BALLISTIC TESTING OF COMMERCIAL ALUMINUM ALLOYS AND ALTERNATE PROCESSING TECHNIQUES TO INCREASE THE AVAILABILITY OF ALUMINUM ARMOR

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The US Army Research Laboratory has been examining commercially available aluminum alloys for substitution for the aluminum armor materials of the current military specifications. Additionally, an investigation of alternate processing techniques was undertaken to increase the availability of current military specification aluminum armor alloys and these techniques were ballistically tested utilizing the current specification requirements. This work was required to reduce the production demand on military specification MIL-DTL-46027J(MR) 5083 aluminum armor, proposed for application in a number of ongoing US vehicle programs. The result of this work has been the revision of the current aluminum armor military specification for 5083 to include 5059 aluminum and issuing a new specification for 6061 aluminum.

INTRODUCTION

This paper documents US Army Research Laboratory (ARL) ballistic testing of commercially available aluminum alloys that could supplement existing standard US military specification aluminum armors. Additionally, a ballistic investigation of alternate processing techniques was undertaken to determine if these techniques could also increase the number of and the availability of current military specification aluminum alloys. This work has been required to reduce the production demand on MIL-DTL-46027J (MR) 5083 aluminum alloys that are proposed in the design of a number of ongoing US vehicle programs. The final intent of this work will be to revise the existing military specification, MIL-DTL-46027J(MR), with the addition of new classes of 5000 series alloys and add a new specification for the 6000 series aluminum alloys.

The demand for ballistic grade aluminum has seen a large increase recently due to the excellent ballistic advantages of this low density metal when utilized as primary armors on tactical trucks and combat vehicles. These materials offer good tradeoffs against small arms and fragment protection, have relatively low cost per pound, have a large industrial base production capacity and have established fabrication, repair and maintenance facilities with trained personnel. The ballistic advantages of aluminum over higher performance non-metallic systems are further illustrated when the armors are subjected to large blast and multiple, simultaneous fragment impacts from improvised explosive devices. The primary aluminum of interest is the 5083 alloy in both wrought plate (MIL-DTL-46027J) and extruded form (MIL-DTL-46083D). 5083 non-heat treatable wrought aluminum derives its properties from strain-hardening, primarily by rolling, that requires large industrial rolling machines and facilities; these strengthening techniques have resulted in limitations on increasing production capacity of 5083. To alleviate this, ARL initiated testing of heat-treatable 6061 alloys, extruded 5083 and 6061 alloys and 5083 alloys strain hardened by stretching. This paper will not further discuss 5083 extrusions or strain hardening of 5083 by stretching as they will be the basis of a future paper. Concurrently, the examination of 5059 aluminum was already in progress and was included in this paper. The ballistic data in this paper will be directly compared with wrought MIL-DTL-46027J(MR) 5083 and amendments to the current military specifications will be defined. The overall intent is to expand the availability of aluminum armor for tactical and armored vehicles. A brief discussion of the current military specification aluminum alloys are provided below.

MILITARY SPECIFICATION MIL-DTL-46027J(MR).

The primary wrought aluminum alloy used in US combat vehicles today is the aluminum-magnesium alloy 5083 that is defined by a set of mechanical properties, corrosion requirements and ballistic standards. These requirements are set forth in MIL-DTL-46027J (MR) [1] and have similar requirements for the related 5456 alloy that is primarily used in naval applications; the current version was last updated on 4 September 1998. The specification sets the minimum ballistic requirements for thicknesses from 6.35mm (0.25”) to 76.2mm (3.00”) that each heat of 5083/5456 has to meet to be certified under the military standard. Thicknesses from 6.35mm to 12.7mm are not required to be ballistically tested. The primary strengthening mechanism over commercial grade 5083 is by strain hardening through rolling and a number of tempers are possible, but the main stain-hardened tempers observed in testing are 5083-H131 or 5083-H321. These alloys are certified as weldable and can be ballistically repaired.

MILITARY SPECIFICATION MIL-DTL-46083D(MR)

A separate military specification MIL-DTL-46083D(MR) [2] exists for extruded aluminum products for two alloy classes:

Class 1 - 5083 and 5456
Class II – 7039 and 2219.

