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Procedia CIRP 46 (2016) 51 – 54

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7th HPC 2016 – CIRP Conference on High Performance Cutting

A pragmatic modeling approach in Abrasive Flow Machining for complex-shaped automotive components

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Abstract

Abrasive Flow Machining (AFM) is a unique machining method used to achieve high surface quality on difficult-to-access contours. In 2011 a model linking numerically calculated parameters to empirical process parameters has been developed to machine ceramic materials. This paper presents first results of a project transferring the model to metallic materials and to current demands of the automotive industry for intersecting holes, fuel rails and feed lines with a high aspect ratio. Technological investigations have been carried out in order to develop functional correlations between setting parameters and work results on inner contours. This data builds the basis of a new process model. A feasibility study validates the performance of the model using referenced workpieces.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair
Prof. Matthias Putz

*Keywords:*Abrasive Processes; Abrasive Flow Machining; Deburring; Regression Analysis; Modeling

1. Introduction to Abrasive Flow Machining

Abrasive **F**low **M**achining (AFM) is a finishing and polishing operation with a gentle material removal mechanism. In contrast to other machining methods for deburring and polishing, it is possible to machine difficult-to-access cavities, inner contours and undercuts in a reproducible manner. Typical parts that could be machined by AFM are extrusion dies, crimping and stamping tools as well as inner contours on common rail components. Use of AFM on these tools showed that within 2 minutes of processing time, an improvement of the surface roughness from Ra = 2 µm to Ra = 0.2 µm could be achieved.

The medium applied during AFM is a fluid consisting of a polymer which carries silicon carbide or super abrasive grains. With a specified pressure and temperature, this fluid flows in alternating directions along the contours of the work piece resulting in an abrasive effect. Fig. 1 illustrates the process principle during machining.

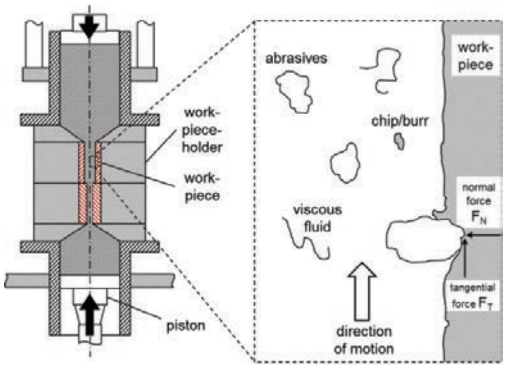

Fig. 1. Abrasive Flow Machining – process principle.

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doi:10.1016/j.procir.2016.03.172

Unlike in conventional grinding process the path curves of the active grains in AFM depend on the existing contact conditions, the geometrical constraints of every workpiece and the actual state of the abrasive media. By using modern simulation techniques it is possible to enhance the knowledge regarding the fundamental principles of the flow process and to anticipate the complex behavior of the visco-elastic media.

2. Process technology – state of the art

Uhlmann and Szulczynski [1] have investigated the process principles for AFM on inner contours on T-pipe-sections made of C45 steal (1.0503). As a result they have presented a mathematical regression between edge rounding r_k, temperature ϑ of the used abrasive media, processing pressure p and number of machining cycles z. Similar approaches have been used by R. Jain [2] and Ali-Tavoli [3]. In the latter cases the process design has been improved by the use of distinctive algorithms like fuzzy logic and artificial neural networks. Using this approach an optimized selection for parameters like the ratio of abrasive to media, abrasive grain size, stream velocity and number of cycles has been achieved. However the validity of all featured models is bound to particular experimental setups. The transferability of models to different geometrical shapes and different production systems can be accomplished to a limited degree.

In addition the authors [1, 2, 3] presented numerical simulations, CFD and FEM, to increase knowledge regarding the contact conditions between the abrasive grain and the surface of the workpiece. Thereby the particular forces on the singular abrasive grain, the strength and resistance of the workpiece material could be determined in order to achieve a more suitable setting for either a grinding process or a lapping process, see applied forces in Fig. 1. Szulczynski [4] improved his approach in using a high-speed-camera to observe the motion patterns of the abrasive grains along a small plexiglass window in situ. Using this information the input and boundary conditions of the numerical models could be validated.

The next development step, the so called "pragmatic model", has been introduced by Uhlmann and Mihotovic [5, 6]. The authors have developed a technological database, which combines the results of experimental investigations directly with the outcome of the numerical CFD-simulation for exposed positions on the workpiece. The 3D-graph in Fig. 2 illustrates the basic principle.

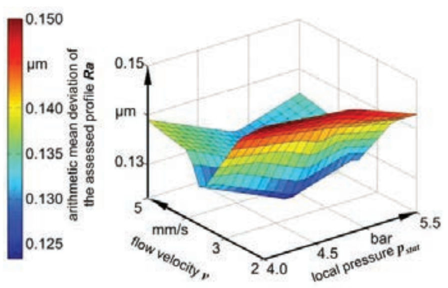

Fig. 2. characteristic diagram of the process model [5].

The local process values for pressure p_{stat} and flow velocity v are results of the CFD-simulation. On the other hand values of the surface quality Ra are empirical results of extensive technological investigations. The "pragmatic model" reduces the process parameters related to the machine setup to a minimum of input data (p_{stat}; v) and combines it to output data (Ra). The quality of the model has been proven by using a new complex shaped workpiece geometry. Using numerical simulation of the given inner contour it was possible to anticipate the results of the surface quality on exposed position with high accuracy. Furthermore preliminary experimental investigations have not been required in order to predict a result.

Initially the pragmatic model has been developed for the AFM of ceramic materials. In addition the quality of the numerical model is limited to the validation quality by observing abrasive grain patterns through a plexiglass window, which changes significantly the abrasive flow. Therefore the scope of the current DFG-project performed by Uhlmann and Roßkamp is to transfer the "pragmatic model" to demands of the automotive industry. In order to increase the accuracy of the numerical model, pressure sensors are being implemented in the experimental setup instead of using visual observation. The following sections present some technological results of the first project phase.

3. Experimental and machining parameter set-up

The geometry and the material of the test workpieces are based on the design parameters of the components used by automotive engineering in common rail engines. To ensure best possible variability within the experimental design, combined workpieces with different borehole sizes were used. Firstly metallic test workpieces made of 50CrMo4 (1.7228) and 100Cr6 (1.3505) were drilled (l = 50 mm). Table 1 gives an overview of the used workpieces. By stacking three pieces a great variety of borehole size combinations with different aspect ratios and transitions has been achieved. Extensive preliminary investigations have shown that the package combinations 4-6-9 and 4-9-4 are suited to create geometries which are related to common rails in particular.

Table 1. used specimens

material properties	50CrMo4 (1.7228); 100Cr6 (1.3505)
borehole length l	50 mm
borehole diameter Ø	4.0 mm (**4**); 6.0 mm (**6**); 9.0 mm (**9**)
combinations of stacked cylinders	4-6-9, 4-9-4

The test pieces are pictured in Fig. 3. The measuring of the surface modification during the process was carried out by using the Mitutoyo SJ-411 surface measuring device. The tactile measurement is performed along marked positions. In AFM the change of edge rounding r_k is of particular interest. To survey that change the system Hommel-Etamic Nanoscan 855 was used.