AVCOAT Density Characterization for Orion Multi-Purpose Crew Vehicle

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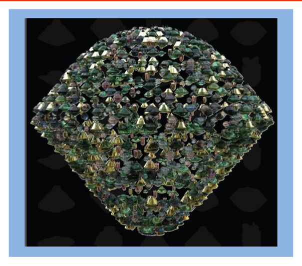

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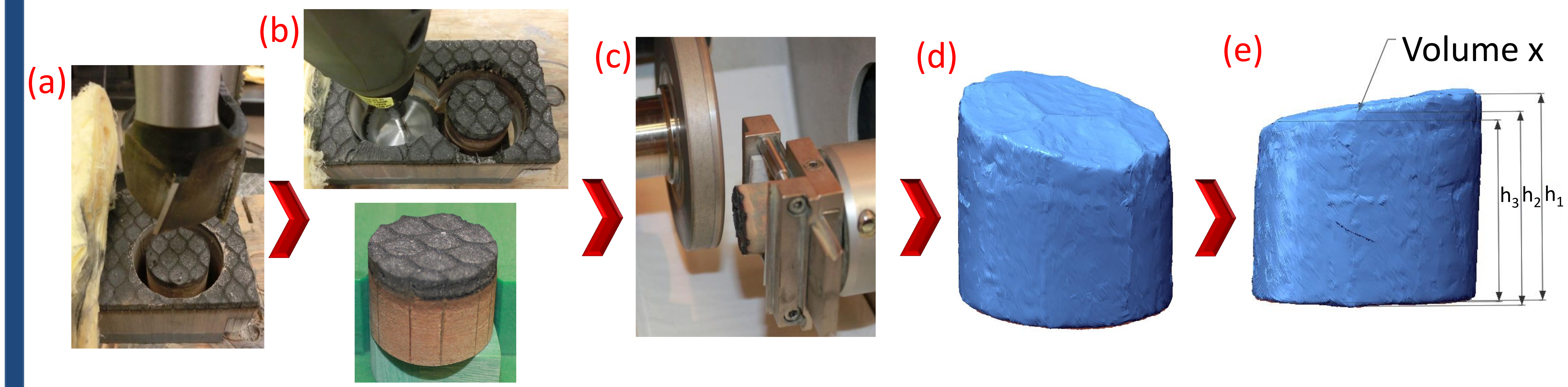
MOTIVATION

- The Orion Multi-Purpose Crew Vehicle (MPCV) will transport four crew members to and from lunar-class orbital destinations. The first orbital unmanned test flight, Exploration Flight Test (EFT-1), is scheduled to launch in Dec 2014 and will provide valuable data on the AVCOAT^{TM} heat shield. AVCOAT^{TM} is a mid-density ablator containing a fiberglass-phenolic honeycomb structure filled with an ablative epoxy novolac resin.
- The EFT-1 flight heat shield is instrumented with 19 aerothermal plugs, each of which contain one hollow aErothermal Ablation and Temperature (HEAT) sensor to track the transient char front of the AVCOAT during atmospheric entry.
- The first objective of the present work is to develop a density characterization process using material from post-test AVCOAT arc jet coupons. Techniques for extracting material cores, progressively machining the cores, and determining a density profile are discussed.
- A secondary objective is to compare the **final** char depth determined from HEAT sensor output to the char profile determined from the density measurements.
- Results from the post-flight characterization of the EFT-1 heat shield can lead to further development of more accurate TPS material response models. This, in turn, can result in heat shield designs for future explorative space missions that carry less margin.

METHODOLOGY



Schematic 1: Schematic showing process of ***(a)*** drilling core and ***(b)*** core extraction from arc jet tested coupon. ***(c)*** Slow speed saw was used to perform progressive machining on AVCOAT core to obtain char profile. ***(d)*** Core was 3D scanned before and after material removal. ***(e)*** Volume and three different depths (h_1, h_2, h_3) along the core diameter pre - and post - material removal was obtained using 3D scanning software. The depth values were obtained by measuring a length from the top face to the base of the core. Volumes and depths were then used to calculate the individual densities of the material removed after each AVCOAT shaving. A density vs. core depth graph was generated to study three material zones.

