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Fin Protection via Combustible Coatings

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13. ABSTRACT ***(Maximum 200 words)***

Fin damage presents a significant problem to the effectiveness of ordnance. Damaged fins commonly induce high yaws and/or projectile deformation. A substantial portion of this fin damage is believed to occur in-bore. Combustible fin protection is designed to function only in-bore. Several supporting tests have been performed to examine the viability of these coatings. Data such as the coating's adhesive and insulative properties, as well as its compatibility with gun propellant, were obtained. The consistently positive results from these tests indicate that fin integrity will be substantially improved using a combustible coating.

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1. INTRODUCTION

Fin damage presents a significant problem to the effectiveness of ordnance. Damaged fins commonly induce high yaws and/or projectile deformation (Pennekamp 1993). A substantial portion of this fin damage is believed to occur in-bore. Two sources of damage are the high-temperature environment and the propellant grain impacts that the fins are subject to as they pull through the propellant bed. Fins of kinetic energy (KE) penetrators are particularly vulnerable since they are exposed to severe aerodynamic heat loads as well.

Eliminating fin damage as much as possible is essential for maximizing projectile performance. Presently, many fins are anodized (hardcoated) to reduce the damage. Although there are drawbacks—high cost and complexity—this measure has proven somewhat successful. The proposed combustible coatings show considerable promise as a method of protecting the fins at low cost and with ease of application.

Ultimately, the problem of fin damage can always be mitigated by using thicker fins. But, since aerodynamic drag is somewhat sensitive to fin thickness, this has the disadvantage of increased weight and drag. A change in fin material to steel fins is also an option, but this would, at least initially, add significant cost to the production process and increased weight to the design. Combustible coatings do not have these drawbacks.

The combustible fin protection suggested provides in-bore protection only. As such, the coating is not exposed to aerodynamic heat loads during flight. Traditional coatings attempt to tackle both environments. Mechanical devices that offer in-bore protection exist (Mudd 1989). Unfortunately, these devices usually have significant cartridge case intrusion and/or poor device discard. Combustible fin coatings, while limited in their abilities, appear to have no detrimental side effects. The optimum use seems to be to combine these coatings with a well-established fin protection method such as hardcoating. It is hoped that, at the very least, these coatings will lessen the severity of the gun chamber environment on the fins.

Combustible coating technologies have been proposed, as in the patents submitted by Wahner (# 5,160,804) and Walker (Eu 0 484 958 A2). Their coating thicknesses are not sized, such that they are consumed by the time the projectile exits the muzzle, and were assumed to burn away or detach in-flight. This discard can adversely affect dispersion and aerodynamic drag.

The research described in this report is primarily qualitative in nature and is derived from several simple tests. These tests were designed to explore some prospective fin coating materials. The coating material must:

- adhere to the material substrate (typically aluminum),
- withstand propellant grain impacts on the order of 90 m/s and remain attached to the material substrate,
- combust completely over approximately a 10-ms launch cycle,
- be inexpensive,
- be compatible for storage in contact with propellant, and
- serve as thermal insulators.

2. ANALYSIS

Nitrocellulose has all of the aforementioned attributes needed for an acceptable coating material and is readily available. It is a component of many propellants and can be chemically separated from them. Two nitrocellulose sources were considered for producing coating materials. One source is an adhesive that is almost completely nitrocellulose and requires no chemical processing for its use. Being so disposed, it was the primary choice for candidate materials, and has been subjected to the most testing. Nitrocellulose was also obtained from an acetone solvated mixture of U.S. Navy 16-in gun propellant (SPD), and additionally from a solvated mixture of M10 propellant.

Nitration levels indicate the amount of substitution of O-H groups with N-H3 groups and affect the flame temperature and burning rate of the coatings. These candidates' chemical compositions represent a range of nitration levels varying from 12.0% to 13.2%. These properties are needed to properly size the thickness of the coating to reasonably assure complete combustion by the time of projectile muzzle exit. Estimates for the coatings' burning rate and various other properties affecting combustion were calculated using the BLAKE code (Freedman 1981). The code produced an estimated flame temperature for the dried adhesive of 2,800 K, while the SPD mixture's estimated flame temperature was 3,260 K. (A typical propellant might have a flame temperature of 3,000 K.)

