Predictive Modeling of Near Dry Machining

IAB Presentation

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OUTLINE

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- PROPOSED RESEARCH PLAN
- ESTIMATED CUTTING FORCES AND CUTTING TEMPERATURES
- TOOL WEAR MODELING
- AEROSOL GENERATION MODELING
- RESULTS AND DISCUSSIONS
- CONCLUSION

INTRODUCTION

- Lubricating
- Cooling
- Chip flushing

Dry machining | **Near Dry machining** | **Wet machining**

- Health
- Environment
- Cost

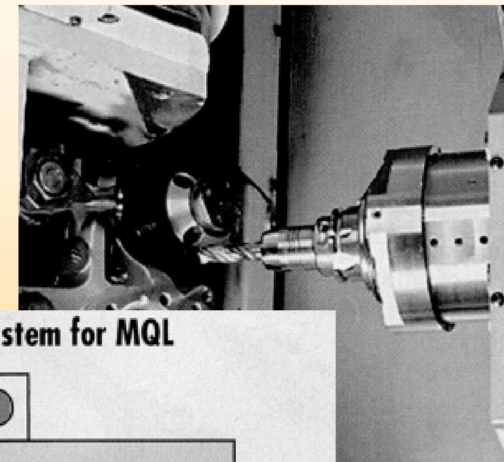
INTRODUCTION (Cont'd)

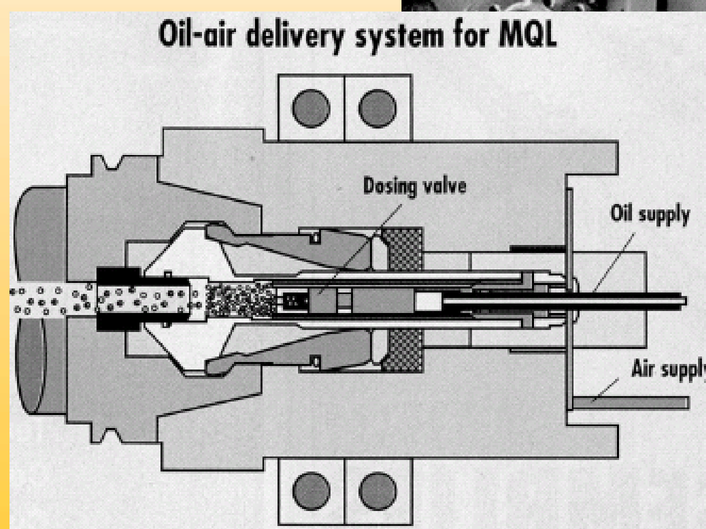
- Near dry machining
  - Use only a small amount of cutting fluids
  - Typically 100 ml/hr or less [Diniz *et. al.*, 2003]
  - Three to four orders of magnitude less than the amount used in flood cooling condition
- Near dry machining has better performances than dry machining and close to traditional flood cooling
  - Turning [Klocke *et. al.*, 1997]
  - Milling [Rahman *et. al.*, 2001]
  - Drilling [Braga *et. al.*, 2002]
  - Reaming [Weinert *et. al.*, 2005]
  - Taping [Weinert *et. al.*, 2005]

INTRODUCTION (Cont'd)

- Current applications in the industrial

Enterprise Automotive Services (EAS)





Cross Huller (Germany)

INTRODUCTION (Cont'd)

AMCOL

TATEKIT Engineering Co. LTD (Japan)

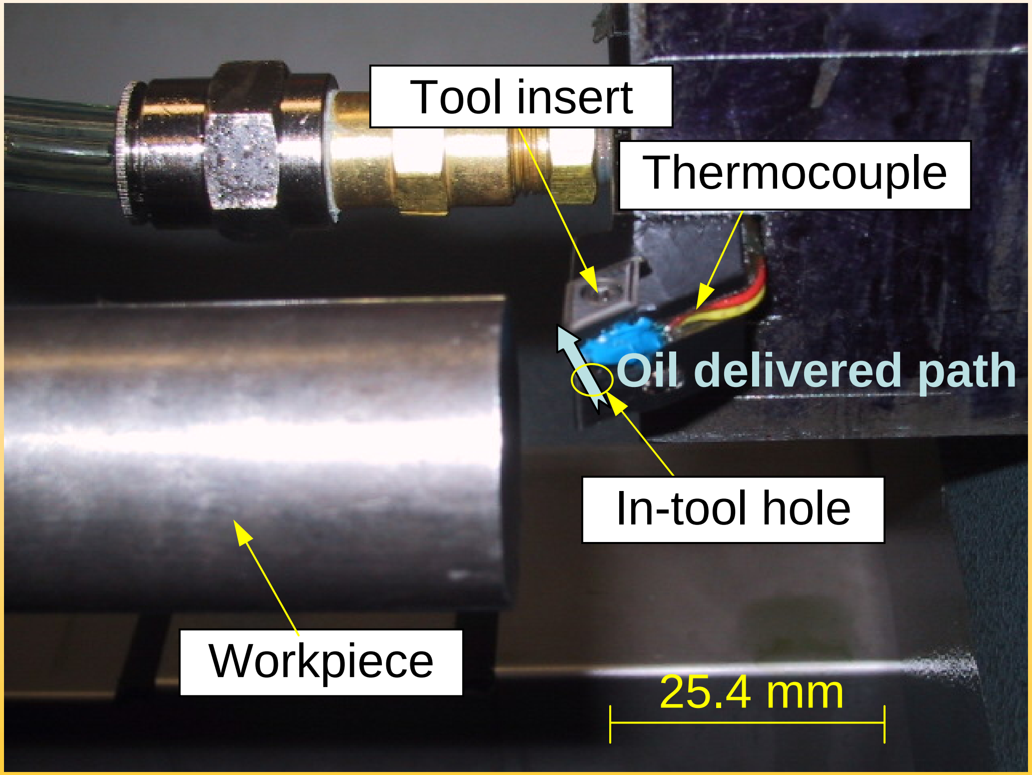
NACHI (Japan)

INTRODUCTION (Cont'd)

