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Military Applications for β Titanium Alloys

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Beta alloys are potentially useful for several types of nonaerospace military applications. The potential applications to be discussed in this article include armor, body armor, mortar barrels, and missile launch canisters.

Keywords armor, ballistic, missile launch canister, mortar barrel, titanium

1. Introduction

This article focuses on β alloys with regard to two aspects of military applications: ballistic protection; and applications requiring good elevated temperature properties. Of course, there are numerous other potential applications for β alloys in military systems, such as structural components (TIMETAL 10-2-3 and 555) and springs/torsion rods (TIMETAL LCB and Beta C), but these are better discussed in the context of the general properties of the respective alloys and therefore are not covered within this article.

2. Ballistic Properties

2.1 Ballistic Testing With Armor-Piercing Projectiles

For overall ballistic performance, Ti-6Al-4V is well established as the preferred titanium alloy for armor applications and is the benchmark against which all other titanium alloys are compared. However, the quest for an even more effective titanium alloy continues. A simplistic (but popular) theory is the concept that higher strength (i.e., higher hardness) will lead to better ballistic performance, especially against armor-piercing (AP) projectiles. This line of thought arises from common experience with the ballistic performance of hardenable steel alloys in certain situations.

As an initial assessment of the ballistic performance of β alloys, several alloys were tested using the 7.62 mm (caliber 0.30) AP projectile shown in Fig. 1.

Ballistic test results are summarized in Fig. 2. The results are compared with the previously published trend for Ti-6Al-4V (Ref 2). None of the β alloys exceeded the Ti-6Al-4V trend line. Because β alloys typically have a higher density than Ti-6Al-4V, the relative performance of the β alloys is further diminished when differences in areal density are considered. The relative mass efficiencies for each alloy are summarized in Table 1.

The ballistic performance is mainly determined by the onset of localized adiabatic shear within the target material, which appears to occur in a similar manner for both Ti-6Al-4V and most of the β alloys. However, the strongest alloy tested, TMETAL LCB, exhibited a somewhat different failure mode.

Although the V50 of TIMETAL LCB was anomalously low, the ballistic behavior of this alloy merits further discussion. The very high strength of this alloy (approximately 1450 MPa [210 ksi]) resulted in premature back-spall formation, which resulted in a low V50 value. However, this alloy exhibited a unique ability to damage the AP projectiles. Against AP ammunition, complete penetrations of Ti-6Al-4V and most of the β alloys are characterized by ductile deformation and/or minor back-spalling of the plate. For partial penetrations, the projectile is typically defeated by the entrapment of an intact projectile; the AP projectile is usually not damaged by the impact. With TIMETAL LCB, the projectiles were fractured for many of the impacts used in the V50 test. Figure 3 shows a remnant of the fractured projectile and corresponding back spall (note that the projectile itself did not penetrate the plate). This observation suggests that a titanium armor system incorporating ultra-strong β titanium alloys might be capable of defeating AP threats. The performance of such a system would depend on having a good capability for preventing or containing the excessive back spall.

2.2 Ballistic Testing With Ball Projectiles for Body Armor

To evaluate the effectiveness of using a hardened titanium plate as part of a system to defeat ball ammunition, an armor system consisting of 4.7 mm (0.185 in.) TIMETAL 15-3 plate backed with aramid fabric was tested against 7.62 × 39 mm

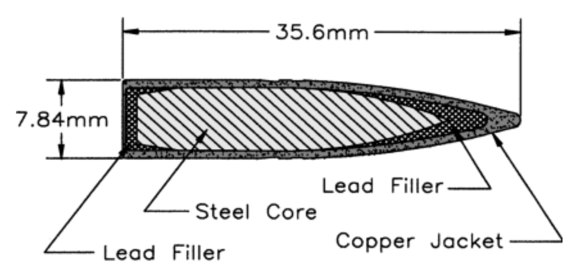

Fig. 1 Schematic diagram of a caliber 0.30 (7.62 mm) AP M2 projectile (Ref 1)

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M43 Soviet (7.96 g [123 gr.]; Full Metal Jacket, mild steel core) ammunition. The results are summarized in Fig. 4, which also includes a comparison with a less titanium-intensive system that consisted of a thin sheet of Ti-6Al-4V backed by a greater thickness of aramid fabric. Note that even though the system areal densities were roughly the same, the titanium-intensive system had a significantly higher V50. The ability of the TIMETAL 15-3 plate to damage the mild steel components of the projectiles potentially provides performance advantages in some systems (Ref 3).

