Insensitive Munitions and Ballistic Performance Assessment of 105-mm Cartridges with Foamed Celluloid Combustible Case

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ABSTRACT

The US Army Futures Command CCDC Armaments Center has successfully demonstrated a new foamed celluloid combustible cartridge case (FCCCC) in a 105-mm tank cartridge used in the Stryker Mobile Gun System that improved the system's Insensitive Munitions (IM) response. Under a Joint Insensitive Munitions Technology Program (JIMTP) project, the FCCCC is being developed to provide effective venting, lower the internal pressure/temperature, and eliminate the steel debris cloud resulting from the energetic response to Fragment Impact and Slow Cook-Off threats. Fragment Impact and Slow Cook-Off results were assessed as Type IV (deflagration) and Type V (burning) respectively; a major improvement over the current Type III (explosion) response exhibited by existing 105-mm cartridges that use a steel case and non-venting packaging container. Ballistic firing, in conjunction with interior ballistics modeling, will demonstrate that the 105-mm cartridges with the FCCCC can match those with steel cases in terms of ballistic performance and post-fire residue. Incorporating FCCCC in the 105-mm system is expected to significantly improve safety and warfighting readiness.

INTRODUCTION

Figure 1

The thermal reaction of 105-mm tank rounds cannot easily be mitigated by IM packaging and/or IM propellant alone due to the confinement of a large amount of propellant inside a steel cartridge case as shown in Figure 1. Various cartridge venting solutions had been investigated in the past with some success but none could provide a full solution. A 105-mm combustible cartridge case made of foamed celluloid could provide sufficient thermal venting to prevent pressure build-up inside the cartridge case, eliminate steel debris cloud, meet current ballistic performance, eliminate post-fire residue (a potential safety hazard), be compatible with the Stryker Mobile Gun System (MGS) autoloader and be cost effective.

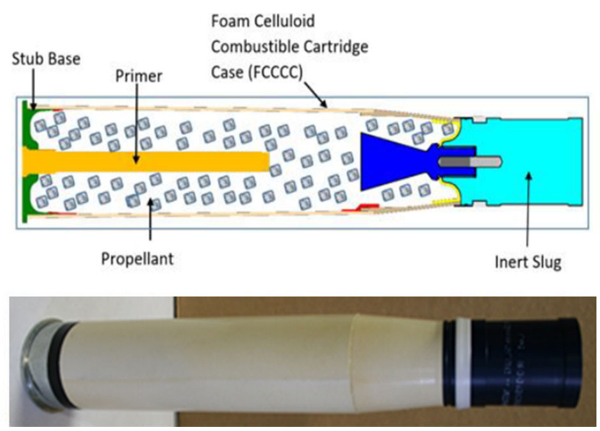
Celluloid (~25% camphor, ~75% NC) is a thermoplastic-like material that was fabricated more than 100 years ago and used in a variety of commercial and military applications. When celluloid is foamed, the density is reduced, a porous structure is introduced, and the surface area is increased. These characteristics lend themselves to a higher burn rate with reduced residue and improved mechanical strength. This version of celluloid – foamed celluloid – has been explored for various applications in gun propulsion systems. The development of foamed celluloid combustible cartridge case (FCCCC) has encompassed the development of celluloid beads, characterization of celluloid beads, design and fabrication of molds, development of foaming and fusing (molding) process, characterization of foamed celluloid specimens, design and fabrication of FCCCC, modeling & simulation of rough handling and interior ballistics and developmental testing. This paper will focus on the subscale fragment impact (FI) test, slow cook-off (SCO) test, ballistic firing and post-fire residue evaluation.

EXPERIMENTS & RESULTS

Test Item

The 105-mm M724A2 Target Practice with Tracer is a training cartridge, fired from the Stryker Mobile Gun System (MGS), which utilizes the M68A3 rifled gun tube, Muzzle Reference System, and an autoloader for storage and handling of 105-mm tank ammunition. The M724A2 is intended to provide the MGS crews with the training capability to maximize the effectiveness of the tactical 105-mm Kinetic Energy, M900 Armor Piercing Fin Stabilized Discarding Sabot with Tracer cartridge. For this developmental effort, the M724A2 projectile was replaced with a simulated inert projectile (metal slug). Figure 2 shows the test item consisting of a projectile slug, a foamed celluloid combustible cartridge case (FCCCC), M14 propellant, an electric primer (M125 thick-walled) and a metal stub base with rubber gas seal. The projectile slug is fixed to the FCCCC.