It is important that the coatings completely combust to negate any fin asymmetry, excess drag, or discard effects that could be caused by residual coatings. The coatings' thickness was calculated using the IBHVG2 code (Anderson and Fickie 1987). This code accounts for the geometry of the gun chamber, the amount and type of propellant(s), the projectile attributes, and several other interior ballistic variables. The environment modeled was that of an M829 launch, which was selected as the most representative of a state-of-the-art KE projectile. In addition, all the information needed for the code was available for this projectile. The thickness suggested by the code, based on a 13-ms launch cycle, was nominally 0.2 mm. This nominal thickness was used on all samples tested. Modifications to this thickness are considered likely as further test data or refined models arise.

3. TESTING

The first test examined the adhesive qualities of the nitrocellulose coatings. M900 fin blades were hand-dipped, dried, and measured. At this point, an attempt to remove the coatings by hand was made. This was followed by a propellant grain impact test. The amount of fragmentation and the amount of material that the fin retained were considered important measures.

The dried adhesive produced excellent results. Once dried, it left a clear, hard film that was very difficult to remove. The dipping process produced some air bubbles that were evident in the dried coating. A better application process could easily mitigate this; this problem was not unique to the adhesive coating. The solution of acetone and ground M10 produced somewhat disappointing results. The coating peeled from the fin blade surface when dry and was thus removed from further consideration as a coating candidate. In retrospect, the peeling away may have been due to the amount of graphite still in the solution. The M10 propellant has a graphite coating that was left in place when the propellant was crushed. The emphasis was on minimal processing of the coating materials.

The mixture of SPD fared far better. It stuck to the fin nearly as well as the adhesive solution, and left an opaque, hard covering. Since this propellant was not available until late in the program, this is where the testing ended for the SPD mixture.

The impact testing consisted specifically of a JA2 propellant grain impacting the coating thickness at roughly 90 m/s. The dried adhesive took the impact and remained essentially unaffected in that all of the coating remained attached and no fracture of the material was detected. As all results from the adhesive coating testing were positive, this is where further testing was concentrated.

After passing the initial tests, a determination of the coating's burning performance was required. Several aluminum disks were soft coated (the process of applying a protective combustible material to the fin) and placed in the chamber of a 120-mm gun. When fired, the propellant charge produced a chamber pressure of 30–40 ksi, far below the typical value of 70–80 ksi for a state-of-the-art KE projectile firing. The disks were recovered, and it was revealed that approximately 10% of the material remained unburnt and attached to the disk. It is assumed that under the higher temperatures and pressures found in a typical firing, the coating would completely combust. It is expected that data from future projectile firings will allow us to verify this assumption.

3.1 Thermocouple Tests. The impact test verified the ability of the coating to offer some in-bore physical protection for the fin. Equally as important is the ability of the coating to afford thermal protection. A simple qualitative test was conducted to examine these attributes. An adhesive-coated thermocouple was attached to a 3.1-mm-thick aluminum plate (simulating coated fins). Another plate was instrumented with a bare thermocouple attached to it. These plates were positioned 20 cm from a loaded primer tube, and the tube was ignited. Figure 1 graphically illustrates the experimental setup.

The results demonstrated that the coating provided a substantial insulative ability, as illustrated by Figure 2. The large spike indicates the temperature rise of the uncoated thermocouple, while the meager rise of the coated thermocouple is barely detectable but indicates that the thermocouple is working.

Thermocouple plate positions were switched for following tests to ensure that a primer asymmetry was not responsible for the effect, and these produced similar results. It is important to state that in an actual gun chamber, the fins would be closer to the primer and the surrounding pressure would be markedly higher. However, the duration of the heat load would be somewhat shorter.

