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FRAGMENTATION PROPERTIES OF AERMET® 100 STEEL IN TWO MATERIAL CONDITIONS

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AerMet® 100 steel cylinders were tested in three warhead geometries to determine performance in terms of case expansion, case rupture, fragment velocity distribution, fragment spatial distribution, and fragment mass distribution. Both as-received and heat-treated material were used to determine the dynamic properties of the materials, as a function of heat treatment. Results were summarized with data from other material property characterization techniques.

INTRODUCTION

Because of the wide use of steel alloys in fragmenting munitions, their fragmentation properties are generally well characterized. We have recently investigated the performance of a relatively new high strength alloy, AerMet® 100. AerMet® 100 is produced by Carpenter Technology Corporation and has been used extensively in the aerospace industry. Its high strength and ductility make it attractive for use in ordnance applications.

In order to determine the fragmentation properties of AerMet® 100, a series of experiments was performed that compared the dynamic properties of the material as a function of its heat treatment. These experiments were conducted using test items of three different cylinder geometries. In each test case, hardware was fabricated using as-received and heat-treated material. The experiments were designed to quantify the performance of the material in terms of case expansion, fragment velocity, and fragment mass distribution.

This paper summarizes the results of these tests, and compares the fragmentation characteristics of AerMet® 100 in its heat-treated and as-received condition.

DESCRIPTION OF EXPERIMENTS

The basic experimental set-up used is illustrated in Figure 1. A detailed description of the test is given in reference 1. The instrumentation for each test included a high speed framing camera and flash radiography. The framing camera recorded the amount of case

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expansion prior to rupture. The flash radiography was used to determine the fragment velocities and spatial distribution. Attapulgite clay and cellulose fiberboard were used as a soft recovery system to collect fragments. The collected fragments were used to determine the fragment mass distribution.

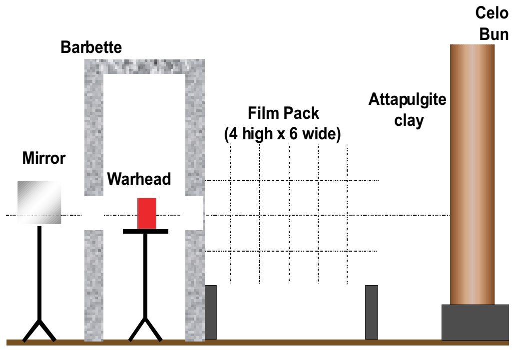

Figure 1. Experimental set-up.

Three different hardware configurations were used in the test series. The first configuration is a cylinder, nominally 20.3 cm in length with an inner diameter of 20.3 cm. As in previous testing [1,2], a charge to mass (C/M) ratio of approximately one and center initiation were chosen. A CH-6 booster was used to initiate the PBXN-110 main charge. This is considered the baseline geometry, and is shown in Figure 2A.

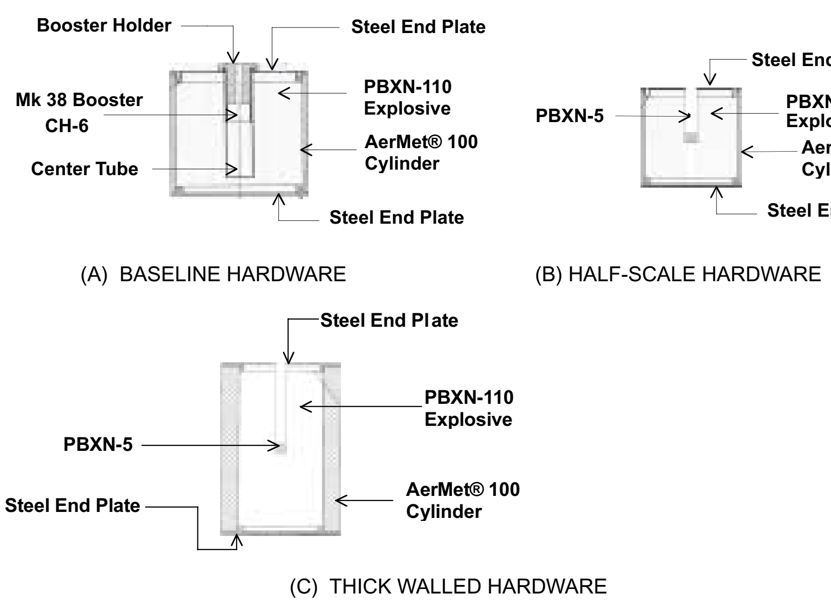

Figure 2. Test hardware.

