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POOL BOILING INVERSION ON FEMTOSECOND LASER SURFACE PROCESSED 304 STAINLESS STEEL AND ITS IMPACT ON STEADY-STATE TIME CONSTANTS

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MOTIVATION

- Increase heat transfer performance through passive surface modification
- Increased heat transfer can occur with changes in surface morphology
- Heat transfer enhancement has been seen through modified surface roughness, wettability, chemistry, and patterned micro/nanoscale features
- Femtosecond laser surface processing (FLSP) has been shown to significantly impact heat transfer performance
- Boiling inversion has recently been shown to dramatically enhance heat transfer coefficients at elevated heat fluxes

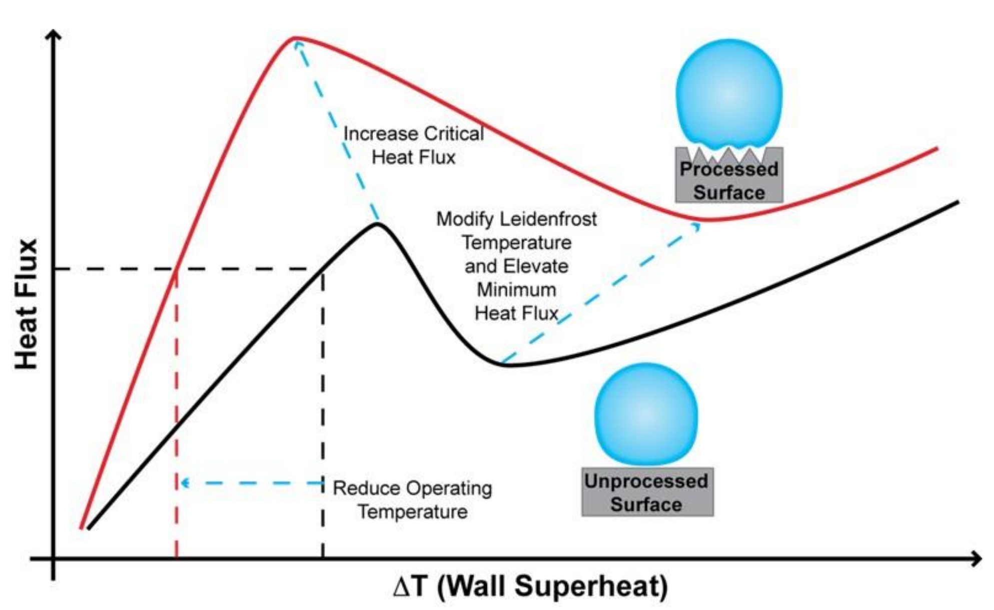

Fig. 1: Typical and enhanced boiling curves.

FLSP PROCEDURE

- Surface is processed with a Ti:Sapphire femtosecond laser (Legend Elite Duo HE+)
- Different settings produce unique surfaces

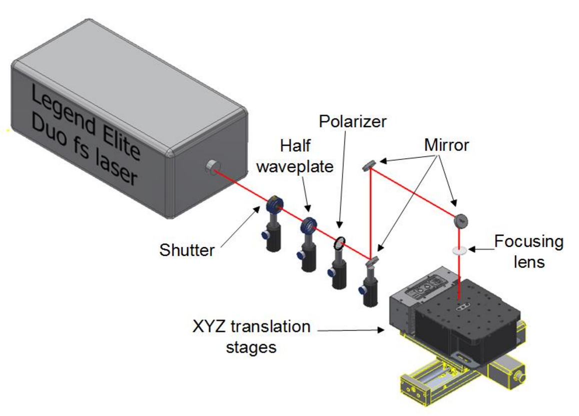

Fig. 2: Schematic of laser processing setup

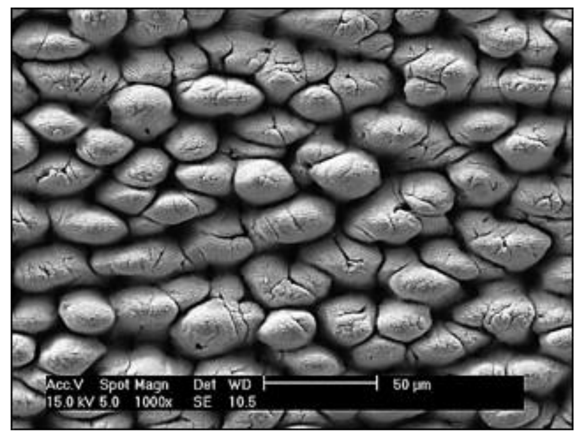

Fig. 3: SEM image taken normal to laser-formed structures

EXPERIMENTAL SETUP

- Processed surface (25.4 mm diameter) is heated using embedded cartridge heaters and two-phase heat transfer occurs at surface/liquid interface
- Heat flux is calculated using temperature gradient measured by thermocouples in copper block
- Surface temperature is extrapolated using the calculated heat flux
- Superheat is calculated by subtracting the liquid saturation temperature from the surface temperature
- Heat flux is plotted with respect to surface superheat