3.2 Reverse Flow Firings. A more realistic simulation of the environment the fins will encounter was produced in the reverse flow tests. Figure 3 shows the fin-adapter-primer configuration used to secure the fin in place during the firing. This test is considered to be more severe on the fins than a typical firing, since much of the hot propellant gas streams by a stationary fin. But the fin is exposed to realistic chamber pressures and temperatures. The charge used for these firings is that of the M829A1 (7.92-kg JA2 Hex).

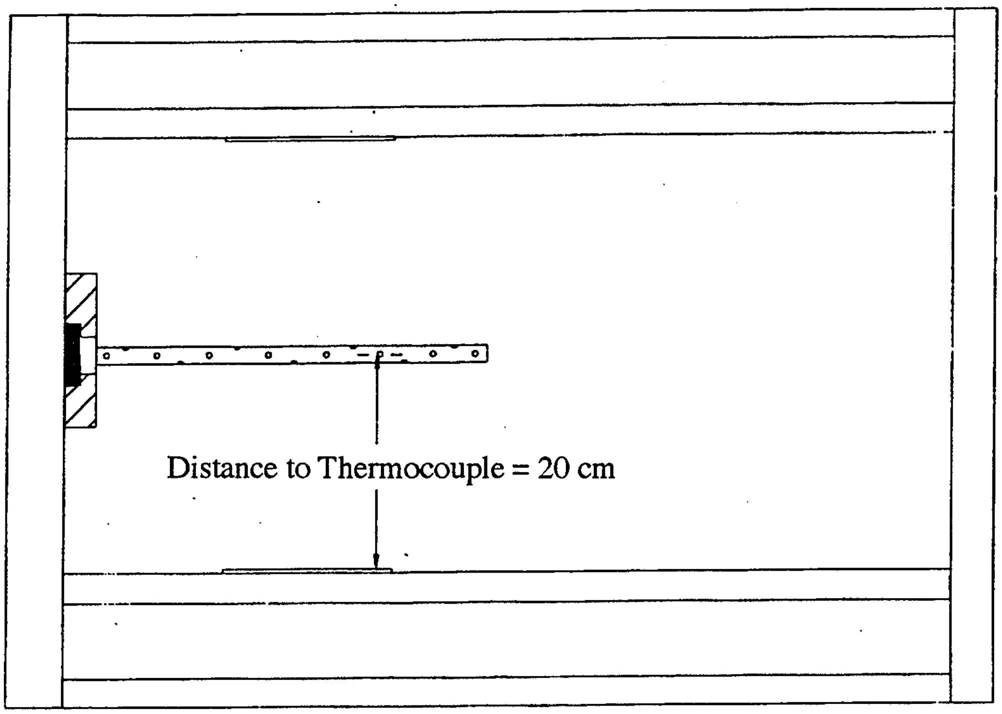

Figure 1. Thermocouple test configuration.

