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SLOW HEATING TESTING OF HIGH DENSITY POLYETHYLENE FOAM DUNNAGE FOR 40-MM M430A1 GRENADE PACKAGING

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U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND ARMAMENTS CENTER

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14. ABSTRACT The packaging of various ammunition items throughout the Department of Defense uses polyethylene foam. Polyethylene foam provides dunnage, cushioning, and filler material that is dependable through a wide variety of temperatures and environments at a low cost. The polyethylene material does begin to lose stability at a high temperature and begins to melt at temperatures above 230 °F. For insensitive munitions systems that are tested at elevated temperatures, the melted polyethylene material can become detrimental to venting mechanisms. This report documents a series of inert slow heating tests to characterize high-density polyethylene packaging foam when exposed to slow heating.						
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INTRODUCTION

High-density polyethylene (HDPE) foams are widely utilized throughout the packaging industry to provide protective cushioning during shipping, storage, and rough handling. The Packaging Division at the U.S. Army Combat Capabilities Development Command (DEVCOM) Armaments Center (AC), Picatinny Arsenal, NJ, uses several classes and grades of HDPE foam (non-crosslinked) with unique properties specific to ammunition packaging. These military grade foams are specified in Commercial Item Description A-A-59136 (ref. 1), which includes requirements for density, temperature stability, electrical resistivity, Lower Explosive Limit, and dynamic cushioning amongst others. The HDPE foams are highly effective at providing cushioning and protection to ammunition items during rough handling in regular operational use temperatures.

Safety of ammunition items throughout their lifecycle is an ongoing concern for the U.S. Army. Insensitive munitions (IM) research is ongoing to develop various technologies that make ammunition less sensitive to external stimuli such as accidental fires. Energetic venting mechanisms such as melt rings have been shown to significantly reduce ammunition reactions to thermal cook-off events. Venting mechanisms for ammunition and packaging containers are designed to release internal pressure due to gas generation during unintended heating of explosives, propellants, and pyrotechnics. This helps to prevent a dangerous gas pressure buildup that can result in an explosive or detonative reaction. The packaging and dunnage required to protect ammunition during shipping and rough handling can hinder these venting mechanisms' performances at the system level.

For a full description of IM tests and response descriptors, see MIL-STD-2015 (ref. 2) or the North Atlantic Treaty Organization (NATO) Allied Ordinance Publication AOP-39 (ref. 3).