The main extruded alloys of interest in this paper are the Class 1 alloys that can be compared to the standard wrought 5083. These alloys have similar compositional requirements to the wrought product, but are hot extruded through dies to produce armor shapes up to 50.8mm (2.00”) in thickness. The main interest here is adding 6061 to this specification and limited testing has been undertaken. As with the wrought military specification 5083, the extrusions must meet a set of mechanical properties and ballistic standards. The ballistic acceptance tables are similar, but are not the same as the wrought 5083 tables and tend to have lower acceptance velocities. The current specification was last updated on 8 September 1998.

MILITARY SPECIFICATION MIL-DTL-46063H(MR)

The only high strength, wrought, 7000 series aluminum alloy with a military specification is the 7039 aluminum-zinc alloy, controlled by MIL-DTL-46063H(MR) [3]. The 7039 alloy was previously used on a number of US armoured vehicles, but further use was curtailed with the observation of stress-induced corrosion issues. Plate thicknesses range from 12.7mm (0.50”) to 101.4mm (4.00”) and 7039 has a specific set of ballistic acceptance criteria. The current specification is dated 14 September 1998.

MILITARY SPECIFICATION MIL-DTL-46192C(MR)

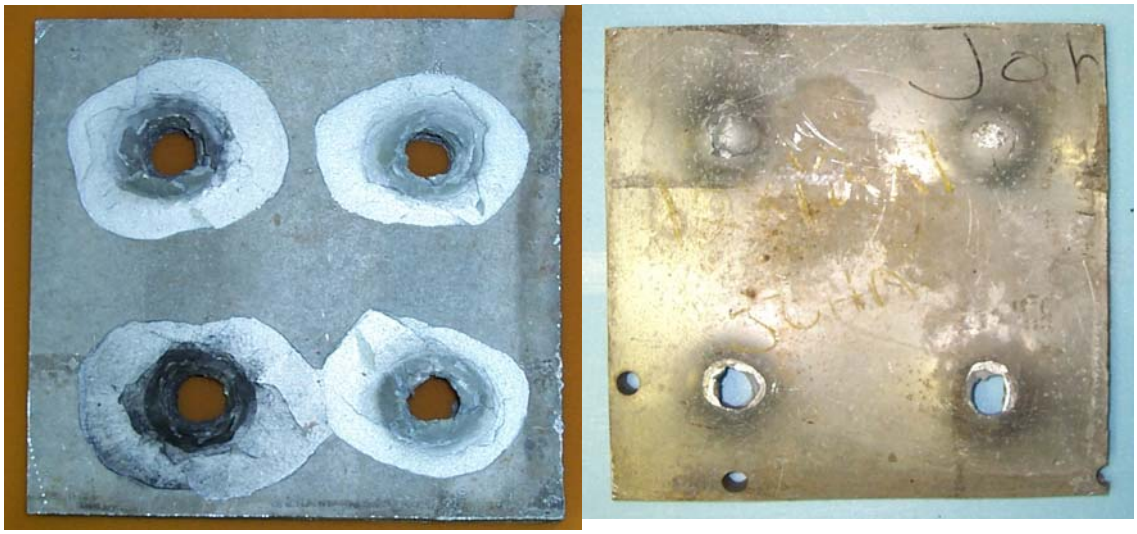
The main 2000 series aluminum alloy with a military specification is the 2519 aluminum-copper alloy, controlled by MIL-DTL-46192C(MR) [4]. This aluminum alloy is weldable and has found application in some US systems. The military specification covers the plate thicknesses from 12.7mm to 101.4mm and 2519 has a specific ballistic acceptance criteria. The current specification amendment is dated 7 February 2000.

MILITARY SPECIFICATION MIL-DTL-46118E(MR)

A second 2000 series aluminum alloy with a military specification is the 2219 aluminum-copper alloy, controlled by MIL-DTL-46118E (MR) [5]. This aluminum alloy is only weldable to 2219 and can be wrought or die forged; the alloy is being considered for application in some US systems. The military specification covers the plate sizes from 19.1mm to 101.4mm; 2219 has a specific ballistic acceptance criteria. The current specification amendment is dated 26 August 1998.

