Feasibility of Silicone Shielding Material for Directed Energy Deposition 'Blisk' Repair

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The thrust needed by aircraft is created by gas turbine engines, with turbine blades experiencing wear due to erosion from regular use as well as foreign objects. To counter this, Rolls-Royce is utilizing the additive manufacturing technique, Directed Energy Deposition (DED), to replace worn blade fins. The company is exploring the use of a silicone-based shield to protect neighboring turbine blades from spatter, laser reflections, and high-intensity thermal degradation during DED. Emulating typical DED conditions, various tests were performed to observe how the silicone compounds thermally react, characterized by shore hardness, microscopy, and spectroscopy. After analysis, Silicone 2 Additive 1 was concluded to be the top performer, showing the greatest resistance to thermal degradation.

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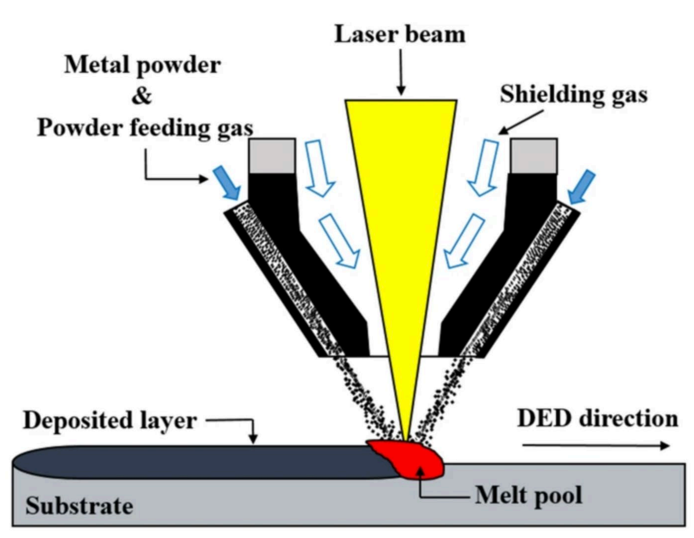
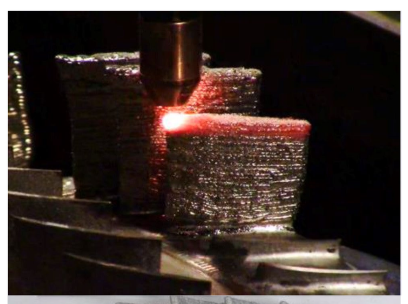
Background

Motivation: It is difficult to replace a single blade within a bladed compressor disk ('blisk') due to the integration of the blades and the annulus. Rolls-Royce wants to utilize DED to repair individual blades because of its accuracy, efficiency, and cost-effectiveness. However, the use of DED without a shield leaves neighboring blades unprotected from thermal degradation through conduction through the annulus as well as molten spatter. This necessitates further machining and cleaning of these parts. To prevent this, the viability of a silicone-based shielding material has been explored as a solution.



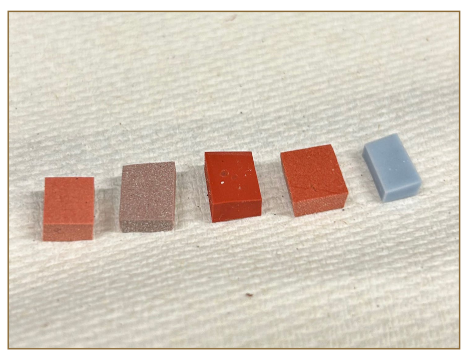


Solution: Five silicone compounds, originally intended for a different form of additive manufacturing, are investigated for their response to heat treatments under standard DED conditions. AIMTEK's silicone compositions made using proprietary elemental additives are referred to as: S1A1, S1A2, S2P, S2A1, and S3P.

Project Goal: The goal of this project is to use microscopy, spectroscopy, and shore hardness testing to characterize the silicone compounds under various times and temperatures when exposed to oven and DED conditions. With these results, we intend to make a recommendation on which silicone compound is best suited for shielding neighboring parts during DED.

