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14. ABSTRACT Development and demonstration of low cost, highly repeatable, high speed production processes in production of hardware prototypes using flexible optical processing cells and sustainable green coating technologies. The optical processes developed and demonstrated expedited the manufacturing process and increased precision, quality control and reduced waste.						
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Final Technical Report

BRG-54

“Prototype Manufacturing Technologies: Conversion of Munitions Components into Higher Value Products”

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Submitted: 21 May 2012



1. Technical/Cost/Schedule Performance

Technical: CLogic demonstrated our extremely low cost, highly repeatable, high speed production processes in production of hardware prototypes using flexible optical processing cells and sustainable green coating technologies. The optical processes for laser welding employed expedited the manufacturing process and increased precision and quality control and reduced waste. CLogic demonstrated the ability to rapidly prototype and test/evaluate material and armor concepts and to get them into the user for test and evaluation.

Cost: CLogic expended a total of \$6,098,891 to complete the required effort.

Schedule: Work was performed on schedule and within costs

2. Initiative Quad Chart:

Conversion of Munitions Components into Higher Value Products	
Goals & Objectives	Initiative Information
Develop prototype conversion and reuse manufacturing technologies for the production of high performance designs in metals fabrication, coating, and finishing that allow for rapid innovation and response. The work requirements below will enable the development of rapid response precision manufacturing technologies using a number of unique material options	Initiative Lead: CLogic LLC Team Members: Force Protection and Explosively Formed Penetrator (FP&EFP) Branch, US Army RDECOM-ARDEC Period of Performance: 36 months Funding: \$6,098,891
Milestones & Technical Achievements	Implementation & Payoff
See section 3.1	Schedule: May 2013 Status: 100% complete The technology developed will enable the development of rapid response precision manufacturing technologies using a number of unique material options
Current Status: Technical = Green Schedule = Green Cost = Green	

3. Supplemental Information

In order to improve the usefulness of the quad charts and provide DOTC with sufficient initiative information, the Quarterly Report must be supplemented with data described below.



3.1 Technical Achievements

CLogic demonstrated an extremely low cost, highly repeatable, high speed production process for hardware required using optical processing and sustainable green coating technologies. CLogic produced the required hardware using this innovative process and hardware is scheduled for delivery. Production of these prototypes using these repeatable processes is important as CLogic, LLC can use this technology to provide new prototype high precision and environmentally friendly technologies to the Industrial Base to expedite the design, manufacturing and rapid response delivery of a variety products.

Flexible manufacturing and automation provides with the capability to meet large increases in demand or a sudden need to shift product mix without a decrease in production efficiency.

The versatility of these cells permits the production of a wide variety of cylindrical and prismatic work pieces to extremely close tolerances. In addition to production components, prototype parts are planned to be routinely processed through these cells.

The advantages of cellular layouts are as follows:

- *Reduced material handling and transit time.* Material movement is more direct. Less distance is traveled between operations. Material does not accumulate or wait long periods of time to be moved. Within a cell, the worker is more likely to carry a partially finished item from machine to machine than wait for material handling equipment, as is characteristic of process layouts, where larger loads must be moved farther distances.
- *Reduced setup time.* Since similar parts are processed together, the adjustments required to set up a machine should not be that different from item to item. If it does not take that long to change over from one item to another, then the changeover can occur more frequently, and items can be produced and transferred in very small batches or lot sizes.
- *Reduced work-in-process inventory.* In a work cell, as with assembly lines, the flow of work is balanced so that no bottlenecks or significant buildup of material occurs between stations or machines. Less space is required for storage of in-process inventory between machines, and machines can be moved closer together, thereby saving transit time and increasing communication.
- *Better use of human resources.* Typically, a cell contains a small number of workers responsible for producing a completed part or product. The workers act as a self-managed team, in most cases more satisfied with the work that they do and more particular about the quality of their work. Labor in cellular manufacturing is a flexible resource. Workers in each cell are multifunctional and can be assigned to different routes within a cell or between cells as demand volume changes.
- *Easier to control.* Items in the same part family are processed in a similar manner through the work cell. There is a significant reduction in the paperwork necessary to document material travel, such as where an item should be routed next, if the right



operation has been performed, and the current status of a job. With fewer jobs processed through a cell, smaller batch sizes, and less distance to travel between operations, the progress of a job can be verified *visually* rather than by mounds of paperwork.

