Pool Boiling of Femtosecond Laser Surface Processed Stainless Steel to maximize Critical Heat Flux

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POOL BOILING

- Pool boiling is the two-phase heat transfer process of boiling a large body of liquid
- Pool boiling data includes Heat Flux (W/cm^2) and Superheat (°C), and result in figure 1, which is referred to as a pool boiling curve. Critical heat flux (CHF) refers to the upper limit of heat that can pass through a surface by the process of pool boiling before an insulating vapor layer is formed
- This research attempted to determine a correlation between the hydrophilic properties of femtosecond laser surface processed surface structures on stainless steel 304 and the CHF value reached during pool boiling

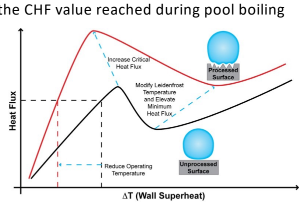


Figure 1: Standard and enhanced boiling curves

EXPERIMENTAL SETUP

- An aluminum chamber with cartridge heaters, attached side heaters, and the working fluid of water
- 5 thermocouples in the sample are used to calculate heat flux and surface temperature
- A PEEK insulator allows for 1-D conduction analysis
- Steady state data was collected when the thermocouple readings were less than 0.25 °C per minute for 5 minutes, then they recorded data for an additional 2 minutes

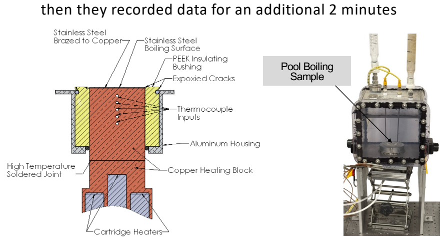


Figure 2: Schematic of cross-section of pool boiling sample and boiling vessel

FEMTOSECOND LASER SURFACE PROCESSING

- Femtosecond laser surface processing (FLSP) is an emerging technology utilizing ultra-short, high energy laser pulses to create self-organized micro-/nano-scale structures
- FLSP has been successfully applied to a wide variety of materials, enabling control over micro-/nano-scale features, chemistry, and subsurface crystal structure in a single step
- A diverse range of unique surface structures can be fabricated by varying two critical parameters: laser fluence (J/cm^2) and total number of pulses (pulse count)
- FLSP samples for this study were kept at a constant pulse count of 2000 with varying fluence

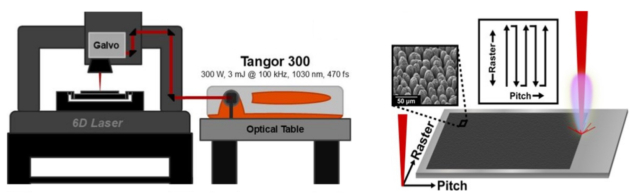
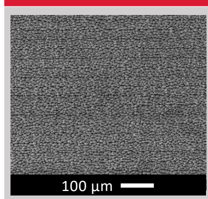
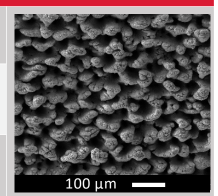


Figure 3: Schematic of Tangor 300 laser and raster pattern

Table 1: Comparison of FLSP A and FLSP B samples

FLSP A		Surface Parameters		FLSP B
	1.27	Fluence (J/cm^2)	3.82	
	7.34	Structure Height (µm)	132.52	
	1.68	Surface Area to Area Ratio	4.24	

WORKING FLUID

- FLSP applied surfaces allow for more heat to be transferred from the surface to the surrounding liquid, compared to smooth surfaces. FLSP surfaces are superhydrophilic, allowing them to wick water quickly to rewet dry spots where vapor bubbles have departed
- Polished stainless steel has a contact angle of 80°, while FLSP superhydrophilic surfaces have a contact angle of 0°

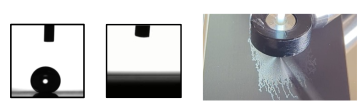


Figure 4: Examples of hydrophobic (A) and superhydrophilic (B) surfaces. Water wetting into FLSP applied stainless steel (C)

RESULTS

- Wicking tests performed on FLSP sample A and sample B show contrasting steady state wicking diffusion rates as shown in figure 5
- Steady state wicking diffusion rates for FLSP A and FLSP B are 0.4 and 2.2 mm^2/s, respectively
- We expect a higher wicking rate to have a higher CHF
- CHF for FLSP A and FLSP B are 107.3 and 106.6 W/cm^2, respectively, as shown in figure 6
  - As of now there appears to be no correlation between wicking diffusion rate and CHF for these FLSP surfaces

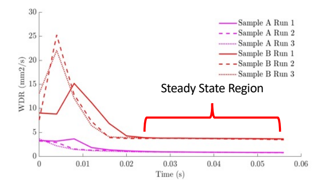


Figure 5: Wicking diffusion rates over time

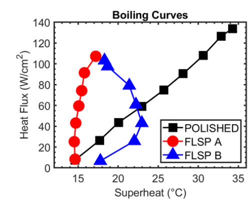


Figure 6: Heat Flux vs. Superheat

- Despite these FLSP surfaces being superhydrophilic which allow them to rewet dry spots where vapor bubbles have departed, the polished sample obtained a higher CHF at 133.9 W/cm^2
- FLSP B demonstrated boiling inversion, which has been shown to be the result of changing nucleation dynamics
  - Boiling inversion was previously thought to be influenced by structure height alone, but wicking rate may also play a role
- Its suspected FLSP samples created bubbles through micro-/nano-scale structures at a higher density than polished, resulting in an earlier than expected vapor film
- At CHF FLSP surfaces sustained lower superheats than polished at a comparative heat flux

CONCLUSIONS / DISCUSSION

In conclusion, the results were not as expected, with the polished sample achieving a higher CHF than the FLSP samples. Numerous nucleation sites on FLSP samples reduced superheats improving efficiency. High pulse count FLSP parameters typically create even more porous material that drops effective thermal conductivity due to multiple laser surface interactions. Stainless steel needs high pulse counts to create the FLSP surface, but that may be a hinderance given the lower CHF. While inversion is present, we don't know if this is due to tall structures or the wicking rate of the samples. Future work may include investigating FLSP surfaces with lower pulse count parameters, structures with similar wicking rates but different structure heights, or similar structure heights and different wicking rates.

ACKNOWLEDGMENTS

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