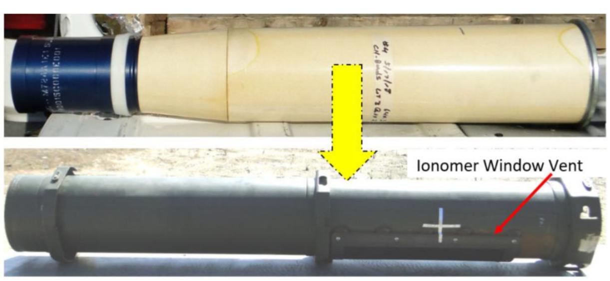
Figure 2. M724A2 Slug with FCCCC



Fragment Impact Test

Fragment impact test was conducted at the Naval Surface Warfare Center, Dahlgren Division Test and Evaluation Division in accordance with MIL-STD-2105D and STANAG 4496. One M724A2 with FCCCC was tested in a packaged configuration (i.e., test item packaged in the PA117 shipping container with ionomer vent windows) in a horizontal orientation. The vents were located on the container side adjacent to the cartridge propulsion system. The packaged configuration is provided in Figure 3.

Figure 3. Fragment Impact Test Item Configuration & Aim Point



The test item was supported on a steel support fixture. The support fixture incorporated a 1-inch-thick aluminum witness plate with dimensions of 49 inches in length by 12 inches in width. The gun was aimed such that the fragment passed through the center of the priming tube, through the centerline of the cartridge, and 11 $^{11/16}$ inches forward of the shipping container lid. The aim point was clear of all container hardware (i.e., vent windows). The test item was impacted by a single conical-tipped steel fragment launched from a smoothbore 40-mm gun using a sabot. The fragment impacted the test item at a velocity of 8300 ± 300 feet per second.

High-speed digital video cameras and standard video cameras were used to record response of the test item. Piezoelectric pressure gauges were used to measure blast overpressures produced by the reactions of the test item. Range markers were used as references for analyzing video records.

Test results indicated that the measured fragment velocity was 8206 feet per second. The fragment impacted the test item at the intended aim point, through the primer. The test item produced low but measurable overpressure as shown in Table 1.

Table 1. Peak Pressure and Pressure Impulse Produced by Fragment Impact Test Item Reactions

Pressure Gauge Number	Gauge Standoff Distance (feet)	Peak Pressure (psi)	Predicted Peak Pressure for Detonation (psi)	Pressure Impulse (ms*psi)	Predicted Pressure Impulse for Detonation (ms*psi)
1	10	1.5	7.3	0.8	5.4
2	13	1.1	4.9	0.7	3.9
3	16	0.8	3.3	0.5	3.1
4	10	1.7	7.3	1.0	5.4
5	13	1.1	4.9	0.7	3.9
6	16	0.8	3.3	0.6	3.1

Figure 4 shows test item remains recovered within 50 feet of the test stand. The shipping container was recovered within 5 feet from the test stand. The foam packaging material and the inert projectile slug were recovered inside the shipping container. The cartridge stub base was recovered 4 feet away. Approximately 90-95% of the unreacted propellant was scattered out to 100 feet.

Figure 5 shows nine test item remains recovered at a range greater than 50 feet from the test stand. These include five pieces of the shipping container, two pieces of the ionomer window vent, and the primer tube (severed into two pieces). Table 2 shows the ranges, angles and weights of item remains. Figure 6 shows the projection energy of these nine test item remains. Five pieces of test item remains exceeded or slightly exceeded the 20-joule projection energy criterion of AOP-39 Edition 3.

Figure 7 shows the post-test condition of witness plate. Some minor pitting was visible on the front edge of the witness plate and four indentations (thought to be imprints from the hardware on the shipping container) were noted. Based on the previous IM test results of M724A2 with steel case (not shown in this paper) and current IM test results of M724A2 with FCCCC, the fragment impact reaction was assessed to be a low Type IV (deflagration).

