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ICT-2012
13th International Conference on Tools
27 – 28 March 2012, Miskolc, Hungary

ACOUSTIC EMISSION DETECTION SIGNALS IN THE EXPERIMENTAL VALIDATION OF NANOMETRIC MACHINING SIMULATIONS

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ABSTRACT
The molecular dynamics simulations of nanomachining processes have provided insight into process parameters, material removal and tool wear mechanisms. Simulation results clearly show the material removal phenomena of rubbing, ploughing and cutting. However, many of the simulation results are not backed up by experimental validations, even though they match intuitive guess. There is an attempt in this study to validate some of these results. In the validations of these molecular dynamics simulation of nanometric machining, experiments were carried out on a Nanoform 250 diamond turning machine tool. The tool-workpiece contact was determined by running preliminary passes and using Acoustic Emission (AE) sensors for the nano touch. The analyses of the acquired AE sensor signals have indicated that they can be useful in the detection of the material removal mechanisms.

Keywords: Acoustic Emission Sensors, Experimental Validations, Nanometric Machining

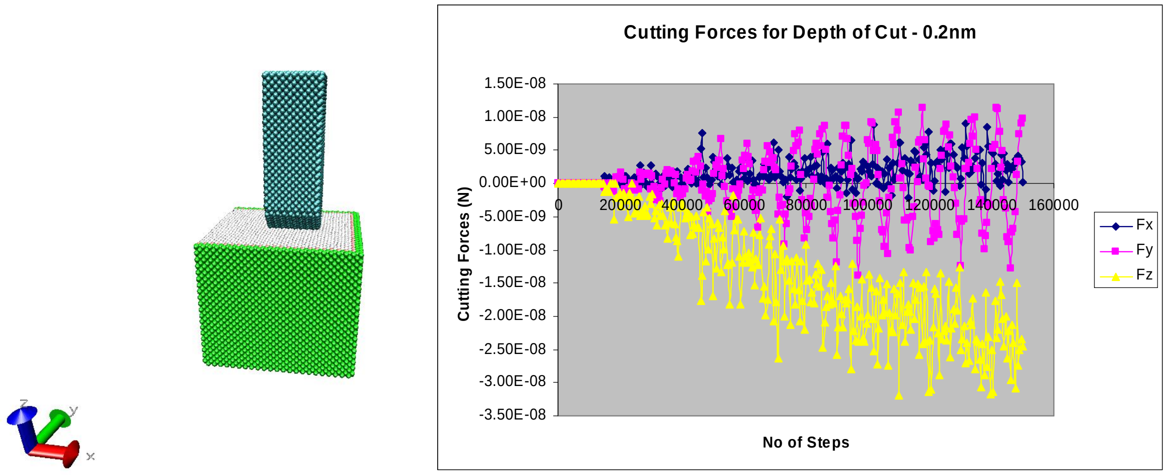
1. INTRODUCTION
There is a trend towards the miniaturization of devices in the electronics, medical and the energy industries and the ultraprecision machining processes are helping to sustain this drive. These machining processes take place in small limited regions of tool-workpiece interfaces, which are difficult to model by continuous mechanics. For over a decade now, the molecular dynamics simulations are being used to provide insight into these nanoscale interactions. However, many of the simulation results are not backed up by experimental validations, even though they match intuitive guess [1]. This study attempts to validate the results of MD simulations of nanometric machining of copper workpiece by a diamond tool, using raw acoustic emission (AE) signals. There is justification for this research direction as Liang and Dornfeld [2], Dornfield et al [3] stated that manufacturing processes that are depended on material deformation have potentials for AE-based monitoring. Also, Webster et al [4] used raw AE signals instead of root-mean-square (RMS) signals to analyze the grinding process. They found out that raw AE signals can be used to detect wheel/workpiece contact processes. Furthermore, Opoz and Chen [5] found out that the AE signals are sensitive enough to characterize grinding material removal process stages.

