



**Development and Ballistic Testing of a New Class of
Auto-Tempered High-Hard Steels Under Military
Specification MIL-DTL-46100E**

**by Dwight Showalter, William Gooch, Matthew Burkins,
Jonathan Montgomery, and Richard Squillacioti**

ARL-TR-4997

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14. ABSTRACT The U.S. Army Research Laboratory (ARL) was directed to investigate various ways to expand current steel armor plate production as the large military demand for armor plate exceeded the current production capacity at U.S. steel facilities for quench and tempered high-hard armor (HHA) steel plate. The solution was to expand the availability of HHA steels under the current HHA military specification (MIL-DTL-46100) to include a new class of air-quenched, auto-tempered steels that do not use existing water quench and temper facilities. Allegheny Technologies Incorporated (ATI) developed an auto-tempered steel alloy, ATI 500-MIL (trademark of ATI Properties, Inc.), that has physical and mechanical properties that meet the current HHA specification. ARL procured sufficient amounts of ATI 500-MIL plate to allow acceptance testing and subsequent certification of ATI 500-MIL plate as complying with the First Article requirements of the newly revised MIL-DTL-46100E specification. This report documents the development of ATI 500-MIL plate and subsequent ballistic testing and inclusion into the specification as Class-2 auto-tempered HHA steel.					
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1. Introduction

The U.S. armor community is currently engaged in accelerated efforts to deliver lightweight armor technologies that can defeat armor-piercing (AP) projectiles at reduced areal weights that are available across a large industrial base. While many of these programs involve the application of lower-density metals such as aluminum and titanium, the selection of steel alloys is still competitive for many ballistic and structural applications; the ability to fabricate armor components in both commercial and military operational areas with available equipment and personnel is a major advantage of steel solutions. To meet these requirements, the U.S. armor community has increased the availability of quenched and tempered armor steels by updating current steel military specifications, the most important of which has been the updated/revised MIL-DTL-46100E, *Armor Plate, Steel, Wrought, High-Hardness*.¹ This improved specification was necessary to supply the large steel demands for combat operations in Iraq and Afghanistan. This high-hard armor (HHA) specification allows modern, continuous processing technologies to be used efficiently as well as introducing a new class of auto-tempered high-hard steels.

The U.S. Army Research Laboratory (ARL) was directed to investigate various ways to expand current steel armor plate production as the large military demand for armor plate exceeded the current production capacity at U.S. steel facilities for quench and tempered HHA steel armor plate. The solution was to expand the availability of HHA steels under the current military specification to include a new class of air-quenched, auto-tempered steels that do not use existing water quench and temper facilities. Allegheny Technologies Incorporated (ATI) developed an auto-tempered ATI 500-MIL* steel alloy that has physical and mechanical properties that meet the current HHA specification. ARL procured sufficient amounts of ATI 500-MIL plate to allow acceptance testing and subsequent certification of ATI 500-MIL plate as complying with the First Article requirements of the newly revised MIL-DTL-46100E specification.

Currently, the highest-performing U.S.-made steel alloys for AP bullet protection are manufactured to MIL-DTL-46100E HHA with a hardness range of 477-534 Brinell hardness number (BHN) and to MIL-A-46099C Dual Hardness Armor (DHA) that is produced by roll-bonding a 601-712 BHN front plate to a 461-534 BHN back plate.² The roll-bonded DHA steels are complex to produce and have known production limitations. In the near-term, the U.S. Army will be releasing a new ultra high-hard steel specification for plate hardness over 534 BHN that will further expand the hardness range for ballistic applications. The improved ballistic resistance of steel as a function of increasing hardness is well established in the ballistic

¹MIL-DTL-46100E. *Armor Plate, Steel, Wrought, High-Hardness* **2008**.

*ATI 500-MIL is a trademark of ATI Properties, Inc.

²MIL-A-46099C. *Armor Plate, Steel, Roll-Bonded, Dual Hardness (0.187 Inches to 0.700 Inches Inclusive)* **1987**.

community, particularly by Rapacki et al. in the 15th International Symposium on Ballistics.³ HHA steel increases AP bullet defeat, reduces armor weight, and is less difficult to manufacture than the DHA. This report documents the development of ATI 500-MIL plate and subsequent ballistic testing and inclusion into the specification as Class-2 auto-tempered HHA steel.

2. Allegheny Technologies ATI 500-MIL Plate

In June 2008, ATI announced the successful launch of a new class of HHA specialty steel. This next-generation armor steel, designated ATI 500-MIL, was developed in response to limited American HHA production and limited performance features of materials in this class. ATI 500-MIL alloy is melted, rolled, and finished in America on fully integrated assets owned and operated by ATI. This new material is designed to offer additional features that were not previously available in traditional quench and temper high-hard armor steels. Product design is also geared to obtain improvements in ballistic and blast resistance when compared with other HHA materials. ATI 500-MIL steel plate is designed to meet the requirements in MIL-DTL-46100E while also offering features that address several common challenges frequently encountered with conventional HHA plates.

The composition of ATI 500-MIL alloy includes appreciable amounts of Ni-Cr-Mo, which results in relatively high hardenability and increased toughness compared to other HHA alloys (tables 1 and 2).⁴ As a result, the balanced combination of unique properties and consistent quality allows this alloy to meet the specifications outlined in the MIL-DTL-46100E, which was recently revised to account for these improvements.

ATI 500-MIL armor addresses secondary processing difficulties associated with various operations. Specifically, operations such as forming (cold and hot), cutting or sectioning, and postoperation heat treatments for restorations of ballistic properties were successfully alleviated.

These postprocess improvements are partly due to the fact that the alloy is auto-tempered upon air cooling, thereby eliminating the traditional liquid-quenching and temper treatment. The slower air cooling combined with ATI's proprietary processing results in significantly higher dimensional armor stability.

³Rapacki, E.; Frank, K.; Leavy, B.; Keele, M.; Prifi, J. Armor Steel Hardness Influence on Kinetic Energy Penetration. *Proceedings of the 15th International Symposium on Ballistics*, Jerusalem, Israel, May 1995.

⁴ATI Defense. ATI 500-MIL High Hard Specialty Steel Armor, version 3; ATI Defense Data Sheet, Washington, PA, 3 September 2008.

Table 1. Chemical composition of ATI 500-MIL plate.

Alloy	% C (max)	% Si	% Mn (max)	% P (max)	% S (max)	% Cr (max)	% Ni (max)	% Mo (max)
ATI 500-MIL	0.22–0.32	0.25–0.45	0.80–1.20	0.020	0.005	1.60–2.00	3.50–4.00	0.22–0.37

Table 2. Mechanical properties of ATI 500-MIL plate.