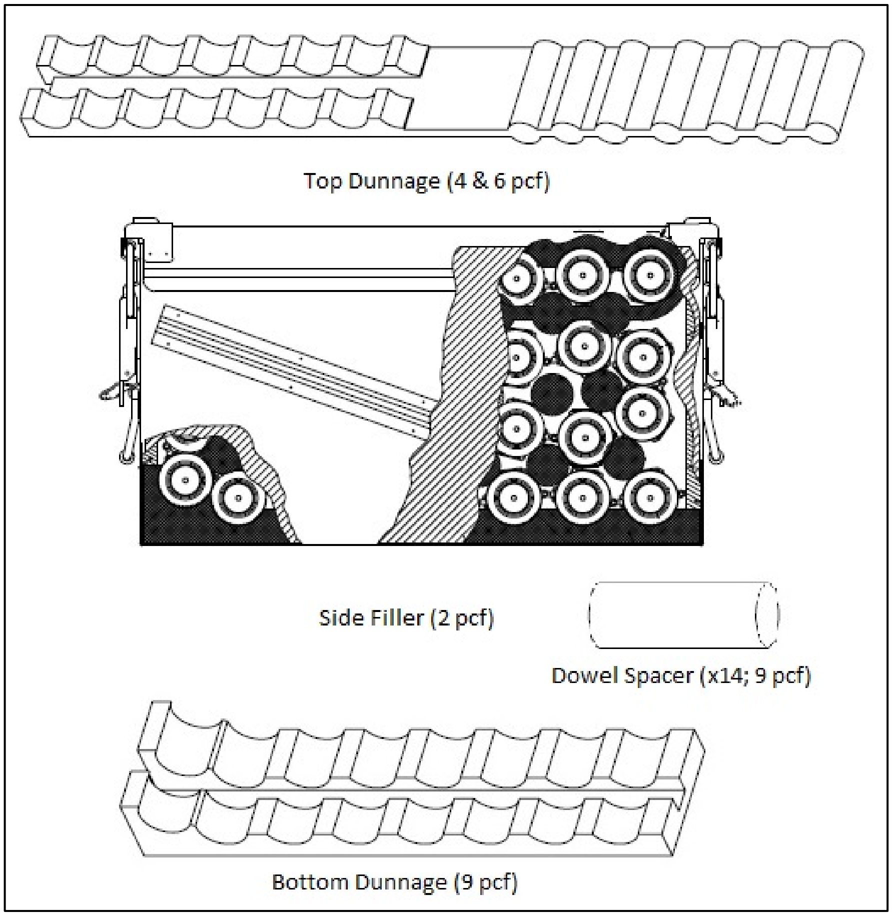
BACKGROUND

The Joint Program Executive Office (JPEO) Armaments and Ammunition tasked DEVCOM AC to improve the IM reactions of the 40-mm high-velocity M430A1 high-explosive dual purpose (HEDP) grenade (fig. 1). The warhead, propulsion, and packaging groups each developed technologies to mitigate cook-off reaction of the ammunition. The propulsion group developed a venting plug that allows propellant to safely vent through a large hole in the cartridge case. The warhead group developed a plastic melt ring that detaches the fuze, allows the high-explosive fill to vent safely, and prevents a detonation. The packaging group developed a vented container design to allow the propellant and high-explosive gases to escape the package and minimize system confinement. While all of these individual technologies were demonstrated successfully at the component level, an integrated system level cook-off test resulted in a violent detonative reaction. This test failure was actually more violent and produced blast overpressures greater than the baseline unvented configuration.

Figure 1
40-mm M430A1 HEDP grenade

The development team began a root cause analysis to determine the cause of the violent reaction. The HDPE foam dunnage used to cushion the grenades within the packaging container was identified as a potential contributor. Figure 2 shows the vented PA120 ammunition container and cutaway view of internal packaging for the M430A1. Each PA120 ammunition container holds 32 linked grenades. The grenades are cushioned from the steel container and each other by a combination of foam dunnage pieces with densities of 2, 4, 6, and 9 lb per cubic foot (pcf) depending on the required cushioning (ref. 4). Figure 3 shows the HDPE foam dunnage used within the packaging system. The HDPE foam occupies about 418 in^3 of volume out of a total container volume of 930 in^3, approximately 45%.

Figure 2
Vented PA120 container and cutaway view of internal packaging



Note: Figure not to scale.

Figure 3
M430A1 HDPE foam dunnage

The HDPE foam is a thermoplastic material because it may be shaped into a solid item, remelted, and reshaped into another solid item. This ability to remelt and recycle HDPE is highly desirable. This also means that the material will begin to transition from solid to liquid phase at elevated temperatures. The HDPE foams do not have a specific melting point since they can have various densities, porosities, or other factors that may affect the melting point. Polyethylene is usually cited with a processing temperature at which the materials is amorphous (ref. 5). This is generally above 340 °F (171 °C) but can be higher or lower depending on the method of production. In its amorphous processing state, polyethylene is viscous and non-Newtonian. U.S. Army packaging is generally tested at temperatures ranging from -65 °F up to +160 °F; however, foam cushioning curves are usually generated at ambient conditions only. Cushioning tests at elevated temperatures revealed that HDPE foams can begin to lose significant mechanical strength above 140 °F (ref. 6).

TEST RESULTS AND DISCUSSION

High-density Polyethylene Foam Characterization Test

In order to evaluate the potential contribution of the HDPE foam to cook-off reaction violence, a slow heating test was conducted using samples of HDPE foam at each density. As a precaution, the ramp rate was modified to hold temperature steady during nonworking hours. Five samples each of 2, 4, 6, and 9-pcf density HDPE foam were cut into 2 x 2 x 2-in. cubes. Additionally, five samples of the foam dowels shown in figure 3 were cut to 2-in. lengths since these pieces were measured to have a density of 10 pcf. A total of 25 samples were subjected to the slow heating test. Figure 4 shows samples representative of the cubes and dowel placed on stainless steel test panels. One sample from each density had a 14-g steel washer placed on top to simulate minor loading. The dowel sample had a smaller 7-g washer due to its smaller diameter (approximately 1.3 in.).

