Non-Hermetic Impulse Cartridge Failures:
“A Case Study”

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This paper is addressing the findings in a Case-Study investigating a group of BBU-36 Impulse Cartridges purchased by the Air Force and later found to be defective. This study is reviewing the problem “Generically” in order to disseminate the findings to those experiencing similar performance problems in other ordnance devices, and, hopefully stimulate changes that will avoid such problems in the future. This Case-Study has uncovered some major weaknesses in: a) The design of the device; b) The materials used in the manufacture of the device; c) The manufacturing processes used; and d) The test procedures used to evaluate the finished product.

I. Introduction

A number of non-functional ordnance Impulse Cartridges were found to exist in the field. This case-study involved an extensive investigation of those devices to establish the nature of the defects that caused them to malfunction or fail, and the root cause for the devices to have been defective. The impulse cartridges were built to an Air Force Specification SP7730680C, and found to involve several design characteristics that made the devices vulnerable to both manufacturing difficulties as well as misapplied hermeticity test methods. A series of investigations was conducted that included chemical and engineering studies, as well as a detailed investigation of the hermeticity of the devices. These cartridges had two separated chambers of concern: a loose powder chamber containing ordnance pellets, and a compressed charge chamber that pressed against the header and encapsulated the bridge-wire. The two chambers were located at opposite ends of the devices, and some devices were found to have leaks into each end. The conventional helium seal testing methods were able to detect some defective seals into the larger cavity pellet chamber, but were incapable of detecting the leakage into the micro-cavity bridge-wire area.

The cartridges were also found to contain corrosive materials within the device. Two sources of corrosive material were suspected to have contributed to the failure of the devices. Acidic residues that were possibly left from the plating and chemical coating processes were found within some of the devices. The defective seals allowed leakage into the devices, which provided a means for moisture to enter the part. The moisture coupled with the corrosives within the devices caused an attack of the dissimilar-metal surfaces including the bridge-wires, which in some samples were completely destroyed. Chlorides were released perhaps from the breakdown of the ordnance material. A typical example of the total corrosive destruction of the bridge wires is shown below in Figure 1.

The defective devices were first detected by ‘open circuits’. They were then subjected to a variety of post mortem evaluations which produced data but not a clear understanding of the root cause for these failures. The chemistry of what took place within the device showed the process of degradation that was occurring, or had occurred. The study reported here shows that the lack of a hermetic seal was a major contributing factor in the failure of these BBU-36 cartridges.

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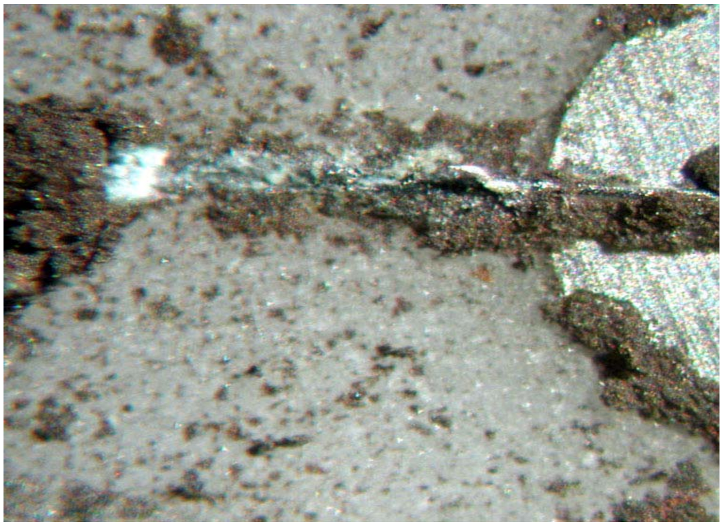

Figure 1
The above photomicrograph shows the effects of the complete corrosion of the bridge-wire, (typical of the findings in these cartridges)

It appears that the seal test procedures used to evaluate the hermeticity of the devices after manufacture were incapable of detecting leakage into the 'Zero-Cavity' bridge-wire area, which was a critical part of these failures.

