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# An evaluation of dust release when machining nano-structured composite materials

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Islam Shyha, Michael E. Deary, Dehong Huo

Alexandria, 11-13 March 2018

# About me

- Educated in Egypt
- PhD from Birmingham, UK
- Work in Newcastle, UK



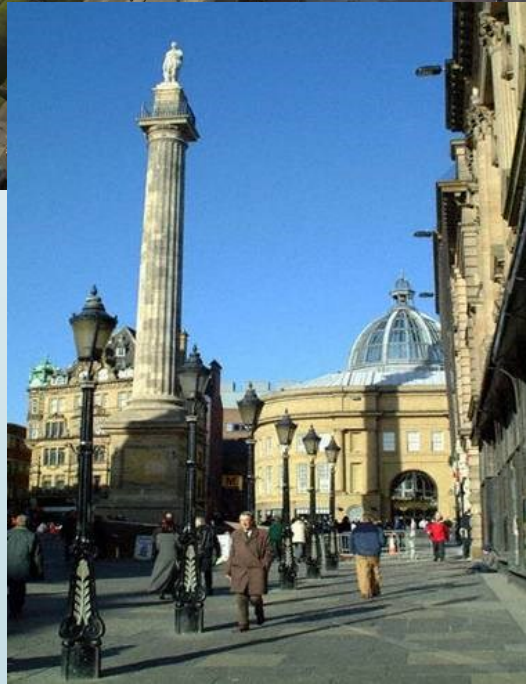
# Newcastle upon Tyne



- Capital of England's North East
- Rich in history and culture
- Britain's "Best University City"



# Newcastle upon Tyne



# Northumbria University



# An evaluation of dust release when machining nano-structured composite materials

# Outline

- ▶ Introduction
- ▶ Nanocomposite Safety
- ▶ Experimental Work
- ▶ Analysis of Results
- ▶ Conclusions and Future Work



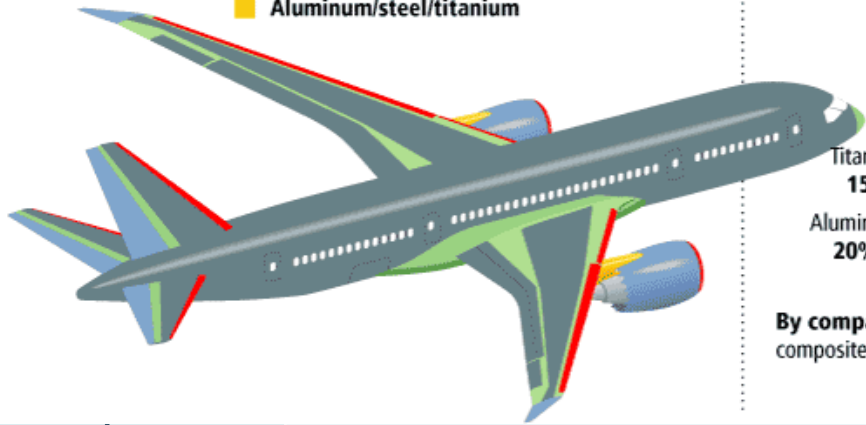
# Introduction

- ▶ Machining produces dust (heavy chips rest on machine beds while finer particulates become **airborne**)
- ▶ Why dry micromachining is chosen: likely to produce the smallest particulates
- ▶ Nano-composites are more hazardous due to the risk of generating/releasing nano-particulates

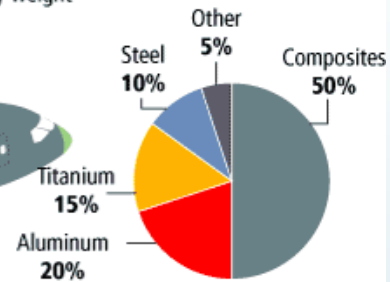
# Composite materials

## Materials used in 787 body

- Fiberglass
- Aluminum
- Carbon laminate composite
- Carbon sandwich composite
- Aluminum/steel/titanium

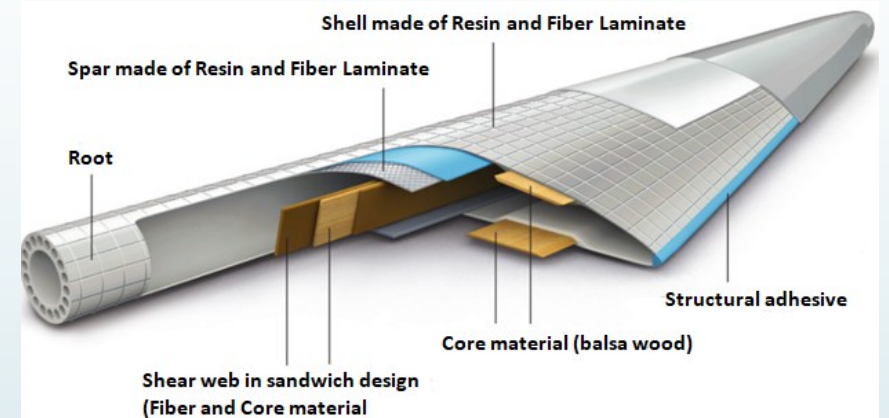


## Total materials used By weight



By comparison, the 777 uses 12 percent composites and 50 percent aluminum.

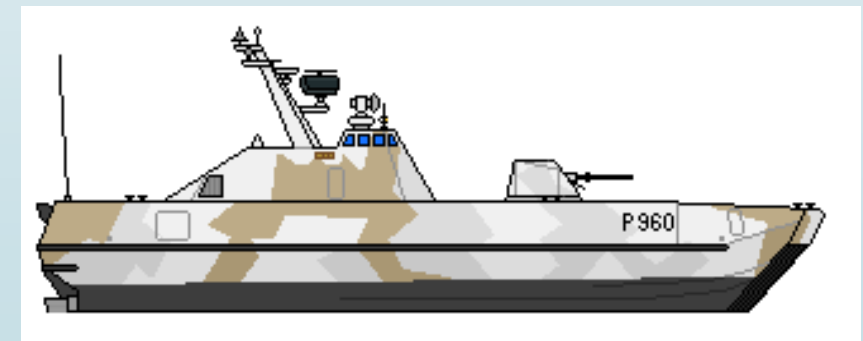
(Source: Modern Airliner)



(Source: 3D printing Industry)