Experimental Procedure

Silicone Heat Treatment in Oven
The five silicone compounds were sectioned into 200-mg coupons, each subjected to temperatures from 200-400 ºC by increments of 50 ºC at 1-, 2-, 8-, and 24-hour time periods. The samples were allowed to cool down to room temperature before further testing.

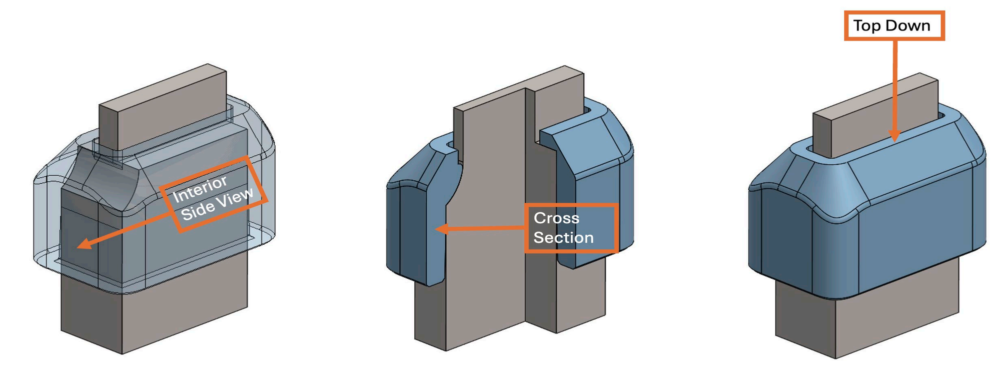


Scanning Electron Microscopy (SEM)/Energy Dispersive Spectroscopy (EDS)
Backscattered electron images and elemental mapping was conducted using the Phenom X desktop SEM by Nanoscience Instruments.

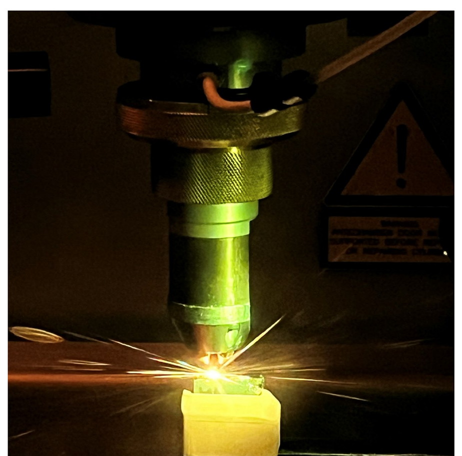
Shore Hardness
Samples were tested according to ASTM Standard D2240 [2]. The load used to create the indents from the Shore D Durometer was 5 kg. For each coupon, 10 measurements were taken.

Fourier Transform Infrared Spectroscopy (FTIR)
Each sample was analyzed from 1500-600 cm^{-1} using the Spectrum 100 FT-IR Spectrometer from PerkinElmer.

Directed Energy Deposition (DED)