II. Background

The type of problem seen in these cartridges is frequently associated with hermeticity problems. [1-7] Forty of the samples were investigated to establish the integrity of the seals. Twenty-nine of the forty cartridges had 'Open-circuits'. By design the device has two seals: One is a crimp closure over the chamber that houses two types of loosely packed ordnance pellets; and the other seal on the opposite end is a 'pressed-fit' header seal to a chamber that holds a compressed ordnance charge. The device configuration is seen in Figures 2 & 3.

Figure 2

Figure 3

BBU-36 Cartridges studied in this effort.

The final seal of these devices was dependent upon the MIL-V-Varnish used to hopefully complete the mechanical seals on each end of the device. The seal test specification was for a 1 x 10^{-5} atm cc/sec. (air), which is in the "Gross-leak rate range".

All of the packages had previously been leak tested before they were submitted to this study. The exact leak testing method used was not known, but it was assumed that they had been subjected to Helium Mass Spectrometer (HMS), leak testing. It is important to note that there are only two commonly applied leak test methods that are used as “dry-gas” leak test methods: HMS and radioisotope Kr85 leak testing.

A. Pellet Chamber

The pellet chamber on these devices contained a loose-pack material in the form of ordnance-pellets. There was some ‘free-volume’ in that chamber of the device, (0.1 – 0.2 cc range).

B. Bridge-wire Chamber

The header-end of this device is where the bridge-wire is mounted flush against the header. In this device ordnance material was compressed onto the bridge-wire, against the header surface. The result of this charge compressed onto the header encapsulating the bridge-wire, is that the resultant free-volume of the bridge-wire cavity was microscopically measured as 10-5 to 10-6 cc. There was a circumferential cavity around the o.d. of the B/W chamber that measured 10-3 to 10-4 cc. However it was filled with compressed ordnance material and what was later determined to be corrosive residues. The ‘nominal free-volume’ of the B/W chamber in these cartridges was considered to be < 0.0001 cc.

The “Pellet-Chamber” & “Compressed-Charge-Chamber” are shown below. Figure 4 shows the loosely packed pellets with ‘intra-pellet’ cavities. Figure 5 shows the compressed charge in the lower ‘header-chamber’ (after the pellets were removed).

Figure 4
Loosely packed pellets in the ‘pellet chamber’

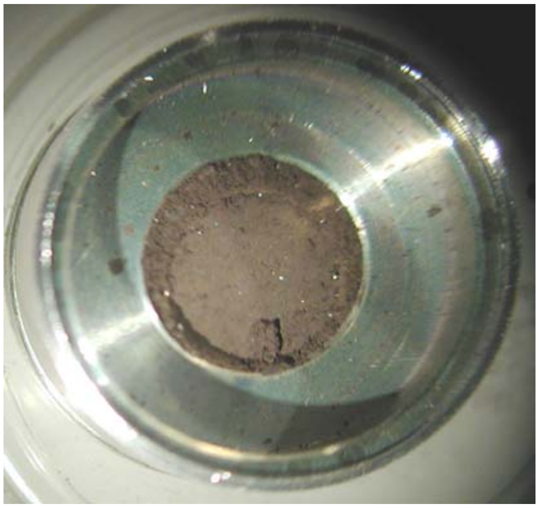

Figure 5
Ordnance compressed onto bridge-wire

III. Cartridge Hermeticity

A. Pellet-Chamber

The leak test method used to evaluate the devices in this study was the radioisotope leak test procedure using Krypton85 tracer-gas. The pellet-chamber was tested using a 45 psia 36 second pressurization which covered the leak test range through 1 x 10-7 atm cc/sec. Eleven devices indicated leakage. Three of these leakers however were leaking at leak rates slightly less than the specification requirements. The theory of the radioisotope leak test is simple. The devices are pressurized in a mixture of ~ 0.01% Kr85 in air. Following the pressurization the devices are measured for gamma radiation coming from any Kr85 gas trapped within the device cavity. This radiation reading is a measurement of the number of molecules of Kr85 that have leaked into the device, or dissolved into the ordnance material. It is important to note that the kr85 gas is measured ‘in-place’ within the device, and is not required to be drawn back out of the device through the hole or leak. The “detectability” of Kr85 in this measurement is so high; it accurately detects as little as one part Kr85 per ten-billion parts of air in a device.