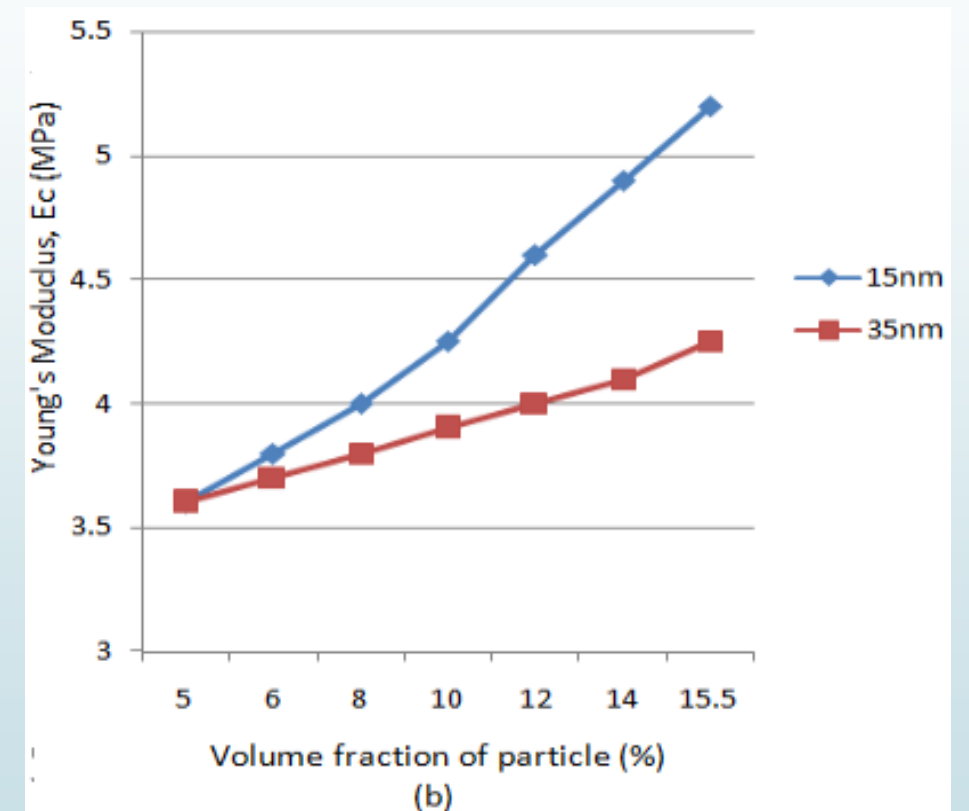
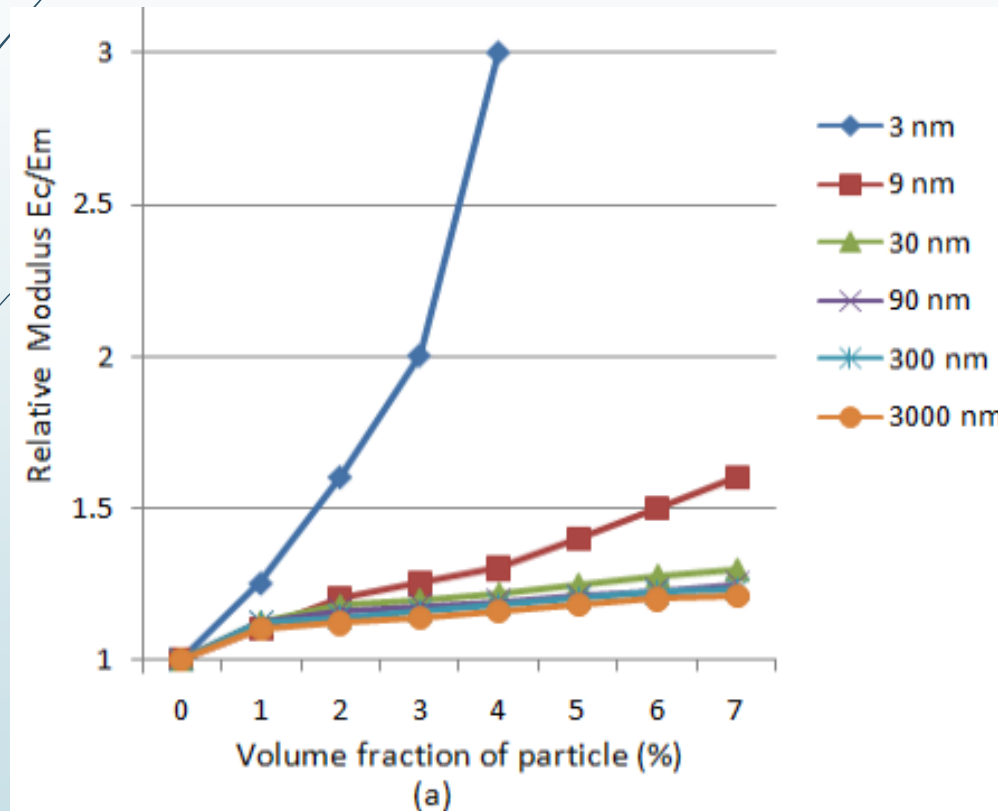


(Source: Otto Bock Health Care)



(Source: Navy Recognition)

# Potential of Nanocomposites



Modulus vs particle size in nano-scale: (a) nylon6/montmorillonite, (b) Polysiloxane/SiO<sub>2</sub>

# Why dry machining

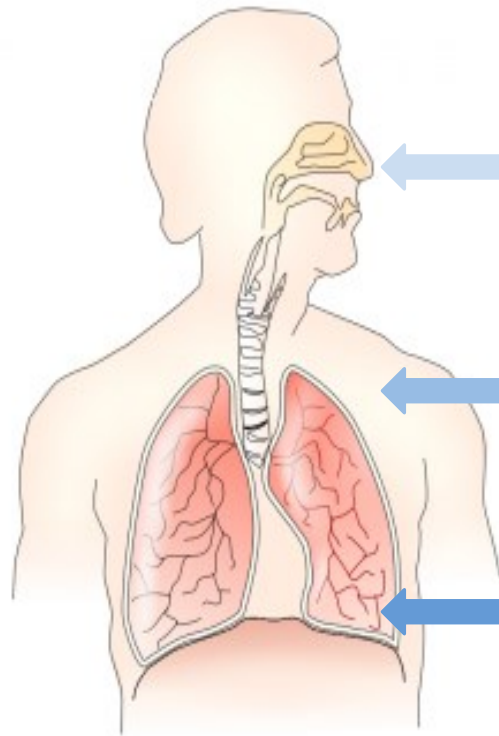
- ▶ The use of cutting fluids can:
  - ▶ have a high adverse impact on human health and ecosystem
  - ▶ have an expensive disposal & waste management costs (low rate of biodegradability 20 -30%)
  - ▶ high consumption rate (EU alone consumes approximately 320,000 tonnes of CFs/year)
- ▶ There is a need for dry machining:
  - ▶ Machine tool capabilities
  - ▶ Potential chemical interaction between cutting fluid and workpiece



