

# Gun-drilling with Modulation-Assisted Machining

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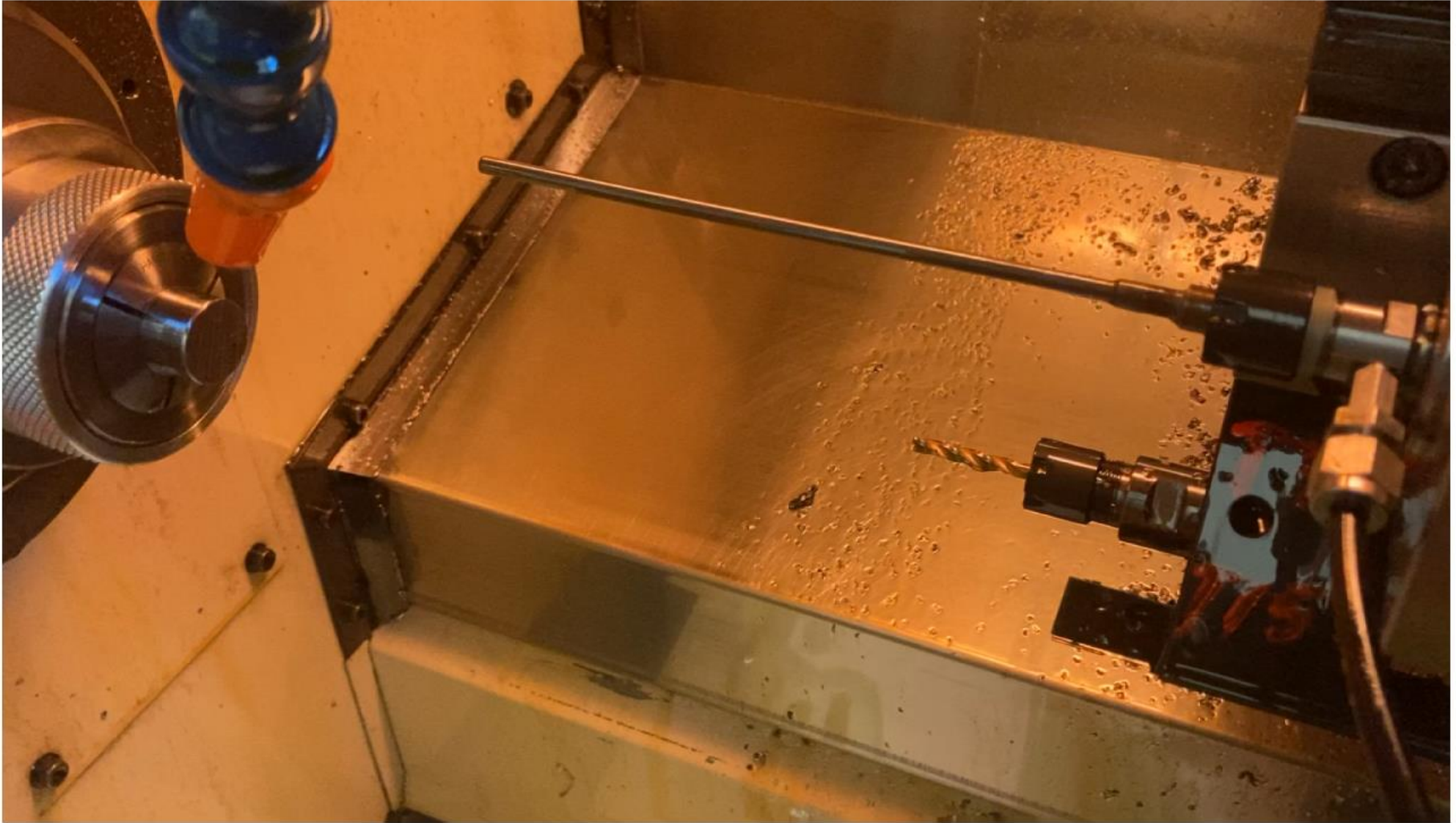
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# Modulation-Assisted Machining (MAM)