The surface of these cartridges was sealed with varnish which absorbed a small amount of Kr85 gas. This absorption was quickly dissipated, as confirmed by the beta emission from kr85, (which is only detected if the Kr85 gas is absorbed onto the outside of the part).

Knowing the approximate cavity free-volume, several of the devices were tested by 'vacuum-decay' which accurately confirms the leakage of the package. The package was placed in a vacuum chamber and the Kr85 reading was monitored to verify the number of Kr85 molecules that leaked out over a period of time. This technique is commonly used with Kr85 to verify leak rates to one tenth of an order of magnitude, using an equation well proven over many decades.

B. Bridge-wire Chamber

All of the cartridges with open circuits that passed the pellet-chamber leak test were then subjected to a Kr85 leak test with an extended bomb time at 45 psia. The objective was to impregnate the ordnance material in the bridge-wire cavity if there is any leakage, (since there is no free volume or cavity in which the tracer-gases may be stored). In the Kr85 test, the Kr85 impregnation of the ordnance material is measured in place without the requirement to 'draw the tracer gas back out' of the device. Drawing a tracer gas back out or desorbing it from the ordnance material is very slow, and in the case of helium, the indication of any leakage would be far below the specification reject threshold, and the defective part would escape. The surface readings were first allowed to dissipate. The devices were then red-dye bombed before opening. The pellet chambers were opened, examined for red-dye entry, and the pellets removed. Eight devices gave a very positive indication of leakage into the bridge-wire area after all pellets were removed, by measuring the Kr85 in the compressed charges. The compressed charges from these eight devices were each removed, placed in a small vial and measured for Kr85 content using a spectrometer, and confirmed that they had been impregnated through a leak through the bridge-wire end of the device. Almost all of the other devices showed marginal Kr85 readings in their compressed charges, indicating that they also may have had some leakage through the headers. These parts were classified as 'questionable'.

The most current "state of the art" method for leak testing "Zero-Cavity" devices is the Kr85 leak test coupled with a few milligrams of coconut shell charcoal mixed with the ordnance material. Even though there is no cavity in the cartridge, the charcoal provides enormous surface area, has very high efficiency gettering for Kr85 gas, and will hold Kr85 by van der Waals forces for up to 30 minutes, assuring detection of the Kr85 that leaked into the part. [9-10]

IV. Seal Testing

The traditional application of the HMS leak test to this type of a device is flawed. The leak rate range of this cartridge specification is for detection of leaks greater than 1 x 10-5 std cc/sec. The specifications do not point out that there are two chambers in this cartridge: The pellet chamber, (~ 0.1 cc), and the bridge-wire chamber, (< 0.0001cc). The bridge-wire chamber is also the more critical.

The shortcomings are:

- The HMS test requires He to be stored in the device cavity, then sucked back out and measured.
- Leaks greater than the 1 x 10-5 std cc/sec spec are "Gross-leaks", or in the "Gross leak rate range"
- The most widely used MIL-STDs do not allow helium leak testing for 'Gross-Leaks'
- A 1 x 10^{-2} atm cc/sec leak into the pellet chamber, (~0.1 cc), will lose 95% of its helium in just 30 seconds, and most HMS require 30-45 seconds just to pump down the test chamber.
- A 1 x 10^{-2} atm cc/sec leak into the bridge-wire chamber will lose 99% of its He in 40 ms.
- A 1 x 10^{-3} atm cc/sec leak into the bridge-wire chamber will lose 95% of its helium in 0.3 sec.
- An attempt to 'back-pressurize' the part with helium will impregnate the surface sealant. That will mask the helium leakage back out of the part. Waiting for that surface material to 'desorb' helium will allow any internally collected helium to be lost.

A. The Pellet Chamber Leakage

The Helium leak rates and the Kr85 leak rates on these parts were compared. Eleven cartridges showed Kr85 leakage and were then subjected to a red-dye penetrant test. Following the red-dye test the cruciform was punctured to release any Kr85 gas trapped in the pellet chamber. All eleven devices instantly vented the Kr85 from within the pellet chamber, thus confirming the leakage was into that chamber.