2. THE MOLECULAR DYNAMICS (MD) SIMULATIONS
The MD simulation of the nanometric machining of copper workpeice with a diamond tool has been carried out. The atomic interactions in the simulation are the following, namely;

Cu-Cu : interactions between copper atoms

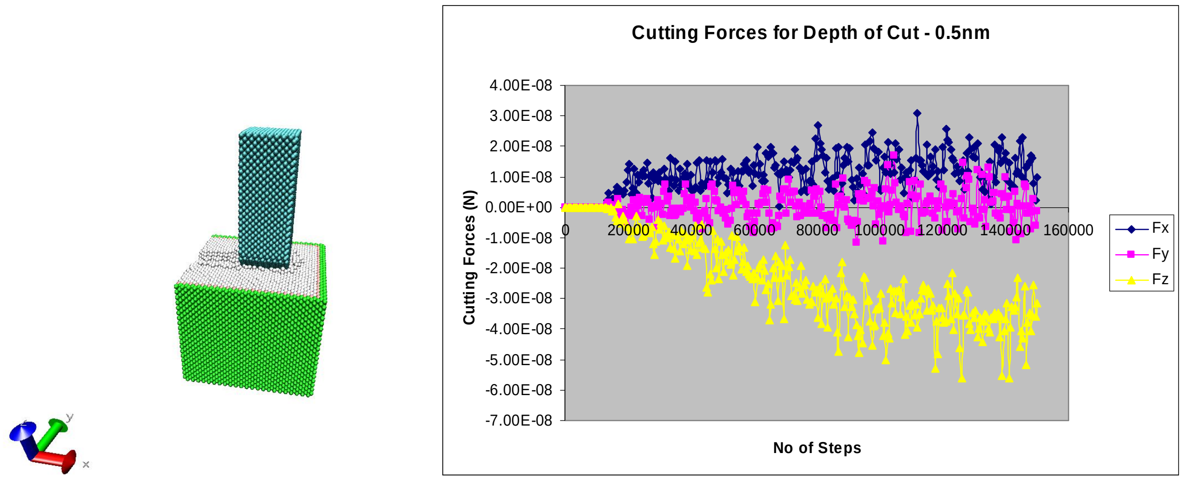
Cu-C : interactions between copper atoms and diamond atoms

C-C : interactions between the diamond atoms
The EAM potential was used for the Cu-Cu interactions and the LJ potential was used for the Cu-C interactions. All the C-C (tool atoms) interactions were modelled by using the Tersoff potential.
Figures 1-3 show MD simulation results of the material removal mechanisms observed from the simulations. Figures 1 (a and b) show the rubbing phenomenon, which was observed for a depth of cut of 0.2nm and the corresponding cutting forces. Figures 2 (a and b) show the ploughing phenomenon, which was observed for a depth of cut of 0.5nm and the corresponding cutting forces. Similarly, Figures 3 (a and b) show the cutting phenomenon, which was observed for a depth of cut of 2.0nm and the associated cutting forces.



(a) (b)

Figure 1: Rubbing Phenomenon
(a) Simulation for Depth of Cut – 0.2nm; (b) Cutting Forces for Depth of Cut – 0.2nm

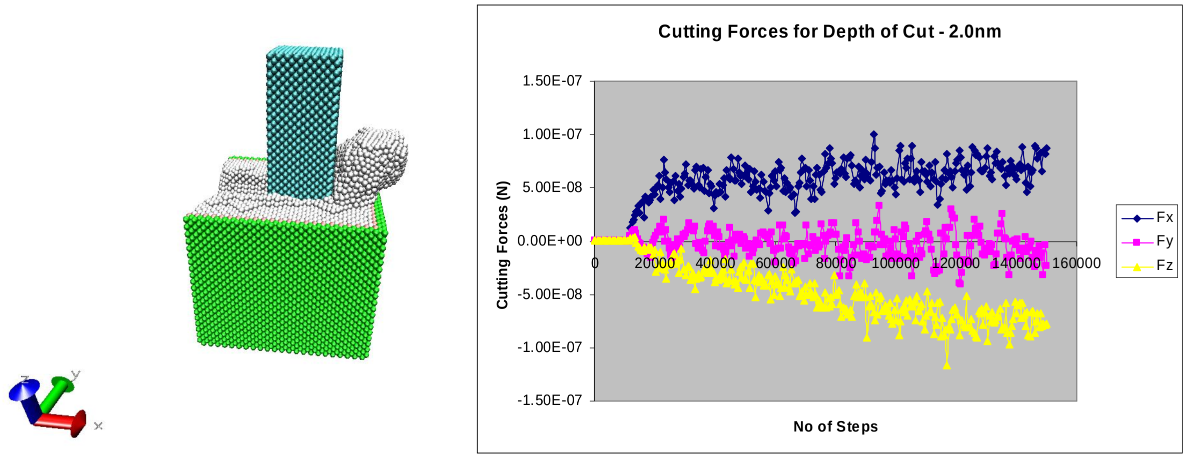


(a) (b)