COMMERCIAL ALUMINUM ALLOYS OF INTEREST

A number of commercial heat-treatable aluminum alloys have been used in military applications even though no ballistic specification exists. The application is generally as an appliqué and commercial specifications were used to procure the alloys. These include the 2024-T351 aluminum-copper alloys, the 6061-T651 aluminum-silicon-magnesium alloys and the 7075-T6 aluminum-zinc alloys. The 7075 alloy is similar to 7039, but with higher strength. A commercial alloy from Aleris Europe (CORUS) in Germany, Alustar 5059-H131 aluminum has also gained interest and is in the same family as the 5083/5456 alloys [6]. The 5059 alloy is being evaluated under an extensive ARL Foreign Comparative Technology program [7] and only some summary data are shown here; complete data will be provided in future ARL technical reports. As with 7039, the high strength 2024 and 7075 alloys have better ballistic protection



Back of 50.8mm 7039 aluminum plate Back of 50.8mm 5083 aluminum plate

Figure 1. Back face Spalling of Higher Strength Aluminum Alloys

against bullets than the 5083, 5059 and 6061 alloys, but suffer from large back plate spalling against large fragment impacts that causes unacceptable behind armor debris. A comparison of the back plate of a 7039 plate to an equal thickness 5083 plate is shown in Figure 1 after impact by four 20mm fragment simulating projectiles (FSP's). Note the large spall and plugging for the 7039 versus the ductile petalling and plugging of the 5083. This effect has significant design implications for monocoque designs where additional back face materials are not desired. Use of a softer aluminum as a backing to the higher strength aluminum front plate may offer some possible applications, but additional parasitic weight for the fasteners as well as additional fabrication requirements may reduce the overall advantage. For these reasons, the main commercial alloys for further investigation in this paper were the 6061-T651 and 5059-H131 alloys.

BALLISTIC TESTING OF 5059 AND 6061 ALUMINUM ALLOYS FOR MILITARY APPLICATION

ARL has completed a significant number of ballistic tests to examine the 6061 and 5059 alloys and this paper only provides a summary of the test data. The primary effort was to build the ballistic tables to allow comparison to the baseline 5083/5456 MIL-DTL-46027J(MR) specification. However, the acceptance tables utilize five different projectiles as the thickness changes from 12.7mm to 76.2mm with an overlap of two projectiles in the thickness range of 25.4mm to 43.2mm. The 7.62mm APM2 is used to qualify 5083 in the thickness range of 25.4mm - 50.8mm and in the overlap thickness of 25.4mm to 43.2mm, acceptance testing with the 20mm FSP is used as an additional test to pass. This requirement has its origins in the original application of 5083 to the M113 Armored Personnel Carrier. In this paper, additional data with these two projectiles were generated outside this thickness range to determine the ballistic fits of the perforation data at the upper boundaries to see if these alloys would meet the MIL-DTL-46027J(MR) specification. Figures 2 and 3 directly summarize the performance of these two alloys for the 7.62mm APM2 and the 20mm FSP projectiles over the thickness range of 25.4 - 57.5mm; the solid line is the current MIL-DTL-46027J(MR) acceptance data for each projectile. The two figures include additional 5083 data (solid circles), 6061 test data (open triangles), 6061 extrusion data (solid triangles), and 5059 data (open squares). A second order fit of the 6061 data is also shown as a dashed line. The following conclusions can be drawn from these figures:

1. 6061-T651 exceeds the 5083 ballistic acceptance requirements for the APM2 and equals the acceptance requirements for the 20mm FSP, particularly in the required thickness range of the military specification.

2. 5059-H131 exceeded the 5083 ballistic acceptance requirements for both the APM2 and the 20mm FSP; the performance for the 20mm FSP was lowest at the

minimum 25.4mm thicknesses, but the performance difference increased as the thickness increased.

3. 5059-H131 generally exceeded the performance of 6061-T651.

4. While limited 6061 extrusion data are shown, the data indicates that these extrusions would pass the 7.62mm AP requirement, but not the FSP requirement when compared to the wrought 5083 MIL-DTL-46027J(MR) specification. However, these data should be directly compared to the requirements of MIL-DTL-46083D(MR) and the data point shown is outside the acceptance thickness for the 20mm FSP. The use of 6061 extrusions as a substitute for wrought 5083 needs further testing to be conclusive, but offers the advantages of making net shape ballistic components through a die. Extruded 5083 is an advantageous forming technique that does not compete with existing 5083 rolling techniques. Vehicle ballistic requirements should be compared to the current MIL-DTL-46083D (MR) military specification and slight changes in application thicknesses can be made to meet design requirements, if necessary.

