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INTERIOR HEAD IMPACT PROTECTIVE COMPONENTS AND MATERIALS FOR USE IN US ARMY VEHICLES

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ABSTRACT

TARDEC researched head impact protective, energy attenuating materials for use in U.S. Army Ground System Vehicle (GSV) applications. The purpose of the project is to reduce potential head impact related mounted crew injuries and deaths which may occur during underbody blast, crash and rollover events. Commercial-off-the-shelf materials were evaluated for their energy attenuating performance. Exposed surface materials in combination with core material were also researched and evaluated. Baseline vehicle testing was conducted to understand the current head impact criterion. The results of this effort identified solutions which may potentially meet the needs of the Army to reduce head impact related injuries which may occur during crash, rollover and blast events. TARDEC used the knowledge gained from this project to create performance specification requirements for interior head impact protective components and materials for use in U.S. Army vehicles.

INTRODUCTION

Mounted soldiers experience underbody blast (UBB) events when an IED is concealed below the ground and detonated as their vehicle is positioned over the device. The resulting blast wave produces a rapid and violent displacement of the underside of the vehicle. U.S. Army vehicle interior structures are typically made of rigid, thick armor and angular, unfriendly surfaces. The occupant space is often very compact leaving minimal packaging space for the addition of energy attenuating materials.

This effort centers on reducing potential head impact related injuries and deaths of mounted crew which may occur during blast, crash and rollover events, through the use of energy attenuating materials. The study is limited to mounted crews, which are assumed to be seated and properly restrained inside the vehicle. Traumatic brain injury, facial, neck, spine, upper and lower extremity injuries are not addressed.

The purpose this report is to develop a greater understanding of the application of energy attenuating materials for use in U.S. Army ground system vehicles intended to reduce potential head impact injuries and deaths which may occur during underbody blast, crash and rollover events.

BACKGROUND

U.S. Army vehicle interior design is typically compact, in which the seated and restrained mounted warfighter is likely to come into contact with the interior surfaces while in motion during a blast event. The high accelerations experienced during these events can result in severe head injury when the occupant's head impacts the rigid interior structures. In theater (combat areas) injury data further proves head injuries are occurring. According to the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) research reports, during the period of 2010 to 2012 blast injury data showed head injuries occurred in nearly one-quarter of total injuries to the body. Head injuries are second only to leg injuries.[1] In another JTAPIC report from 2011 to 2012, it is reported just over half of the mounted crew casualties experienced head injury. The report further breaks down injuries; showing just under half of the wounded in action experience head injuries and slightly higher percentage of killed in action exhibited head injuries, although it is not apparent whether the head injury is the cause of death.[2] Skull fractures account for a small number of wounded in action head injuries. However skull fractures account for greater than half of the mounted crew killed in action.[3] Looking at this data, it becomes clear,

[1] Getz, John, Clouser, Mary, (10JAN2013) p. 4
[2] Eberius, Natalie, (10APR2013) p. 7
[3] Eberius, Natalie (10APR2013) p. 10

improved mounted crew survivability is needed by instituting strategies to mitigate head impact related injuries.

Energy attenuating materials are extensively used for interior head impact protection in automobiles. Therefore TARDEC benchmarked the automotive industry to identify potential commercial-off-the-shelf (COTS) materials. TARDEC initially tested the energy attenuating materials without any additional protective, durable exposed surface sheet. TARDEC calls energy attenuating materials without exposed surface sheets, 'core materials'. The core material samples were secured the material test samples to a rigid test fixture for head impact testing.

METHODOLOGY

TARDEC utilized the Soldier System Interface Impactor Laboratory located at Selfridge Air National Guard Base, Harrison Township, Michigan (SANG SSII) to conduct head impact testing, Figure 1. The SANG SSII is equipped with head impact test equipment consistent with the FMVSS 201U standard using a Free Motion Headform.

Figure 1: Head impact fixture

Head Impact Criteria (HIC)

The Head Injury Criteria (HIC) threshold for this effort leverages the performance criterion used in the automotive industry according to SAE TP201U-01, FMVSS (Federal Motor Vehicle Safety Standard) 201U, HIC(d) ≤ 1000. The following formula is used to calculate HIC(d):

$$HIC(d) = 0.75446\ (\text{Free Motion Headform HIC}) + 166.4 \quad (1)$$

The Free Motion Headform HIC is calculated in accordance with the following formula:

$$\text{HIC} = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\right]^{2.5} (t_2 - t_1) \quad (2)$$

Where $A_R = [A_x^2 + A_y^2 + A_z^2]^{½}$ is the resultant Acceleration magnitude in g units at the center of gravity (CG) of the Free Motion Headform (FMH); t_1 and t_2 are any two points in time during the impact event separated by not more than a 36 millisecond time.

FMH Impact Speed Measurement

The FMH targeted impact speed is 24 kph ± 1.0 kph. The FMH velocity was derived from cadaveric underbody blast (UBB) testing conducted by the Warrior Injury Assessment Manikin (WIAMan) program at Aberdeen Proving Ground (APG) Aberdeen, Maryland.

Approach Angle

FMVSS 201U defines horizontal and vertical angles at which the FMH could strike a target located on the stand alone flat panel test fixture. These angles are referred to as approach angles and are expressed using a specified orthogonal reference system. The direction of travel by the FMH is required to be within the specified range as specified in SAE TP201U-01, FMVSS (Federal Motor Vehicle Safety Standard) 201U.

Advanced Combat Helmet (ACH)

Measurement system analysis was conducted on the SANG SSII with and without the use of an ACH (Army Combat Helmet), mounted onto the Free Motion Headform. The results of this analysis was that the use of an ACH with the FMVSS 201U test equipment had too much variation for repeatability. Testing was conducted without an ACH where applicable. During baseline testing, certain impact target locations would damage the skin on the FMH in these instances an ACH was used during testing. The expectation is that testing conducted without an ACH would have higher HIC(d) values and it is assumed that mounted warfighters are always wearing their ACH when in theater.

Flat Fixture Testing Method

TARDEC tested different COTS energy attenuating (EA) core materials at the SANG SSII laboratory using a rigid flat fixture, Figure 2. The core material requires an additional layer of protection for durability. The additional durable layer of material is referred to by TARDEC as an exposed surface sheet. Each core material was tested with a different durable exposed surface sheet to understand the effects the exposed surface sheet had on the energy attenuation characterizes of the core materials.