- *Easier to automate.* Automation is expensive. Rarely can any manufacturing site afford to automate an entire factory all at once. Cellular layouts can be automated one cell at a time. Automating a few workstations on an assembly line will make it difficult to balance the line and achieve the increases in productivity expected. Introducing automated equipment in a job shop has similar results, because the "islands of automation" speed up only certain processes and are not integrated into the complete processing of a part or product.

Flexible cell layouts differ based on the variety of parts that the system can process, the size of the parts processed, and the average processing time required for part completion. There are four basic types of layouts:

- *Progressive layout:* All parts follow the same progression through the machining stations. This layout is appropriate for processing a family of parts and is the most similar to an automated group technology cell.
- *Closed-loop layout:* Arranged in the general order of processing for a much larger variety of parts. Parts can easily skip stations or can move around the loop to visit stations in an alternate order. Progressive and closed-loop systems are used for part sizes that are relatively large and that require longer processing times.
- *Ladder layout:* So named because the machine tools appear to be located on the steps of a ladder, allowing two machines to work on one item at a time. Programming the machines may be based on similarity concepts from group technology, but the types of parts processed are not limited to particular part families. Parts can be routed to any machine in any sequence.
- *Open-field layout:* The most complex and flexible FMS layout. It allows material to move among the machine centers in any order and typically includes several support stations such as tool interchange stations, pallet or fixture build stations, inspection stations, and chip/coolant collection systems.

Traditional assembly lines, designed to process a single model or type of product, can be used to process more than one type of product, but not efficiently. Models of the same type are produced in long production runs, sometimes lasting for months, and then the line is shut down and changed over for the next model. The next model is also run for an extended time, producing perhaps half a year to a year's supply; then the line is shut down again and changed over for yet another model; and so on. The problem with this arrangement is the difficulty in responding to changes in customer demand. If a certain item is in demand, they have to wait until the next batch of that model is scheduled to be produced. On the other hand, if demand is low for models that have already been produced, the manufacturer is stuck with unwanted inventory.



Recognizing that this mismatch of production and demand is a problem, we have concentrated on devising more sophisticated forecasting techniques. Others changed the manner in which the assembly line was laid out and operated so that it really became a mixed-model assembly line. First, they reduced the time needed to change over the line to produce different models. Then they trained their workers to perform a variety of tasks and allowed them to work at more than one workstation on the line, as needed. Finally, they changed the way in which the line was arranged and scheduled. The following factors are important in the design and operation of mixed-model assembly lines:

- *Line balancing:* In a mixed-model line, the time to complete a task can vary from model to model. Instead of using the completion times from one model to balance the line, a distribution of possible completion times from the array of models must be considered. In most cases, the expected value, or average, times are used in the balancing procedure. Otherwise, mixed-model lines are balanced in much the same way as single-model lines.
- *U-shaped lines.* To compensate for the different work requirements of assembling different models, it is necessary to have a flexible workforce and to arrange the line so that workers can assist one another as needed.
- *Flexible workforce.* Although worker paths are predetermined to fit within a set cycle time, the use of average time values in mixed-model lines will produce variations in worker performance. Hence, the lines are not run at a set speed. Items move through the line at the pace of the slowest operation. This is not to say that production quotas are not important. If the desired cycle time is exceeded at any station on the line, other workers are notified by flashing lights or sounding alarms so that they can come to the aid of the troubled station. The assembly line is slowed or stopped until the work at the errant workstation is completed. This flexibility of workers helping other workers makes a tremendous difference in the ability of the line to adapt to the varied length of tasks inherent in a mixed-model line.
- *Model sequencing.* Since different models are produced on the same line, mixed-model scheduling involves an additional decision--the order, or sequence, of models to be run through the line. From a logical standpoint, it would be unwise to sequence two models back-to-back that require extra long processing times. It would make more sense to mix the assembling of models so that a short model (requiring less than the average time) followed a long one (requiring more than the average time). With this pattern, workers could "catch up" from one model to the next. Another objective in model sequencing is to spread out the production of different models as evenly as possible throughout the time period scheduled.

A prototype demonstration was conducted using contractor owned equipment that included a Horizontal Machining Cell, a Vertical Turning Cell, and a Vertical Boring Cell. These cells consist of three CNC Horizontal Machining Centers, two Vertical Turning Centers and four Vertical Boring Machines. Each cell was equipped with a mini-computer and rail guided material handling system. These cells have the capacity to perform work which would require 20 machines and an equivalent staff.



The Horizontal Machining Cell control system is a MicroVAX 3100 with tool and fixture management; automatic data collection; report generation; dynamic system display; and an interface with the DNC system. Its material handling system is a rail-guided vehicle with two pallet transfer arms and a capacity of 12,000 pounds. It has 18 queue stands, and 34 pallets.