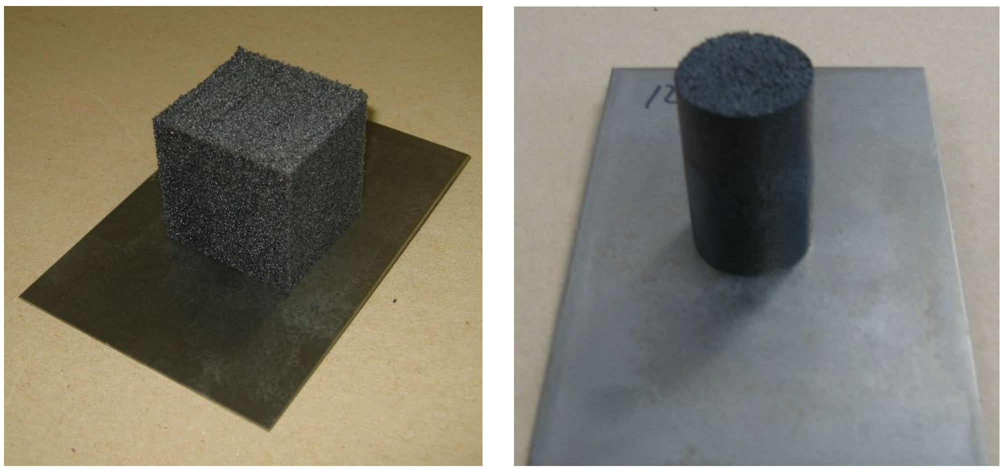
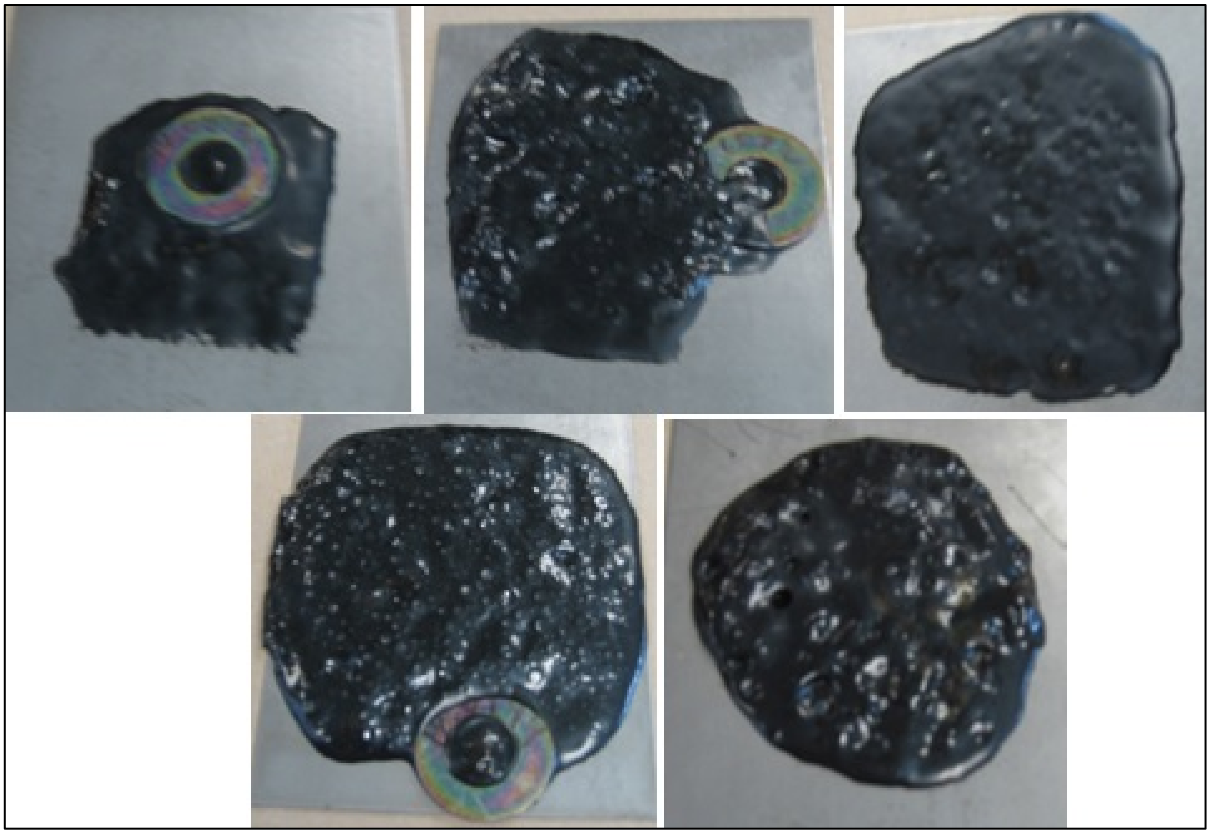


