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# A Study on CVD Diamond Coated Cutting Tools Wear Performance using Vibration and Acoustic Emission Signals

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**Abstract**

Maximizing the use of cutting tool inserts and effectively utilizing them in the automated manufacturing process is critical to reducing machine down time and improving part quality. Early removal of tooling inserts can lead to less productivity and increased costs. Utilization of tooling inserts beyond its stipulated life time can cause dimensional inaccuracies and undesirable surface deterioration. Optimizing the cutting tool insert life will require an appropriate method for finding out remaining useful life of tooling inserts based on respective machining conditions. In this present work, acoustic signals and vibration signals were acquired during machining to monitor the tool failure. The change in signal variations in acoustic emission and vibration signals were correlated to the corresponding tool wear during machining. In this regard, machining experiments were performed on AA2124/25%/$SiC_p$ material using four different CVD Diamond coated tungsten carbide cutting tools (MCD-Microcrystalline diamond coating, NCD-Nano-crystalline diamond coating, BDD-Boron doped diamond coating, BMTN-Boron doped graded layer diamond coating) at an suitable cutting conditions. The results indicated that burst type AE signals observed in MCD and NCD coated tools correlated to chip entanglement, edge chipping, and the corresponding vibration analysis shows a similar increase in amplitude in the final cutting pass. However, there was no abnormality seen in BDD and BMTN coated tools signal variation which indicates least tool wear.



*Keywords:* CVD Diamond coating, Acoustic emission signals, Vibration signals, Tool wear

## 1. Introduction

Composite materials such as (Al-SiC, CFRP (Carbon fibre reinforced plastic), GFRP (Glass fibre reinforced plastic)) are difficult to machine due to its hard reinforcement in the primary material [1]. In specific, Aluminium (Al) based composite widely used in automotive and aerospace industries due to its enhanced mechanical properties. Hence cutting tool with high hard and good toughness required to machine this composite effectively. From the perspective of hardness, diamond tools are suitable to machine MMC (Metal Matrix Composite) effectively. CVD Diamond coated tungsten carbide satisfies this requirement by providing both hardness and toughness [2]. However during machining, tool edge chipping, tool breakage can affect the stability of the machine tool which in turn affects the surface finish of the machined component.

Hence an appropriate tool wear identification method required to diagnose the failure of the cutting tool in early stages of the event. Ping Lu et.al investigated the machining of Al-20%SiC using diamond coated tools by Acoustic signals (AE) method. He inferred that AE FFT method shows intensity reductions during the occurrence of tool failure [3], [4]. F Qin et.al


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studied AE signals evolution while machining A359/SiC-20 composite using nano diamond-coated tools. He observed that signification reduction in intensity during tool failure pass [5]. H.K.Tonshoff et.al investigated AE signals generated during turning of hardened steel [6]. He inferred that increase in flank wear increases the damping rate which reduces the intensity of AE amplitude.

Ichiro implemented AE sensors in turning operation and classified Signals into burst type and continuous type AE signals. Burst type AE signals infer tool chipping, chip entangling and initiation of crack in the material. Continuous type AE signals exhibit plastic deformation in the ductile material [7]. Li et.al studied AE signals in turning operation during tool wear [8]. He observed that increase in wear decreases the amplitude of burst type AE signals. Y.S Varadarajan et.al analyzed AE signals while machining Al-SiC MMC by carbide tools [9]. Tool fracture results burst to type AE signals while tool wear indicates continuous type AE signals. Increase in tool wear can alter the machine tool dynamics produces chatter and vibrations during machining.

In this study, four distinct CVD Diamond coated WC-Co cutting tools namely MCD, NCD, BDD and BMTN tools are considered to machine AA2125/25%SiC MMC in a suitable cutting condition. Acoustic emission sensor and accelerometer sensor are used in this study to monitor the influence of four morphological variations of the diamond coated tool during machining. A detailed investigation was performed through these indirect monitoring to identify the early stages of tool failure.