Figure 2: Rigid Flat Fixture

The core materials target thickness range from 25.4 mm (1.0 inches) to 38.1 mm (1.5 inch) was based on occupant space claim in the military vehicles. The core materials' thickness tested ranged from 12.7 mm (0.50 inch) to 41 mm (1.6 inch). The range varied due to availability to procure COTS material. Both fabric and rigid exposed surface sheet materials were assembled to the energy attenuating materials for head impact testing. Figure 3 illustrates the material test matrix used in testing the COTS materials.

Core Material ID	Facesheet Material ID	Facesheet Material	Material	Thickness
A	1	Fabric	Plastic	1.4 inch (35.5 mm)
A	2	Fabric		
A	3	Fabric		
A	4	Fabric		
B	1	Fabric	Plastic	0.8 inch (20.3 mm)
B	2	Fabric		
B	3	Fabric		
B	4	Fabric		
C	1	Fabric	Plastic	0.5 inch (12.7 mm)
C	2	Fabric		
C	3	Fabric		
C	4	Fabric		
C	5	Rigid		
D	1	Fabric	Plastic	1.5 inch (38.1 mm)
D	2	Fabric		
D	3	Fabric		
D	4	Fabric		
D	5	Rigid		
D	6	Fabric		
E	1	Fabric	Plastic	1.5 inch (38.1 mm)
E	2	Fabric		
E	3	Fabric		
E	4	Fabric		
E	5	Rigid		
F	1	Fabric	Plastic	0.5 inch (12.7 mm)
F	2	Fabric		
F	3	Fabric		
F	4	Fabric		
F	5	Rigid		
G	1	Fabric	Foam	1.0 inch (25.4 mm)
G	2	Fabric		
G	3	Fabric		
G	4	Fabric		
G	7	Fabric		
H	1	Fabric	Foam	0.5 inch (12.7 mm)
H	2	Fabric		
H	3	Fabric		
H	4	Fabric		
H	7	Fabric		
I	1	Fabric	Non-resilent	1.6 inch (40.6 mm)
I	2	Fabric		
I	3	Fabric		
I	4	Fabric		
I	5	Rigid		
J	1	Fabric	Non-resilent	0.78 inch (19.8 mm)
J	2	Fabric		
J	3	Fabric		
J	4	Fabric		
J	5	Rigid		
J	8	Rigid		

Figure 3: AoA Material Test Matrix

The core and exposed face sheet materials were conditioned before testing. The material samples were soaked in an ambiance air environment of 19°C to 26°C (66.2°F to 78.8°F) and a relative humidity between 10 percent and 70 percent.

Vehicle Baseline Testing Method

Vehicle baseline testing is defined as testing on the original structure without the addition of interior impact protective solutions, IIPS. Baseline data also demonstrates the head impact injury performance of the vehicle's current design state and determines whether adding energy attenuating materials would be beneficial in reducing potential head impact injuries. Impact locations were selected based upon the proximity to the occupant's head in the upward and lateral motion typical of an underbody blast.

Data from baseline testing will enable an understanding if interior impact protective solutions, IIPS, are needed to reduce head injury during blast events and in what locations of the vehicle. Figure 4 shows the impact locations for the three vehicles and trim buck used for baseline testing. Figure 5 shows the material ID used during vehicle head impact testing with an IIPS.

Vehicle	Impact Location
A	Driver Front Roof
	Left Rear Roof
	Right Rear Door
	Right Rear Roof
	Passenger Front Roof
	Driver Front A Pillar
	Driver Front Roof Rail
	Left Rear Turret
	Right Rear B Pillar
	Passenger Front A Pillar
B	Rear Forward/Left Roof, "Pos-1"
	Rear Hatch Edge, "Pos-2"
	Rear Hatch, "Pos-3"
	Driver Hatch, "Pos 4"
	Driver Sidewall, "Pos 5"
	Rear Door "Pos 6"
C	Pos-2, Dashboard
	Pos-2, Duct
	Pos-3, Roof
	Pos-4, Roof
	Pos-5, Electrical Component
	Pos-5, Roof
	Pos-6, Roof
Trim Buck	Roof
	Ancra Track w/o clip

Figure 4: Vehicle Baseline Test Matrix

Material ID	Core Material ID	Facesheet Material ID	Material	Thickness
1	B	5	Plastic	0.8"
2	B	9	Plastic	0.8"
3	A	5	Plastic	1.4"
4	A	9	Plastic	1.4"
5	H	N/A	Foam	0.5"
6	G	N/A	Foam	0.78"
7	J	5	Non-resillent	0.78"
8	J	9	Non-resillent	0.78"
9	I	5	Non-resillent	1.6"
10	I	9	Non-resillent	1.6"
11	K	N/A	Foam	0.78"
12	E	N/A	Plastic	1.0"
13	J	8	Non-resillent	0.78"
14	J	2	Non-resillent	0.78"
15	J	4	C	0.78"
16	L	4	Honeycomb	1"
17	L	N/A	Honeycomb	1"
18	L	8	Honeycomb	1"
	Reference AoA where apicable			

Figure 5: Vehicle Baseline Material Test Matrix

All instrumentation channels from the FMH were recorded and analyzed, including HIC 36, HIC 15, and HIC (d). After each test with a helmet, the helmet is inspected to determine if major or minor damage to the helmet could be identified after each impact test

RESULTS

The primary focus of the testing was to evaluate the baseline head impact criteria of COTS materials. Each material tested was composed of a core material and facesheet material. The core material was identified with a core material ID A through K. The facesheet material ID was identified 1 through 8. This material ID number represents a specific material configuration that was testing either on the flat fixture and/or on a vehicle for baseline testing.

The baseline vehicle testing was conducted either with or without COTS materials. When COTS materials were used a combination of the core and facesheet materials were used. The material ID was denoted 1 through 12.

