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CLOSED MOLDING OF CONFORMAL ABLATIVE THERMAL PROTECTION SYSTEM MATERIAL

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Introduction and Background

Introduction

Ablative thermal protection systems (TPS) have been used almost exclusively for planetary probes to date because of their high heat rate and heat load capabilities [1]. Manufacturing and installing these TPS materials can present significant engineering and processing challenges due to limited tile size (resulting in heat shields with large part counts) and/or complex, costly fabrication processes. Conformal ablators, C-PICA and C-SIRCA, show promise in alleviating these difficulties by utilizing a flexible fibrous substrate, which results in a higher stain-to-failure than traditional rigid ablative TPS [2]. The present work aims to select a closed mold manufacturing process for conformal ablators with the goal of facilitating larger tile sizes and reducing labor, cost and waste.

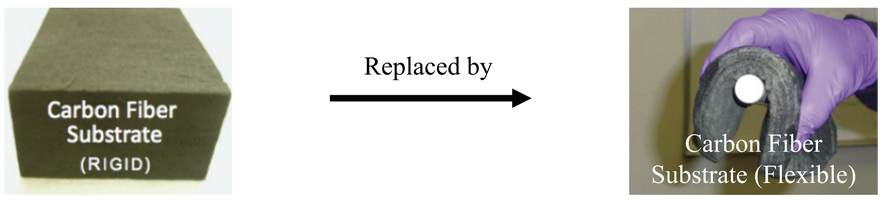
Conformal Ablators

Lightweight ceramics ablators (LCAs), including PICA and SIRCA, utilize porous, fibrous ceramic or carbon substrates impregnated with a polymer resin filler. These ablators have improved mass efficiency and superior strength over traditional ablators, which consist of short disconnected fibers and/or organic filler in a polymeric mixture [3,4].

The rigid carbon preform of PICA contributes to processing and integration challenges:

- Material waste due to post-processing / machining
- Limited tile size / high part count
- Strain isolation pad, SIP, necessary for bonding to aeroshell structure

Conformal ablators replace the rigid substrate with a flexible felt – the resulting material has a higher strain-to-failure and can be manufactured and integrated more easily.

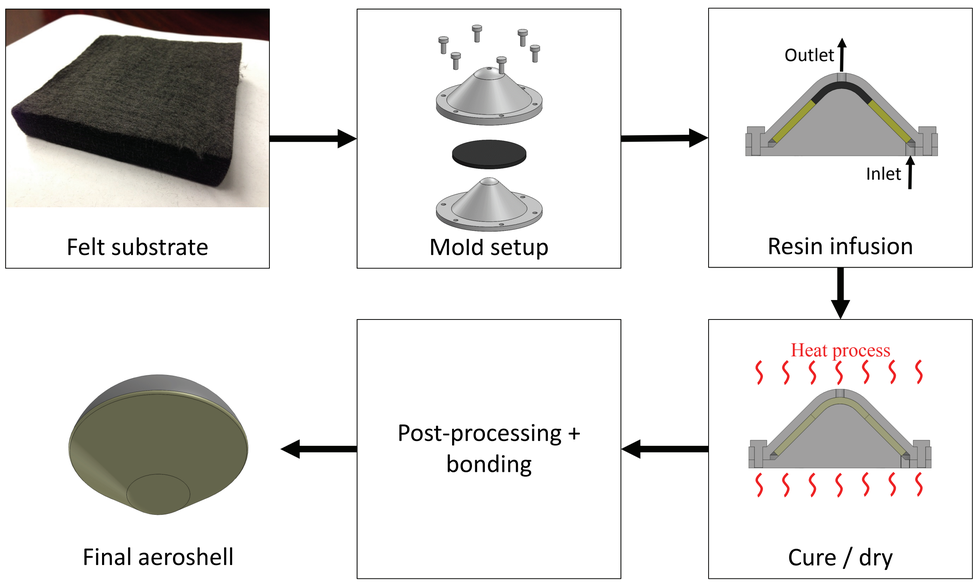


Closed Molding

Closed molding utilizes sealed, rather than open, tooling to improve resin infiltration and control volatile compounds. Established techniques exist for fiber-reinforced plastics (FRP).

- Tooling can be rigid and/or flexible.
- An applied pressure differential between the inside and the outside of the tool enables flow of resin and evacuation of volatiles during curing.
- Some processes utilize fiber preforms pre-impregnated with resin (prepreg); other processes (i.e. resin infusion processes) use a dry preform with resin injected from an external reservoir.