Table 1 Ballistic mass efficiency of β alloys compared to Ti-6Al-4V for 0.30 (7.62 mm) AP M2 projectiles

Alloy	Density g/cm^3	Density $lb/in.^3$	Mass efficiency
Ti-6Al-4V	4.46	0.161	1.00
Ti-5.5Al-5V-5Mo-3Cr-0.12O [555] STA	4.65	0.168	0.97
VST3553 + 0.6Zr STA	4.65	0.168	0.86
Ti-6.8Mo-4.5Fe-1.5Al [LCB] STA	4.79	0.173	0.66
Ti-15V-3Cr-3Sn-3Al-0.12O [15-3] STA	4.79	0.173	0.90

Note: STA, solution heat treated and aged

2.3 Sharp Implement Thrust Protection

TIMETAL 15-3 sheet was tested for personal protection against thrusts from sharp instruments. An ice pick with an HRC of C 42 was used as the prototypic sharp instrument (Ref 4). Testing consisted of attaching the ice pick to a mass of 18.2 kg (40 lb), then varying the drop height from 640 to 760 mm (25-30 in.) to impact the TIMETAL 15-3 target at various energy levels. For each impact, an assessment was made as to whether penetration occurred, and the maximum indentation of the underlying clay was measured. At a thickness of 0.8 mm (0.033 in.), the TIMETAL 15-3 sheet was able to provide effective protection against ice picks up to an impact energy of approximately 131 J (1160 in./lb or 96.7 ft/lb). The results are summarized in Fig. 5 and Table 2. The best results were obtained for TIMETAL 15-3 in the solution-treated (continuous vacuum annealed [CVA]) condition, which has a relatively low elastic modulus. In this resilient condition, the peak stress exerted on the sheet is reduced because the effective collision

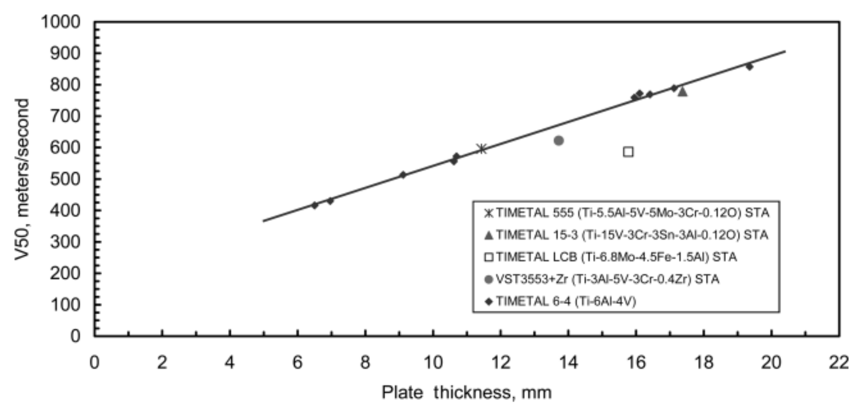

Fig. 2 V50 ballistic limit versus plate thickness for titanium alloys tested against caliber 0.30 (7.62 mm) AP M2 ammunition. All testing was performed at room temperature and zero degree obliquity per MIL-STD-662F.