Compressed air/vapour/gas

# Dust Inhalation in the Workshop Environment

## Dust Inhalation in the Workshop Environment



**Inhalable dust ( $< 100 \mu\text{m}^*$ ):** fraction of a dust cloud that is inhaled into the nose and mouth

UK WEL for inhalable dust:  $10 \text{ mg/m}^3$  8-hr TWA  
IOM recommended WEL<sup>\*\*</sup>:  $5 \text{ mg/m}^3$  8-hr TWA

**Thoracic dust ( $< 10 \mu\text{m}^*$ ):** dust that penetrates beyond the head airways and enters the airways of the lungs

**Respirable dust ( $< 4 \mu\text{m}^*$ ):** dust that can penetrate deeply into the lungs beyond the gas exchange region

UK WEL for respirable dust:  $4 \text{ mg/m}^3$  8-hr TWA  
IOM recommended WEL<sup>\*\*</sup>:  $1 \text{ mg/m}^3$  8-hr TWA

\* BS EN 481:1993 Workplace Atmospheres.

\*\*Since 2011, the Institute for Occupational Medicine (IOM) has stated the current UK legal limits for inhalable and respirable dusts are too high to protect worker health. The IOM recommendations can be taken as best practice.

# Nanocomposite Safety

- ▶ Throughout their lifecycle nanocomposites will undergo machining: safety concerns relate to the **rate and volume of nanomaterial** release from the matrix
- ▶ Research into nanomaterial safety has expanded alongside their use in research and industry but few studies focus on the **release of nanomaterials from nanocomposites**
- ▶ Lack of studies into nanomaterial release from nanocomposites makes rigorous risk assessment and management of occupational exposure impossible
- ▶ Available studies do show release of nanomaterials from the composite matrix during a variety of machining activities

# Occupational Exposure to Nanomaterials: Safety Limits

- ▶ There are no specific exposure limits for nanomaterials
- ▶ UK WELs found on Safety Data Sheets for nanomaterials are either:
  - ▶ Those listed for inhalable and respirable dusts: **10 mg/m<sup>3</sup> 8-hr TWA and 4 mg/m<sup>3</sup> 8-hr TWA** respectively
  - ▶ Those listed for the **parent material** e.g. halloysite nanoclay: **2 mg/m<sup>3</sup> 8-hr TWA**, graphene: **2 mg/m<sup>3</sup> 8-hr TWA**

## Research Aims

- ▶ quantitatively assess the particulates released when machining nano structured composites.
- ▶ study the effect of distance and operating conditions on particulate distribution.



# Experimental work

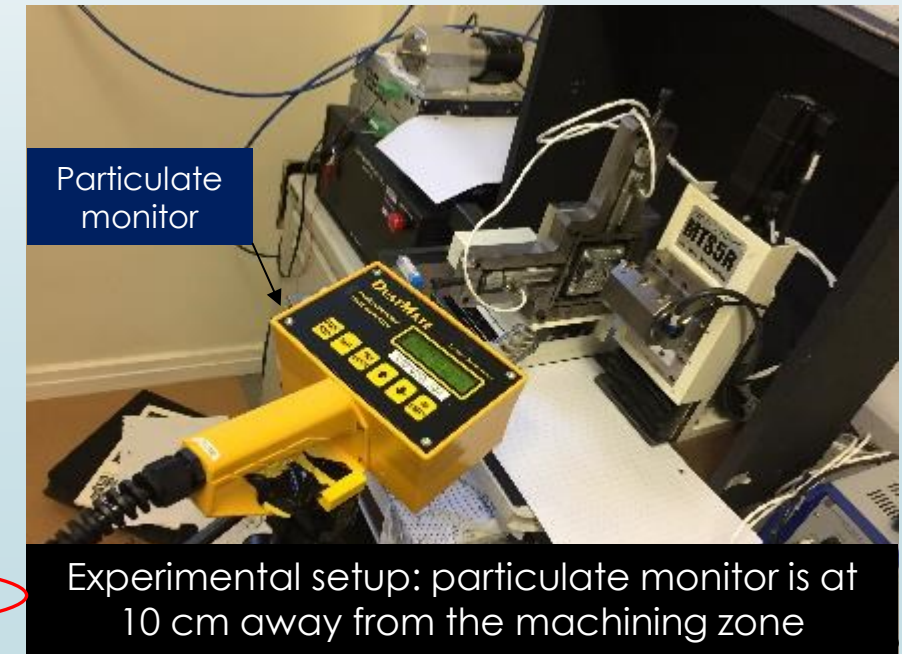
- Two 0.5% filler nanocomposite materials (graphene/epoxy & halloysite nanoclay/polyester) were micro slotted.
- Using 1 mm diameter carbide end mills under various cutting conditions.
- Machine tool: Nanowave MTS5R micro milling machine.

Variable/Level	1	2	3	4
Workpiece material	Graphene/epoxy	Nano-clay/polyester		
Cutting Speed (m/min)	31.4 (10,000 rpm)	94.2 (30,000 rpm)	157 (50,000 rpm)	
Feed rate ( $\mu\text{m}/\text{rev}$ )	5	15	25	
Depth of cut ( $\mu\text{m}$ )	50	100	150	
Location of Dustmate (cm)	10	30	50	100



