Surface Roughness Effects on Manufacturing Thermal Imaging

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Introduction

Friction Stir Additive Manufacturing (FSAM) relies on thermal cameras to monitor temperature during machining and processing. Readings can allow for control systems, wear detection, and quality oversight.

However, metals are hard to measure, and aluminum reflects its surroundings like a mirror. Surface finish (roughness) strongly affects emissivity[5], but there is no quick way to determine whether a surface can be measured reliably.

Goal: To develop a software tool that links measured surface roughness to expected thermal-measurement accuracy for 6061 series aluminum.

Methodology

Surface Analysis
- Olympus LEXT OLS5000 confocal laser microscope
- One 6061 plate, two sections
  - As-received vs. wire-brushed

Parameters Measured
- Profile – Basic Line (R_a, R_z) [1]
- Areal – Advanced 3D map(S_a, S_{dr}, S_z) [2]

Rougher Surfaces trap more infrared radiation meaning they have high more stable emissivity[5][6].

Process is repeatable for any metal or alloy which needs to be measured for FSAM.

Data

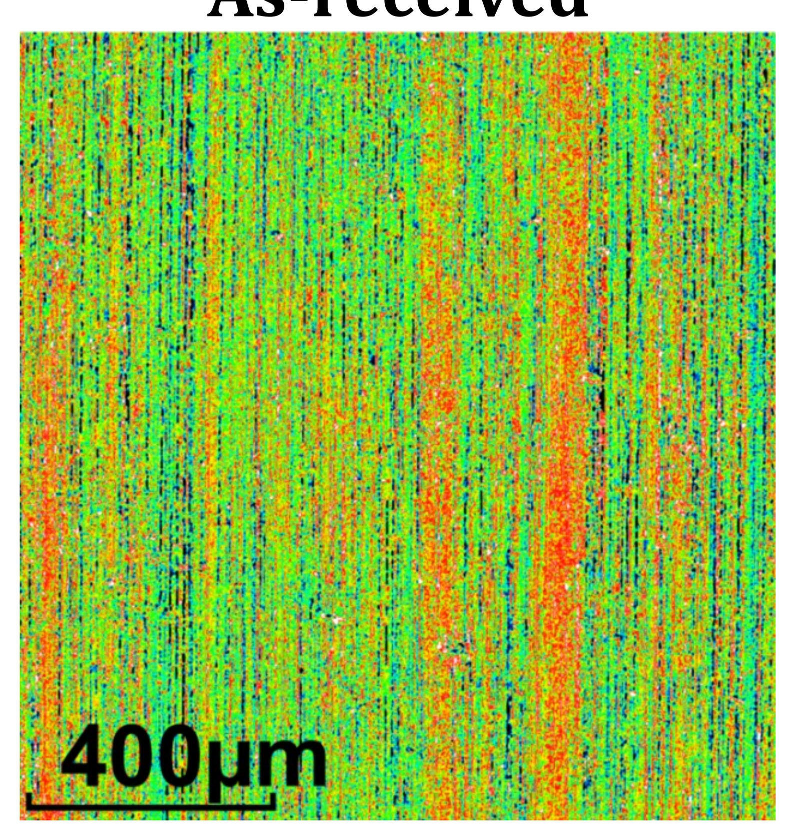
Parameter	As-machined	Wire-brushed
Average roughness deviation (S_a)	1.0–1.1µm	2.0–2.4µm
Extra surface area added vs flat (S_{dr})	~42%	~84%
Largest Peak to Valley (S_z)	22µm	~40µm

Thermal Imaging Technology

- FLIR A700 thermal camera on a fixed tripod, viewing the target surface from a stationary position
- The camera outputs data where each pixel value maps to a temperature, and it sends that data to the computer over an Ethernet connection[3]
- Object parameters: emissivity, reflected temperature, distance set the accuracy of every reading
- On low-emissivity metal, an incorrect emissivity can lead to a shift in a reading by over 100 °C