Material Analysis of Alternative (AoA) Flat Fixture

The material samples with fabric exposed surface sheets generally performed better than the hard exposed surface sheet samples, facesheet material IDs 1 through 4, 6, and 7. Figure 6 shows the data from the flat fixture testing. The thicker core materials with fabric based surface sheets, core material IDs D and E, performed below HIC(d) ≤ 1000 requirement at HIC(d) 636 to 855 for the 38 mm (1.5 inch) thick TPE engineered core material and HIC(d) of 847 to 1131 with the 41 mm (1.6 inch) thick aluminum non-resilient core material, core material ID I. The foam covered in fabric in 25.4 mm (1 inch) thick samples covered in fabric, core material ID G, also showed results around the HIC(d) threshold at HIC(d) 1088. None of the thinner samples tested performed below the HIC(d) requirement, core material IDs B, C, F, H and J. The lowest HIC(d) value of the thinner samples was HIC(d) of 1254 which is a resilient plastic core material covered in fabric, core material ID B. The thin material samples, core material IDs B, C, F, H, and J, with hard surface sheets, facesheet material ID 5 and 8, showed significantly higher test results with the lowest HIC(d) value of 1768.

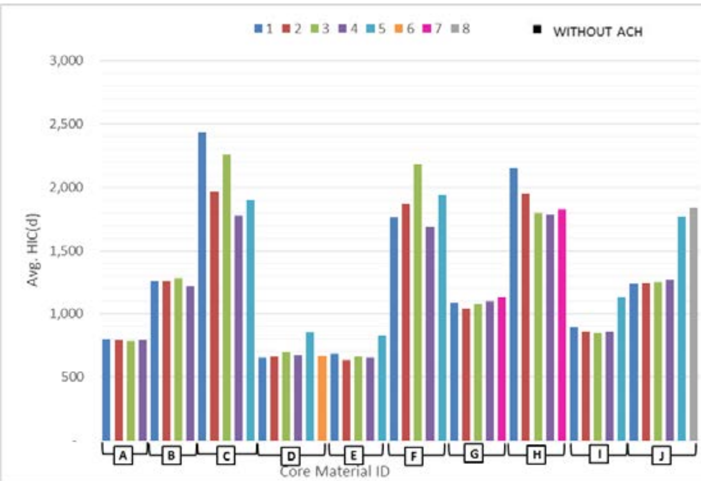

Figure 6: Material AoA HIC(d)

One of the TPE engineered materials, core material ID A, test results showed an average HIC (d) of 792 at a thickness of 35.56 millimeters (1.4 inches). A non-resilient material, core material ID I and J, (does not retain fit and form after impact) such as aluminum formed in a tubular shape, also uses air-space for enhanced energy attenuation. The 40mm (1.6 inch) thick non-resilient material, core material ID I, resulted in an average HIC(d) of 919.

Vehicle A Baseline Testing

Vehicle baseline testing was conducted using the head impact laboratory facility at SANG. In order to quantify the injury reduction due to the introduction of the IIPS, baseline testing was conducted with and without an ACH affixed to the FMH. The baseline testing data of vehicle A can be seen in Figure 7.

The baseline testing at the driver front roof, left rear roof, and right rear roof were within the threshold requirement of HIC(d).The driver front roof impact position without an ACH has HIC(d) of 939. The HIC(d) for the left rear roof target location without an ACH was on average 601. The right rear roof location without an ACH had an average HIC(d) of 470.

The baseline testing at the following locations exceed the injury criteria: right rear door, passenger front roof, driver front a-pillar, driver front roof rail, left rear turret, righter rear b-pillar, passenger front a-pillar. The HIC(d) for the driver front a-pillar location with an ACH was on average 1,841. The driver front roof rail with an ACH had an average HIC(d) of 2,055.The HIC(d) for the a-pillar with ACH target location had a HIC(d) of 1,294. The roof target location without an ACH had an average HIC(d) of 1,086. The turret location with an ACH had an average HIC(d) of 1,489. The HIC(d) for the b-pillar location with an ACH was on average 2,420. The door location without an ACH had an average HIC(d) of 2,781.

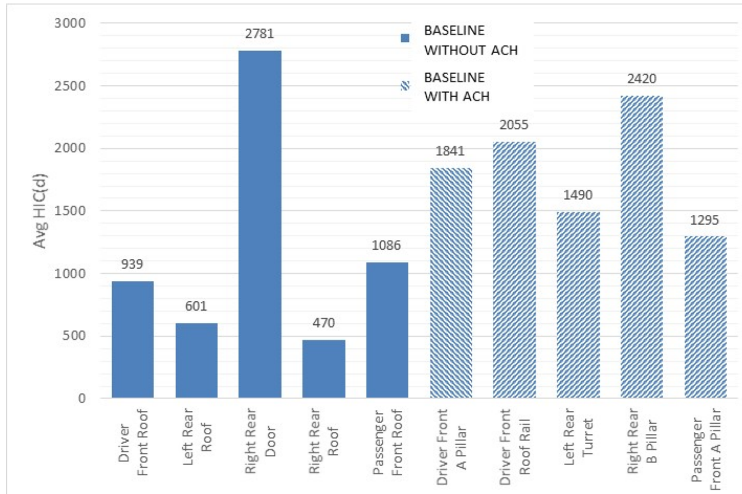

Figure 7: Vehicle A HIC(d)

Vehicle B Baseline Testing

The vehicle B has a very rigid interior design, testing for the vehicle was conducted without the helmet on the FMH, to improve test repeatability. Figure 8 shows the data from vehicle baseline testing at head impact test locations: driver hatch, driver sidewall, rear passenger roof and the rear hatch.

All of the locations that were baseline tested with the exception of the driver sidewall, far exceeded the performance criteria of HIC(d) $\leq$ 1000. The driver hatch showed the highest test results at HIC(d) 10,556.8. The rear hatch also showed high test results at HIC(d) 5596.0 and the rear passenger roof results were HIC(d) 2308.5.