DRAFT MILITARY SPECIFICATION MIL-DTL-46027K(MR)

The current 5083/5456 MIL-DTL-46027J(MR) specification has been rewritten to include the 5059 alloy and this draft specification will be identified as MIL-DTL-46027K(MR) when issued. The specification has been modified to cover three classes of 5000 series alloys, specifically Class 1 (5083), Class 2 (5456) and Class 3 (5059). This classification scheme will allow additional 5000 series alloys to be added, if desired, in the future. All three alloys are weldable and the specification is currently under review and should be issued by the publication of this paper. The existing 5083 acceptance tables have been retained, but the 20mm FSP requirement for thicknesses of 25.4mm to 43.2mm has been removed; the 7.62mm APM2 requirement remains for the thickness range of 25.4mm-50.8mm. This improved specification will allow a wider range of alloys to be selected for vehicle armor applications.

DRAFT MILITARY SPECIFICATION MIL-DTL-XXXX(MR)

A new military specification has been prepared that would cover the 6000 series of aluminum alloys. Class 1 will be 6061 and additional Classes in the 6000 series can be added as required. The ballistic acceptance tables in the draft are the same as the current 5083 MIL-DTL-46027J(MR). The draft is currently being reviewed and should also be issued by the time this paper is published. The 6061 alloy will only be certified to be used for non-welded applications and will cover the thickness range from 6.4mm to 76.2mm. This additional specification will allow the use of heat-treated 6000 series alloys versus the 5000 series strain-hardened alloys and creates a larger availability of ballistic aluminum for vehicle applications.

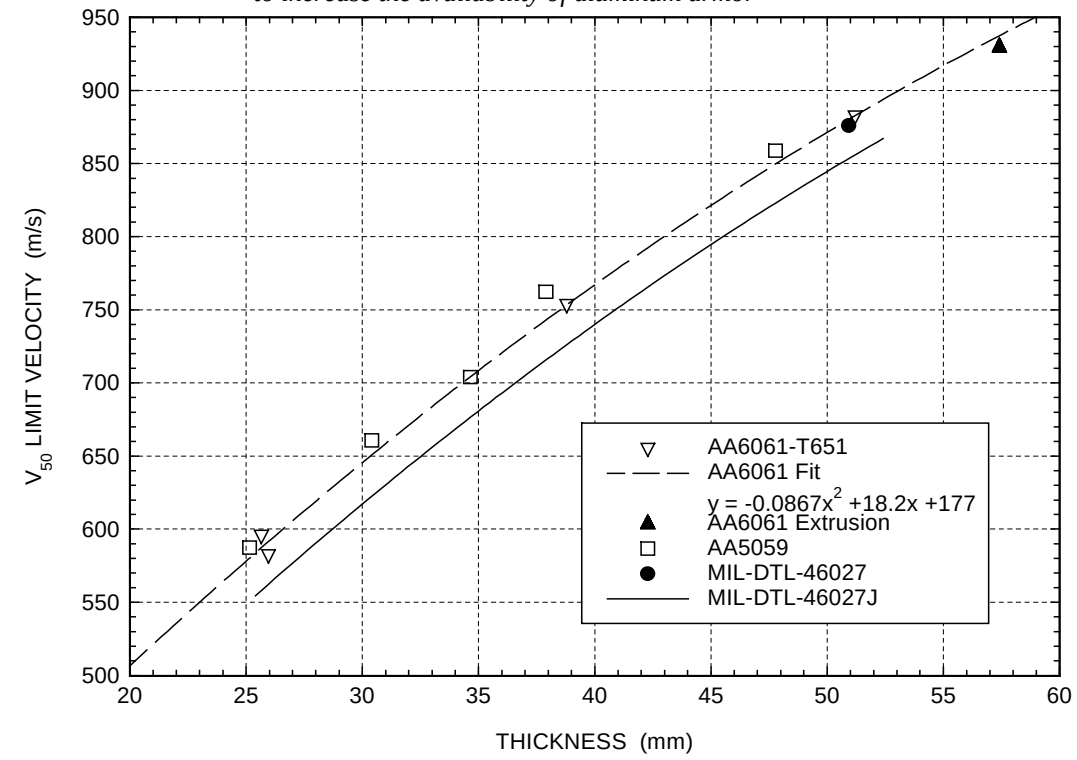


Figure 2. Comparison of 6061 & 5059 Test Data to 5083 MIL-DTL-46027J(MR) for 7.62mm APM2

