Submitted to the Journal of Dynamic Behavior of Materials: 02/19/2021
Revision 1: 05/12/2021

Ballistic-Limit Velocities for 7.62 mm APM2 Bullets and Aluminum Alloy Armor Plates

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Abstract

In a previous paper, we presented a scaling law for the ballistic-limit velocity for the 7.62 mm APM2 bullet and aluminum armor plates. This scaling law predicts that the ballistic-limit velocity is proportional to the square root of the product of plate thickness and a material strength term. In this note, we present additional ballistic data from the US Army Research Laboratory (ARL) and the Norwegian University of Science and Technology (NTNU) to show that this scaling law is accurate for eight aluminum alloys, plate thicknesses from 10-60 mm, and yield strengths from 51-414 MPa.

Keywords APM2 bullets, Aluminum armor plates, Scaling law.

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Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work done in this paper.

Introduction

Over the last decade, the US Army Research Laboratory (ARL) and the Norwegian University of Science and Technology (NTNU) have conducted many experimental studies on the perforation of aluminum alloy armor plates with the 7.62 mm APM2 bullet (Fig. 1). Forrestal et al. [1] presented a scaling law for the ballistic-limit velocities and compared predictions with some ARL and NTNU data. This scaling law predicts that the ballistic-limit velocity is proportional to the square root of the product of the plate thickness and a material strength term. The material strength term [1,2] is the quasi-static, radial stress required to open a cylindrical cavity in the plate described as an elastic, power-law hardening material. So the scaling law requires material properties for the plate as well as ballistic data.

Reference [1] presents material and ballistic data for 5083-H116, 5083-H131, 6061-T651, and 6082-T651 aluminum alloys. In this study, we present additional material and ballistic data for 6070-0 [3], 6070-T4 [3], 6082-T6 [4], and 2139-T8 [5,6] aluminum alloys. So we now show that the scaling law is accurate for eight alloys, plate thicknesses between 20-60 mm, and yield strength between 51-414 MPa.

Scaling Law

In [1,2], we conducted analytical and experimental studies to understand the mechanisms and dominant parameters for the 7.62 mm APM2 bullet that perforates aluminum armor plates. Our observations suggested a scaling law for the ballistic-limit velocity of the form

$$\begin{aligned} V_{bl} &= K\sqrt{\sigma_s h} \\ \sigma_s &= \frac{Y}{\sqrt{3}}\left\{1+\left[\frac{E}{\sqrt{3}Y}\right]^n \int_0^b \frac{(-\ln x)^n}{1-x}\,dx\right\},\ \ b = 1-\gamma^2 \\ \gamma^2 &= \frac{2(1+\nu)Y}{\sqrt{3}E} \end{aligned} \quad .$$

(1a-c)

In 1(a-c), K is a constant, h is the plate thickness, and σ_s is the quasi-static radial stress required to open a cylindrical cavity in the aluminum plate. The plate material is described as elastic, power-law hardening. Material properties are obtained from quasi-static, large strain, uniaxial compression or tension data that are curve fit with

$$\sigma = \begin{cases} E\varepsilon & ,\sigma < Y \\ Y\left(\dfrac{E\varepsilon}{Y}\right)^n & ,\sigma \geq Y \end{cases} ,$$

(2a,b)

where σ is true stress, ε is true strain, E is Young's modulus, Y is the yield stress, and n is the strain hardening exponent. Data in [7] show that aluminum alloys are nearly rate insensitive.

Material parameters from uniaxial compression tests for 5083-H116, 5083-H131, 6061-T651, and 6082-T651 are tabulated in [1]. The additional material data used in this study are given in Table 1. In Table 1, test samples were taken from plates with thickness h. Data for 2139-T8 [5,6] were from compression tests. The authors from NTNU [3,4,8] prefer to use the tension test and obtained data for 6070-0, 6070-T4, and 6082-T6. Ballistic-limit velocity data are tabulated in [1] and Table 2.

Results and Discussion

As previously discussed, large strain data were obtained from both compression [1] and tension [3,4] experiments. Figure 2 presents ballistic-limit V_{bl} versus $\sqrt{\sigma_s h}$ calculated from four compression and four tension tests. These results show good agreement from both materials experiments. Additionally, a linear regression analysis in the sense of least squares was done with the experimental data giving a slope of $K = 107\ \left(\mathrm{m/s}\right)\left(\mathrm{GPa} \bullet \mathrm{mm}\right)^{-1/2}$ with a coefficient of determination of $R^2 = 0.97$. As discussed in [9], this implies very good correlation between the data and linear least-squares fit.