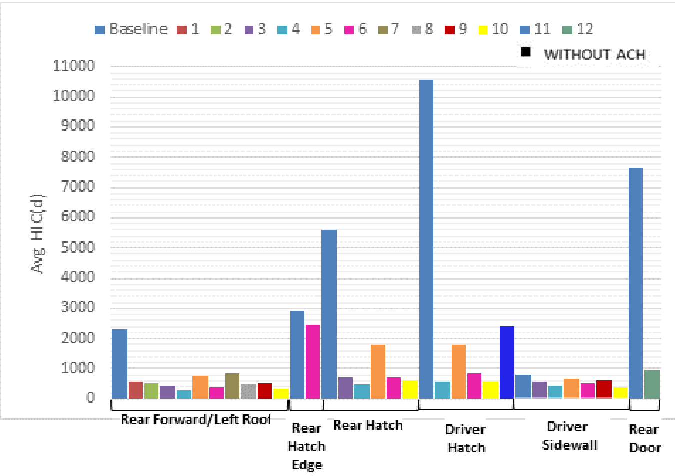

Figure 8: Vehicle B HIC(d)

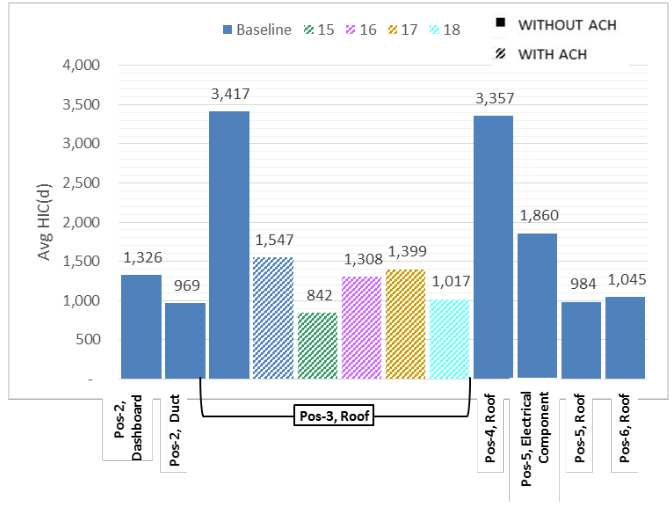

Figure 9: Vehicle C HIC(d)

The addition of EA material to the rear forward/left roof significantly contributed to the reduction of the injury criteria. The EA material tested at the rear hatch edge exceeded the injury threshold requirement. Four of the five EA materials evaluated reduced the injury criteria for the rear hatch below the threshold. The driver hatch HIC(d) injury criteria were within the injury criteria with the addition of three of the five EA materials tested. The baseline HIC(d) for the driver sidewall meet the threshold injury criteria, the addition of EA materials further reduced the HIC(d) value. The EA material evaluated at the rear door was able to meet the injury threshold for HIC(d).

Vehicle C Baseline Testing

Figure 9 shows Vehicle C baseline testing data. Baseline testing without an ACH at the following locations exceed the injury threshold requirement: Pos-2 dashboard, Pos-3 roof, Pos-4 roof, Pos-5 electrical component, and Pos-6 roof. Pos-2 duct and Pos-5 roof did meet the threshold requirement for baseline testing with a HIC(d) of 969 and 984 respectfully.

Further head impact testing was conducted on Pos-3 roof, which had a baseline HIC(d) of 3,417. Baseline testing as repeated with the addition of an ACH, the resulting HIC(d) was 1,547. Four EA materials were impact tested at this position. One of the four EA materials tested met the threshold requirement with a HIC(d) of 842.

Trim Buck Baseline Testing

Baseline testing was conducted in the two target locations in trim buck: roof and Ancra track without clip. The Ancra track clip's function is to secure basic issue items, bii. The baseline testing on the roof was conducted with and without an ACH. This baseline testing exceeded the injury threshold criteria with an HIC(d) of 1,245 and 5,006 respectfully. Ancra track baseline testing was not conducted without a helmet due to the probability of damage to the FMH skin. The design intent of Trim Buck is to have the Ancra track located out of the head impact zone. Baseline testing on the Ancra track was conducted with an ACH and resulted in a HIC(d) of 1,134, which exceeded the injury threshold requirement. The data from this testing can be seen in Figure 10.

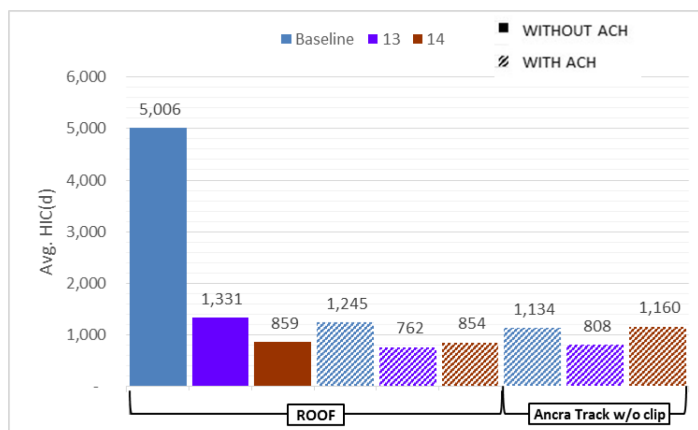

Figure 10: Trim Buck HIC(d)

Due to the high HIC(d) values experienced during baseline testing, IIPS testing in the target locations was conducted. Material ID 13 and 14 have the same core material, however material ID 13 has a rigid exposed surface sheet, while material ID 14 has a fabric exposed surface sheet.

Material ID 13 was the first IIPS solution tested in the target locations: roof and Ancra track. The roof target location with material ID 13 was testing with and without an ACH. The material with an ACH meet the injury threshold requirement, while the material without an ACH exceed the injury threshold. Material ID 13 was tested with an ACH at the Ancra track and met the injury threshold criteria.

Material ID 14 was then second tested in the target locations: roof and Ancra track. Material ID 14 meet the injury threshold requirements at the roof location with and without an ACH. The material exceeded the requirement when tested at the Ancra track with an ACH.

DISCUSSION

Material Analysis of Alternative (AoA) Flat Fixture

Core material thickness appears to be the main characteristic affecting HIC(d) energy attenuating performance independent of the type of surface sheet material or attachment method as seen in Figure 11. The thicker core materials performed better than the thinner core materials. The average peak value of HIC(d) for the materials with a thickness of 12.7 mm (0.5 inch) is 1,953. The materials with a thickness of 25.4 mm (1 inch) has an average peak value of HIC(d) equal to 1,088. As the core material increases its thickness to 38.1 mm (1.5 inch) the average peak HIC(d) value continues to decrease to 693, supporting the observation that a thicker material reduces the head impact criterion. Looking at the materials with a thickness of 25.4 mm (1 inch) and less have an average peak HIC(d) value of 1,612. Whereas materials with a thickness of greater than 25.4 mm (1 inch) has an average peak HIC(d) value of 772. The material thickness threshold for achieving the head injury criteria is greater than 25.4 mm (1 inch).

