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Fluid structure interaction of thin graphite electrodes during flushing movements in sinking electrical discharge machining

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ABSTRACT

In sinking electrical discharge machining (SEDM) use of thin graphite electrodes with high aspect ratio sporadically results in geometrical errors. Empirically, such deviations have been attributed to the dynamic bending of electrodes arising from jump flushing movements of modern SEDM machine tools. Due to the process characteristics experimental in situ investigation of the occurring stresses and strains within the electrode appears disproportionately complex. Therefore, in this paper, bending effects are modelled taking into account fluid structure interactions. Results are validated by particle image velocimetry and high-speed camera recordings.

Introduction

Sinking electrical discharge machining (SEDM) is oftentimes used when cavities with sharp edges and high-aspect ratios have to be manufactured in hard-to-machine materials. Major industries with typical applications are die and mold making [1] and aerospace sector [2,3]. Nowadays, graphite is the predominant electrode material in common use and modern sinking EDM machine tools generally use flushing by motion when machining mentioned cavities [1,3,4]. Especially in micromachining or for finishing operations planetary movement of the electrodes leads to significantly increased process quality in terms of stability, material removal rate and reduction of wear [5–7].

Nevertheless, in this regard lastly deformations of thin graphite electrodes with high aspect ratio have sporadically occurred. As reason for the deformation potential residual stresses caused by material defects or inadequateness in processing the electrodes by milling or wire EDM, e.g. shown by Kawakami and Kunieda could be sorted out [4,8]. Empirically, such deviations have been attributed to the dynamic bending of electrodes arising from jump flushing movements of the machine tool axis when initiating flushing operation. However, to date no work has been presented that analyses the strain in electrodes during jump flushing movements. As irreversible deformations occur probabilistic, their reason could be found in unfavourable concentrations of discharges leading to high localized temperature loads on the graphite material, cp. Fig. 1.

In EDM comprehensive work has been done in analysing gap conditions directly related to the electrical discharge [3,9]. In that course research was predominantly done on plasma temperature and pressure [7], gas bubble formation and debris distribution [10] as well as energy distribution [11–14]. Besides, for the first time Garzón investigated the deflection of thin graphite electrodes due to continuous discharge forces. In his work the electrode was clamped free to oscillate that potential damping effects due to the dielectric and the normally surrounded workpiece were neglected. Although he could show that unfavourable discharge frequencies could lead to deviations he stated that hydrodynamic forces on thin electrodes due to flushing are magnitudes higher than the ones caused by discharges [7,15].

At an early stage Koenig et al. examined flow fields using pressure or suction flushing through the electrode which can only be used in selected applications [16]. Lonardo and Bruzzone did basic experimental research on the effect of flushing and electrode material on die sinking EDM using standard technology parameters given by machine tool manufacturers. Differencing only between with and without flushing they re-proved the beneficial effect of jet flushing for roughing and planetary movement for finishing operations [17]. In terms of jet flushing Masuzawa et al. showed that jetting the dielectric merely from one direction results in less machining accuracy [18]. For the first time Cetin et al. calculated and numerically optimized fluid flow for circular symmetric electrodes when using periodically lifting movements for flushing [19]. Similar work was performed by Pontelandolfo et al. for more complex shaped electrode geometry in three

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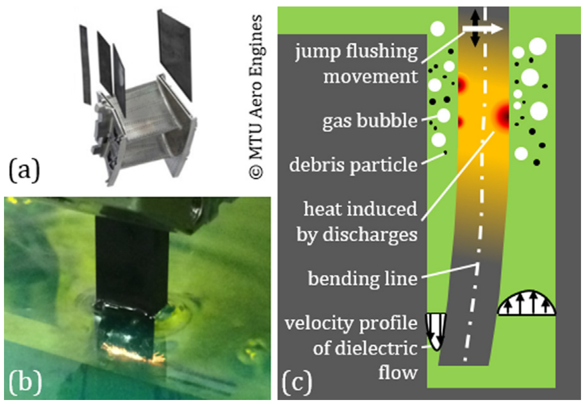

Fig. 1. Effects on thin electrodes during electrical discharge sinking.

dimensions but with low aspect ratio [20]. Both, Cetin et al. and Pontelandolfo et al. validated their simulations by particle image velocimetry (PIV) measurements. In case of wire EDM same approach of flushing simulations and PIV validation were successfully applied by Okada et al. [21]. Nastasi and Koshy optimized EDM drilling operations by improving flushing conditions and thereby whole process performance using slotted tool electrodes [22]. Latest investigations on the field of fluid flow in EDM were carried out by Goodlet and Koshy who successfully evaluated acoustic emissions to be a promising approach for flushing-related adaptive control of EDM [23]. However, no research has been done taking into account the interaction of electrode and dielectric during jump flushing movements. In this paper the bending of thin graphite electrodes in sinking EDM is analysed by means of fluid structure interaction (FSI) simulation. Therefore, in a first step flushing conditions in SEDM are examined experimentally via particle image velocimetry (PIV) and compared to computational fluid dynamics (CFD) simulation results. In a second step high-speed camera recordings are taken of thin graphite electrode on a modern SEDM machine tool in order to visualize fluid structure interaction (FSI). In parallel FSI simulation model is set up under same boundary conditions to understand the phenomenon during planetary movement in terms of fluid velocities, pressures, stresses and bending of graphite.

