Characterization and Properties of Surface Modified Steels for Fuel System Components

Student names: Lute Lahman, Mitchell Brezina, Renee DiNino, Praneet Kabra
Faculty Advisors: Dr. David Bahr, Dr. Mark Gruninger
Industrial Sponsors: Brian Wright, Ashwin Balasubramanayam
Acknowledgements: Dr. Gary Cheng, Sen Xiang

The purpose of this project was to characterize the effects of laser surface texturing on four different types of steel coupons and determine which type of laser and surface pattern provides optimal properties. A continuous or pulsed laser was used to make a line or grid texture. The characterization methods performed were residual stress, contact angle, microhardness, surface profilometry, and surface analysis by AFM. Contact angle results showed that all laser textured surfaces were hydrophilic. The residual stress results determined that pulsed laser texturing maintained compressive stress better than continuous laser texturing. Pulsed laser texturing was also optimal for hardness because it did not cause softening while the continuous laser did.

Project Background

- Technical problem: Significant wear and corrosion on steel components within Cummins’ fuel system due to impurities.
- Insufficient lubrication and wetting behavior decreases the overall efficiency and allows for impurities to come in contact with the steel surface of the fuel system.

- Scope: Characterize and quantify properties of the alloys before and after laser texturing on surfaces.
- Correlate and explain trends between varying textures/morphologies and their properties and performance.

- Materials (Steels):
  - 4140 - Vacuum hardened, <20% bainite, avg. 610 HV
  - 8620 - Atmosphere carbureitized, avg. 750 HV
  - H13 - Vacuum hardened and nitrided, avg. 1108 HV
  - M2 - Vacuum hardened, tempered, avg. 820 HV

Experimental Procedure

Residual stress:
- Pulse 3 μ-X360
- Testing completed parallel and perpendicular to line textures.
- Notable results were Debeye ring and residual stress

Contact angle:
- Coupons cleaned in ultrasonic bath
- Static contact angle measured using the ramé-hart goniometer
- Liquids used: DI water, calibration fluid, and oil
- Five angles were measured for each type of liquid

Hardness:
- Arrays of 10 indents
- 500 g load
- Tests performed on and around textured regions

AFM:
- Bruker multimode AFM was used in contact mode.
- Ra, Rz values and other topographical features were analyzed.
- The scan areas were 150 um, 100 um and 50 um with scan height set at 1 um, 2 um and 5 um.
- The 50 um scans were performed at a lower speed to adjust for sharper surface features.

Optical Profilometry: Images/data produced were from the ZYGO 3D Optical Profilometer and analyzed using the website https://www.profilometeronline.com/.

- Coupon Geometry and Texture Parameters:
  - Coupon Set 1 – ground steels, no texture
  - Coupon Set 2 – continuous laser, line texture
  - Coupon Set 3 – pulsed laser, line texture
  - Coupon Set 4 – pulsed laser, grid texture
  - Coupon Set 5 – pulsed laser, line ten pass texture

Results

Residual Stress

![Image of residual stress chart](Image)

Contact Angle

![Image of contact angle chart](Image)

Surface Analysis AFM & Optical Profilometry

![Image of surface analysis chart](Image)

Discussion

- Contact angle did not change for current textures, larger groove geometry differences may cause surface behavior change
- Contact angle was determined to be unnecessary for coupon set 4 because of its similar groove geometry to the previous coupon sets
- Future contact angle measurements are needed to determine hydrophobic/hydrophilic behavior if the ratio of groove width to spacing between the grooves changes dramatically
- Depth of grooves is also important and can influence which wetting model the surface follows
- Pulsed laser retained significant or increased compressive stress than continuous laser
- MS reached an apex performance over all steels in parallel orientation for Coupon Set 3
- Residual stress between textures on some coupon are significantly different from fixed (not repeatable accurately)
- Residual stress was not uniform across the coupon prior to texturing so may be potentially stress variation after texturing
- Texturing can be done without softening steel
- Pulsed laser showed no softening in any steel coupons
- Softening is likely due to increased exposure time with continuous laser, potentially resulting in a microstructural change
- Laser Texturing is driven by thermal diffusion length, Heat Affected Zone & Surface Roughness
- Higher thermal diffusion length allows HAZ to dissipate heat outwards into the material lattice at faster rate in M2 and H13, which hinders ablation.
- In 4140 and lower, however, thermal diffusion length provides HAZ with enough energy to underlie ablation but sometimes excess energy causes plastic yielding
- The average surface roughness could dictate how laser will interact with the material surface.

![Image of graph showing depth of trench vs hardness](Image)

Recommendations

- Specific heat and coefficient of thermal expansion are significant factors in laser texturing of steels
- Different width to spacing ratios in the grooves could affect surface behavior
- Microstructure of coupons after laser texturing affects strength of steel
- Coupon Set 5 (multiple line pass) investigates changes in depth of grooves

MSE 430-440: Materials Processing and Design