Cold Gas Dynamic Spray

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Abstract
Cold gas dynamic spray is a method for applying various coatings to different substrate materials. Metal, ceramic, or polymer powder are introduced into a high velocity flow and directed through a converging-diverging nozzle, which accelerates the particles towards the substrate at such a high speed that the powder particles bond to the material. The benefits of this technology range from increased hardness of the material being coated to the ability to coat certain materials that are sensitive to high temperatures. Northeastern University has developed a need for a safe, low cost, mobile cold spray system for research and software calibration purposes. The group has designed a converging-diverging nozzle with the proper geometry to create the conditions needed to reach proper flow velocities. A heater has been designed to heat the flow in order to accelerate it to those proper flow velocities. A hopper was designed to introduce the powder particles into the flow. The system has been set up and has shown that the heater will get the gas up to the necessary temperature for deposition and will theoretically deposit particles to a substrate. Testing will continue over the next week to confirm deposition.
The Need for Project

Northeastern University will benefit from a Cold Gas Dynamic Spray system for software verification and research.

Northeastern University's College of Engineering is very interested in this technology for its use as a coating method. Right now, the school only has the capability to shoot one 1/64” particle at a time with a velocity of 100 ft/sec. This particle size is too large and the velocity is insufficient to be able to make it bond with a substrate. The University requires a safe, low cost, mobile solution that will allow the university to research this technology in different labs within The Egan Research Center. The college would also be able to use this technology to calibrate modeling software such as ABAQUS, comparing the outcome of CGDS with the computed results.

The Design Project Objectives and Requirements

The design must use existing Cold Gas Dynamic Spray technology for a safe, low cost, mobile solution.

Design Objectives

CGDS is already a proven technology and already has commercial products available on the market. These products are very expensive, with all systems exceeding $45,000. These units are built for constant commercial use, and therefore are very robust, increasing the price. The college does not have the funding to buy one of these commercial units, as it will only be for limited lab use. The design must use existing Cold Gas Dynamic Spray technology for a safe, low cost, mobile solution to be used for research at the University.

Design Requirements

There are some specific design specifications for this project must adhere to in order for it to be successful. The overall goal is to compare the theoretical computer simulations using the ABAQUS software package to the experimental results obtained from the CGDS system. To do this the system must be able to cover a 75mm x 75mm plate of copper or aluminum with a desired thickness of .2mm for the coating. This must be done in a reasonable amount of time; the team determined this to be about 5 minutes. This must be completed by supplying a steady flow rate of particles. Another critical design specification for this system is its portability. This system will be primarily used in Egan Research Center and only brought out when needed. The system should be able to be rolled over to a ventilation hood and easily set up, used, and stored back in an out of the way location. A portable system will
be crucial, considering the limited space in laboratories. All these requirements must be fulfilled while supplying a safe and reliable system.

**Design Concepts Considered**

We developed several design concepts for both hopper and integration plans. Several iterations were considered for the major components of the design in order to design an optimal system for the University’s use. The following section contains descriptions of some of the concepts considered.

**Hopper Design Concepts**

A major deciding factor in how long it takes to coat a plate is the feed rate or mass flow of the powder from the hopper into the flow. The feed system will need to house and inject 10 micron sized particles into the gas flow upstream of the nozzle. The team narrowed the options down to 2 major concepts; a gravity fed hopper and a lead screw feed system. The lead screw concept uses a lead screw to draw powder from the hopper into the flow.

One iteration of the lead screw idea places the lead screw into the middle of the flow to ensure a good carrier gas and particle mix. The second concept recognizes that if the feeder is placed early enough in the system, the gas and particle mix will be uniform by the time it reaches the end of the nozzle. However, sealing this system and adding electronic control will become complicated.

The gravity fed system is a simple design with a hopper mounted above the gas flow. A correctly sized nozzle will allow the exact amount of powder to be vacuumed into the flow. The team recognized the flow of the passing gas might not be a significant pressure drop over the opening to the feeder. There is no way of ensuring a constant particle stream into the carrier gas flow. A possible solution to this issue could be to divert the flow of the gas to inside the powder hopper and force the particles out through an opening into the flow. One complication with this design is regulating the flow of particles into the system.

**Integration Design Concepts**

Another critical success factor is the integration of the entire
system. From past research it was found that some systems had the powder in a carrier flow and another flow of pure gas. Both gases converge, then were heated and then pass through a convergent-divergent nozzle. One of the team’s concepts had a stopper fixed in the center of the flow that could be moved forward and back with an external switch or trigger system. This stopper, when in the “off” position, would move forward and block the entrance to the converging-diverging nozzle, stopping the flow of inert gas from entering the nozzle. This stopper would be surrounded by a seal to prevent particles from entering the flow until the trigger has been pulled to a certain extent. This system has many benefits, but is also quite complicated.