Alloy	Hardness BHN	Charpy-V –40 °C ft/lb (J)	Yield Strength ksi (MPa)	Tensile Strength ksi (MPa)	Elongation (%)
ATI 500-MIL	477–534	20 (27)	150 (1034)	260 (1792)	13

Residual stresses in ATI 500-MIL products are also reduced compared to traditional liquid-quenched and tempered products. These improvements result in flatter armor products that exhibit minimal distortion during fabrication operations, such as hot or cold cutting. Since the product is auto-tempered, the alloy does not require any special postwelding operations involving liquid quenching and temper to restore ballistic properties.

3. Experimental Procedure

The ballistic performance of ATI 500-MIL steel plates was determined by obtaining the V_{50} ballistic limit for each thickness of plate against the corresponding specified test projectile. The test methodology is described in detail in the MIL-STD-662F.⁵ The V_{50} ballistic limit is the velocity at which an equal number of fair-impact complete penetration (target is defeated) and partial penetration (target is not defeated) velocities are attained using the up-and-down firing method. Fair impact is defined as occurring when a projectile with an acceptable yaw strikes the target at a distance of at least two projectile diameters from a previously damaged impact area or edge of plate. A complete penetration is determined by placing a 0.5-mm (0.020-in) 2024 T3 aluminum witness plate 152.6 mm (6 in) behind and parallel to the target. If any penetrator or target fragment strikes this witness plate with sufficient energy to create a hole through which light passes, the result is considered a complete penetration. A partial penetration is any impact that is not a complete penetration. For the MIL-DTL-46100E specification, the V_{50} ballistic limit is defined as the average of six fair impact velocities comprising the three lowest velocities resulting in complete penetration and the three highest velocities resulting in partial penetration. A maximum spread of 45.7 m/s (150 ft/s) shall be permitted between the lowest and highest velocities employed in determining ballistic limits. The data for the ATI 500-MIL steels are compared to the baseline ballistic acceptance data of MIL-DTL-46100E.

⁵MIL-STD-662F. *Department of Defense Test Standard 1997.*

4. Test Projectiles

The eight ATI 500-MIL plates tested for First Article certification ranged in thickness (nominal) from 0.1875 in (4.8 mm) up to 1 in (25.4 mm). The corresponding test projectiles and plate obliquities required for each thickness under MIL-DTL-46100E are listed in table 3. The weights and sizes of the projectiles are shown in table 4. These projectiles are shown in figures 1 and 2, with the 14.5-mm BS41 being a tungsten carbide core and the rest hardened steel. In some cases, additional testing was conducted outside this range to allow the data to be graphed. This is noted for the nominal 8-mm (0.315-in) thickness.

Table 3. Thickness ranges and corresponding test projectiles for First Article testing.

Nominal Thickness Range in (mm)	Obliquity (°)	Test Projectile
0.118 (3.0) to 0.300 (7.62) incl.	30	cal. 0.30 APM2
0.301(7.62) to 0.590 (15.0) incl.	30	cal. 0.50 APM2
0.591 (15.0) to 0.765 (19.4) incl.	30	14.5-mm B32
0.766 (19.4) to 1.130 (28.7) incl.	30	14.5-mm BS41

Table 4. Geometries and weights of projectiles utilized in ATI 500-MIL plate testing.

Projectile Type	Projectile			Core		
	Length in (mm)	Diameter in (mm)	Weight gr (g)	Length in (mm)	Diameter in (mm)	Weight gr (g)
0.30-cal. APM2	1.39 (35.3)	0.31 (7.85)	166 (10.8)	1.08 (27.4)	0.24 (6.2)	81 (5.3)
0.50-cal. APM2	2.31 (58.7)	0.51 (12.98)	708 (45.9)	1.87 (47.5)	0.43 (10.9)	400 (25.9)
14.5-mm B32	2.61 (66.3)	0.59 (14.86)	990 (64.1)	2.09 (53.1)	0.49 (12.4)	633 (41.0)
14.5-mm BS41	2.07 (52.6)	0.59 (14.94)	975 (63.2)	1.27 (32.3)	0.43 (10.9)	585 (37.9)

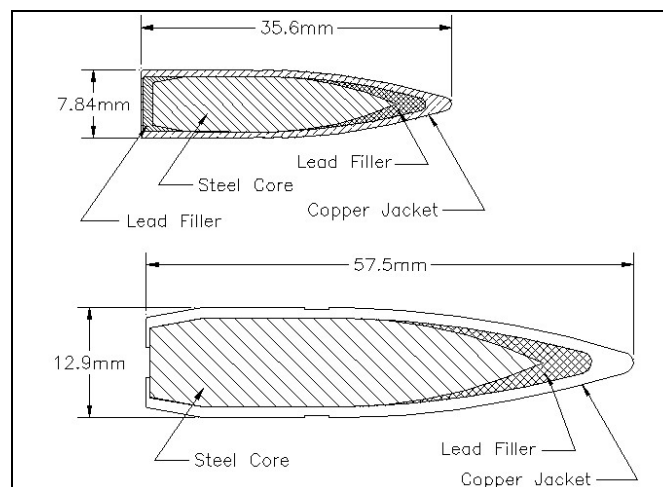


Figure 1. The 0.30-cal. APM2 and 0.50-cal. APM2 test projectiles.

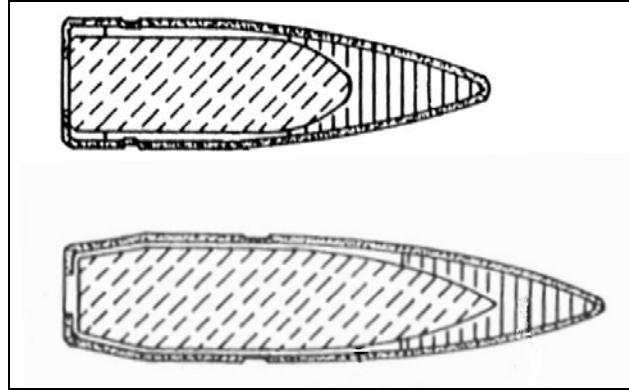


Figure 2. The 14.5-mm BS41 (top) and B32 test projectiles (bottom).