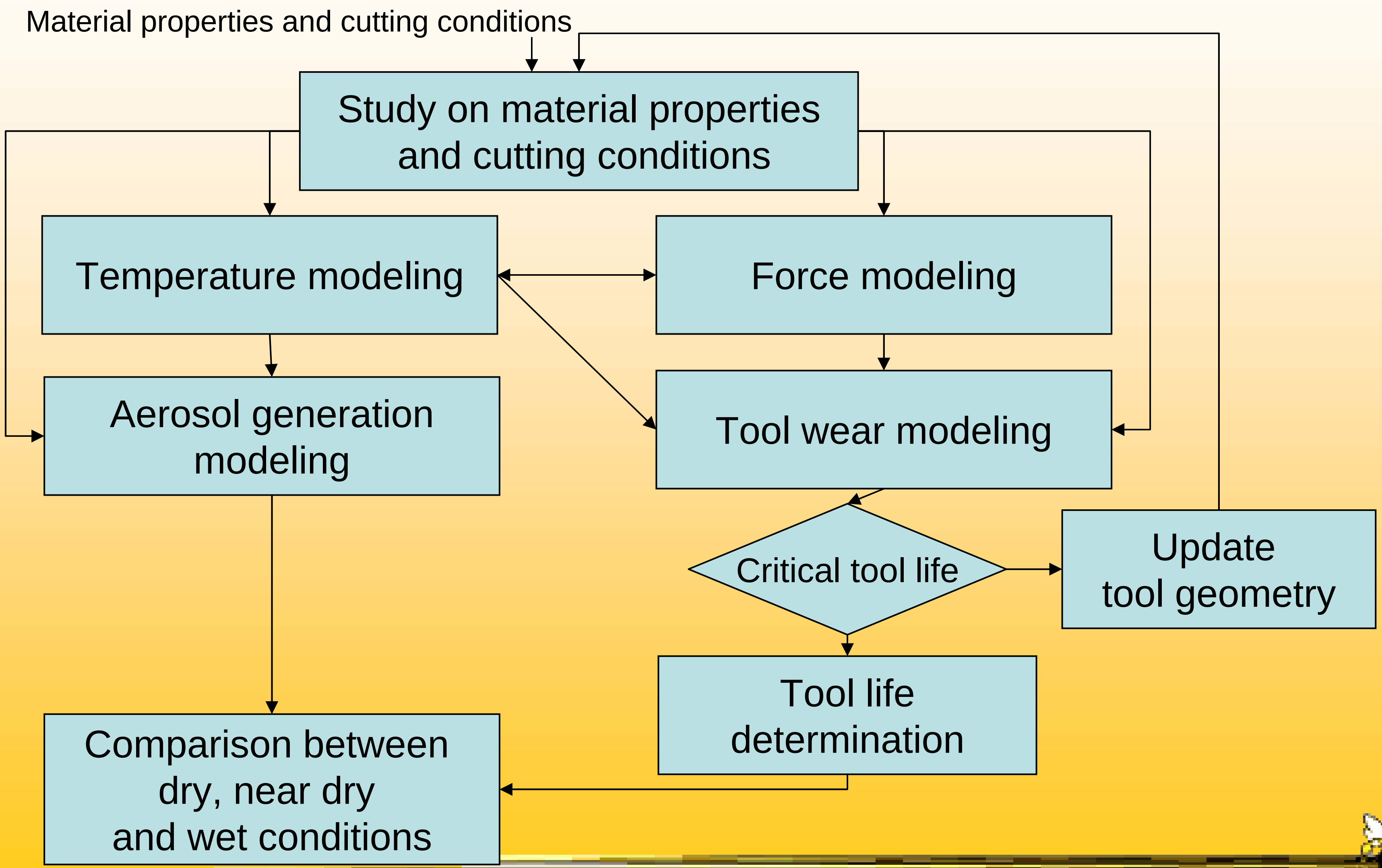
- Current researches are **ONLY** for **Experimental observations.**
- This research quantitatively investigates the ***tool performance*** and ***air quality*** for near dry turning with the in-tool hole configuration
- Including:
  - Temperature modeling
  - Force modeling
  - Tool wear modeling
  - Aerosol generation modeling

INTRODUCTION (Cont'd)

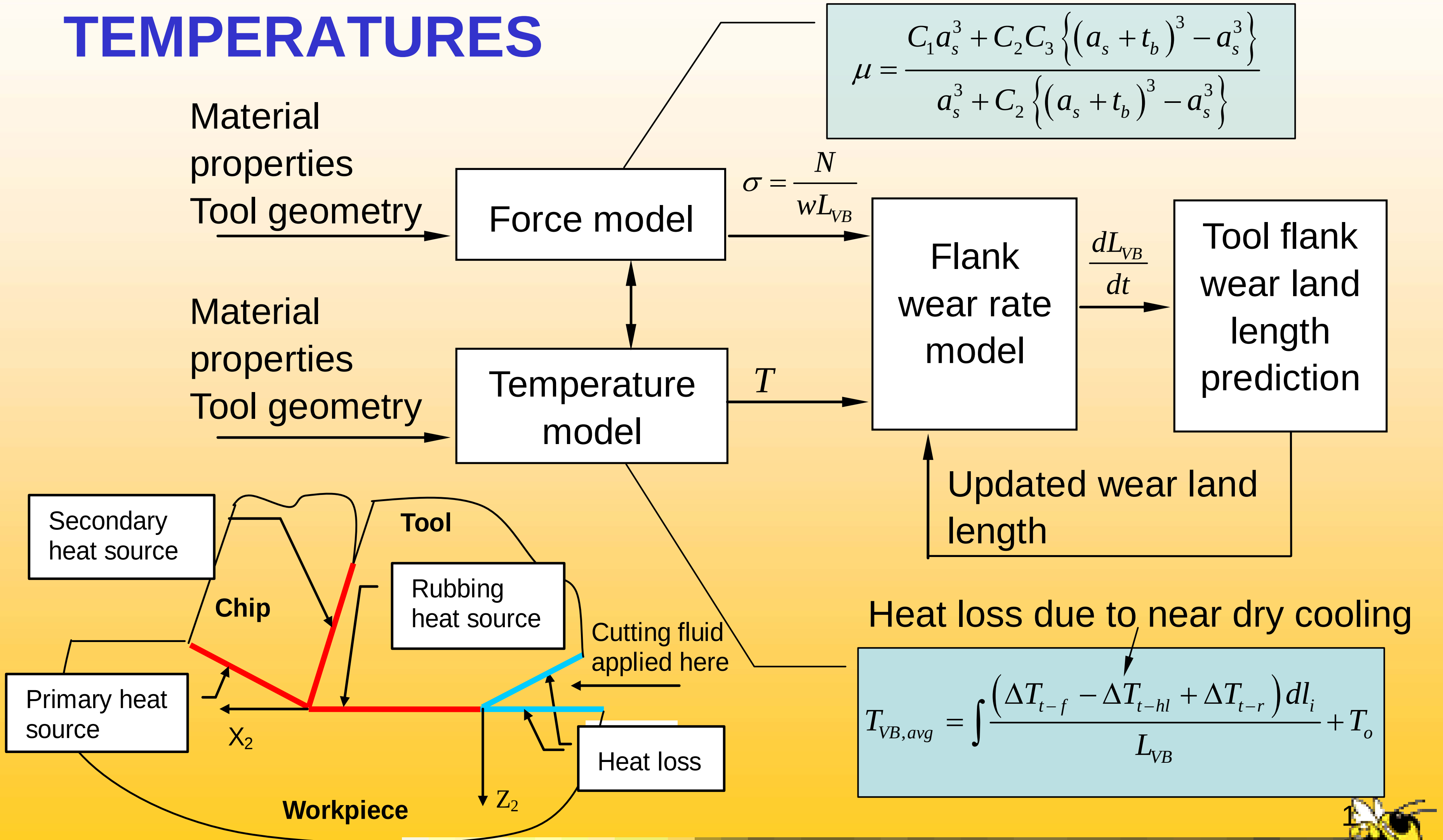
- In-tool hole configuration in this study



