K-9 Training Aids for Improvised Explosives by Additive Manufacturing

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LLNL-PRES-734226 (885816)

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Background—K-9 Explosives Detectors

- One of the best explosive detection method
- Require scent training to recognize target routinely
- Quality of ability to detect derives directly from training
- Easily trained improperly on contaminants
- Fatigues easily if not properly trained and handled

German Shepherd

Background

- K-9 training for Explosive Detection requires
  - Active ingredient required for training
  - No other volatile components interfere (give false positives)
  - Enhanced training with shape recognition (i.e., 155 mortar shell recognition)
- Explosives Training aids require
  - Low concentration of explosive for non-hazardous shipping and handling
  - No other volatile components so the dog does not training on them
  - Realistic matrices to simulate real world conditions
- Additive Manufacturing at LLNL can print
  - With a wide variety of non-volatile matrix mixtures
  - Wide array of compositions as different shapes
  - Laminate structures

Background—Additive Manufacturing at LLNL

- Forms objects by layering solids in slurries
- Forms wide variety of shapes and sizes
- Utilizes wide variety of compositions and substrates
- Technology well established and invested in at LLNL

AM Printed Aston Martin for the movie Skyfall

Background—Improvised Explosives

- Generally a mixture of two or more components
- Usually do not react until mixed
- Training aids hard to make by traditional methods because once mixed, they are unstable
- Potentially hundred of different mixtures
- Can be classified based on oxidizer and fuel categories

Potassium chlorate (oxidizer)

+

Sugar (fuel)

Approach

- The training aids will be produced by additive manufacturing (AM); explosives or explosive components at concentrations less than 10% are mixed with a matrix and then are printed into shapes; the final product is cured to strengthen and to remove volatiles
- AM is capable of printing alternate layers of two or more components, therefore producing an object that has both components in it that are not in contact (critical to make training aids for improvised explosives)

Market Need

- Training Aids are limited in their matrices (usually silica and gel); limited in their explosives (no improvised explosives); have no shape selection (powder or goo); limited in availability
- Training aids are made by physically mixing explosive in the matrix (not necessarily well dispersed)
- Market need is more types of training aids, better dispersion of explosive component, more variations in matrices, and the ability to make better ***training aids for improvised explosives (****essentially no training aids but there is and abundance of improvised explosives****)***

Benefits

- Benefits clearly indicate a better detection of a wider range of explosives at check points, specifically improvised explosives
- Currently, there are no safe explosive training aids that adequately represent improvised explosives but the terrorist market has shown improvised materials as real threats; this project would provide dial-in capabilities to make these aids safely and broadly designed

Technical and Market Competition

- LLNL is a pioneer in explosives training aids with the development of NESST http://www.xm-materials.com
- Many commercial outlets, but few actual manufacturers; production is limited to usually only one of the components of the improvised explosive mixed with matrix
- Training aids for improvised explosives are unstable if produced by current methods

NESTT training aids

Omni Explosives black powder training aid

Black Powder (KNO_3, C, S), KNO_3, $NaNO_3$, C, S, Graphite

NESTT Aids

- Substrates—coated silica and petrolatum suspension
- Containers—tins, cloth bags, quart cans, petroleum tubes
- Explosives—RDX, TNT, $KClO_3$, PETN, KNO_3
- Distractor odors
- Distributors—Ray Allen (www.rayallen.com; www.xm-materials.com)

TrueScent K-9 Scent Training Aids (or TrueScent K-9)

- Substrates—unknown
- Containers—special bags
- Explosives—HMTD, TATP, RDX, TNT, $KClO_3$, PETN, AN, Uni
- Drugs also
- Black distractor aid
- Distributors—Ray Allen (www.rayallen.com; www.signaturescience.com; www.elitek9.com)

Omni Explosives

Note: Information is difficult to find. Looks like they dilute full strength materials.

