2019 Insensitive Munitions & Energetic Materials Technology Symposium
Seville, Spain

Structural Analysis of Commonly Used Materials for Slow Heating Ovens and Their Effects on the Projection of Hazardous Debris

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Oven construction is an extremely important factor when properly setting up a Slow Cook-Off (Slow Heating) test. While each test facility utilizes their own unique methods to achieve the thermal requirements, many considerations must be taken into account to ensure the thermal requirements are met.

Per STANAG 4382 Ed (2) 2003, 'The oven should be constructed so as to provide the least possible confinement for any reactions that occur, and it should have a window to permit video coverage'. Additionally, 'The presence of the oven will affect the blast pressure, so the oven should be as light as possible'. The requirements in this STANAG are generic and do not specify the metrics for the construction of the oven. This leaves a wide variety of materials to choose from during material selection. Typically, test facilities tend to select materials that are convenient for their unique oven construction, based on their r-value and strength to support and protect their equipment. Unfortunately, robust materials are used that result in overly confined ovens, preventing clear evaluation of evidence from the munition reaction.

Oven materials should be selected based on more than r-value and equipment support/protection. Fragment projection, propulsivity, and blast pressure evidence should also be considered. It may be acceptable to use a slightly more robust design for large munitions, and munitions that are expected to react violently (Type I, II, III) as the reaction evidence might be more obvious, however; smaller munitions, and munitions that are expected to react benignly (Type IV or V) require much lighter construction to allow for evidence such as hazardous fragment projection, blast pressure, and propulsivity. Regardless of test facility and equipment circumstances, oven construction material must be selected to meet all the requirements per STANAG 4382. It is extremely important to not inhibit hazardous fragment projection, especially when evaluating TYPE IV and TYPE V reactions. This paper compares how commonly used oven construction materials can affect hazardous fragment projection, discusses supporting modeling analyses, and provides a recommended acceptable oven material and design for evaluating any munition, regardless or reaction type. Moreover, this paper raises the topic to the IM community that an issue exists regarding the construction/design of oven materials, and the importance of its negative impact on the proper evaluation of munition response to Slow Heating tests, especially those that may result with a benign (Type IV/V) reaction. Initial analyses have been to verify the concern, however planned/required future work is proposed to quantify the solution through experimental test and evaluation.

1. Introduction

When conducting a Slow Cook-Off (SCO) test in accordance with STANAG 4382, an oven is used to provide a control volume to simulate an environment in which a munition is subject to a constant rate of heat flux. In most cases, the oven used for each test is uniquely designed for each specific munition under test. The oven must meet several specifications in order to meet the requirements of the test. The ovens must be constructed with thermally insulative materials, and in many cases be sturdy enough to mount components for the test such as heating elements, and cameras. Historically, common materials used to construct these ovens include: silica based foam board (left), foam (bottom left), steel sheet metal, and plywood & double pane glass (below).

Figure 1. Silica-based foam board (top, left/right), foam-board (bottom left), steel sheet metal, and plywood & double pane glass (below).

Aside from meeting the test requirements, test facilities typically select their preferred materials based on several other factors, including: material availability, cost, workability; as well as strength to support heavy/complex equipment and weather durability.

Oven volume must also be spacious enough to provide room for thermocouple placement and clearance between item and oven walls (Figure 2). Very large ovens tend to require support systems (brackets, braces, etc.) to support the integrity of the oven walls, especially enduring extreme heat throughout a long time duration (e.g. several days).

While the materials being selected based on these additional factors lead to a robust design for the test facility to successfully complete the SCO test, the design / materials end up inhibiting the munition response, skewing the test results. Not only do robust designs risk reducing pressure data from response blast, but they reduce fragment debris projection by reducing/eliminating fragment kinetic energy and array dispersion.