B. The Bridge-wire Chamber Leakage

The remaining cartridges were subjected to an extended pressurization time in Kr85. Since there was no cavity in the Bridge-wire (B/W) zone, the extended time would allow impregnation of the compressed charge should a leak exist through the header seal. Following the Kr85 test, the parts were red-dye bombed and then opened. The pellet chambers showed no red-dye leakage into that zone, and the pellets were removed. Several devices were then confirmed to contain Kr85 impregnated into the compressed charges. The charges were removed and measured and confirmed Kr85 impregnation. This impregnation was confirmed to be on the header surface of the ordnance material, as detected by measuring the beta emission from the Kr85 on that surface. Almost all of the devices contained some Kr85 in the compressed charges, (without any gas found in the pellet chamber).

V. Hermetic Seal Findings

A. Tracer-gas leak-testing

Of the 40 cartridges tested:

- Almost all devices had been incorrectly evaluated by helium.
- Four parts were passed by helium but confirmed gross leakers into the pellet chamber by Kr85.
- Two devices were leakers by He and confirmed as good to < 1 x 10-7 by Kr85, (realizing the He test would only detect leaks into the pellet chamber).
- Eight parts had confirmed gross leaks into the B/W chamber, (not detected by He).
- Seven cartridges were found to be non-leakers to < 1 x 10-7 by Kr85 and red-dye. (One of those was found to be a marginal leaker with He).
- All other devices indicated possible leakage into the B/W area.

B. Pellet-Chamber Evaluation

The parts were opened by removing the crimp seal.

- Each pellet chamber that failed Kr85 gross leak, also showed red-dye entry. (Figure 6).
- Many crimp seals were compromised by the entrapment of pellets under the aluminum cruciform and steel washer. (Figure 7)
- Substantial amounts of varnish were found to have leaked into some pellet chambers.
- The varnish flow into the pellets on the crimp shoulder actually created a seal on some parts.

Figure 6
Red-dye leakage into pellet chamber

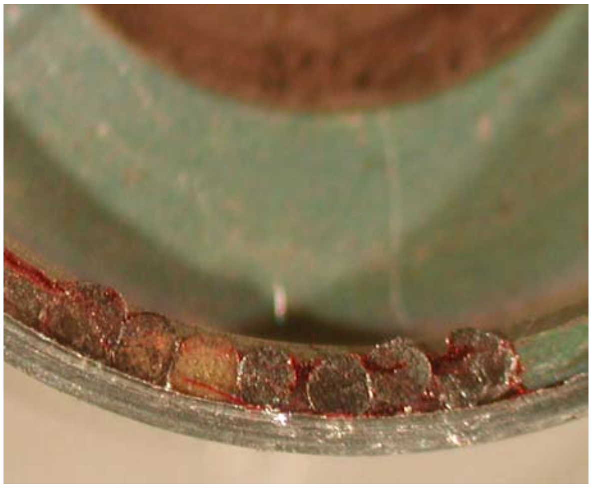

Figure 7
Pellets trapped under crimp seal

C. Bridge-Wire Chamber Evaluation

- The B/W zone in all 29 “open” devices was opened and the B/Ws were corroded away.
- The corrosive attack was on all surfaces including the B/W. The circumference of the feed-through pin at the glass-metal interface, at the edge of the pin plating, was also corroded. There was corrosion seen on the steel-header-barrel interface
- The corrosion was evident on the compressed charge surface in contact with the header. (Figure 8). This compressed charge was removed from contact with the header, turned over and photographed. It was also impregnated with Kr85.
- The header was inserted into the aluminum barrel as a”press-fit”. The cartridge was cross-sectioned, the header removed, and the aluminum-header interface examined. The aluminum surface showed a combination of abrasion followed by corrosion. Corrosive and/or acidic residues were also found at the interface between the header body and the compressed charge. (Figure 9.)