PROPOSED RESEARCH PLAN



ESTIMATED CUTTING FORCES AND CUTTING TEMPERATURES



$$\mu = \frac{C_1 a_s^3 + C_2 C_3 \left\{ \left(a_s + t_b \right)^3 - a_s^3 \right\}}{a_s^3 + C_2 \left\{ \left(a_s + t_b \right)^3 - a_s^3 \right\}}$$

$$\sigma = \frac{N}{w L_{VB}}$$

$$\frac{dL_{VB}}{dt}$$

$$T_{VB,avg} = \int \frac{\left(\Delta T_{t-f} - \Delta T_{t-hl} + \Delta T_{t-r} \right) dl_i}{L_{VB}} + T_o$$

TOOL WEAR MODELING

- Abrasive wear mechanism
  - Three-body abrasion: $V_{abration} = K_{abrasion} K \left(\frac{H_a^{n-1}}{H_t^n} \right) V_c w L_{VB} \sigma \Delta t$
  - Two-body abrasion: $V_{abration} = K_{abrasion} \frac{1}{H_t} V_c w L_{VB} \sigma \Delta t$
- Adhesive wear mechanism
  - $V_{adhesion} = K_{adhesion} e^{aT} V_c w \sigma \Delta t$
- Diffusive wear mechanism
  - Dominant at high temperature: $V_{diffusion} = K_{diffusion} \sqrt{V_c L_{VB}}\, e^{-\left(\frac{K_Q}{T+273}\right)}$

- Tool flank wear rate
  - Two-body abrasion

$$\frac{dL_{VB}}{dt} = \frac{\cot\gamma - \tan\alpha}{L_{VB}} \left\{ K_{abrasion} \left(\frac{1}{H_t} \right) V_c L_{VB} \sigma + K_{adhesion} e^{aT} V_c \sigma \right.$$

TOOL WEAR MODEL CALIBRATION

- Test cutting conditions

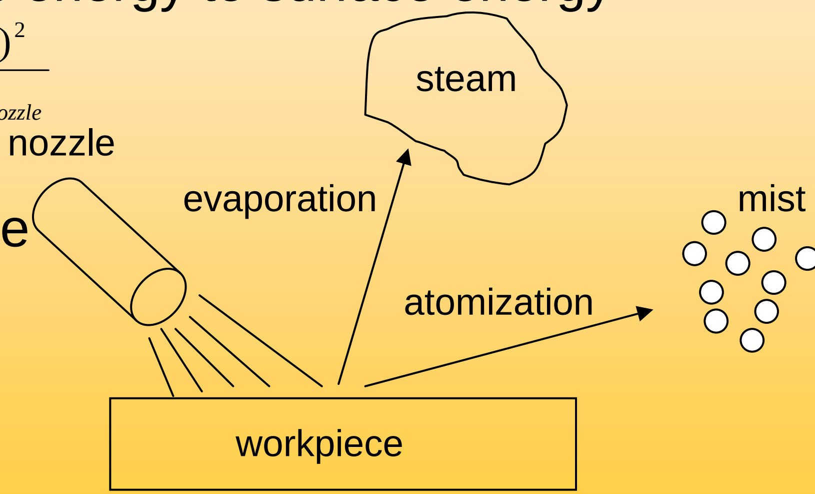
Test No.	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	45.75	0.0508	0.508
2	45.75	0.0762	1.016
3	45.75	0.1016	0.762
4	91.5	0.0508	1.016
5	91.5	0.0762	0.762
6	91.5	0.1016	0.508
7	137.25	0.0508	0.762
8	137.25	0.0762	0.508
9	137.25	0.1016	1.016

- Tool flank wear rate equation (two-body abrasion)

$$\frac{dL_{VB}}{dt} = \frac{\cot\gamma - \tan\alpha}{L_{VB}} \left\{ 3.697\times10^{-7} \left(\frac{1}{H_t}\right) V_c L_{VB} \sigma + 3.6761\times10^{-16} e^{7.456\times10^{-4}T} V_c \sigma + 1.29\times10^{5} \sqrt{V_c L_{VB}}\, e^{\frac{-20570}{T+273}} \right\}$$

