ARMY RESEARCH LABORATORY

Measurement of V_{50} Behavior of a Nylon 6-Based Polymer-Layered Silicate Nanocomposite

by David Ostermayer, Frederick L. Beyer, Peter G. Dehmer, and Melissa A. Klusewitz

ARL-TR-2605 September 2001

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-2605 **September 2001**

Measurement of V_{50} Behavior of a Nylon 6-Based Polymer-Layered Silicate Nanocomposite

David Ostermayer
University of Delaware

Frederick L. Beyer, Peter G. Dehmer, and
Melissa A. Klusewitz
Weapons and Materials Research Directorate, ARL

Abstract

The performance under ballistic impact conditions of a nylon 6-based polymer-layered silicate (PLS) nanocomposite was examined using a V_{50} test. The commercially available nanocomposites contained approximately 2.5-wt.% montmorillonite clay mineral and were fabricated by *in situ* polymerization of ε-caprolactam in the presence of an organosilicate clay mineral. The velocity at which 50% of 0.22-cal. fragment simulator projectiles penetrated the unmodified nylon 6 and 0.5-mm aluminum witness plate (V_{50}) was determined to be 436 ft/s. The PLS nanocomposite nylon 6-clay hybrid was found to have a V_{50} of 338 ft/s. Therefore, it was found that the addition of the layered silicate clay mineral filler did not improve the impact properties of nylon 6 under these conditions.

Acknowledgments

The authors would like to thank Dr. Dana Granville of the U.S. Army Research Laboratory (ARL) and Mr. Anand Thadani of the University of Massachusetts Lowell Department of Plastics for their assistance with the fabrication of plaques.

INTENTIONALLY LEFT BLANK.

Contents

INTENTIONALLY LEFT BLANK.

1. Introduction

In 1987, researchers at Toyota Central Research and Development in Japan began patenting and later publishing in the open literature research detailing work done with a novel, polymer-based composite system comprised of nylon 6 and layered silicate clay minerals including montmorillonite [1–9]. This material was found to have significantly improved mechanical properties, barrier properties, and thermal properties, which make it a candidate material for Army applications requiring a high performance, lightweight material.

The Toyota material is the prototypical polymer-layered silicate (PLS) nanocomposite system. PLS nanocomposites are composite materials having a polymer matrix with a layered silicate clay mineral filler which usually totals no more than 5 wt.% of the final product [10]. The Toyota material is filled with 2.5-wt.% montmorillonite, a 2:1 layered silicate clay mineral similar to mica and talc [11]. Montmorillonite is comprised of individual silicate layers 1 nm in thickness and on the order of 1 µm in the lateral dimension. These silicate layers stack together to form clay particles called tactoids, with the gaps between individual layers called galleries [11, 12]. The individual silicate layers are crystalline and are comprised of three sublayers—a layer of aluminum hydroxide octahedra edge shared with two layers of silicon hydroxide tetrahedra (see Figure 1). Isomorphous substitution of magnesium for aluminum and aluminum for silicon in the crystal structure leads to a net charge within the layers, which is balanced by the presence of hydrated cations in the galleries. Sodium, calcium, potassium, and lithium are common interlayer cations.

Cation exchange reactions are often used to replace these naturally occurring cations with alkylammonium cations, which facilitate the penetration of polymer into the silicate galleries. It has been shown empirically that modification of the clay mineral with an organic surfactant facilitates the formation of an exfoliated morphology, which is critical to achieving substantial improvements in physical properties.

Kojima et al. [8] reported dramatic improvements in the mechanical, thermal, and barrier properties of nylon 6 after modification of the polymer with 4.7 wt.% montmorillonite. These included a 91% increase in the tensile modulus, a 55% increase in tensile strength, and an increase of 80 °C in the heat distortion temperature. Impact strengths have been reported to be improved, but over all have been found to be decreased [8, 10]. The Toyota researchers also collected data indicating that the nylon 6-hybrid material had decreased permeability. Their work showed a 37% decrease in the water adsorption characteristics of

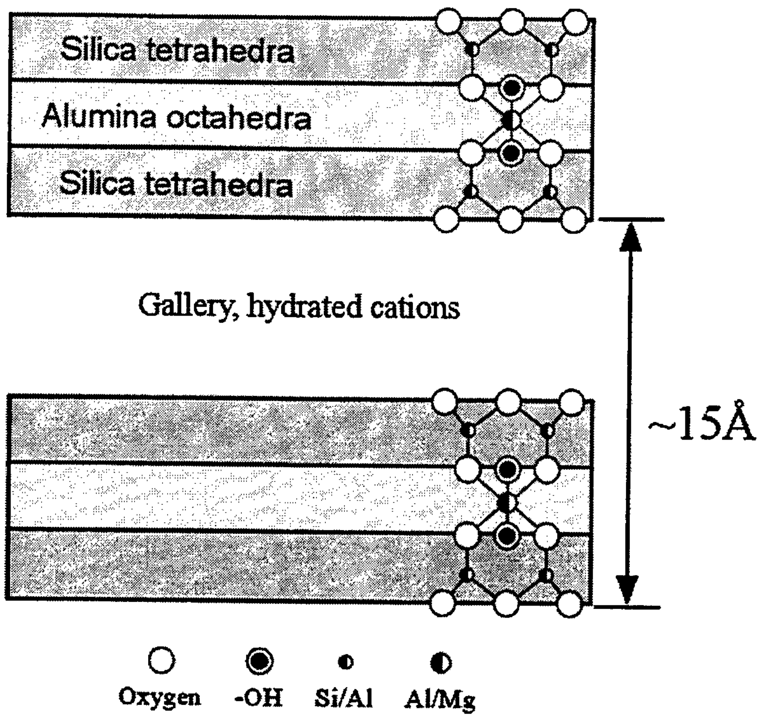

Figure 1. Illustration of two crystalline silicate layers of montmorillonite with interlayer gallery of approximately 5 Å.

nylon 6 as well as improvements in other systems [9, 13]. Additionally, more recent work on this class of materials indicates that the formation of a nanocomposite significantly improves the ablative properties of the material [14, 15].

