ESRF	**Experiment title: Local in-situ study of the built-up edge development during metal cutting using an orthogonal chip forming process**	**Experiment number**: MA_2111
Beamline: ID 15A	**Date of experiment**: from: 02.07.2014 to: 06.07.2014	**Date of report**: 22.12.2014
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Report:

In machining of metals the chip formation zone is crucial for the surface layer state in the workpiece and the wear behaviour of the cutting tool. Between the three main parts of the chip formation zone (chip, workpiece and cutting tool) highly deformed workpiece material (built-up edge (BUE)) can be built-up during metal cutting, which is formed under certain conditions as a stagnant layer on the rake face of the cutting tool. The formation mechanisms and micostructural evolution during the cutting process of BUEs are still ambiguous, therefore the aim was to study the evolution of microstructure and BUE morphology by applying in-situ diffraction in combination with radiography to get an in-situ view with high time and spatial resolution of the BUE evolution.

<u>Experimental Setup</u>

The workpiece material was SAE 1045 plain carbon steel in a normalised state and an aluminium alloy type EN AW-5754. The choice of the two different workpiece materials is due to known BUE formation for this state of material during machining. The experimental setup is shown in Figure 1. An orthogonal cutting operation was used applying cylindrical (hollow cylinders) workpieces with length of 50 mm and outside diameter of 54 mm. Machining was performed by orthogonal cutting using a lathe, that was built (self constructed) in such a way that the tool holder and therefore the cutting tool insert is localized and the rotating workpiece is moving along the feed direction. The cutting tools used for the experiments were uncoated industrial fine-grained cemented carbide (K10) with a composition of 94 vol.-% WC and 6 vol.-% Co. The designation of the tool is SNMA 120408 according to the standard DIN ISO 1832 without any chip breakers. Additionally ceramic cutting inserts were used, consisting of Si_3N_4 (grade SL 500) with geometry of SNMA 120408 T02020 (instead of cutting edge radius of 30 µm a chamfered cutting edge geometry is applied for the ceramic cutting insert). The cutting parameters were selected for targeted BUE formation that allowed the conservation of BUE on the cutting tool. The applied cutting parameters are summarized in Table 1 for the cutting process.

