Exploration of Novel Technologies to Reduce Lifecycle Maintenance Costs – Phase III

Final Report

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Acronyms and Abbreviations

Term	Definition
CTMA	Commercial Technologies for Maintenance Activities
DOD	Department of Defense
NCMS	National Center for Manufacturing Sciences
ODASD-MR	Office of the Deputy Assistant Secretary of Defense, Material Readiness
OSHA	Occupational Safety and Health Administration
PLC	Programmable Logic Controller
RPM	Rotations Per Minute
U.S.	United States
VRC	VRC Metal Systems LLC

1. Executive Summary

VRC Metal Systems LLC (VRC) established a first-of-its-kind prototype capability to coat items for the United States (U.S.) Army. Excellent results have been demonstrated, but with process inconsistencies and performance variabilities between prototypes based on the work performed on the prototype system, and characterizations of the coatings produced. The system was designed for proof-of-concept to show the ability to coat smaller sections, with the intent of spraying six full size items. Since the installation of the system, there have been over 20 subscale and full-scale items sprayed, plus numerous test sprays.

The original system was developed based on the knowledge the team had from the research and development done on a traditional cold spray machine with standard equipment. Typical equipment included a robot that was capable of handling smaller items. To spray a full size item, the equipment needed to be specialized with a larger capacity and dedicated cold spray equipment. The prototype design evolved through trial and error as the team learned more about the nuances of spraying such items. In addition, there was a short time frame to execute the build of the equipment. Due to the short time frame for execution on the original equipment, the system was developed by more than one entity. Separate entities took on the subsystem component builds. While this helped with the time frame, it also created systems that were not fully compatible with each other. This caused communication inconsistencies and created more room for operator error.

The intent of this phase of work was to refine prototype hardware, software, and processes to yield more reliable, consistent, and repeatable cold spray outcomes. This will ensure that future use of the system will be able to produce repeatable items. The system will continue to be used to conduct further research and recipe development, which will extend the lifecycle of the system well beyond its intended use.

Through prior sprays with the system, it was recognized that motion controls and sensors need to be improved to eliminate variabilities in the spray process because the quality of coating was being impacted. These variabilities have caused significant performance inconsistencies across various prototype articles. Upgrades to hardware for the motion system and sensors were required, as were enhancements to the system’s high-voltage cabinet, support channel, and cold spray delivery mechanisms. These improvements will yield more reliable and repeatable results across all future prototype articles and help in lowering overall costs and reducing waste.

VRC quickly identified the parts that needed to be upgraded or replaced and worked with vendors and internal groups to begin the work. From the execution of the contract, VRC Engineering spent approximately two months at the headquarters making software improvements, building new hardware, and procuring replacement parts for the system. VRC traveled to complete the upgrades, replace components as needed, and complete preliminary testing on the system.

After the upgrades to the system were made, the system underwent validation to prove that the subsystems were functioning as good as or better than before. This validation consisted of verifying that equipment speeds, pressures, temperatures, and flows were functioning within an acceptable, pre-determined range. The final test concluded with coating two full size items, which were then sent out for further testing.

Funding was secured for the collaborative initiative through the National Center for Manufacturing Sciences (NCMS) Commercial Technologies for Maintenance Activities (CTMA) Program and the Office of the Deputy Assistant Secretary of Defense, Materiel Readiness (ODASD-MR).

1.1 Results

The efforts under this phase were intended to improve the performance and longevity of the system. The previous system configuration allowed for inconsistencies, increased operator error, and it proved to be cumbersome and difficult to use. The improvements increased consistency and ease of use, reduced the number of consumables and points of failure, and yielded an item that out-performed every other item coated on the previous system.

1.2 Recommendations

VRC recommends that this system will be used to upgrade and develop a next generation of cold spray systems to match the iterative nature of improved future systems for research and development.

1.3 Invention Disclosure

Invention Disclosure Report(s):

DD882 Invention Report sent to NCMS ☐

No Inventions – (DD882 Negative Report sent to NCMS) ☒

1.4 Project Partners

- U.S. Army Combat Capabilities Development Command (DEVCOM)
- Solvus Global LLC
- VRC Metal Systems LLC
- National Center for Manufacturing Sciences (NCMS)

2. Introduction

2.1 Background

The benefits of new commercial cold spray technology are obvious; the technology offers a host of advantages to manufacturers including minimal oxidation during the process, maintaining minimum wall thickness requirements through multiple repair cycles, allowing retention of composition/phases of the initial particles, reducing or eliminating solidification stresses while enabling thicker coatings to be created, and providing low defect coatings. Moreover, cold spray benefits various industries by reducing or eliminating grit blasting requirements for substrate adhesion, producing a better surface finish, and eliminating distortion. This innovative process allows parts to be repaired multiple times during the lifecycle of the base material, which can lower overall product cost, extend the life of consumer products, and help the environment. Phase I of this effort focused on initial process development to yield high quality coatings over complex part features. Phase II focused on improving upon piloted processes developed under prior work. Phase III was focused on performing system upgrades to a prototype system developed under previous efforts, which are needed to yield a reliable and repeatable cold spray process.