5. Results and Discussion

The V_{50} ballistic limits and standard deviation, σ , for each plate thickness were determined experimentally for the ATI 500-MIL plates; the data is shown in table 5 for each test projectile. Figures 3–6 plot the V_{50} velocities vs. the ATI 500-MIL plate thickness as well as the acceptance velocity specification curve for HHA steel (MIL-DTL-46100E). The ballistic advantage of increased alloying can be seen in figures 3–6 where all the plates exceeded the minimum velocity acceptance velocities of the specification. The differences were significant for the thinner plates and approached the acceptance line as the thickness increased. The solid lines of the acceptance curves for MIL-DTL-46100E incorporate approximately two standard deviations reduction below typical performance, which provides an acceptable variance to allow the high-hard plate to meet the specification.

Table 5. V_{50} plate acceptance results.

Nominal Thickness in (mm)	Projectile	Actual Thickness in (mm)	Obliquity Angle (°)	V_{50} ft/s (m/s)	Standard Deviation ft/s (m/s)
0.1875 (4.8)	0.30-cal. APM2	0.202 (5.1)	30	2174 (663)	43 (13)
0.250 (6.35)	0.30-cal. APM2	0.272 (6.9)	30	2688 (819)	36 (11)
0.3125 (7.94)	0.30-cal. APM2	0.305 (7.7)	30	2672 (814)	40 (12)
0.3125 (7.94)	0.50-cal. APM2	0.305 (7.7)	30	2058 (627)	47 (14)
0.375 (9.53)	0.50-cal. APM2	0.381 (9.7)	30	2373 (723)	43 (13)
0.500 (12.70)	0.50-cal. APM2	0.517 (3.1)	30	2582 (787)	56 (17)
0.625 (15.88)	14.5-mm B32	0.614 (15.6)	30	2396 (730)	43 (13)
0.625 (15.88) ^a	14.5-mm B32	0.607 (15.4)	30	2424 (739)	32 (9)
0.750 (19.05)	14.5-mm B32	0.742 (18.8)	30	2760 (841)	43 (13)
1.000 (25.40)	14.5-mm BS41	0.966 (24.5)	30	2851 (869)	56 (17)

^a Retest.

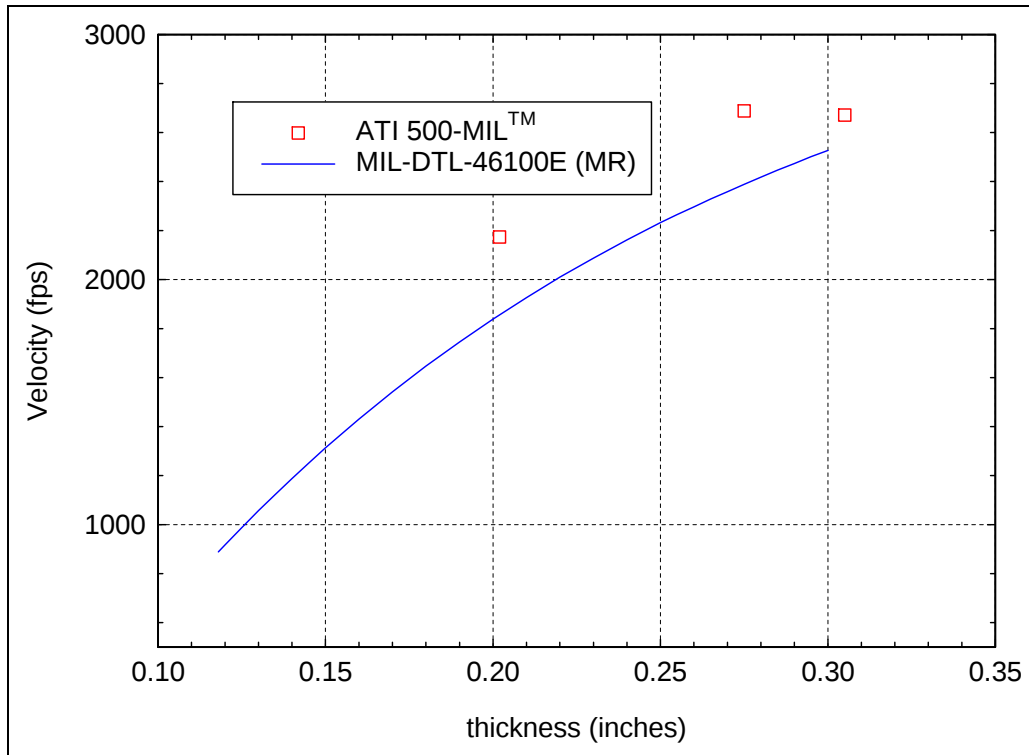


Figure 3. ATI 500-MIL plate thickness vs. V_{50} velocity for the 0.30-cal. APM2 at 30° obliquity.

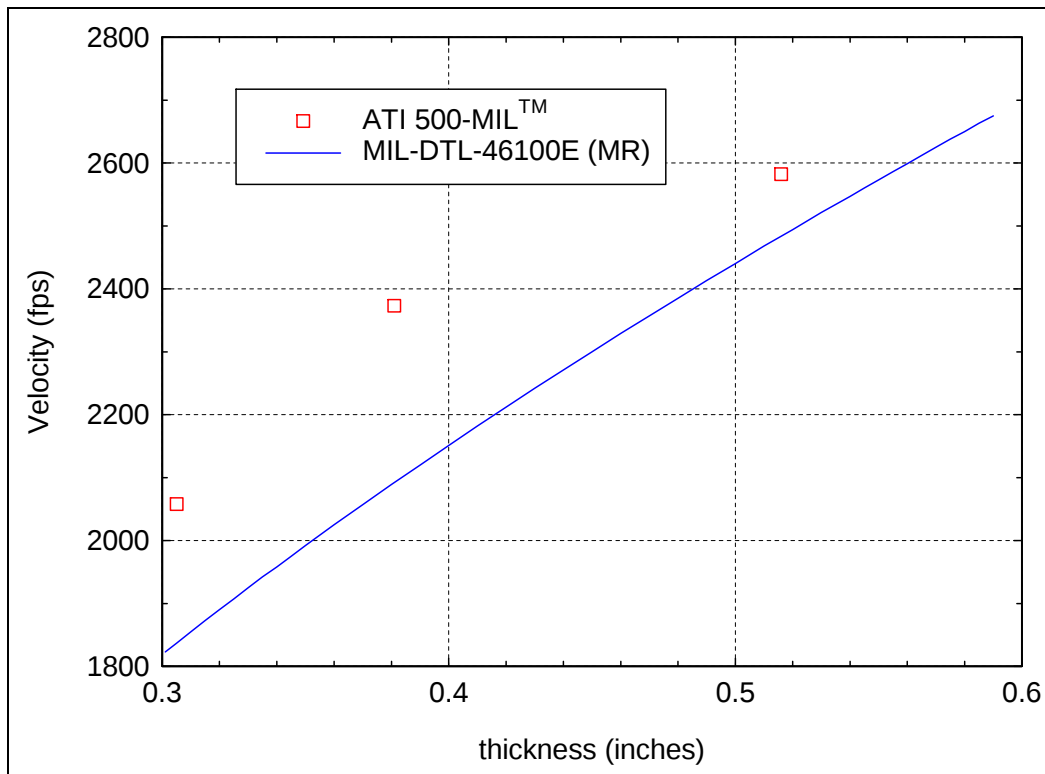


Figure 4. ATI 500-MIL plate thickness vs. V_{50} velocity for the 0.50-cal. APM2 at 30° obliquity.

