

The Perforation Behavior of the Anodized Al Light Armor under High Velocity Impact

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ABSTRACT

In order to investigate the effect of surface treatment (Anodizing) and rolling on Al 5083-H131 alloy, under hyper velocity impact, a ballistic testing was conducted. Ballistic resistance of these materials was measured by a protection ballistic limit (V_{50}), a statistical velocity with 50% probability of penetration.

Perforation behavior and ballistic tolerance, described by penetration modes, were respectfully observed, by V_{50} test and Projectile Through Plates (PTP) test at velocities greater than V_{50} .

PTP tests were conducted with 0° obliquity at room temperature using 5.56mm ball projectiles. V_{50} tests with 0° obliquity were also done with projectiles that were able to achieve near or complete penetration during PTP tests.

Resistance to penetration, and penetration modes of Al 5052-H34 alloy were compared to those of Al 5083-H131 alloy.

Key Words : Anodizing, Protection ballistic limit, Resistance to penetration, Penetration mode

1. Introduction

Components used for military applications often require ballistic tolerance for prevention of structural failures in service. Mechanical tests cannot replace the conditions of ballistic impact or reliably predict ballistic performance (by Manganello et al. ¹). In this paper, fracture behavior (penetration modes) and the resistance to penetration during ballistic impact of surface treated Al 5083-H131 alloy used for armor materials were studied. Resistance to penetration is determined by the V_{50} ballistic limit test method². Fracture behaviors resulting from V_{50} test and PTP tests at velocities greater

than V_{50} ³ are observed. Resistance to penetration, and penetration modes of surface treated Al 5083-H131 alloy are compared to those of alloy Al 5052-H34 and Al 5083-H131 alloy.

2. Experimental Background

2.1 The V_{50} and PTP ballistic test methods

Ballistic impact during the V_{50} test is defined in terms of penetration, the depth or process of projectile traveling into target material (by Backman and Goldsmith ⁴). Penetration from ballistic impact is defined as either CP (complete penetration) or PP (partial penetration) by criteria of the Army, Navy and Protection Ballistic Limits (by Zukas et al. ⁵), as shown in Fig. 1

2.2 Failure modes of impacted plates

Failure modes of targets and projectiles are

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dependent on impact velocity, angle of obliquity, projectile shape, relative dimensions of projectile and target in addition to material properties and their fracture behaviors. The failure modes of plates impacted may include a single dominant mode, or the penetration may be complex, involving several modes. Fig. 2 shows typical failure modes of impacted plates used in this study.

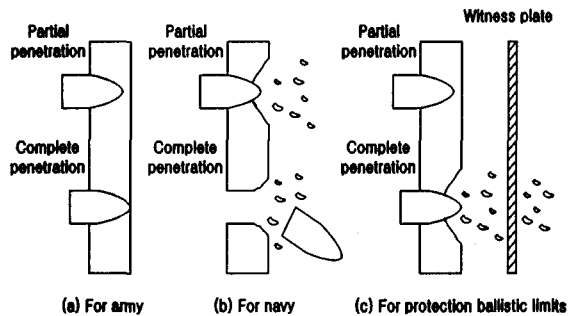


Fig. 1 Penetration mode by criteria of the army, navy and protection ballistic limits

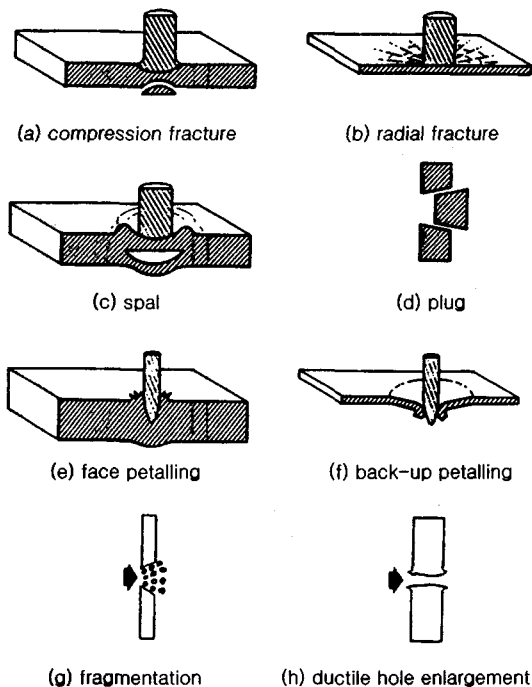


Fig. 2 Typical failure (penetration) modes of impacted plates

2.3 Experimental setup

The experimental setup was prepared according to U.

