Determination of the mathematical model of the micro cutting force for the granite Jošanica in the ductile mode

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Keywords: *micro cutting; mathematical model; brittle; ductile mode; cutting force*

In order to mechanically process materials that are brittle by their nature, such as glasses, ceramics, stone-based materials, etc. it is required to cross from the macro to the micro cutting level [1-4]. As shown in the previous research [5-9], those materials can be machined in both ductile and brittle fracturing modes. If the focus is set to the micro cutting materials based on the granite (Jošanica), which belong to highly heterogeneous materials, micro cutting force is hardly predictive. To do so, it is necessary to determine critical penetration depth, which separates ductile mode from the brittle fracturing mode. Thereafter, mathematical model of the micro cutting force can be established in the both modes separately.

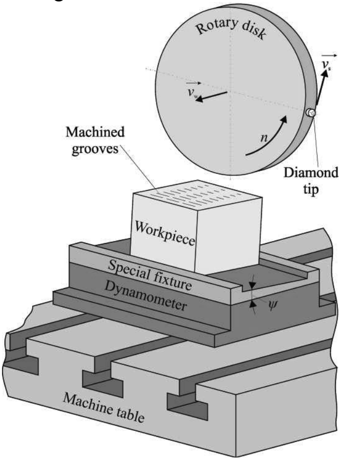

Fig. 1. Experimental setup

As the micro cutting force is in the function of tool tip radius and cutting conditions (micro cutting speed and cutting depth), in order to establish mathematical model of the micro cutting force, experiments were conducted with two different tools, with tip radius R0.2 and R0.15 [mm], while micro cutting speed was 15 and 25 [m/s]. Variation in the cutting depths was achieved with the inclination of the workpiece cutting surface [10].

Experiments were conducted on the horizontal machine center ILR HMC-500 with tool composed of the rotary disk and single grain diamond tip with defined geometry. Prismatic shape workpiece 50x50x50 [mm] was attached on the machine table via dynamometer Kistler 9257B and special fixture. Experimental setup is presented on the Fig. 1.

During the experiments, measurements of the normal and tangential components of the micro cutting force were conducted, Fig. 2.

As the material itself is highly heterogeneous, high dispersion of the measured data is noticeable. Increase of the cutting depth leads to the further increase in the dispersion of the measured data. The cause of this is initialization and the uncontrolled growth of the cracks within the material in the brittle fracturing mode.

As in ductile mode micro cutting takes place by a mechanism that differs from one in brittle fracturing mode, which leads to change in the micro cutting force between this two modes, it is necessary to determine mathematical model in each of them separately.

Since the critical penetration depth for granite Jošanica is 7.3 and 6 [μm] for R0.2 [mm] and v_s=15 [m/s], v_s=25 [m/s] respectively, i.e. 6.3 and 5 [μm] for R0.15 [mm] and v_s=15 [m/s], v_s=25 [m/s] respectively [11], mathematical model is established for the cutting depth up to 5 [μm]. Reason for this limit of the cutting depth is the need for including all the values of the micro cutting force for different cutting conditions.