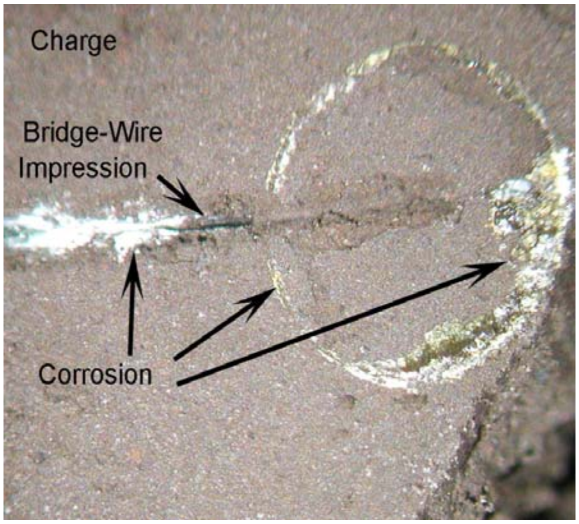

Figure 8
Corrosive residue on compressed charge surface

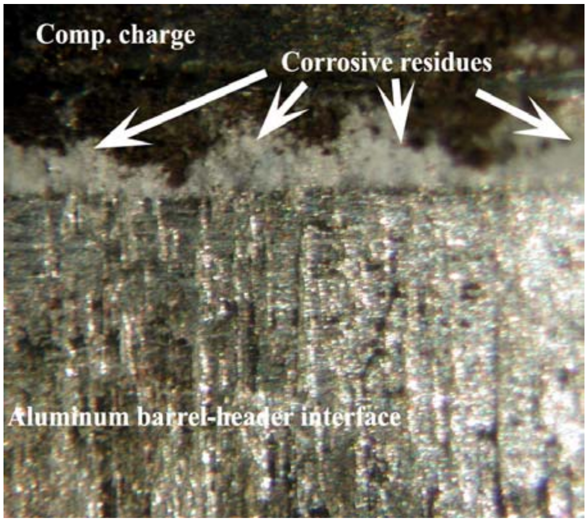

Figure 9
Corrosives at compressed charge/header interface

- The steel header had been pressed into the plated or chemically treated surface of the aluminum barrel. The header scraped off the coating of the aluminum body, (as well as some aluminum), exposing bare aluminum and creating a ‘dissimilar-metal’ junction which appeared to have then corroded. (Figure 9 & 10)
- It is assumed that the chemical treatment of the aluminum body was not properly cleaned, and corrosive residues were left inside the cartridge. (Figure 9)
- The corrosion of the aluminum-header interface created gross-leaks into the B/W zone. Red-dye was found leaking into the cartridge through those passages. (Figure 11)
- Red-dye was found to have leaked through one pin-glass seal. (Figure 12)
- Red-dye was also found to have leaked through a header-glass seal. (Figure 13)