As a result, it is anticipated that a PLS nanocomposite system based on montmorillonite and nylon 6 would be a good candidate material for certain U.S. Army applications. The improved mechanical properties suggested that the ballistic properties of the modified clay might be noteworthy. Other characteristics, such as the decreased permeability and improved ablative properties, may allow the nanocomposite material to be used for multiple purposes including chemical and biological threat protection applications. Enhanced thermal stability has already been proven to allow use of these materials in automotive applications including gasoline tanks, oil tanks, air ducts, and intake manifolds, cylinder head covers, timing belt covers, power steering, and fluid reservoirs [2, 4].

For the purpose of establishing an initial estimate of the behavior of PLS nanocomposites in lightweight armor applications, a set of tests to determine the V_{50} of the unmodified nylon 6 and PLS nanocomposite based on nylon 6 were undertaken. These tests approximately followed the MIL-STD-622F [16] standard for determining this property.

2. Experimental

Unmodified nylon 6 and the nylon 6-based PLS nanocomposite materials were obtained from the UBE-Hanna Compounding Company, LLC, New York, NY. The materials are designated by UBE as 1015B for the unmodified nylon 6 and 1015C2 for the PLS nanocomposite and are nearly identical in composition and fabrication to those used by Kojima et al. [8, 17] and Usuki et al. [18]. The hybrid material is produced by the *in situ* polymerization of ε-caprolactam containing approximately 2.5-wt.% montmorillonite which has been modified with alkylammonium cation surfactants based on amino carboxylic acid.

Fabrication of plaques suitable for ballistics tests were fabricated using an HPM 90-ton injection molder. Both materials were dried 4 hr at 74 °C. Barrel temperatures ranged between 440 °F and 500 °F, with the nozzle temperature being the highest. Injection velocity was 2 in/s at 1000 psi, while the mold temperature was held between 150 °F and 180 °F. Plaques produced in this manner were approximately 3.44 in wide, 6.79 in long, and 1/8 in thick. After several weeks' storage in an atmosphere of approximately 50% relative humidity, the areal density of the unfilled nylon was determined to be 2.9 mg/mm^2, while the nanocomposite was found to have an areal density of 3.0 mg/mm^2.

Ballistic tests were performed following Department of Defense standard MIL-STD-622F [16]. In these tests, 0.22-cal., 1.1-g fragment simulator projectiles (FSP) were propelled at the target using a helium-pressurized gas gun described elsewhere [19, 20]. Projectile velocities were determined by recording the time differential between the penetration of two pieces of silver grid paper using an electronic chronograph. Impacts were made at zero degrees obliquity, and the extent of penetration of the projectile was determined by visual inspection of a witness plate located 6 in behind the target. A calculation of the V_{50} velocity was made after an equal number of complete and partial penetrations of the target were recorded in the same velocity range.

To determine average water content, thermogravimetric analysis (TGA) was performed using a TA Instruments 2950 Thermogravimetric Analyzer. Samples were brought to 110 °C and held isothermally for 240 min. Water content was determined directly from equilibrium weight loss. Clay content was also determined by TGA, where a sample of the hybrid material was heated to complete decomposition of the organic phase.

3. Results

Visual inspection of plaques manufactured from both the unmodified nylon 6 and nylon 6-based PLS nanocomposite clearly revealed that the two materials were not equally processible. While both materials were predried under the same conditions, the unmodified nylon 6 formed plaques of low quality; voids were visually evident and numerous in the unmodified material. The majority of plaques manufactured from the nylon 6-based PLS nanocomposite were of better quality with fewer voids. This was contrary to expectations based on the effect on gas permeation in PLS nanocomposites, but may be attributed to the thixotropic nature of smectite clays.

TGA results from both materials indicate slight water adsorption. The unmodified nylon 6 was found to have 1.9% water by weight. The PLS nanocomposite material was found to contain 2.1% water by weight. The total weight-percent of clay mineral in the hybrid material was indeterminate. TGA results indicated that approximately 3.8 wt.% of the hybrid material was inorganic, whereas 1.9 wt.% of the unmodified nylon 6 was inorganic. This suggests that approximately 2% of the hybrid material was layered silicate.

The results of the ballistics testing are listed in Table 1. The unmodified material was found to have a higher V_{50}, 436 ft/s, than the nanocomposite material, which was found to have a V_{50} of 338 ft/s. Both samples displayed significant spalling and radial fracture.

Table 1. Ballistics properties of nylon 6 and a nylon 6-based PLS nanocomposite.

Sample	V_{50} (ft/s)	8 Shot Spread (ft/s)
1015B (nylon 6)	436	10
1015C2 (hybrid)	338	12

4. Discussion

The lower V_{50} of the modified nylon 6 is consistent with the physical characteristics of the plaques observed during sample preparation. The modified system appeared to be more brittle than the unmodified nylon 6. This result is not inconsistent with the impact behavior of the clay hybrid reported in the literature; while some references described the modified material as having better impact resistance, most show decreased toughness consistent with the behavior observed here. The observed spalling is also an undesirable behavior because fragments of an armor material can be as dangerous as a projectile; a ductile response to penetration would be preferable.

5. Conclusions

V_{50} tests were performed on commercially available nylon 6 and nylon 6-based PLS nanocomposite materials. The data showed a decrease by 22% in the velocity required for 50% penetration of a 0.22-cal. fragment projectile on a witness plate, according to testing standard MIL-STD-622F [16]. These results are consistent with the observed toughnesses of the two materials and toughness data reported in the literature.

INTENTIONALLY LEFT BLANK.

6. References

1. Toyota Central Research & Development Laboratories (Toyw). "Composite Resin-Based Material—Manufactured by Polymerizing Monomer Containing Dispersed Layer-Silicate Which Has Been Ion-Exchanged With Onium Salt Containing Polymer-Forming Groups." Patent US4889885-A, United States, 1989.