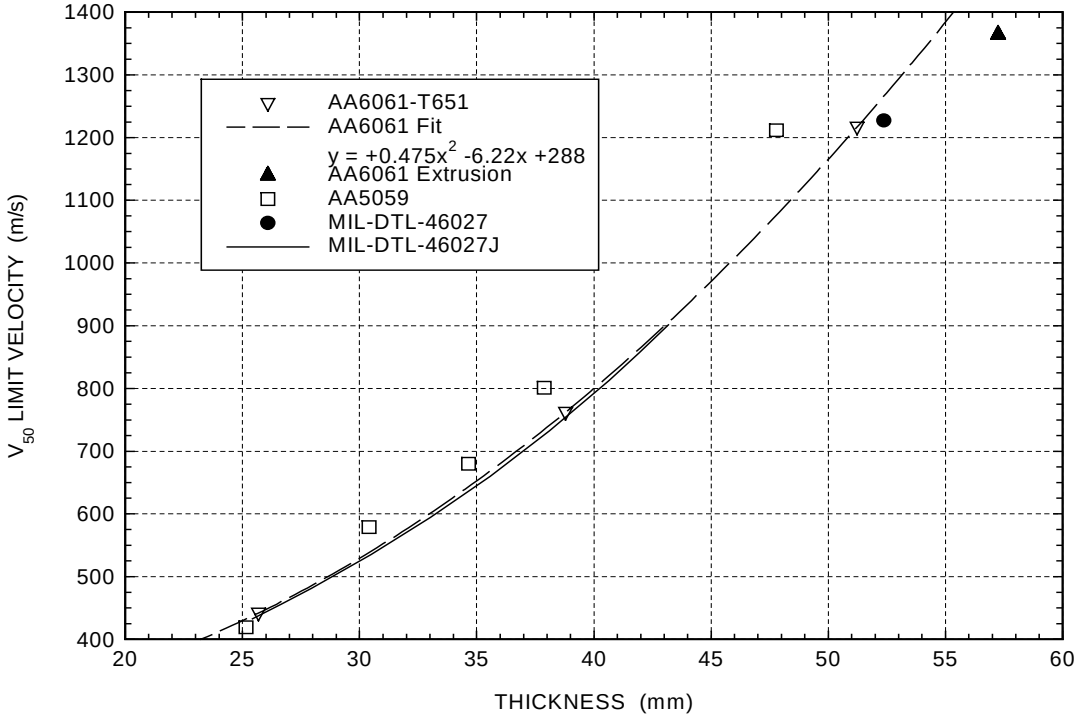


Figure 3. Comparison of 6061 & 5059 Test Data to 5083 MIL-DTL-46027J(MR) for 20mm FSP

CORROSION RESISTANCE OF ALUMINUM ALLOYS

While not part of this study, some comments on the corrosion resistance of the aluminum alloys discussed in this paper are necessary. Analysis of the aluminum alloy corrosion resistance is ongoing, but some general comments can be made. The 5000 series alloys have the best overall corrosion resistance with 6061 ranking just below 5083 for general corrosion resistance. 7039 approaches 6061 for general corrosion resistance, but is significantly worse for stress corrosion cracking. 2519 and 2219 are lower than the 5000 and 6000 alloys. Use of the 5000 and 6000 series aluminum should not incur corrosion issues.

CONCLUSIONS

The US Army Research Laboratory has examined two commercially available aluminum alloys that can supplement the supply of the primary strain-hardened 5083 aluminum armor. Additionally, the ballistic investigation of alternate processing techniques was undertaken to further increase the availability of current military specification aluminum alloys. The result of this analysis has been updating of the current aluminum military specification for 5083 to include the 5059 alloy and drafting a new specification for 6061 aluminum. This effort was required to reduce the production demand on MIL-DTL-46027J(MR) 5083 aluminum, proposed for application in a number of ongoing US vehicle programs.

REFERENCES

[1] Military Specification MIL-DTL-46027J (MR), “Armor Plate, Aluminum Alloy, Weldable 5083 and 5456”, issued 4 September 1998, AMSRL-WM-MA, US Army Research Laboratory.
[2] Military Specification MIL-DTL-46083D (MR), “Aluminum Alloy Armor, Extruded, Weldable”, issued 30 September 1998, AMSRL-WM-MA, US Army Research Laboratory.
[3] Military Specification MIL-DTL-46063H, “Armor Plate, Aluminum Alloy, 7039”, issued 14 September 1998, AMSRL-WM-MA, US Army Research Laboratory.
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