Mechanical Properties Characterization and Accelerated Aging of Comp C-4 Explosive

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Composition C-4 explosive is a common demolition material used by the USMC. To address concerns regarding the age degradation of mechanical properties of M112 Demolition Charges in the Marine Corps inventory, the Expeditionary Systems Evaluation Division (ESED) of NSWC Crane, in concert with National Technical Systems (NTS), developed and performed a series of tests to quantify this degradation. This work was done in support of the Program Manager for Ammunition of the Marine Corps System Command, Service Life Accelerated Age Testing (SLAAT) Program.

Tests performed were used to characterize the mechanical properties of C-4 as a function of sample age. The mechanical properties of the C-4, were determined using the following different test methods: plasticity (modulus of compressibility), penetrometer method, compressive load-deflection, velocity of longitudinal sound waves, and hands-on user evaluations.

Results from hands on user evaluation were used to determine a test methods effectiveness on determining the acceptability of the C-4 material. The plasticity test and the longitudinal sound velocity of the bulk material were found to best distinguish excessively hard C-4.

Composition C-4 is a common demolition material used by the USMC. It is designed to be flexible to facilitate molding into various charge shapes and consists of a mixture of RDX, polyisobutlyene, dioctyl adipate, and process oil. The demolition block form of Composition C-4 is the M112 demolition charge shown in Figure 1. C-4 charges are manufactured by the extruding and cutting the material into blocks, followed by wrapping in mylar, backed with an adhesive tape. The dimensions of C-4 block are shown in Figure 2.