The gas selection was also a major decision for a successful design. It was first though that compressed air could be sued to save money because the system only needed to prove the concept of CGDS. Later it was determined that an inert gas would actually be cheaper because the air would have been treated to be very dry. Inert gases also have the added benefit of being relatively inexpensive and will guard against oxidation of the deposited particles.

**Recommended Design Concept**

The team’s final design heats Nitrogen, then introduces the powder, and finally the mixture passes through a converging-diverging nozzle and on to the substrate.

**Design Description**

The team’s final design heats Nitrogen, then introduces the powder, and finally the mixture passes through the nozzle and on to the substrate. It does this using a gravity fed hopper with a piped in back flow pressure. The N₂ is heated by piping it through copper tubing wrapped in MINCO electric heaters. These two flows mix in a specially designed mixing chamber. The flow is then pumped through nozzle designed by the team. The final nozzle dimensions were extrapolated from nozzle inlet, exit and throat relationships. The inlet of the nozzle is 6.35 mm in diameter and it then converges down to a throat diameter of 0.797 mm. After the throat the nozzle then diverges to a diameter of 0.938 mm. A converging-diverging nozzle with these dimensions will theoretically provide a supersonic gas flow, having a Mach number equal to 1.75. This system will sit on a extruded aluminum frame with a fixture with handles for moving
Analytical Investigations

A supersonic flow must be achieved due to the fact that the projected particles must reach a critical velocity greater than the speed of sound. In order to reach supersonic flow, a de Laval, or converging – diverging nozzle must be used in a compressible fluid flow. To begin the analysis, the team defined all of the known conditions in the system. If the nozzle is depicted as a control volume, and the surroundings are in a lab, the pressure and temperature directly after the exit must be the conditions of the room. Similarly, the conditions at inlet will be those of the connecting system. To simplify the calculations, it was assumed that the friction along the inside of the nozzle is negligible. This claim is supported because the ultimate goal is to produce a very smooth finish and the amount of surface area is minimal. Due to relatively small nozzle passage surface, one can also assume that heat transfer to or from the fluid flow in the nozzle will be negligible. With these two conditions in place, no heat or energy will be added to the system, thus making it an isentropic process i.e. reversible, and adiabatic. The target critical particle velocity to bond both Al and Cu particles to a substrate was found to be approximately 600 m/s. To determine the geometry for the nozzle, a spreadsheet was used to calculate and organize all of the necessary information. This was designed to update dynamically based on certain input criteria.

Using copper pipe for the system's heater allowed for the assumption of a constant pipe surface temperature. Finding Reynolds and Nusselt numbers, the convection heat transfer coefficient was found for the inside of the heated copper pipe. Using principles of free convection, the heat transfer coefficient was then found for the outside of the pipe. Using this information in radial conduction equations, the thickness of the insulation around the copper pipe was found to be 2 inches.

Experimental Investigations

Rudimentary tests have been run on the heater assembly, to ensure that the necessary temperatures are reached. After running for 15 minutes, the heater reaches the necessary temperature of 200°C, however when compressed gas is passed through the heater the
temperature drops dramatically. The team believes that this is due to the lack of insulation on the heater and will be remedied when the insulation has been delivered. Testing will continue this week to confirm deposition of particles to substrate. The system has been set up in a hood and will be tested on samples of copper and aluminum. The team will attempt bonding both copper and aluminum particles.

**Key Advantages of Recommended Concept**

The major advantages the chosen design is its simplicity and very low cost over other concept ideas and commercially available systems. This simplicity allows the system to be manufactured and used inexpensively and easily.

**Financial Issues**

As cost was a major design constraint of this design, the cost of every component of the design was tracked very closely. Off-the-shelf components were used as often as possible to keep costs down. Also many of the unique parts were machined by team members to ensure quality while also reducing cost. The most expensive item was the supersonic nozzle due to its complexity and inherent precision required. The cost of this was kept down by using a machinist the team has a personal relationship with through FIRST robotics. This allowed us to get the nozzle machined professionally at a reduced price.

**Recommended Improvements**

A major improvement the team would make if given the time and financial backing would be to add automated control. Automated control would allow the operator to ensure even coating on the sample substrate. Also the team would recommend machining components particularly the nozzle out of a more robust material to prevent erosion and wear by the particles passing through the system.