THERMAL PROTECTION SYSTEM CHALLENGES FOR THE MARS SCIENCE LABORATORY HEATSHIELD

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Introduction

The Mars Science Laboratory (MSL) is NASA's next robotic mission to Mars. At 4.5 m in diameter, the MSL aeroshell is the largest built to date. The MSL aeroshell (shown in Figure 1) protects the rover from the harsh heating environment during Mars atmospheric entry. The MSL baseline heatshield design was to utilize SLA-561V, an ablative material that has successfully flown on Viking, Mars Pathfinder, Mars Exploration Rovers, Genesis (backshell), Stardust (backshell), and Phoenix missions. After an exhaustive series of arc jet tests and analyses that spanned 18 months, it was determined that SLA-561V could not be qualified for the mission after a series of unpredictable and puzzling catastrophic failures in arc jet tests. In an unprecedented step, MSL Project management decided to change the heatshield Thermal Protection System (TPS) material 23 months from its original launch date. The decision was to change the TPS material to Phenolic Impregnated Carbon Ablator (PICA), which successfully flew on the Stardust Sample Return Capsule (SRC) and entered the earth's atmosphere in January 2006 at the fastest speed to date (of a man-made object). Unlike the SRC application, which used a single-piece PICA heatshield, the exceptionally large size of the MSL heatshield required the PICA TPS to be applied using a tiled approach; a first for a NASA mission utilizing an ablative TPS. At the time of the material change, the Aeroshell Subsystem was past its Critical Design Review milestone, and the NASA/Lockheed Martin Space Systems team was faced with the challenge to develop, qualify, and deliver the flight PICA heatshield within 18 months. This aggressive schedule required development approaches that were atypical of the NASA TPS design process, and this paper will discuss some of the resulting material development and manufacturing challenges.

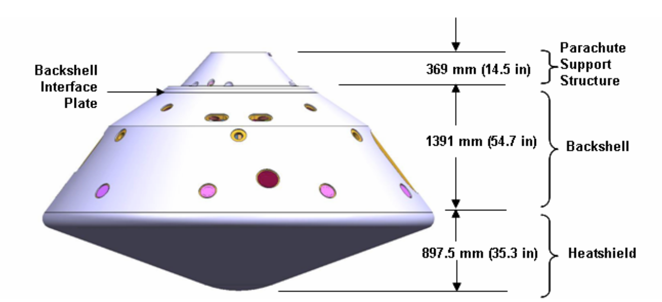

Figure 1: MSL Aeroshell Configuration

Material

The PICA material, invented by NASA Ames Research Center in the early 1990's, is composed of a pre-formed fibrous carbon substrate called FiberForm®, manufactured by Fiber Materials Inc. (FMI), which is then infiltrated with phenolic. The result is a very low density, high performance ablative material [1]. The PICA technology was transferred to FMI for the manufacture of the Stardust SRC heatshield.

PICA was an enabling technology for the Stardust mission because of its low density and ability to withstand the harsh aerothermodynamic re-entry conditions. Post-flight analyses of the recovered SRC showed no anomalies and graceful recession [2]. FMI manufactured a single-piece PICA heatshield for the 0.8-m diameter SRC in 1997 and subsequently mothballed PICA production due to the lack of need for large quantities of PICA. Nine years later, in late 2006, FMI began manufacturing PICA for the Crew Exploration Vehicle (CEV) Advanced Development Program (ADP), when PICA became a candidate for the CEV heatshield TPS. Due to the large size of both CEV and MSL, a single-piece PICA heatshield is not feasible, thus PICA is manufactured in billet form and is then machined into the required tile shapes. By mid-2007, a second large infiltration vessel was brought on-line and certified, fortuitously in time for MSL's need in late 2007. The trailblazing effort by the CEV ADP team and FMI in getting PICA production up and running, as well as the certification of a second infiltration vessel, was critical in enabling MSL to meet the challenging manufacturing schedule. The schedule dictated that over 100 PICA billets, 450 test coupons, and over 250 tiles, required for development, qualification, and flight tile installation, had to be fabricated in nine (9) months.

Even though there had been significant efforts in getting PICA production back on-line for CEV ADP, flight quality PICA had still not been made for 10 years. Therefore the immediate focus was the generation of an MSL PICA Material Specification that included requirements and acceptance criteria for Lot Acceptance testing. In order to meet the aggressive manufacturing schedule, PICA billet manufacturing had to commence immediately to produce coupons for the structural and arc jet test development programs, as well as tiles for the Manufacturing and Engineering Development Units. Therefore the development of the material specification occurred in parallel with billet production. Each PICA billet produced had a small area of material removed for material property testing, and the results were used to define the acceptance criteria in the flight PICA Material Specification.

