortion (a). The field intensity between the chip and the metallic bonding increases due to the constant voltage, the small distance and the shape of the chip. A further growth of the chip increases the field distortion. If the field intensity reaches the discharge conditions, an arc-over between the chip and the metal bonding occurs (b). The field intensity which is necessary for discharge conditions depends on the permittivity of the medium between the electrode and the grinding wheel. This intensity is lower for air than for deionized water or grinding oil. During the arc-over, the chip vaporizes and a plasma channel is formed (c). The heat from the plasma channel locally melts the metal bonding. The molten metal bonding is blown away partly by the centrifugal force and partly by the collapsing plasma channel (d). The dressing process is controlled by the selected electrode voltage and current as well as the infeed and feed of the electrode. The mean chip thickness depends on the cutting speed as well as on the infeed and feed of the electrode. The voltage defines the width of the gap between the chip and the metal bonding, which can be crossed by an arc-over. The mean chip thickness and the dressing voltage define the grain protrusion and thereby the sharpness of the grinding wheel [10, 11].

Effect of ECDD onto the Segment Topography

The operating conditions in the stone machining sector differ from those in metal or ceramic machining. Main differences are e.g. the diamond grain dimension, the segmented tool layout and the oscillation sensitivity of the tool and moreover the coolant. For grain sizes around 300 µm to 600 µm, which are necessary for stone machining, the applicability of the ECDD process has not been investigated yet. On the test rig shown in Fig. 2 a segmented cutting disk for hard stone
machining was used in ECDD experiments for the first time. A graphite electrode was fed to the rotating cutting disk with a variation of electrode current and voltage. The parameters were deduced from the metal fine machining [12] and were enhanced until a significant arc-over was detected. The change of the segment topography was analysed by means of silicone rubber casts and a confocal microscope. Fig. 3 shows the development of the grain protrusion exemplarily for one diamond after specific periods.

Fig. 3: Continuous grain protrusion enlargement by means of ECDD

Fig. 3 clarifies that the chip space and as a consequence the effective grain protrusion in front of the diamond grows by 44% due to bonding melting. The diamond itself is undamaged (no break outs or wear faces), which shows the advantage of this technology against mechanical dressing methods. These trials demonstrate the feasibility of ECDD with a segmented tool and a grain size $d_g = 301 \, \mu m$.

**New ECDD Device for a Stone Bridge Saw**

The newly designed ECDD device for the use in the stone bridge saw Hensel Gigant is shown in Fig. 4. Main component for the ECDD process is the infeed device positioning the electrode which erodes the cutting segment. Reichstein and Hahmann showed the possibility of using ECDD for creating complex profiles on grinding wheels with a multi-axes system [12, 13]. As the contour of cutting segments for stone machining is usually planar a simpler system can be applied. Therefore, a nanometer-precision linear stage M-714 (PI) with only one axis was used. It realizes the infeed of the aluminium holder, which adjusts the contact electrode with high accuracy radially towards the tool center.

To prevent the sensitive electronic from slurry and splash water the axis is encapsulated. For a stable fixing this housing is adapted on a 15 mm aluminium carrier plate. The plate is mounted on the cast structure of the spindle via two fixing points. In this way, the infeed axis is almost unaffected from vibrations of the tool housing, consisting of 3 mm rust-proof steel sheet. The infeed axis is positioned on 320° so that it is as far as possible away from coolant and slurry.

The second pole of the direct current circuit is connected to the counter flange by carbon brushes. To minimize electrical resistance and wear on the outer contact rim, the counter flange is made of the copper alloy CuSn7Zn4Pb7, showing a good compromise of high electrical conductivity and heat resistance.
The electrode is ashlar-formed with planar end contour. Its width is 0.5 mm larger than the segment width of $w_{\text{seg}} = 7.0$ mm in order to cover the whole segment and to be able to compensate axial tool vibrations. Measurements with an inductive distance sensor indicate a maximum axial deflection of 0.41 mm when cut-off grinding granite with a cutting speed of $v_c = 30$ m/s.

The cut-off grinding disk used in the experiments has a diameter of $d = 1000$ mm, a core width of $w_s = 5$ mm and is equipped with 70 segments. The bonding consists of Co-Fe with a relatively high rockwell hardness of 35 HRC to 40 HRC which is recommended for cutting abrasive soft stone.

The diamond size range is wide spread with 30/50 mesh. In this way, a small shock-resistant grain of $d_g = 427$ µm is being able to withstand the mechanical impact when machining hard stone. On the other hand, the larger grain size of $d_g = 602$ µm is advantageous when machining soft stone as it provides a higher grain protrusion which is positive for high cutting rates.

As the cutting speeds for soft stone and hard stone differ between $v_c = 30$ m/s and $60$ m/s the core tension is adjusted for a cutting speed range of $v_c = 40$ m/s to 45 m/s. Due to the tensioning tolerances the dynamic tool stability is sufficient for machining both types of stone with high axial runout precision.
Conclusions

Test trials with the new tool and the ECDD device were conducted under dry and water cooled conditions. The aim of the trials was to evaluate in which way the variation of electrode current, voltage and infeed influences the discharge frequency and the grinding layer topography. The discharge frequency almost rises linearly with increasing electrode cutting rate $Q_{ds}$, which is related to a segment width of 1 mm (Fig. 5).

By the linear increasing graphite chip volume there are more graphite chips per time unit which can initiate the discharge process. Furthermore, the electrode cutting rate depending increase is higher the higher the preselected voltage is. This can be explained by the higher electric field strength which increases the probability of discharges initiated by even short chips.

![Fig. 5: Discharge frequency depending on electrode voltage and related electrode cutting rate](image)

The discharge frequency rises exponentially with increasing voltage. Below a voltage level of $U_{ds} = 60$ V no discharges occur. Here, the potential difference between grinding layer and electrode is insufficient for a graphite chip induced field distortion and discharge.

Fig. 6 exemplarily displays the machining of granite with parallel use of the new ECDD device. The picture on the right hand side shows statistically distributed bonding meltings over the whole grinding layer. These support the diamond uncovering which increases the diamond surface and the microfracturing.

<table>
<thead>
<tr>
<th>Tool:</th>
<th>Dressing:</th>
<th>Tool speed:</th>
<th>Coolant:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_S = 1000$ mm</td>
<td>electrode: graphite</td>
<td>$v_c = 30$ m/s</td>
<td>water</td>
</tr>
<tr>
<td>$w_S = 5.0$ mm</td>
<td>$U_{ds0} = 10$-90 V</td>
<td>$I_{ds0} = 10$ A</td>
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</tr>
<tr>
<td>$w_{Seg} = 7.0$ mm</td>
<td>$v_{fe} = \text{var.}$</td>
<td>$n_{Seg} = 5$</td>
<td></td>
</tr>
<tr>
<td>bonding: Co, Fe, Cu</td>
<td>diamond: 30/50 mesh</td>
<td></td>
<td></td>
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Summary and Outlook

The flexibility of the cut-off grinding process on different natural stones is currently limited due to the required adjustment of the tool specifications and cutting parameters to the properties of the work piece material. Especially modern factories processing many different materials have economic disadvantages due to multiple tool changes causing high tool costs and long non-productive times. A dressing technique based on electro-contact discharge presented here is a method to substitute the traditional system. In this way, many different tools can be replaced by a new dressing device and only one tool. Examinations demonstrate the technological feasibility of ECDD on a cut-off grinding disk for natural stone. Further research is done to identify parameter combinations affecting the segment topography fast and effectively. An improved adjustment of the segment composition and the electrode material is considered, too.

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References