Figure 4
Representative pretest samples on stainless steel test plates

The 25 samples were placed into a large programmable convection oven and conditioned to 165 °F for 15 hr. After the overnight soak, the temperature was ramped at 6 degrees per hour for 10 hr up to 225 °F. The temperature was again held steady at 225 °F overnight as a fire safety precaution. The 6 degrees per hour ramp was started again the next morning after a 14-hr soak at 225 °F. At that point in time, all 25 samples appeared normal through a viewing port in the oven. There was no visible difference in any samples including those with a washer on top. Opening the door and physically inspecting the samples was not possible as it would cause a large temperature drop. The first visible sign of melting was observed at a temperature of approximately 240 °F (116 °C). All of the 2-pcf samples quickly lost approximately half their initial height. The 4-pcf samples had shrunk by approximately 1/4 of their initial height. The 6 pcf, 9 pcf, and 10-pcf dowels still appeared unchanged. At an oven air temperature of approximately 246 °F (119 °C), all samples began to show signs of melting and slumping. The 2-pcf samples were all less than 50% of their initial height. All samples with washers caused the foam to tip over likely due to uneven loading. The samples all continued to degrade throughout the remainder of the day. At an oven air temperature of 285 °F (140 °C), all of the samples had completely melted and the test was stopped. The 2 and 4-pcf samples had begun to show signs of erosion with the edges beginning to dry out and form a hard crust. All of the samples had a visible surface shine and several began to leak off the sides of the flat test plates. The test items were allowed to cool overnight before physical inspection. Figure 5 shows the remaining test samples for each density of foam after the test.



Note: Top row from left: 2-pcf sample with washer, 4-pcf sample with washer, 6-pcf sample without washer. Bottom row from left: 9-pcf sample with washer, 10-pcf dowel sample without washer. Pictures are not to the same scale.

Figure 5
Post-test samples

Post-test examination showed that each sample created a strong adhesive bond to its test plate. Several efforts to remove the post-test remains were unsuccessful without damaging the sample. All of the foam samples began to melt well below the reaction temperature of the M430A1 HEDP grenade. These results reinforced the theory that the HDPE foam dunnage is melting over the grenade venting features and clogging the designed vent paths. Further full-scale testing was warranted.

Inert 40-mm Packaging Tests

Two slow cook-off tests were conducted using fully inert 40-mm cartridges and see-through containers. Size matched containers were assembled using high-temperature borosilicate glass to allow for visibility of the foam and inert test items during the test. New foam dunnage and linked inert 40-mm dummy cartridges were packaged in the borosilicate glass containers and subject to slow heating in accordance with NATO STANAG 4382 Edition 2 (ref. 7). Per the standard, the test item was conditioned at 122 °F (50 °C) for a minimum of 8 hr and then slowly ramped at 6 °F (3.3 °C) per hour. It should be noted that work has begun to revise the standard heating rate to 15 °C per hour, however, that is not expected to change the reaction of the HDPE foam. The first test was conducted up to a maximum temperature of 266 °F, which is just below the air temperature for the recorded propellant reaction. The second test was conducted up to 320 °F, which is just below the air temperature for the recorded explosive reaction. These temperatures were selected so that the foam state could be examined just prior to the failure of venting mechanisms. Figure 6 shows a clear container with the inert rounds packaged inside. Side filler foam dunnage is removed to show the general location of each round. Those fillers are 2-pcf flat foam planks and were included in the tests. A square grid was drawn onto the front and back to aid in evaluation of round movement post-test.