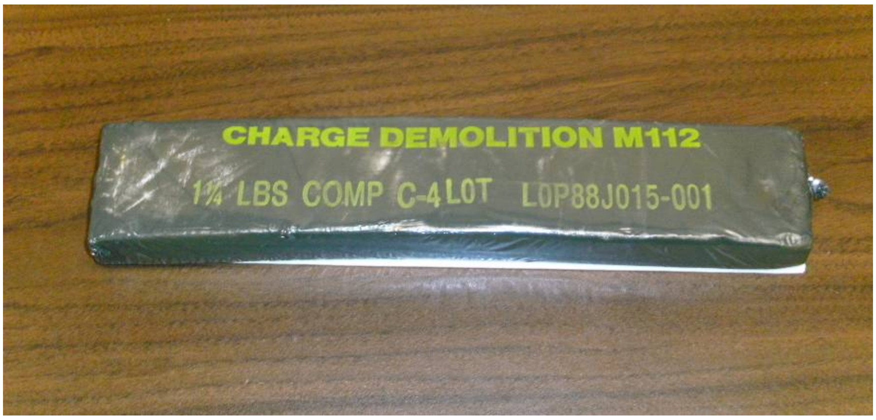

Figure 1. Photograph of the M112 Demolition Charge

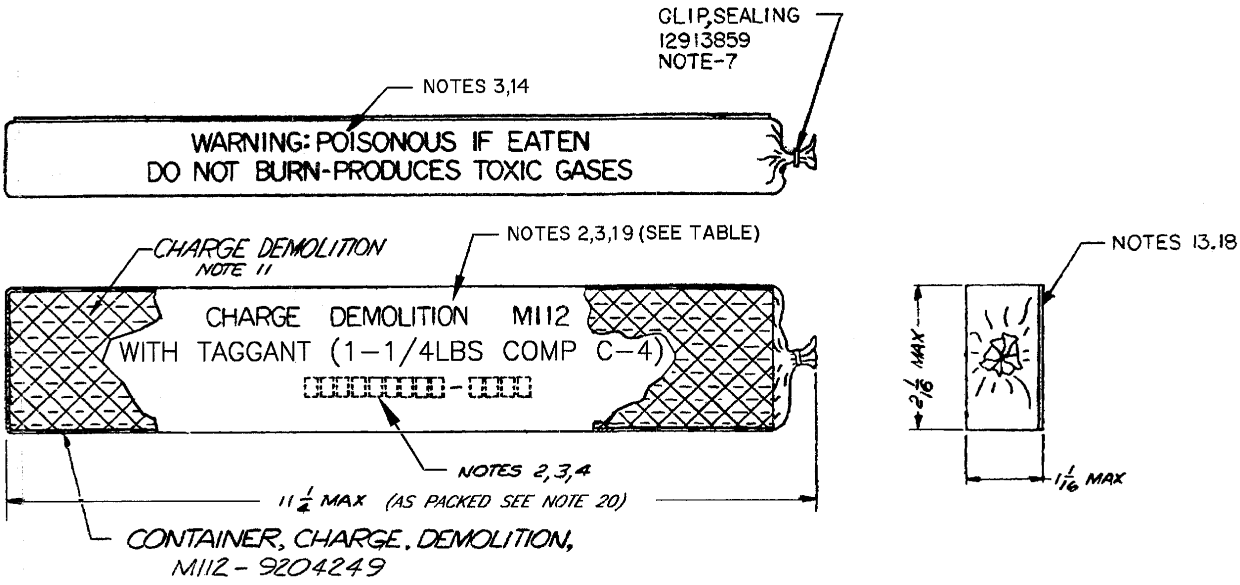

Figure 2. Design of the M112 Demolition Charge

1.0 Test Program Objectives. As C-4 ages it experiences changes in its material properties. These changes are manifested as an increase in material "hardness." One of the life limiting characteristics is the ability to mold charges into the desired configuration. The objectives of the test program were to quantify the material hardness using both traditional test methods and two newly developed test methods. These results will be compared to hands on user evaluation and used to determine the serviceability of the material.

2.0 Traditional Test Methods. The mechanical property test method that is currently used to accept M112 demolition charges after manufacture is referred to as the "Penetrometer" method. The method measures the maximum compressive force required to press a 0.26 inch diameter conically shaped steel tip into the surface of an a charge to a depth of 0.25 inch at a rate of 6 inches/minute. The currently allowed range in the specification at production is 3-9 lbf. Historically this method has failed to accurately characterize the harder C-4 samples due to the propensity of the explosive to crack under loading. In this study, four measurements were performed at equally spaced positions along the length of the block. The test charges were conditioned for a minimum of 4 hours at 73°F prior to testing. An Instron Model 3342 Single Column materials tester was used to perform the penetrometer tests, as shown in Figure 3.

Figure 3. Penetrometer Test Setup

The mechanical property test method that is currently used to accept the bulk C-4 material after manufacture is referred to as the “Plasticity” method. This method measures creep stress relaxation. The test is performed on a molded cylindrically shaped sample 2 inches in diameter by 0.75 inch thick. The test samples are temperature conditioned at 70°F for a minimum of 4 hours prior to test. The sample thickness is measured at three locations around the edge at the start and end of the test. The test is performed by applying a constant 5000 gram force to the entire surface of the 2 inch diameter sample for 20 minutes. The load is then removed and the sample thickness measured. The drawbacks of this test methodology are the overall time to perform the test and the destructive nature of the test. In this study, the Instron Model 3342 Single Column materials tester was used to perform the plasticity tests. The test setup is shown in Figure 4.

Figure 4. Plasticity Test Setup

3.0 New Test Methods. To address the issue of localized cracking of the Composition C-4 material during the penetrometer test, a compressive load/deflection type test method was developed. This method consists of preparing cylindrically shaped samples 1 inch in diameter by 1 inch thick and measuring the maximum compressive force required to crush the test samples. Samples were tested at a compression rate of 6 inches/minute to a distance of 0.3 inch. The test samples were conditioned at 73°F for a minimum of 4 hours prior to test. The Instron Model 3342 Single Column materials tester was utilized to perform the compressive load/deflection test. Like the plasticity measurement, the drawbacks of this test methodology are the overall time to perform the test and the destructive nature of the test. The test setup is shown in Figure 5.

Figure 5. Compressive Load/Deflection Test Setup

To address the test sample preparation efforts required by both the Plasticity and Compressive Load/Deflection test methods, the Ultrasonic Velocity Test Method was developed. This method leverages the relationship between the material sound velocity and the modulus of the material. This method measures the time of flight of longitudinal sound waves transmitted through the M112
Demolition Charge. The test samples consisted of complete M112 Demolition Charges with the mylar packaging removed. The test samples were conditioned at 73°F for a minimum of four hours prior to test. Measurements were taken at four positions along the length of the charges corresponding to the same locations used for the subsequent penetrometer test measurements. The time of flight measurements were made using an Olympus NDT EPOCH XT Ultrasonic Flaw Detector with 1 inch diameter 0.5 MHz transducers. After the time of flight measurements were recorded, the demolition charge sample thickness was measured at each location. The advantage of this test method is the non-destructive nature of the measurement and minimal test sample preparation. The test setup is shown in Figure 6.