## 2. Experimental work

The work-piece material was considered as an Al-SiC composite material with 25% reinforcement and an average particle size of 3-5 µm as shown in Fig.1. CVD Diamond coated tungsten carbide with four distinct morphological variations of the coating were used as a cutting tool to machine this MMC material. The detailed coating variations were shown in Table 1. Coating thickness was maintained constant for all four coating variants with a thickness of 4-5 µm. The coating process parameters such as boron concentration, methane-hydrogen flow ratio were shown in Table.2.

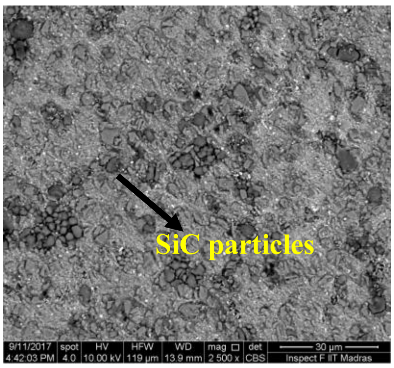



Fig. 1. Microstructure of Al-SiC MMC

Machining experiments were performed using VDF high-speed lathe with a cutting velocity of 250 m/min, 0.05 mm/rev and 0.2 mm depth of cut respectively. The detailed experimental set up was shown in Fig.2.

Table.1. Cutting tool types

| S.No | Cutting tool | Coating thickness (µm) | Relief angle(°) | Nose radius (mm) |
|---|---|---|---|---|
| 1 | MCD/WC-Co | 4-5 | 11 | 0.8 |
| 2 | NCD/WC-Co | 4-5 | 11 | 0.8 |
| 3 | BDD/WC-Co | 4-5 | 11 | 0.8 |
| 4 | BMTN/WC-Co | 4-5 | 11 | 0.8 |

**MCD**------ Microcrystalline diamond coating
**NCD**------- Nanocrystalline diamond coating
**BDD**------- Boron-doped diamond coating
**BMTN**----- Boron doped graded layer diamond coating

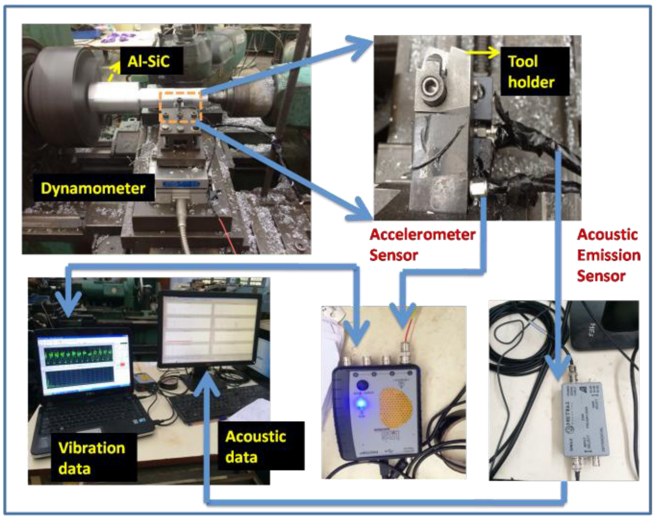



Fig. 2. Experimental setup

The VDF high-speed lathe was coupled with two sensors namely acoustic sensor and accelerometer sensor. The acoustic sensor generates low and high-frequency signals during machining correlated to edge chipping and tool wear. The accelerometer sensor used to record machine fluctuations and chatter during the course of machining. The sampling rate for the acoustic sensor was set to 200 kHz whereas for accelerometer sensor sampling rate was fixed at 16 kHz.

Table.2. Coating process parameters

| Type of coating | $CH_4/H_2$ ratio (%) | Boron concentration (%) |
|---|---|---|
| MCD | 2 | |
| NCD | 4 | |
| BDD | 2 | 0.22 |
| BDD | 2 | 0.22 |
| Transition Layer | Gradually changes from BDD to NCD | |
| NCD | 2 | |

## 3. Results and discussion

### *3.1 Surface Morphology*

The shape and size of the grain can be inferred through the surface morphology. The surface morphology of the distinct diamond coating variants was studied by scanning electron microscopy (SEM) as shown in Fig.3. The grain size of the MCD coating observed in the range of ~ 0.7 to 1.3 µm as shown in Fig.3a. Fig.3b shows grain size of NCD coating lies in the range of ~60-80 nm. On the other hand, the grain size of the BDD and BMTN coating found in the range of ~ 1-2 µm and 300-500 nm as shown in Fig.3d.