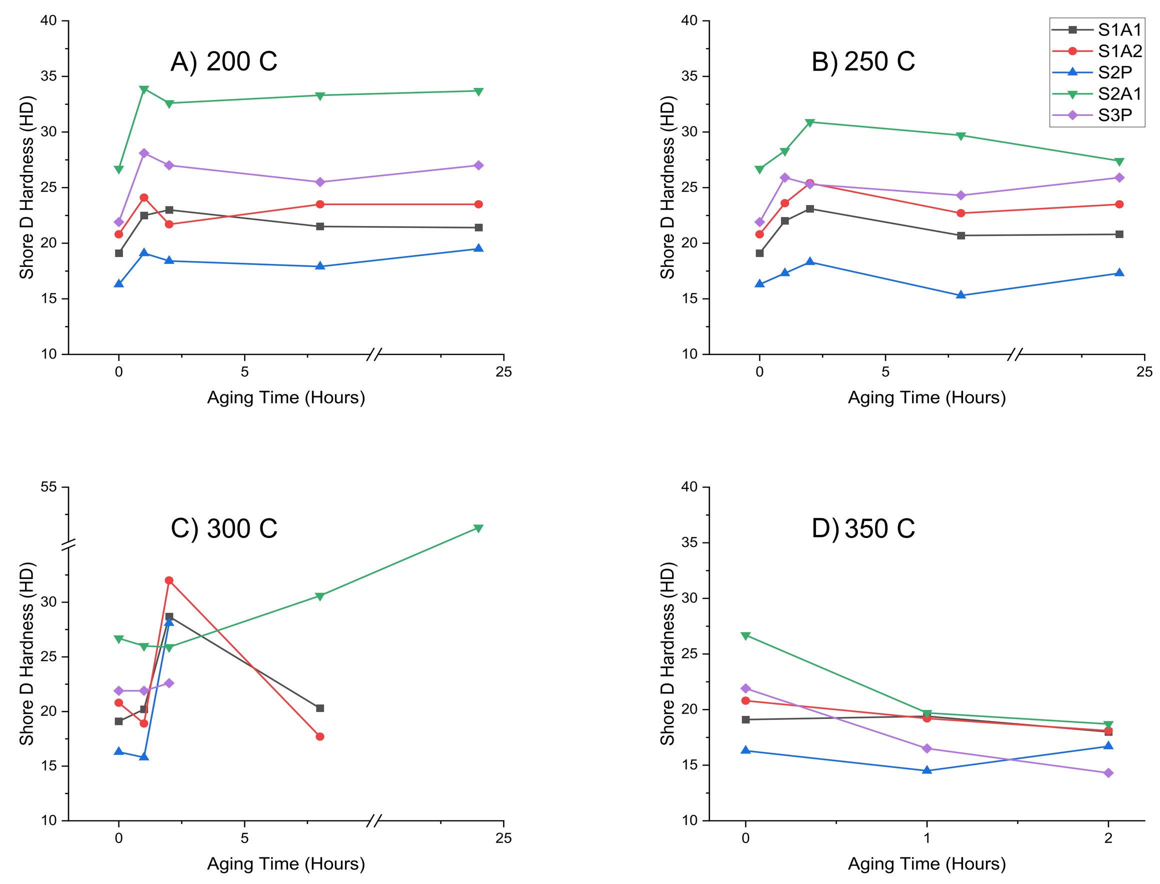


Silicone-based shields with customized geometries fit over a titanium piece. Three different runs were conducted without a metal-powder input using Rolls-Royce's DED instrument. The first run had a vertical standoff of 0.25-in and used standard laser parameters. The second run was identical to the first but had no standoff. The third run was like the first but reduced the hatch speed by 25%. The temperature of each silicone was taken after each run, ranging from 170-230 ºC.