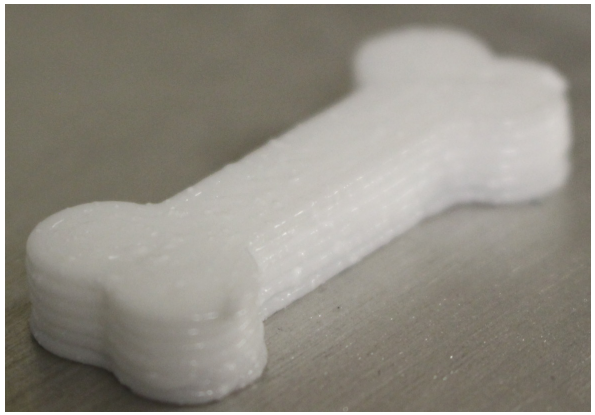
Black Powder (KNO_3, C, S), KNO_3, $NaNO_3$, C, S, Graphite

C-4 (91% RDX, 9% Plastic) + taggants, C-4 (M112 Block) + taggants, RDX, DMDNB, DMNB

COMP B (60% RDX, 40% TNT)
RDX, TNT, Wax

Semtex 1A

AM Printed Training Aids—example dog bone

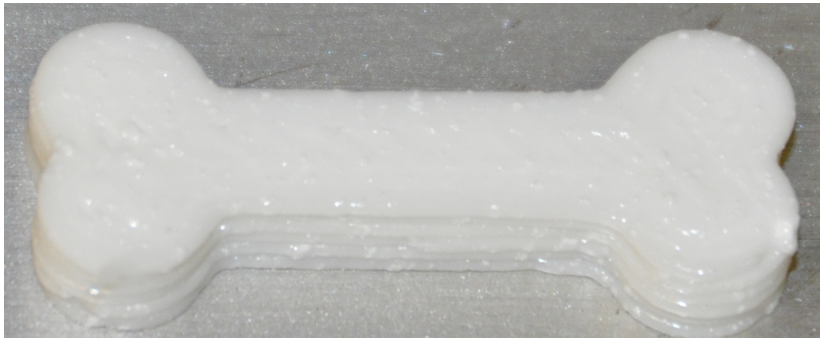


AM printed training aid with HMX uncured

AM printed training aid with HMX cured

- Training aids printed with 8 wt. % HMX and PDMS (poly dimethyl siloxane)
  - ½ hour printing
  - 5 hours curing
  - Shape selected as dog bone (for demonstration only)
  - Demonstrates AM printing of training aids possible
  - Formulations for other explosives and matrixes the next step

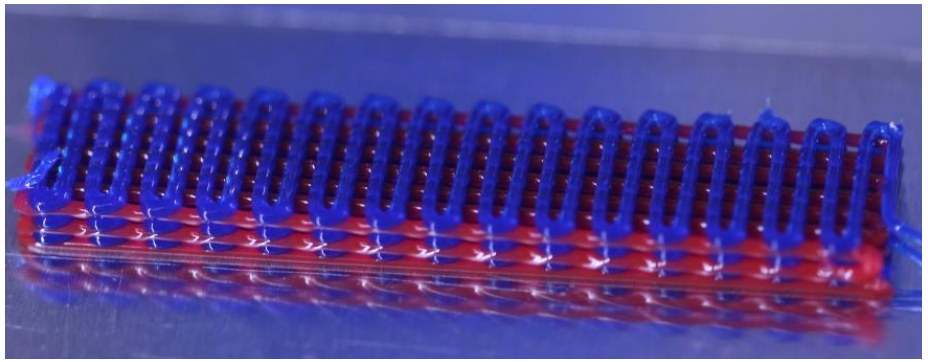
Project Summary—Current Status



Printed AM training Aid with HMX before curing

- HMX is proof of concept for traditional explosives
- Type of traditional explosive can be varied (PETN, RDX, TNT, etc.)
- Construction of any shape or size (dog bone to cell phone case or bigger)
- Wide variety of matrices available (more realistic for training)
- Safe to transport and handle as non-hazardous materials