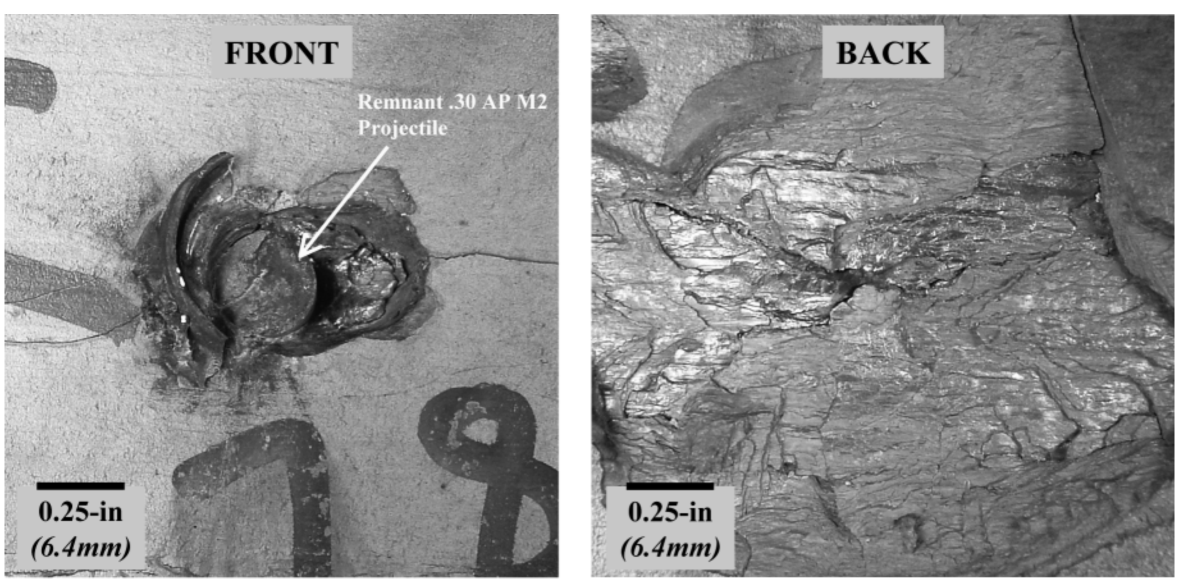

Fig. 3 High partial penetration of a TIMETAL LCB monolithic plate after testing against caliber 0.30 (7.62 mm) AP M2 ammunition. Note the fractured remnant of a projectile in front of the plate and the large spall ejection from the back of the plate.

time is increased and the point load is distributed over a slightly larger area. These characteristics may enable weight reduction and improvements in the flexibility, comfort, and durability of inserts for protective vests.

Table 2 Sharp instrument penetration testing of 0.84 mm (0.033 in.) TIMETAL 15-3 versus Rc 42 ice picks

	Kinetic energy		Depth of penetration(a)		Deformation(b)	
Drop No.	J	in./lb	mm	in.	mm	in.
1	158.3	1400	143	5.6	…	…
2	113.1	1000	0	0	2	0.079
3	135.7	1200	143	5.6	…	…
4	122.1	1080	0	0	2	0.079
5	131.2	1160	0	0	2	0.079
6	144.7	1280	0	0	2	0.079

(a) Depth of penetration into clay backing at 27 °C (80 °F); (b) Depth of indentation of clay backing at 27 °C (80 °F)

3. Gun Barrel and Missile Launcher Applications

3.1 Introduction

Critical requirements for gun barrel and missile launcher applications include strength at elevated temperature and resistance to attack by hot propellant gases. Note that, due to the galling tendency of titanium, it is usually not suitable for direct contact with projectiles, so a liner of steel or another resistant material is typically required in those instances.

3.2 Strength at Elevated Temperature

The good elevated temperature properties of TIMETAL 21S make it a candidate for these types of applications. Tensile properties at elevated temperatures are provided in Fig. 6 (note that at temperatures above approximately 677 °C [1250 °F], overaging will occur, so these values are valid for short-term exposures only).