2 Toyota Central Research & Development Laboratories (Toyw). "Automobile Parts Used in Engine Compartment—With No Warpage and High Rigidity at High Temperatures, Manufactured From Compositions of Polyamide Resin, Lamellar Silicate and Fibrous Reinforcing Material." Patent JP02240160-A, Japan, 1990.

3. Toyota Central Research & Development Laboratories (Toyw). "Heat and Weather Resistant Car Interior Part Material—Comprises Polyamide Resin Containing Uniformly Dispersed Lamellar Silicate." Patent JP02208357-A, Japan, 1990.

4. Toyota Central Research & Development Laboratories (Toyw). "Hollow Polyamide Moulding Material—Comprises Polyamide Resin and Silicate of Layered Structure, Used for Oil Tank, Drinking Water Bottles Etc." Patent JP03024155-A, Japan, 1991.

5. Usuki, A., Y. Kojima, M. Kawasumi, A. Okada, Y. Fukushima, T. Kurauchi, and O. Kamigaito. "Synthesis of Nylon 6-Clay Hybrid." *Journal of Materials Research*, vol. 8, pp. 1179–1184, 1993.

6. Kojima, Y., A. Usuki, M. Kawasumi, A. Okada, T. Kurauchi, and O. Kamigaito. "Synthesis of Nylon-6-Clay Hybrid By Montmorillonite Intercalated With ε-Caprolactam." *Journal of Polymer Science, Part A: Polymer Chemistry*, vol. 31, pp. 983–986, 1993.

7. Kojima, Y., A. Usuki, M. Kawasumi, A. Okada, T. Kurauchi, and O. Kamigaito. "One-Pot Synthesis of Nylon-6 Clay Hybrid." *Journal of Polymer Science, Part A: Polymer Chemistry*, vol. 31, pp. 1755–1758, 1993.

8. Kojima, Y., A. Usuki, M. Kawasumi, A. Okada, Y. Fukushima, T. Kurauchi, and O. Kamigaito. "Mechanical-Properties of Nylon 6-Clay Hybrid." *Journal of Materials Research*, vol. 8, pp. 1185–1189, 1993.

9. Kojima, Y., K. Fukumori, A. Usuki, A. Okada, and T. Kurauchi. "Gas Permeabilities in Rubber Clay Hybrid." *Journal of Materials Science Letters*, vol. 12, pp. 889–890, 1993.

10. Giannelis, E. P. "Polymer Layered Silicate Nanocomposites." *Advanced Materials*, vol. 8, pp. 29–35, 1996.

11. Grim, R. E. *Clay Mineralogy*. New York: McGraw-Hill, 1968.

12. Moore, D. M., and R. C. Reynolds, Jr. *X-ray Diffraction and the Identification and Analysis of Clay Minerals*. Second ed., New York: Oxford University Press, 1997.

13. Kojima, Y., A. Usuki, M. Kawasumi, A. Okada, T. Kurauchi, and O. Kamigaito. "Sorption of Water in Nylon-6 Clay Hybrid." *Journal of Applied Polymer Science*, vol. 49, pp. 1259–1264, 1993.

14. Vaia, R. A., G. Price, P. N. Ruth, H. T. Nguyen, and J. Lichtenhan. "Polymer/Layered Silicate Nanocomposites as High Performance Ablative Materials." *Applied Clay Science*, vol. 15, pp. 67–92, 1999.

15. Gilman, J. W., T. Kashiwagi, and J. D. Lichtenhan. "Nanocomposites: A Revolutionary New Flame Retardant Approach." *Sampe Journal*, vol. 33, pp. 40–46, 1997.

16. Department of Defense. "V50 Ballistic Test for Armor." MIL-STD-622F, Aberdeen Proving Ground, MD, 1997.

17. Kojima, Y., T. Matsuoka, H. Takahashi, and T. Kurauchi. "Crystallization of Nylon 6-Clay Hybrid by Annealing Under Elevated Pressure." *Journal of Applied Polymer Science*, vol. 51, pp. 683–687, 1994.

18. Usuki, A., A. Koiwai, Y. Kojima, M. Kawasumi, A. Okada, T. Kurauchi, and O. Kamigaito. "Interaction of Nylon-6 Clay Surface and Mechanical-Properties of Nylon-6 Clay Hybrid." *Journal of Applied Polymer Science*, vol. 55, pp. 119–123, 1995.

19. Mascianica, F. S. "Ballistic Concepts Employed in Testing Lightweight Armor." WAL-MS-12, Watertown Arsenal Laboratories, Watertown, MA, 1959.

20. Wilde, A. F., R. W. Matton, J. M. Rogers, and S. E. Wentworth. "Synthesis and Ballistic Evaluation of Selected Transparent Polyurethane Block Copolymers." AMMRC-TR-73-53, Army Materials and Mechanics Research Center, Watertown, MA, 1973.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TL 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR DA OASARDA SARD SO 103 ARMY PENTAGON WASHINGTON DC 20310-0103
1	DPTY ASST SECY FOR R&T SARD TT THE PENTAGON RM 3EA79 WASHINGTON DC 20301-7100
1	COMMANDER US ARMY MATERIEL CMD AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
4	COMMANDER US ARMY ARDEC AMSTA AR CC G PAYNE J GEHBAUER C BAULIEU H OPAT PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY ARDEC AMSTA AR AE WW E BAKER J PEARSON PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR TD C SPINELLI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSE PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCH A W ANDREWS S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH P J LUTZ PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSF T C LIVECCHIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA ASF PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T C C PATEL PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR M D DEMELLA PICATINNY ARSENAL NJ 07806-5000
3	COMMANDER US ARMY ARDEC AMSTA AR FSA A WARNASH B MACHAK M CHIEFA PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR FSP G M SCHIKSNIS D CARLUCCI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSP A P KISATSKY PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR CCH C H CHANIN S CHICO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T D RIGOGLIOSO PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR WET T SACHAR BLDG 172 PICATINNY ARSENAL NJ 07806-5000
9	COMMANDER US ARMY ARDEC AMSTA AR CCH B P DONADIA F DONLON P VALENTI C KNUTSON G EUSTICE S PATEL G WAGNECZ R SAYER F CHANG PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCL F PUZYCKI R MCHUGH D CONWAY E JAROSZEWSKI R SCHLENNER M CLUNE PICATINNY ARSENAL NJ 07806-5000
5	PM SADARM SFAE GCSS SD COL B ELLIS M DEVINE W DEMASSI J PRITCHARD S HROWNAK PICATINNY ARSENAL NJ 07806-5000
1	US ARMY ARDEC INTELLIGENCE SPECIALIST AMSTA AR WEL F M GUERRIERE PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	PEO FIELD ARTILLERY SYS SFAE FAS PM H GOLDMAN T MCWILLIAMS PICATINNY ARSENAL NJ 07806-5000
12	PM TMAS SFAE GSSC TMA R MORRIS C KIMKER D GUZIEWICZ E KOPACZ R ROESER R DARCY R KOWALSKI R MCDANOLDS L D ULISSE C ROLLER J MCGREEN B PATTER PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR WEA J BRESCIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC PRODUCTION BASE MODERN ACTY AMSMC PBM K PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY TACOM PM ABRAMS SFAE ASM AB 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM AMSTA SF WARREN MI 48397-5000