Results

In order to meet the schedule, the first six (6) lots of PICA billets were used to evaluate the statistical results of the material property test data that then defined the allowable ranges for the acceptance criteria in the material specification. The remaining thirteen (13) lots of material were then manufactured to this final specification. In the end, nearly 2,000 Lot Acceptance tests were performed with zero material rejections. As an example of the repeatability of the billet production, Figure 2 shows the results of bulk density measurements for all PICA billets within each lot.

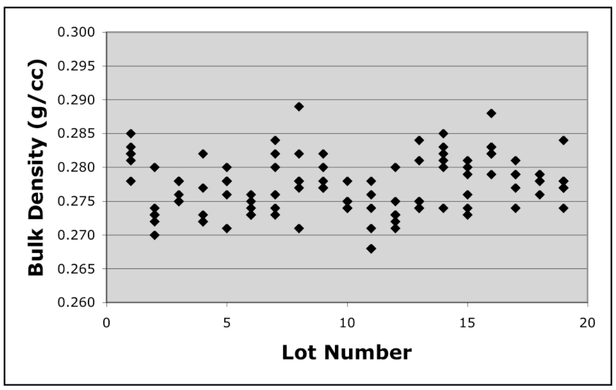

Figure 2: PICA Billet Bulk Density Repeatability

One of the unique challenges of bulk PICA material manufacturing is ensuring that the phenolic content is uniform through the thickness of a billet. Since the PICA material system had only recently been brought out of "moth-ball" status, it was critical to ensure that the current materials and processes yielded uniform phenolic through the billet. Due to the aggressive manufacturing schedule, every MSL PICA billet was allocated to tiles or test coupons and there was little material available for infiltration studies. Creative cut plans within two billets allowed for a slice, through the thickness of the billet, which could be used for this study. One of these slices yielded forty small samples, distributed in four rows from billet top to bottom, and each sample represented 0.02% of the total volume of the billet. Thus the phenolic content uniformity, through the thickness of the billet, could be evaluated at a fine level. The samples were heated and weighed to determine the phenolic content initially in each sample. Figure 3 shows the percentage difference of phenolic content for each sample compared with the billet's bulk phenolic content measurement.

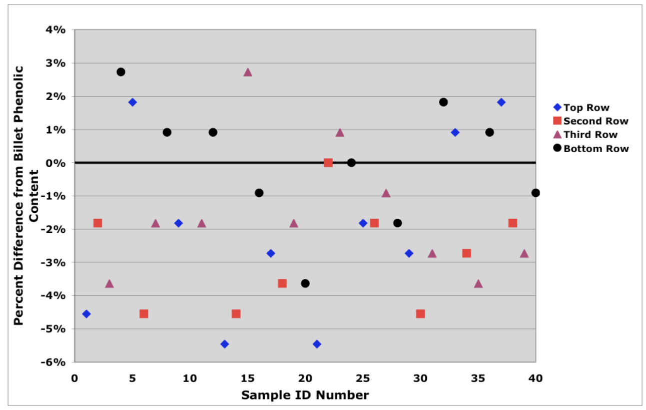

Figure 3: Phenolic Infiltration Uniformity

The data shows no strong trend from the billet top to the billet bottom, though half of the samples within the bottom row had a phenolic content slightly higher than the billet's bulk phenolic content. Overall, this data shows excellent phenolic content uniformity through the billet thickness. The second billet yielded similar results, and this study provided confidence that the current PICA manufacturing materials and processes yielded uniform billets.

Conclusions

The unprecedented, late change of the MSL heatshield TPS material resulted in an aggressive schedule for the manufacture of the PICA material for the tiled heatshield system. As a result, the material manufacturing and specification development efforts were performed in parallel. Additionally, there was little material available for processing verification through the thickness of the billets. In the end, nearly 2,000 Lot Acceptance tests were performed with zero material rejections. Additional testing to determine phenolic uniformity through the thickness of two billets showed excellent uniformity. In total, this data yields confidence that the heatshield tiles machined from the PICA billets will perform as expected during the MSL entry into the Martian atmosphere.

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References

1. Tran, H., et. al., "Phenolic Impregnated Carbon Ablators (PICA) as Thermal Protection Systems for Discovery Missions," NASA TM 110440, April 1997.
2. Kontinos, D., Stackpoole, M., "Post-Flight Analysis of the Stardust Sample Return Capsule Earth Entry," AIAA 2008-1197, January 2008.