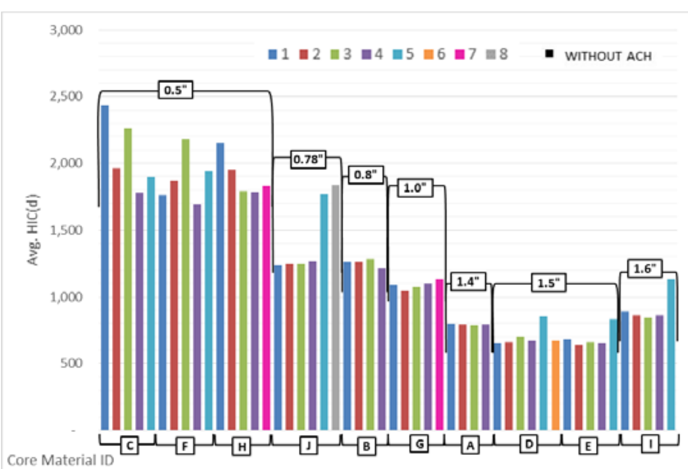

Figure 11: AoA Flat Fixture Material Thickness

Only some of the fabric based surface sheet samples with the low profile core material thickness, performed below the threshold HIC(d) < 1000 requirement and only one of the hard surface sheet samples with low profile core materials achieved the threshold requirement. These observations indicate the low profile core materials are more sensitive to the type of surface sheet material used, than the high profile, thicker core materials. AoA Test Material Matrix shows that facesheet material IDs 1 through 4, 6, and 7 are fabric and facesheet material IDs 5 and 8 are rigid. Figure 12 shows core material ID J with a thickness 19.8 mm (0.78 inch) and how the fabric and rigid face sheets directly affect the core material's response to the injury criteria. The rigid face sheet increases the HIC(d) by an average of 553.

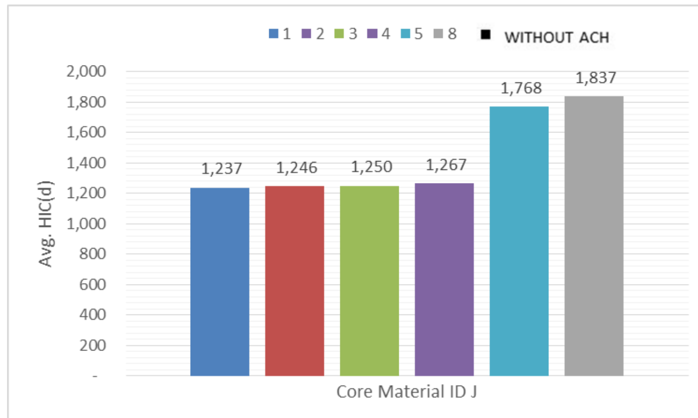

Figure 12: Core Material ID J, 19.8 mm (0.78 inch) thickness

Vehicle A Baseline Analysis

As shown in the Figure 13, the average HIC (d) for baseline testing on Vehicle A shows that the vehicle exceeds the threshold requirement for HIC (d) of equal to or less than 1,000 on the impact positions associated with the right rear door and passenger front roof without an ACH and driver front a-pillar, driver front roof rail, left rear turret, right rear b-pillar, passenger front a-pillar with an ACH.

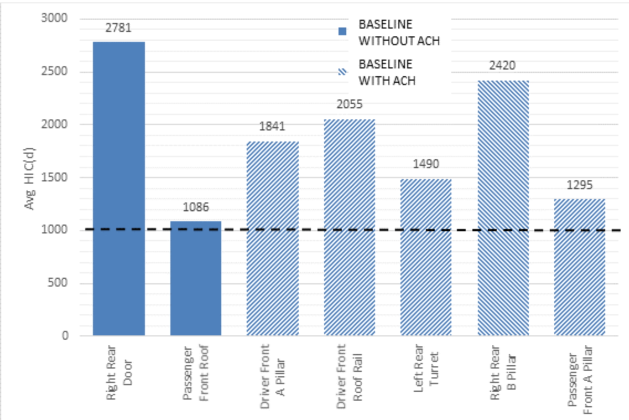

Figure 13: Vehicle A Positions that Exceeds Threshold

The baseline testing on the roof location testing was conducted without an ACH, Figure 14. In three of the four roof locations tested the head injury criterion was below the threshold and in two of three locations was also below the objective. The passenger front roof location had an average HIC(d) of 1,086.4 without an ACH. Previous testing has indicated that the ACH can reduce HIC(d) by 100 to 300. There is confidence that with an ACH the HIC(d) would be below the threshold requirement.

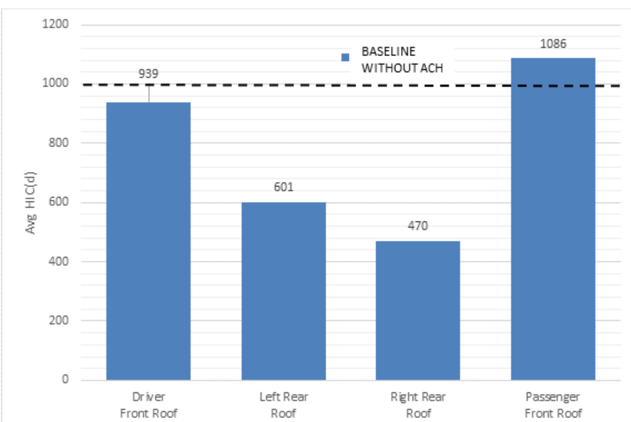

Figure 14: Vehicle A Roof Position Head Impact Testing

Vehicle B Baseline Analysis

Material ID 6 resilient foam material was the only material tested at the rear hatch edge location because of its capability to form around complex edge surfaces. The first impact of the free motion head form on the rear hatch edge covered with Material ID 6 was aborted because the edge cut through the material cutting the skin on the free motion head form. To date, edge protection solutions still need to be addressed.

Figure 15 shows the HIC(d) test results of the vehicle baseline without energy attenuating materials and the HIC(d) test results with the material samples. The baseline HIC(d) results are significantly higher than the injury criteria requirements (HIC(d) < 1000) with the exception of the driver sidewall location. The driver sidewall location consists of an electrical door panel which may act as an energy attenuator providing enough energy dissipation to prevent impact related head injuries without needed additional protection.