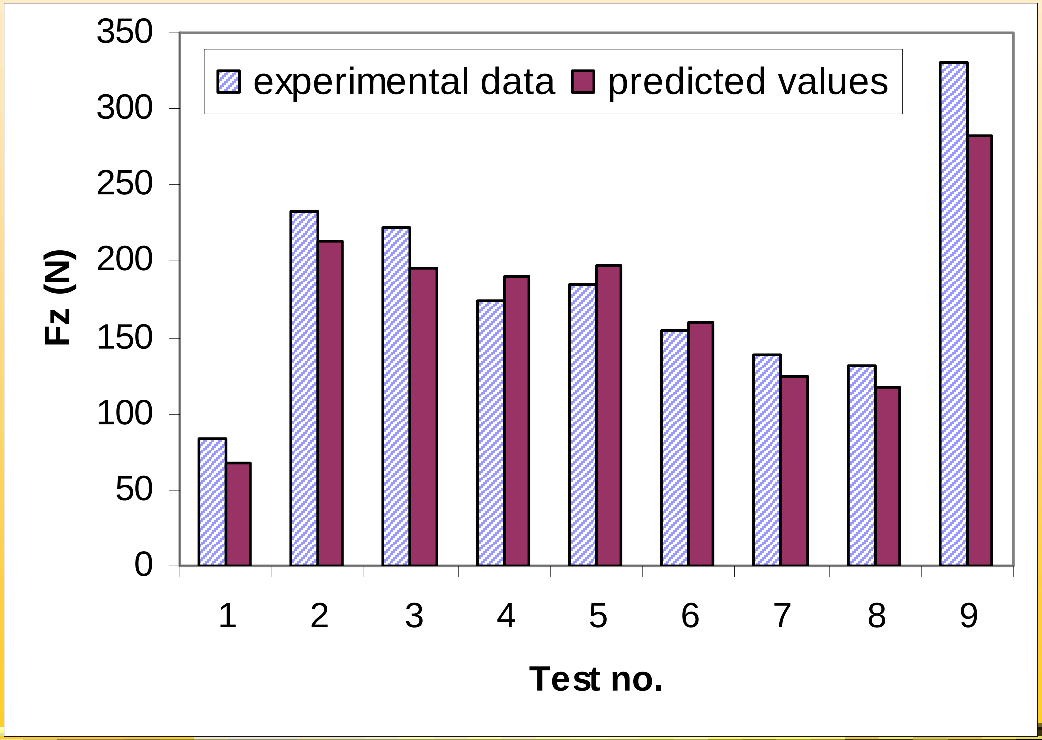
AEROSOL GENERATION MODEL

- Spin-off
  - Centrifugal force on the workpiece in rotational motion
  - Insignificant in near dry machining
- Runaway aerosol generation (overspray)
  - Energy transformation, from kinetic energy to surface energy
  - $TE = a + b(SMR) + C(SMR)^2 + d \times D_{32}$; $SMR = \frac{(\dot{m}_l)^2}{\rho_l A_{nozzle}}$
- Evaporation
  - High temperature at the cutting zone
  - $\eta_{evap} = k\Phi(D)\left(\frac{p_{tr}}{\sqrt{T_{tr}}} - \frac{p_{atm}}{\sqrt{T_v}}\right)$
- Aerosol dissipation
  - $D_{AB} \frac{1}{s^2} \frac{\partial}{\partial s}\left(s^2 \frac{\partial \eta}{\partial s}\right) = \frac{\partial \eta}{\partial t}$



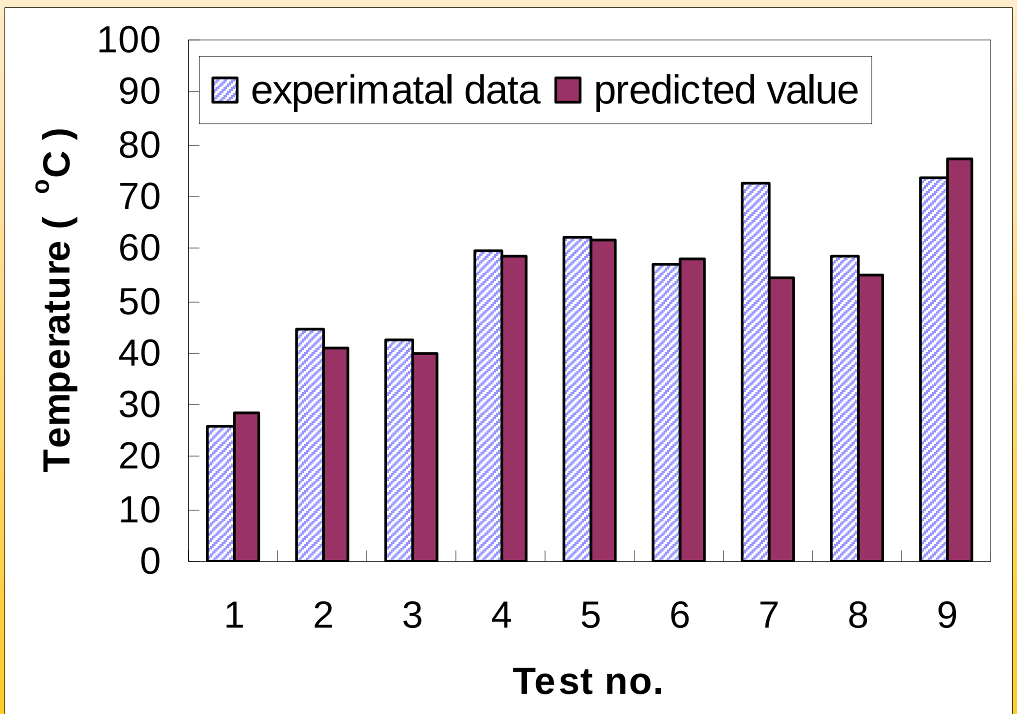
RESULTS AND DISCUSSIONS

- Model-experiment comparison for cutting force in near dry turning
  - ➢ Force comparisons for the cutting velocity direction for sharp tools