Closed molding concept (adapted from [2]):



Potential advantages to TPS manufacturing [6,7]:

- Near net-shape molding (and thus reduced waste)
- High levels of controllability and repeatability
- Reduced labor
- Larger part sizes

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References

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Methodology and Results

Evaluation of Closed Mold Processes

Closed mold process were narrowed down to resin infusion processes, exclusively, because of similarity/applicability to TPS fabrication. Evaluation based on qualitative criteria (with scale in parentheses):

- Cost (low / medium / high)
- Process time (short / medium / long)
- Amount of labor (low / medium / high)
- Surface finish quality on both the inner mold line (IML) and outer mold line (OML) (good / fair / poor)
- Maximum typical operating pressure (low / medium / high) [Note: lower pressure results in relaxed equipment requirements]

To compare processes, criteria are assigned numerical scores between 1 (best) and 3 (worst), e.g. long process time = 3. Both surface finish categories are weighted by 50% so as not to have an overly large influence on the final score. Cost and labor are weighted by 150% indicating their relative importance to the goals of the research. Resulting category scores are summed to produce the combined score (with a lower score corresponding to a better option).

Process Selection

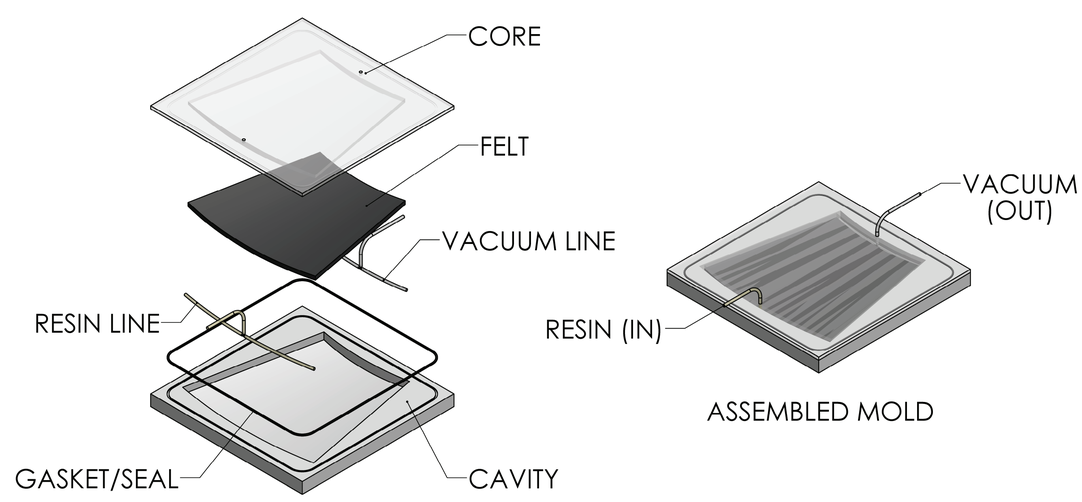
Processes were evaluated based on the above criteria. Selected results are presented in the table below. Vacuum Infusion Processing (VIP) was selected as the candidate process. Both the scoring process and other indicators point to VIP as the appropriate selection. VIP is suited to low viscosity resins. Also, low operating pressures may allow the use of non-metallic tooling, simplifying mold design.

Process	Cost	Process Time	Labor	Surface Finish – IML	Surface Finish – OML	Max. Pressure	Combined Score*
Resin Transfer Molding	High	Short	Low†	Good	Good	Medium	10
Vacuum Infusion Processing	Low	Medium	Low†	Fair	Fair	Low	7.5

*Lower scores are better. †Fully automated processes are possible albeit after substantial development.

Preliminary Process Concept

VIP encompasses a family of similar processes. A VIP mold is illustrated below for a notional 1m^2 tile. The design is conceptual only.



Important process parameters to control [7]

1. Resin viscosity
2. Pressure differential
3. Injection ports (number and locations)
4. Fiber substrate compaction (high compaction reduces thermal performance)

Conclusion

Conclusion and Future Work

Manufacturing conformal ablators using closed molding has the potential to reduce processing waste and labor at relatively low cost. The low strain-to-failure of conformal ablators can also simplify assembly and integration to the aeroshell structure. These advancements reduce burden on project schedule and budget. Vacuum Infusion Processing (VIP) was selected as a candidate manufacturing process for conformal ablators. A preliminary concept of the infusion process was outlined. In future work, these processes will be implemented in the laboratory on a small scale. Once successfully demonstrated, the process will be scaled up to produce larger TPS segments (with a goal of 1m^2 tiles).