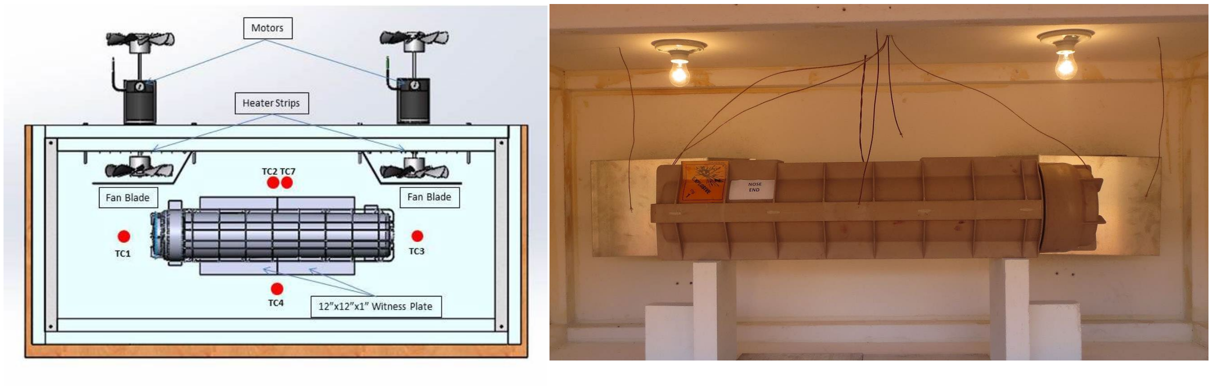

Figure 2. Example of oven design space.

Most importantly, sturdier ovens make it difficult to determine whether a munitions reacted with either a Type IV or Type V response as the tougher walls prevent debris from being projected. This is extremely important as this is a point at which a Program Manager must decide whether to invest defense funding to further improve the IM signature of a munition, or if the munition is IM compliant and “safe” for fielding. In many instances, Program Managers have already spent time and funding to improve a munitions response to SCO from Type I to Type IV/V and a SCO test is conducted for verification of the IM technology/design. Proper evaluation of this verification test is extremely important, as this may determine whether the munition requires additional IM improvement, or if it is ready for production.

2. Test & Analysis

Various candidate materials have been used in the past by a number of test facilities. One common SCO oven design utilizes walls consisting of silica-based foam board (Super Firetemp L). Another design utilizes foam walls (Thermax and ductboard). In an effort to obtain the highest practical “transparency” to debris projection, modeling and testing were planned to investigate the extent to which data would be lost if the lighter foam oven wall design was not used.

Super Firetemp L has a density of 20pcf, and a compressive strength of 450 psi at 10% deformation according to its datasheet. Thermax has a density of 2-3 pcf and a compressive strength of 25psi at 10% deformation. The areal density difference alone is considerable, however even more problematic is the significant amount of strength the Firetemp has, giving it a ceramic-like stiffness.

Preliminary analysis was performed using the EPIC hydrocode. EPIC is a Lagrangian high rate continuum hydrocode which can use tetrahedral elements and conversion to smooth particle hydrodynamics (SPH) particles based on excessive grid distortion. Custom material models were constructed based off the limited data available in the datasheets. A linear stress-strain response was assumed up to the compressive strength, at which point failure was assumed to occur. Describing permanent compaction of porosity would require a more detailed model. The shear modulus and bulk modulus were calculated from the modulus of elasticity and an estimate of the Poisson’s ratio. These parameters are required to estimate the volumetric and deviatoric response of the material in a code that is designed to model shock physics and plastic flow. Failure was treated by turning off the material’s strength if the yield criterion was exceeded and any “plastic flow” occurred. A small number of high rate continuum modeling calculations were performed to investigate the interaction of a typical fragment with an oven wall. A 2” oven wall was assumed, and a 60g projectile, such as a fuze being ejected from a warhead, was assumed to be thrown at 20J (25 m/s, or ~56 mph). Clearly no perforation of the Firetemp is predicted, whereas only a 12% velocity loss is expected for the Thermax/ductboard, shown in Figure 3.

