IV Conferencia Panamericana de END
Buenos Aires – Octubre 2007

Development of Natural Flaw Samples for Evaluating Nondestructive Testing Methods for Foam Thermal Protection Systems

Gary L Workman, Jason Davis, Seth Farrington, and Chris Spalding
University of Alabama in Huntsville
Huntsville, Alabama, 35899, USA
Telephone: 1.256.8246578
Telefax: 1.256.8246791
Email: workmang@uah.edu

James L Walker
National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama, USA 35812

ABSTRACT

Low density polyurethane foam has been an important insulation material for space launch vehicles for several decades. The potential for damage from foam breaking away from the NASA External Tank (ET) was not realized until the foam impacts on the Columbia Orbiter vehicle caused damage to the Wing Leading Edge thermal protection systems (TPS). Development of improved inspection techniques on the foam TPS is necessary to prevent similar occurrences in the future. Foamed panels with drilled holes for volumetric flaws and Teflon inserts to simulate debonded conditions have been used to evaluate and calibrate nondestructive evaluation (NDE) methods. Unfortunately the symmetric edges and dissimilar materials used in the preparation of these simulated flaws provide an artificially large signal while very little signal is generated from the actual defects themselves. In other words, the same signals are not generated from the artificial defects in the foam test panels as produced when inspecting natural defects in the ET foam TPS.

A comparison of images between natural flaws and machined flaws generated from backscatter x-ray radiography (BSX), x-ray laminography, terahertz imaging and millimeter wave imaging show significant differences in identifying defect regions. In order to improve detection of critical voids during the evaluation of potential NDE methods, it became necessary to create more realistic voids similar to what actually occurs in the foam during manufacturing operations. These flaw creation techniques were developed with both sprayed foam and poured foam used for insulation on the External Tank. Test panels with simulated defects have been prepared and distributed to various laboratories to evaluate the potential of their NDE methods for the inspection of the External Tank.

1. Introduction

A major part of evaluating and verifying NDE methods is to prepare test specimens with simulated flaws to determine the method's actual capabilities in finding and quantifying the various types of flaws which can occur in production. Traditionally most of the simulated flaws embedded in spray test panels were implemented with machined voids and Teflon inserts which could be inserted into a foam panel prior to and during spray and pour operations. The NDE methods listed above display the most potential for detecting voids in foam and also require inspector interpretation of the existence of voids from image maps created in single-sided scans on the test article. The smooth surfaces of the machined voids and the Teflon insert are easily picked up by the human eye than the void itself in the interpretation of these image maps.

The types of voids which occur under natural processing look significantly different from the smooth straight surfaces of a machined void. Figure 1 shows an example of natural void formation. Notice the lack the symmetry and straight lines or smooth surfaces.

Figure 1. Example of a naturally occurring void.

2. Natural Void creation

Natural voids have been prepared in several different ways to enable a more realistic evaluation of what flaws in production might look like to the NDE methods under consideration,. For spray operations the “shadow method” has been used to create voids at several locations over the foam acreage, PAL Ramp and Flange regions. Figure 2 shows an example of the process used to create the type of void shown in Figure 1 using a single object to block part of the spray stream. The general approach is to place an object in the path of the sprayed foam leaving a void in the area behind the object. Typically this object is sized proportionately to the size of void desired. Multiple voids can be created on a test panel using multiple objects assembled with wire or fishing line tied to a frame. The foam can then be sprayed onto the panel through the assembly of objects in several quick thin layers. The objects block the foam in small areas, thus allowing the foam to rise and build up around the void. The voids are then closed out with a tangential shot across the top of the voids. This method does not create small voids easily with 0.25” being about the smallest that can be reliably created.