NO. OF COPIES	ORGANIZATION
3	COMMANDER US ARMY TACOM PM TACTICAL VEHICLES SFAE TVL SFAE TVM SFAE TVH 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFVS SFAE ASM BV 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM AFAS SFAE ASM AF 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM RDT&E SFAE GCSS W AB J GODELL 6501 ELEVEN MILE RD WARREN MI 48397-5000
2	COMMANDER US ARMY TACOM PM SURV SYS SFAE ASM SS T DEAN SFAE GCSS W GSI M D COCHRAN 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	US ARMY CERL R LAMPO 2902 NEWMARK DR CHAMPAIGN IL 61822

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY TACOM PM SURVIVABLE SYSTEMS SFAE GCSS W GSI H M RYZYI 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFV SFAE GCSS W BV S DAVIS 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM CHIEF ABRAMS TESTING SFAE GCSS W AB QT T KRASKIEWICZ 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER WATERVLIET ARSENAL SMCWV QAE Q B VANINA BLDG 44 WATERVLIET NY 12189-4050
2	TSM ABRAMS ATZK TS S JABURG W MEINSHAUSEN FT KNOX KY 40121
3	ARMOR SCHOOL ATZK TD R BAUEN J BERG A POMEY FT KNOX KY 40121

NO. OF COPIES	ORGANIZATION
14	COMMANDER US ARMY TACOM AMSTA TR R R MCCLELLAND D THOMAS J BENNETT D HANSEN AMSTA JSK S GOODMAN J FLORENCE K IYER D TEMPLETON A SCHUMACHER AMSTA TR D D OSTBERG L HINOJOSA B RAJU AMSTA CS SF H HUTCHINSON F SCHWARZ WARREN MI 48397-5000
14	BENET LABORATORIES AMSTA AR CCB R FISCELLA M SOJA E KATHE M SCAVULO G SPENCER P WHEELER S KRUPSKI J VASILAKIS G FRIAR R HASENBEIN AMSTA CCB R S SOPOK E HYLAND D CRAYON R DILLON WATERVLIET NY 12189-4050
2	HQ IOC TANK AMMUNITION TEAM AMSIO SMT R CRAWFORD W HARRIS ROCK ISLAND IL 61299-6000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY AMCOM AVIATION APPLIED TECH DIR J SCHUCK FT EUSTIS VA 23604-5577
1	DIRECTOR US ARMY AMCOM SFAE AV RAM TV D CALDWELL BLDG 5300 REDSTONE ARSENAL AL 35898
2	US ARMY CORPS OF ENGINEERS CERD C T LIU CEW ET T TAN 20 MASS AVE NW WASHINGTON DC 20314
1	US ARMY COLD REGIONS RSCH & ENGRNG LAB P DUTTA 72 LYME RD HANOVER NH 03755
1	SYSTEM MANAGER ABRAMS ATZK TS LTC J H NUNN BLDG 1002 RM 110 FT KNOX KY 40121
1	USA SBCCOM PM SOLDIER SPT AMSSB PM RSS A J CONNORS KANSAS ST NATICK MA 01760-5057
2	USA SBCCOM MATERIAL SCIENCE TEAM AMSSB RSS J HERBERT M SENNETT KANSAS ST NATICK MA 01760-5057

NO. OF COPIES	ORGANIZATION
2	OFC OF NAVAL RESEARCH D SIEGEL CODE 351 J KELLY 800 N QUINCY ST ARLINGTON VA 22217-5660
1	NAVAL SURFACE WARFARE CTR DAHLGREN DIV CODE G06 DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR TECH LIBRARY CODE 323 17320 DAHLGREN RD DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR CRANE DIVISION M JOHNSON CODE 20H4 LOUISVILLE KY 40214-5245
8	DIRECTOR US ARMY NATIONAL GROUND INTELLIGENCE CTR D LEITER M HOLTUS M WOLFE S MINGLEDORF J GASTON W GSTATTENBAUER R WARNER J CRIDER 220 SEVENTH ST NE CHARLOTTESVILLE VA 22091
2	NAVAL SURFACE WARFARE CTR U SORATHIA C WILLIAMS CD 6551 9500 MACARTHUR BLVD WEST BETHESDA MD 20817
2	COMMANDER NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R PETERSON CODE 2020 M CRITCHFIELD CODE 1730 BETHESDA MD 20084