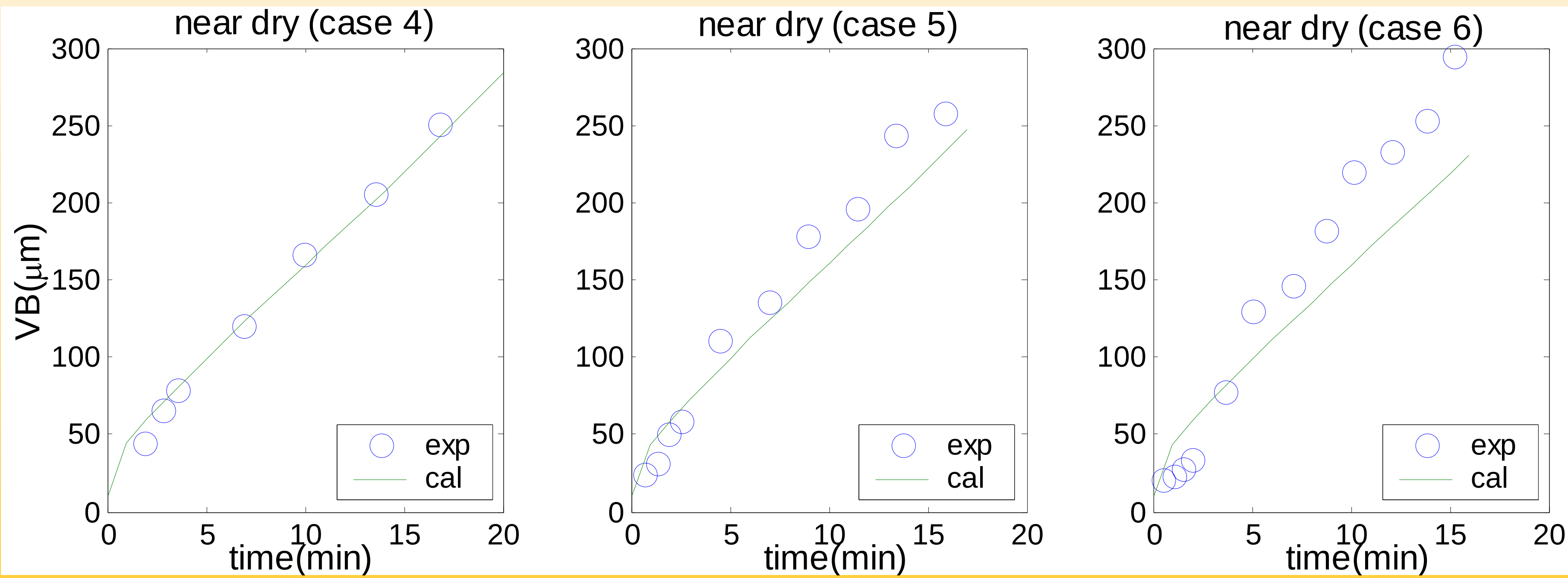
RESULTS AND DISCUSSIONS (Cont'd)

- Model-experiment comparison for cutting temperature in near dry turning
  - Temperature comparison between predicted values and measured values at thermocouple location for sharp tool



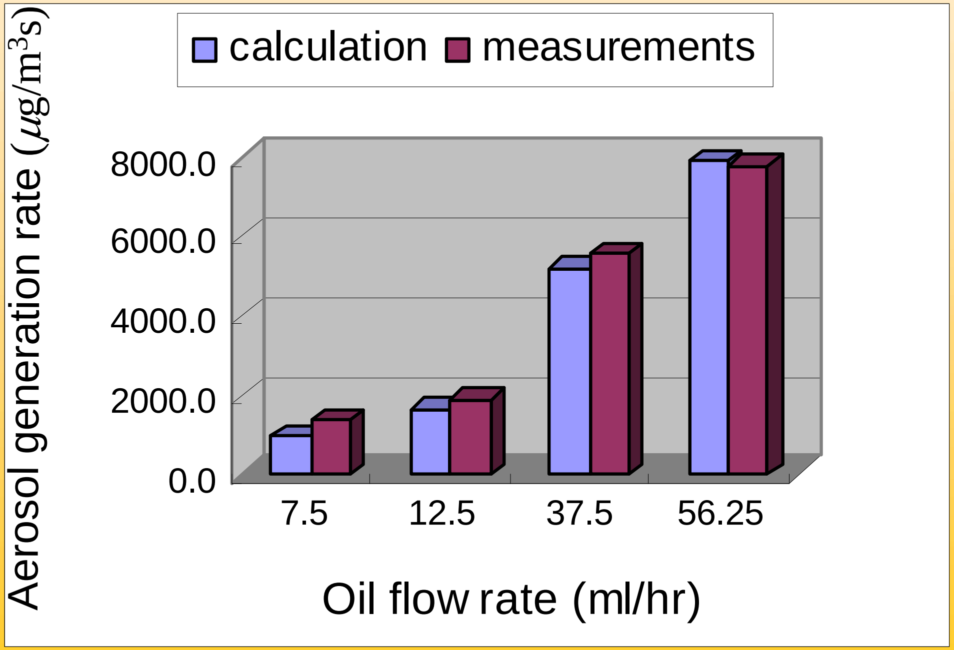
RESULTS AND DISCUSSIONS

- Tool flank wear: Case 4 ~ 6 (V = 91.5 *m/min*)
  - Good agreement with experimental data