Figure 4. Test Item Remains Recovered within 50 Feet of the Test Stand, Fragment Impact Test

Figure 5. Test Item Remains Recovered at a Range Greater than 50 Feet from the Test Stand

Table 2. Test Item Remains Recovered at a Range Greater Than 50 Feet from Test Stand

Item Number	Item Description	Range (feet)	Angle (°)	Weight (lb.)
1	Priming tube piece	57	120	0.68
2	Container piece	110	145	0.22
3	Container piece	125	130	0.23
4	Container piece	69	190	0.36
5	Ionomer window piece	115	135	0.04
6	Container piece	65	115	0.04
7	Container piece	129	45	0.22
8	Window flange	208	135	0.41
9	Priming tube piece	144 ½	150	0.46

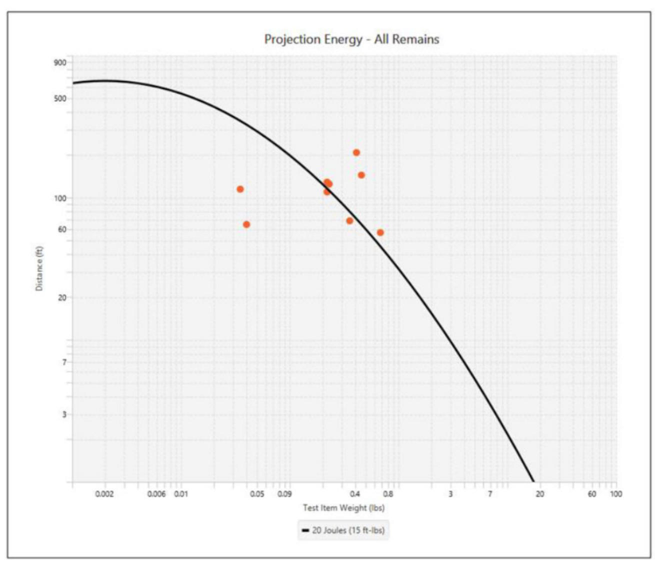


Figure 6. Projection Energy of Test Item Remains Recovered at a Range Greater Than 50 Feet from Test Stand, Fragment Impact Test.

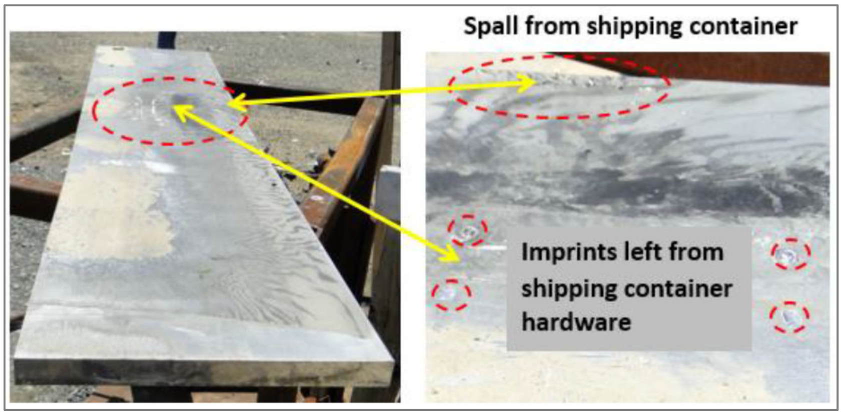


Figure 7. Post-Test Condition of Witness Plate, Fragment Impact Test

Slow Cook-Off

Slow cook-off test was conducted in accordance with MIL-STD-2105D and STANAG 4382. Figure 8 shows one test item in packaged configuration was supported on a steel fixture and centered in the oven in a horizontal orientation. The test item was insulated from direct contact with the support fixture by using strips of ceramic insulating cloth. The support fixture incorporated a 1-inch-thick aluminum witness plate with dimensions of 49 inches in length by 12 inches in width. The witness plate was placed beneath the test item with 8 inches of air space between the test item and witness plate.

Figure 9 shows the thermocouple locations. Four thermocouples were used to measure the temperature of the air in the oven. Two thermocouples were used to measure the surface temperature of the test item shipping container. Two additional thermocouples were used as control thermocouples. The response of each thermocouple was recorded on a digital data recording system.

Figure 10 shows the completed test setup. Standard video cameras were used to record the response of the test item. Piezoelectric pressure gauges were used to measure blast overpressures produced by the reactions of the test item. Range markers were used as references for analyzing video records. Two halogen stadium lights were used to illuminate the oven at night.

The test item was initially heated at a rate of 9°F per minute until the oven air temperature reached 122±5°F. The test item was then conditioned at 122±5°F for 8 hours and 24 minutes. After the temperature soak was completed, the oven temperature was increased 27°F per hour until the test item reacted.