There have been several development items identified over the past several years that would improve spray quality and result in more reliable, consistent, and repeatable outcomes. The following items are major tasks and objectives for this portion of the program that will help to address these issues.

2.2 Purpose

The specific technical objectives are enumerated as follows.

1. Upgrade Motion System
2. Upgrade Motion System Sensors
3. Upgrade High Voltage Cabinet
4. Lengthen Support Channel
5. Hot Gas Tube Improvements
6. Re-machine and Replace Existing Parts as Needed

2.3 Scope/Approach

The items needed to be completed for the DOD for testing and the participants involved wanted to use specific items to test the validity of the system improvements. This meant that VRC had only several few months to complete the upgrades.

To ensure that the work would be completed in time, VRC, along with the government partner, identified the processes, procedures, and equipment that needed to be improved. A task list with execution plans was created.

The items that were identified were done so by looking at all the aspects of the system to determine what should be improved. These were broken out into three main categories: process, equipment, and labor.

Process:

The process of coating an item included set up, spray, tear down, inputting parameters, and the ability to change or adjust any of those listed as needed. This led to identification of the areas that were simple to adjust, and those that required more time, more steps, more personnel or could not be adjusted at all but were needed. The process that fell in the latter categories were the items that VRC focused on improving. Some of these items included programming changes and improvements.

Equipment:

Equipment plays a vital role in the overall ability to successfully coat an item. Since this system was the first of its kind prototype, most of the components were manufactured specifically for this project. They are one-off, made-to-order components that are not always easily replaceable. In addition to this, some of the components have to be disassembled and reassembled at various stages. This leads to inconsistencies in reassembly and a greater chance for operator error. VRC identified the components that could be reconfigured to provide stability, ease of use, and repeatability.

Labor:

The number of employees performing the work, and the number of hours it takes them to perform it can be costly to the entire process. Prep work, set up, actual spray, tear down, and post work can all add up quickly when it comes to the overall cost. VRC evaluated the entire process to determine what more could be done to automate the system, make it more user friendly, and require less inputs. This rolled back into the process and equipment improvements.

3. Project Narrative

3.1 Upgrades to Motion System

The original motion control subsystem was sourced outside of VRC. The original design of the system utilized automation components (motor, drive, cables), that differed from the cold spray components. This led to having two separate controls for the system. One Programmable Logic Controller (PLC) for the cold spray system and one for the motion system. This caused multiple issues in the operation of the system. One issue was that because of the separate controls requiring an operator to enter two separate recipes, there was a higher chance for operator error. The larger issue was that there were two controls that didn't communicate with each other beyond analog signals waiting for a handshake. This also led to issues with the system getting out of sync during a spray which caused an entire system shutdown and restart. To simplify the system and alleviate these issues, VRC removed the different motion system components and second PLC. These were replaced with alike components, similar to the cold spray system. The only major modifications that this required was providing a bigger control cabinet in order to house bigger drives for the new components. In addition to the bigger cabinet, VRC added a new control pendant to replace the old one.

In addition to hardware improvements, numerous improvements to the programming that controls the systems were made. These improvements included adding speed changes, additional passes, specific start and stop points as needed, improved graphics, and improved homing functionality.

The programming changes included many upgrades that resulted in a system that is more robust, more user-friendly, and more repeatable. Future updates will also make it easier to deploy with the new components.

3.2 Start and Stopping Point Equipment Improvements

The original method of starting and stopping the spray in the system relied on equipment that had to be disassembled and reassembled for each spray. This led to inconsistencies in location, which led to incorrect starting and stopping points on the item. The subsystem also had a part that was a consumable item. Although this piece was replaced routinely before a spray, it could easily fail during a spray which could cause a scrapped item. A new subassembly was designed and implemented that didn't have to be reassembled prior to each spray, and it no longer included a part that was known to fail.

3.3 Upgrades to Electrical Cabinets

The original cold spray system had a high-voltage cabinet that contained the heater control that required 480V. The electronics inside the cabinet would generate heat during a spray which built up in the cabinet. The heat buildup would cause the other components to overheat and shut down. Having the cold spray shut down in the middle of a cycle is unacceptable. The solution before the upgrades was to run the system with the cabinet door open, however this was a significant safety issue. Having the door open to a 480V power source while the system was on was not only dangerous, but not allowed per OSHA Standards. In addition to the excess heat, the low-voltage cabinet opposite the high-voltage cabinet was full and did not allow room for additional electrical components. The upgrades included adding new motor controller drives for the motion system. These two issues combined drove the need for a new, larger cabinet.