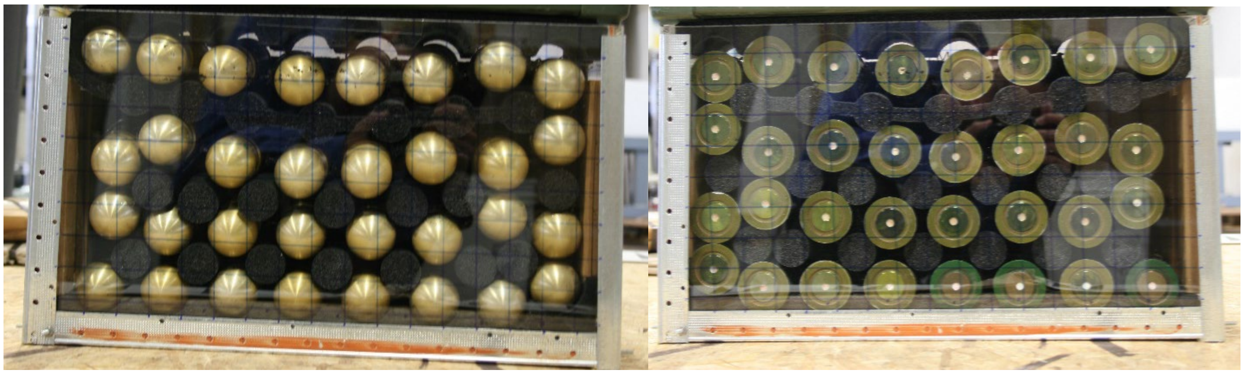


Figure 6
Clear container pretest, slide fillers removed

The first signs of melting in test 1 were observed around 233 °F oven air temperature when the side filler began to drop slightly and reveal the top row of rounds. At an air temperature of 243 °F, the rounds began to show signs of sinking as well. At 250 °F, the melting began to accelerate more rapidly. The side filler dropped by over 2 in. from the top of the container, and it was evident that the rounds were slumping down and forward onto the filler. By 266 °F, the side filler dropped over 4 in. The rounds were allowed to cool overnight. The next day, the inert rounds and melted dunnage were removed from the container as a single piece. There was minor resistance due to HDPE foam adhering to the glass, however, the entire mass of foam and cartridges slid out fairly easily. The top row of rounds was clearly slumped down and forward, which in turn pushed the lower layers of rounds aft inside the container. With the side fillers removed, the mass of inert cartridges and melted dunnage was placed back into the glass container and the round movement was analyzed via mapping software using the 1-in. square grid. The worst case displacement of 3 in. occurred in the top row of cartridges. Figure 7 shows the mapped movement of the noses and bases of each cartridge during test 1. Figure 8 shows the post-test remains. It is worth noting that the melted HDPE dunnage separated from the inert rounds easily. The adhesion was light and no HPDE residue remained on the rounds or the glass container.