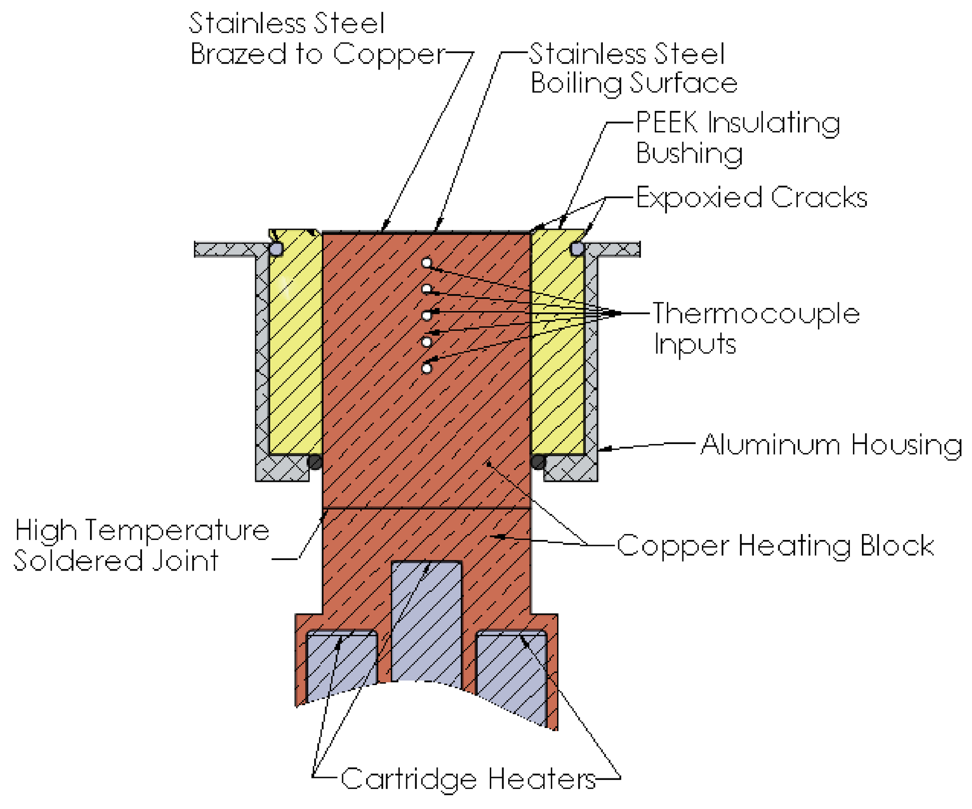

Fig. 4: Schematic of cross-section of pool boiling sample.

RESULTS

- A baseline curve was generated using the steady-state criterion and is shown in Fig. 5 (HF)
- Additional runs were done where a particular heat flux was chosen to allow for extended boiling times
- Heat fluxes of 25, 40, 60, and 70 W/cm^2 were chosen which corresponded to two points below the boiling inversion point and two above the boiling inversion point
- Heat fluxes below the inversion point showed no major change compared to baseline curve (Fig. 5)
- Heat fluxes above the inversion point showed significant temperature changes compared to the baseline curve (Fig. 6)