Figure 2: Ploughing Phenomenon
(a) Simulation for Depth of Cut – 0.5nm; (b) Cutting Forces for Depth of Cut – 0.5nm

3. SAMPLE PREPARATION

Copper specimen were obtained from the laboratory, They were then cut into smaller pieces of roughly 15 x 10 mm. Circular moulds were made using a metallographic sample moulding machine, with the copper inserted in them. The resulting workpiece specimens were later hand polished to mirror finish, using the following 2-stage procedural steps below:



(a) (b)

Figure 3: Cutting Phenomenon
(a) Simulation for Depth of Cut – 2.0nm; (b) Cutting Forces for Depth of Cut – 2.0nm

Stage 1
The copper specimen were hand grinded using abrasive grits of 320, 800, and 1200 micron on a grinding machine, in that order, for around 3-5 minutes each.

Stage 2
The copper specimen were then hand polished using 6, 1 and 0.5 micron abrasive cloth on a polishing machine for 2-3 minutes each. These produced mirror finish surfaces.

Table 1: Process Breakdown

Stage	**Abrasive Type**	**Process Time**
Stage 1- Grinding	Abrasive Grit: 320 800 1200 2500	3-5 Minutes
Stage 2- Polishing	Abrasive Cloth: 6 1 0.5	2-3 Minutes

4. EXPERIMENTAL SET-UP

The validation experiments were carried out on a Nanoform 250, shown below.

Figure 4: The Nanoform 250 Ultraprecision Machine

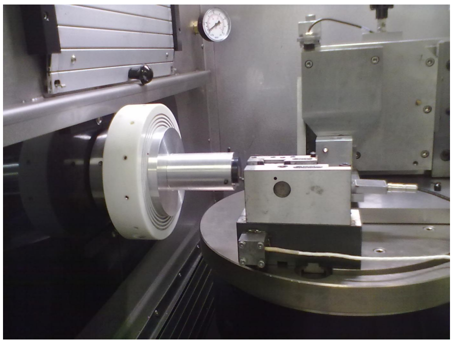


Figure 5: The Experimental Rig

5. EXPERIMENTAL PROCEDURE

The experiments were set-up on the Nanoform 250 diamond turning machine, by mounting the copper workpiece on the vertical spindle and the diamond tool on the horizontal spindle. The tool-workpiece contact was determined by running some preliminary passes and using Acoustic Emission (AE) sensor for the nano touch. The AE sensor, model WD from Physical Acoustic was used. It has an operating frequency range between 100 and 900 kHz and the temperature range is from -65^{o}C to 177^{o}C. The workpiece was fed in steps of 100nm and the diamond cutter was allowed to cut the copper specimen. The feed used was 15mm/min and the spindle speed was varied from 2000rpm to 7000rpm in steps of 1000. For each of the spindle speed, three passes/scratches were made on the workpiece. It should be stated that it was very difficult to obtain force sensor signals during the experiments.