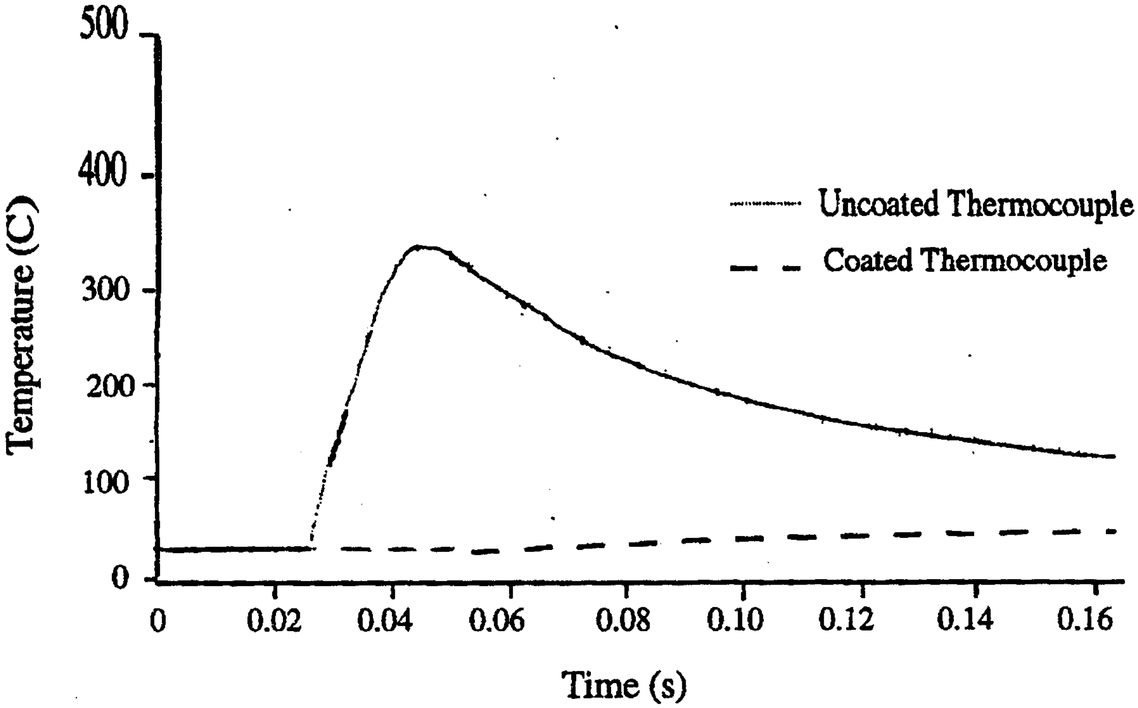

Figure 2. Coated and bare thermocouple primer blast response.

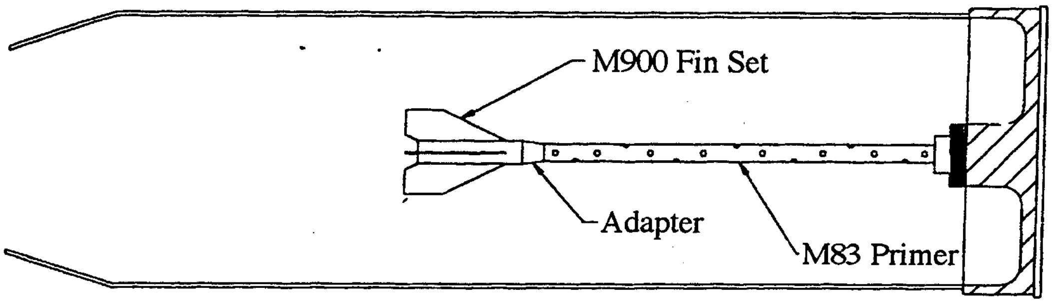

Figure 3. Reverse flow test fin configuration (charge not shown).

Figure 4 shows a fin set after firing with only a hard coat. Figure 5 displays a combustible-coated (soft coated) and hard coated aluminum fin after firing in the same reverse flow conditions. These photos clearly indicate that the fins that were hard coated, then topped with a soft coat, fared substantially better. The loss of planform area on the hard-coated-only fin has rendered it essentially nonfunctional, whereas the hard-coated and soft-coated fin retains basically all of its fin area. Pressures for the two firings were 72 ksi. It is likely that the tribology of each firing varies and different fin wear patterns are possible and in fact have been observed. However, in each case, the hard- and soft-coated fins survived the firing better. These photos (Figures 4 and 5) depict a typical firing result.

