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THERMAL ANALYSIS OF THE ROBOT SUPPORTED BELT GRINDING WITH ELASTIC CONTACT WHEEL

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ABSTRACT
Because of the friction in the contact zone between the tool and a work piece during the robot supported belt grinding process of metallic work pieces, high temperatures can be generated, causing modifications of material microstructure and change of material properties.
The results of first experiments, which describe the effects of diverse process parameters (grinding time, material of work piece, pre-heating) to the quality of work piece surface and to the process removal rate, are shown in this paper.
Keywords: industrial robots, belt grinding, thermal analysis

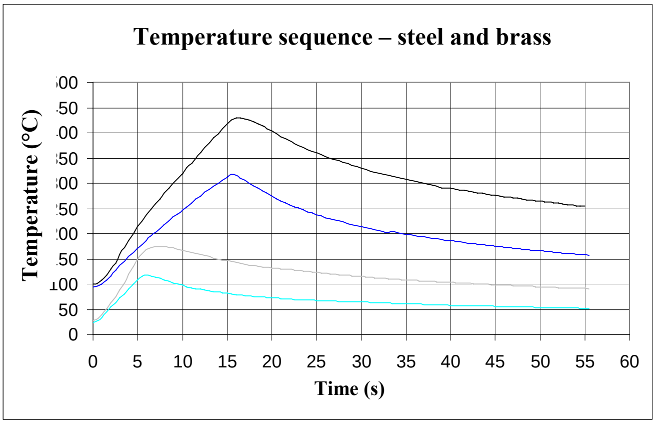
1. INTRODUCTION
Belt grinding is a standard step of material processing automated with the aid of industrial robots to release workers and to optimize economic efficiency of the manufacturing process.
In comparison to other finishing processes belt grinding is characterized by a higher removal rate as well as by a higher endurance with comparable surface quality. Using high-elastic contact elements, belt grinding is particularly suitable for finishing of free-formed surfaces, for example the processing of turbine blades or sanitary fittings.
Because of the friction in the contact zone between tool and work piece, during the belt grinding process of metallic work pieces high temperatures can be generated, causing modifications of material microstructure and change of material properties. These changes can either damage functional properties of the processed surface (e.g. by turbine blades) or have a negative effect to the appearance of the product surface (e.g. by sanitary fittings).
Many authors (e.g. [1, 2, 3, 4, 5]) dealt with the temperature influence on the work piece surface (mostly at grinding with rigid tool) and developed temperature models to determine optimal setting parameters for the processing. However, their results are applicable only on a specific process or a certain cut geometry (external cylindrical grinding, plane grinding, etc.) and are very rarely transferable to other situations, because the mathematical modeling of the thermodynamic processes during grinding is so far possible only with simplistic, process specific assumptions.
Therefore, a complex heat distribution model for belt grinding with elastic contact element based on the mathematical solution of the 3D heat conduction problem should be developed. This model

expands an already existing process model [6, 7] and makes possible the determination of optimal process parameters to avoid negative heat influence to the work piece. The results of first experiments, which are the basis for further investigations, are shown in this paper.

2. THERMAL TESTS WITH A THERMOCOUPLE

In order to analyse the temperature development in the belt grinding process, a sequence of experimental tests was carried out, using work pieces made of construction steel (St37) and brass with a cross section of 20 x 20 mm^2. The temperature during grinding was measured with the help of a thermocouple. The results of these experiments are shown in Figure 1.

Because of the friction forces between tool and work piece, the temperature increases in the work piece during the belt grinding process. Due to different heat conduction properties much higher temperatures arise by the grinding of construction steel than by the grinding of brass (see Figure 1.). The temperature peaks out at around 450°C shortly after the end of the grinding process. Significant changes on the surface of the grounded work pieces of construction steel are visible when temperatures over 200°C are reached (Figure 2.a). By contrast no visible changes of the surface can be observed by the work pieces of brass (Figure 2.b) for given grinding conditions.



Color	Init. temp.	Grinding time	Material
-----	100	15	steel
-----	100	15	brass
-----	25	5	steel
-----	25	5	brass

Figure 1. Temperature sequence by the grinding of construction steel and brass

By the grinding of high-strength steel alloys, that are used e.g. by turbine blades even higher temperatures are reached. By the grinding of Inconel temperatures over 550°C occur. Thereby, only slight changes on the surface of the work pieces of Inconel at such high temperatures can be observed. However, even so small changes of the surface must be considered by the process planning in order to increase the quality of production.

a) *b)*

Figure 2. Surface of the work piece after grinding, a) construction steel, b) brass

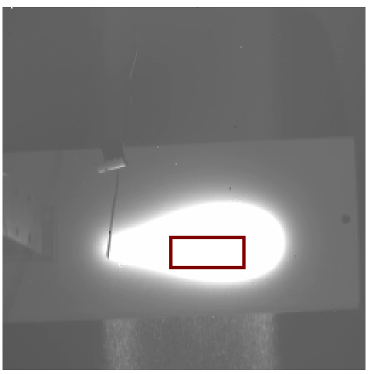
Another experimental series showed that the temperature in both construction steel and brass has no significant influence on the removal rate by the grinding process.
Because of the negative impact on the surface of the work piece and thermal strains in the work piece and the tool in the contact zone, the heat must be considered as a disturbance factor for the process model. Therefore, the input parameters in the process planning must be chosen that way the work piece temperature becomes not too high and has no adverse effects on process quality.