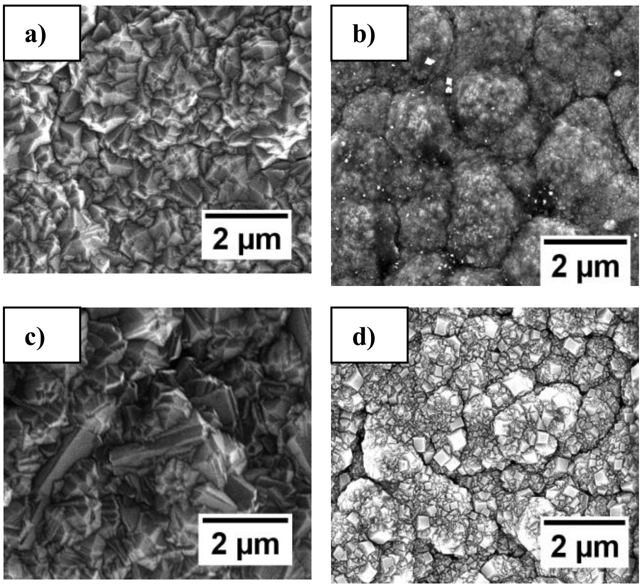



Fig.3. Surface morphology of coating variants
a) MCD b) NCD c) BDD d) BMTN

### *3.2. Tool wear study*

Tool wear study was conducted at an interval of each 38 seconds during machining. The tool wear was performed for a time of 200 seconds. Tool wear was limited till it reaches a threshold value of 0.2 mm. So in each pass, the corresponding tool wear was measured through stereomicroscope to quantify actual wear.

Fig.4 (a,b,c,d) shows scanning electron microscopy image of cutting tool after 200 seconds duration of machining. The Rake surface of the cutting tool after 200 seconds machining was taken through stereo microscopy as shown in Fig. (a1, b1, c1, d1). MCD and NCD attain a flank wear of 0.23 mm and 0.28 mm whereas BDD and BMTN yield a value of 0.19 mm and 0.18 mm respectively. The high flank wear in NCD could be due to the presence of sp$^2$ phase in the NCD coating. This can cause negative effects and it results in coating delamination and edge chipping.

With respect to MCD coating, the more accumulation of BUE (built-up edge) accelerates the flank wear. There are two possible reasons for low flank wear in BDD, BMTN coating compared to MCD, NCD coating. The first one could be due to good interface adhesion through boron-cobalt interaction which suppresses diffusion of cobalt in the diamond lattice. The second one could be due to change in surface frictional energy in boron-carbon chemical bonds in BDD films yields lower frictional force thus reduces tool wear.

In addition Fig. 5 shows flank wear with respect to each interval of time during machining.