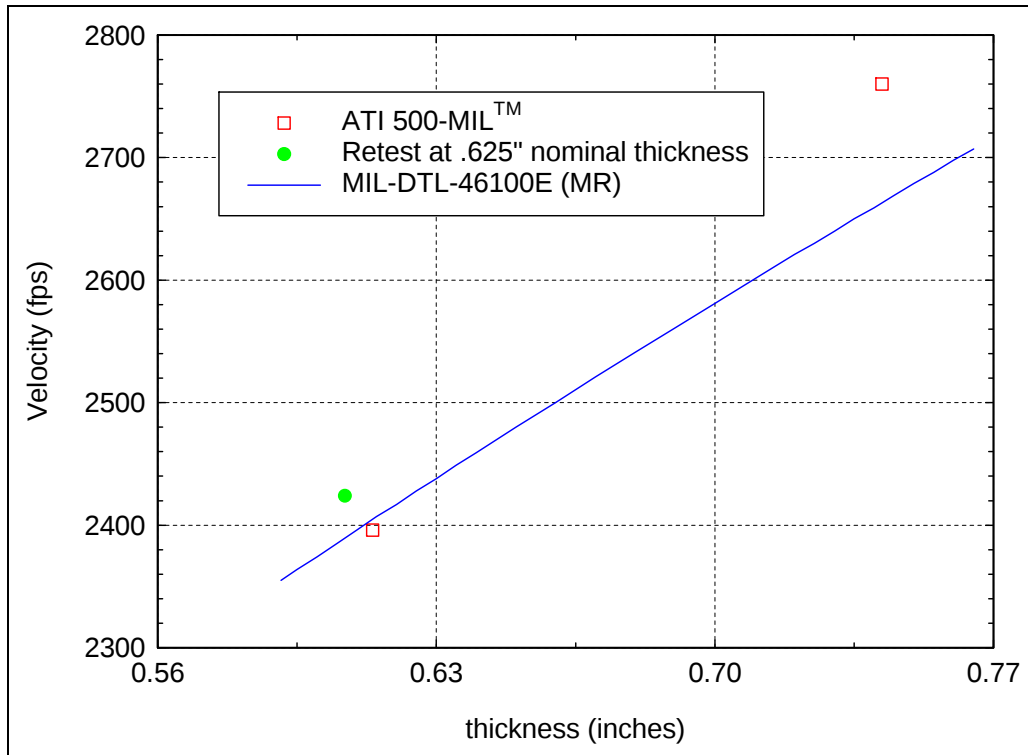


Figure 5. ATI 500-MIL plate thickness vs. V_{50} velocity for the 14.5-mm B32 at 30° obliquity.

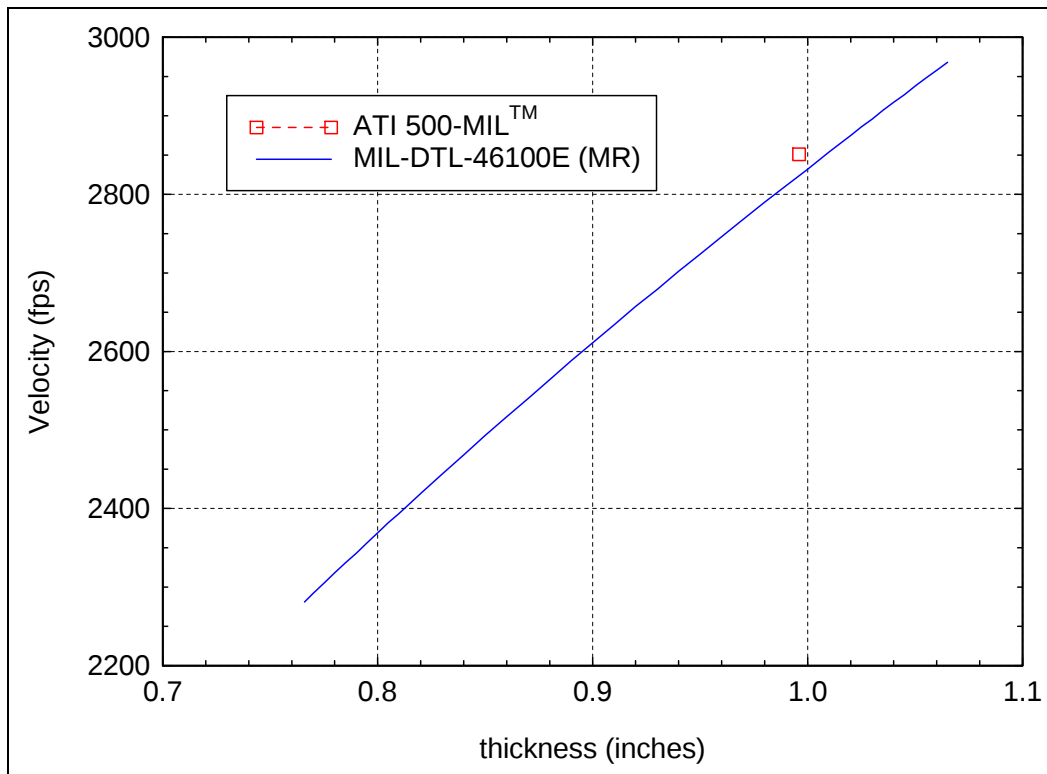


Figure 6. ATI 500-MIL plate thickness vs. V_{50} velocity for the 14.5-mm BS41 at 30° obliquity.

The 0.625-in-thick plate that did not meet the velocity requirement for the first ballistic plate was retested in accordance with the procedures in the specification. The second plate passed by 35 ft/s. The effect of the projectile diameter to the plate thickness may be a contributing factor on possible plug formation for this projectile thickness. At 1-in thickness, the ability to harden the plates by air quenching may be reaching a limit, resulting in the V_{50} velocity approaching the requirement. The armor applications for HHA plates over 0.750 in are limited, and the most important observation is the response of the thinner plates to the ballistic test projectiles. This significant performance is a direct result of the alloying of ATI 500-MIL steel. The first ordered thickness of MIL-DTL-46100E starts at 0.118 in (3 mm); ATI Defense is expected to eventually produce plates between 0.118 and 0.1875 in.