Figure 7
Cartridge movement post-test 1

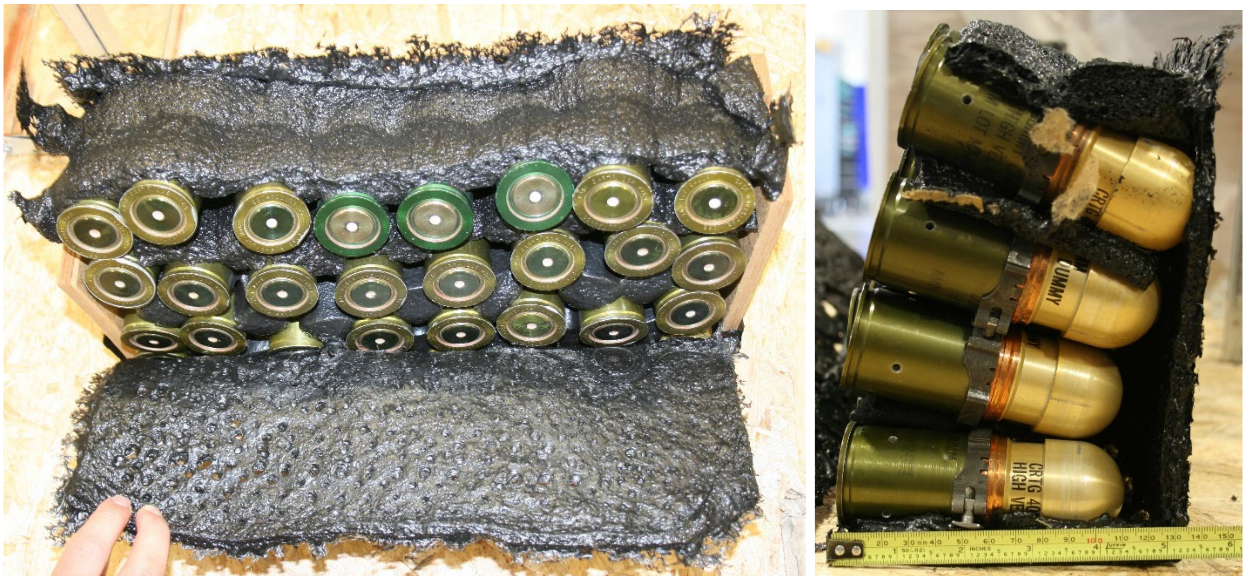


Figure 8
Post-test 1 remains; inert 40-mm slow heating

The second test was very similar to the first test up to 266 °F. As the temperature kept increasing, the melting and slumping of rounds became increasingly noticeable. At an air temperature of 300 °F, the foam dunnage melting was significantly worse than test 1. None of the pieces retained any of their original shape, and the material was in an amorphous liquid state. The top row of cartridges was clearly pushed all the way forward and resting against the inner glass wall of the container. The lower layers of cartridges were pushed aft inside the container as in test 1. After reaching a final temperature of 320 °F (160 °C), the test items were allowed to cool overnight. The next day, the rounds and melted dunnage could not be removed from the glass container due to extreme adhesion to the inside walls. The entire container had to be disassembled. The HDPE material was severely melted, and adhesion to the inert rounds was very high, permanent for all intents and purposes. Numerous attempts to remove the melted foam, including hot and cold temperature cycling, were unsuccessful. This suggests that the material reached its amorphous processing state temperature. The slumping of rounds was comparable to the first test as the rounds themselves act as positive stops. Figure 9 shows the post-test remains from test 2. Figure 10 shows the mapped movement of the noses and bases of each cartridge during test 2.

Figure 9
Post-test 2 remains; inert 40-mm slow heating

Figure 10
Cartridge movement post-test 2

This series of inert tests suggests that the HDPE foam used to brace and cushion 40-mm M430A1 grenades is causing a violent system level failure during slow cook-off testing. There are two mechanisms contributing to this. First, the melted HDPE foam loses its structural stability and cannot support the weight of the cartridges. This allows the top row to fall forward and compress each row of cartridges beneath it. This in turn adds resistance to the front of each cartridge and impedes the fuze from separating from the warhead. The linked configuration makes this worse since movement of each round affects those linked to it. Second, the melted foam becomes a viscous liquid with adhesive properties. The liquid HDPE flows over the venting mechanism, fills in the open vent area, and, in effect, reseals the fuze onto the warhead body. Previous component level testing of the vented 40-mm HDPE grenades showed that even slight resistance can prevent the warhead vent feature from functioning correctly.

SUMMARY AND CONCLUSIONS

The high-density polyethylene (HDPE) foam is widely used throughout industry and government as a cushioning and dunnage material. It is a low-cost commodity with excellent cushioning, chemical resistance, and environmental resistance properties. The HDPE foams have been shown to melt during slow and fast cook-off, become highly viscous, and clog venting mechanisms, therefore preventing successful pressure relief of explosive gases. Small-scale testing of sample HDPE foams shows that the material begins to melt and lose structural stability at approximately 230 to 240 °F with higher densities capable of withstanding slightly higher temperatures. Even the highest densities were not able to withstand exposure to 300 °F. Testing with inert 40-mm cartridges showed that the HDPE foam is not notably viscous up to 266 °F. After exposure to that level of heating, the material was still capable of maintaining some of its original form factor and did not adhere to its surroundings. Testing to over 300 °F revealed that the HDPE material reaches a liquid state and becomes highly adhesive. This reaction to high temperature exposure is detrimental to insensitive munitions venting features, especially in systems that contain a substantial amount of cushioning foam for packaging purposes. New packaging dunnage solutions are needed to work in concert with venting mechanisms for systems such as the 40-mm M430A1 high-explosive dual purpose grenade.

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