AVCOAT DENSITY PROFILE

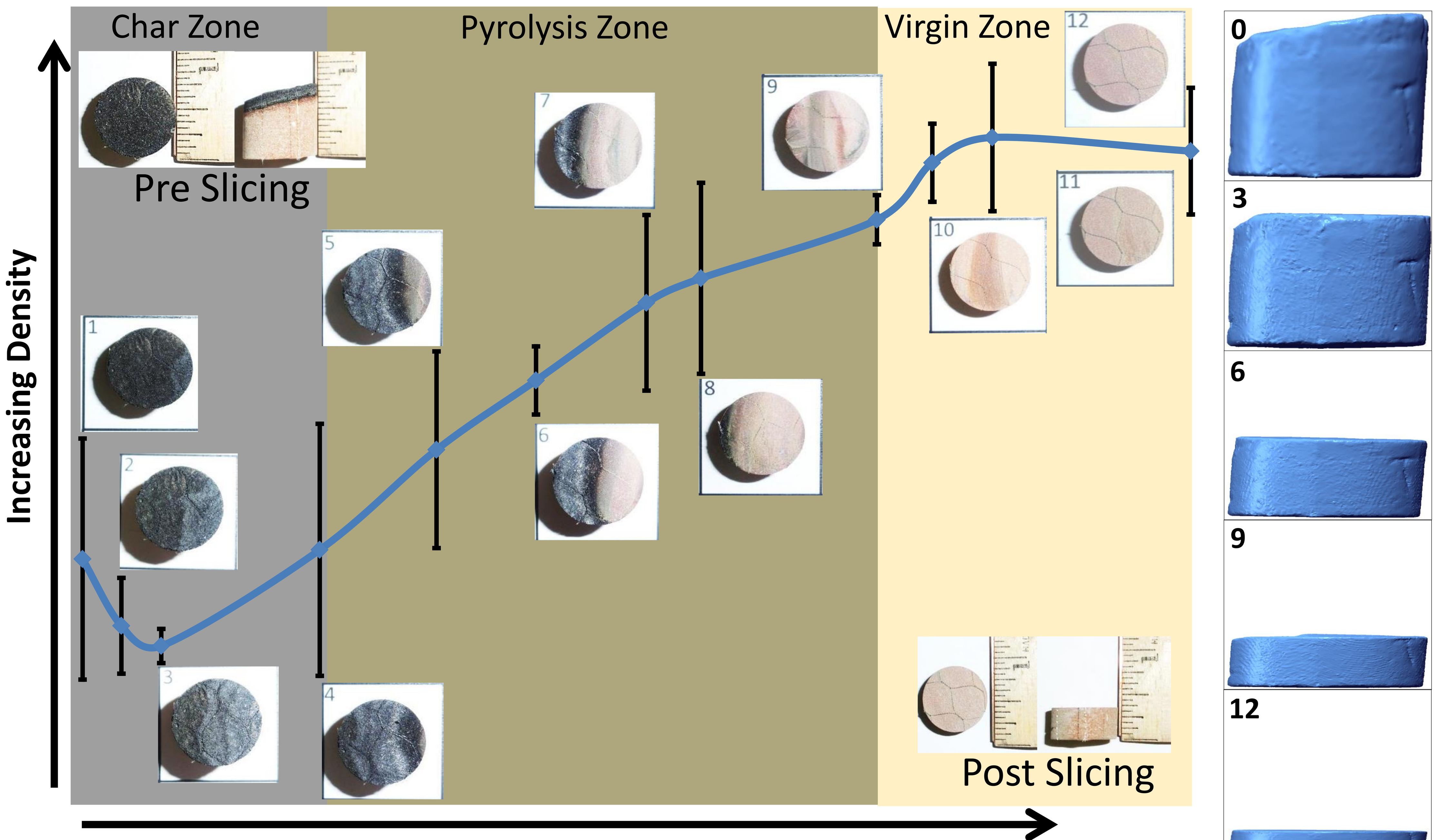


Figure 1: Graph shows a representative AVCOAT density profile with accompanying snapshots of the TPS surface topography after material removal for an average of three specimens. AVCOAT char zone shows to have a low density range, pyrolysis zone with a mid-density range and virgin zone with the highest density range. 3D scans of the AVCOAT core are highlighted to show the difference in core height after material removal. It is hypothesized that the slight increase in density shown at shaving 1 may be due to material depositing at the surface during outgassing. Further investigation is required to confirm this hypothesis.

Several of the cores that will be extracted from the EFT-1 heat shield are expected to have a tapered char geometry similar to the core shown above. This is particularly true for the cores extracted from the shoulder and compression pad ramp areas of the heat shield. A tapered char profile poses a challenge in identifying the complete char zone as evident in the 5 – 8 snapshots. These topographies show a combination of both char, pyrolysis and/or virgin zones hence the broad shoulder in the mid range of the graph.

The accuracy of the progressive machining technique will be driven by the uncertainty of the following: (1) the amount of material being removed after each shaving, (2) how flat the specimen's base is relative to the tapered charred surface, (3) curved OML geometry of the core which results in a char profile that is not parallel to the base of the core, and (4) pockets of AVCOAT falling out during progressive machining due to open honeycomb cells.