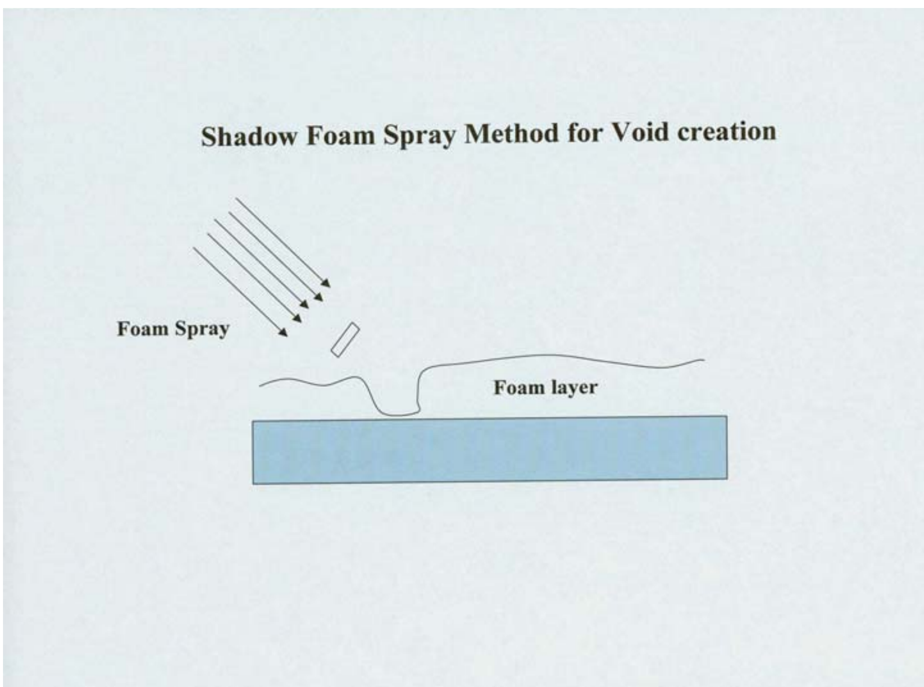

Figure 2. Shadow Method for Natural void creation

A natural void creation method for poured foam uses air injection into the rising foam. Figure 3 shows a schematic of the process. Once the containment apparatus is assembled and after some practice, the voids are fairly consistently formed. This method works well when care is taken to insure that the air does not come out with the inlet tube as it is extracted. Also the shape of the void has a fairly large range, depending upon whether the containment is a low pressure container (such as a plastic cup) or a high pressure metal mold.

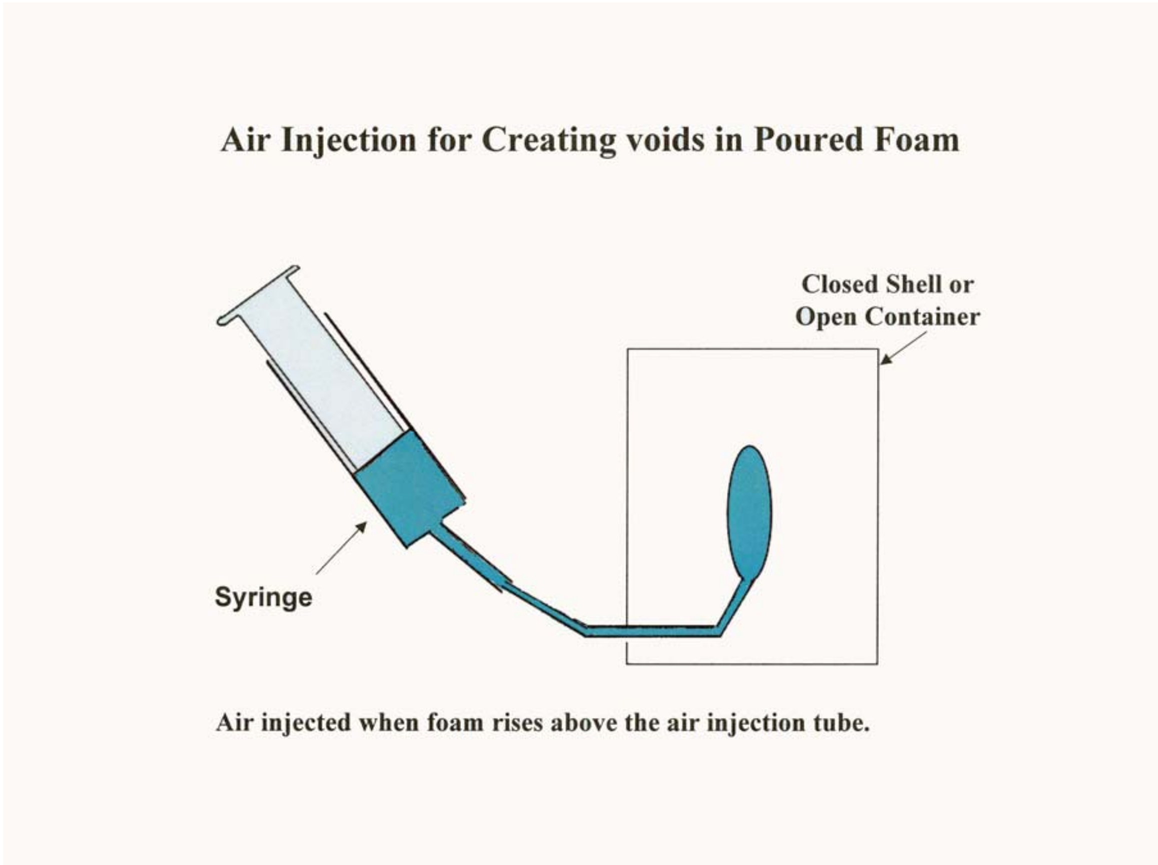

Figure 3. Air injection Method for Natural Void creation

Experiments have also been performed to investigate a "hybrid method," which is a variation of the above methods. In this method machined holes larger than the desired dimensions of the final void were formed and a wire brush was then used to rough up the surfaces and prepare them for a small addition of more foam. This final step was to spray a small amount of foam into the hole, giving it the appearance of a natural void. The roughed up surfaces broke up the smooth edges of the machined holes to reduce the inspector's focus on the symmetric edges of the machined surfaces. This approach did somewhat improve the indications from the voids. It was also noted that similar improvements were observed for the natural voids when no vertical paths due to machined surfaces (or sharp breaks in consistency from these surfaces), existed around the foam insert containing the void as shown in Figure 4.