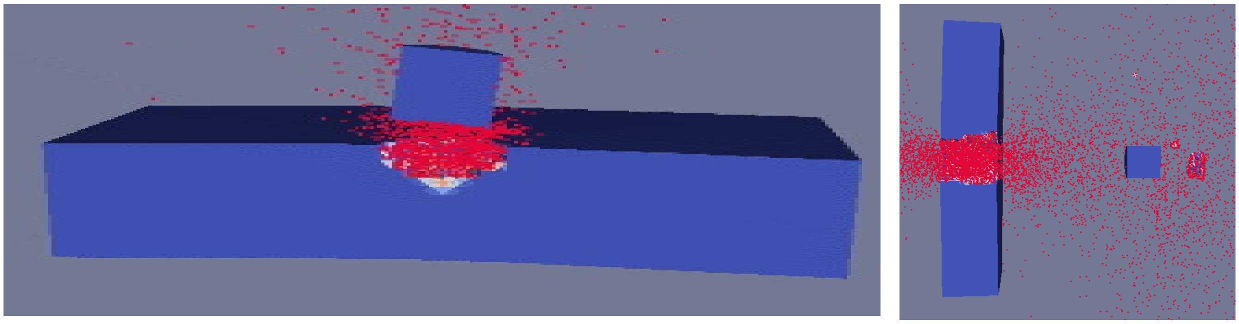

Figure 3. Silica Based Foam Board (Super Firetemp L), density 20pcf, 450 psi compressive strength – no perforation, bounces off (left); Thermax/Ductboard, density 2-3 pcf, 25 psi compressive strength – 12% velocity reduction (right).

Hydrocode predictions are only as good as the material models they utilize, and the response of nonmetallic materials can be quite challenging to quantify, especially based on limited static test data. As a result experimental verification of models should always be performed to the extent practical when important decisions are to be made based on the results. An air gun is currently being constructed at Picatinny Arsenal to experimentally determine what materials it makes sense to use for the oven, and what kinds of velocity reductions to expect. It consists of a steel tube with a plastic sabot that can launch a projectile at various velocities of interest. The setup is shown in Figure 4 for a 1.25” diameter, 2.4” long, 130g aluminum fragment.

Figure 4. Air gun for fragment wall penetration studies

Various masses, impact velocities and obliquities against the oven walls will be tested, and quantities such as ballistic limit and residual velocity will be obtained. This experimental data will help provide the IM community with better guidance for constructing ovens for the SCO test, and provide a better understand the importance of how the materials influence the test results.

Additionally, the data obtained through a combination of modeling and experiment can be used to make better predictions about whether dangerous fragments were thrown. If velocity reduction through the oven wall is reasonably low and can be reliably predicted as a function of mass, velocity and obliquity, a modification to the 20J fragment projection curve in the STANAG specific to the SCO test that accounts for the oven wall may be possible.

3. Conclusion

Determination of the type of reaction in Insensitive Munitions testing is based on several types of evidence including fragment projection, propulsivity, and blast pressure. In SCO testing these types of evidence can be affected, if not entirely suppressed, by the oven walls. To this end it is desirable that the oven materials should be selected based on more than r-value and equipment support/protection. However, care should be taken when designing the oven to ensure the oven does not fail due to breaches from minor propulsive events (e.g. medium caliber primers) during the test and prior to the major munition response of interest, which otherwise would result in loss or disruption of the oven temperature and declaration of a No-Test. This is a topic for further discussion in a follow-on paper which should also be included in future guidance for STANAG 4382.

Oven construction material must be selected to meet all the requirements per STANAG 4382, and thus if Type IV / V reactions are expected, lighter (less inhibitive) materials should be used. Modeling has been performed to estimate the response of candidate oven materials to debris impact at velocities of interest. These predictions indicate that oven construction based on preferred materials from a heat transfer standpoint are suppressing potentially hazardous debris that could affect the type of reaction that is declared, and that such debris should be reasonably expected to pass through a lighter oven material. In light of this, an air gun is being constructed to experimentally determine the velocity reduction of various sized fragments, at various impact velocities and obliquities. This information may be utilized to provide guidance on material selection for SCO ovens, and possibly to modify the projection criterion in the STANAG to account for debris passing through the oven walls.

In an effort to completely quantify the influence candidate oven materials has on munition projection debris through experimental test and evaluation, this future proposed work should be supported by the IM community. The results of these analyses will benefit the IM community, as excess time and funding due to inaccurate result evaluation can be avoided, and the confidence of munition IM-ness (munition safety) can be warranted.

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