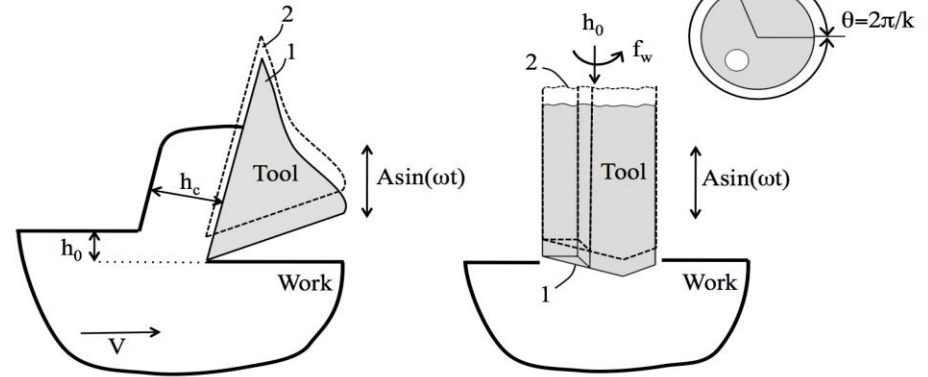
- ▶ Application of controlled oscillation during machining
  - Low-frequency ( $\sim < 1000\text{Hz}$ )
  - Disrupt severe contact conditions (reduced contact time)
  - Improve effectiveness of cutting fluids (reduces temperatures)
  - Discrete chip formation (chip evacuation)
  
- ▶ Effects of MAM on surface texture
  - Surfaces generated by geometric tool path
  - Opportunities for additional development
  - Commercial impact