NO. OF COPIES	ORGANIZATION
8	US ARMY SBCCOM SOLDIER SYSTEMS CENTER BALLISTICS TEAM J WARD W ZUKAS P CUNNIFF J SONG MARINE CORPS TEAM J MACKIEWICZ BUS AREA ADVOCACY TEAM W HASKELL AMSSB RCP SS W NYKVIST S BEAUDOIN KANSAS ST NATICK MA 01760-5019
9	US ARMY RESEARCH OFC A CROWSON J CHANDRA H EVERETT J PRATER R SINGLETON G ANDERSON D STEPP D KISEROW J CHANG PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709-2211
8	NAVAL SURFACE WARFARE CTR J FRANCIS CODE G30 D WILSON CODE G32 R D COOPER CODE G32 J FRAYSSE CODE G33 E ROWE CODE G33 T DURAN CODE G33 L DE SIMONE CODE G33 R HUBBARD CODE G33 DAHLGREN VA 22448
1	NAVAL SEA SYSTEMS CMD D LIESE 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	NAVAL SURFACE WARFARE CTR M LACY CODE B02 17320 DAHLGREN RD DAHLGREN VA 22448

NO. OF COPIES	ORGANIZATION
2	NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R CRANE CODE 2802 C WILLIAMS CODE 6553 3A LEGGETT CIR BETHESDA MD 20054-5000
1	EXPEDITIONARY WARFARE DIV N85 F SHOUP 2000 NAVY PENTAGON WASHINGTON DC 20350-2000
1	AFRL MLBC 2941 P ST RM 136 WRIGHT PATTERSON AFB OH 45433-7750
1	AFRL MLSS R THOMSON 2179 12TH ST RM 122 WRIGHT PATTERSON AFB OH 45433-7718
2	AFRL F ABRAMS J BROWN BLDG 653 2977 P ST STE 6 WRIGHT PATTERSON AFB OH 45433-7739
1	WATERWAYS EXPERIMENT D SCOTT 3909 HALLS FERRY RD SC C VICKSBURG MS 39180
5	DIRECTOR LLNL R CHRISTENSEN S DETERESA F MAGNESS M FINGER MS 313 M MURPHY L 282 PO BOX 808 LIVERMORE CA 94550
1	AFRL MLS OL L COULTER 7278 4TH ST BLDG 100 BAY D HILL AFB UT 84056-5205

NO. OF COPIES	ORGANIZATION
1	OSD JOINT CCD TEST FORCE OSD JCCD R WILLIAMS 3909 HALLS FERRY RD VICKSBURG MS 29180-6199
1	DEFENSE NUCLEAR AGENCY INNOVATIVE CONCEPTS DIV 6801 TELEGRAPH RD ALEXANDRIA VA 22310-3398
3	DARPA M VANFOSSEN S WAX L CHRISTODOULOU 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
2	SERDP PROGRAM OFC PM P2 C PELLERIN B SMITH 901 N STUART ST STE 303 ARLINGTON VA 22203
1	FAA MIL HDBK 17 CHAIR L ILCEWICZ 1601 LIND AVE SW ANM 115N RESTON VA 98055
1	US DEPT OF ENERGY OFC OF ENVIRONMENTAL MANAGEMENT P RITZCOVAN 19901 GERMANTOWN RD GERMANTOWN MD 20874-1928
1	DIRECTOR LLNL F ADDESSIO MS B216 PO BOX 1633 LOS ALAMOS NM 87545
1	OAK RIDGE NATIONAL LABORATORY R M DAVIS PO BOX 2008 OAK RIDGE TN 37831-6195

NO. OF COPIES	ORGANIZATION
3	DIRECTOR SANDIA NATIONAL LABS APPLIED MECHANICS DEPT MS 9042 J HANDROCK Y R KAN J LAUFFER PO BOX 969 LIVERMORE CA 94551-0969
1	OAK RIDGE NATIONAL LABORATORY C EBERLE MS 8048 PO BOX 2008 OAK RIDGE TN 37831
1	OAK RIDGE NATIONAL LABORATORY C D WARREN MS 8039 PO BOX 2008 OAK RIDGE TN 37831
5	NIST J DUNKERS M VANLANDINGHAM MS 8621 J CHIN MS 8621 J MARTIN MS 8621 D DUTHINH MS 8611 100 BUREAU DR GAITHERSBURG MD 20899
1	HYDROGEOLOGIC INC SERDP ESTCP SPT OFC S WALSH 1155 HERNDON PKWY STE 900 HERNDON VA 20170
3	NASA LANGLEY RSCH CTR AMSRL VS W ELBER MS 266 F BARTLETT JR MS 266 G FARLEY MS 266 HAMPTON VA 23681-0001
1	NASA LANGLEY RSCH CTR T GATES MS 188E HAMPTON VA 23661-3400
1	FHWA E MUNLEY 6300 GEORGETOWN PIKE MCLEAN VA 22101

NO. OF COPIES	ORGANIZATION
3	CYTEC FIBERITE R DUNNE D KOHLI R MAYHEW 1300 REVOLUTION ST HAVRE DE GRACE MD 21078
1	USDOT FEDERAL RAILRD M FATEH RDV 31 WASHINGTON DC 20590
1	MARINE CORPS INTLLGNC ACTVTY D KOSITZKE 3300 RUSSELL RD STE 250 QUANTICO VA 22134-5011
1	DIRECTOR NATIONAL GRND INTLLGNC CTR IANG TMT 220 SEVENTH ST NE CHARLOTTESVILLE VA 22902-5396
1	SIOUX MFG B KRIEL PO BOX 400 FT TOTTEN ND 58335
2	3TEX CORPORATION A BOGDANOVICH J SINGLETARY 109 MACKENAN DR CARY NC 27511
1	3M CORPORATION J SKILDUM 3M CENTER BLDG 60 IN 01 ST PAUL MN 55144-1000
1	DIRECTOR DEFENSE INTLLGNC AGNCY TA 5 K CRELLING WASHINGTON DC 20310
1	ADVANCED GLASS FIBER YARNS T COLLINS 281 SPRING RUN LANE STE A DOWNINGTON PA 19335