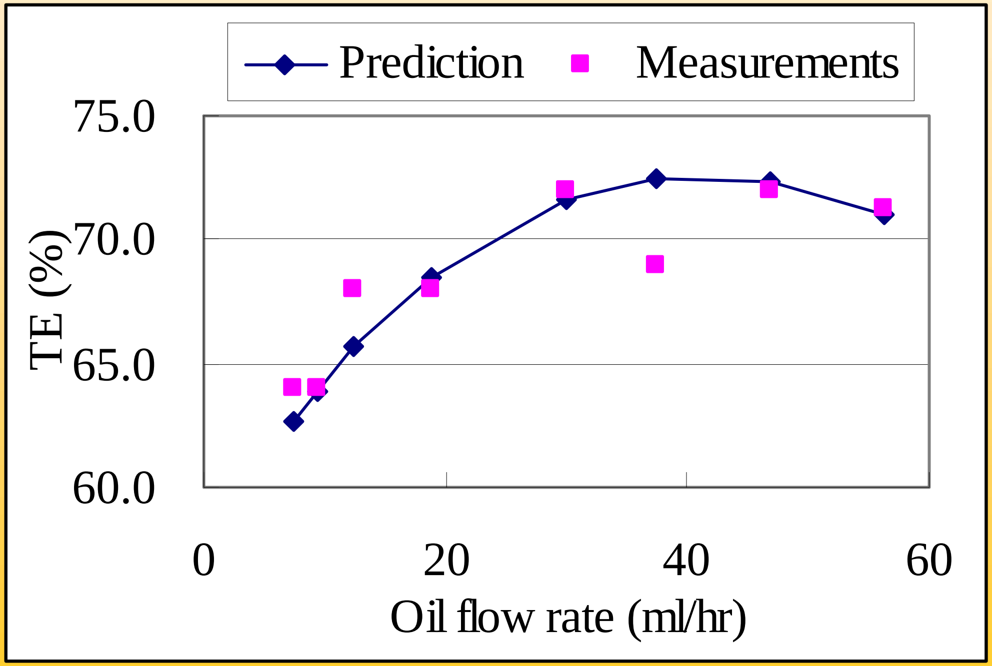
RESULTS AND DISCUSSIONS (Cont'd)

- Cutting velocity = 61 m/min, feed rate = 0.0762 mm/rev, depth of cut = 0.508 mm
- Oil flow rate is the major factor for aerosol generation rate



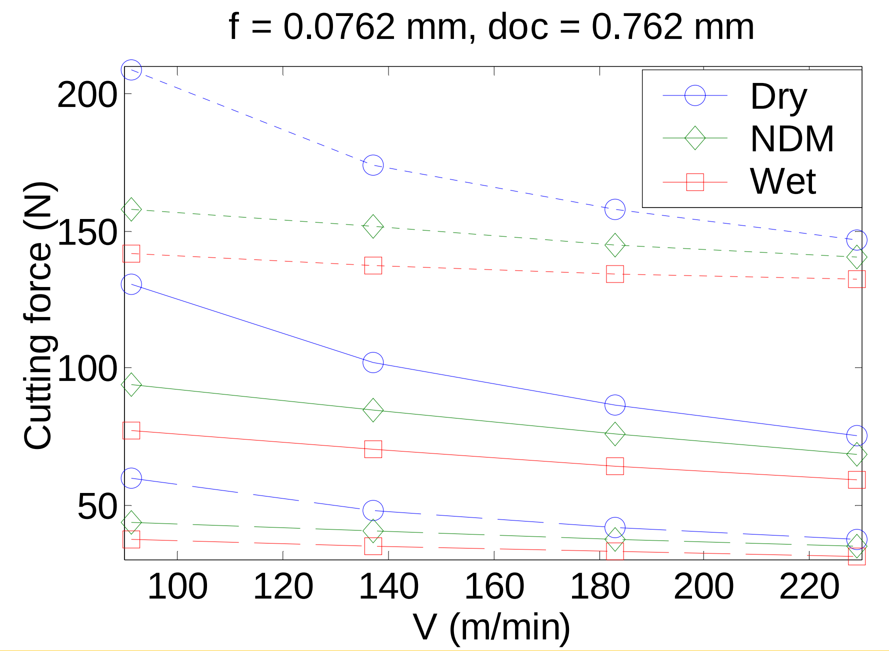
RESULTS AND DISCUSSIONS (Cont'd)

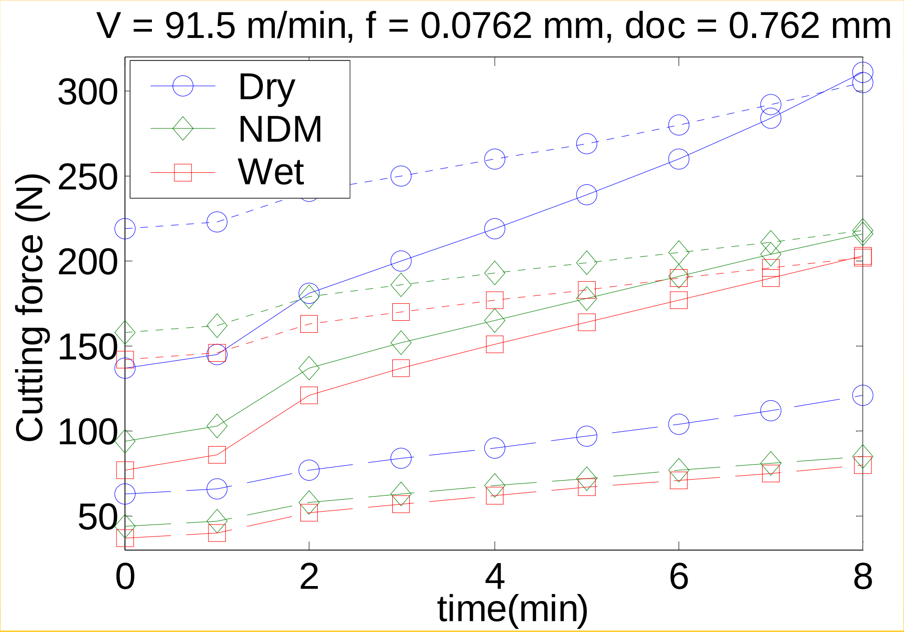
- Predicted transfer efficiency for different oil flow rate
- TE has a maximum value around 40 ml/hr oil flow rate
- The variation of TE is small compared with that of oil flow rate



RESULTS AND DISCUSSIONS (Cont'd)