Figure 3 shows data from twenty ballistic tests with eight aluminum alloys, plate thicknesses between 20-60 mm, and yield strengths between 51-414 MPa. These results demonstrate that the scaling law is accurate for a broad range of parameters. A linear regression analysis was also done with this experimental data giving a slope of $K = 109\ \left(\mathrm{m/s}\right)\left(\mathrm{GPa} \bullet \mathrm{mm}\right)^{-1/2}$ with a coefficient of determination of $R^2 = 0.99$, and implies very good correlation between the data and linear least-squares fit.

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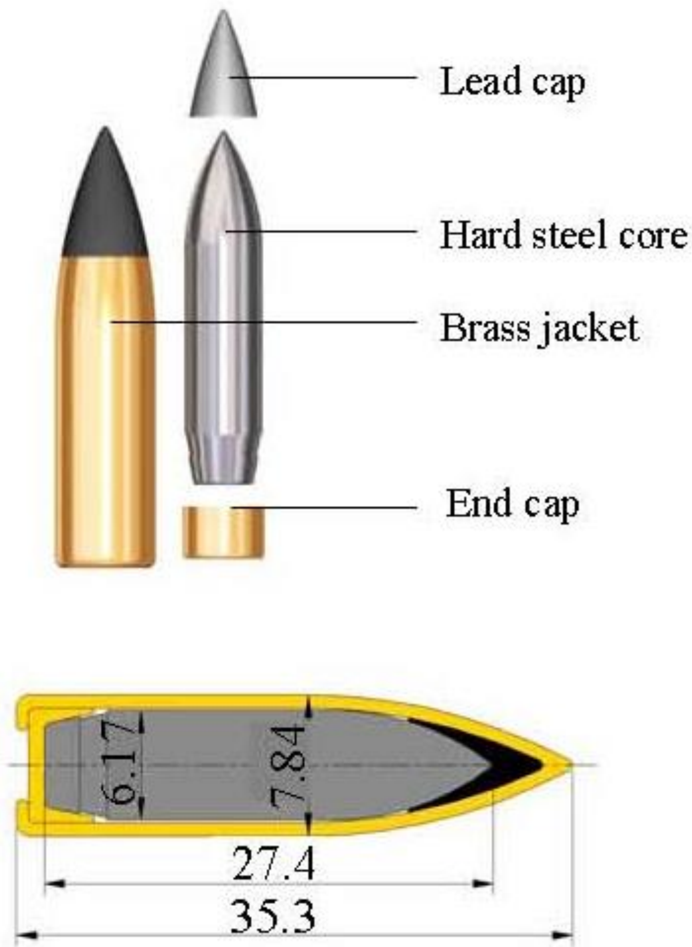
Table 1 Material parameters.

Material	h (mm)	E (GPa)	ν	Y (MPa)	n	σ_s (GPa)
6070-0	20	70	0.33	51	0.20	0.46
6070-T4	20	70	0.33	191	0.22	1.30
6082-T6	10	70	0.33	329	0.07	1.31
6082-T6	30	70	0.33	280	0.06	1.13
2139-T8	39	73	0.33	414	0.087	1.62

Table 2 Ballistic-limit velocity data.

Material	h (mm)	V_{bl} (m/s)
6070-0	20	348
6070-T4	20	506
6082-T6	10	347
6082-T6	30	581
2139-T8	25.2	682
2139-T8	32.3	783
2139-T8	39.0	860
2139-T8	40.9	892