# Gun-drilling with MAM

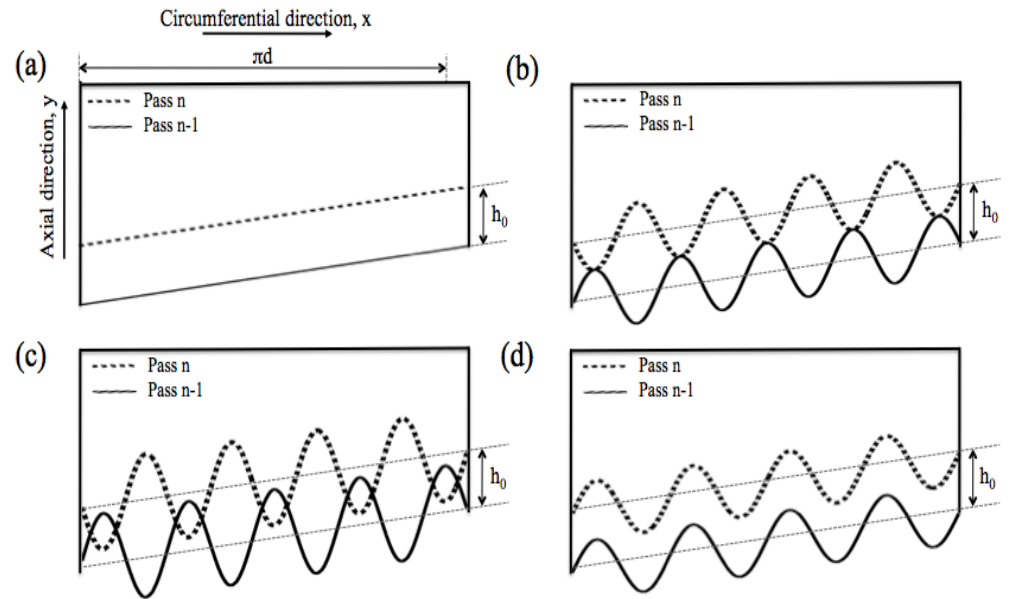


# MAM Kinematics

- ▶ Geometric tool paths
  - 2-D cutting and drilling models



*Critical conditions*  
 $f_m = k/2 * f_w * (2N+1)$ ,  $2A > h_0$

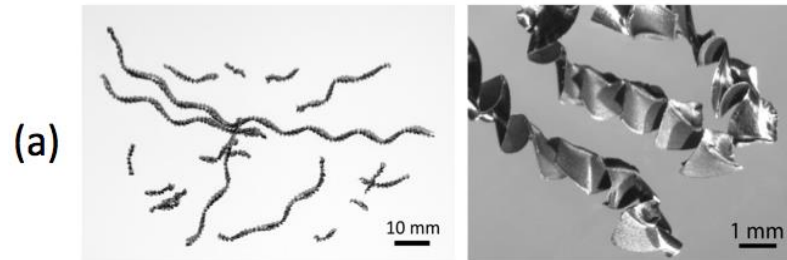


# Drilling with MAM

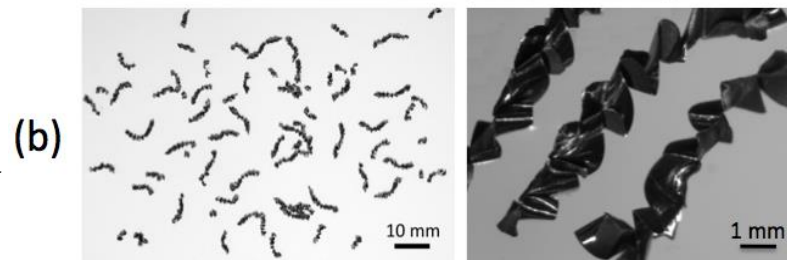
## ▶ Chip control

- Increased drilling productivity

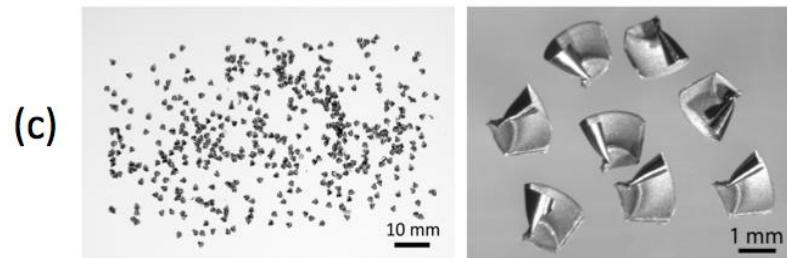
Conventional  
gun-drilling



Gun-drilling with  
MAM  
– incorrect frequency

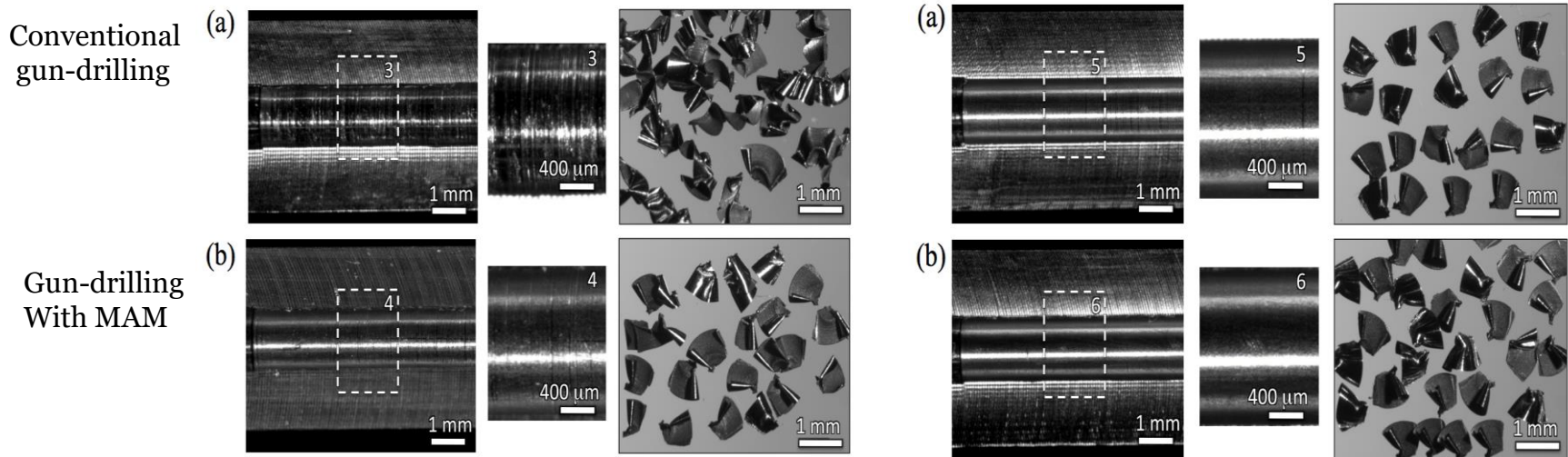


Gun-drilling with  
MAM  
– correct frequency



# MAM surface textures

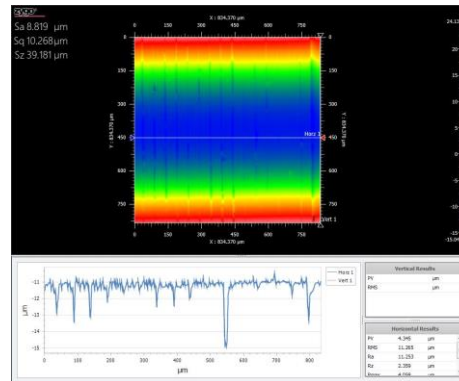
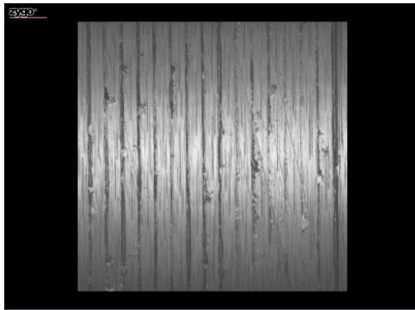
- ▶ Deep hole gun-drilling Ti alloys
  - Increased productivity (feedrate, tool life)
  - Reduction in surface finish
  - Commercial impact across orthopedic sector