The Vertical Turning Cell control system is a MicroVAX 4000 with tool and fixture management; automatic data collection; report generation; dynamic system display; an interface with the DNC system. Its material handling system is a rail-guided vehicle with one transfer arm and a capacity of 6,000 pounds. It has 14 queue stands, 3 load stands and 12 pallets.

The Vertical Boring Cell control system is a MicroVAX 4000 with tool and fixture management; automatic data collection; report generation; dynamic system display; and an interface with the DNC system. Its material handling system is a rail-guided vehicle with one transfer arm and a capacity of 6,000 pounds. It has 18 queue stands, four load stands, and 15 pallets.

Parts manufactured in these cells were demonstrated to be of higher quality compared to parts produced through conventional methods. Improved quality was attained due to the combining of manufacturing processes without re-fixturing, probing capabilities, and continuous monitoring/feedback of the status of the machine tool. The net effect of cellular manufacturing demonstrated is the increased efficiency of production operations.

These flexible manufacturing cells provided benefits in addition to producing high quality parts. These benefits include a more effective utilization of manufacturing floor space, reduction of WIP inventory, and prompt delivery of the product to the customer.

After a review of the current state of the art for lighter weight materials as well as the practicality of producing prototypes for testing, the following materials are the most viable candidates that are readily available, with no research and development required for advanced hybrid armor materials:

- **ULTRA-HIGH STRENGTH INTERMEDIATE FRACTURE TOUGHNESS STEELS** The combination of strength and fracture toughness of this alloy provides an indication that it may also turn out to provide excellent ballistic protection. If the performance is indeed superior to other armor steels, it will enable the fabrication of lighter weight armored platforms of equivalent survivability. In addition, it is expected to find uses in aircraft and missile components and integral helicopter armor.
- **LOW-COST TITANIUM** Future vehicles must be lightened to improve deployability, bridge crossing capability, and maneuverability while maintaining lethality and survivability. Development of lower cost alloy and "high rate" fabrication capabilities are key to weight reduction by means of replacement of steel with titanium in vehicle structures and components



- **AMORPHOUS ZIRCONIUM-BASED ALLOYS** High hardness typically accompanies high strength in metallic systems. Consequently, a material with a very high strength-to-weight ratio is a potential candidate for lightweight armor application. These new classes of alloys with amorphous (noncrystalline) microstructures are being investigated to determine if ballistic performance comparable to current systems can be achieved at lighter weight. If so, these materials will become candidates for use in personnel and vehicle armor systems.
- **CERAMIC MATRIX COMPOSITES** Comparatively lightweight armor that can be used to protect propulsion and power-generation equipment in vulnerable high-temperature locations.
- **METAL MATRIX COMPOSITES** A lightweight armor that will remain intact, capture fragments, and provide multihit ballistic protection for a number of applications in military systems.
- **POLYMER COMPOSITE ARMOR MATERIAL SYSTEMS** As with many of the other ballistic protection systems, the requirement that motivates the research is to substantially reduce the weight of the armor system needed to prevent penetration by a specific threat, be it projectiles or fragments. Such a system can be expected to be utilized for personnel protection, for specific air- and ground-vehicle applications, and as an applique to protect critical equipment.
- **LAMINATED TRANSPARENCIES** Improved visibility along with lighter weight and decreased volume are needed for personnel protection. The same materials in thicker variations will provide increased survivability when used in transparencies for air and ground vehicles.

Milestone Status:

Milestone No.	Deliverable Description	Due Date	% Complete
1	Quarterly Technical and Business Status Report	9/20/2009	100%
2	F26 Test Hardware (200 each)	9/30/2009	100%
3	Husky Reactive Armor Vehicles Sets (6.5 sets)	10/15/2009	100%
4	Husky Test Coupons (200 each)	10/15/2009	100%
5	Mine Resistant Ambush Protected Armor Prototype Materials	10/30/2009	100%
6	Inert Warhead Prototypes	10/30/2009	100%
7	Prince Reactive Armor Kits (30 each)	10/30/2009	100%
8	JIEDDO Phase I Prototype	10/30/2009	100%
9	TR Strategic Video Phase 1	11/18/2009	100%