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The second configuration, Figure 2B, is a cylinder nominally 10.15 cm in length with an inner diameter of 10.15 cm. The C/M ratio is approximately one. This cylinder is a one-half geometrically scaled version of the baseline geometry and is used to study the effects of scaling. Due to limited availability of boosters of the required size, there was no centertube. An N5 pellet was used to detonate the PBXN-110 main charge. The third geometry is a thick walled cylinder, nominally 20.3 cm in length with an inner diameter of 10.15 cm, with a C/M of approximately 0.2. The thick walled case was used in order to study material spall strength effects. This hardware is shown in Figure 2C. Table 1 summarizes the hardware used in this test series.

Table 1. Test hardware

Test Unit	*Inside Diameter (cm)*	*Outside Diameter (cm)*	*Explosive Mass (kg)*	*Fragmenting Case Mass (kg)*
Baseline HT	20.32	21.97	10.14	8.85
Baseline AR	20.32	21.98	8.36	8.85
Half-scale HT	10.18	10.99	1.14	1.10
Half-scale AR	10.18	10.98	1.14	1.10
Thick walled HT	10.17	14.29	2.50	12.70
Thick walled AR	10.17	14.29	2.49	12.70

RESULTS

Fragment Velocity

The velocity results are summarized in Table 2. The table provides a comparison of the fragment velocity of the heat-treated and as-received materials for each of the three geometries.

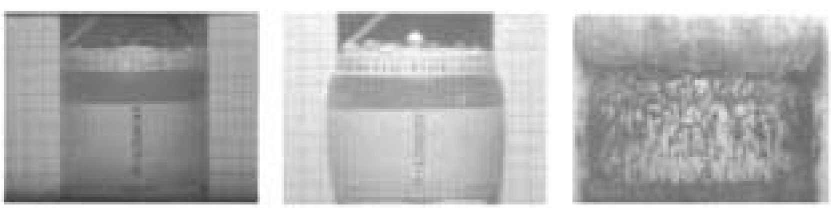
Table 2. Summary of fragment velocities

Test Unit	*Velocity HT (m/s)*	*Velocity AR (m/s)*	*Δ Velocity (m/s)*	*Standard Dev. HT (m/s)*	*Standard Dev. AR (m/s)*	*Δ Standard Dev. (m/s)*
Baseline	1913	1825	88	52	75	23
Half-scale	1900	1857	43	67	89	22
Thick Wall	936	846	90	72	132	60

As shown above, the heat-treated AerMet® 100 cylinder had a higher fragment velocity than the as-received material. This is counterintuitive in that a hardened material would be assumed to be more brittle, thus fragmenting sooner and allowing premature venting of the detonation products. This premature venting would be expected to produce lower fragment velocity. However, note that the as-received data had consistently greater scatter in it than did the data from the heat-treated material experiments. Thus, the significance of this finding may be doubtful.