- Laminated structures have been printed without explosive components as proof of concept
- Improvised explosives formulations (oxidizer and fuel) can be made
- Laminates keep oxidizer and fuels separate but in the same part (with-out reaction)

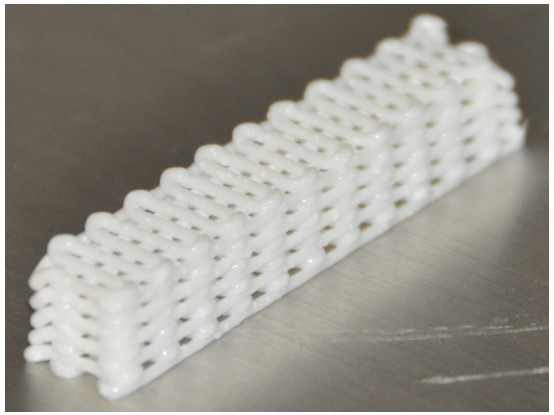


Printed laminate with row composition alternating (after curing)

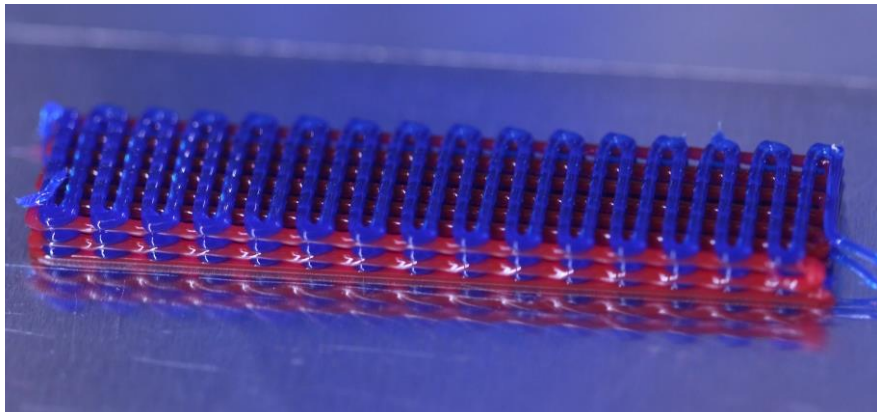
AM Printed Training Aids—example cell phone cover

- Simulant printed as cell phone case
  - 1 hour printing
  - 5 hours curing
  - Shape selected as cell phone
  - Demonstrates flexibility of printing shapes
  - Printing with low concentration of explosives is next step

AM Printed Training Aids-examples of lattice structures



Open Structure with 8 wt. % HMX



Laminate Structure with alternating compositions

- Lattice and laminate structure easy to print
  - Can be made with low concentration of explosives
  - Has open access
  - Layers do not mix
  - Demonstrates oxidizer and fuel can be printed in same structure
  - Next step to print $KClO_3$ and sugar to demonstrate reaction stability

Properties desired in Training Aids

- K-9 explosives training aids have to minimally meet the following
  - low concentration of explosive or explosive mixture (allows handling and transportation without special requirements)
  - low-volatile matrix (so the K-9 will not be trained on a false signature)
  - flexibility in form (so the aid can be used in various configurations and applications)
- Current technology meets some of these issues
  - There are companies (few), such as NESTT and ScentLogic, that produce training aids that can be shipped and handled normally
  - list of explosives is somewhat limited
  - including no real improvised materials (just one component)
  - Matrices are limited to silica and thick gel hydrocarbons
  - Little flexibility of form; current aids are generally pastes or powders that must have secondary containment, such as a bag, or applied as a smear.
- Future technology should broaden to include other matrices, large swath of explosives, improvised mixtures (all components), shape specific