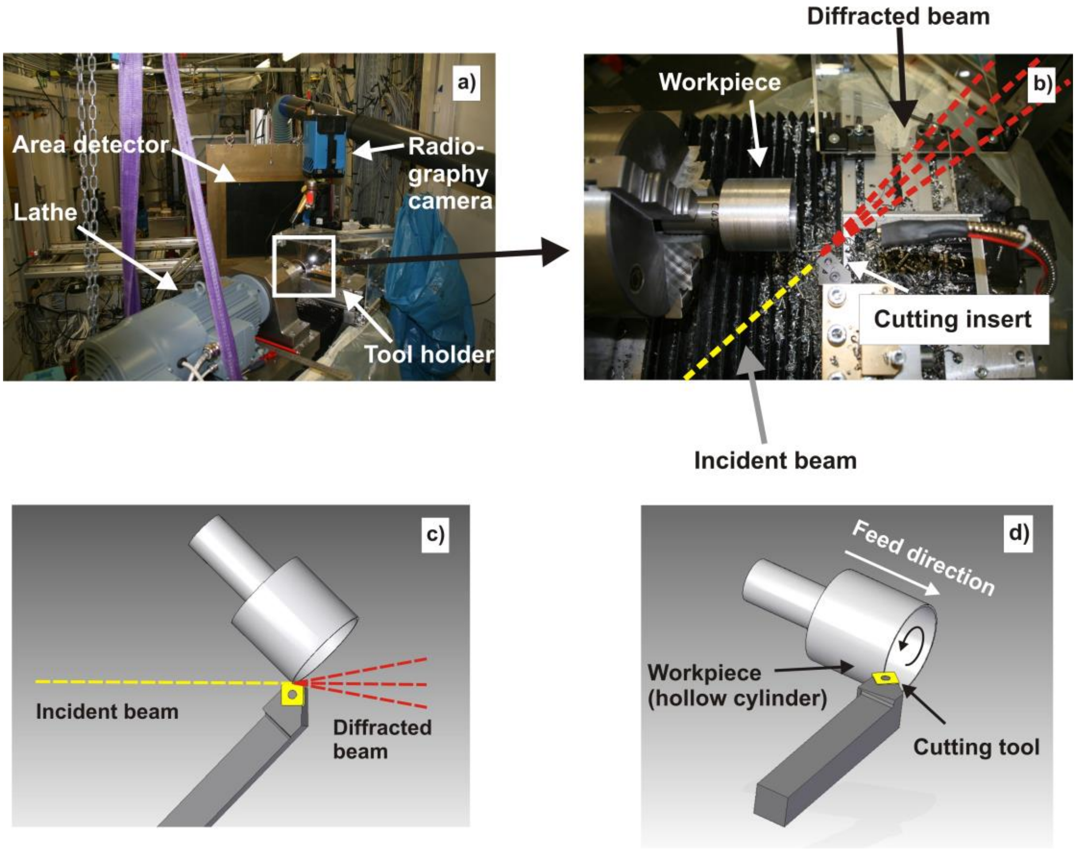

Figure 1: *Documentation of orthogonal metal cutting operation in measurement hutch of ESRF beamline ID 15A (a) and b)). The lathe, detectors, workpiece, cutting tool and the optical paths of the incident and the diffracted beam are indicated. In the second row (c) and d)) the schematic setup is shown with drawing of workpiece and tool.*

In Figure 1 an overview of the orthogonal cutting process is displayed. Using a tool cutting edge angle κ_r of 45° in combination with our hollow cylinder samples (wall thickness = 1 mm) it is possible to perform orthogonal metal cutting without any shadowing effects of the diffracted beam by the workpiece itself (see Figure 1 c) and d)). The diffraction patterns were acquired during the cutting process for different rotation speed and feed velocity (see Table 1). The cutting length in feed direction was 10 mm resp. 20 mm per measurement.

The experiment was performed with monochromatic synchrotron radiation corresponding to an X-ray wavelength of 0.0133725 nm. The beam size for diffraction mode was in the range of 300 x 300 µm for two different positions (one measurement position for "built-up edge" and another position for "chip formation zone"). To provide fast in-situ angular resolved diffraction pattern detection an area detector (Perkin Elmer XRD 1621 detector, frame rate of 14 Hz) in 2 x 2 binning mode (resulting in a pixel size of 400 µm) was used. For the radiographic set-up an X-ray camera was used with pixel size of 5.1 µm and a beam size of 2 x 2 mm. The frame rate was 1000 Hz.

Table 1: *Cutting parameters used for orthogonal cutting operation for in-situ examination of BUE.*

Rotation speed range n [1/min]	100 - 1500
Feed velocity range v_f [mm/min]	3 - 40
Rake angle γ [°]	-8
Clearance angle α [°]	8
Wedge angle β [°]	90
Cutting edge radius r_β (only WC/Co insert) [µm]	30
Tool cutting edge angle κ_r [°]	45

Results and Discussion

(a) Angle dispersive in-situ diffraction

The 2D-diffraction patterns, were analysed using the ESRF-software fit2D. The integral widths IB and peak positions 2θ were evaluated for the 111, 220 and 311 peaks of aluminium, which were fitted using Pearson VII functions. An example for the evolution of 2θ and integral width IB for the 311 peak of aluminium (position: built-up edge; tool: Si_3N_4) is shown in Figure 2. The 2θ and IB values were compared for rotational speed of 1000 min^{-1} and 1500 min^{-1}. The feed rate f = 0.024 mm/rev was held constant by applying a feed velocity of 24 mm/min for n = 1000 min^{-1} resp. 36 mm/min for n = 1500 min^{-1} for a cutting length of 10 mm in feed direction.