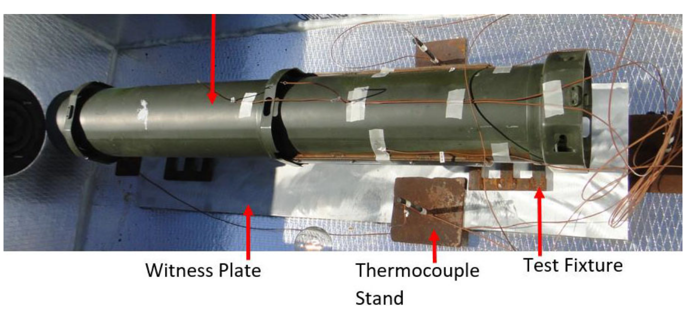


Figure 8. Test Item Packaged in PA117 Container & Positioned on Steel Fixture in Oven, Slow Cook-Off Test

Figure 9. Thermocouple Locations, Slow Cook-Off Test

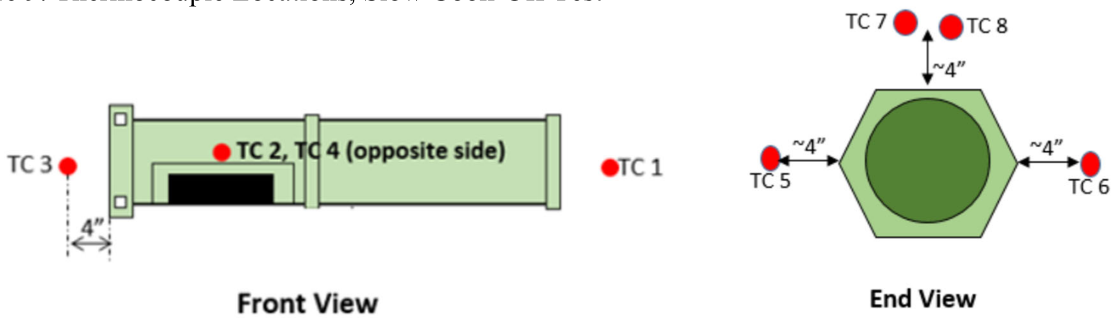


Figure 10. Photograph of completed test Setup, Slow Cook-Off Test

Test results indicated that the first observable reaction (the ionomer window vent starting to separate from the window flange) was viewed on the internal video when the average oven air temperature was 283°F and the average shipping container surface temperature was 268°F. The first audible reaction, accompanied with fire and smoke, was observed when the average oven air temperature was 317°F and the average container surface temperature was 304°F. A second audible report, the primer initiation, was observed approximately 2 minutes 21 seconds later when the average oven air temperature was 320°F (304.6°F test item temperature). Multiple audible reports (crackling/popping/sizzling noises, believed to be a result of the oven materials burning) occurred over the next 4 minutes 53 seconds. Fire was observed for approximately 11 minutes and the smoke started to die down approximately 17 minutes after the reaction that was observed. However, the reactions did not produce any measurable overpressure. Reactions observed are summarized in Table 3.

Table 3. Reactions Observed During Slow Cook-Off Test

Reaction Number	Time (UTC)	Observations
1	12:22:00	Ionomer window vents start to separate from window flange (viewed on internal video)
2	13:02:20	Foam starts to swell/extrude and window vent located on the backside of the container, detaches, and falls to oven floor
3	13:29:29	Smoke visible exiting internal camera enclosure (assumed to be outgassing of the silicone material used to seal the oven/window; as no smoke was visible in the oven on the internal camera view)
4	13:36:42	First audible report accompanied with fire and smoke, oven slightly lifted upward (propellant reacting)
5	13:39:04	Debris visible exiting oven (propellant and burning oven materials)
6	13:39:07	Audible report accompanied with increased fire and smoke (Priming tube reacting)
7	13:39:53 – 13:44:00	Crackling/popping/sizzling noises (assumed to be the oven materials burning)
8	13:41:30	Oven walls start to collapse
9	13:47:50	Fire dies out
9	13:53:41	Smoke begins to die down

Figure 11 shows the oven and the surrounding area after the test. Figure 12 shows the container was recovered on the test stand. The shipping container end cap was still attached to the container. Figure 13 shows all post-test remains were recovered inside the shipping container, including the projectile slug, primer and stub base. The plastic projectile support which was encased in the foam packaging had melted and was adhered to the projectile slug. All energetic material was consumed (i.e., no energetic material was present in the priming tube, and no combustible case and propellant were recovered). Figure 14 shows the post-test condition of the witness plate. No damage to the plate was observed. Base on the previous IM test results of M724A2 with steel case (not shown in this paper) and current IM test results of M724A2 with FCCCC, the slow cook-off reaction was assessed to be a Type V.