Simulants

- • **Type 1 simulant:** Presents the odor picture of the active ingredient
- • **Type 2 simulant:** Presents the odor picture of a byproduct or impurity
- • **Type 3 simulant:** Presents the odor picture of a filler or additive
- • **Type 4 simulant:** Mimics the odor of the material of interest using alternate chemicals in hopes to produce a similar odor. This is what we call a “pseudo” scent

Why AM (what does AM bring to the table)

- Unique objects and shapes (designer shapes)
  - anything that is physically reasonable (dog bone)
  - Many shapes part of public domain software
- Wide choice of matrices
  - Silica (resilient, through siloxane and curing)
  - Clays (match environment such as ground)
  - Ceramics (high strength and mostly water based)
  - Custom (vast selections in industry)
- Staged or Intermixing
  - Layered or laminate formulations (two materials with out mixing)
  - Compositionally based formulations that can vary (stoichiometry and density gradients)

AM produced Aston Martin

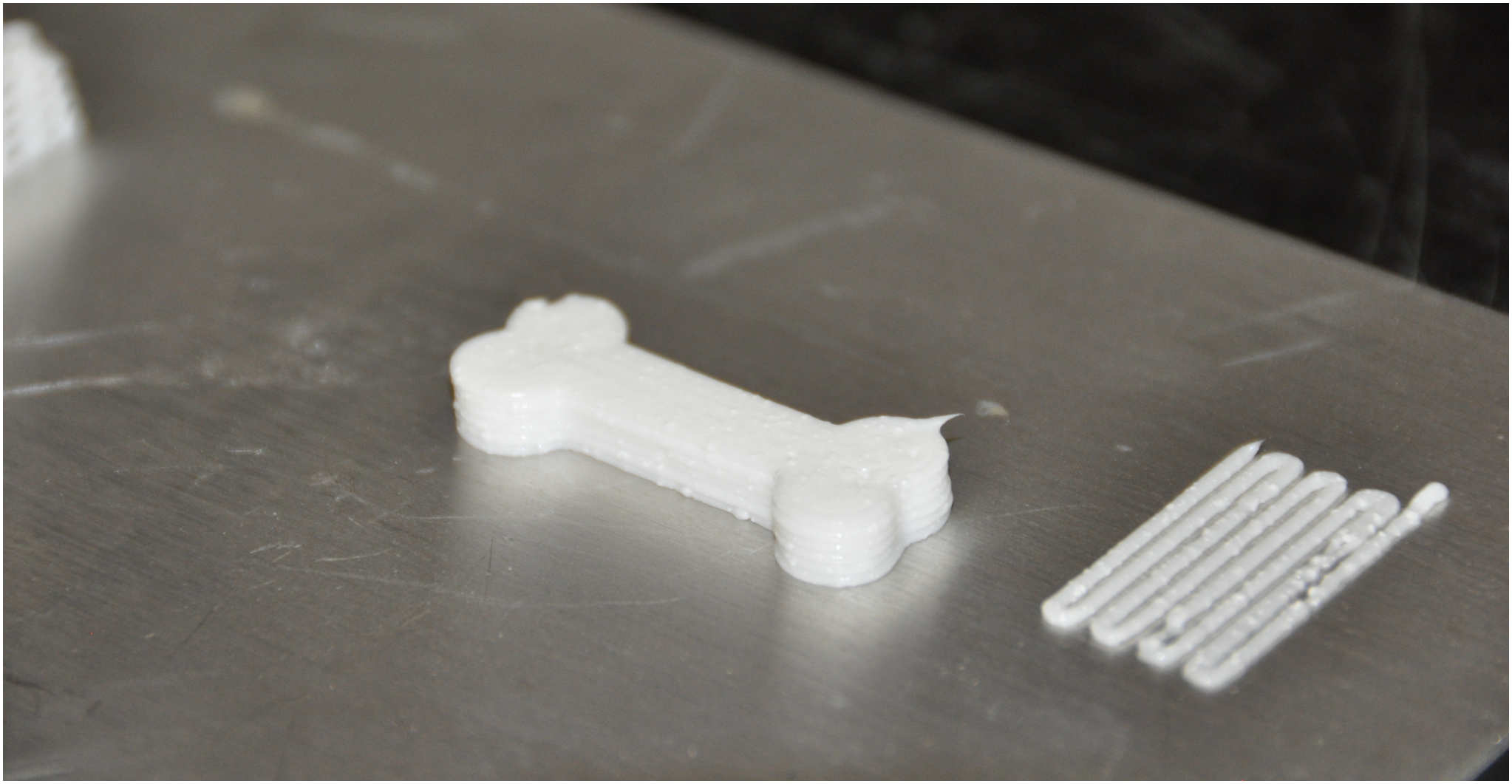
Why AM (what does AM bring to the table)