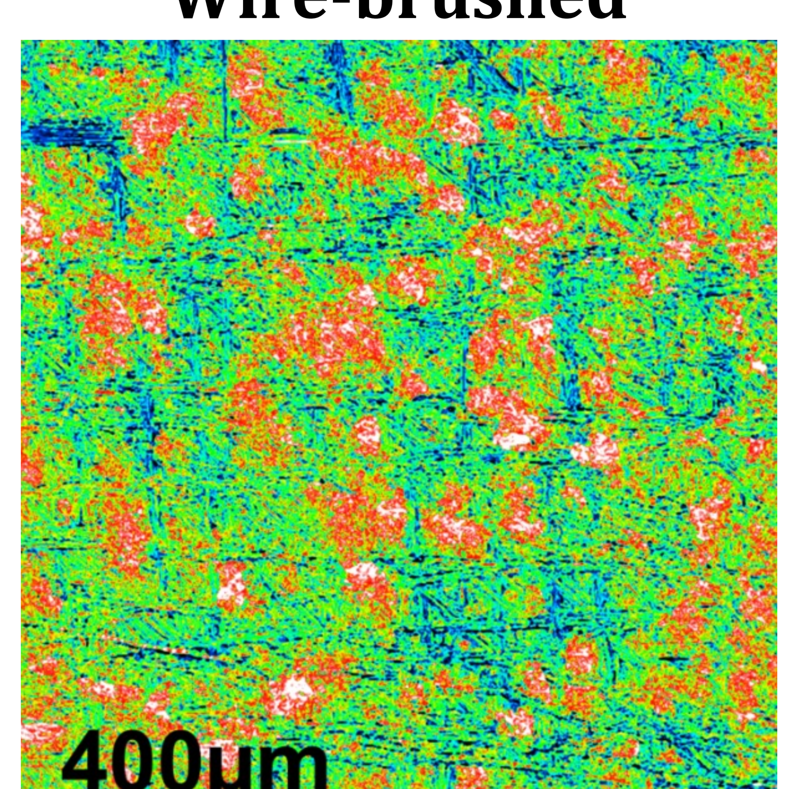
Surface Measurements

As-received



(−3µm to 3µm height color scale)

Wire-brushed



(−6µm to 6µm height color scale)

Manufacturing Implementation

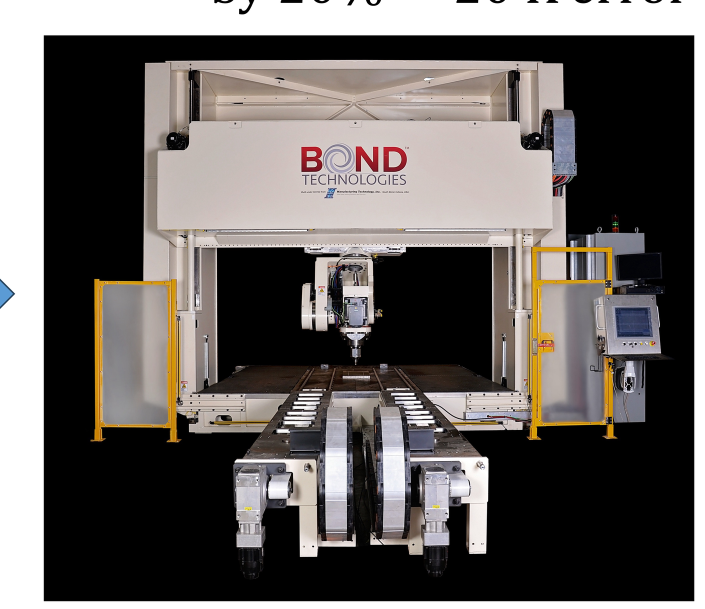
Software tool (C++)

I. Roughness (S_a/R_a) → smooth/rough → published emissivity[9] → Stefan-Boltzmann equation → temperature uncertainty (°C)

II. Stefan-Boltzmann relation

  I. $\frac{\Delta T}{T} \approx -\frac{1}{4} \cdot \frac{\Delta \varepsilon}{\varepsilon}$

III. T = 400 K and your emissivity guess is off by 20% → 20 K error



Control System Integration

Estimator to be used to guide thermal camera to accurate readings and machine control systems.

Integration of this system will give the deposition machine more accurate readings, therefore protecting the machine and granting better material flow.

Results

Working proof-of-concept
- Emissivity uncertainty matters more at higher temperatures
- Roughness in, emissivity and uncertainty out

Agababov Model can be used to geometrically derive emissivity from roughness. It calculates a rough surface's emissivity by modifying a smooth surface's emissivity based on its roughness and internal cavities.

Correct trend
The rougher (wire-brushed) surface is predicted to give higher, more stable emissivity and a more trustworthy reading. Validated theory of being applicable for FSAM applications.

Conclusions

Stakes:
An incorrect thermal reading drives wrong process decisions. This can include overheating or damage. Machine downtime can inhibit research progress.

Future Work:
Validate the emissivity estimates against direct measurement, then integrate into real-time machining control.

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References

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