Graphene/epoxy

Halloysite nanoclay/polyester

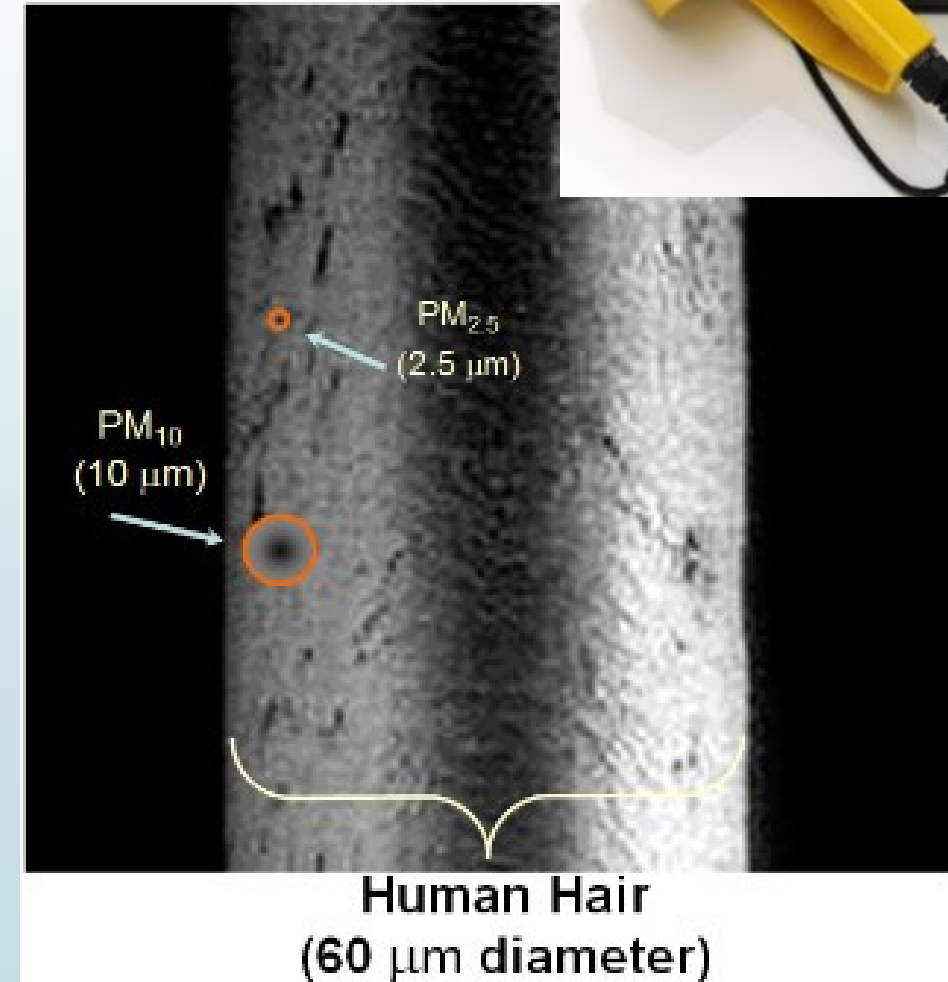


Particulate monitor

Experimental setup: particulate monitor is at 10 cm away from the machining zone

# Experimental Work

- ▶ A portable **particulate monitor** was used at different locations away from the machining zone (tool tip).
- ▶ Measured the released  $PM_{10}$ ,  $PM_{2.5}$ ,  $PM_1$  concentrations.
- ▶ Workplace Exposure Limit: UK EH40.
- ▶ One average concentration reading per second.

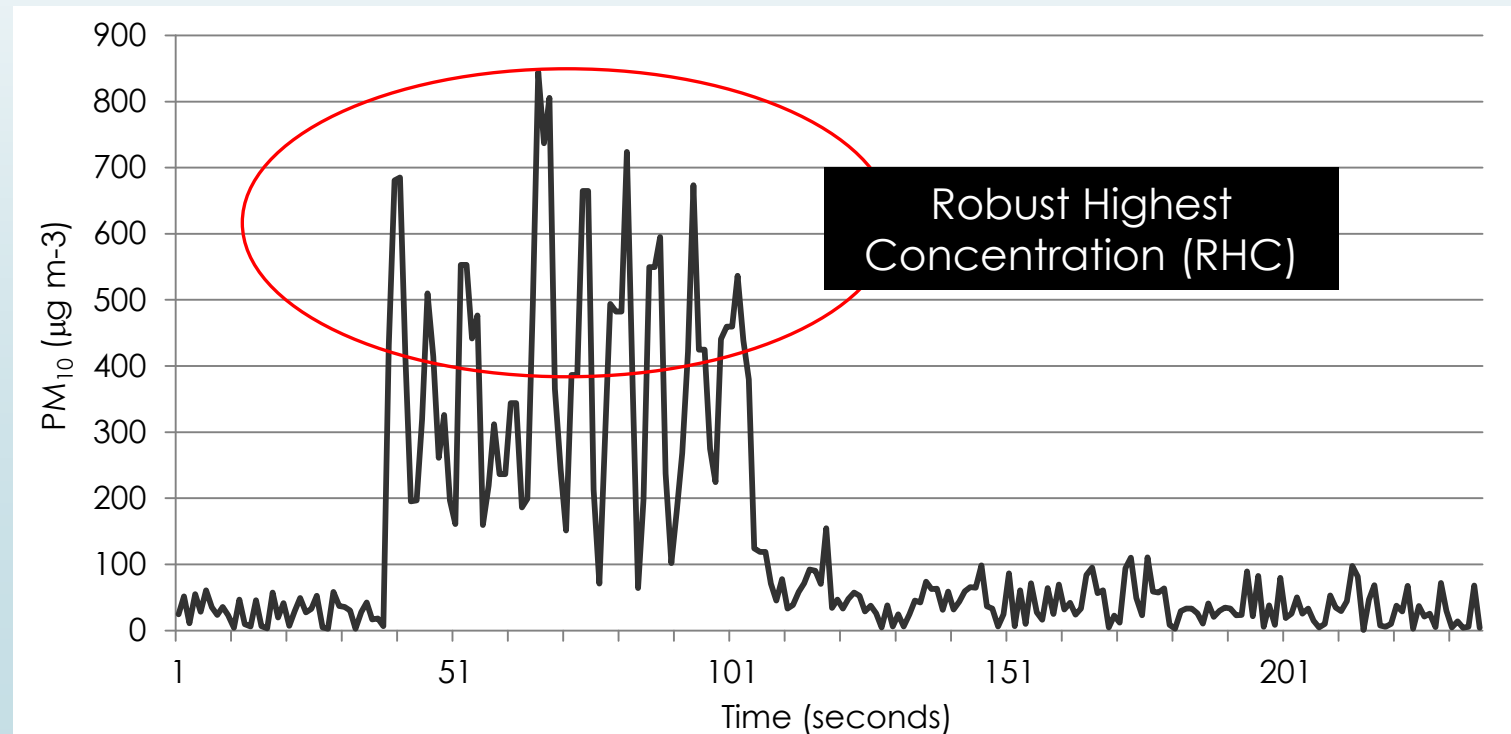


# Analysis of results

- ▶ Robust Highest Concentration (RHC) was calculated: this is a statistical parameter used in ambient air quality studies (worst case parameter).