Results & Discussion

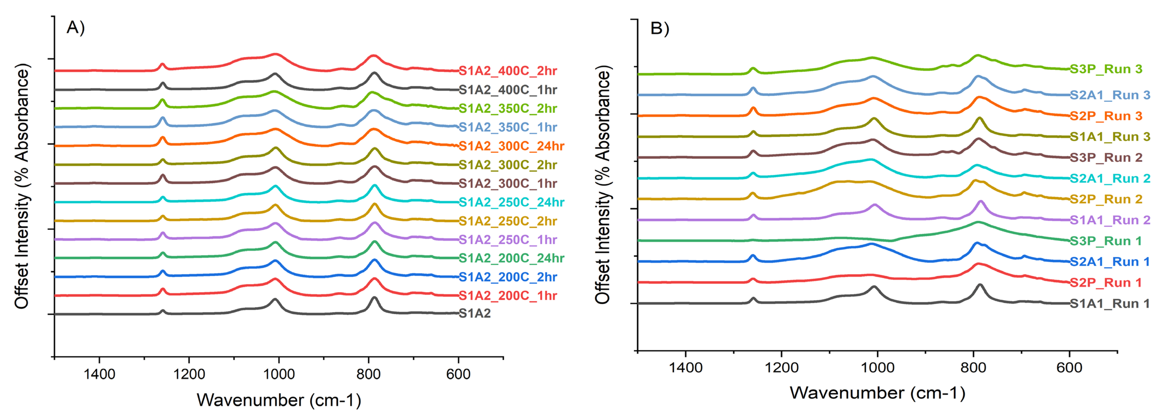
Shore D Hardness

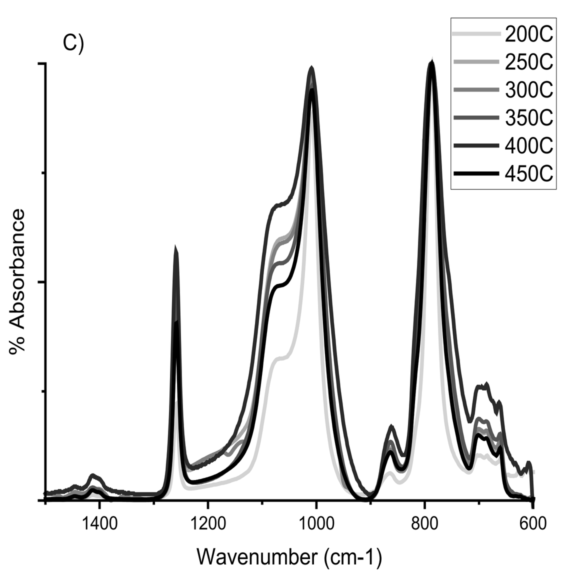


The results of the average Shore D hardness with respect to aging time in hours for each silicone compound are shown above. Hardness measurements are from using a Shore D Durometer after being aged at 200 (A), 250 (B), 300 (C), and 350 (D) ºC.

- Silicone 2 Additive 1, appears to be both the hardest as well as survived the longest in the oven, being the only silicone compound to yield hardness values after 350 ºC for 24 hours.
- An increase in hardness is attributed to an increase in crosslinking which is brought upon by increased temperatures [3].
- Hardness tests following DED revealed overall lower values similar to initial hardness values from no heat treatment; This is due to the temperature of the silicones only reaching 230 ºC on the hottest run.
- No significant difference was seen between runs for each silicone compound, which can be attributed to low temperatures as well as lower exposure times under DED than the oven.

Fourier Transform Infrared Spectroscopy (FTIR)





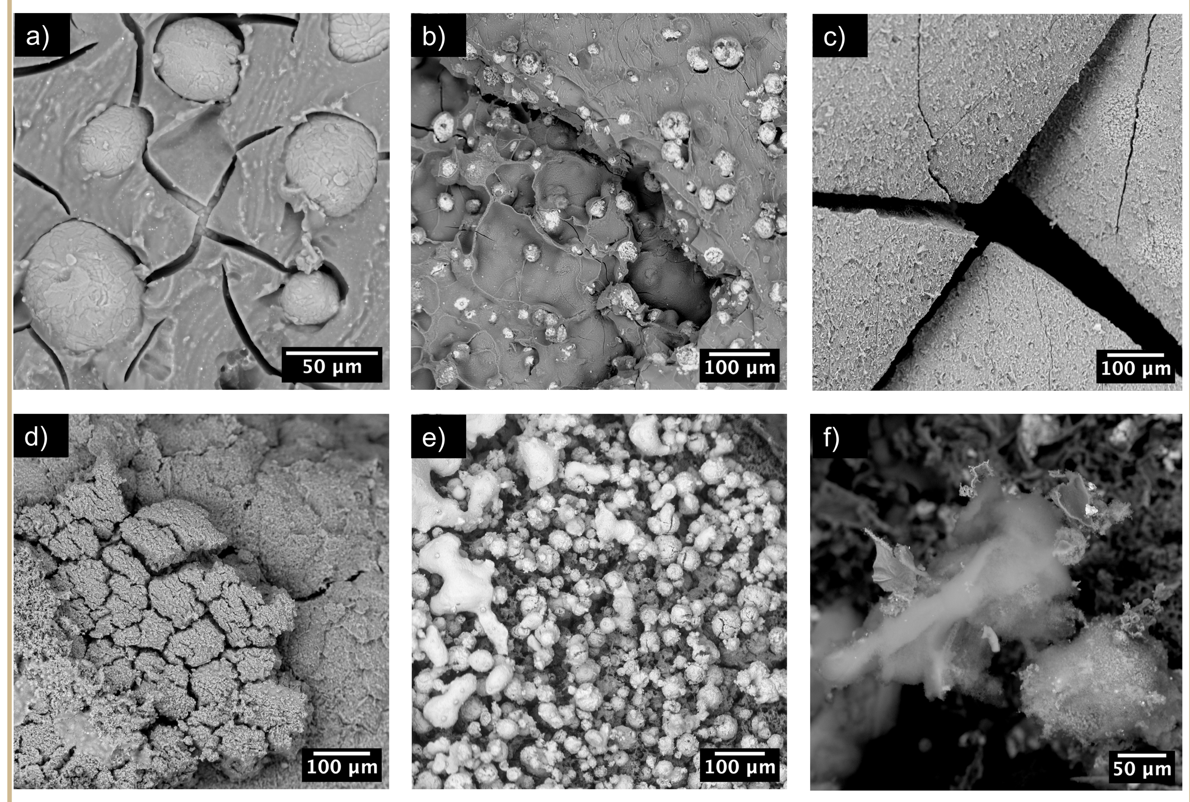
Peak Position (cm^{-1})	Group
2963	$-CH_3$ stretching vibration
1410	$-CH_2-$ rocking vibration
1259	$Si-CH_3$ rocking vibration
864	$Si-CH_3$ rocking vibration
1080, 1009	Si-O-Si stretching vibration
787	Si-C stretching vibration & $-CH_3$ rocking vibration