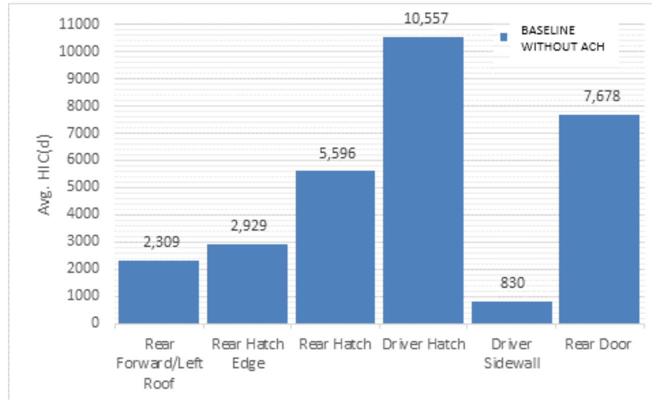

Figure 15: Vehicle B Baseline Head Impact Testing

IIPS solutions were testing at the rear forward/left roof position. Material IDs 1 through 10 were impacted to evaluate the influence EA materials have on HIC(d). Figure 16 shows the percent reduction and average HIC(d) values. All ten material ID solutions proposed met the injury threshold requirement for HIC(d) and had a significant percent reduction over the baseline testing ranging from 63% to 88% reduction.

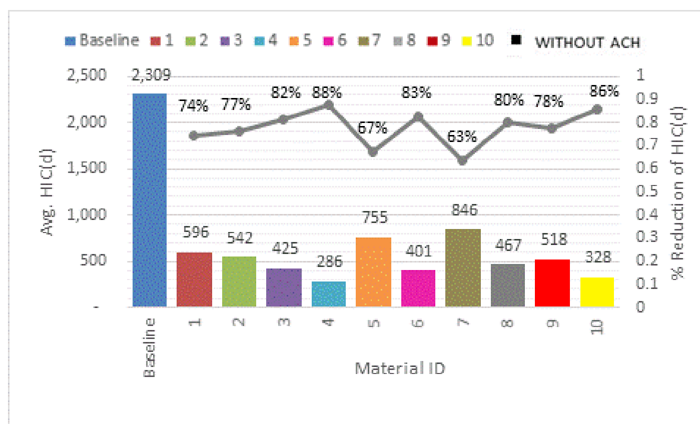

Figure 16: Rear Forward/Left Roof HIC(d) and Percent Reduction

Material ID 6 was tested at the rear hatch edge position in Vehicle B, Figure 17. Material ID 6 improved the performance of HIC(d) by 17%, but still exceeded the injury threshold requirement. Additional material ID testing at this location needs to occur.

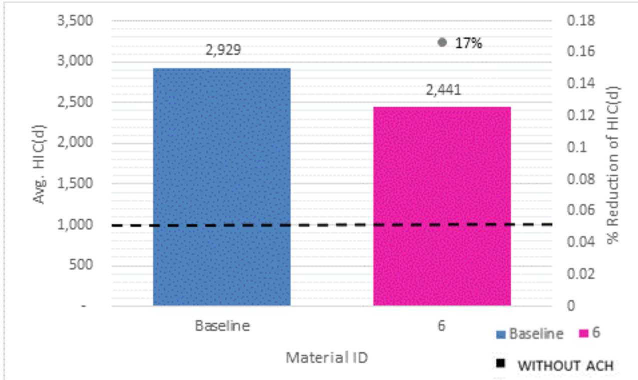

Figure 17: Rear Hatch Edge HIC(d) and Percent Reduction

The rear hatch vehicle position was tested with material IDs 3, 4, 5, 6, and 10 to see if reduction of baseline would occur, Figure 18. Material IDs 3, 4, 6, and 10 meet the injury threshold criteria. Material ID 5 exceeded the injury threshold criteria and is not a viable solution. However each material ID provided significant percent reduction over baseline HIC(d) ranging from 68% to 91% reduction.

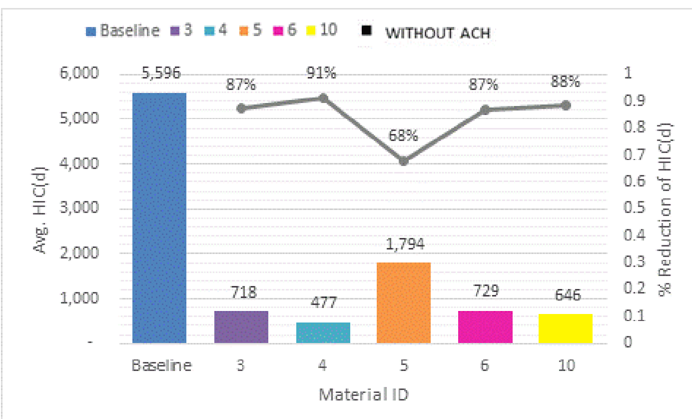

Figure 18: Rear Hatch HIC(d) and Percent Reduction

The driver hatch position had a baseline HIC(d) of 10,557, which exceeds the injury threshold criteria. Material ID solutions 4, 5, 6, 10, and 11 were tested to see if viable solutions to achieve the threshold injury criteria. The results can be seen in Figure 19. The material IDs showed a 77% to 95% reduction of HIC(d) over baseline testing. Material IDs 4, 6, and 10 are solutions for the driver hatch position to meet the injury threshold criteria.

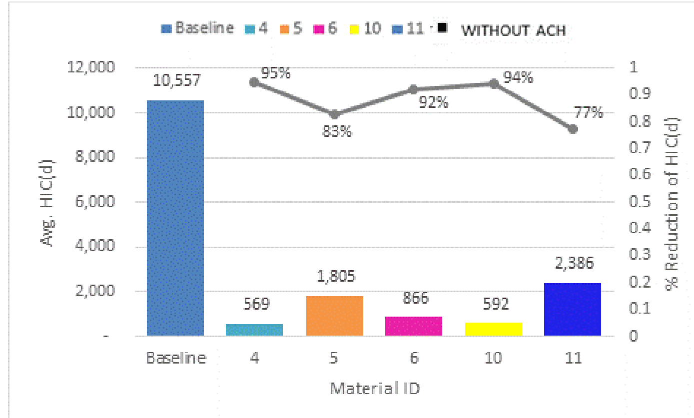

Figure 19: Driver Hatch HIC(d) and Percent Reduction

The driver sidewall position baseline HIC(d) value is 830. This position meets the injury threshold criteria, however material ID solutions were tested at this position, Figure 20. There was a reduction in HIC(d) from 27% to 53%, all material solutions are viable options to continually reduce the head injury criteria.