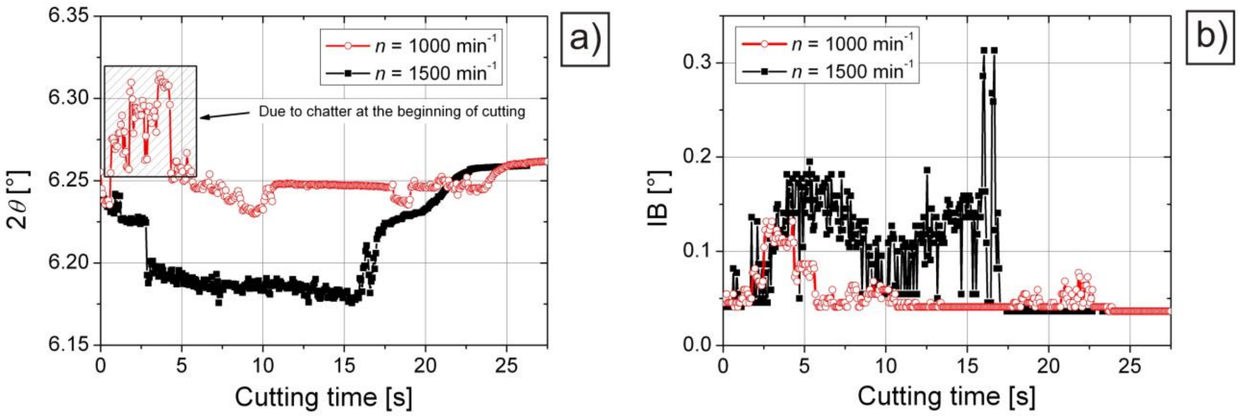

Figure 2: *Evolution in time for the 2θ value (a) and integral width IB (b) for the 311 peak of aluminium during the cutting process.*

As an example in Figure 2 a) the evolution of 2θ can be seen in a very high time resolution (Δt = 70 ms) for the whole cutting process (cutting time for n = 1000 min^{-1}: 25 s; for n = 1500 min^{-1}: 16.7 s). The higher rotational speed leads to higher cutting temperatures that are amongst other factors responsible for peak shifts due to thermal expansion and increase of lattice parameter (see Figure 2 a)). For the higher rotational speed n = 1500 min^{-1} (corresponding to higher cutting velocity) the IB values are also higher due to higher strain rates in the primary and secondary shear zone. This leads to higher dislocation density and grain refinement in the BUE, all influencing the IB value (see Figure 2 b)).

(b) In-situ radiography of built-up edges in dry cutting process

To examine the BUE evolution with respect to its morphology and also with respect to the inner structure with a high time resolution (evolution of small inhomogenities, cracks and pores), radiographic investigations were realized. This radiographic approach leads to deeper view inside the structure evolution in the built-up edge compared to classical high speed camera analysis. An example of radiographic imaged recorded for the BUE (here: aluminium sample) is displayed in Figure 3 for two different rotational speeds n.

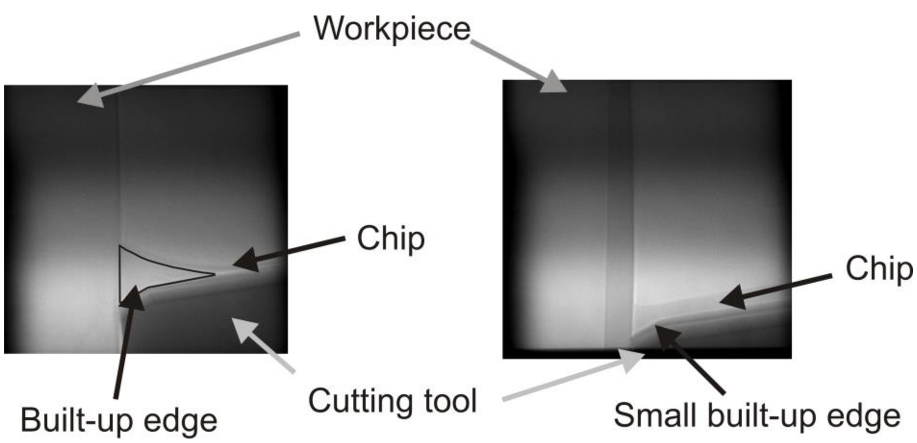

Figure 3: *Radiagraphic images of built-up edge formation of aluminium for n = 1000 min^{-1} (left: very large and stable BUE outlined in black) and n = 1500 min^{-1} (right: negligible instable BUE).*