6. VALIDATION OF THE MD SIMULATIONS

The AE results of the experimental runs are shown in Figures 6 – 10

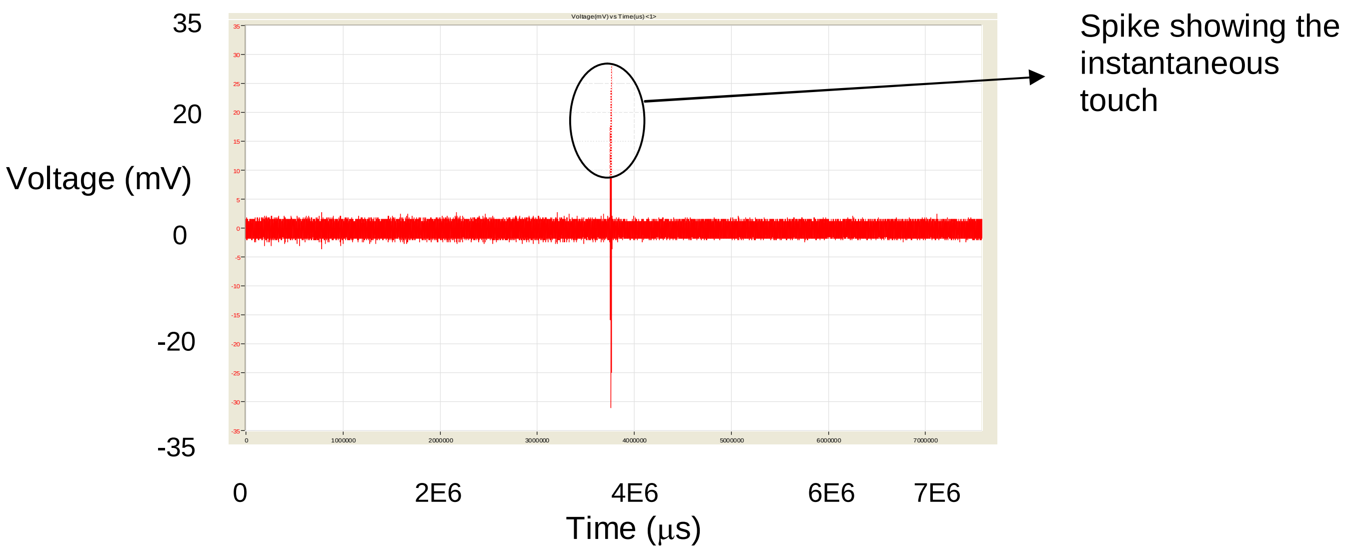


Figure 6: Raw AE Signal for RPM 7000 (Touch)