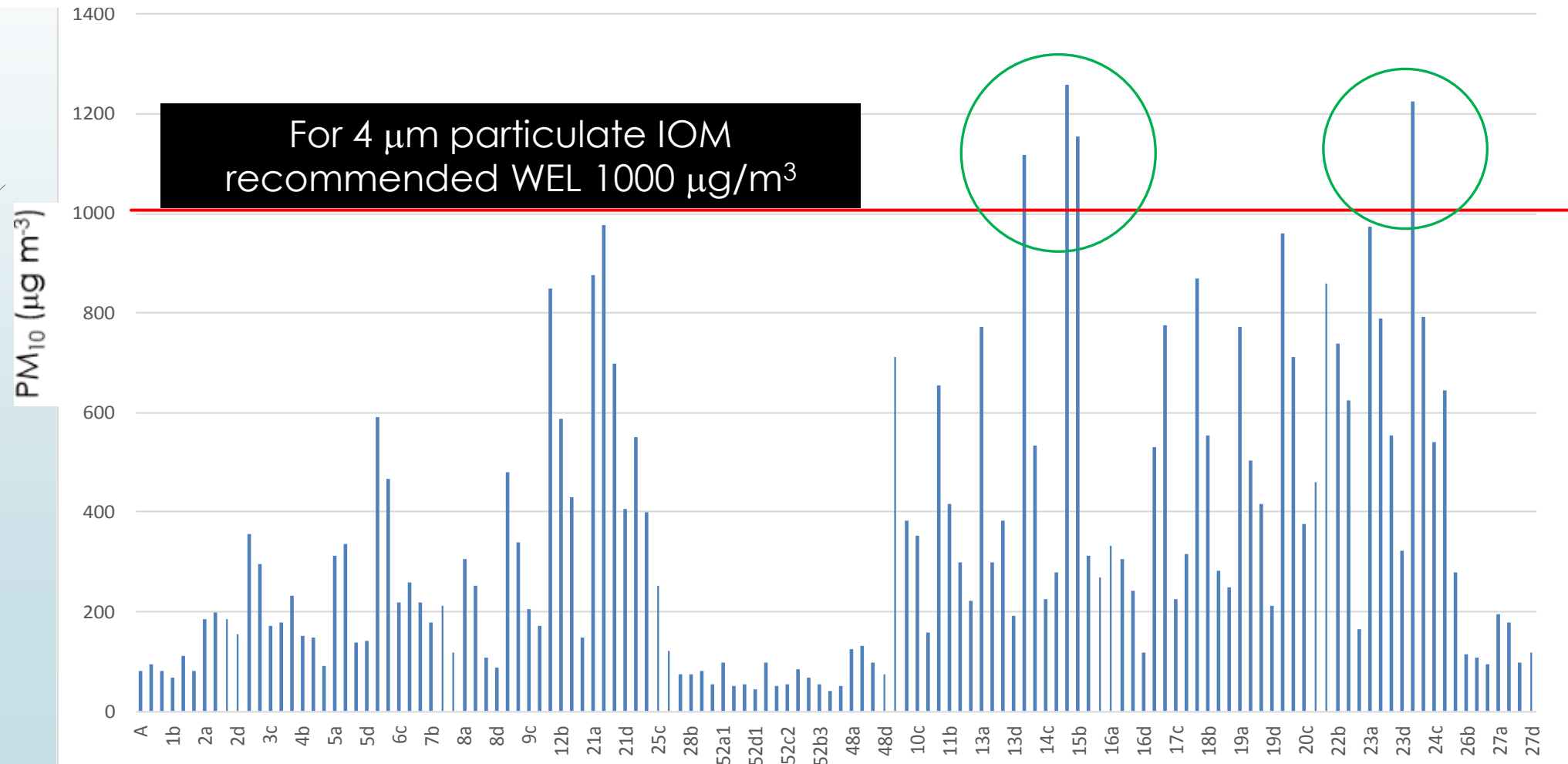
$$RHC = X_n + (\bar{X}_{n-1} - X_n) \ln\left(\frac{(3n-1)}{2}\right)$$

**Profile of PM<sub>10</sub> concentration:**  
graphene/epoxy, 94.2 m/min, 5  
μm/rev, 150 μm, 30 cm distance



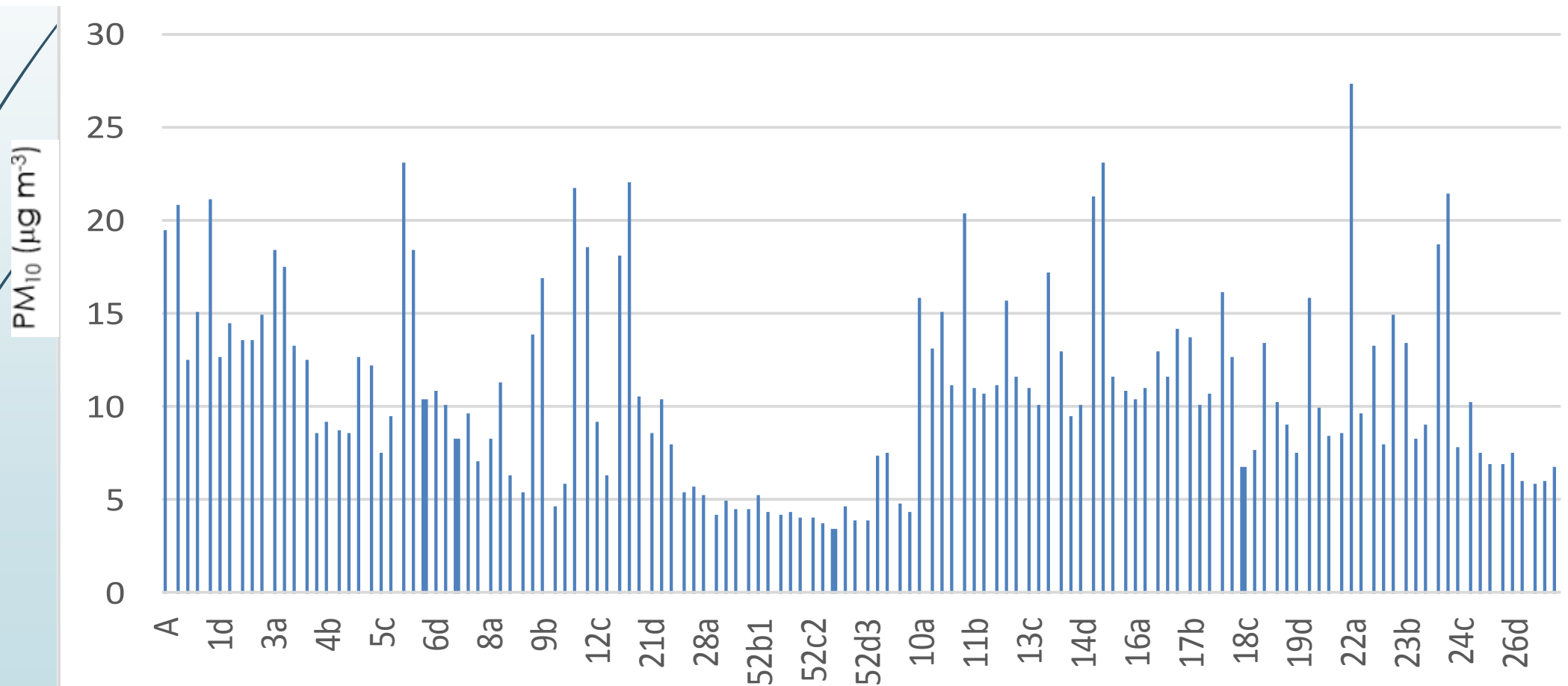
# RHC of $PM_{10}$ ( $\mu\text{g m}^{-3}$ )