3. MEASURING OF THE TEMPERATURE FIELD USING THERMAL IMAGING

In previous studies the temperature during grinding was measured with the help of the thermocouple. However, the thermocouple measures the temperature only within a small area where it touches the work piece. Therefore, no information is provided about the heat distribution within the work piece. The measured temperature depends on the measuring point of thermocouple. A detailed measurement of the temperature in the grinding zone can be provided by means of a thermal camera, determining the temperature distribution on the work piece surface.

Figure 3. Experiment set-up

Figure 3 shows the experimental setup for temperature measurement with the thermographic camera. The work piece is mounted on the robot hand in a belt grinding workcell. The thermographic camera (front left in Figure 3) take images of the heat distribution on the back side of the work piece. Thus, the heat distribution during the machining process can be recorded. Due to the high refresh rate of the camera (up to 880 frames per second) studies with high time resolution can also be carried out, for example, the temperature of small particles of material taken away from the work piece can be examined. Thus, with the help of the thermographic camera the simultaneous temperature measurement of the work piece as well as of the chip is possible, allowing an extensive analysis of the machining process.
Through the use of different lenses the heat distribution can be recorded on the whole work piece's surface as well as more detailed on the chosen parts of the surface.



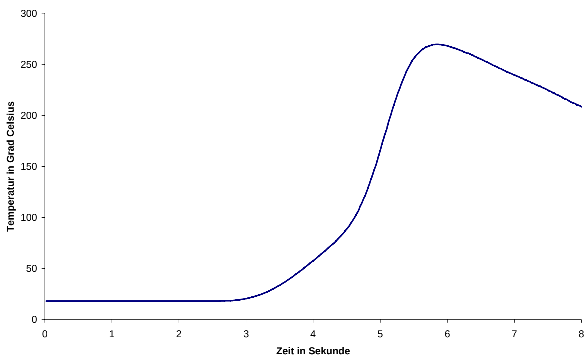


Figure 4. left: Heat distribution and measuring area; right: Temperature sequence by grinding

The temperature produced during the grinding of a construction steel sample with the sequence of the absolute temperature is presented in Figure 4. The image on the left side shows the temperature distribution after the grinding process. In addition, a red rectangle is inscribed as the measuring field through which area the temperature was averaged. The grinding zone is due to the high temperatures (represented as a white field on the figure) clearly visible on the back side of the work piece. It turns out that the heat is more intense in the right than in the left side of the sample. The cause of this may be an uneven pressure of the sample to the grinding belt or an unconformable one-sided wear of the belt. These results show the relative distribution of heat.

The absolute temperatures can be measured after calibration of the measuring system. The result is given on the right side of the Figure 4. Before grinding the temperature of the work piece was 20°C. During the processing the temperature increased to almost 300°C. Afterwards, the work piece was slowly cooled down. This result is similar to the results obtained using a thermocouple.

The preliminary experiments show that with the thermographic camera, after appropriate calibration, absolute temperatures on the work piece can be determined. Furthermore, the temperature distribution on the surface can be determined at any stage of the grinding process and, after appropriate treatment, directly included into model calculations.

4. CONCLUSION AND FUTURE WORK

The preliminary thermal tests by belt grinding show the correlation between several process parameters (pre-heating, grinding time, material of work piece) and the resulting temperature on the surface of the work piece. Critical temperatures, which cause damage on the surface, are also determined for several different materials. With the help of a themographic camera the temperature distribution on the surface can be determined at any stage of grinding, what is very useful by the thermal analysis of the process.

The programming of optimal grinding paths by robot supported belt grinding of free-form surfaces requires knowledge of the resulting removal and the resulting strain on the work piece's surface as a function of all process parameters. The quality of the work piece surface is strongly influenced by the spatial and temporal temperature distribution in the work piece. However, this influence is not sufficiently taken into account by all existing process models, leading to suboptimal grinding paths and to damage of the work piece's surface. As a result, the grinding of critical surface areas can be automated only after a very time-consuming optimization process. Therefore, the objective of further investigations is the extension of an existing modular process model with regards to thermal effects in belt grinding processes, making the design of the automated belt grinding more efficient.

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