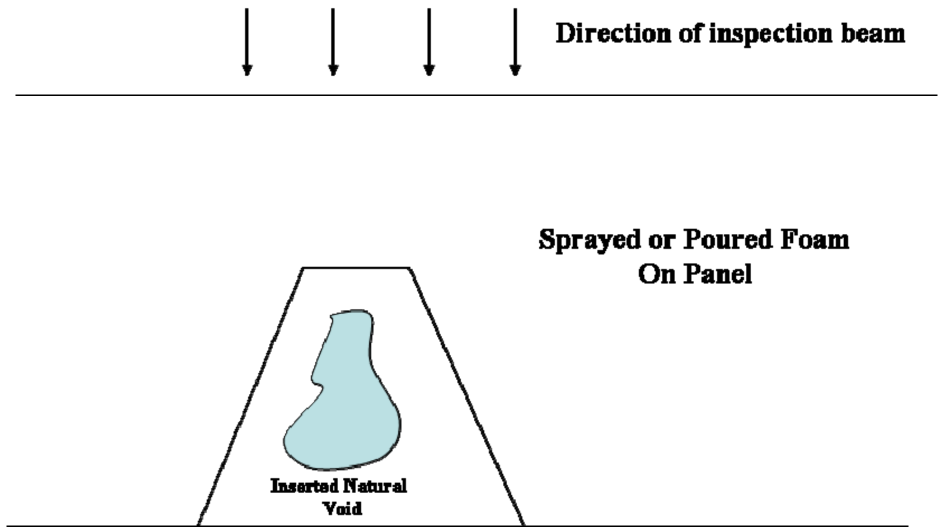

Figure 4. Effect of Void Insert Geometry

The results of an experiment to compare these approachesis shown in Figure 5. The four columns compare the four approaches using the Backscatter x-ray imaging by preparing a sample containing machined flaws, machined flaws which are then roughed up to eliminate smooth surfaces, hybrid flaws as described above and natural flaws. Note that when comparing images of each column; the images of the natural voids are more difficult to pick out quickly since rounded smooth surfaces are not present.

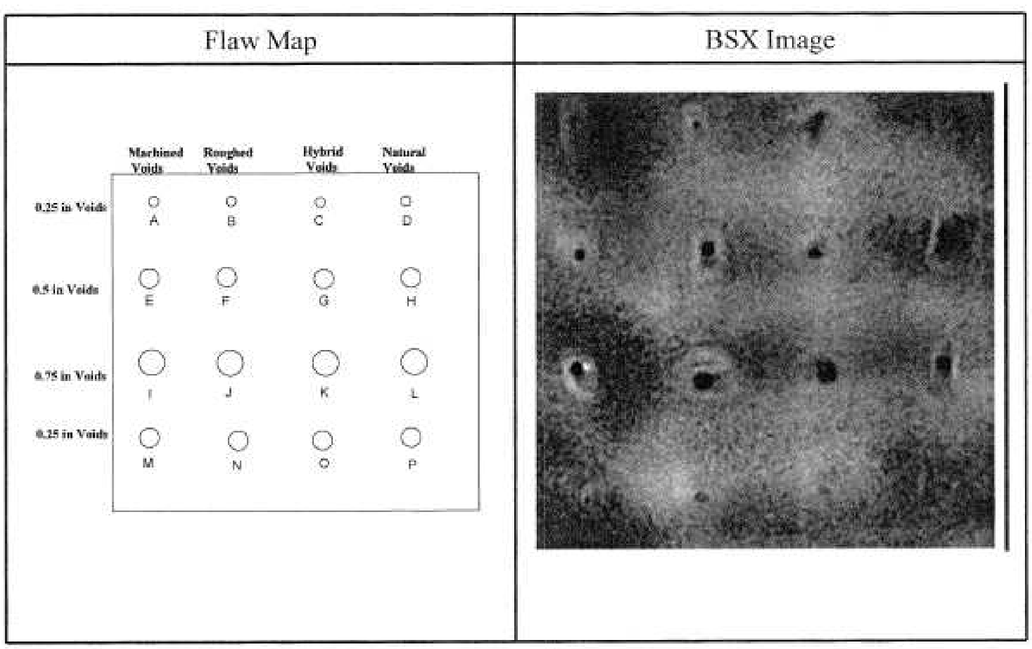

Figure 5. Flaw map and BSX Image of panel comparing machined, roughed, hybrid and natural flaws.