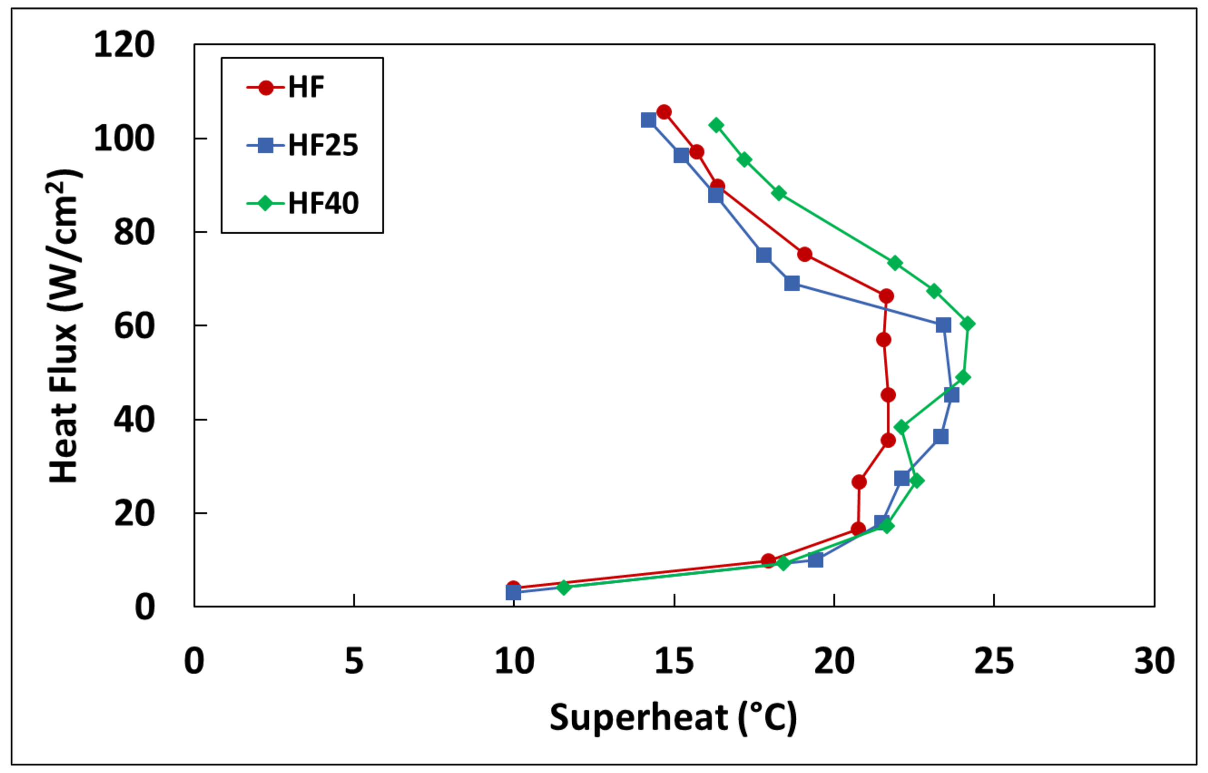

Fig. 5: Increasing heat flux curves for extended boiling at heat fluxes below boiling inversion point.

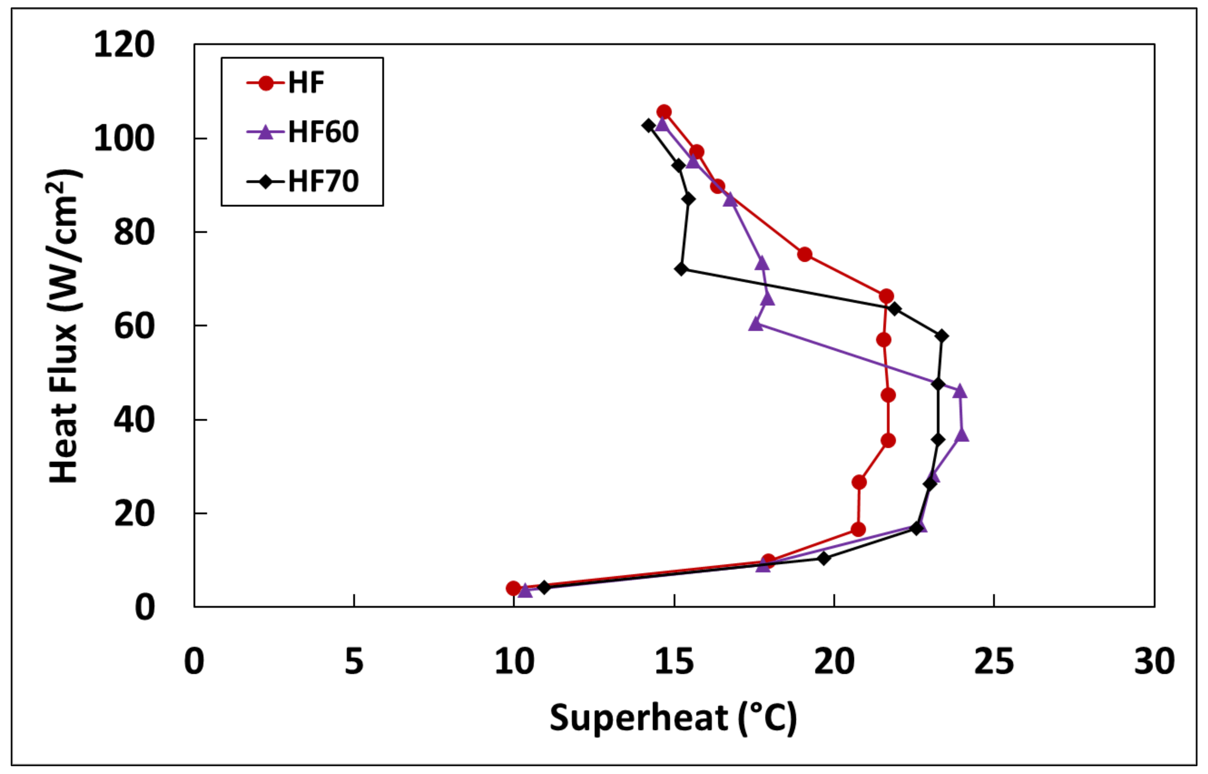

Fig. 6: Increasing heat flux curves for extended boiling at heat fluxes above boiling inversion point.