6. Conclusions

This report has documented the ballistic performance of the first Class-2 auto-tempered HHA steel under MIL-DTL-46100E. The increased alloying of ATI 500-MIL steel has resulted in a very tough high hard steel for both blast and ballistic applications. The development and availability of an air-quenched, auto-tempered HHA steel increases the availability of high-hard plate, as traditional water or oil quench and temper facilities are not required. This new class of tough HHA steel plates will increase the metallic armor solutions to armor designers.

Appendix. Shot Data

This appendix appears in its original form, without editorial change.

Plate Type:	ATI 500
Nominal Thickness (mm)	4.8
Nominal Thickness (in)	0.188
Measured Thick. (in)	0.202
BHN	512
Penetrator:	.30 AP M2
Obliquity:	30
Date:	11-Jan-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
6505	1954	596	PP
6506	1985	605	PP
6507	2079	634	PP
6508	2137	652	CP +
6509	2131	650	PP -
6510	2129	649	PP
6511	2160	659	CP -
6512	2166	660	PP -
6513	2242	684	CP +
6514	2209	673	CP +

Low CP	2137
High PP	2166

	(ft/s)	m/s
V50	2174	663
Std Dev	43	13
Vel Spread	111	34
ZMR	29	9

Plate Type:	ATI 500
Nominal Thickness (mm)	6.4
Nominal Thickness (in)	0.250
Measured Thick. (in)	0.272
BHN	532
Penetrator:	.30 AP M2
Obliquity:	30
Date:	15-Jan-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
6523	2352	717	PP
6524	2472	754	PP
6525	2593	791	PP
6526	2635	803	PP -
6527	2679	817	PP -
6528	2790	851	CP
6529	2731	833	CP +
6530	2720	829	CP +
6531	2699	823	CP +
6532	2663	812	PP -

Low CP	2699
High PP	2679

	(ft/s)	m/s
V50	2688	820
Std Dev	36	11
Vel Spread	96	29
ZMR	0	0

Plate Type:	ATI 500
Nominal Thickness (mm)	7.9
Nominal Thickness (in)	0.313
Measured Thick. (in)	0.305
BHN	532
Penetrator:	.30 AP M2
Obliquity:	30
Date:	14-Jan-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
6515	2613	797	PP -
6516	2809	856	CP
6517	2767	844	CP
6518	2698	823	PP -
6519	2718	829	CP +
6520	2690	820	CP +
6521	2677	816	CP +
6522	2633	803	PP -

Low CP	2677
High PP	2698

	(ft/s)	m/s
V50	2672	815
Std Dev	40	12
Vel Spread	105	32
ZMR	21	6

Plate Type:	ATI 500
Nominal Thickness (mm)	7.9
Nominal Thickness (in)	0.313
Measured Thick. (in)	0.305
BHN	532
Penetrator:	.50 AP M2
Obliquity:	30
Date:	7-May-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
6464	1972	601	PP
6465	2179	664	CP
6466	2127	648	CP +
6467	2068	630	CP +
6468	2080	634	CP +
6469	1941	592	PP
6470	1989	606	PP -
6471	2031	619	PP -
6472	2054	626	PP -

Low CP	2068
High PP	2054

	(ft/s)	m/s
V50	2058	627
Std Dev	47	14
Vel Spread	138	42
ZMR	0	0

Plate Type:	ATI 500
Nominal Thickness (mm)	9.5
Nominal Thickness (in)	0.375
Measured Thick. (in)	0.381
BHN	512
Penetrator:	.50 AP M2
Obliquity:	30
Date:	5-Feb-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
6138	2281	695	PP
6139	2477	755	CP
6140	2376	724	CP +
6141	2300	701	PP -
6142	2413	736	CP +
6143	2348	716	PP -
6144	2388	728	PP -
6145	2413	736	CP +

Low CP	2376
High PP	2388

	(ft/s)	m/s
V50	2373	723
Std Dev	43	13
Vel Spread	113	34
ZMR	12	4

Plate Type:	ATI 500
Nominal Thickness (mm)	12.7
Nominal Thickness (in)	0.500
Measured Thick. (in)	0.517
BHN	512
Penetrator:	.50 AP M2
Obliquity:	30
Date:	6-Feb-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
6146	2644	806	CP +
6147	2544	776	CP +
6148	2497	761	PP
6149	2525	770	PP -
6150	2559	780	PP -
6151	2561	781	PP -
6152	2659	811	CP +

Low CP	2544
High PP	2561

	(ft/s)	m/s
V50	2582	787
Std Dev	56	17
Vel Spread	134	41
ZMR	17	5

Plate Type:	ATI 500
Nominal Thickness (mm)	15.9
Nominal Thickness (in)	0.625
Measured Thick. (in)	0.514
BHN	
Penetrator:	14.5mmAPIB32
Obliquity:	30
Date:	12-Mar-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
200825854	2355	718	CP +
200825853	2373	723	PP -
200825852	2438	743	CP +
200825851	2400	732	PP -
200825850	2421	738	CP +
200825849	2472	754	CP

Low CP	2355
High PP	2400

	(ft/s)	m/s
V50	2396	730
Std Dev	43	13
Vel Spread	83	25
ZMR	45	14

Plate Type:	ATI 500
Nominal Thickness (mm)	15.9
Nominal Thickness (in)	0.625
Measured Thick. (in)	0.607
BHN	
Penetrator:	14.5mmAPIB32
Obliquity:	30
Date:	24-Mar-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
200825814	2601	793	CP
200825815	2435	742	CP +
200825816	2371	723	PP -
200825817	2409	734	PP -
200825818	2446	746	CP +
2008258419	2425	739	PP -
2008258420	2461	750	CP +

Low CP	2435
High PP	2425

	(ft/s)	m/s
V50	2424	739
Std Dev	31	9
Vel Spread	90	27
ZMR	0	0

Plate Type:	ATI 500
Nominal Thickness (mm)	19.5
Nominal Thickness (in)	0.750
Measured Thick. (in)	0.742
BHN	
Penetrator:	14.5mmAPIB32
Obliquity:	30
Date:	12-Mar-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
200825861	2810	857	CP +
200825860	2753	839	PP -
200825859	2727	831	PP -
200825858	2796	852	CP +
200825857	2776	846	CP +
200825856	2696	822	PP -