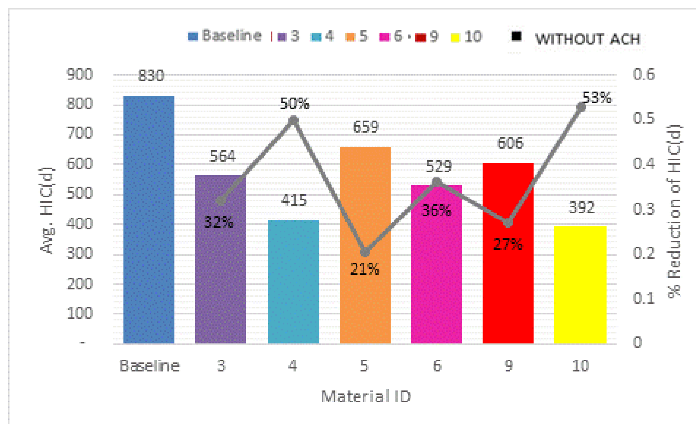

Figure 20: Driver Sidewall HIC(d) and Percent Reduction

The rear door position was impact tested using material ID 12, Figure 21. The HIC(d) value during baseline testing was 7,678 and the IIPS solution reduced the value by 88%. The rear door potion with material ID 12 meets the injury threshold value and is a solution at this location.

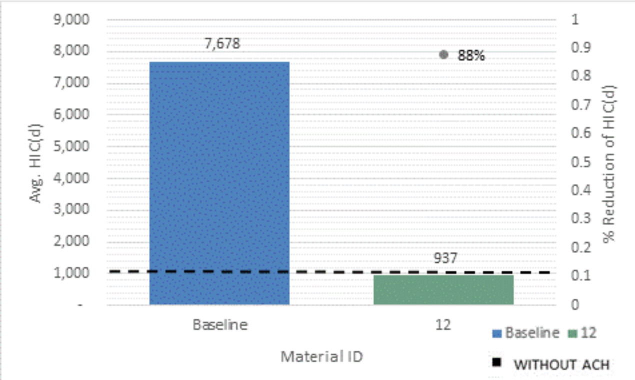

Figure 21: Rear Door HIC(d) and Percent Reduction

Vehicle C Baseline Analysis

As shown in the Figure 22, the average HIC (d) for baseline testing on Vehicle C without and ACH shows that the vehicle exceeds the threshold requirement for HIC (d) at the impact positions associated with position two: dash board, position 3: roof, position 4: roof, and position 5: electrical component, roof. Pos-2 duct and Pos-5 roof did meet the injury threshold requirement during baseline testing without an ACH. IIPS are needed at the locations that exceeded the injury threshold.

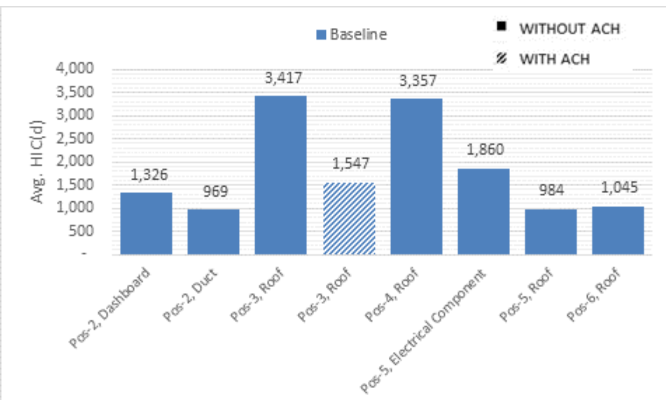

Figure 22: Vehicle C Baseline HIC(d)

Figure 23 shows percent reduction and the average HIC(d) for the additional head impact testing was conducted on Pos-3 roof. Pos-3 roof baseline testing was conducted with an ACH, which yielded a 55% reduction over baseline without an ACH. Material IDs 15 through 18 where then tested with an ACH on impact location Pos-3 roof. Material ID 15 met the injury threshold requirement with a HIC(d) of 842. Material IDs 16 through 18 exceeded the injury threshold requirement with an average HIC(d) of 1,308, 1,399, and 1,017 respectfully. All materials ID solutions had a significant percent reduction in HIC(d) from the baseline without ACH testing ranging from 59% to 75% reduction. Material ID 15 is the only viable solution tested that could be utilized in Pos-3 roof to meet the threshold requirements.

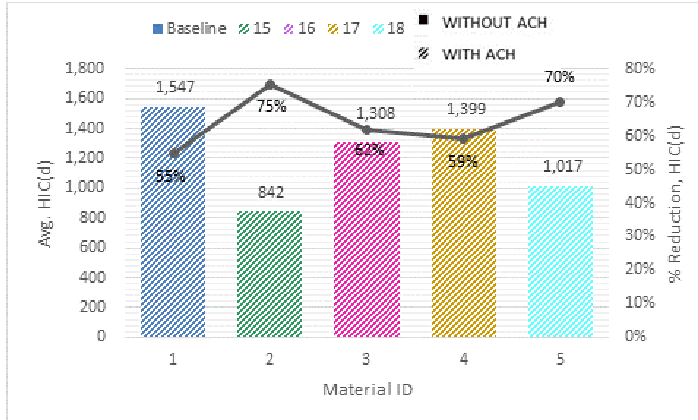

Figure 23: Pos-3 Avg. HIC(d) and Percent Reduction

Trim Buck Baseline Analysis

The HIC (d) for baseline testing on the roof location with and without an ACH shows that the introduction of a helmet greatly reduces HIC (d). The introduction of an ACH into the baseline testing produces a 75% reduction over the baseline testing without an ACH. The use of Material ID 13 with an ACH has an 85% reduction over the baseline testing without an ACH. The minimal crush pattern on the Material ID 13 core material show that the Material ID 13 exposed surface sheet absorbs significant amounts of energy during impact. Material ID 14 wan an ACH reduced the value of HIC(d) by 83% over the baseline testing without ACH. Figure 24 illustrates the reduction an ACH and the introduction of EA material solutions have on reducing the injury criteria to meet the threshold requirement.