NO. OF COPIES	ORGANIZATION
1	COMPOSITE MATERIALS INC D SHORTT 19105 63 AVE NE PO BOX 25 ARLINGTON WA 98223
1	JPS GLASS L CARTER PO BOX 260 SLATER RD SLATER SC 29683
1	COMPOSITE MATERIALS INC R HOLLAND 11 JEWEL CT ORINDA CA 94563
1	COMPOSITE MATERIALS INC C RILEY 14530 S ANSON AVE SANTA FE SPRINGS CA 90670
2	SIMULA J COLTMAN R HUYETT 10016 S 51ST ST PHOENIX AZ 85044
2	PROTECTION MATERIALS INC M MILLER F CRILLEY 14000 NW 58 CT MIAMI LAKES FL 33014
2	FOSTER MILLER M ROYLANCE W ZUKAS 195 BEAR HILL RD WALTHAM MA 02354-1196
1	ROM DEVELOPMENT CORP R O MEARA 136 SWINEBURNE ROW BRICK MARKET PLACE NEWPORT RI 02840

NO. OF COPIES	ORGANIZATION
2	TEXTRON SYSTEMS T FOLTZ M TREASURE 1449 MIDDLESEX ST LOWELL MA 01851
1	O GARA HESS & EISENHARDT M GILLESPIE 9113 LESAINT DR FAIRFIELD OH 45014
2	MILLIKEN RSCH CORP H KUHN M MACLEOD PO BOX 1926 SPARTANBURG SC 29303
1	CONNEAUGHT INDUSTRIES INC J SANTOS PO BOX 1425 COVENTRY RI 02816
1	BATTELLE NATICK OPNS B HALPIN 209 W CENTRAL ST STE 302 NATICK MA 01760
1	ARMTEC DEFENSE PRODUCTS S DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236
1	NATIONAL COMPOSITE CENTER T CORDELL 2000 COMPOSITE DR KETTERING OH 45420
3	PACIFIC NORTHWEST LAB M SMITH G VAN ARSDALE R SHIPPELL PO BOX 999 RICHLAND WA 99352
2	AMOCO PERFORMANCE PRODUCTS M MICHNO JR J BANISAUKAS 4500 MCGINNIS FERRY RD ALPHARETTA GA 30202-3944

NO. OF COPIES	ORGANIZATION
8	ALLIANT TECHSYSTEMS INC C CANDLAND MN11 2830 C AAKHUS MN11 2830 B SEE MN11 2439 N VLAHAKUS MN11 2145 R DOHRN MN11 2830 S HAGLUND MN11 2439 M HISSONG MN11 2830 D KAMDAR MN11 2830 600 SECOND ST NE HOPKINS MN 55343-8367
1	SAIC M PALMER 1410 SPRING HILL RD STE 400 MS SH4 5 MCLEAN VA 22102
1	SAIC G CHRYSSOMALLIS 3800 W 80TH ST STE 1090 BLOOMINGTON MN 55431
1	AAI CORPORATION T G STASTNY PO BOX 126 HUNT VALLEY MD 21030-0126
1	APPLIED COMPOSITES W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174
1	CUSTOM ANALYTICAL ENG SYS INC A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
3	ALLIANT TECHSYSTEMS INC J CONDON E LYNAM J GERHARD WV01 16 STATE RT 956 PO BOX 210 ROCKET CENTER WV 26726-0210
1	OFC DEPUTY UNDER SEC DEFNS J THOMPSON 1745 JEFFERSON DAVIS HWY CRYSTAL SQ 4 STE 501 ARLINGTON VA 22202

NO. OF COPIES	ORGANIZATION
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
5	AEROJET GEN CORP D PILLASCH T COULTER C FLYNN D RUBAREZUL M GREINER 1100 WEST HOLLYVALE ST AZUSA CA 91702-0296
3	HEXCEL INC R BOE PO BOX 18748 SALT LAKE CITY UT 84118
1	HERCULES INC HERCULES PLAZA WILMINGTON DE 19894
1	BRIGS COMPANY J BACKOFEN 2668 PETERBOROUGH ST HERNDON VA 22071-2443
1	ZERNOW TECHNICAL SERVICES L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773
1	GENERAL DYNAMICS OTS L WHITMORE 10101 NINTH ST NORTH ST PETERSBURG FL 33702
3	GENERAL DYNAMICS OTS FLINCHBAUGH DIV E STEINER B STEWART T LYNCH PO BOX 127 RED LION PA 17356
1	GKN AEROSPACE D OLDS 15 STERLING DR WALLINGFORD CT 06492

NO. OF COPIES	ORGANIZATION
5	SIKORSKY AIRCRAFT G JACARUSO T CARSTENSAN B KAY S GARBO MS S330A J ADELMANN 6900 MAIN ST PO BOX 9729 STRATFORD CT 06497-9729
1	PRATT & WHITNEY C WATSON 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
1	AEROSPACE CORP G HAWKINS M4 945 2350 E EL SEGUNDO BLVD EL SEGUNDO CA 90245
2	CYTEC FIBERITE M LIN W WEB 1440 N KRAEMER BLVD ANAHEIM CA 92806
1	UDLP G THOMAS PO BOX 58123 SANTA CLARA CA 95052
2	UDLP R BARRETT MAIL DROP M53 V HORVATICH MAIL DROP M53 328 W BROKAW RD SANTA CLARA CA 95052-0359
3	UDLP GROUND SYSTEMS DIVISION M PEDRAZZI MAIL DROP N09 A LEE MAIL DROP N11 M MACLEAN MAIL DROP N06 1205 COLEMAN AVE SANTA CLARA CA 95052
4	UDLP R BRYNSVOLD P JANKE MS 170 4800 EAST RIVER RD MINNEAPOLIS MN 55421-1498

NO. OF COPIES	ORGANIZATION
1	UDLP D MARTIN PO BOX 359 SANTA CLARA CA 95052
2	BOEING DFNSE & SPACE GP W HAMMOND S 4X55 J RUSSELL S 4X55 PO BOX 3707 SEATTLE WA 98124-2207
2	BOEING ROTORCRAFT P MINGURT P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086
1	BOEING DOUGLAS PRODUCTS DIV L J HART SMITH 3855 LAKEWOOD BLVD D800 0019 LONG BEACH CA 90846-0001
1	LOCKHEED MARTIN SKUNK WORKS D FORTNEY 1011 LOCKHEED WAY PALMDALE CA 93599-2502
1	LOCKHEED MARTIN R FIELDS 1195 IRWIN CT WINTER SPRINGS FL 32708
1	MATERIALS SCIENCES CORP G FLANAGAN 500 OFC CENTER DR STE 250 FT WASHINGTON PA 19034
1	NORTHRUP GRUMMAN CORP ELECTRONIC SENSORS & SYSTEMS DIV E SCHOCH MS V 16 1745A W NURSERY RD LINTHICUM MD 21090
1	GDLS DIVISION D BARTLE PO BOX 1901 WARREN MI 48090

