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Space Shuttle Stiffener Ring Foam Failure Analysis, a Non-conventional Approach

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The Space Shuttle Program was all too familiar with the dangers of solid rocket booster (SRB) foam debonding and potentially striking the Shuttle during ascent into space. The Space Shuttle Program used lightweight, rigid polyurethane foam for cryogenic tank insulation and for structural protection of the SRB stiffener rings. Although the foam application on the stiffener ring was not in the flight path of the Shuttle; during ascent, a piece of foam could have become caught in the flight turbulent flow and re-directed back into the Shuttle Aft Engine Compartment or the External Tank.

During the years of the Space Shuttle Program, tens of thousands of hours were spent optimizing the process parameters and studying the chemistry of the foam in order to produce a successful application. The foam application process called for an initial bond coat of 1/8 inches to be applied and then successive layers until the ten inch thick application was completed. Extensive "trial and error test matrix" studies were conducted to control the application parameters such as the urethane two part mix ratios, operator application techniques, and humidity and temperature control of the solid rocket motor structure as well as the facility. The chemistry of the foam also underwent two formulation changes of the catalyst and the blowing agent in response to environmental regulations; which added additional variables and an overall confusion to the true mode of failures.

For example, during the preparation of the SRBs for the STS-117 mission; four foam application attempts failed. The foam failure was submitted to the NASA, Kennedy Space Center Chemistry laboratory for failure analysis. When previous foam applications failed; the classical methods of failure analysis: evaluating the process, performing chemical residue extractions for adhesive failure, bulk mechanical testing and fracture analysis, did not provide the root cause of the failure of the foam.

A new approach had to be found. Realizing that foam is the ideal media to document and preserve its own mode of failure; thin-sectioning was immediately identified as a logical approach for foam failure analysis. To observe the foam cell morphology, the foam samples were cross sectioned at 90 degrees relative to the application to observe the three dimensional morphology of the cells. The morphology was examined by polarized light microscopy (PLM) and scanning electron microscopy (SEM).

SEM analyses of the foam cells discovered that the bond coat cells had been distorted 40 to 100 times larger than the normal size. This was due to the expansion of the second layer application while the bond coat was still uncured. The failure occurred within a narrow range of approximately 500 micrometers of the bond coat. Using the special cross-section technique and then examining the cell foam morphology, provided a much greater understanding of the foam failure modes than previously achieved. The Shuttle is no longer with us, but this failure analysis approach will be applied to America's next generation of spacecraft using the Space Shuttle legacy flight hardware.

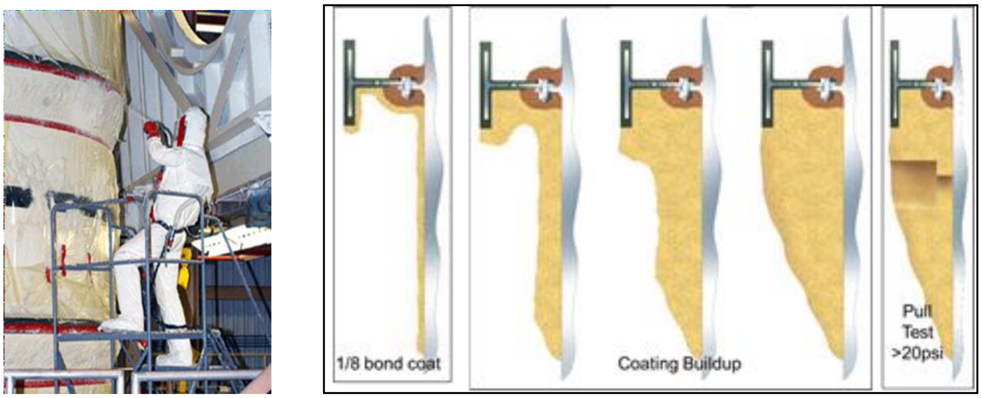

Figure 1. Application of the foam to the SRB stiffener rings and the build-up by layers.

Figure 2. A two foot section of foam application that failed at less than 10 pounds per square inch (psig) pressure which for a normal application should have been 50 psig.

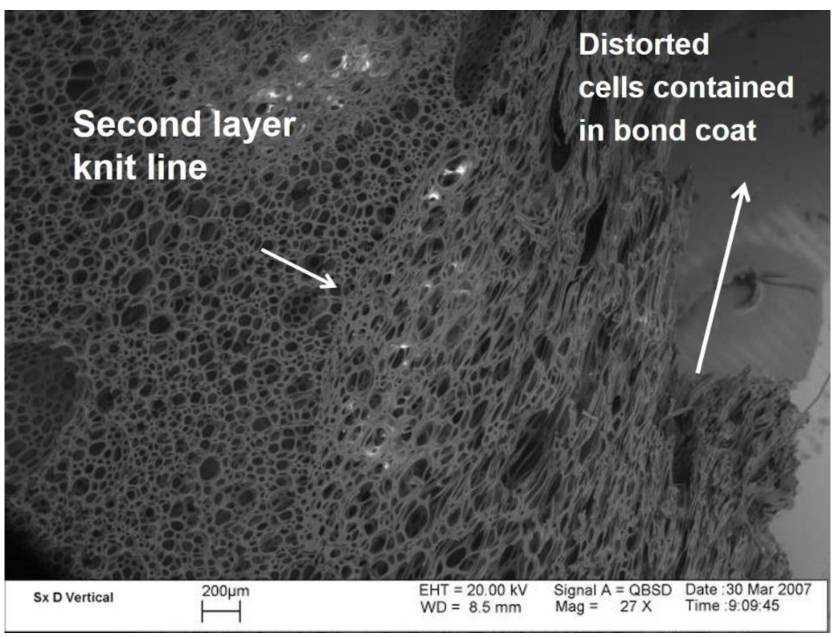

Figure 3. Cross-section examination of the foam revealed that the bond coat had not been cured before the second coating distorted and destroyed structure of the bond coating.