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Demonstration/Validation of Hazardous Air Pollutant-Free Adhesive Replacement for Federal Specification MMM-A-1617 Used on the M109A6 Paladin Heavy Brigade Combat Vehicle

by Faye R. Toulan, Patricia E. Dodson, and John J. La Scala

ARL-TR-6693 **September 2013**

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14. ABSTRACT
The goal of the Sustainable Painting Operations for the Total Army (SPOTA) program is to significantly reduce the amount of hazardous air pollutant (HAP) emissions produced in coating operations, including adhesives application and removal. Adhesives and sealants account for approximately 5% of U.S. Army-wide HAP emissions from surface coating operations. Materials conforming to Federal specification MMM-A-1617 have been recognized as one of the largest contributors. Laboratory test results previously conducted identified 3M-847 as a suitable HAP-free replacement adhesive that conforms to MMM-A-1617. This report focuses on the field trial conducted at Anniston Army Depot, AL, on a M109A6 Paladin heavy brigade combat vehicle. In particular, the hydraulic compartment door seal was bonded with HAP-free 3M-847 adhesive in place of the baseline (Clifton FA-1051) with successful results. The technicians found that processing the alternative adhesive was similar to that of the baseline, and after six months, the adhesive did not have any signs of blistering, delamination (either cohesively or adhesively), substrate failure, or deterioration of any kind. Overall, the HAP-free 3M-847 adhesive was qualified for use on MMM-A-1617 Army platforms.

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1. Introduction

The U.S. Environmental Protection Agency (EPA) is planning to propose the Defense Land Systems and Miscellaneous Equipment (DLSME) National Emission Standard for Hazardous Air Pollutants (NESHAP) that will affect U.S. Army surface coating operations (*1*). Hazardous air pollutants (HAPs) are pollutants that are known or suspected to cause cancer or other serious health effects or adverse environmental effects. A survey of many Army installations found numerous adhesives, sealants, and other coating materials that contain significant amounts of HAPs (*2*). The Army has determined that it is more cost-effective to reduce or eliminate HAP emissions from surface coating operations rather than using emissions control devices to capture and treat them (*2*). The goal of the Sustainable Painting Operations for the Total Army (SPOTA) program is to significantly reduce the amount of HAP emissions produced in coatings operations, including application and removal of adhesives and sealants. The federal specification MMM-A-1617 was recognized as a significant contributor of HAP emissions and would benefit the Army if alternate HAP-free adhesives could be identified (*2*).

2. Background/Previous Work

The MMM-A-1617 federal specification covers natural and synthetic rubber based adhesives. These elastomeric adhesives are classified into three types (*3*):

- Type I: Non-oil-resistant natural rubber base, synthetic natural (polyisoprene), styrene butadiene (SBR), reclaim, or combination.
- Type II: Oil-resistant polychloroprene rubber base.
- Type III: Fuel-resistant butadiene acrylonitrile (nitrile) rubber base.

According to MMM-A-1617, these adhesives will bond duck, leather, and felt to themselves or to relatively nonporous materials such as wood, aluminum, steel, rubber, and plastics (*3*). Table 1 contains the substrate combinations, conditioning parameters, and strip adhesion requirements for MMM-A-1617. All variations in the immersion and heat aging sections of table 1 required standard conditioning of seven days at room temperature prior to any additional conditioning parameters.

Table 1. Strip adhesion requirements (*3*).

Substrate Combinations and Conditioning	Requirements		
	Type I (lbf)	Type II (lbf)	Type III (lbf)
After standard conditioning:			
Al/duck 7 days at RT	12	15	10
Al/rubber 7 days at RT	—	15	—
Al/vinyl 7 days at RT	—	—	8
After immersion for 22 h:			
Al/duck DI H_20 at RT	6	12	5
Al/duck IRM-901oil at 70 °C	—	12	8
Al/duck JP-8 fuel at RT	—	—	8
After accelerated heat aging:			
Al/duck 7 days at 70 °C	12	15	10

Note: DI = deionized and RT = room temperature.