NO. OF COPIES	ORGANIZATION
2	GDLS D REES M PASIK PO BOX 2074 WARREN MI 48090-2074
1	GDLS MUSKEGON OPERATIONS W SOMMERS JR 76 GETTY ST MUSKEGON MI 49442
1	GENERAL DYNAMICS AMPHIBIOUS SYS SURVIVABILITY LEAD G WALKER 991 ANNAPOLIS WAY WOODBRIDGE VA 22191
6	INST FOR ADVANCED TECH H FAIR I MCNAB P SULLIVAN S BLESS W REINECKE C PERSAD 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
2	CIVIL ENGR RSCH FOUNDATION PRESIDENT H BERNSTEIN R BELLE 1015 15TH ST NW STE 600 WASHINGTON DC 20005
1	ARROW TECH ASSO 1233 SHELBURNE RD STE D8 SOUTH BURLINGTON VT 05403-7700
1	R EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613

NO. OF COPIES	ORGANIZATION
1	UCLA MANE DEPT ENGR IV H T HAHN LOS ANGELES CA 90024-1597
2	UNIV OF DAYTON RESEARCH INST R Y KIM A K ROY 300 COLLEGE PARK AVE DAYTON OH 45469-0168
1	UMASS LOWELL PLASTICS DEPT N SCHOTT 1 UNIVERSITY AVE LOWELL MA 01854
1	IIT RESEARCH CENTER D ROSE 201 MILL ST ROME NY 13440-6916
1	GA TECH RSCH INST GA INST OF TCHNLGY P FRIEDERICH ATLANTA GA 30392
1	MICHIGAN ST UNIV MSM DEPT R AVERILL 3515 EB EAST LANSING MI 48824-1226
1	UNIV OF WYOMING D ADAMS PO BOX 3295 LARAMIE WY 82071
2	PENN STATE UNIV R MCNITT C BAKIS 212 EARTH ENGR SCIENCES BLDG UNIVERSITY PARK PA 16802
1	PENN STATE UNIV R S ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801

NO. OF COPIES	ORGANIZATION
1	PURDUE UNIV SCHOOL OF AERO & ASTRO C T SUN W LAFAYETTE IN 47907-1282
1	STANFORD UNIV DEPT OF AERONAUTICS & AEROBALLISTICS S TSAI DURANT BLDG STANFORD CA 94305
1	UNIV OF MAIN ADV STR & COMP LAB R LOPEZ ANIDO 5793 AEWC BLDG ORONO ME 04469-5793
1	JOHNS HOPKINS UNIV APPLIED PHYSICS LAB P WIENHOLD 11100 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	UNIV OF DAYTON J M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
5	UNIV OF DELAWARE CTR FOR COMPOSITE MTRLS J GILLESPIE M SANTARE S YARLAGADDA S ADVANI D HEIDER 201 SPENCER LABORATORY NEWARK DE 19716
1	DEPT OF MATERIALS SCIENCE & ENGINEERING UNIVERSITY OF ILLINOIS AT URBANA CHAMPAIGN J ECONOMY 1304 WEST GREEN ST 115B URBANA IL 61801

NO. OF COPIES	ORGANIZATION
1	NORTH CAROLINA STATE UNIV CIVIL ENGINEERING DEPT W RASDORF PO BOX 7908 RALEIGH NC 27696-7908
1	UNIV OF MARYLAND DEPT OF AEROSPACE ENGNRNG A J VIZZINI COLLEGE PARK MD 20742
3	UNIV OF TEXAS AT AUSTIN CTR FOR ELECTROMECHANICS J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
3	VA POLYTECHNICAL INST & STATE UNIV DEPT OF ESM M W HYER K REIFSNIDER R JONES BLACKSBURG VA 24061-0219
1	DREXEL UNIV A S D WANG 32ND & CHESTNUT ST PHILADELPHIA PA 19104
1	SOUTHWEST RSCH INST ENGR & MATL SCIENCES DIV J RIEGEL 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510
10	D OSTERMAYER 24 DEVONSHIRE RD MT LAUREL NJ 08054

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY P DIETZ 392 HOPKINS RD AMXSY TD APG MD 21005-5071

ABERDEEN PROVING GROUND (CONT)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP AP L APG MD 21005-5066
121	DIR USARL AMSRL CI AMSRL CI H W STUREK AMSRL CI S A MARK AMSRL CS IO FI M ADAMSON AMSRL SL BA AMSRL SL BL D BELY R HENRY AMSRL SL BG AMSRL SL I AMSRL WM J SMITH AMSRL WM B A HORST AMSRL WM BA D LYON AMSRL WM BC P PLOSTINS J NEWILL S WILKERSON A ZIELINSKI AMSRL WM BD B FORCH R FIFER R PESCE RODRIGUEZ B RICE AMSRL WM BE C LEVERITT AMSRL WM BF J LACETERA AMSRL WM BR C SHOEMAKER J BORNSTEIN AMSRL WM M D VIECHNICKI G HAGNAUER J MCCAULEY AMSRL WM MA F BEYER (10 CPS) L GHIORSE S MCKNIGHT