3.4 Support Channel Upgrades

The original cold spray system relied on a two-piece system to support the cold spray as it traveled along the item. The design was originally intended to accommodate installation as it was known at that time. In addition, finding a manufacturer that could make a one-piece support system also proved difficult. These factors led to a two-piece design. The connection between two pieces required a part that saw a high amount of wear and rotation. This was a point of possible failure during a spray and although it was an inexpensive part to replace, it led to inconsistencies in the assembly and placement. To solve this problem, VRC designed a single support piece with added structural supports that could span the dimensions that were needed. VRC worked with multiple vendors to produce the support piece. This proved to be a difficult process as very few manufacturers had the equipment that could make it and be willing to produce a one-off piece. After multiple vendors and multiple test pieces, a solid vendor was located that could create the piece to match the design.

Once VRC received the support system at the facility and it was fully assembled, work began on fitting it to the top-level system components. When the original prototype was made, VRC made multiple versions of the support system. The knowledge that was gained from that process was applied to the new support piece and it was fit to match the best-performing old support piece. The process of creating a well-performing support piece was heavily documented for use on future support pieces for similar projects.

3.5 Cold Spray Delivery Mechanism

The assembly that is responsible for depositing the cold spray on the asset consists of an inner tube surrounded by an outer tube, with insulation between the two. The insulation serves to keep the inner tube centered as well as to keep as much heat as possible in the tube. The original assembly had two pieces that were connected by a union inside a sleeve. The assembly had not been disassembled since the initial build and was likely leaking gas at the union. This assembly was redesigned to a single piece system. This eliminated the likelihood of leaks, plus also provided a quick method to replace fittings if needed.

3.6 Re-machine and Replace Sub-components as Needed

There were numerous machined parts and consumable items located within the mechanical portions of the system. Some of these components were identified as needing to be replaced, either due to wear or to improve upon designs. Multiple bearings and seals were replaced, along with hoses and other consumable parts.

3.7 Test Trials

Testing of the equipment upgrades was required to ensure the changes made were not only beneficial, but also improved the performance of the cold spray activities. The scope of work included spraying two items. One was considered the destructible test and the other was a non-destructible test. The non-destructible test item was sent to another facility for testing. Before starting the improvements to the system, the team agreed upon acceptance criteria. That criteria included reaching certain RPM, velocity, temperature, flow, and pressure for the various subcomponents. It also required a visual test, coating thickness, and clear start and stop locations for the item coating. At the completion of the spray, all criteria were met, and the non-destructible item was sent on for further testing.

3.8 Conclusions

The results of the upgrades to the system ultimately led to the best performing item to date. This shows that the upgrades made to the system were a success and provided valuable improvements. The changes that were made to make the system more robust, easier to use, and more consistent and repeatable. The work done in this phase will only help to improve the overall program as well as research and development for future programs.

4. Benefits

4.1 Benefits for the General Public

Being able to repair intricate or expensive parts rather than replacing them is a very beneficial capability. There are also opportunities to repair hard-to-remove components in-place, rather totally removing and either repairing or replacing them. Traditional repair methods would require disassembling systems or subsystems to reach the damaged part to remove it, which is often laborious, time consuming, and costly. Repairing these components, especially in place, is a significant factor in why cold spray technology is gaining popularity. It is invaluable to be able to perform targeted repairs as opposed to requiring entire components be removed and replaced.

Using additive techniques to repair parts on site can increase manufacturing up time. Waiting for new parts to arrive or dissembling systems to replace a part can affect the efficiency of a manufacturing operation. Every minute that a line is down will increase the costs for the goods produced on that line. The longer a line is out of commission, the less product that can be produced. This can create shortages of goods for consumers to purchase which will affect their purchase behavior. Developing a process where small, intricate machine part repairs can be accomplished quickly and efficiently will result in a more efficient manufacturing process with a higher manufacturing line availability. This will make manufacturing more efficient and will lower the overall cost of the production of goods which can be passed on to the consumer in the form of lower costs.

4.2 Benefits for the DOD

The overall improved performance helped to save time and money, which ultimately benefits the government. The change to a single piece support system greatly reduced the set-up time, by as much as 25%. Creating a single point of data entry not only cut down on time for set up, but also reduced the chance for user error. Other improvements reduced the risk of a shutdown in the middle of a spray, but also allow for a restart of the system in the rare instance that could occur. Overall, this phase improved an existing system, but also gave the government valuable data to use on future systems and projects.

Over time, the improvements made to the system will yield better results for the overall program. Prior to the upgrades, the system was complicated to use and required replacing multiple parts for each workpiece. This meant that only a small number of people could operate it to perform a spray, and equipment costs were high. Additionally, requiring multiple parts to be replaced for every spray led to inconsistencies with equipment. The upgrades saved the DOD time and money at face value, but also lessened the probability of having failures during a spray due to equipment failure or fatigue. The changes also added ease of use so that other personnel can use it.