UK EH40 WEL for respirable dust ( $<4\mu\text{m}$ ) is  $4,000 \mu\text{g m}^{-3}$ , well above all of the experimental conditions tested but few trials exceeded the IOM recommended limits.



# RHC of $PM_{2.5}$ ( $\mu\text{g m}^{-3}$ )

UK EH40 Workplace Exposure Limit (WEL) for respirable dust ( $<4\mu\text{m}$ ) is  $4,000 \mu\text{g m}^{-3}$ , clearly well above all of the experimental conditions tested

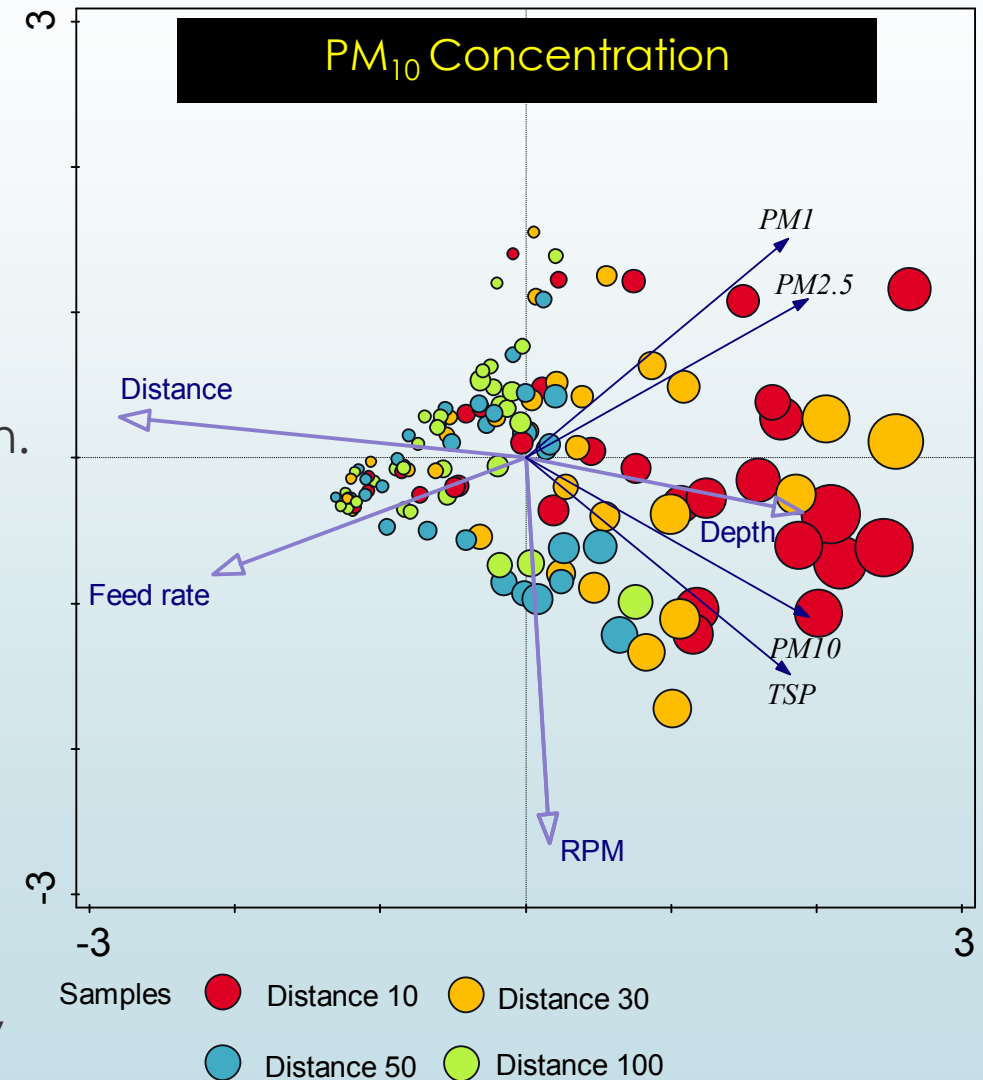


# Observations

- ▶ The key point with nanomaterials is the **applicability of the precautionary principle**.
- ▶ It doesn't mean coming in under the available WELs, it is ok to machine nanocomposites with no extraction.
- ▶ Therefore, this work draws attention to the need for **WELs for nanomaterials** and output from nanocomposites because current legal limits applied could really lull people into a false sense of security.