NO. OF COPIES	ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

AMSRL WM MB
B FINK
J BENDER
T BOGETTI
R BOSSOLI
L BURTON
K BOYD
S CORNELISON
P DEHMER (10 CPS)
R DOOLEY
W DRYSDALE
G GAZONAS
S GHIORSE
D GRANVILLE
D HOPKINS
C HOPPEL
D HENRY
R KASTE
M KLUSEWITZ (10 CPS)
M LEADORE
R LIEB
E RIGAS
J SANDS
D SPAGNUOLO
W SPURGEON
J TZENG
E WETZEL
A FRYDMAN
AMRSL WM MC
J BEATTY
E CHIN
J MONTGOMERY
A WERECZCAK
J LASALVIA
J WELLS
AMSRL WM MD
W ROY
S WALSH
AMSRL WM T
B BURNS
M ZOLTOSKI
AMSRL WM TA
W GILLICH
T HAVEL
J RUNYEON
M BURKINS
E HORWATH
B GOOCH
W BRUCHEY
M NORMANDIA

NO. OF COPIES	ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

AMRSL WM TB
D KOOKER
P BAKER
AMSRL WM TC
R COATES
AMSRL WM TD
A DAS GUPTA
T HADUCH
T MOYNIHAN
F GREGORY
M RAFTENBERG
M BOTELER
T WEERASOORIYA
D DANDEKAR
A DIETRICH
AMSRL WM TE
A NIILER
J POWELL
AMSRL SS SD
H WALLACE
AMSRL SS SE DS
R REYZER
R ATKINSON

NO. OF COPIES	ORGANIZATION
1	LTD R MARTIN MERL TAMWORTH RD HERTFORD SG13 7DG UK
1	SMC SCOTLAND P W LAY DERA ROSYTH ROSYTH ROYAL DOCKYARD DUNFERMLINE FIFE KY 11 2XR UK
1	CIVIL AVIATION ADMINSTRATION T GOTTESMAN PO BOX 8 BEN GURION INTERNL AIRPORT LOD 70150 ISRAEL
1	AEROSPATIALE S ANDRE A BTE CC RTE MD132 316 ROUTE DE BAYONNE TOULOUSE 31060 FRANCE
1	DRA FORT HALSTEAD P N JONES SEVEN OAKS KENT TN 147BP UK
1	DEFENSE RESEARCH ESTAB VALCARTIER F LESAGE COURCELETTE QUEBEC COA IRO CANADA
1	SWISS FEDERAL ARMAMENTS WKS W LANZ ALLMENDSTRASSE 86 3602 THUN SWITZERLAND
1	DYNAMEC RESEARCH AB AKE PERSSON BOX 201 SE 151 23 SODERTALJE SWEDEN

NO. OF COPIES	ORGANIZATION
1	ISRAEL INST OF TECHNOLOGY S BODNER FACULTY OF MECHANICAL ENGR HAIFA 3200 ISRAEL
1	DSTO AMRL WEAPONS SYSTEMS DIVISION N BURMAN RLLWS SALISBURY SOUTH AUSTRALIA 5108 AUSTRALIA
1	ECOLE ROYAL MILITAIRE E CELENS AVE DE LA RENAISSANCE 30 1040 BRUXELLE BELGIQUE
1	DEF RES ESTABLISHMENT VALCARTIER A DUPUIS 2459 BOULEVARD PIE XI NORTH VALCARTIER QUEBEC CANADA PO BOX 8800 COURCELETTE GOA IRO QUEBEC CANADA
1	INSTITUT FRANCO ALLEMAND DE RECHERCHES DE SAINT LOUIS DE M GIRAUD 5 RUE DU GENERAL CASSAGNOU BOITE POSTALE 34 F 68301 SAINT LOUIS CEDEX FRANCE
1	ECOLE POLYTECH J MANSON DMX LTC CH 1015 LAUSANNE SWITZERLAND

NO. OF COPIES	ORGANIZATION
1	TNO DEFENSE RESEARCH R IJSSELSTEIN ACCOUNT DIRECTOR R&D ARMEE PO BOX 6006 2600 JA DELFT THE NETHERLANDS
2	FOA NATL DEFENSE RESEARCH ESTAB DIR DEPT OF WEAPONS & PROTECTION B JANZON R HOLMLIN S 172 90 STOCKHOLM SWEDEN
2	DEFENSE TECH & PROC AGENCY GROUND I CREWTHER GENERAL HERZOG HAUS 3602 THUN SWITZERLAND
1	MINISTRY OF DEFENCE RAFAEL ARMAMENT DEVELOPMENT AUTH M MAYSELESS PO BOX 2250 HAIFA 31021 ISRAEL
1	TNO DEFENSE RESEARCH I H PASMAN POSTBUS 6006 2600 JA DELFT THE NETHERLANDS
1	B HIRSCH TACHKEMONY ST 6 NETAMUA 42611 ISRAEL
1	DEUTSCHE AEROSPACE AG DYNAMICS SYSTEMS M HELD PO BOX 1340 D 86523 SCHROBENHAUSEN GERMANY

INTENTIONALLY LEFT BLANK.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Final, June 2000–August 2000

4. TITLE AND SUBTITLE
Measurement of V_{50} Behavior of a Nylon 6-Based Polymer-Layered Silicate Nanocomposite

5. FUNDING NUMBERS
AH42

6. AUTHOR(S)
David Ostermayer,* Frederick L. Beyer, Peter G. Dehmer, and Melissa A. Klusewitz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
Aberdeen Proving Ground, Maryland 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2605

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

* University of Delaware, Newark, DE 19716

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT*(Maximum 200 words)*

The performance under ballistic impact conditions of a nylon 6-based polymer-layered silicate (PLS) nanocomposite was examined using a V_{50} test. The commercially available nanocomposites contained approximately 2.5-wt.% montmorillonite clay mineral and were fabricated by *in situ* polymerization of ε-caprolactam in the presence of an organosilicate clay mineral. The velocity at which 50% of 0.22-cal. fragment simulator projectiles penetrated the unmodified nylon 6 and 0.5-mm aluminum witness plate (V_{50}) was determined to be 436 ft/s. The PLS nanocomposite nylon 6-clay hybrid was found to have a V_{50} of 338 ft/s. Therefore, it was found that the addition of the layered silicate clay mineral filler did not improve the impact properties of nylon 6 under these conditions.

14. SUBJECT TERMS
V_{50}, polymer-layered silicate, nanocomposite, montmorillonite

15. NUMBER OF PAGES
29

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.