S. Military specification (MIL-STD-662F) and National Institute of Justice (NIJ) standards 0108.01. These standards are widely used by government agencies and armor manufacturers for product acceptance testing. The energy absorption values for various hybrid configurations can be obtained using these standards. A schematic diagram of the hypervelocity impact apparatus used in this study is shown in Fig. 3. It consists of following parts: (a) an impact rifle of 5.56mm caliber, firing standard lead bullets; (b) a long steel test stand used to support individual components of the testing arrangement; (c) frames used for velocity measurement (for each projectile, three frames were prepared for measuring the impact velocity, each frame was connected to an electronic counter to measure traveling time of the projectile in microsecond); (d) square type target plates and witness plates (the size of the plate 30cm*30cm; a witness plate was located behind the target, and complete penetration was defined as perforation of both target and witness plate): (e) a high speed camera located at the lateral side of the target material to investigate perforation phenomena.

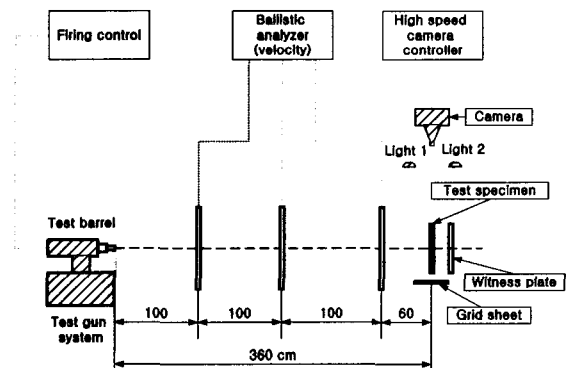


Fig. 3 Experimental setup for high velocity impact test

Test results were reported as a hypervelocity impact limit, V_{50} , at which theoretically 50% of the traveling projectiles penetrate the target and the other traveling projectiles are stopped. The exact methodology calculating the hypervelocity impact limit is described in MIL-STD-662F. In the simplest case, V_{50} is determined by averaging four projectile-striking velocities that include the two lowest velocities which result in complete penetration (CP), and the two highest velocities that result in partial penetration (PP). A spread of 16ms^{-1}

or less is required between the lowest velocity for PP and the highest velocity for CP.

Perforation phenomena were analyzed using the high-speed camera during the penetration of target materials. The test weapon was a 292 model (5.56mm barrel) made by AVL corp. The gun was mounted on a Ransom Rest from Ransom international corp. with a laser sight attached for accuracy in firing. The chronograph, Model 35P of Oehler Research was used to determine the velocity of the projectile.

The test specimens were rigidly clamped between two steel frames. Bolts at the corners and mid sections of the steel frames were tightened to insure a rigid mount on all four edges of the test specimen. A half inch of material was clamped around the perimeter of the test specimens. These two steel frames were attached to support the structure. The test specimen was perpendicular to the line of flight of the bullet at the point of impact. Located 5" behind the specimen was a 0.02" thick 2024-T3 Al alloy witness plate used to record specimen penetration.

3. Experiments

3.1 Materials

The chemical composition and mechanical properties of Al alloys used in this study are given in Table 1 and 2.

In order to investigate the effect of surface treatment (Anodizing) and rolling in Al 5083-H131 alloy on the hypervelocity impact resistance, specimens with 24 types were prepared, as shown in Table 5.

Table 1 Chemical composition of Al 5052-H34 alloy & Al 5083-H131 alloy

Wt(%)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 5052-H34	0.25	0.4	0.1	0.1	2.8	0.35	0.1	.	Bal.
Al 5083-H131	0.4	0.4	0.1	0.4~1.0	4~4.9	0.05~0.25	0.25	0.15	Bal.

Table 2 Mechanical properties of Al 5052-H34 alloy & Al 5083-H131 alloy

Material (Alloy)	Tensile Strength (MPa)	Yield Strength (MPa)	Young's Modulus (GPa)	Elongation (%)
Al 5052-H34	260	180	69.58	10
Al 5083-H131	300	190	70.3	16

4. Results and Discussions

4.1 Impact velocity

Standard 54 grains (3.55g) round nose lead projectiles (5.56mm, M193) with a copper outer coating (jacket) were used as impact materials. The projectiles had a weight variance less than 1% ($\pm 0.01g$). The projectile velocity was controlled by altering the propellant weight. A series of ammunition tests was initially performed to develop a charge weight vs. velocity curve to be used in subsequent firings.

The projectile-striking velocity according to propellant weight is represented in Fig. 4, and the required striking velocity was achieved through a change of propellant weight.