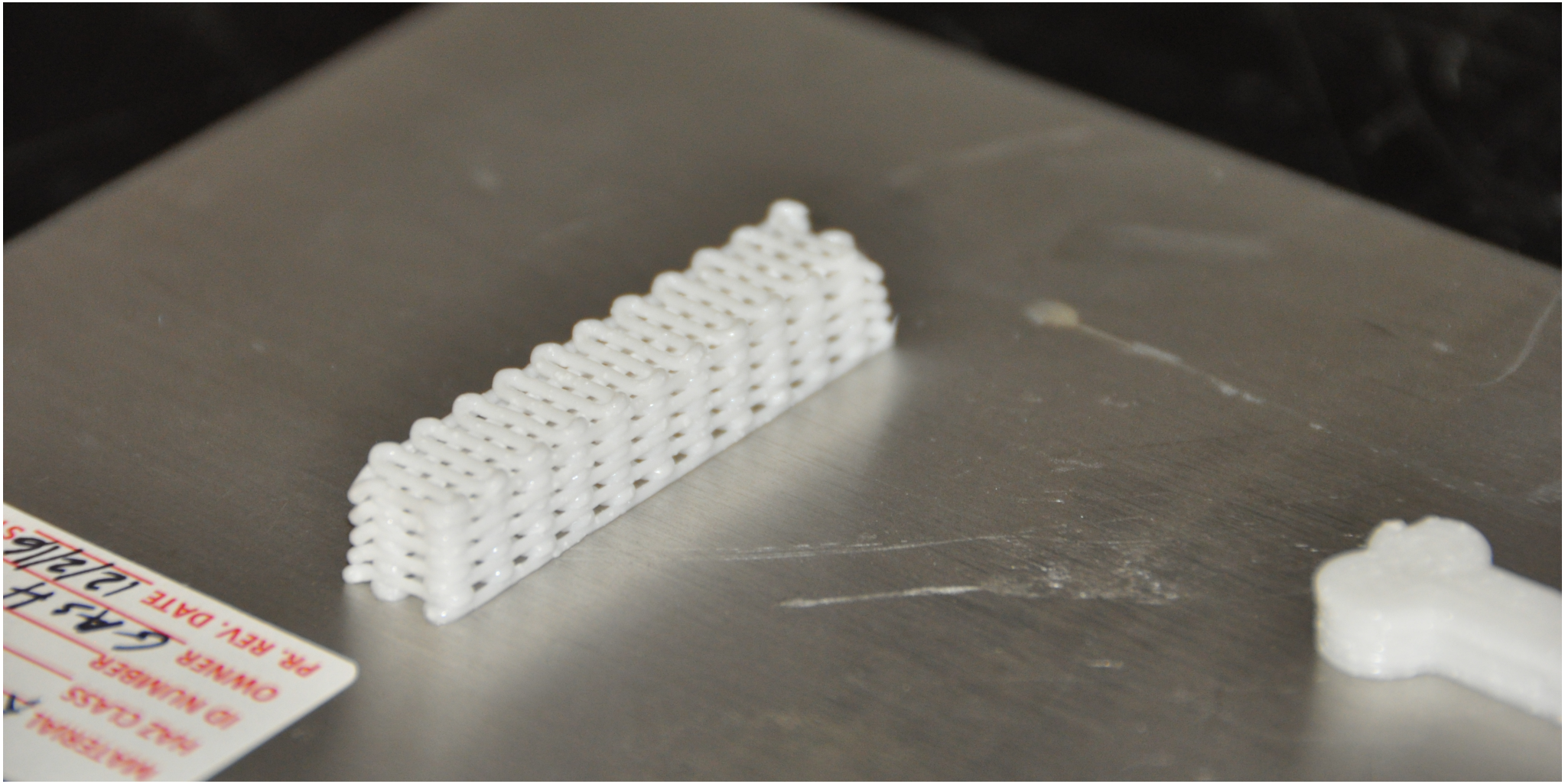
AM produced house

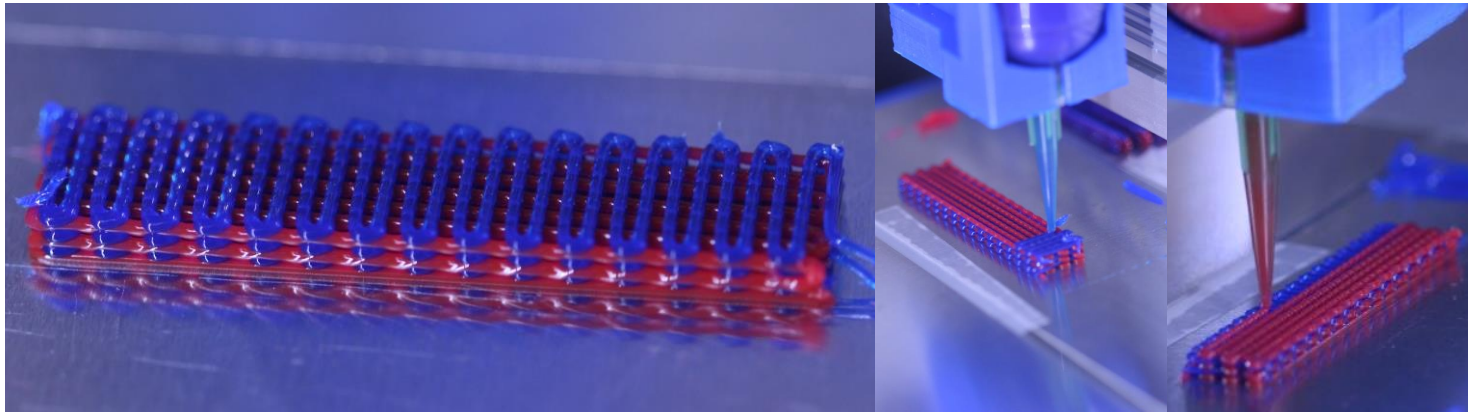
- Low volatility matrices
  - Water based formulations (few if any emissions)
  - Low or no solvent necessary for formulation
    (volatiles from curing can be baked out if necessary)
- Lattice diffusion (open throughout)
  - Structures are open materials (allowing access to inner structure)
  - Matrix is open and allows infusion methods (could build matrix first, then infuse analyte)
- On-demand production
  - Single unit, can be changed quickly (some printing units are inexpensive)
  - Possible field production is needed (some printing units are portable)
- Easy to make mixture simulants
  - Explosive + real world components

Applications of AM printed Training Aids

- K-9 explosive training aids
- K-9 narcotic training aids
- Simulants for radiography
- Simulants for explosive detection equipment
- Concentration limited release of calibration agents (like peroxide)
- LLNL has patented processes (U.S. 9890092 “Explosives mimic for testing, training, and monitoring,” and U.S. 9897419 “K-9 training aids made using additive manufacturing”)
- LLNL has facilities that can print energetic materials