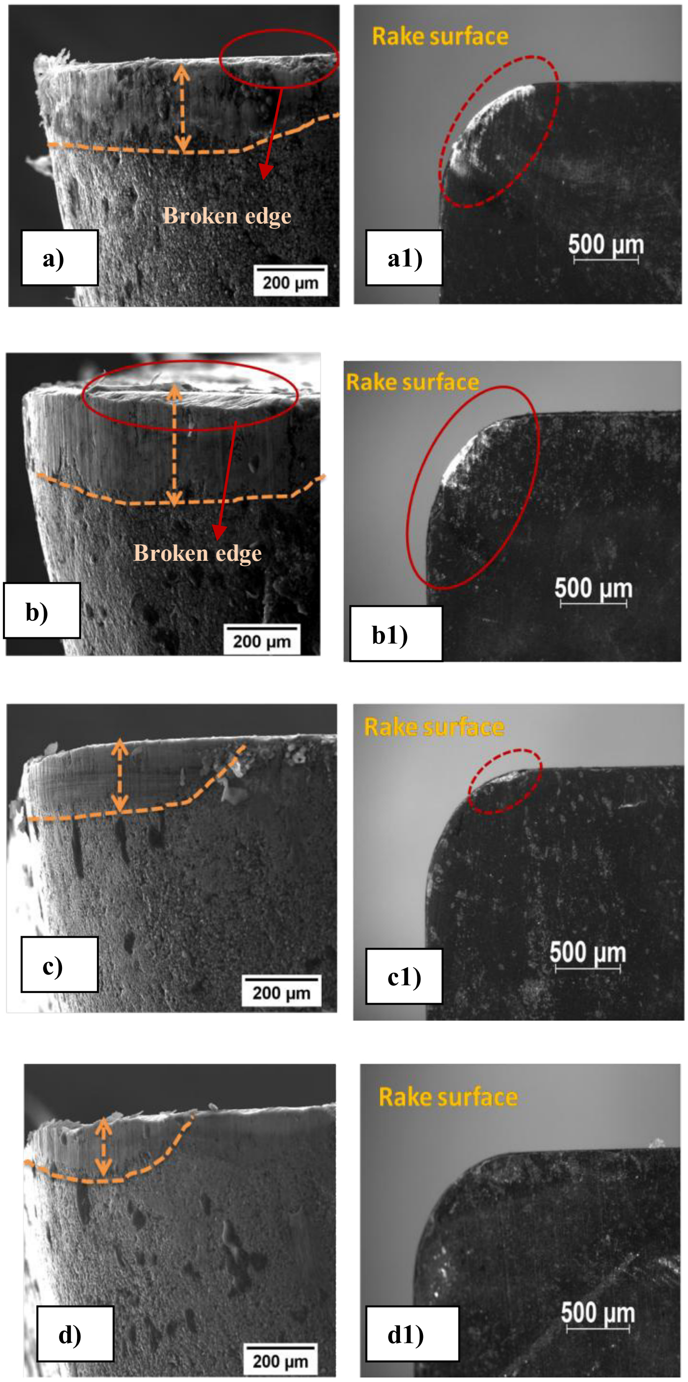



Fig. 4. SEM (a,b,c,d) and Stereo microscopic (a1,b1,c1,d1) image of cutting tool after final cutting pass
a) MCD b) NCD c) BDD d) BMTN
a1) MCD b) NCD c) BDD d) BMTN