Previous work identified 3M Scotch-Weld (alternative) Nitrile High-Performance Rubber and Gasket Adhesive 847 (3M-847) as a HAP-free product that meets the specification MMM-A-1617, as detailed in ARL-TR-5529 (*4*). 3M-847 was determined to be a suitable HAP-free replacement for all three types of MMM-A-1617 adhesives (*4*). Overall, the results indicate that the 3M-847 adhesive (alternative) was higher performing than the Clifton (baseline) products (figure 1). The HAP-free adhesive performed equal to or better than the baseline regardless of the conditioning requirements and substrate combinations. This adhesive formulation contains a nitrile polymer base, also known as acrylonitrile butadiene. Nitrile has good resistance to oil, water, and heat (*5*). The adhesive properties can be increased by increasing the nitrile content in the formulation (*5*). According to the material safety data sheet (MSDS), 3M-847 has a content of 10%–30% nitrile and 5%–10% phenol formaldehyde polymer (phenolic resin), which is a tackifier and adhesion promoter (*6*). Tackifiers in adhesive formulation are materials used to enhance the "wet-grab" property that causes bonding surfaces to adhere to each other upon initial contact prior to chemical curing (*6*). According to the American Society for Testing Materials (ASTM), wet bond strength in the context of this research is used to describe the strength of a joint when the adherends are brought together with the adhesive still in the wet state (*7*). In particular, 3M-847 had a perceptible "wet grab" that far exceeded all the other adhesives. Phenol-formaldehyde adhesion promoters are capable of enhancing adhesion durability due to improvement in substrate wetting and the formation of chemical bonds across the film/substrate interface (*6*). Adhesives with nitrile-phenolic blends have enhanced peel strength without reduction in high-temperature strength, high wet and dry strength, and are resistant to moisture (*6*). The material "glycerol esters of rosin acids" is specified at a level of 7%–13% on the 3M-847 MSDS. This material is used as a thermoplastic resin, also known as a "modifier" that is unique to the 3M-847 formulation in this test series. Thermoplastic resin is defined as a material that becomes soft and pliable when heated without change in its other properties and hardens

when cooled again (*8*). The addition of a thermoplastic resin to a nitrile-phenolic blend in a contact adhesive formulation assists in the flexibility of the product, thus increasing the fracture toughness and decreasing brittleness of the adhesive interface, allowing for better adhesion (*9*).