Figure 11. Oven and Surrounding Area, SCO

Figure 12. Post-Test Condition of Test Item Container, Slow Cook-Off Test

Figure 13. Test Item Remains Removed from the Shipping Container, Slow Cook-Off Test

Figure 14. Post-Test Condition of Witness Plate, Slow Cook-Off Test

Ballistic Performance & Post-Fire Residue Evaluation

A total of twelve M724A2 projectile slugs with empty FCCCC were preassembled at CCDC-AC (Picatinny Arsenal). LAP and ballistic firing were conducted at the Aberdeen Test Center, Aberdeen Proving Ground. Each cartridge case was ported for piezoelectric pressure gauges. In addition, two M11 gauges were inserted in each cartridge, via primer port, at approximately 180 degrees apart. All individual cartridge weight (empty), propellant charge weight, primer weight, and cartridge weight (loaded) were recorded. All cartridges were serialized, and the lids of the metal ammunition shipping containers were labeled with the temperature-conditioning requirements, as well as serial number.

A M68 cannon tube was ported to provide pressure-time data and negative differential pressures. The cannon was equipped with a thermal shroud and inoperable bore evacuator to evaluate any post-fire residue.

The charge establishment (CE) test consisted of three M724A2 cartridges with FCCCC. The three cartridges were fired at a conditioned temperature of 21°C, using three different charge weights estimated by the IBHVG2 interior ballistics code. The purpose of this test is to determine a final charge weight required to meet a target velocity in order to match the performance of M724A2 with steel case.

The charge verification (CV) test consisted of nine M724A2 cartridges, which were fired at conditioned temperatures of -46°C, -32°C, +21°C, +52°C, and +62°C. The purpose of this test is to evaluate both performance and safety in terms of muzzle velocities, breech and shoulder pressures, negative differential pressures, flareback and post-fire residue. The CV charge weight was based upon the outcome of the CE test.

All 21°C cartridges were temperature-conditioned for a minimum of 24 hours. All others were conditioned for a minimum of 48 hours prior to testing. Tables 4-5 provides the cartridge temperature-conditioning and ballistic test matrix.

Table 4. Charge Establishment Test Matrix

Test Round #	Temp (°C)	Charge Weight (kg)
TRN 1	21	4.980
TRN 2	21	5.365
TRN 3	21	4.600

Table 5. Charge Verification Test Matrix

Test Round #	Temp (°C)	Charge Weight (kg)
TRN 4, 5	-46	4.955
TRN 6	-32	4.955
TRN 7, 8	21	4.955
TRN 9, 10	52	4.955
TRN 11, 12	63	4.955

Figure 15 shows FCCCC velocities were comparable to steel case velocities at ambient and hot. At cold FCCCC velocities were higher than steel case velocities. Figure 16 shows FCCCC pressures were higher than steel case pressures but still well below the gun's Safety Maximum Pressure. Pressure-time traces appeared to be within the norm. The higher velocities and pressures at cold might indicate an increase in burning surface area of FCCCC.

The first two CE rounds ignited the grass upon impact. The team believed that the flame came from the burning Ultem (a temporary solution to attach the case adaptor to the projectile slug). The Ultem will be replaced with foamed celluloid in the final design.

Breech IR camera revealed all CE and CV rounds had flying ember during stub base extraction. The CE and CV rounds with lower propellant charge weights (4.600 and 4.955 kg) had flareback during and after stub base extraction. Some were observed to have burning ember inside the gun tube. However, the first two CE rounds with higher charge weights (4.980 and 5.365 kg propellant) didn't seem to have flareback issues.

The side of each recovered stub base was covered with soot, suggesting the stub base had a poor gas seal. These stub bases were made from spent steel cartridge cases. Figure 17 shows a sheet of epoxy from inside the lap joint nearly an inch wide and a half in long still stuck to the base stub.

The team believe the embers came from the thick double-walled lap joint between the case bottom and the case body. The epoxy adhesive did not burn and in spots where there was plenty of epoxy in the lap joint, prevented the flame from spreading from one layer to the next. The foamed celluloid under the epoxy needed to burn from the edge, and the pressure dropped before it finished burning.