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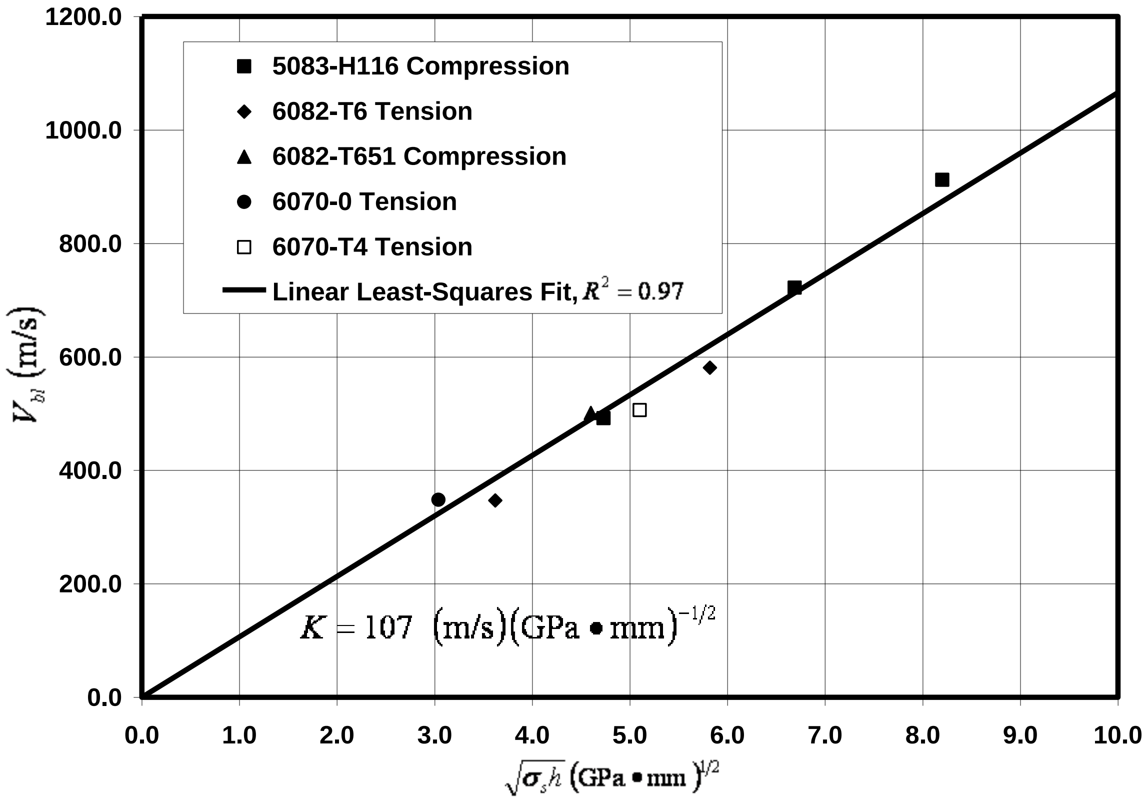
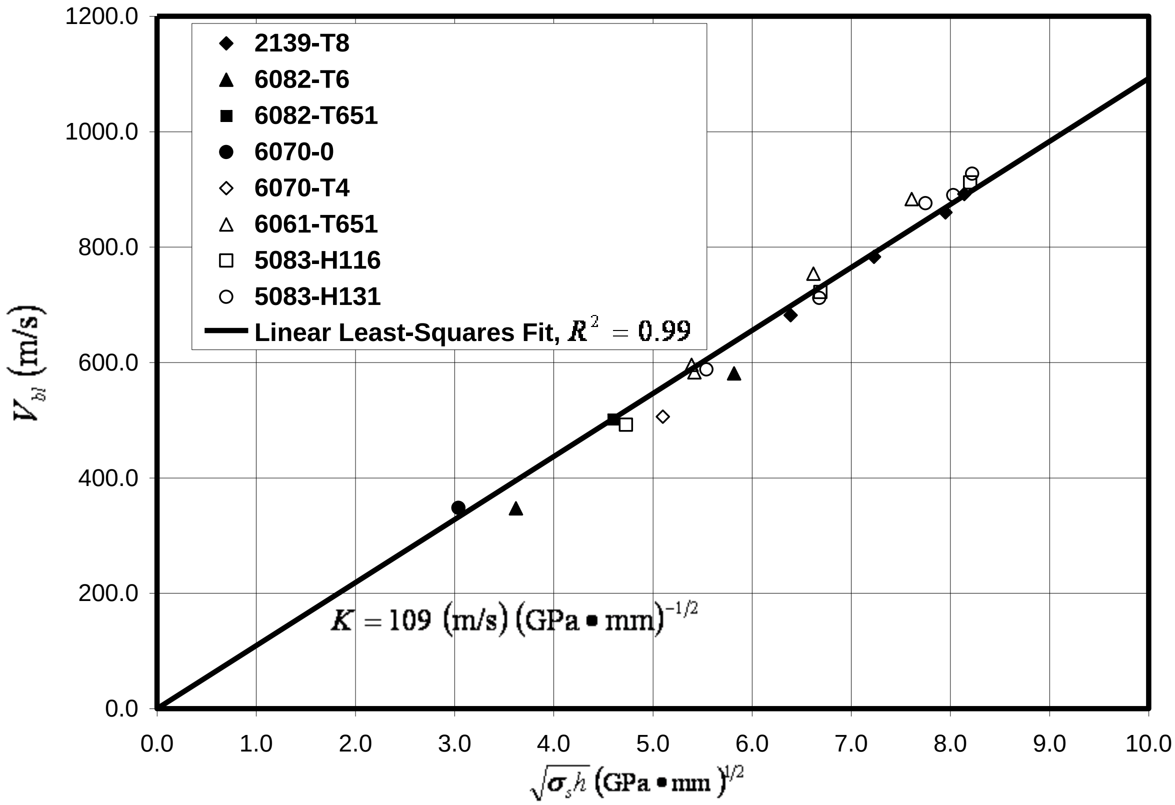


Fig. 2 Scaling law and data for material tests with uniaxial compression and tension experiments.



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