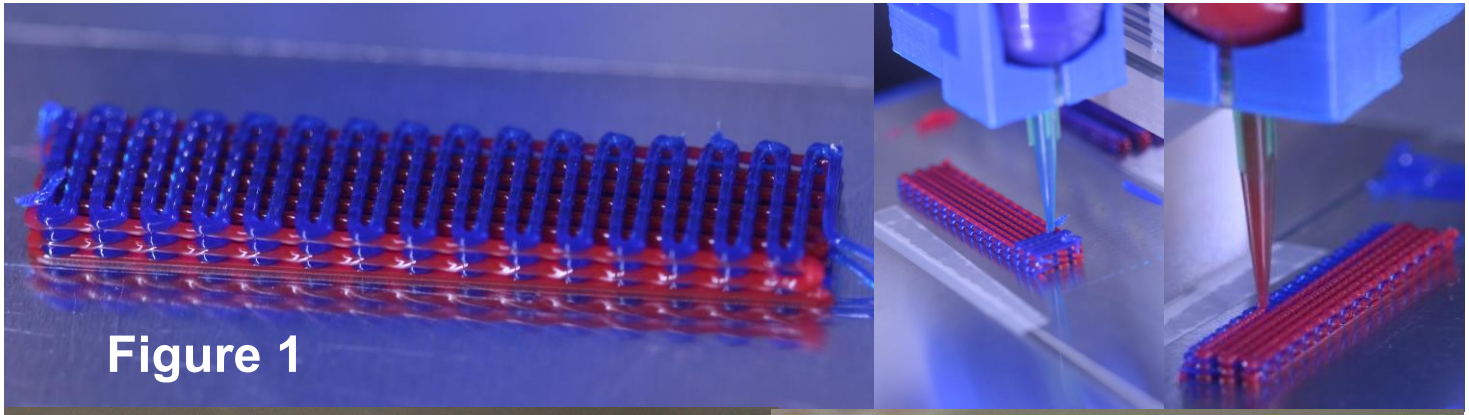


Figure 1

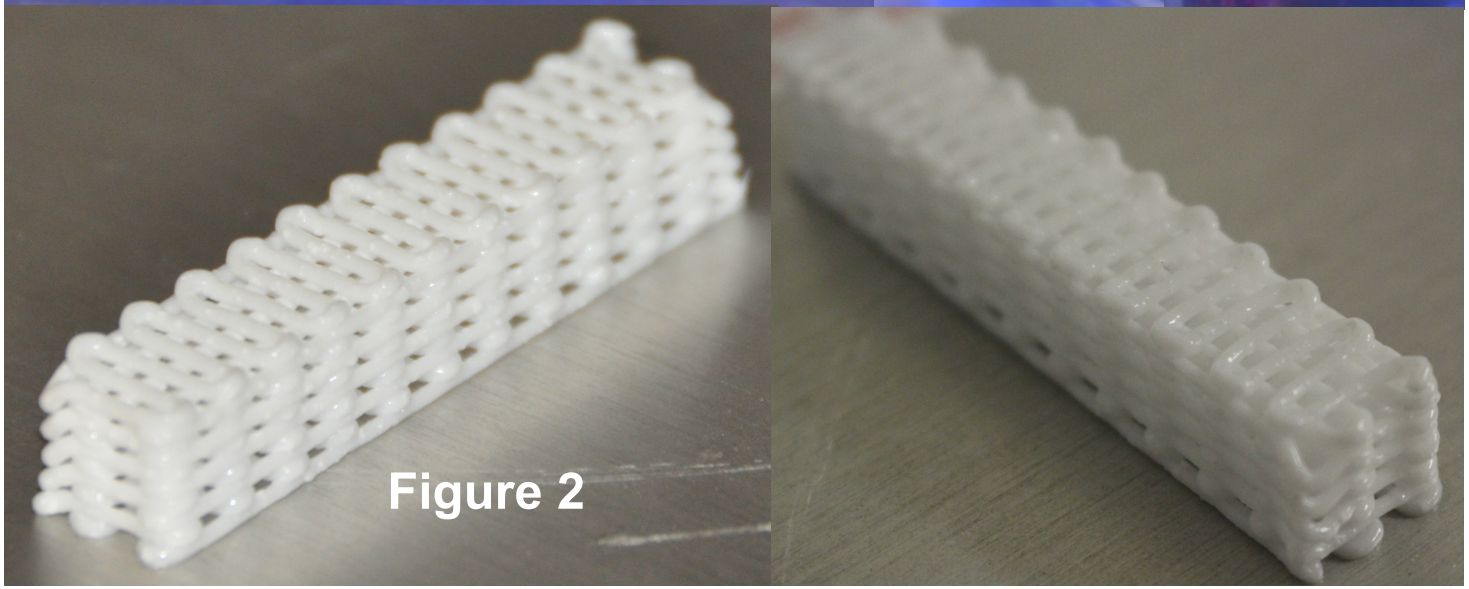