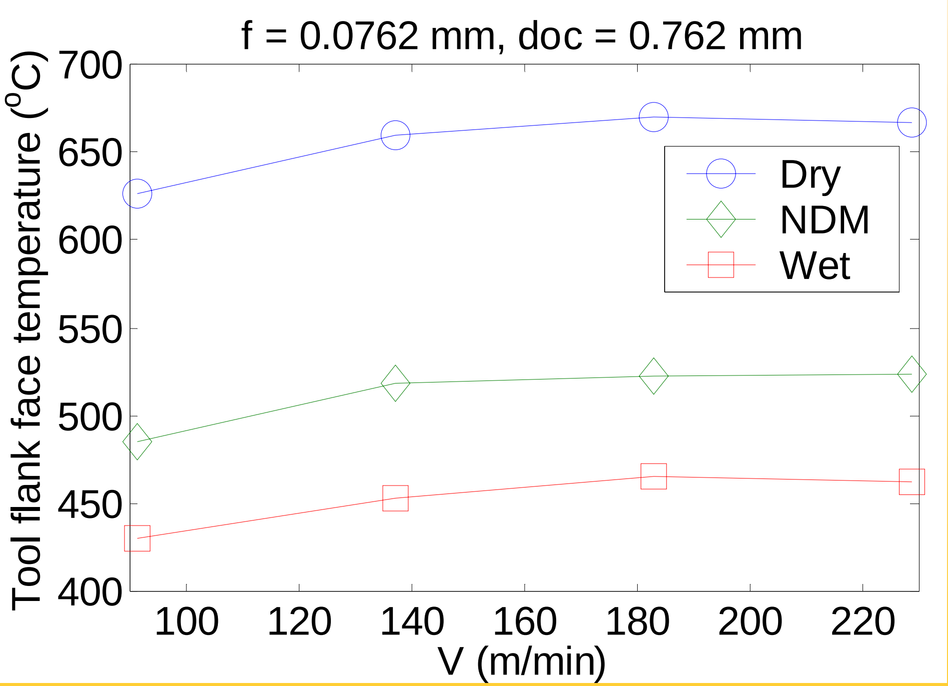
- Predicted cutting forces
- Dry > NDM > Wet
- The difference becomes small when cutting velocity increases

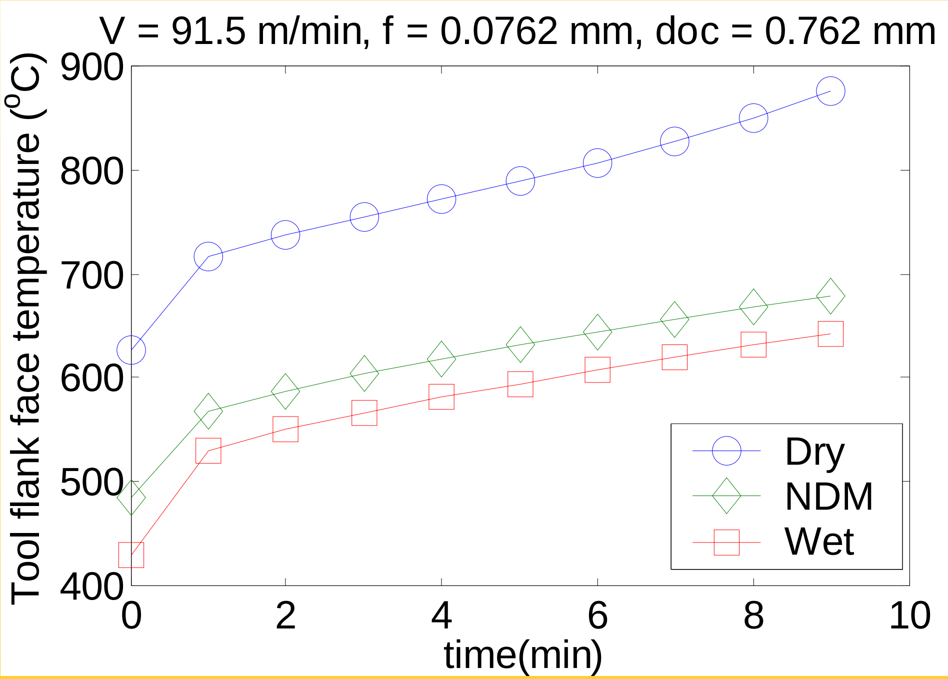




RESULTS AND DISCUSSIONS (Cont'd)

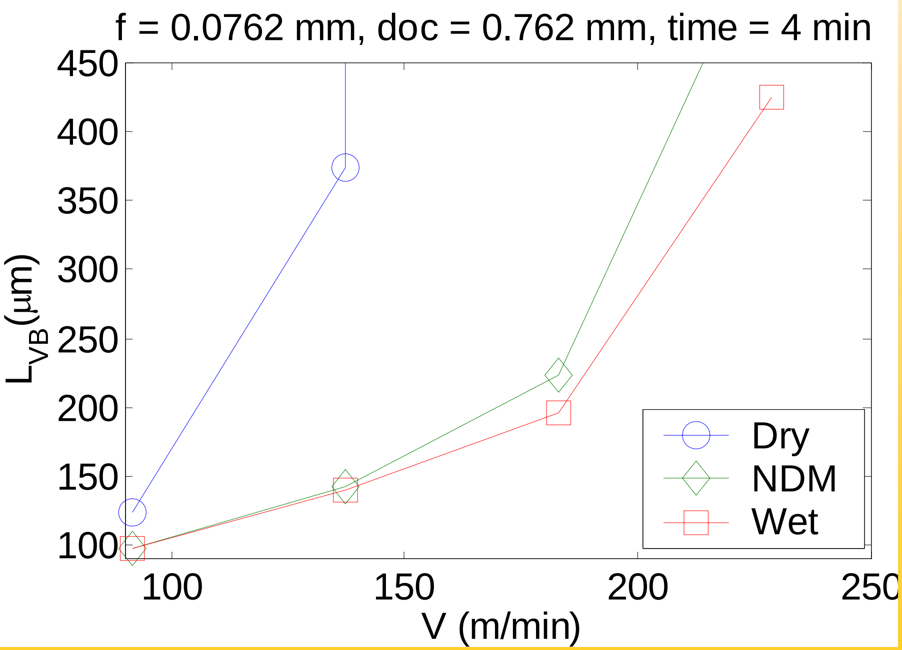
- Predicted tool flank face temperatures
- Dry > NDM > Wet
- NDM close to Wet