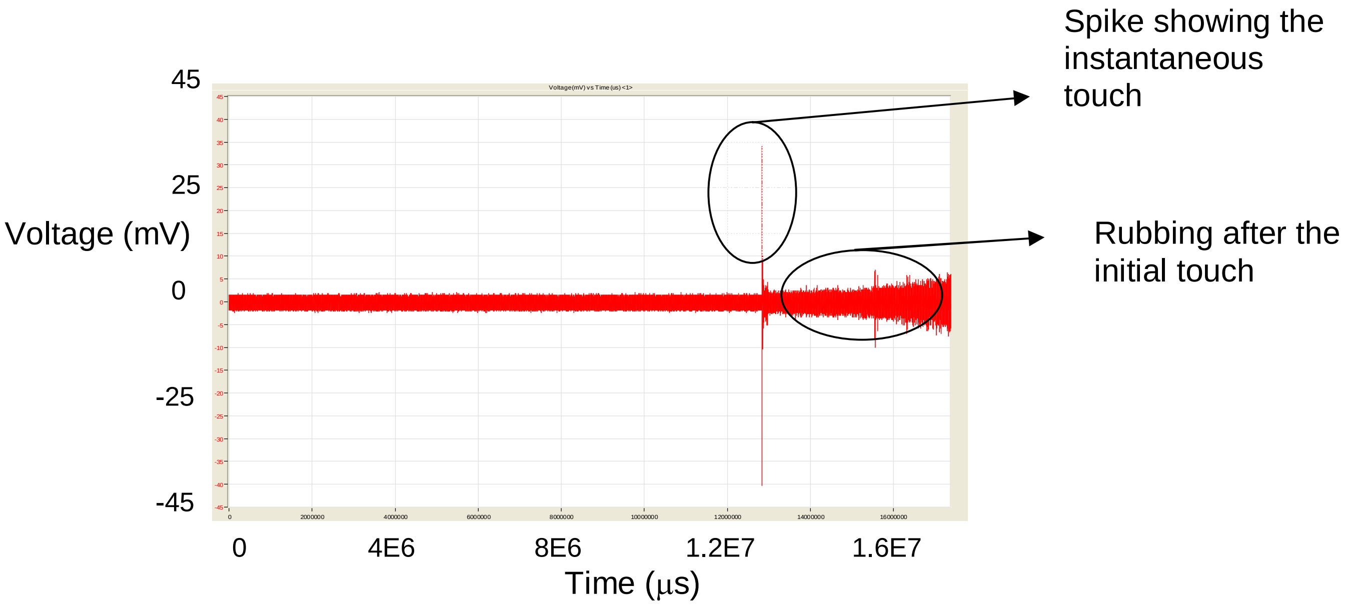


Figure 7: Raw AE Signal for RPM 7000 (Touch and rubbing)

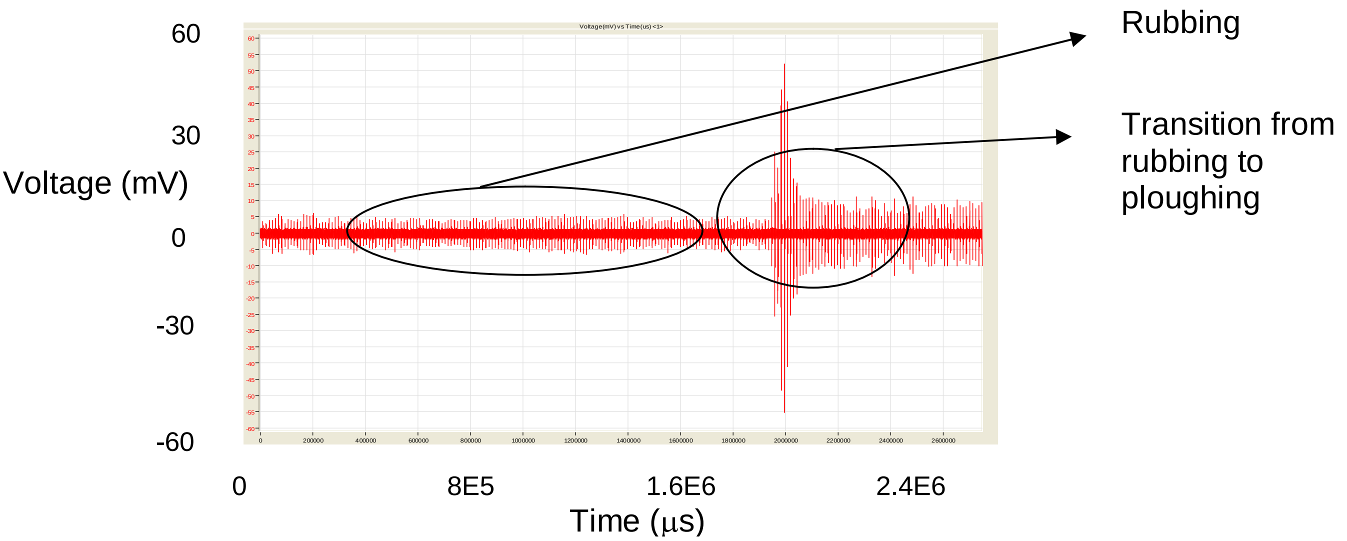


Figure 8: Raw AE Signal for RPM 5000 (Rubbing and Ploughing)