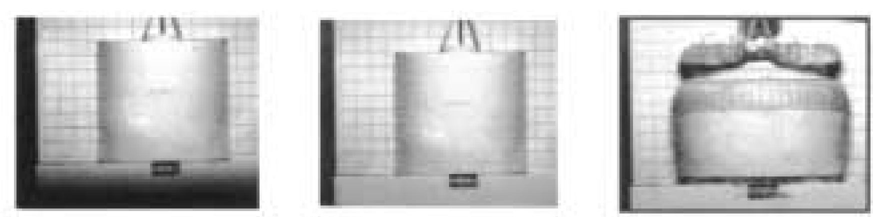
Case Expansion

In Figure 3, the case expansion of each test unit is shown. The baseline units, the half-scale units, and the as-received thick walled units are shown at initial conditions, the on-set of rupture, and at rupture. The thick walled heat-treated case took longer to rupture than originally predicted, so we could not capture the complete venting of the unit. All of the cases, with the exception of the baseline heat-treated case, contain small circumferential and longitudinal scribe marks around the top region of the cylinder. These marks were designed to study the differences in circumferential and longitudinal strains of recovered fragments. It is apparent in the high-speed framing camera photos that the scribe marks affected the fragmentation of the cylinder. Fragments from the scored region were not used for fragment mass distribution comparisons in the next section. In the baseline and half-scale geometries the heat-treated cylinders vented sooner than the as-received cylinders. However, because of the increased time to rupture in the heat-treated thick walled case, we could not observe complete venting of the unit, thus the trend cannot be confirmed for the thick walled case.



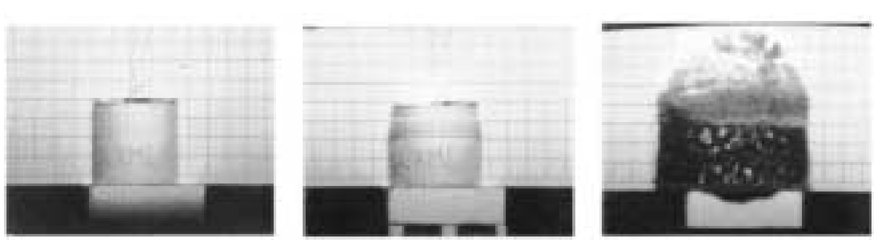
T=0 μS T=25 μS T=50 μS

A. Heat-treated baseline



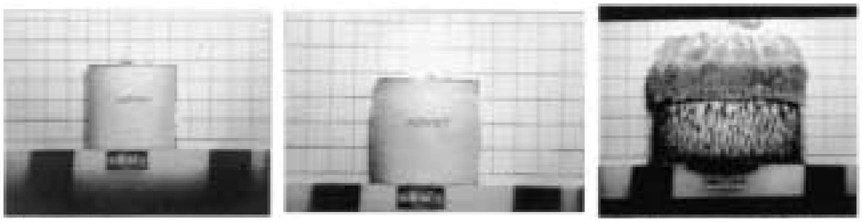
T=0 μS T=25 μS T=50 μS

B. As-received baseline



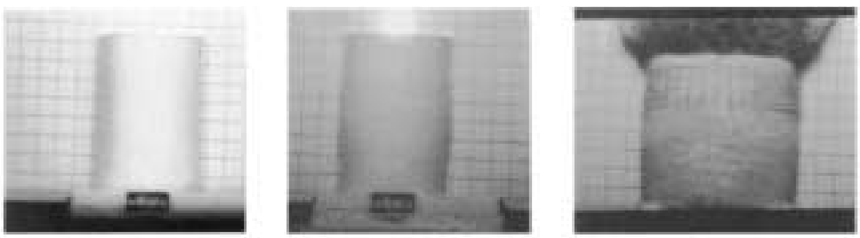
T=0mS T=20mS T=40mS

C. Heat-treated half-scale



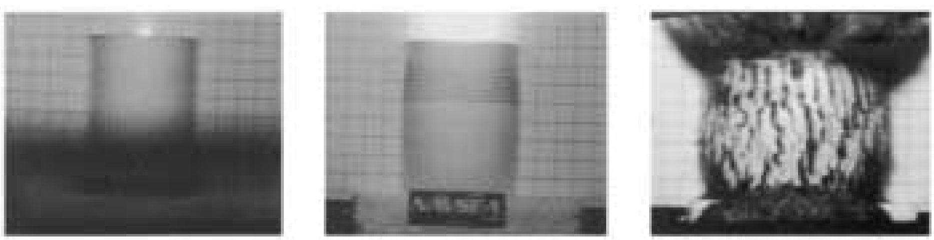
T=0mS T=20mS T=40mS

D. As-received half-scale



T=0mS T=25mS T=66mS

E. Heat-treated thick wall



T=0mS T=25mS T=89mS

F. As-received thick wall

Figure 3. High-speed photos of case expansion.