Experimental

For the validation of the simulation models two experimental configurations were set up. Referring to Cetin et al. [19] PIV measurements of the flow field in a round cavity were conducted at the Institute of Aerodynamics (AIA) of RTWH Aachen University (Fig. 3(a)). In contrast to this work two improvements were introduced. First, lateral gap was reduced from 0.5 mm to 0.1 mm to reproduce actual EDM conditions. Second, fluorescent rhodamine B marked melamine resin particles of 5 μm diameter were used as tracer particles instead of glass powder particles of 22 μm diameter. The smaller particles have less impact on the fluid flow and lead to a higher accordance between the particle velocity and the actual fluid velocity [24]. The motion function of the electrode had an amplitude of 5 mm with a frequency of 2 Hz and a linear velocity function. The PIV measurements serve for the validation of the used CFD module.

For the second experiment, shown in Fig. 2(b), a graphite electrode with a thickness of 0.7 mm, length of 46 mm and width of 20 mm (SGL Carbon R8710, Fig. 3(c)) was positioned in cavity of acryl glass with a thickness of 2 mm, length 41 mm and width 20.4 mm. The frontal gap was 0.2 mm. As dielectric the low viscosity fluid IME110 (Oelheld GmbH) specialized for finishing operations was chosen. Due to the non-conductivity of acryl glass the jump flushing movements had to be executed without application of voltage. Therefore a maintenance routine with a jerk of 55 m/s^3 was executed while recording with 6700 fps and a resolution of 800 × 600 pixels. The recordings served for the validation of the FSI model.

Jump flushing movements of EDM machine tools are defined by maximal values for jerk, acceleration and velocity (cp. Fig. 2). The maximal jerk is applied until the maximal acceleration is reached. At this point the acceleration is kept constant until the maximal velocity is reached. For deceleration this procedure is inverted. For short jump flushing movements as investigated in this paper the maximal acceleration is not reached, meaning that the applied jerk is sufficient to completely describe the motion function. For the reference geometry investigated the machine tool (AgieCharmilles Form 2000) gives a jerk of 200 m/s^3.

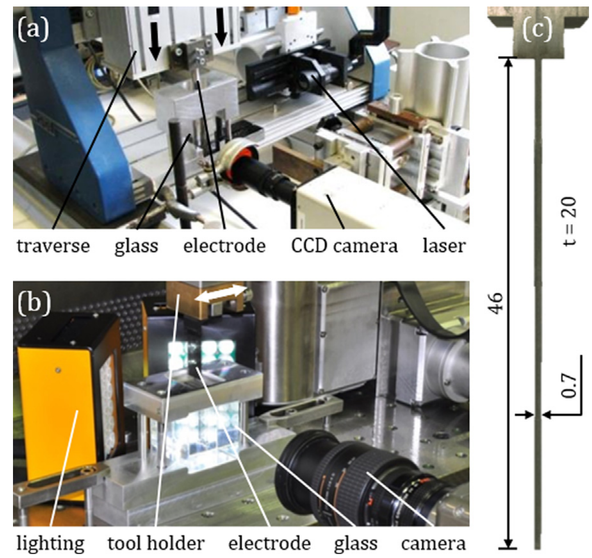

Fig. 2. Experimental set up for PIV measurements (a) and high speed camera recordings (b) with high aspect ratio electrode (c).

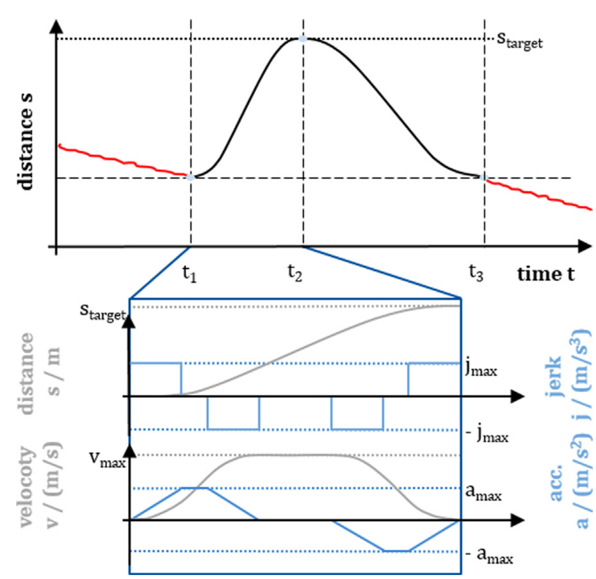

Fig. 3. Systematic representation of jump flushing movements of EDM sinking machines.

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