- Surface superheat was plotted versus time during four hour extended boiling time (Fig. 7)
- Extended boiling times at heat fluxes below the inversion point showed no significant changes in temperature, indicating true steady-state had been reached
- Extended boiling times at heat fluxes above the inversion point showed significant changes in temperature, requiring nearly 3 additional hours to reach true steady-state, compared to the typical 15-20 minutes reported in the literature
- Temperature migration at a chosen heat flux can be attributed to changing nucleation dynamics, which are the cause of boiling inversion
- Boiling inversion occurs when a large number of nucleation sites suddenly activate

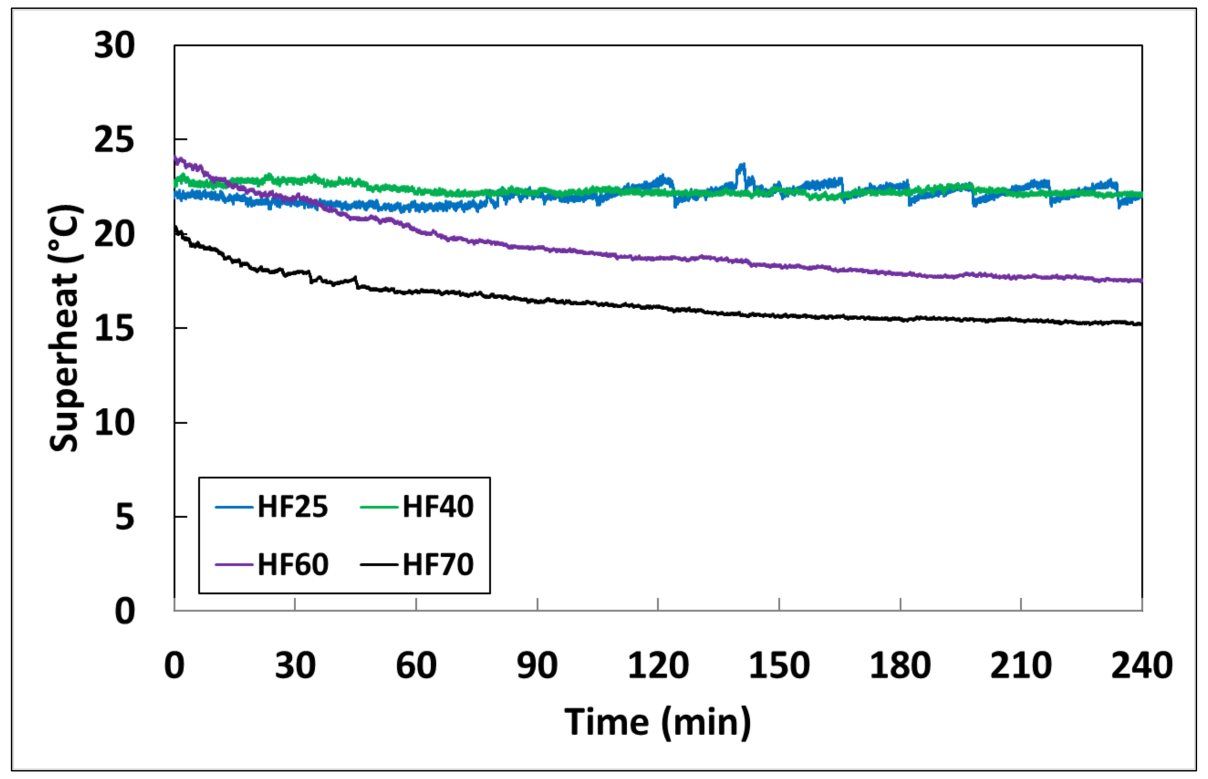

Fig. 7: Surface superheat versus time during extended boiling

- After inversion occurs, a large number of nucleation sites activate, however, the rate of activation is not well understood
- The increased time constants for reaching steady-state are a result of the slow activation of additional nucleation sites following boiling inversion

CONCLUSIONS

- FLSP surfaces resulting in boiling inversion require longer times to reach steady-state once inversion has occurred
- Boiling inversion has been shown to be the result of changing nucleation dynamics in which a large number of nucleation sites activate
- Increased time required to reach steady-state is linked to the rate at which these nucleation sites activate
- Heat fluxes above the boiling inversion point can require up to an additional 3 hours to reach steady-state, compared to the typical 15-20 minutes reported in the literature

ACKNOWLEDGEMENTS

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