HEAT SENSOR ANALYSIS

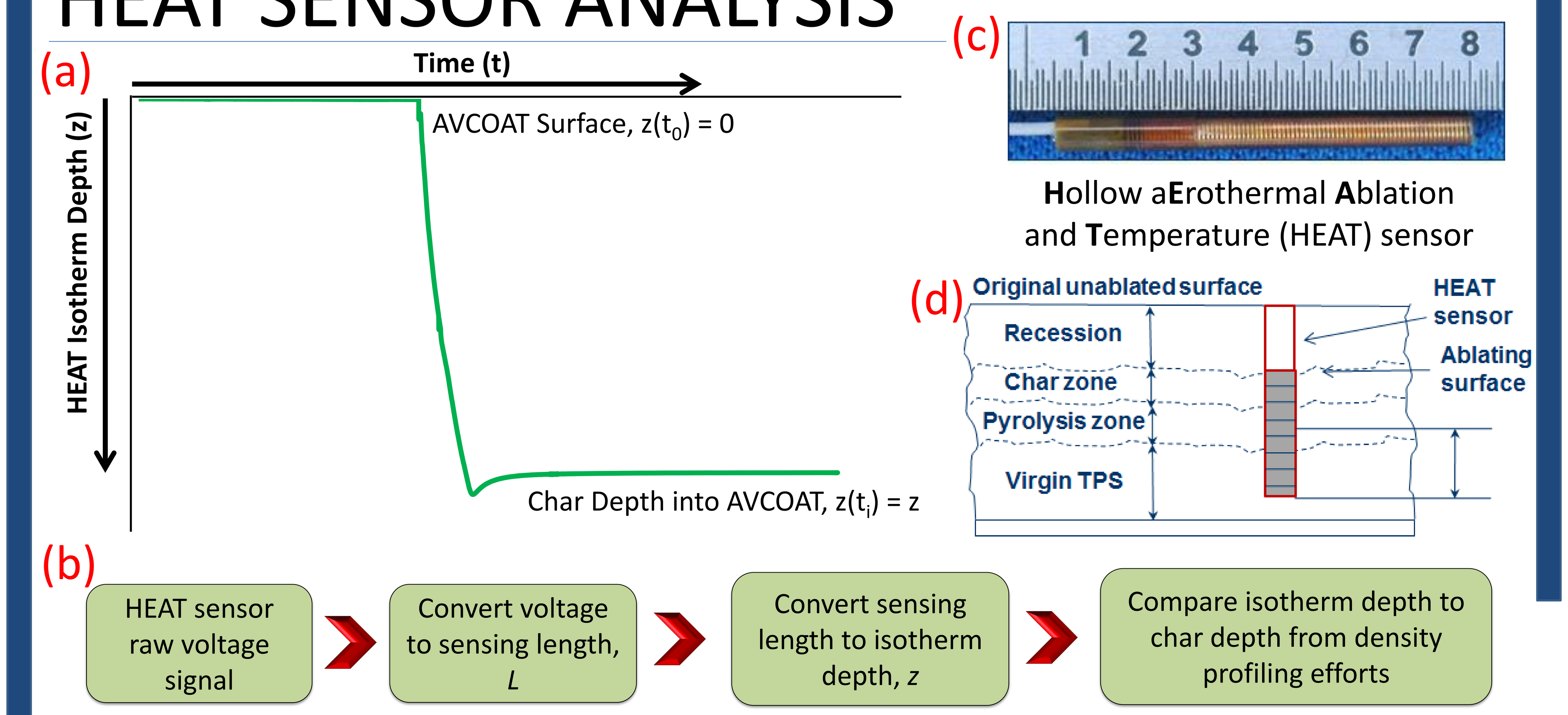


Figure 2: ***(a)*** Representative graph showing post-processed HEAT sensor date output using the ***(b)*** flow chart indicating steps required to convert voltage signal from HEAT sensor to an isotherm depth (z). z will be used to compare the char depth from the density profile characterization. ***(c)*** Image of HEAT sensor architecture. ***(d)*** Schematic of material zones in relation to HEAT sensor location.

CONCLUSION and FUTURE WORK

CONCLUSIONS

The progressive machining technique implemented on post-test AVCOAT arc jet models proved to be an effective method for the development of an AVCOAT density profiling procedure. Removing small amounts of material from an AVCOAT core has been demonstrated, along with laser scanning the core to capture its geometry after each shaving. Refinements to the progressive machining equipment, such as improved cutting tools and fixturing, should result in more accurate results. Although not presented here due to ITAR restrictions, the density values obtained for AVCOAT in its char, pyrolysis and virgin states are in family with values obtained from material property tests performed in the past by the Orion program. The results obtained in this study give high confidence that a refined progressive machining technique will be used for the post-flight material characterization of the EFT-1 heat shield.

FUTURE WORK

- Refine the progressive machining technique to allow for material removal perpendicular to the AVCOAT core's OML normal vector. This will help address the curved OML geometry of the AVCOAT core.
- Conduct progressive machining on a variety of arc jet models tested across a range of conditions and flow exposure times to build a database of density profiles.
- Make a direct comparison between HEAT sensor data and final char depth of the arc jet models (as determined from progressively machined AVCOAT cores).
- Core the EFT-1 flight heat shield and perform progressive machining to characterize the flight AVCOAT char profile.

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