Low CP	2776
High PP	2753

	(ft/s)	m/s
V50	2760	841
Std Dev	43	13
Vel Spread	114	35
ZMR	0	0

Plate Type:	ATI 500
Nominal Thickness (mm)	25.4
Nominal Thickness (in)	1.000
Measured Thick. (in)	0.996
BHN	
Penetrator:	14.5mmAPIB32
Obliquity:	30
Date:	13-Mar-08

Shot #	Velocity (ft/s)	Velocity (m/s)	Result
200825956	2924	891	PP -
200825957	2924	891	CP
200825958	2937	895	CP
200825959	2901	884	CP
200825960	2901	884	CP +
200825961	2871	875	CP +
200825962	2819	859	PP -
200825963	2798	853	CP +
200825964	2793	852	PP -

Low CP	2798
High PP	2924

	(ft/s)	m/s
V50	2851	869
Std Dev	55	17
Vel Spread	131	40
ZMR	126	38

NO. OF
COPIES ORGANIZATION

1 DEFENSE TECHNICAL
 (PDF INFORMATION CTR
 only) DTIC OCA
 8725 JOHN J KINGMAN RD
 STE 0944
 FORT BELVOIR VA 22060-6218

1 DIRECTOR
 US ARMY RESEARCH LAB
 IMNE ALC HRR
 2800 POWDER MILL RD
 ADELPHI MD 20783-1197

1 DIRECTOR
 US ARMY RESEARCH LAB
 RDRL CIM L
 2800 POWDER MILL RD
 ADELPHI MD 20783-1197

1 DIRECTOR
 US ARMY RESEARCH LAB
 RDRL CIM P
 2800 POWDER MILL RD
 ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

1 DIR USARL
 RDRL CIM G (BLDG 4600)

NO. OF
COPIES ORGANIZATION

3	CDR US ARMY TACOM AMSTA TR S T FURMANIAK L FRANKS D TEMPLETON MS 263 WARREN MI 48397-5000
1	CDR US ARMY TACOM AMSTA TR R D HANSEN WARREN MI 48397-5000
1	PM SFAE GCSS HBCTS J ROWE MS 325 WARREN MI 48397-5000
2	US ARMY RSRCH DEV & ENGRG CTR AMSRD NSC IPD B P CUNNIFF J WARD KANSAS ST NATICK MA 01760-5019
5	NATL GROUND INTLLGNC CTR D EPPERLY T SHAVER T WATERBURY W GSTATTENBAUER D DOBROWLSKI 2055 BOULDERS RD CHARLOTTESVILLE VA 22091-5391
2	PM MRAP J PEREZ (JPO) E BARSHAW SFAE CSS MRE MS 298 6501 E 11 MILE RD BLDG 229 WAREN MI 48397-5000
1	PM BFVS ATTN SFAE GCSS W BV S M KING WARREN MI 48397-5000
1	SANDIA NATL LAB D CRAWFORD MS 0836 9116 PO BOX 5800 ALBUQUERQUE NM 87185-0307

NO. OF
COPIES ORGANIZATION

1	NVL SURFC WARFARE CTR NSWC CARDEROCK DIV R PETERSON CODE 2810 9500 MACARTHUR BLVD WEST BETHESDA MD 20817-5700
2	LAWRENCE LIVERMORE NATL LAB R LANDINGHAM L372 J REAUGH L282 PO BOX 808 LIVERMORE CA 94550
2	LOS ALAMOS NATL LAB F ADDESSIO M BURKETT PO BOX 1663 LOS ALAMOS NM 87545
1	THE AIR FORCE RSRCH LAB AFRL/MLLMP T TURNER BLDG 655 RM 115 2230 TENTH ST WRIGHT-PATTERSON AFB OH 45433-7817
1	AIR FORCE ARMAMENT LAB AFATL DLJW W COOK EGLIN AFB FL 32542
4	UNIV OF TEXAS INST FOR ADVNCD TECH S BLESS H FAIR J HODGE R SUBRAMANIAN 3925 W BRAKER LN AUSTIN TX 78759-5316
1	UNIV OF DAYTON RSRCH INST N BRAR KLA 14 300 COLLEGE PARK DAYTON OH 45469-0182
2	SOUTHWEST RSRCH INST C ANDERSON J WALKER 6220 CULEBRA RD SAN ANTONIO TX 78238