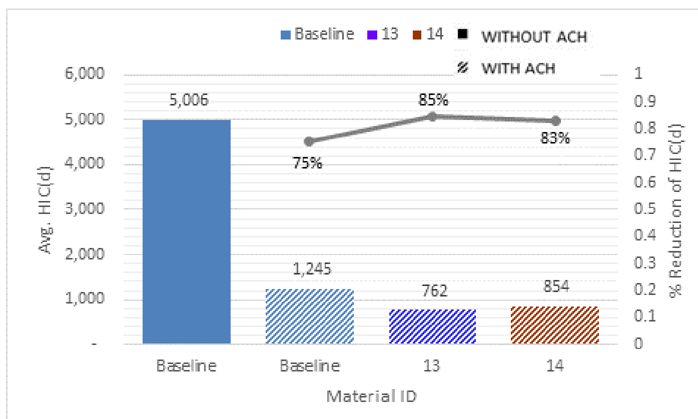

Figure 24: Roof HIC(d) and Percent Reduction

Figure 25 shows the Ancra track testing head injury criteria results. The baseline testing on the Ancra track conducted with an ACH show a 77% reduction in head injury criterion from the roof baseline testing without a helmet. Material ID 13 with an ACH has a 29% reduction in the head injury criteria over the baseline Ancra track testing with an ACH. The HIC(d) of material ID 13 with an ACH at the Ancra track is 808 meeting the injury threshold requirement.

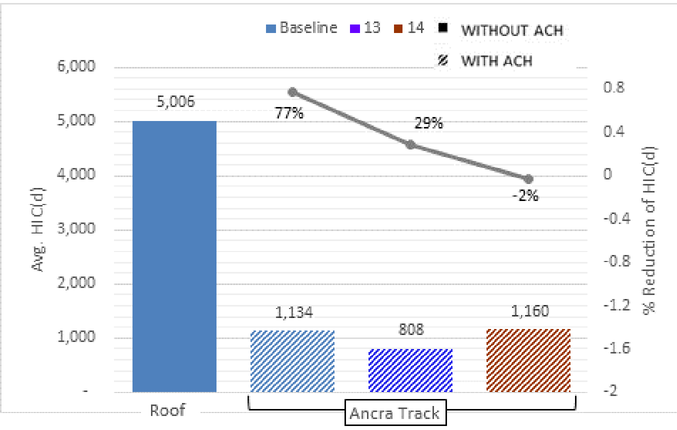

Figure 25: Ancra Track HIC(d) and Percent Reduction

Material ID 14 had a -2% reduction, Figure 25, over the baseline Ancra track testing with an ACH. This was the result of the core material not being fully engaged on the Ancra tract. The backing of material ID 14 was reinforced with steel, this resulted in the core material being too rigid and simulated testing equivalent to the stand alone fixture. In the second test of the material ID 14 with ACH Ancra track series, the FMH impacted the steel reinforcement through the IIPS resulting in a HIC(d) of 1,435. This result is greater than the average HIC (d) of the Ancra track baseline testing. The properties of the Material ID 14 core material and the ability to absorb energy are affected by the addition of the steel backing. A different attachment method needs to be developed to keep form while using a non-formed exposed surface sheet.

CONCLUSION

The flat fixture and vehicle baseline testing and evaluation performed on COTS materials provided TARDEC with an objective assessment of materials performance with respect to the head injury criteria. The vehicle baseline testing showed certain materials consistently reduced HIC while on a flat vehicle surface. Further studies need to be conducted to identify material ability to contour to corners.

The conclusion drawn from Vehicle A test series is that interior impact protective solutions need to be implemented on the A-pillar, B-pillar, door, and turret locations in vehicle A. The addition of energy attenuation materials will reduce head injury during blast events, this will assist in the warfighter having an increased likelihood of completing his or her mission.

Vehicle B head impact testing shows the needs to incorporate interior impact protective solutions to reduce HIC at all vehicle locations tested: rear forward/left roof, rear hatch edge, rear hatch, driver hatch, driver sidewall, and rear door. The rear hatch edge EA material solution did not reduce the HIC(d) to meet the threshold requirement. Further evaluation of materials needs to be conducted. EA material tested at the rear forward/left roof locations shows that 10 of the 10 materials are viable solutions to meet the threshold injury requirement. Four of the five EA materials tested at the rear hatch are validated solution to meet the threshold requirement. Driver sidewall baseline testing met the injury threshold requirement. Material ID 12 is a viable solution for the rear door in achieving the injury threshold. Further research needs to be done on interior protective solutions on rear door locations. Rear doors are in the head impact zone and also an ingress/egress into the vehicle.

Vehicle baseline testing and evaluation of Vehicle C is that interior impact protective solutions need to be implemented for: Pos-2, Dashboard, Pos-3 Roof, Pos-4, Roof, Pos-5 Electrical Compart and Roof, and Ros-6 Roof. Pos-3 Roof also demonstrations how the introduction of the ACH reduces HIC(d) by 55%. One of the four EA materials tested using an ACH was met the threshold injury requirement and is a solution for head impact injury reduction at Pos-3 Roof.

Trim Buck baseline testing conclusions are the introduction of an ACH reduced HIC(d), however interior impact protective solutions are still needed to meet the injury threshold requirement. Material ID 13 met the injury requirement at both the roof and Ancra track locations thus a feasible IIPS solution to encompass all target locations.

Through the use of the Design Review Based on Failure Modes tool, the need for improved fire resistant materials when large overhead (i.e. roof) protective materials are incorporated into the vehicle design is identified as an important design feature. The direction towards the use of fire resistant materials, although through the development efforts associated with this project modified and novel materials were developed which meet the needs of the Army.

TARDEC used the knowledge gained through this effort to create a general performance specification for interior head impact protection for use in U.S. Army ground system vehicles. This performance specification is based upon the subject knowledge to date. TARDEC acknowledges the performance specification requires further development of durability and fire resistance requirements. As such, TARDEC continues to research and develop these requirements and materials which provide sufficient energy attenuating characteristics while also being resistant to fire, durable and capable of performing in U.S. Army ground system vehicle environments.

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