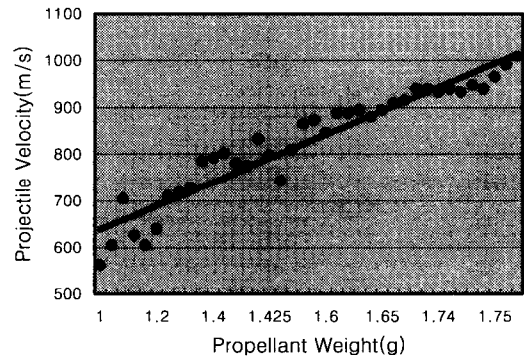


Fig. 4 Projectile velocity(m/s) vs. propellant weight(g)

4.2 Surface hardness

Surface hardness test results of Al alloys and surface treated Al alloys are presented in Table 3. As shown in Table 3, In case of Al 5052-H34, significant increment of the surface hardness was found by the surface treatment. A 48% increment was observed in cold rolled Al alloy and 464% increment was observed in anodized Al alloy compared with the surface hardness of non-treated Al alloy.

In case of Al 5083-H131, significant increment of surface hardness was found by the surface treatment. A 95% increment was observed in cold rolled Al alloy and 390% increment was observed in anodized Al alloy compared with the surface hardness of non-treated Al alloy.

It was thought that anodizing after cold rolling was more effective than just cold rolling or non-treating case for increment of surface hardness.

V₅₀ test results are shown in Table 4 and Fig. 5 – 6.

Ballistic test results of surface treated Al 5052-H34 alloy are represented by Fig. 6. V₅₀ of Al alloy increased proportionally with the ply number. In case of 25 plies, V₅₀ of non-treated Al alloy, cold rolled Al alloy, and anodized Al alloy were 481.5m/s, 571.8m/s, and 545.6m/s, respectively. For the same thickness specimen, V₅₀ of surface treated Al alloy was superior to that of non-treated Al alloy.

Table 3 Hardness of test specimen by micro vicker's hardness tester

No.	Material	Condition	Thickness (mm/ ply)	Surface Hardness (Hv, 50g)
1	Al 5052-H34	Al alloy	0.5	78.15
2		Cold-Rolled Al alloy	0.5	115.36
3		Anodized Al alloy	0.5	440.65
4		Anodized Al alloy after cold-rolling	0.5	403.39
5	Al 5083-H131	Al alloy	0.5	92.33
6		Cold-Rolled Al alloy	0.5	180.36
7		Anodized Al alloy after cold-rolling	0.5	455.65

It was thought that increasing of surface hardness by surface treatment affected the impact performance during the high velocity impact.

Ballistic test result of surface treated Al 5083-H131 alloy, is shown in Fig. 6. V₅₀ of Al alloy also increased linearly with the ply number. In case of 25 plies(0.5mm/ply), V₅₀ of cold rolled Al alloy was 501.4m/s, and that of anodized Al after cold rolling was 578.5m/s. That is, under the same thickness, V₅₀ of anodized Al alloy after cold rolling was 15.37% (77.1m/s) superior to that of rolled Al alloy.

In case of 13 plies(1.0mm/ply), V₅₀ of cold rolled Al alloy was 550.2m/s, and V₅₀ of anodized Al after cold rolling was 624.5m/s. For the same specimen thickness, anodized Al alloy after cold rolling shows 13.5% (74.3m/s) better impact performance than rolled Al alloy.

As a result, it was thought that anodizing after cold rolling is more effective to resistance to penetration than that of cold rolling or non-treating.

Table 4 Ballistic test results of specimens (Protection Criteria)

No.	Material	Thickness (mm/ply)	Ply	V ₅₀ (m/s)
1	Al 5052-H34	0.5	15	388.8
2			20	466.7
3			25	481.5
4		0.5	15	448.8
5			20	511.1
6			25	529.8
7		0.5	15	444.6
8			20	520.6
9			25	571.8
10	0.5	15	436.2	
11		20	472.1	
12		25	545.6	
13	Al 5083-H131	0.5	15	384.1
14			20	486.0
15			25	501.4
16		0.5	15	448.0
17			20	508.7
18			25	578.5
19		1.0	7	405.1
20			10	487.2
21			13	550.2
22	1.0	7	461.5	
23		10	539.3	
24		13	624.5	

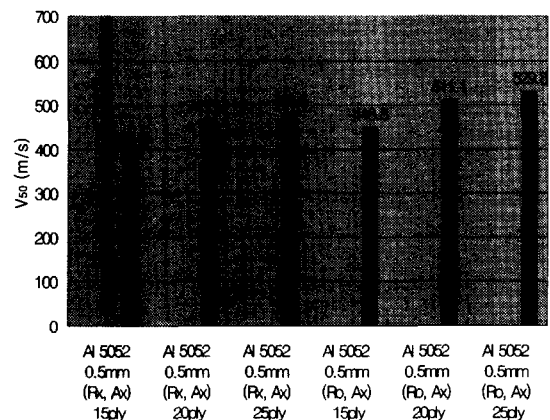


Fig. 5(a) Protection ballistic limits(V₅₀) of Al 5052-H34 (0.5 mm/ply) from No. 1 to No. 6