Table 6 shows residue collected after each firing. The residue is a mixture of ash and epoxy. Attempt was made to separate the ash from the epoxy. Most of the residues had an ash content well below the safety limit of 0.5 grams.

Figure 15. Velocity versus Temperature

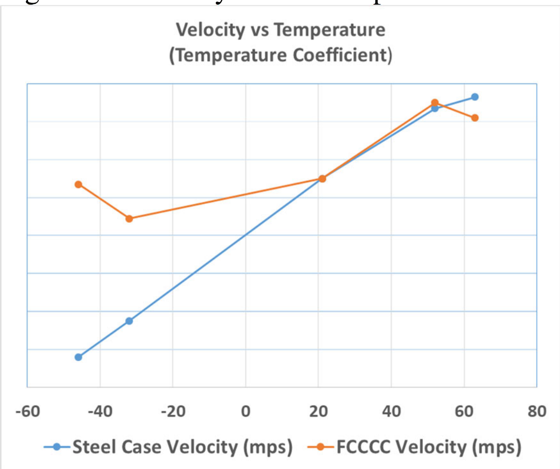


Figure 16. Pressure versus Temperature

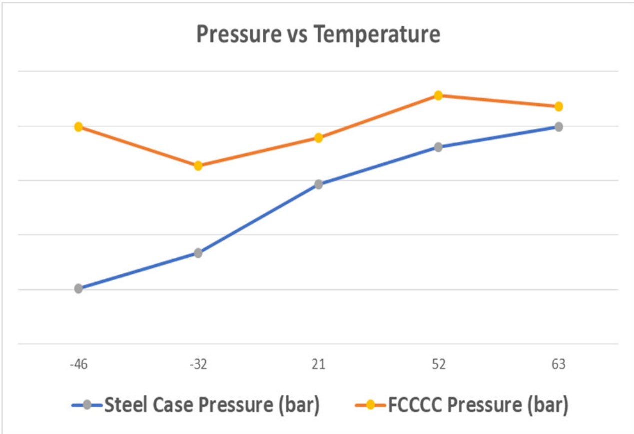


Figure 17. Post-Fire Stub Base

Table 6. Post-Fire Residues

Test Round Number	Total Residues (gram)	Epoxy (Estimated)	Ash (Estimated)
TRN 1, 2, 3	0.398	0.282	0.116
TRN 4	1.125	0.380	0.745
TRN 6	0.595	0.314	0.281
TRN 7	0.898	0.143	0.755
TRN 8	1.002	0.700	0.302
TRN 9	0.102	0.097	0.005
TRN 10	1.159	0.745	0.414
TRN 11	0.255	0.000	0.255
TRN 12	0.785	0.769	0.016

CONCLUSIONS & RECOMMENDATIONS

The IM tests on the M724A2 with FCCCC have been successfully completed with satisfactory results. By replacing the steel case and unvented packaging container with combustible case and vented packaging container, Fragment Impact had improved from Type III reaction (explosion) to low Type IV reaction (deflagration); Slow Cook-Off had improved significantly from Type III (explosion) to Type V reaction (burning) as shown in Figure 7 below.

Table 7. IM Scores of M724A2 with Steel Case and Combustible Case

	105-mm M724A2 with Steel Case & Unvented PA117 Container	105-mm M724A2 with FCCCC & Vented PA117 Container
Fragment Impact	Type III	Type IV
Bullet Impact	Type IV	
Slow Cook-Off	Type III	Type V
Fast Cook-Off	Type III	

Ballistic firing results has shown that FCCCC matches the steel case in performance at ambient and probably at hot. Although FCCCC had a flatter temperature coefficient than steel case at cold, it may be considered an improvement in performance.

The flareback, burning embers and residue might have come from the thick double-walled lap joint between the case body and the case bottom. We believe these issues could be resolved by replacing the double-walled lap joint and epoxy adhesive with a one-piece design, increasing the propellant to foamed celluloid ratio, and redesigning the stub base/rubber gas seal. Depending on the application, we may also reduce the case wall thickness from 4-mm to 3-mm with or without fiber reinforcement. As foamed celluloid material is reduced, the amount of propellant will need to be increase to balance the energy, reducing the chance of flareback and post-fire residue.

Technology may be transitioned during upgrade of Stryker autoloader and firing tables and/or any future 105-mm vehicles/munitions. A slight improvement on the roller bearing units could significantly improve survivability of any combustible case.