Fragment Mass Distribution

Recovered fragments from each test were cleaned and weighed. Then, a cumulative fragment mass distribution was determined for each test. It is assumed that the case break-up follows an exponential frequency. Cumulative fragment mass distribution and the resulting exponential fit applied to each is shown in Figure 4.

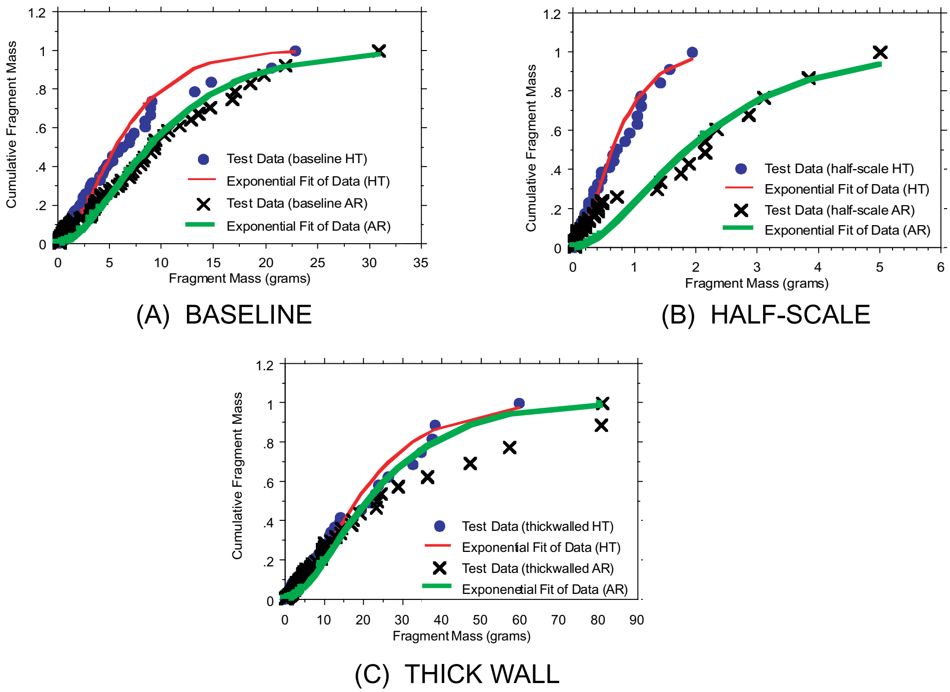


Figure 4. Cumulative fragment mass distributions heat-treated and as-received materials.

Table 3 provides the regression analysis summary. Note that the exponential distribution assumption results in excellent agreement for all cases, except the half-scale as-received unit where the unexplained variance approaches 15%. Table 3 shows that, on average, the heat-treated cylinders broke into smaller fragments than the as-received cylinders for all three test configurations.

Table 3. Regression analysis summary

Material	***Number of Collected Fragments***	***Mean Fragment Mass (grams)****	***Explained Variance (R^2)***
Baseline HT	159	3.32	0.9447
Baseline AR	315	7.84	0.9880
Half-scale HT	97	0.38	0.9528
Half-scale AR	138	1.11	0.8556
Thick Wall HT	200	10.85	0.9591
Thick Wall AR	202	12.51	0.9422

*The mean is determined from an exponential fit of the cumulative fragment mass data.

CONCLUSIONS

The data presented in this paper has highlighted several differences in the fragmentation properties of AerMet 100 due to differences in heat treatment. First, the average fragment mass is significantly smaller for the material in its heat-treated condition than in its as-received condition. Second, the framing camera results indicate that the dynamic ductility of the material in its heat-treated condition is less than that of the material in its as-received condition. The third conclusion we draw is that the ejection velocity of fragments from the as-received cylinders is slightly higher than that of the heat-treated cylinders. This last conclusion is somewhat contradictory based upon the case expansion data which shows that the heat-treated cylinders vent sooner than the as-received cylinders.

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