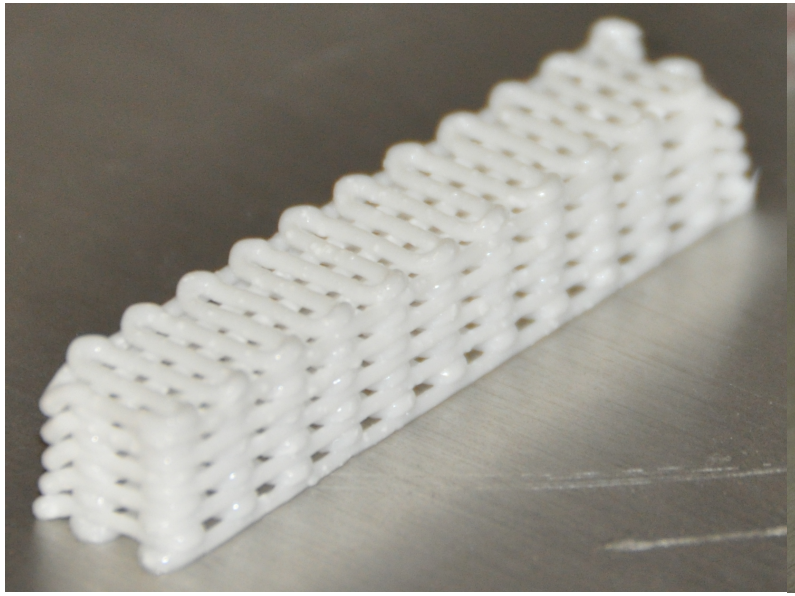
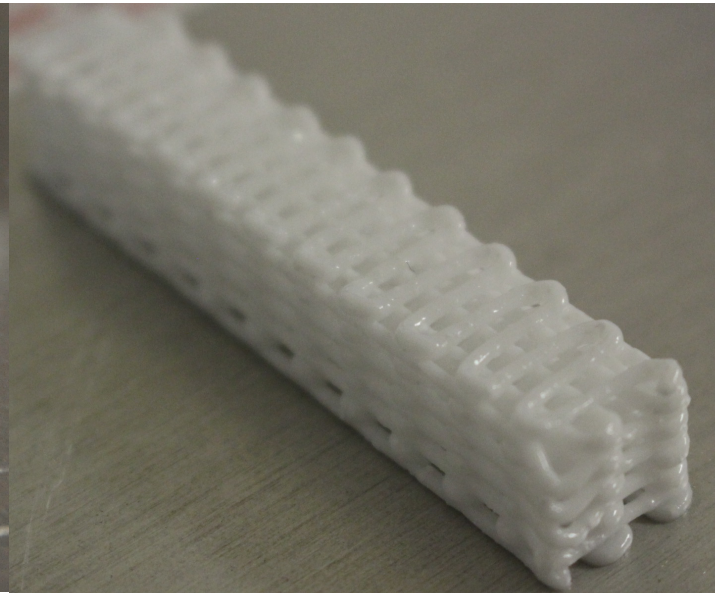


Figure 2





Dogs as Explosives Detectors