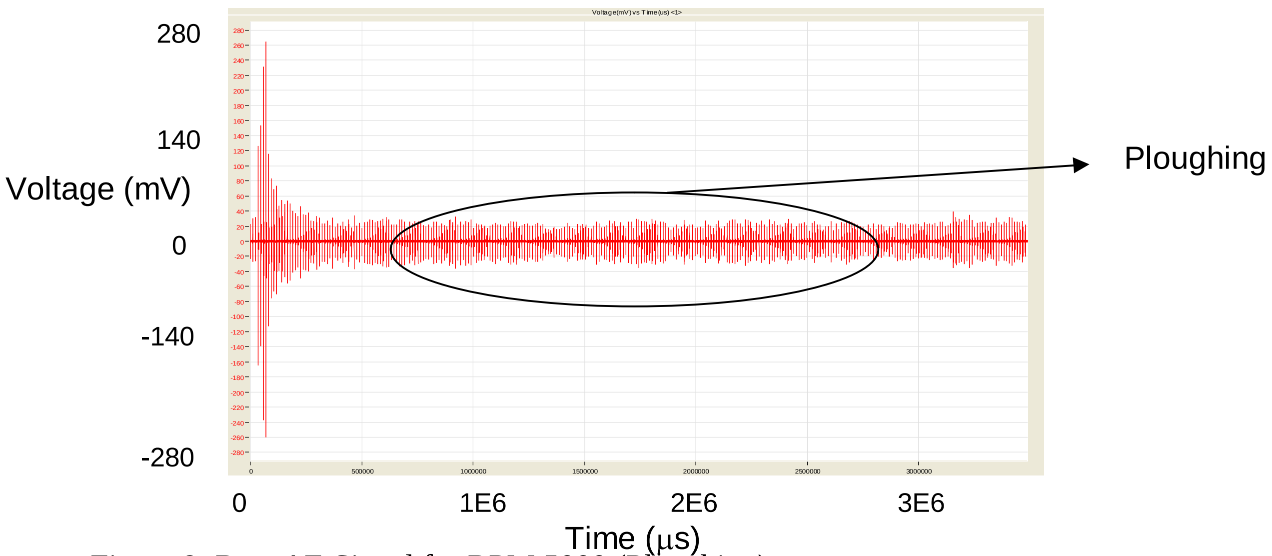


Figure 9: Raw AE Signal for RPM 5000 (Ploughing)

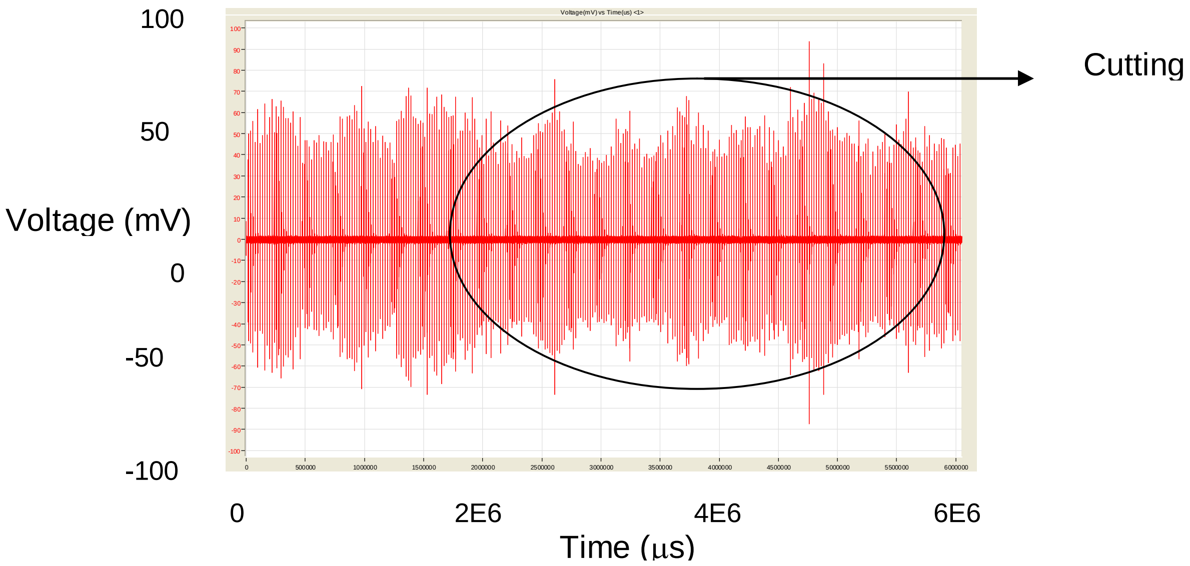


Figure 10: Raw AE Signal for RPM 3000 (Cutting)

The above Figures 6-10 show an attempt to characterize the phenomena of rubbing, ploughing and cutting by using raw AE signals.

7. CONCLUSION

An attempt has been made to use AE raw signals to characterize the material removal mechanisms in nanometric machining and thus validate some MD simulation results. There is an indication that the AE raw signals may be able to detect the phenomena of rubbing, ploughing and cutting.

8. REFERENCES

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