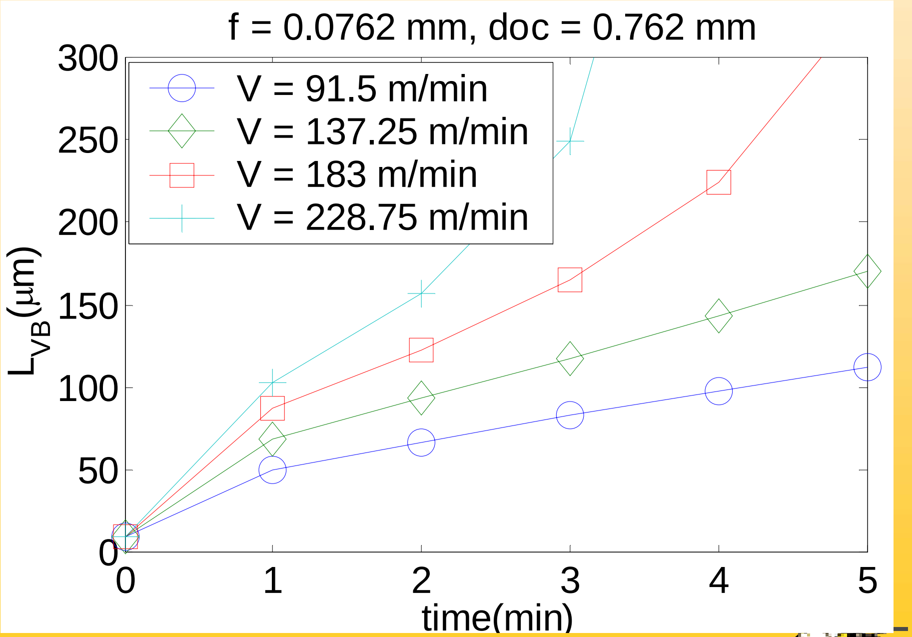




RESULTS AND DISCUSSIONS (Cont'd)

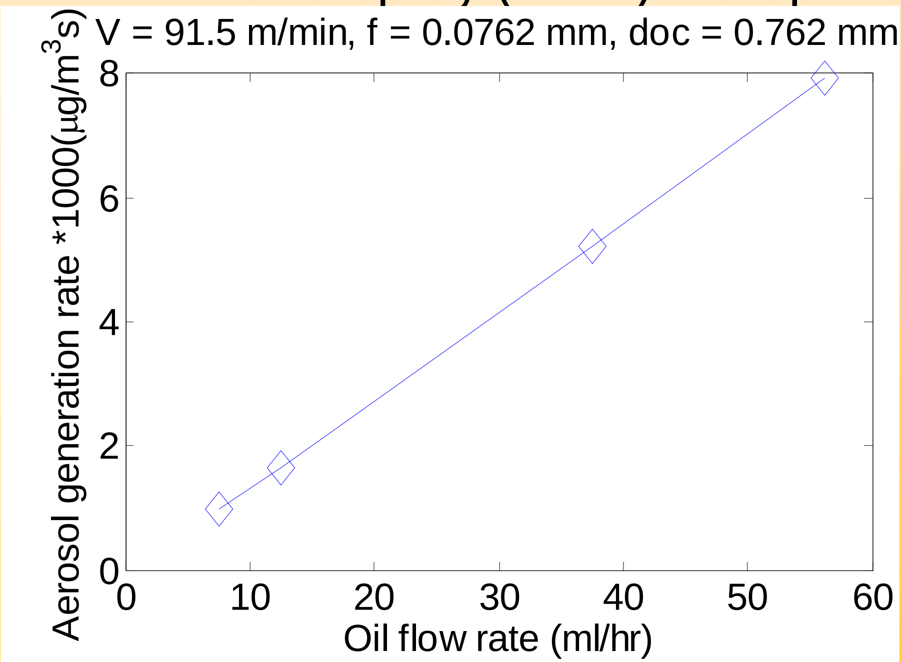
- Predicted tool flank wear
- Dry > NDM > Wet
- NDM close to Wet
- Significant differences for high cutting velocity

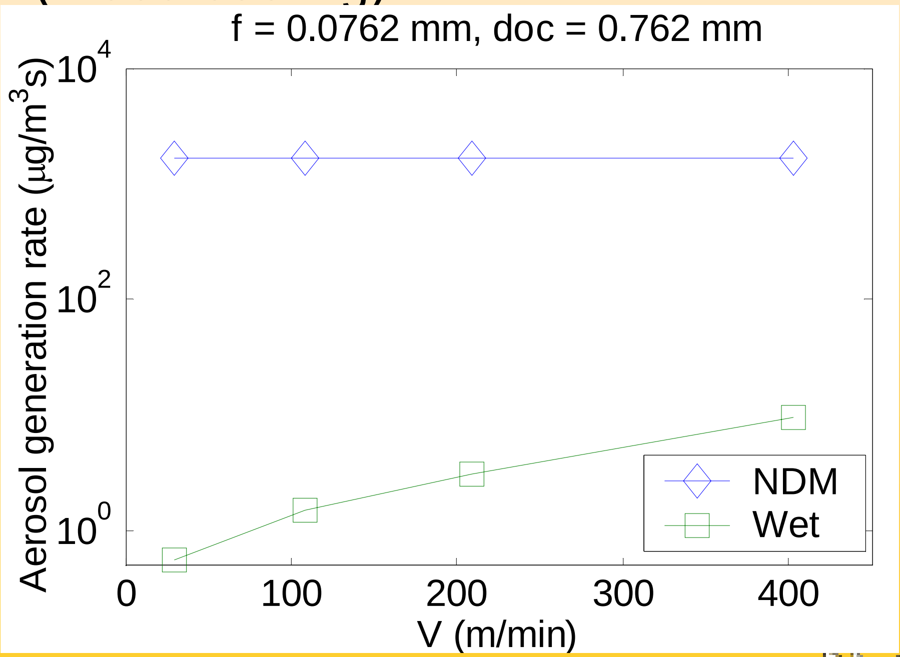




RESULTS AND DISCUSSIONS (Cont'd)

- Aerosol generation
- Much higher aerosol generation rate under NDM
- Major aerosol generation mechanism
  - Overspray (NDM) VS Spin-off (Flood cooling)





CONCLUSION

- Analytical models
  - Force, temperature, tool wear and aerosol generation models
- No measured data were required for predicting the tool wear rate
- Consider both lubricating and cooling
- Different major aerosol generation mechanism for NDM and wet cutting
- Future researches: apply the developed models for different tool/work materials and machining processes

Thank you. Any questions?