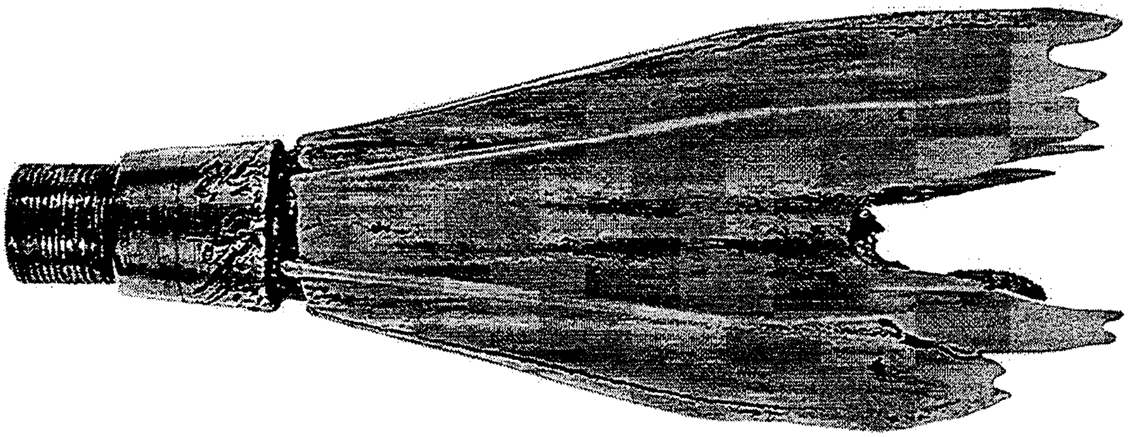

Figure 4. Hard-coated-only M900 fins after reverse firing.

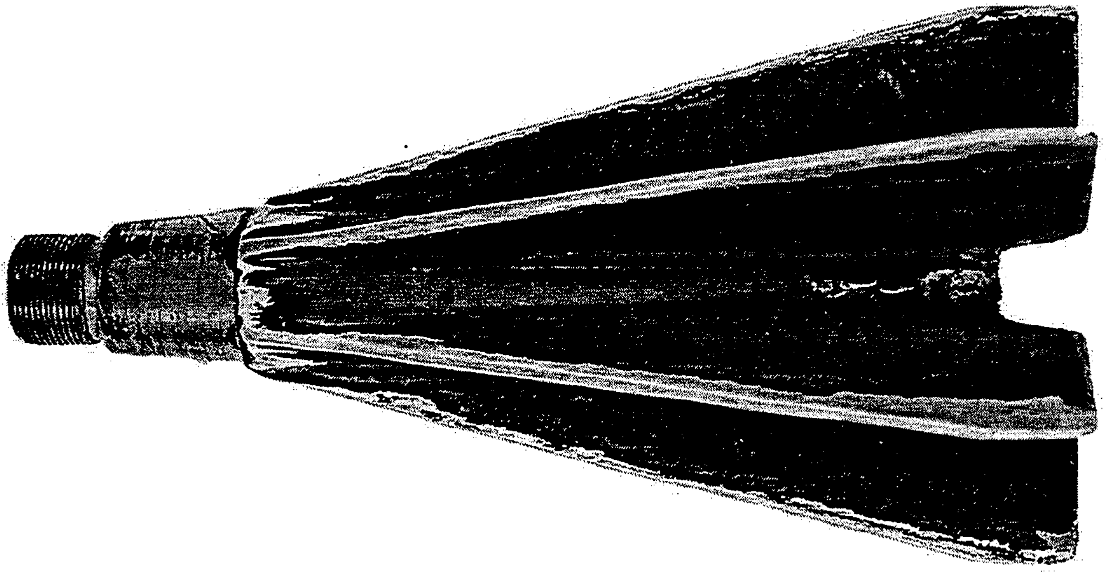

Figure 5. Hard-coated and soft-coated M900 fins after reverse firing.

4. CONCLUSIONS

Combustible fin coatings have proven to be effective as a protection device against in-bore fin damage. Their low cost, ease of application, and compatibility are attributes that suggest their practicality. Based on this, their use to reduce drag and save weight in comparison to costly steel fins seems logical.

Soft coats have additional benefits not highlighted in this series of tests. The coatings are nonflammable outside the gun bore, and have been shown to be compatible with propellant since their composition is basically the same as the propellant. Round storage does not present a problem. The hardness of the coating material should also absorb some of the bumps and scratches that the fin might encounter in handling while outside the case. The cost of the coating material is perhaps as low as $0.05 per fin. It is likely that quality assurance may be the most expensive part of the production/application process.

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