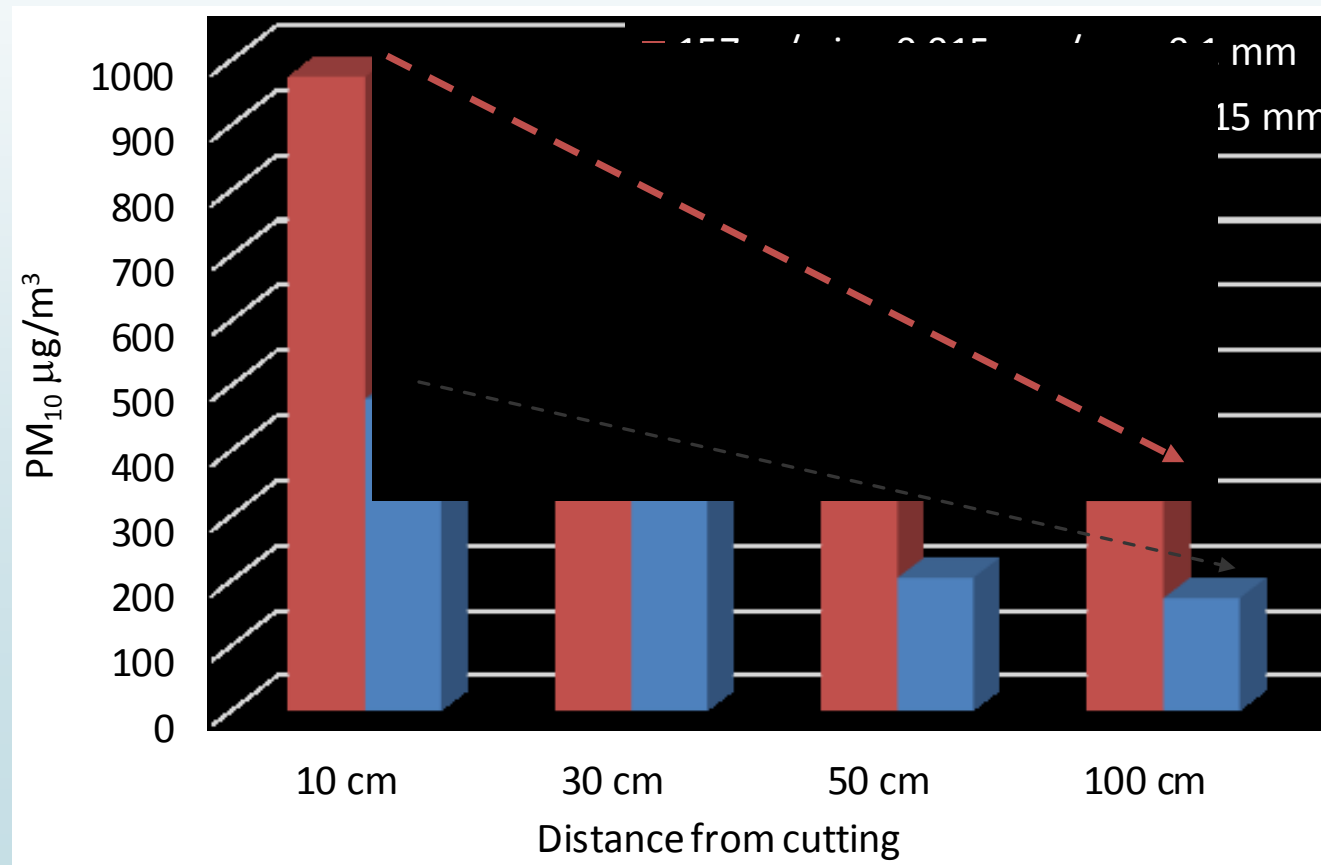
# Results: Principal Component Analysis (PCA)

- ▶ PCA used to determine the relationships between concentrations and the factors.
- ▶ Size of circle is proportional to  $PM_{10}$  concentration.
- ▶ Colours indicate distance categories.
- ▶ Closely aligned arrows indicate positive correlations (e.g.  $PM_{10}$  with depth of cut)
- ▶ Oppositely aligned arrows indicate negative correlation, e.g.  $PM_{10}$  and distance
- ▶  $PM_1$  and  $PM_{2.5}$  not closely aligned with  $PM_{10}$ , therefore not strongly correlated.
- ▶ Orange and red circles (closer distances), clearly associated with highest concentrations.



# Effect of distance on $PM_{10}$ concentration

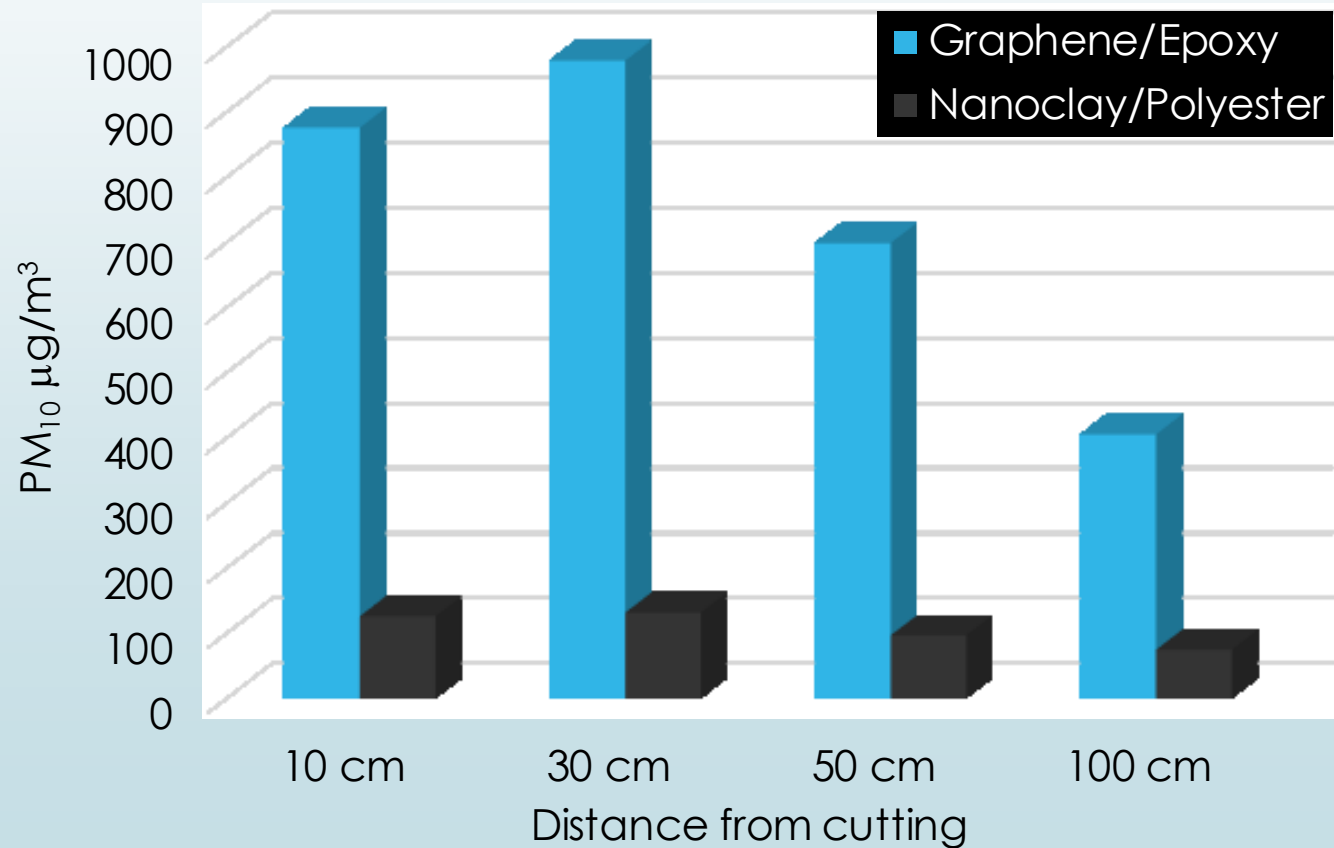
- ▶ Peak of particulates concentration at 10 cm away from the tool tip