Mechanical properties at very high temperatures were mea-

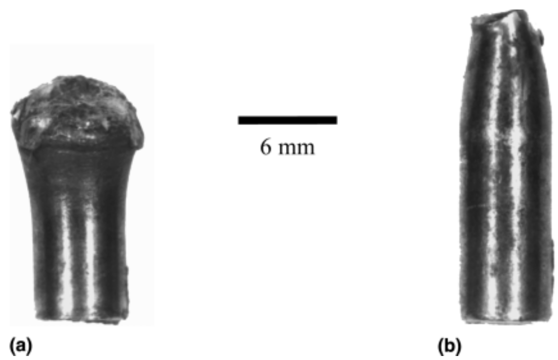

Fig. 4 (a) 4.8 mm *TIMETAL* 15-3 plus aramid fabric, system areal density = 30 kg m^{-2} (6.2 psf), V50 = 721 m s^{-1} (2365 fps). (b) 2.0 mm *TIMETAL* 6-4 plus aramid fabric, system areal density = 28 kg m^{-2} (5.8 psf), V50 = 484 m s^{-1} (1579 fps). Residual projectiles recovered from aramid fabric after the partial penetration of armor panel with a 4.8 mm TIMETAL 15-3 strike plate (a) and a 2.0 mm Ti-6Al-4V strike plate (b) (Ref 3)

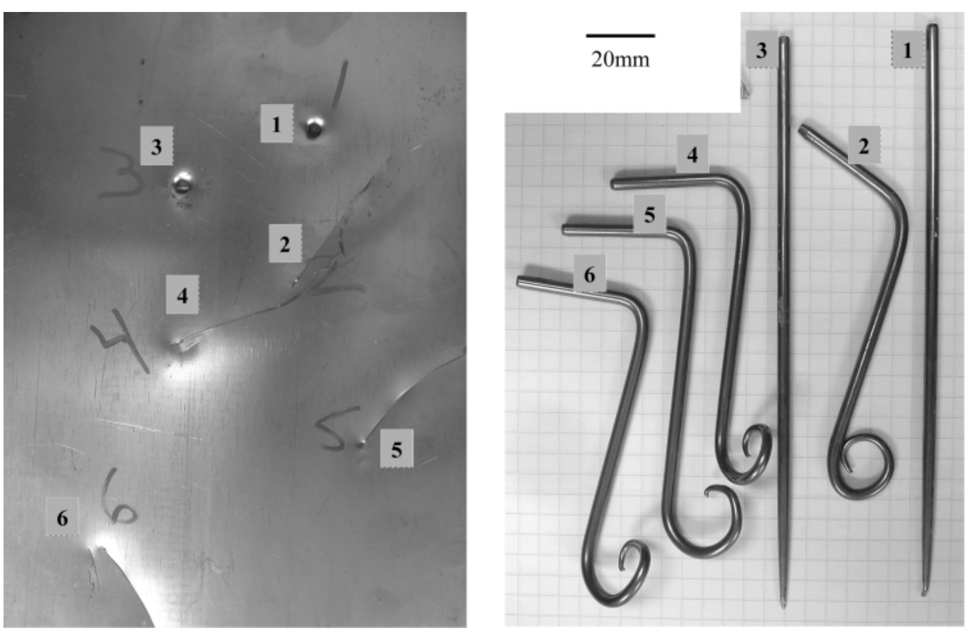

Fig. 5 Left: front face of a 0.8 mm (0.033 in.) TIMETAL 15-3 strip after testing against ice picks. Right: residual ice picks after testing. The numbers correspond to impact locations and the results in Table 2.

sured by the Naval Surface Warfare Center (Ref 5). The results for selected alloys are shown in Fig. 7.

3.3 Gun Barrel Erosion Testing

Erosion testing under simulated gun barrel conditions showed promising performance for TIMETAL 21S when tested at moderate pressures (Ref 6). The results for tests conducted at a moderate combustion pressure are summarized in Table 3. The low-strength/high-ductility condition performed significantly better than the high-strength/low-ductility condition. This was attributed to the formation of numerous superficial cracks on the surface of the material in the high-strength/low-ductility condition. Note that tests performed at a high combustion pressure (400 MPa [58 ksi]) resulted in severe erosion, so an ablative liner would be required for use in these conditions.

3.4 Mortar Barrel

In an attempt to reduce the weight of the barrel on the 81 mm M253 mortar, a TIMETAL 21S mortar barrel was designed, manufactured, and tested by the U.S. Army (Ref 7). Titanium was selected instead of aluminum- or graphite-reinforced epoxy composites based on computational modeling of the thermal and mechanical characteristics of a lightweight mortar tube constructed from each of the candidate materials. In all cases, it was assumed that the interior of the tube would contain a steel liner for direct contact with the projectile. The most efficient overall design was titanium, with TIMETAL 21S selected based on the strength and oxidation resistance at the anticipated operating temperature for a titanium barrel (427 °C [800 °F]). A prototype mortar was manufactured (Fig. 8) and tested. The concept is still under evaluation.