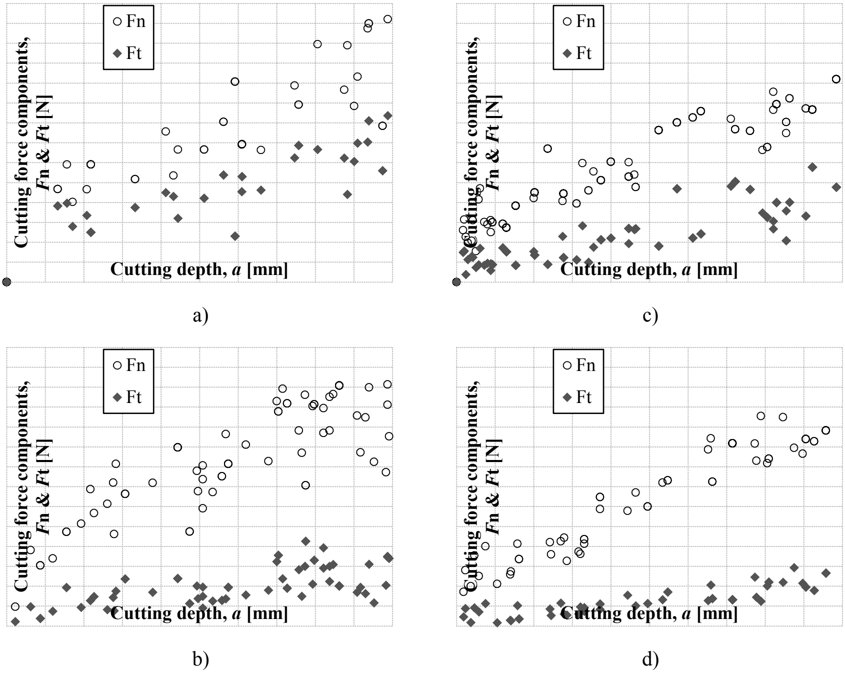

Fig. 2. Experimental results for a) R0.2 [mm], v_s=15 [m/s], b) R0.2 [mm], v_s=25 [m/s], c) R0.15 [mm], v_s=15 [m/s] and d) R0.15 [mm], v_s=25 [m/s] cutting conditions.

Proposed mathematical models of the normal and tangential components of the micro cutting force are given in the equations (1) and (2), and their graphical representation is shown on the Fig. 3.

$$F_{\mathrm{n}}^{\mathrm{m}} = 119{,}6675 \cdot v_{\mathrm{s}}^{-0.1448} \cdot a^{0.5015} \cdot r^{0.9623}, \quad (1)$$

$$F_{\mathrm{t}}^{\mathrm{m}} = 44004.8938 \cdot v_{\mathrm{s}}^{-1.692} \cdot a^{0.464} \cdot r^{2.2972}. \quad (2)$$

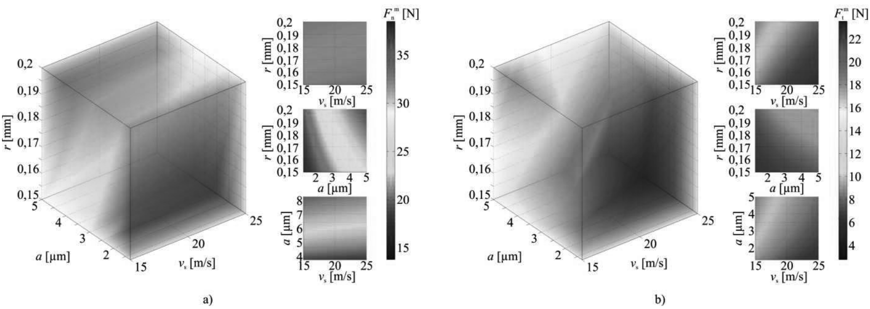

Fig. 3. Mathematical model of the a) normal and b) tangential components of the cutting force.

As can be seen on the Fig. 3a, cutting speed does not have significant influence on the normal component of the micro cutting force. Increase of the intensity of the normal component is present with the increase of the tool tip radius and cutting depth. On the other hand, tangential component shows the dependence on all these varied parameters. Increase of the tangential component values (Fig. 3b) are achieved while micro cutting depth and tool tip radius had the maximum values, while the cutting speed had the minimal value.

Micro cutting of stone-based material, such as granite Jošanica, requires the understanding of the mechanisms that occur during chip formation. In order to adequately implement the micro cutting, it is necessary to know the value of the components of the micro cutting force for the desired processing conditions, which is one of the quality indicators for the micro cutting. To enable this, the developed mathematical model gives a precise picture of the value of the components of the cutting force within the values of the tool tip radius from R0.15 to R0.2 [mm], as well as the micro cutting speeds from 15 to 25 [m/s]. Presented mathematical model provides only values of the normal and the tangential components of the micro cutting force when granite Jošanica is processed in ductile mode.

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