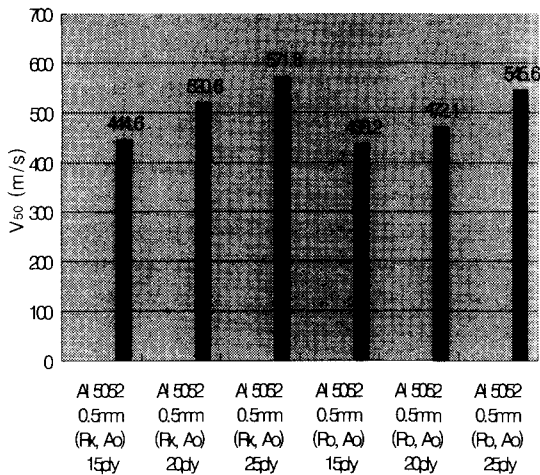


Fig. 5(b) Protection ballistic limits(V_{50}) of Al 5052-H34 (0.5 mm/ply) from No. 7 to No. 12

Ballistic test result of surface treated Al 5083-H131 alloy, is shown in Fig. 6. V_{50} of Al alloy was also increased linearly as increasing the ply number. In case of 25 plies(0.5mm/ply), V_{50} of cold rolled Al alloy was 501.4m/s, and that of anodized Al after cold rolling was 578.5m/s. That is, under the same thickness, V_{50} of anodized Al alloy after cold rolling was 15.37% (77.1m/s) superior to that of rolled Al alloy.

In case of 13 plies(1.0mm/ply), V_{50} of cold rolled Al alloy was 550.2m/s, and V_{50} of anodized Al after cold rolling was 624.5m/s. For the same specimen thickness, anodized Al alloy after cold rolling shows a 13.5%(74.3m/s) better impact performance than rolled Al alloy.

As a result, it was thought that anodizing after cold rolling is more effective to resistance to penetration than that of cold rolling or non-treating.

5. Conclusions

(1) In case of Al 5052-H34 alloy, significant increment in V_{50} was found by surface treatment. 18.75% increase was observed in cold rolled Al alloy and 13.31% increase was observed in anodized Al alloy compared with V_{50} of non-treated Al alloy.

(2) It was found that anodizing after cold rolling was more effective to the resistance to penetration than cold rolling. In case of Al 5083-H131, V_{50} of anodized Al

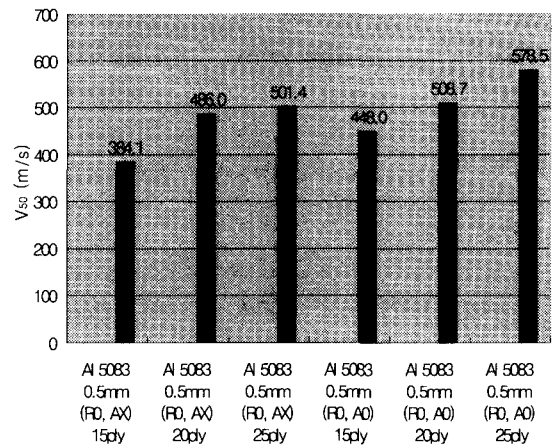


Fig. 6(a) Protection ballistic limits(V_{50}) of Al 5083-H131 (1.0mm/Ply) from No. 13 to No. 18

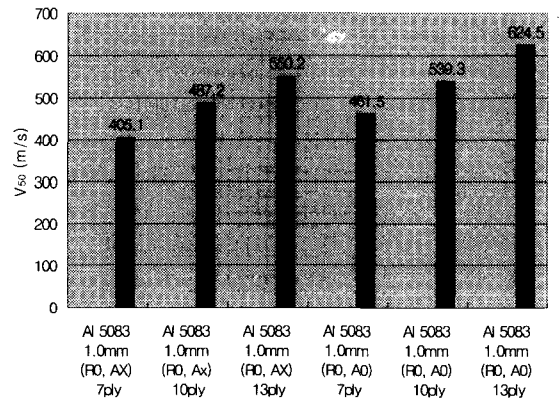


Fig. 6(b) Protection ballistic limits(V_{50}) of Al 5083-H131 (1.0mm/Ply) from No. 19 to No. 24

alloy after cold rolling was 14.5% superior to that of only cold rolled Al alloy.

(3) Surface hardness of Al alloys can be increased by surface treatment of those alloys. Especially, anodizing after cold rolling is more effective to increase the surface hardness than single cold rolling or non-treating cases.

(4) As the surface hardness increases, resistance to penetration during high velocity impact was increased linearly.

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