3.5 Missile Launchers

TIMETAL 21S and other titanium alloys were evaluated for a concentric canister launcher (CCL) for the Mk41 Vertical Launch System (Ref 5). The hemispherical head (lower left-hand corner of Fig. 9) requires exceptionally good high-temperature properties that should be capable of withstanding

Table 3 Summary of erosion testing of 21S under simulated gun barrel conditions (Ref 6)

Material condition		Combustion parameters		Test results	
Heat treatment	**Hardness, Hv_1**	**Temperature**	**Pressure**	**Weight loss(a), %**	**Comments**
Aged 538 °C (1000 °F) for 8 h	420	3900 °C (7052 °F)	230 MPa (33 ksi)	1.68	Erosion related to superficial surface cracking
Aged 691 °C (1275 °F) for 8 h	290	3900 °C (7052 °F)	230 MPa (33 ksi)	0.04	Favorable result

(a) Average

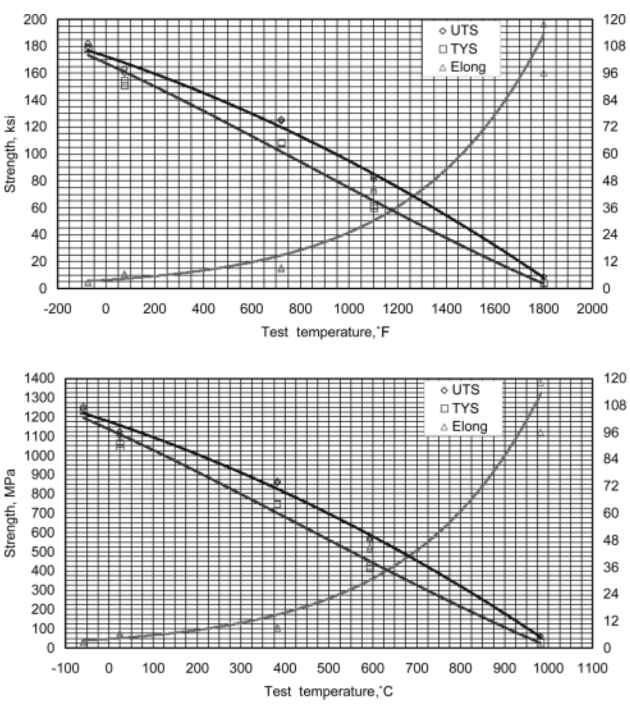

Fig. 6 The effect of test temperature on the tensile mechanical properties of a 44 mm (1.75 in.) TIMETAL 21S plate in the solution heat-treated plus overaged (677 °C [1250 °F], for 8 h) condition, with longitudinal orientation and tested in air. Specimens were soaked for 40 min at temperature prior to the start of the test. The strain rate was 0.005 in./in./min. English units (top) and SI units (bottom) are shown.