It is normally difficult to hand place a large number of voids with good positional accuracy since there is approximately a 5 sec window in which the voids can then be placed on the newly sprayed foam before it is too hard to be of any adhesive value. This problem led to the investigation of another new concept called the Plexiglas Frame Mapping method, which is able to place a number of flaw inserts onto the sprayed panel at a particular height of the SOFI in a single step. In this method a grid is constructed that will allow positioning all the voids correctly on a Plexiglas frame with pins prior to the spraying, as shown in 6.

This method essentially uses the foam itself as the glue which will eliminate the problem of seeing the glue instead of the void. The inserts are formed initially using the voids created with the Shadow Method described above using inserts attached to pins at the locations desired for the voids This method also works for panels with voids at different heights as a different Plexiglas frame can be prepared for each level in which voids are to be place. It's also possible to place inserts at several levels if several Plexiglas frames are set-up to apply the inserts to the foam.

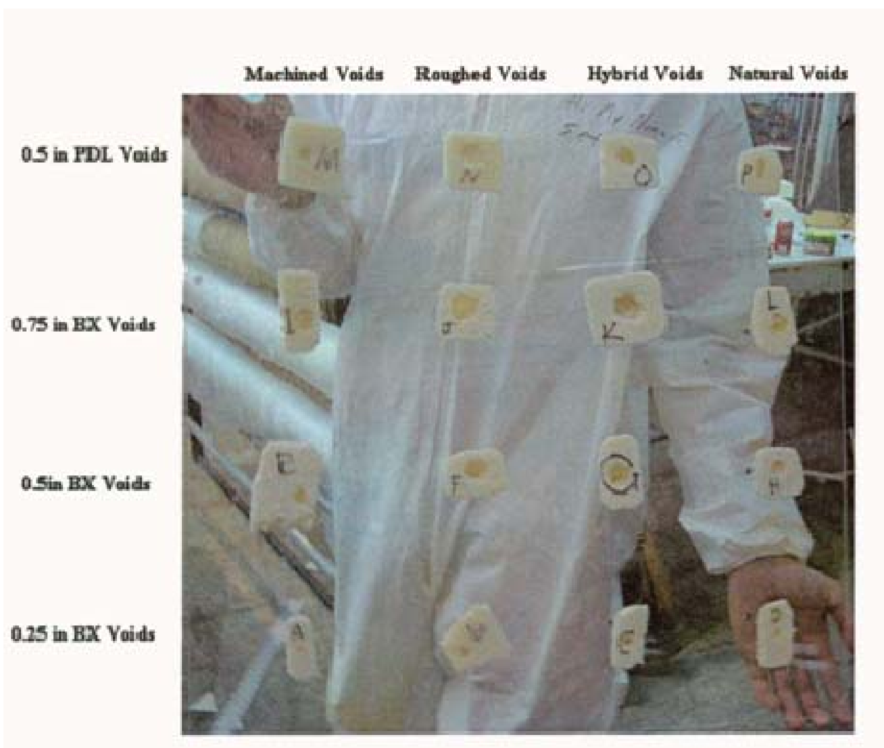

Figure 6. Plexiglass Panel with multiple flaws inserts

The Projection Method was developed to improve the ability to place simulated inserts into a test panel at several levels with accurate positioning similar to the Plexiglas Frame method above. This method uses a projection on the spray surface to identify where the inserts are to be placed using a layout schematic in Powerpoint. This method worked well in trial runs and shows a lot of potential for complex test panels.

3. Conclusions

A variety of methods for creating simulated flaws in foam test panels has been demonstrated. This list includes several new methods which incorporate more realistic flaws as would occur on the External Tank Spray-On-Foam-Insulation and the Ice Frost Ramp (IFR). Both the Shadow and Air Injection voids were used to prepare several test panels simulating the PAL Ramp, Flange regions and IFR for evaluation of potential NDE methods for these regions of the External Tank. The Plexiglas Frame and Projection Methods are two methods which have not been incorporated into official test panels for distribution yet; but do show promise for preparing complex foam panels in which a large number of flaws are required for statistical or probability of detection activities.

Acknowledgements

In addition to the authors, Gene Nelson, Zack Taylor and Austin Webb also assisted in the foam spray and pour activities. This work was funded by the NASA Engineering Safety Center through the NDE Laboratory at Marshall Space Flight Center on cooperative agreements NCC8-200 and NNN05AA22A.