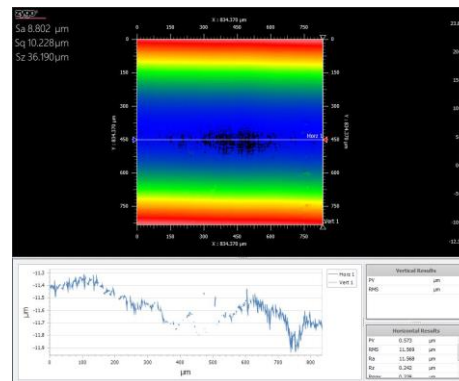
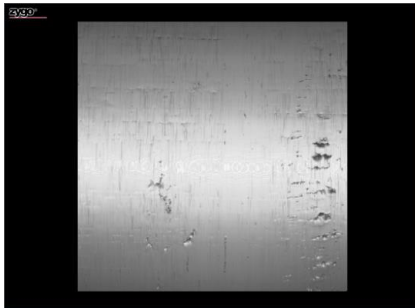
# MAM surface textures

- ▶ Deep hole gun-drilling in 4140
  - Improved surface finish
  - Characteristics observed in drilling of Ti6Al4V

Conventional  
gun-drilling



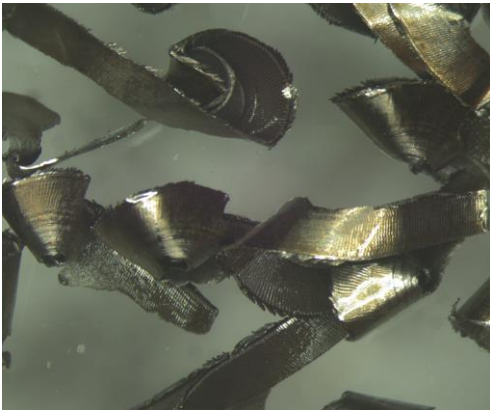
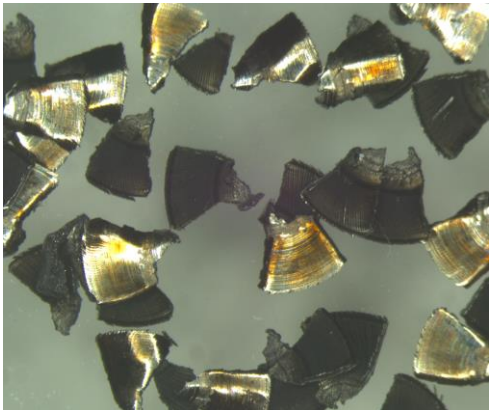
Gun-drilling  
With MAM



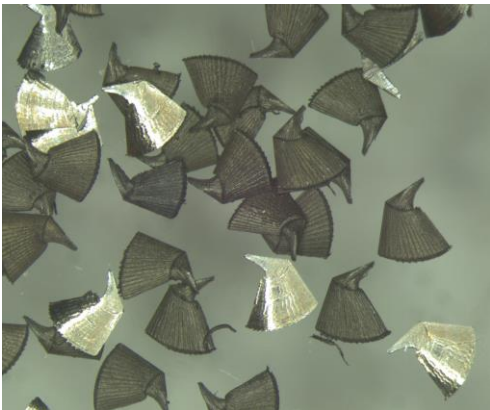
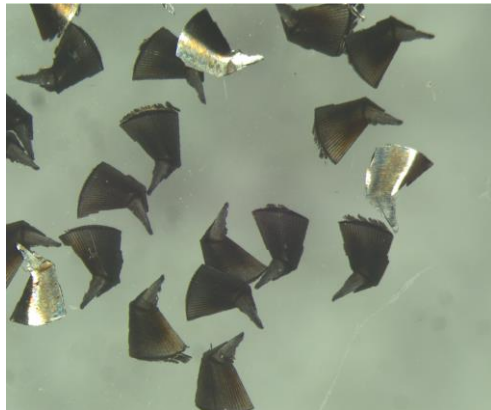
# MAM chip control

- ▶ Deep hole gun-drilling in 4140 and 304L

Conventional  
gun-drilling



Gun-drilling  
with MAM



4140 steel

304L steel





# Conclusions

- ▶ Gun-drilling with MAM
  - Improved productivity – ability to drill range of alloys
  - Improved quality (size control, surface finish)
  - Successful industrial application (>10 yrs, up to 500mm length)
  - Pathway to implementation of difficult to machine alloys
  
- ▶ Results demonstrate effectiveness of MAM
  - Significant opportunities in the gun-manufacturing industry
  - Future investigation of MAM on hardened steel alloys

# Acknowledgements

- NSF STTR program IIP- 0822879 (M4 Sciences)
- Crane Division, NSWC



# Thank you! Questions?

- ▶ Commercial TriboMAM systems
- ▶ [www.m4sciences.com](http://www.m4sciences.com)

**5x**  
faster cycles.

**2x**  
the tool life.

**DRILLING**  
has changed.