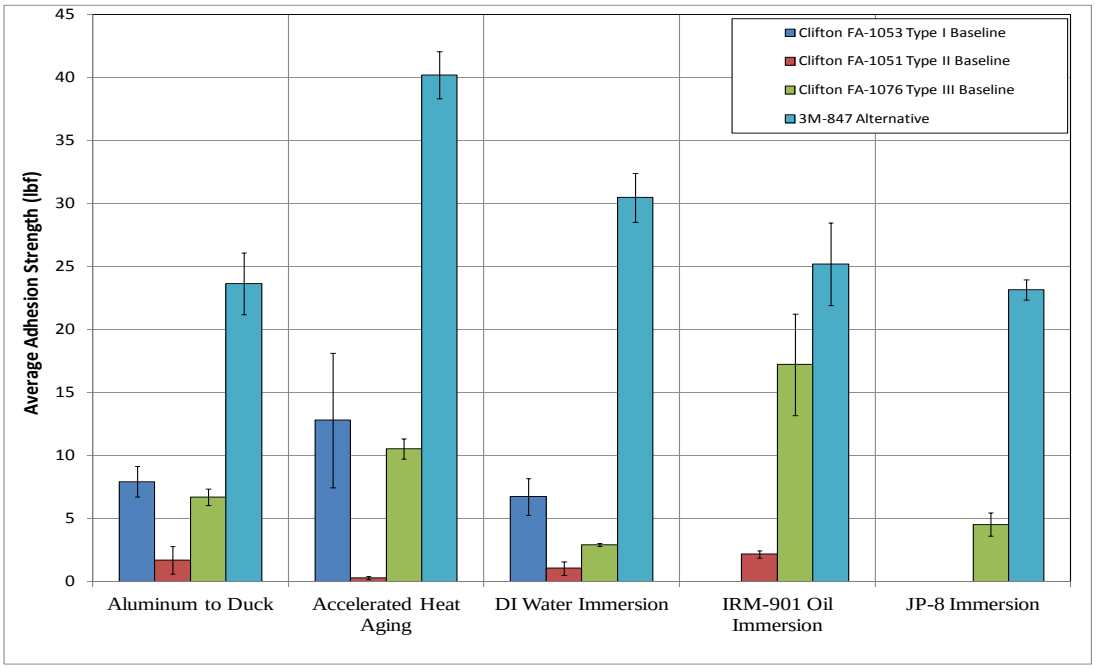

Figure 1. Comparison of various conditioning parameters on bond strength.

Laboratory testing alone is insufficient to replace a material on a weapons platform. Thus, this report focuses on the demonstration and validation of HAP-free (3M-847) for the federal specification MMM-A-1617 on the hydraulic compartment door gasket of an M109A6 Paladin armored vehicle.

3. Materials

Clifton FA-1051 adhesive (baseline) is currently registered on the qualified product list (QPL) for a MMM-A-1617B type-II adhesive (*10*, *11*). This adhesive is oil resistant with a polychloroprene rubber base and is recommended for bonding natural and neoprene rubber. This product contains hexane and toluene, which are both HAPs and Volatile Organic Compounds (VOCs) (*12*). This adhesive also contains methyl ethyl ketone (MEK), which is non-HAP but is a VOC (*13*).

The 3M Scotch-Weld (alternative) Nitrile High-Performance Rubber and Gasket Adhesive 847 (3M-847) is a medium-viscosity grade for brush or flow application while providing strong, flexible bonds; 3M-847 is quick drying with excellent resistance to many fuels and oils. This adhesive bonds leather, nitrile rubber, most plastics, and gasketing materials to a variety of substrates. The carrier solvent is acetone (*14*), which is exempt from the EPA VOC and HAP lists (*15*). This product meets the requirements for MIL-C-4003 Federal Specification: Cement General Purpose and Synthetic Based. MIL-C-4003 was cancelled and superseded by MIL-A-5092 Federal Specification: Adhesive, Rubber Base and General Purpose. MIL-A-5092 was cancelled and superseded by MMM-A-1617A and superseded by the updated specification MMM-A-1617B. 3M-847 should meet the requirements of MMM-A-1617B. However, this adhesive is not currently included on the QPL (*11*).

Table 2 contains a summary of physical properties for the MMM-A-1617 baseline adhesive currently used on the M109A6 Paladin combat vehicle in addition to the HAP-free alternative to be demonstrated and validated. These properties were compiled from the MSDSs and technical data sheets (TDSs).

Table 2. Physical properties of adhesives.

Adhesive	Type	Solvents	HAP (wt. %)	VOC (g/L)	Density (lb/gal)
Clifton FA-1051 (baseline)	II	Toluene Hexane MEK	15–30	716–752	6.75–7.05
3M-847 (alternative)	NA	Acetone (exempt)	0	0	7.40–7.80

4. Demonstration/Validation on M109A6 Paladin Combat Vehicle

The M109A6 Paladin is a further upgrade of the M109 self-propelled howitzer, which was introduced in the early 1960s (*16*). Also, the M109A6 is the most technologically advanced self-propelled cannon system in the U.S. Army (figure 2). The “A6” designation identifies several changes to the standard model that provide improvements to weapon survivability, responsiveness, reliability, availability, and maintainability, armament and terminal effects (*17*).

Figure 2. M109A6 Paladin heavy brigade combat vehicle (*16*).