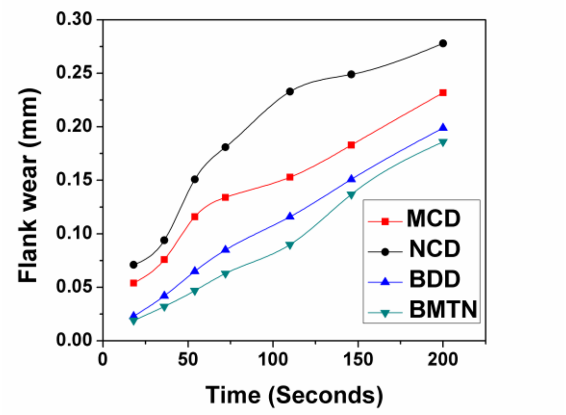


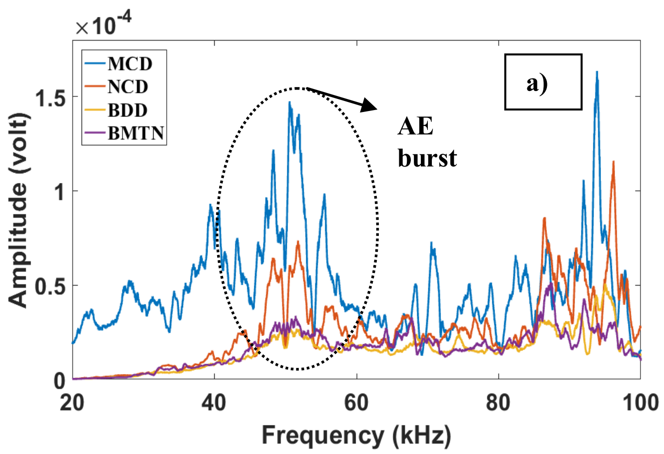

Fig.5. Time vs Flank wear

### 3.3. Acoustic Emission analysis

The Acoustic data was collected for each 38-second pass during machining. Then raw data was converted into frequency domain through Fast Fourier Transform (FFT) code using MATLAB. Then wavelet denoising was done to filter the noise from the FFT data. The AE signals were analyzed for each cutting pass and FFT graphs were shown for initial and final cutting pass. The changes in the AE signal were observed accurately to examine tool wear and edge chipping.

Fig.6a. shows AE FFT analysis for an initial cutting pass. FFT graph plotted between Frequency vs. Amplitude. Two prominent signal variations were observed at low frequency (40-60 kHz) and high frequency (80-100 kHz). Low frequency correlated to AE burst signals whereas high frequency related to tool wear.

During the initial cutting pass, peaks were observed for the low frequency with a value of $1.5 \times 10^{-4}$, $5 \times 10^{-3}$, and $2 \times 10^{-3}$, $2 \times 10^{-3}$ for MCD, NCD, BDD and BMTN cutting tools respectively. On the other hand for higher frequency, peaks observed at $1.5 \times 10^{-4}$, $1 \times 10^{-4}$, and $4 \times 10^{-3}$, $4 \times 10^{-3}$ respectively. It can be seen that for MCD tools, chip entanglement and mild edge chipping causes the release of AE burst whereas, for NCD tool, high edge chipping releases the sudden energy of AE burst during initial cutting condition.



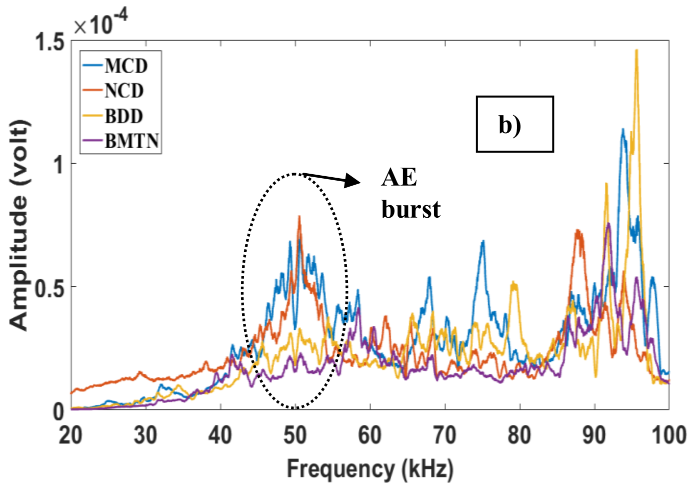
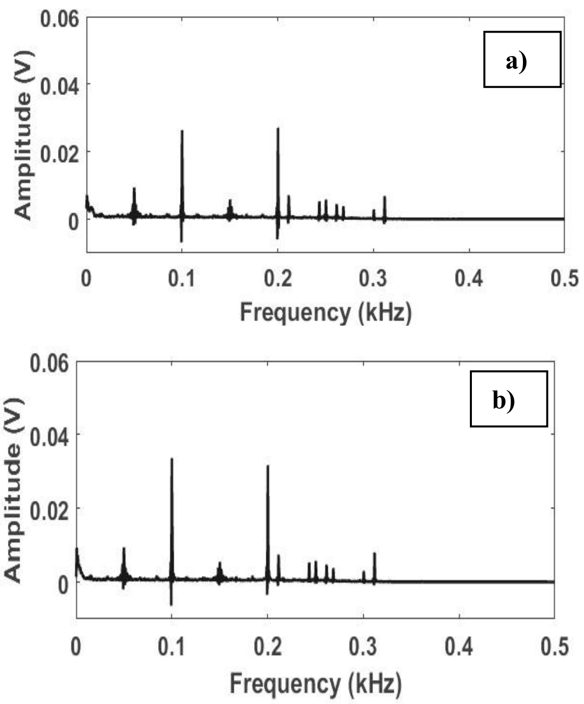