Figure 6. Ultrasonic Velocity Test Setup

4.0 User Evaluation. To establish criteria for the usability of the Composition C-4, a hands-on user evaluation of the material was performed. This work was performed by retired members of the United States Marine Corps with demolition experience. Testing consisted of hand shaping C-4 into the following configurations per US Army Field Manual 3-34.214:

- Ribbon Charge - Capable of cutting a 1 inch thick piece of steel
- Diamond Charge – Capable of cutting a 3 inch diameter bar
- Booster Charge
- Timber Cutting Charge
- Shape Charge

The task which most clearly demonstrated the mechanical property characteristics of the C-4 charges was the construction of a diamond charge, as shown in Figure 7. For all user evaluation tests, the samples were conditioned to 73 degrees F for 4 hours prior to testing. Samples of successful and failing diamond charges are shown in Figure 8.

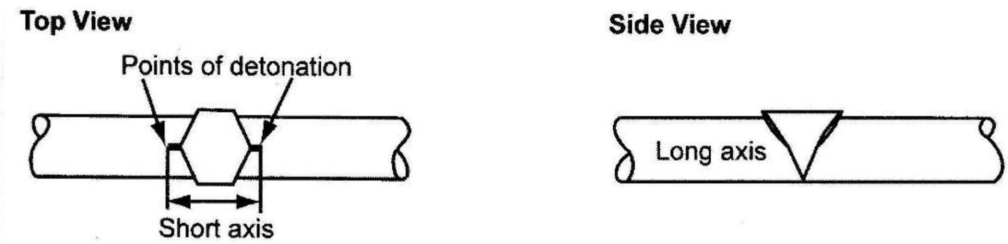

Figure 7. Construction of a Diamond Charge with C-4

Figure 8. Example of Successful (left) and Failed (right) Diamond Charges

5.0 Accelerated Aging. To perform the accelerated aging test, an 11 year old lot of M112 Demolition Charges manufactured from a "re-blended" lot of Composition C-4 was used. The M112 Demolition Charge samples were subjected to thermal aging at three temperatures and various times:

- 165°F for 35, 45, and 55 days
- 185°F for 10, 15, and 20 days
- 210°F for 2, 4, and 6 days

In addition to these temperature conditioned samples, baseline demolition charges with no prior thermal conditioning history were also tested from this lot. Unfortunately, user evaluations performed on the baseline samples from this re-blended lot of Composition C-4 failed to meet mold-ability requirements as was the case with all of the accelerated aged samples.

6.0 Test Results. For each of the test methods described above, measurements were performed on a total of 15 each M112 Demolition Charges sampled from various lots ranging from 17 to 42 years of age from the date of manufacture and the results were averaged across these samples to obtain results for each lot. The 11 year old re-blended lot is also included, but its effective age is in question due to the original production date of the base material. Results from each test method are show below in Figures 9 – 12. In each figure, the two lots with the lowest user evaluation success ratios are outlined with ovals and the four lots with the highest user evaluation success ratios are outlined with rectangles.

Hands-on User Evaluations showed a high degree of variability in the scoring of each age group (lot). However, the 40 year old lot and the re-blended lot were the only two lots which showed unacceptable mechanical properties. These two lots were used to validate each technique's ability to identify failing material.