In an effort to validate the laboratory test results detailed in ARL-TR-5529 (*4*), a field trial was conducted at Anniston Army Depot (ANAD), AL, March 27, 2012, on the M109A6 Paladin combat vehicle ID no. PAL258-0780. This demonstration/validation substituted the QPL registered baseline adhesive (Clifton FA-1051) for specification MMM-A-1617 with the HAP-free alternative (3M-847). The specific application was to replace the rubber gasket of the hydraulic compartment, located on the cab door of the M109A6 Paladin combat vehicle (FY11 Reset program) (figure 3). This platform was identified during a scouting visit to ANAD in January 2011. The hydraulic compartment is located on the cab of the vehicle.

Figure 3. Paladin hydraulic compartment hatch door.

The procedure was in accordance with the technical manual (TM 9-2350-314-34-2) *Direct Support and General Support Maintenance for Cab Systems and Components Howitzer, Medium, Self-Propelled: 155MM, M109A6*. The old hatch seal and adhesive was removed and the aluminum channel on the perimeter of the hatch door was thoroughly cleaned with MEK solvent (figure 4).

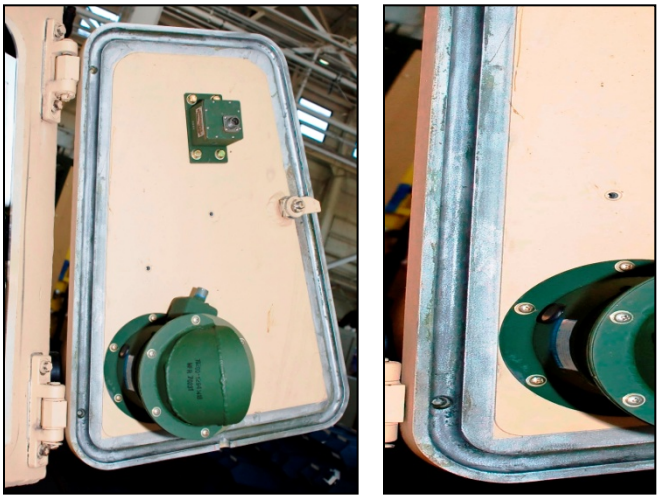

Figure 4. Cleaned aluminum channel on the perimeter of the hatch door.

One coat of 3M-847 (alternative) adhesive was applied by brush on both the rubber gasket and the aluminum channel located on the perimeter of the hatch door (figure 5). The adhesive was allowed to dry before a second coat of adhesive was applied on both surfaces in increments of 6–12 in and then bonded together (figure 6). The hatch door was closed to hold the rubber gasket in place until the adhesive cured.

Figure 5. Adhesive application on rubber seal (left) and aluminum channel (right).

Figure 6. Bonded gasket on hydraulic compartment hatch door.

During the field trial, the Paladin technician applying the 3M-847 adhesive (alternative) was instructed to observe several properties, such as brush-ability and assembly time, then compare to the baseline product (Clifton FA-1051). Resistance to sagging, which is run or flow of the adhesive before or during the bonding process from an adherend surface due to low viscosity is an important property because there are vertical surfaces on the perimeter of the hydraulic compartment door (figure 4) (*7*). The Paladin technician described 3M-847 as easy to apply with a brush and was similar to the baseline. The technician conducting the six-month inspection evaluated the 3M-847 adhesive for several performance properties, such as blistering, delamination (failure of the adhesive bond cohesively or adhesively), substrate failure, or deterioration of any kind.

Table 3. Adhesive performance properties and terminology.

Adhesion Failure	A rupture of an adhesive bond in which the separation appears to be at the adhesive/adherend interface. This is a type of delamination.
Blistering	An elevation of the surface of an adherend, the boundaries may be indefinitely outlined and it may have burst and become flattened. This may be caused by inadequate curing time, temperature, pressure, trapped air, water, or solvent vapor.
Cohesion Failure	A rupture of an adhesive bond, such that the separation appears to be within the adhesive. This is a type of delamination.
Substrate Failure	A rupture or tare of the substrate (rubber seal) at the adhesive/adherend interface.