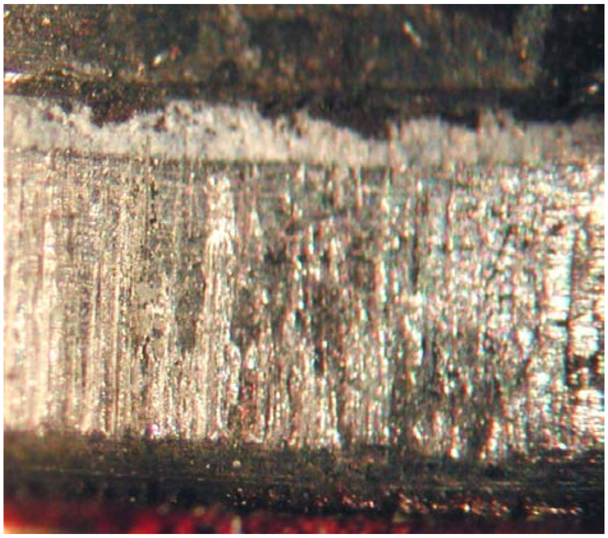

Figure 10
Corroded aluminum surface at header interface

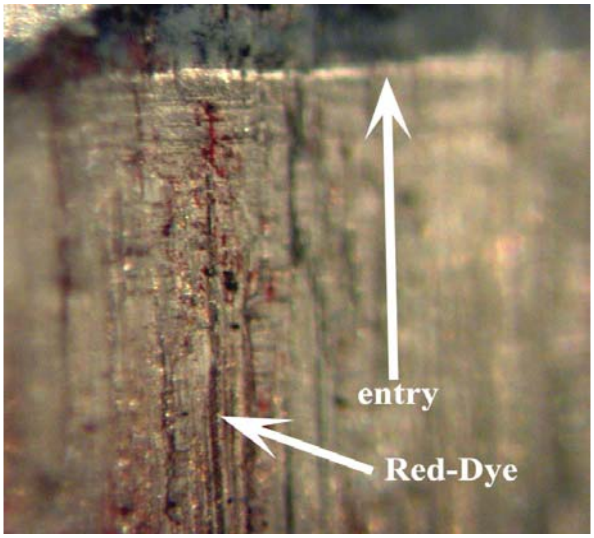

Figure 11
Red-dye leakage into compressed charge chamber

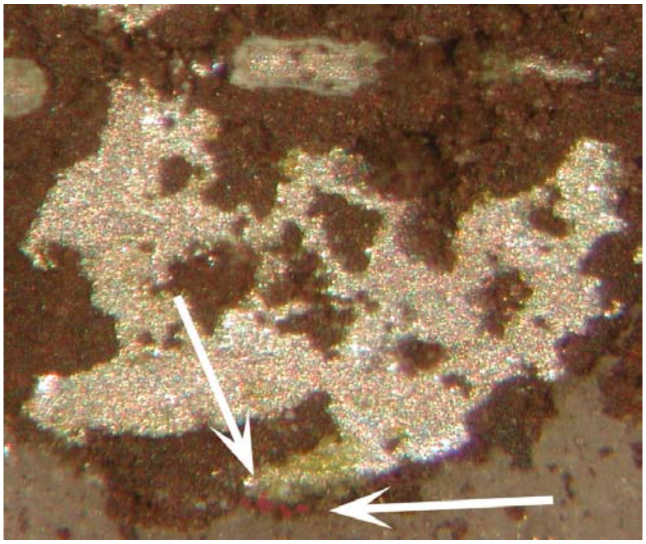

Figure 12
Corrosion on pin and Red-dye entry at pin/-glass seal

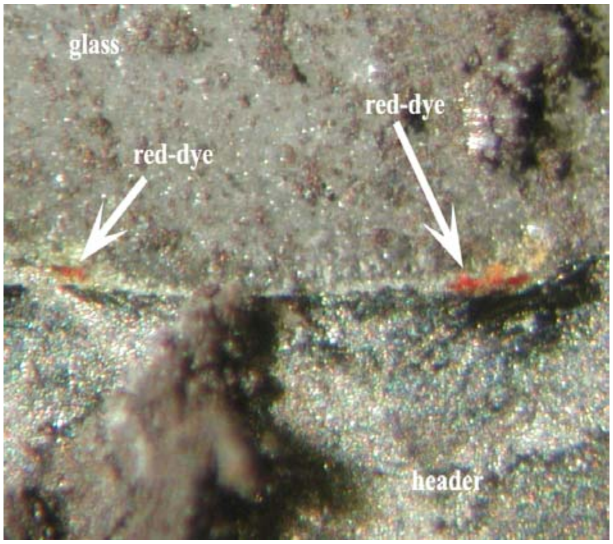

Figure 13
Read-dye entry at glass/header interface

D. External Sealant Evaluation

- An examination of the sealant bonding characteristics showed that the external surfaces of many parts were apparently not properly cleaned, and the sealant did not seal to that surface.
- The MIL-V- Varnish used to seal these parts had inadequate specification controls in the procurement specification. There was neither control on the allowable dilution nor pre-cleaning of surfaces.
- No bond strength testing was called out.
- No ‘Dummy-package’ testing was called out.
- The HMS leak testing procedure was unable to reliably evaluate the true sealing efficiency.

VI. Conclusions and Recommendations

- The Procurement specification was not adequate to assure a good part.
- Many of the parts would never have functioned in the field.

- The manufacturing processes were not adequate.
- The Procurement Specification for these types of devices must be revised and up-dated.
- A better choice of 'External-Sealant' must be chosen.
- Parts must be properly cleaned, (inside and outside).
- The HMS testing of this type of cartridge was proven to be an unreliable misapplication.
- The radioisotope leak testing using Kr85 was the only method capable of reliably detecting leaks in these zero-cavity devices. If the leaks are gross leaks a gettering medium such as charcoal should be used. [9-10]
- The parts should be leak tested using Kr85 at manufacture, and re-tested with Kr85 at 1-5 year intervals to assure that they do not lose their seal.
- Properly built, this type of cartridge should easily pass a 5 x 10^{-6} atm cc/sec leak test.

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