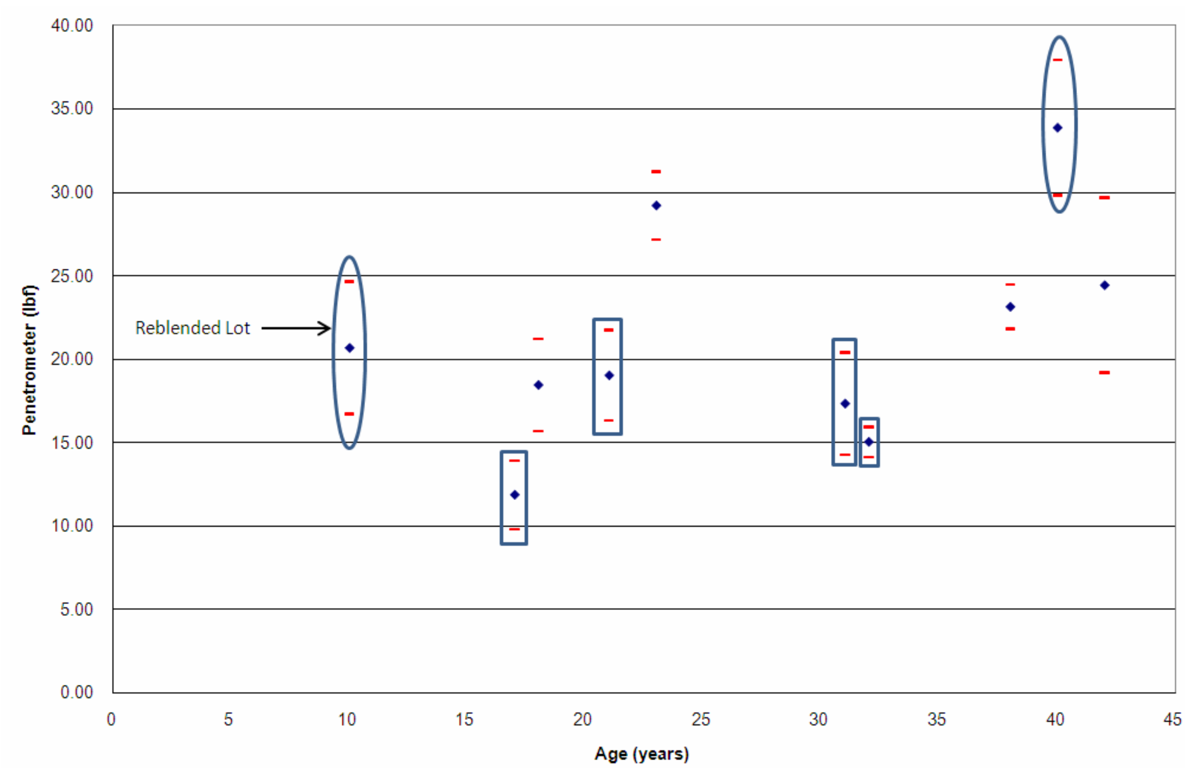

Figure 9. Penetrometer Reading vs. Age Including Reblended C-4

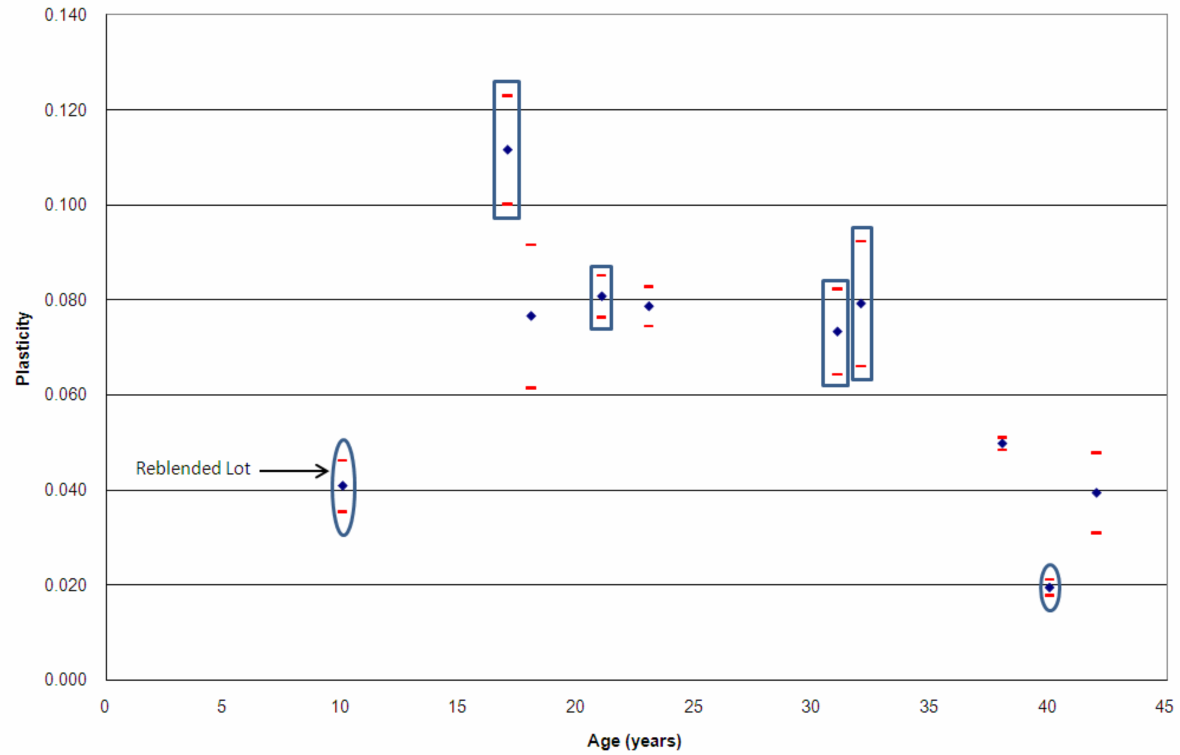

Figure 10. Plasticity vs. Age Including Reblended C-4

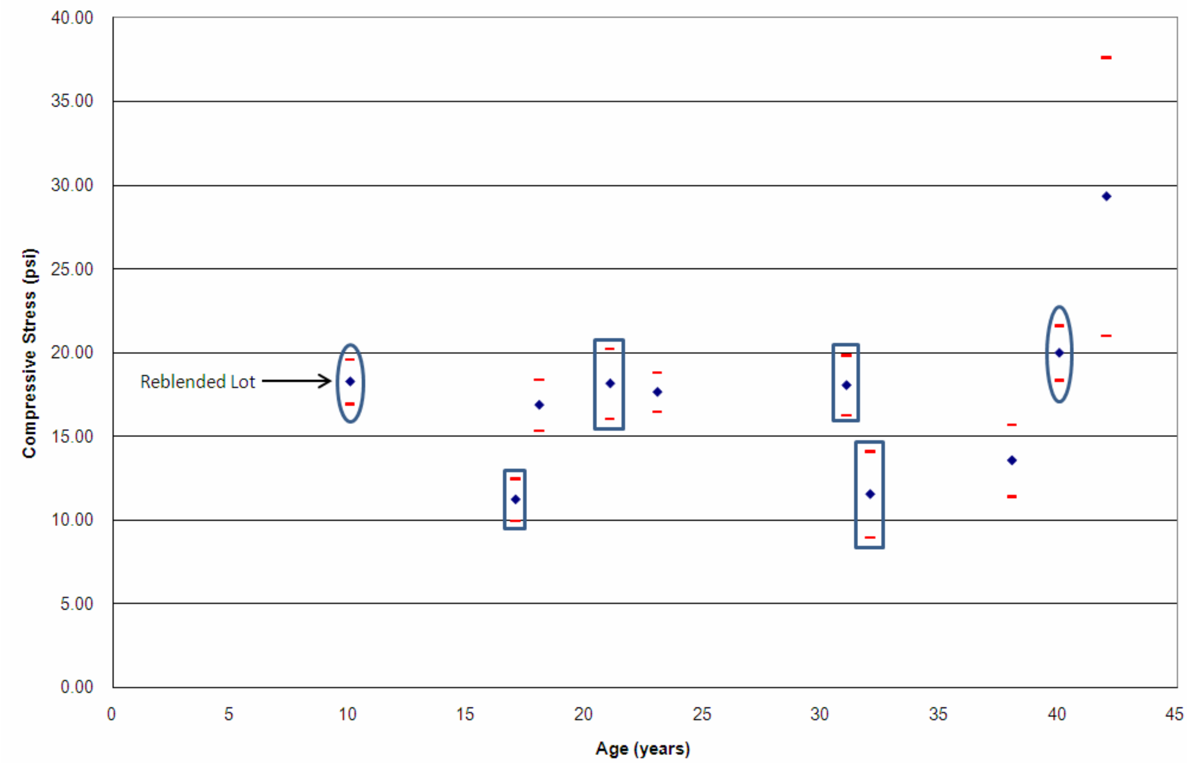

Figure 11. Compressive Stress vs. Age Including Reblended C-4

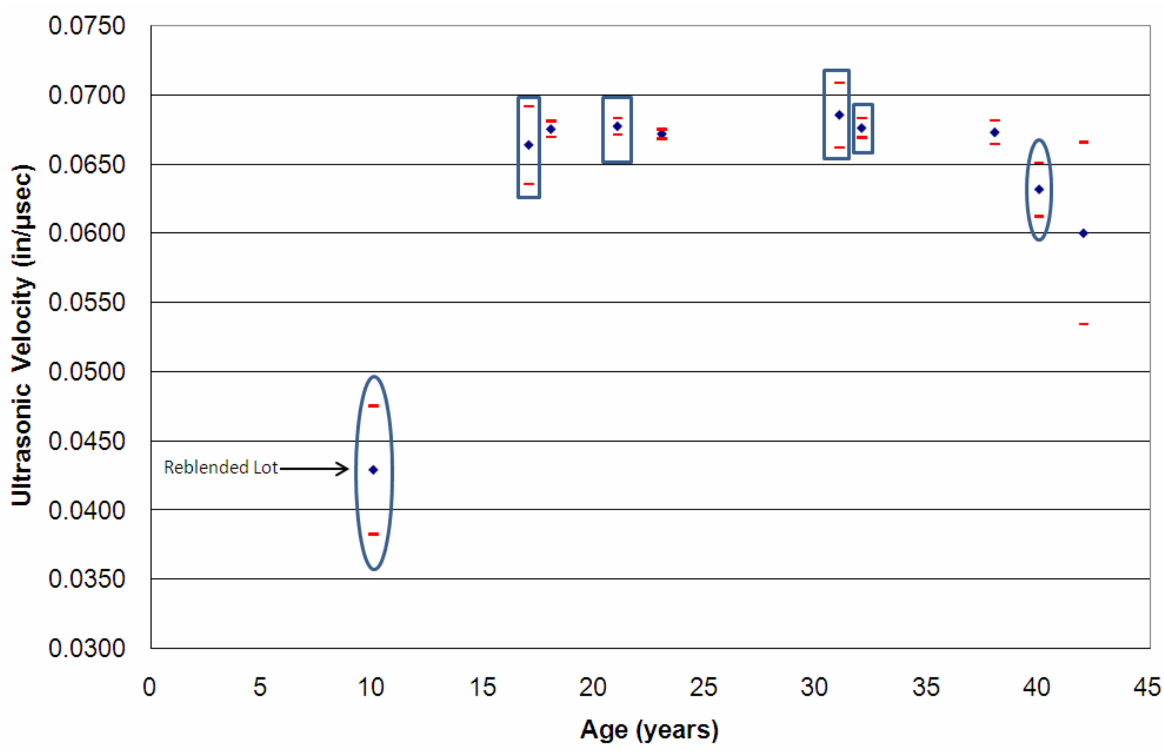

Figure 12. Ultrasonic Velocity vs. Age Including Reblended C-4

7.0 Summary and Conclusions. Each technique was analyzed as to its ability to segregate acceptable material from unacceptable material, as determined by the user evaluation. When comparing results from each test method to the results from the user evaluation, the follow observations were made:
Penetrometer testing failed to distinguish the re-blended material as unacceptable. Plasticity testing successfully identified both the 40 year old lot and the re-blended material as unacceptable. However, this method is time consuming and requires destroying a sample to make each measurement. Compressive Load Deflection testing failed to distinguish any material as being unacceptable. Ultrasonic Velocity testing successfully identified both the 40 year old lot and the re-blended material as unacceptable. This method is non-destructive to the C-4 sample and can be performed as a rapid screening process.

The ultrasonic velocity test method correctly distinguished the two failing lots, however there was a large amount of scatter in the resulting data. More work needs to be done to refine the details of this test method. Future work will focus on the investigation of lower frequency transducers, attenuation effects, and examining the shear sound wave velocity vs longitudinal sound wave velocity of the material.