10	Quarterly Technical and Business Status Report	12/20/2009	100%
11	TR Strategic Video Phase 2	1/31/2010	100%
12	Quarterly Technical and Business Status Report	3/20/2010	100%
13	LAB JIEDDO Phase II Prototype	3/10/2010	100%
14	LAB Active Armor Prototypes Phase I	3/10/2010	100%
15	TR Strategic Video Phase 3	3/10/2010	100%
16	LAB JIEDDO Phase III Prototype	3/10/2010	100%
17	LAB Test hardware, plates, materials	3/10/2010	100%
18	Test hardware, plates, materials	4/15/2010	100%
19	Test hardware, plates, materials – CSI	3/10/2010	100%
20	LAB Active Armor Prototypes Phase II	3/10/2010	100%
21	TR Strategic Video Phase 4	3/10/2010	100%
22	Manufacturability Reports	4/30/2010	100%
23	Technical Drawings	4/30/2010	100%
24	Final Technical Report	5/30/2012	100%
25	Final Business Status Report	5/30/2012	100%
26	Quarterly Technical and Business Status Report	6/20/2010	100%
27	Task 1A Identify candidate material	6/30/2010	100%
28	Task 1B Prepare Armor Panels	7/31/2010	100%
29	Task 1C Design & prototype multi-functional armor in various sizes & shapes	7/31/2010	100%
30	Task 1D Characterize Properties Phase 1	8/31/2010	100%
31	Task 1D Characterize Properties Phase 2	8/31/2010	100%
32	Annual Technical and Quarterly Business Status Report	9/20/2010	100%
33	Task 1E: Produce prototype multifunctional, lightweight layered material panels that perform two or more primary functions	9/30/2010	100%
34	Task 1EA: Produce prototype multifunctional, lightweight layered material panels that perform two or more primary functions	12/30/2010	100%
35	Task 1EB: Produce prototype multifunctional, lightweight layered material panels that perform two or more primary functions	12/30/2010	100%
36	Task 1EC: Produce prototype multifunctional, lightweight layered material panels that perform two or more primary functions	12/30/2010	100%
37	Task 1FA: Produce Prototypes for Government Testing	6/30/2011	100%
38	Task 1FB: Produce Prototypes for Government Testing	8/30/2011	100%



39a	Task 1FC: Produce Prototypes for Government Testing – Part 1	10/30/2011	100%
39b	Task 1FC: Produce Prototypes for Government Testing – Part 2	10/30/2011	100%
39c	Task 1FC: Produce Prototypes for Government Testing – Part 3	10/30/2011	100%
39d	Task 1FC: Produce Prototypes for Government Testing – Part 4	10/30/2011	100%
39e	Task 1FC: Produce Prototypes for Government Testing – Part 5	10/30/2011	100%
39f	Task 1FC: Produce Prototypes for Government Testing – Part 6	10/30/2011	100%
39g	Task 1FC: Produce Prototypes for Government Testing – Part 7	10/30/2011	100%
40a	Task 1FD: Produce Prototypes for Government Testing – Part 1	12/30/2010	100%
40b	Task 1FD: Produce Prototypes for Government Testing – Part 2	12/30/2010	100%
40c	Task 1FD: Produce Prototypes for Government Testing – Part 3	12/30/2010	100%
40d	Task 1FD: Produce Prototypes for Government Testing – Part 4	12/30/2010	100%
40e	Task 1FD: Produce Prototypes for Government Testing – Part 5	12/30/2010	100%
41a	Task 2A1: Identify candidate materials	2/28/2011	100%
41b	Task 2A2: Identify candidate materials	6/30/2011	100%
42	Quarterly Technical and Business Status Report	12/20/2010	100%
43	Task 2BA Prepare Armor Panels	12/30/2011	100%
44	Task 2BB Prepare Armor Panels	2/28/2012	100%
45	Task 2BC Prepare Armor Panels	4/30/2012	100%
46	Task 2BB Prepare Armor Panels	5/30/2012	100%
47	Task 2C Design and prototype multi-functional armor in various sizes and shapes	2/28/2011	100%
48	Quarterly Technical and Business Status Report	3/20/2011	100%
49	Task 2D: Characterize Properties	8/30/2011	100%
50	Task 2E: Produce prototype multifunctional, lightweight layered material panels that perform two or more primary functions	10/30/2011	100%
51	Task 2F: Produce Prototypes for Government Testing	5/30/2012	100%



52	Quarterly Technical and Business Status Report	6/20/2011	100%
53	Annual Technical and Quarterly Business Status Report	9/20/2011	100%
54	Quarterly Technical and Business Status Report	12/20/2011	100%
55	Quarterly Technical and Business Status Report	3/20/2012	100%

Technical Readiness Level Status: 5

3.2 Problems Encountered and Action Taken

- None

3.3 Technology Transfer

- None

3.4 Plans for Next Quarter: None. Work is complete on this BRG.