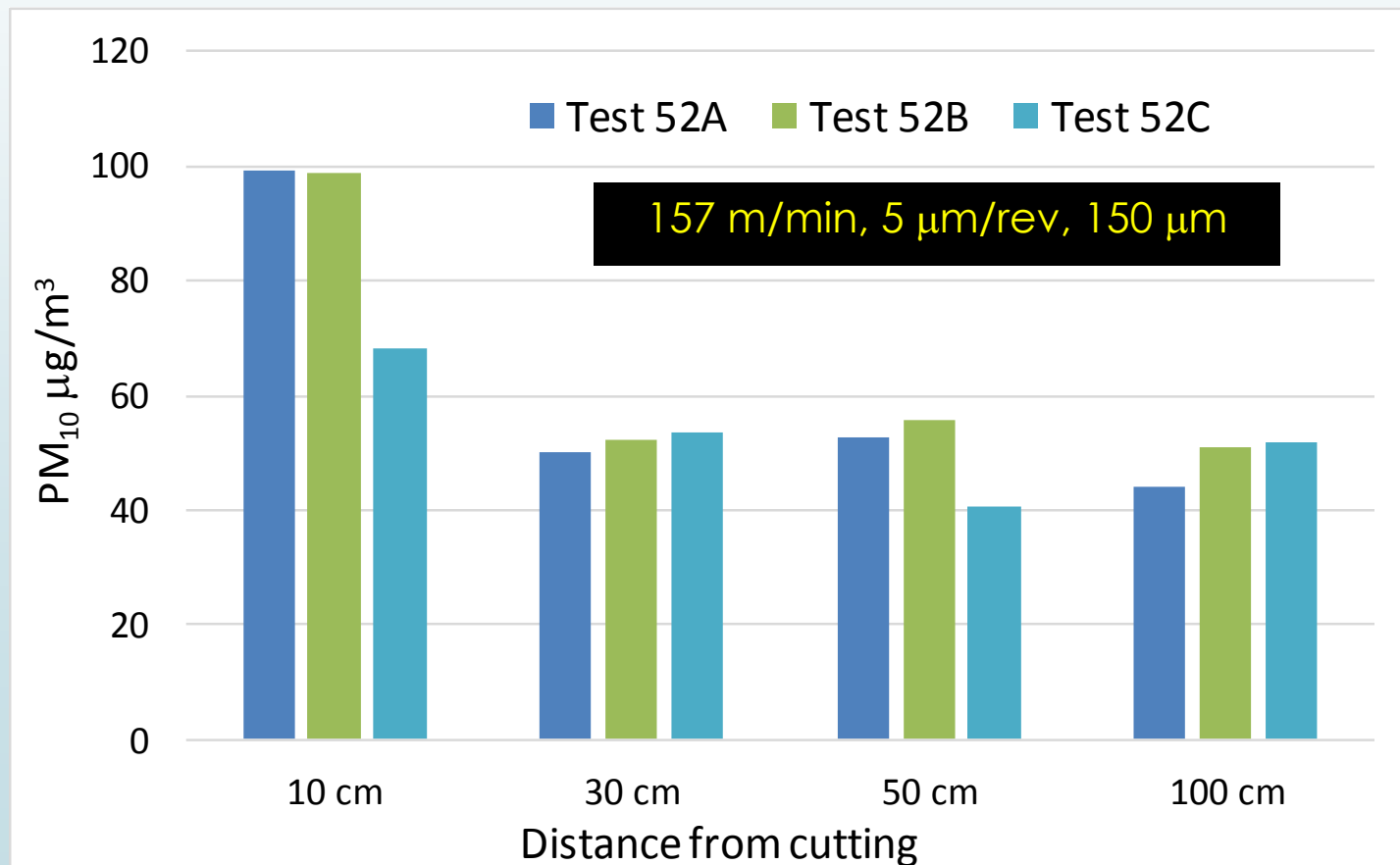
# Effect of material on $PM_{10}$ concentration

- ▶ Graphene/epoxy has in general higher concentration compared with clay/polyester



# Repeatability of tests

- High repeatability of measurement with a maximum error 1.5% of the IOM WEL (i.e.  $1000 \mu\text{g}/\text{m}^3$ )



## Conclusions and Future Work

- Within the operating conditions tested, released particulate concentrations are well below the recommendation WEL for respirable dust.
- If IOM recommended limits are considered ( $1 \text{ mg/m}^3$ ), few conditions are above such limits indicating the potential risk.
- In the range of 50 cm away from the cutting zone, particulate concentrations are below recommended limits.

## Conclusions and Future Work

- ▶ It is the PM10 fraction that is most closely associated with changes in cutting the parameters (i.e. compared to PM2.5 and PM1), suggesting that most dust produced is within this category (or higher, i.e. TSP).
- ▶ However, there is limited information on health hazards of nanoparticles ( $<0.1\mu\text{m}$ ) and so, even though our study suggests low concentrations of this size fraction are generated, these concentrations may still be associated with significant health effects. **Adequate precautions need to be taken.**
- ▶ **The further work** will focus on characterising the specific nano particles that are produced, especially by scanning electron microscopy.