FTIR peak analysis plots for (A) S1A2 that underwent heat treatment in an oven, (B) all types of silicone samples that underwent DED, (C) intensity comparison plot for S1A2 heat treated at a temperature range of 200-400°C for 1 hour in an oven, as well as (D) key peak positions for silicone that match with peaks identified in plots (A) to (C).

- Peak positions and their intensities for various temperatures and times of heat treatment as well as respective runs of DED that each correspond to different experimental parameters displayed minimal variations, indicating minimal chemical or compositional changes across different testing methods.
- The broadening of curves with increasing temperature signify decreasing presence of certain chemical bonds/functional groups.
- Noises or absence of certain peak positions in plots for the samples tested with DED could imply that some functional groups may have been destroyed by the heat energy from the laser at a faster rate compared to the oven samples.

Results & Discussion

Scanning Electron Microscopy



Key indications of degradation under heat treatment in an oven (a-c) and under DED (d-f) are shown in the scanning electron micrographs above: a) microscopic cracking in S1A2 at 350 ºC for 2 hr, b) macroscopic cracking in S1A1 at 400 ºC for 2 hr, c) macroscopic and microscopic embrittlement in S3P at 400 ºC for 2 hr, d) macroscopic degradation in S2P for DED Run 3, e) change in additive morphology in S2A1 for DED Run 3, and f) disintegration of the silicone-additive matrix in S1A1 for DED Run 2.

- The mode of heat transfer influences the type and extent of silicone degradation – DED is more destructive than the oven due to conduction, convection, and radiation at a higher intensity.
- Run 2 (no standoff) resulted in the greatest degradation while Run 1 (baseline/standard) resulted in the least for all four silicone types.
- For Run 1, S2A1 performed the best (least degradation) while S2P performed the worst (most degradation); ranking from best to worst: S2A1, S1A1, S3P, S2P.
- More damage was endured by the top-down surface rather than the interior side view for all runs and amongst all four silicone types.
- No damage was observed in the cross-section, indicating little to no thermal degradation occurred in the bulk of the silicone samples.

Recommendations

i) Based on our characterization studies, S2A1 displayed the least thermal degradation and crosslinking for both heat treatment in the oven as well as laser exposure during DED, making it the preferred choice for Rolls-Royce's blisk-repair application.
ii) Depth profiling can be conducted to further quantify silicone damage during DED.
iii) Shore A Hardness data can be collected to obtain more comprehensive results.
iv) The reusability of AIMTEK's silicone shielding materials can be evaluated through thermal cyclability testing; additional characterization techniques that could be employed include thermogravimetric analysis (TGA) and Differential Scanning Calorimetry (DSC).
v) Geometrical constraints of the silicone shielding material can be evaluated through more complex experimental setups for DED.

Acknowledgements & References

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References

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