Fig.6. AE FFT analysis during machining
a) Initial cutting pass b) Final cutting pass

However, there was no abnormality seen in AE burst for BDD and BMTN cutting tool during the initial cutting pass. Fig.6b. shows AE FFT analysis for a final cutting pass. During the final cutting pass, low-frequency peak observed at $5 \times 10^{-3}$, $6 \times 10^{-3}$, $3 \times 10^{-3}$, $2 \times 10^{-3}$ for MCD, NCD, BDD, BMTN tools respectively. For high frequency, the peaks observed at $1 \times 10^{-4}$, $8 \times 10^{-3}$, $1.5 \times 10^{-4}$, and $4 \times 10^{-3}$ respectively. Reduction in signal intensity correlated to increase in wear. BDD and BMTN observed as least tool wear compared to MCD and NCD through AE analysis.

### 3.4. Vibration analysis

In process variations such as chatter and sudden fluctuation due to the tool, wear can be examined through vibration analysis. Increase in the amplitude of vibration leads to increase in tool wear. Fig.7. shows Vibration FFT analysis during initial cutting pass for four distinct diamond-coated tools.



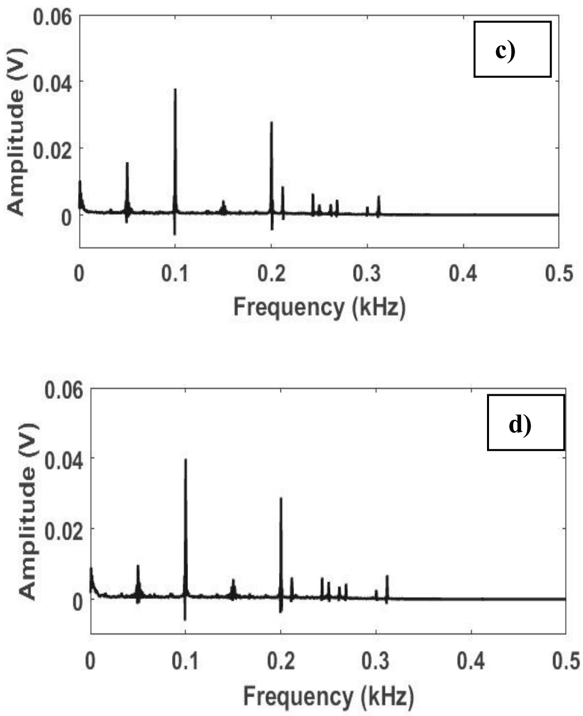
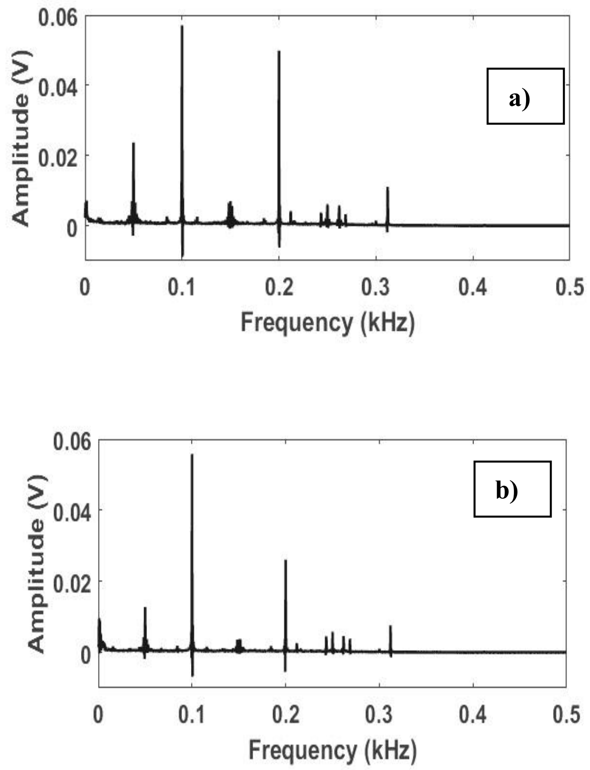