NO. OF
COPIES ORGANIZATION

3 US DEPT OF ENERGY
NETL
J HANSEN
P TURNER
P KING
1450 QUEEN AVE SW
ALBANY OR 97321-2198

1 ALCAN ROLLED PRODUCTS
J OFFER
39111 W SIX MILE RD
STE 173
LIVONIA MI 48152

1 ALCOA
R KANE
4879 STATE ST
PO BOX 8025
BETTENDORF IA 52722-8025

1 ALCOA DEFENSE
R HEIPLE
100 TECHNICAL DR
ALCOA CENTER PA 15069-0001

2 ALLVAC OREMET FACLTY
J KOSIN
B MAHONEY
530 34TH AVE SW
PO BOX 460
ALBANY OR 97321

2 AM GENERAL
S GRATE
J RITTER
12200 HUBBARD RD
PO BOX3330
LIVONIA MI 48151-3330

1 ARMORWORKS
W PERCIBALLI
305 N 54TH ST
CHANDLER AZ 85226

2 ARCELOR MITTAL STEEL USA
T DEAN
J BABICH
139 MODENA RD
PO BOX 3001
COATESVILLE PA 19320-0911

NO. OF
COPIES ORGANIZATION

2 ATI ALLEGHENY LUDLUM
R BAILEY
G SWIATEK
500 GREEN ST
WASHINGTON PA 15301

1 ATI DEFENSE
A NICHOLS
500 GREEN ST
WASHINGTON PA 15301

1 ATI DEFENSE
L MARTIN
1600 OLD SALEM RD NE
ALBANY OR 97321-0460

1 ALLEGHENY TECHNOLOGIES
J OGILVY
20370 HOLLYWOOD
HARPER WOODS MI 48225

1 BROWN UNIV
DIV OF ENGRG
R CLIFTON
PROVIDENCE RI 02912

3 BAE LAND COMBAT SYS
B KARIYA
M MIDDIONE
D SCHADE
1205 COLEMAN AVE
SANTA CLARA CA 95050

4 BAE SECURITY AND SURVIVABILITY
M REYNOLDS
M BOCZAK
T RUSSELL
M BERNING
9113 LE SAINT DR
FAIRFIELD OH 45014

2 BAE ADVANCED CERAMICS
R PALICKA
G NELSON
991 PARK CTR DR
VISTA CA 92083-7933

1 BAE SYSTEMS STEEL PRODUCTS
J DORSCH
2101 W 10TH ST
ANNISTON AL 36201

NO. OF
COPIES ORGANIZATION

2 BAE LAND COMBAT SYSTEMS
E BRADY
R JENKINS
1100 BAIRS RD
YORK PA 17405-1512

1 UNITED DEFNS LIMITED
PARTNERS GROUND SYS DIV
K STRITTMATTER
PO BOX 15512
YORK PA 17405-1512

2 BAE SECURITY AND SURVIVABILITY
R MONKS
V KELSEY
7822 S 46TH ST
PHOENIX ARIZONA 85044

1 CARPENTERSTEEL
P THOMPSON
PO BOX 14662
READING PA 19612-4662

2 CERADYNE INC
M KING
M NORMANDIA
3169 RED HILL AVE
COSTA MESA CA 92626

1 CLIFTON STEEL COMPANY
J SOMOGYI
16500 ROCKSIDE RD
MAPLE HTS OH 44137

1 COMMERCIAL METALS CORP
G BREVADA
6565 N MACARTHUR BLVD
IRVING TX 75039

1 CONCURRENT TECHNOLOGIES
J PICKENS
100 CTC DR
JOHNSTOWN PA 15904-1935

1 CYPRESS INTERNATIONAL
R ASOKLIS
47345 FEATHERED CT
SHELBY TOWNSHIP MI 48315

1 DAMILER TRUCKS NA LLC
R ENGEL
2477 DEERFIELD DR
FORT MILL SC 29715

NO. OF
COPIES ORGANIZATION

1 DYNACORP
W SNOWDEN
4001 FAIRFAX DR
ARLINGTON VA 22203-1615

1 HARDWIRE LLC
G TUNIS
1000 QUINN AVE
POCOMOKE CITY MD 21851

1 INTERNATL RSRCH ASSN
D ORPHAL
4450 BLACK AVE
PLEASANTON CA 94566

1 IDEAL INNOVATIONS INC
R KOCHER
4601 N FAIRFAX ST
STE 1130
ARLINGTON VA 22203

4 GDLS
W BURKE MZ436 21 24
G CAMPBELL MZ436 30 44
J ERIDON MZ436 21 24
W HERMAN MZ435 01 24
38500 MOUND RD
STERLING HTS MI 48310-3200

1 KAIROS PARTNERS INC
D AKERS
PO BOX 3629
CHESTER VA 23831-3629

1 KAISER ALUMINUM
J SANDERSON
27422 PORTOLA PKWY
STE 350
FOOTHILL RANCH CA 92610-0892

1 MAGNESIUM ELEKTRON NA
R DELORME
1001 COLLEGE ST
PO BOX 258
MADISON IL 62060

1 INDUSTEEL USA LLC
B HOLCOME
1631 SENDWAY
LUTZ FL 33549

NO. OF
COPIES ORGANIZATION

1 INDUSTEEL USA LLC
R GARVIN
139 MODERNA RD
COATESVILLE PA 19320

1 FORCE PROTECTION INDUST INC
V JOYNT
9801 HWY 78
LADSON SC 29456

1 MISTRAL
E BANAI
7910 WOODMONT AVE
STE 820
BETHESDA MD 20814

1 NEW LENOX ORDNANCE
A SENIW
1200 E MAZON AVE
BOX 188
DWIGHT IL 60420

1 EVRAZ OREGON STEEL
J ROSMUS
14400 N RIVERGATE BLVD
PORTLAND OR 97203

2 OSHKOSH DEFENSE
D PELCO
M IVEY
370 W WAUKAU
PO BOX 2566
OSHKOSH WI 54903-2566

1 FOSTER-MILLER
R SYKES
195 BEAR HILL RD
WALTHAM MA 02451

1 RMI TITANIUM CO
W PALLANTE
PO BOX 269
1000 WARREN AVE
NILES OH 44446

2 SOUTHWEST RSRCH INST
T HOLMQUIST
G JOHNSON
5353 WAYZATA BLVD STE 607
MINNEAPOLIS MN 55416

NO. OF
COPIES ORGANIZATION

1 STEEL WAREHOUSE
G AUBUCHON
2722 W TUCKER DR
SOUTH BEND IN 46619

1 STEEL WAREHOUSE
J CLARK
4066 SR 500
PAYNE OH 45880

2 TENCATE ADVANCED COMPOSITES
D PUCKETT
E SIEFFERT
18410 BUTTERFIELD RD
MORGAN HILL CA 95037

2 TIMET
J FANNING
S FOX
PO BOX 2128
HENDERSON NV 89009

1 TIMET
M GUSTIN
224 VALLEY CREEK BLVD
EXTON PA 19341

2 UNIV OF CA SAN DIEGO
DEPT OF APPL MECH & ENGR
SVC RO11
S NEMAT NASSER
M MEYERS
LA JOLLA CA 92093-0411

ABERDEEN PROVING GROUND

1 DIR USAMSAA
AMSRD AMS D
BLDG 392

1 CDR USATEC
STEAC LI LV
E SANDERSON
BLDG 400

1 CDR US ARMY DTC
CSTE DTC TT T
M SIMON
RYAN BLDG

NO. OF
COPIES ORGANIZATION

73 DIR USARL
RDRL SL
R COATES
RDRL SLB
BOWEN
RDRL WM
J MCCAULEY
RDRL WMB
J NEWILL
RDRL WMM B
R BANTON
R GUPTA
R CARTER
L KECSKES
S MATHAUDHU
D SNOHA
RDRL WMM
R DOWDING
J BEATTY
RDRL WMM C
R SQUILLACIOTI
W ROY
RDRL WMM D
E CHIN
B CHEESEMAN
J CHINELLA
K CHO
G GAZONAS
J LASALVIA
P PATEL
J MONTGOMERY
J SANDS
S WALSH
RDRL WMM S
T JONES
RDRL WMT
C HOPPEL
RDRL WMT A
A BARD
P BARTKOWSKI
S BARTUS
M BURKINS
R DONEY
M DUFFY
D GALLARDY
W GOOCH
D HACKBARTH
T HAVEL
V HERNANDEZ
E HORWATH
S HUG

NO. OF
COPIES ORGANIZATION

M KEELE
D KLEPONIS
C KRAUTHAUSER
B LEAVY
M LOVE
H MEYER
J RUNYEON
B SCOTT
D SHOWALTER
K STOFFEL
S SCHOENFELD
RDRL WMT C
T BJERKE
T FARRAND
K KIMSEY
L MAGNESS
S SEGLETES
D SCHEFFLER
S SCHRAML
R SUMMERS
W WALTERS
RDRL WMT D
S BILYK
D CASEM
J CLAYTON
D DANDEKAR
N GNIAZDOWSKI
M GREENFIELD
Y HUANG
B LOVE
M RAFTENBERG
E RAPACKI
M SCHEIDLER
T WEERASOORIYA
RDRL WMT E
C HUMMER
B RINGERS