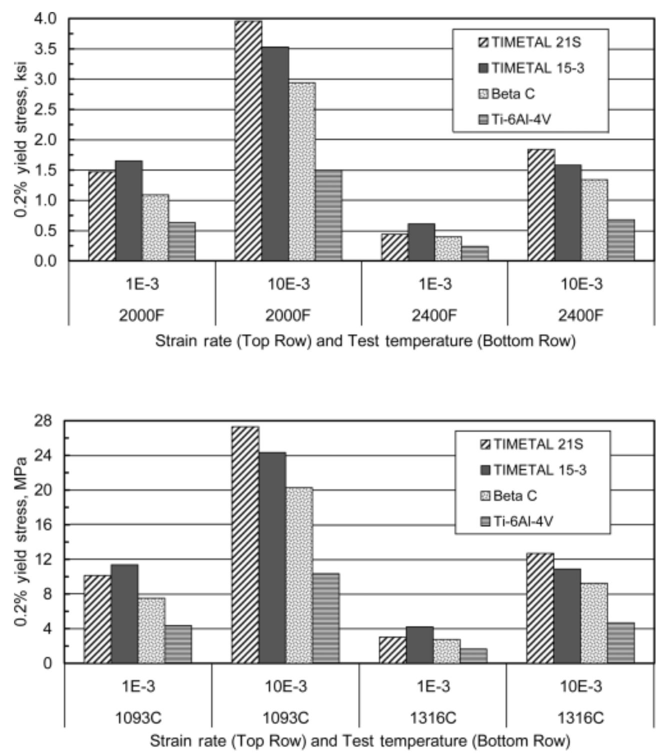

Fig. 7 Effect of test temperature and strain rate on the yield strength of several titanium alloys at very high temperatures. The heat-up time to test temperature was 3 to 3.5 min. English units (top) and SI units (bottom) are shown (Ref 5).

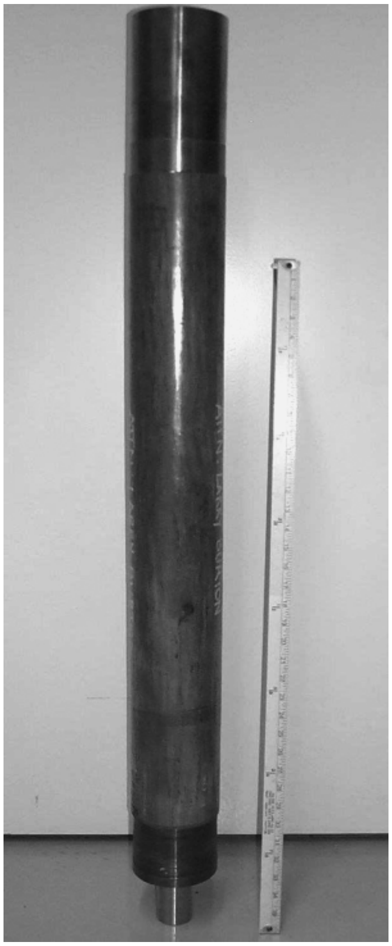

Fig. 8 Prototype barrel for a lightweight 81 mm mortar manufactured from TIMETAL 21S (Ref 7)

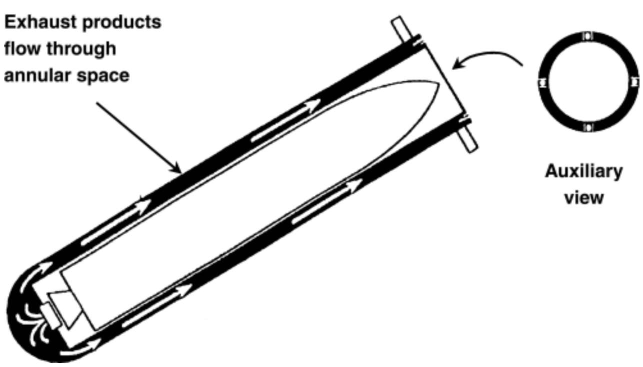

Fig. 9 Concentric canister launcher (Ref 5)

the extremely high temperatures during a missile flyout. A prototype titanium CCL was manufactured and tested with a hemispherical head made from TIMETAL 21S. Although the results were favorable, titanium has not yet been incorporated into this design concept.

4. Summary

Beta titanium alloys have mechanical, physical, and ballistic properties that are potentially of interest in a variety of nonaerospace military applications. As discussed in this article, observations of interest so far include:

- As monolithic armor, the ballistic performance of β alloys is generally less than that of Ti-6Al-4V. However, the higher strength and hardness of β alloys may offer advantages in certain types of armor systems for AP projectiles.
- TIMETAL 15-3 plate backed with aramid fabric can provide an effective system for defeating ball ammunition.
- Due to its relatively high strength and low elastic modulus in the solution-annealed condition, TIMETAL 15-3 can be effective for personal protection against thrusts from sharp instruments.
- The good elevated temperature properties of TIMETAL 21S make it potentially suitable for mortar barrel and missile launch canister applications.

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