Fig. 7. Vibration FFT analysis during initial cutting pass
a) MCD b) NCD c) BDD d) BMTN



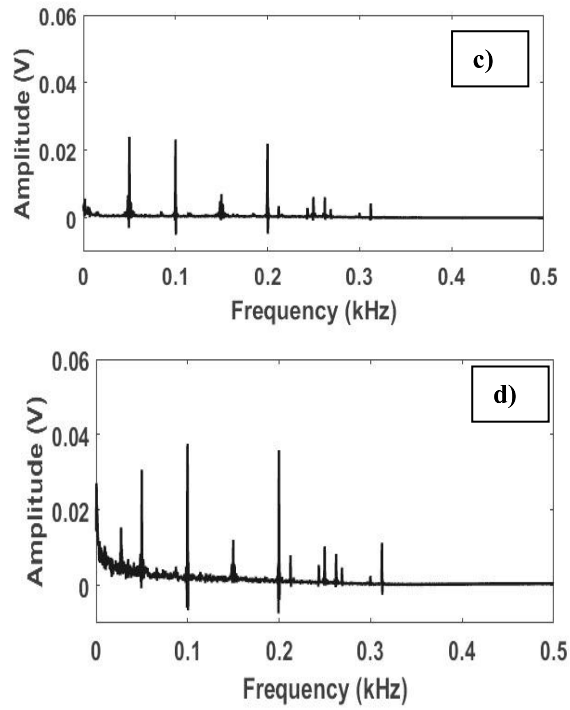




Fig. 8.Vibration FFT analysis during final cutting pass
a) MCD b) NCD c) BDD d) BMTN

In vibration analysis, there are four frequencies considered for signal variations. During the initial cutting pass, 0.05 kHz and 0.15 kHz frequencies have lower intensity compared with other two frequencies such as 0.1 kHz and 0.2 kHz as shown in Fig.7. Four distinct diamond coating variants show similar pattern during the initial cutting pass. In the final cutting pass, there was a respective change in 0.05 kHz, 0.1 kHz, 0.15 kHz and 0.2 kHz as shown in Fig.8. For MCD and NCD coated tools, the intensity of amplitude increases in above-said frequencies which confirm the higher vibrations experienced by machined tools confirms the corresponding tool failure. On the other hand, BDD and BMTN tools show lower amplitude intensity correlated to least tool wear.

Thus it can be concluded that AE signals and vibration signals are accurate in tool wear prediction during machining. In addition, it clearly depicts the nature of material removal and tool failure phenomenon.

## Conclusion

1) AA2124/25%SiC MMC was machined using four CVD diamond coated tools and its corresponding AE signals and vibration signals were studied in detail.

2) Acquired AE signals during machining were analyzed using FFT method. Frequency domain parameters were analyzed at low and high-frequency peak during initial and final cutting pass. Final cutting pass shows reduction in intensity compared to initial pass correlated to increase in tool wear.

3) In addition, burst type AE signals show tool edge chipping in NCD coated cutting tools. Poor interface adhesion strength in NCD coating leads to high tool wear. On the other hand, BDD and BMTN tools show lesser intensity reductions in AE FFT analysis compared to MCD and NCD coating.

4) Vibration analysis shows that increase in amplitude in final cutting pass compared to initial pass shows increase in tool wear. MCD and NCD undergo higher intensity confirms respective higher vibration during machining. On the other hand, BDD and BMTN tools show lower amplitude signals exhibits least tool wear.

5) Thus Acoustic signals and vibration signals are effective in analyzing the tool wear phenomenon during machining of aluminum-based MMC material.

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