NO. OF
COPIES ORGANIZATION

1 ALCOA EUROPE
G BEVAN
PO BOX 383
KITTS GREEN RD KITTS GREEN
BIRMINGHAM B33 9QR
UNITED KINGDOM

1 ALCOA EUROPE
A ARMIGLIATO
ALCOA TRASFROMAZIONI
VIA DELL'ELETTRONICA 31
30030 FUSINA (VENEZIA)
ITALY

3 ARCELOR MITTAL
INDUSTEEL CREUSOT
E DERASSAT
S CORRE
D HERITIER
56 RUE CLEMENCEAU
BP 19
71201 LE CREUSOT CEDEX
FRANCE

2 ARMOR AUSTRALIA
A FAIRBAIRN
H OLDFIELD
2/461 THE BOULEVARDE
KIRRAWEE NSW 2232
AUSTRALIA

3 BAE SYSTEMS HÄGGLUNDS AB
T GUSTAFSSON
L PETTERSSON
A BERGKVIST
SE-891 82 ÖRNSKÖLDSVIK
SWEDEN

2 BISALLOYS STEELS PTY LTD
W PANG
R BARNETT
18 RESOLUTION DR
PO BOX 1246
UNANDERRA NSW 2526 AUSTRALIA

1 BLUESCOPE STEEL LTD
J DRYDEN
PO BOX 1854
WOLLONGONG NSW 2500
AUSTRALIA

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COPIES ORGANIZATION

1 CARLOS III UNIV OF MADRID
C NAVARRO
ESCUELA POLTEENICA SUPERIOR
C/BUTARQUE 15
28911 LEGANES MADRID
SPAIN

1 CONDAT PROJEKT GMBH
J KIERMEIR
MAXIMILIANSTR 28
SCHEYERN 85298
GERMANY

2 DSTO
MARITIME PLATFORMS DIV
S CIMPOERU
S ALKEMADE
506 LORIMER ST
FISHERMANS BEND
VIC 3207 AUSTRALIA

2 DSTO
WEAPONS SYSTEMS DIV
N BURMAN
J ANDERSON
PO BOX 1500
EDINBURGH SA 5111
AUSTRALIA

2 DEFENSE RESEARCH AGENCY
B JAMES
B SHRUBSALL
PORTON DOWN
SALISBURY WTTTS SP04 OJQ
UNITED KINGDOM

1 DEFENCE RESEARCH AND
DEVELOPMENT-VALCARTIER
R DELAGRAVE
2459 PIE XI NORTH
VAL-BELAIR QC G3J 1X5
CANADA

1 DEUTSCH FRANZOSISCHES
FORSCHUNGSINSTITUT ST LOUIS
CEDEX 5 RUE DU
GENERAL CASSAGNOU
F 68301 SAINT LOUIS
FRANCE

NO. OF
COPIES ORGANIZATION

2 ETBS DGA
P BARNIER
M SALLES
ROUTE DE GUERAY
BOITE POSTALE 712
18015 BOURGES CEDEX
FRANCE

3 FRANHOFFER INSTITUT FUR
KURZZEITDYNAMIK
ERNST MACH INSTITUT
E STRASSBURGER
K THOMA
M WICKERT
ECKERSTRASSE 4
D 79 104 FREIBURG
GERMANY

2 GD LAND SYSTEMS CANADA
P GALLAGHER
K BENARD
PO BOX 7003
LONDON ONTARIO N5Y 6L8
CANADA

1 INDUSTRIE BITOSS
R ROVAI
VAI PIETRAMARINA 53
I-50053 SOVIGLIANA-VINCI
ITALY

1 INGENIEURBURO DEISENROTH
F DEISENROTH
AUF DE HARDT 33 35
D 5204 LOHMAR 1
GERMANY

3 INST FOR PROBLEMS IN MATLS SCI
B GALANOV
V KARTUZOV
Y MILMAN
3 KRHYZHANOVSKY STR
252142 KIEV 142
UKRAINE

1 MOFET ETZION
M COHEN
KFAR ETZION
MP NORTH JEDEA 90912
ISRAEL

NO. OF
COPIES ORGANIZATION

2 NORDMETALL GBR
L MEYERS
S ABDEL-MALEK
EIBENBERG
EINSIEDLER STGR 18H
D 09235 BURKHARDSDORF
GERMANY

1 NATL DEFENCE HDQRTRS
PMO LAV A HODAK
OTTOWA ONTARIO KIA OK2
CANADA

1 RAFAEL
D YAZIV
PO BOX 2250
HAIFA 31021
ISRAEL

1 ROYAL NETHERLANDS ARMY
JHOENEVELD
V D BURCHLAAN 31
PO BOX 90822
2509 LS THE HAGUE
NETHERLANDS

1 RIMAT
M RAVID
8B SIMTAT HAYEREK
HOD HASHARON 45264
ISRAEL

2 RUKKI
V-M MANNER
J ASUNMAA
RAUTARUUKINTIE 155
PO BOX 93
FI 92101 FAAHE
FINLAND

2 DEFENCE MATERIEL ADMIN
WEAPONS DIRECTORATE
A BERG
R LINSTRÖM
S 11588 STOCKHOLM
SWEDEN

1 SECRAB
B JANZON
PO BOX 97
SE-147 22 TUMBA
SWEDEN

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COPIES ORGANIZATION

- 1 SSAB SWEDISH STEEL LTD
C NASH
DE SALIS CT DE SAILS DR
HAMPTON LOVETT DROITWICH
WORCESTERSHIRE WR9 OQE
UNITED KINGDOM
- 1 SSAB OXELÖSUND AB
ARMOR PLATE MANAGER
SE-613 80 OXELÖSUND
SWEDEN
- 4 SWEDISH FOI
P LUNDBERG
J OTTOSSON
E LIDEN
L WESTERLING
SE-147 25 TUMBA
SWEDEN
- 2 THYSSENKRUPP STEEL
H-J KAISER
S SCHARF
MANNESMANNSTRASSE GATE 9
47259 DUISBURG
GERMANY
- 2 TNO DEFENCE SECURITY & SAFETY
A DIEDEREN
F T M VAN WEGEN
LANGE KLEIWEG 137
PO BOX45
2280 AA RIJSWIJK
THE NETHERLANDS
- 1 TDW EADS
M HELD
PO BOX 1340
SCHROBENHAUSEN D 86523
GERMANY