5. Results and Discussion

Six months (9/30/2012) after the hydraulic compartment door gasket was replaced with HAP-free 3M-847 adhesive, the M109A6 Paladin combat vehicle (PAL258-0780) was inspected at Fort Hood, TX. The bonded gasket did not have any signs of blistering, delamination (either cohesively or adhesively), substrate failure, or deterioration of any kind (figure 7). Overall the

inspector concluded the 3M-847 performed well and similarly to the baseline product (Clifton FA-1051) in maintaining the bond between the aluminum channel located on the perimeter of the hydraulic compartment door and the rubber gasket similarly to the baseline.

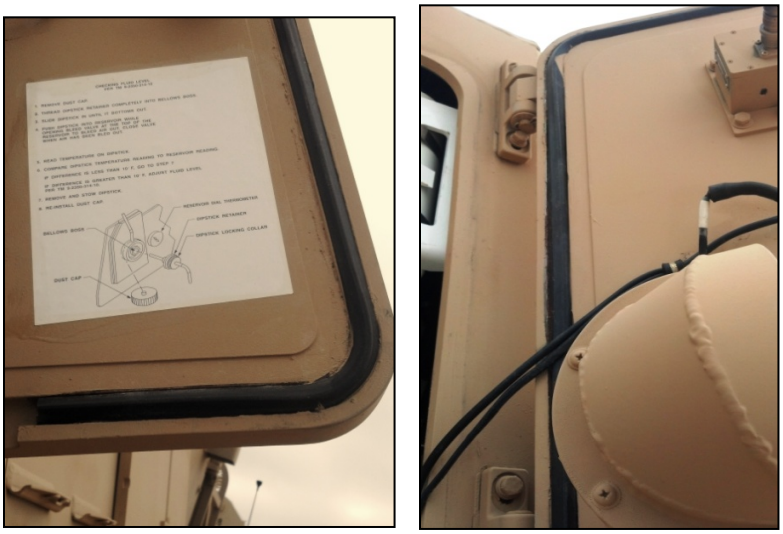

Figure 7. Paladin (PAL258-0780) hydraulic compartment gasket at the six-month inspection.

6. Conclusions

Laboratory testing outlined in the ARL technical report (ARL-TR-5529) resulted in identifying the HAP-free adhesive 3M-847 as a suitable alternative to the Clifton FA-1051 baseline adhesive listed on the QPL for MMM-A-1617. The field trial conducted at ANAD in March 2012 on the M109A6 Paladin combat vehicle proved successful. The six-month inspection conducted at Fort Hood, TX, confirmed that 3M-847 was an appropriate HAP-free substitution for the Clifton FA-1051 baseline adhesive, when bonding the rubber gasket to the aluminum channel located on the perimeter of the hydraulic compartment door. Thus, not only is 3M-847 qualified to be used on the Paladin hydraulic compartment hatch door, we recommend its use in place of all HAP-containing adhesives for use in MMM-A-1617 efforts on weapons platforms and other applications.

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List of Symbols, Abbreviations, and Acronyms

ANAD	Anniston Army Depot
ASTM	American Society for Testing Materials
DI	deionized
DLSME	Defense Land Systems and Miscellaneous Equipment
DSI	Dynamic Science, Inc.
EPA	U.S. Environmental Protection Agency
HAP	hazardous air pollutant
MEK	methyl ethyl ketone
MSDS	manufacturer's material safety data sheet
NESHAP	National Emission Standard for Hazardous Air Pollutants
QPL	qualified product list
RT	room temperature
SBR	styrene butadiene
SPOTA	Sustainable Painting Operations for the Total Army
TDS	technical data sheets
VOC	Volatile Organic Compound

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