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Using Fiber Optics for Laser Cladding

IVB-1

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ABSTRACT

In many Navy structures, there are many large components that are coated for wear protection (valve seats) and/or for corrosion protection (hatch seals) that require periodic refurbishment. This refurbishment is normally accomplished using conventional arc welding processes which in many cases require that the part be removed from the structure to properly control the pre-, interpass and post- weld temperatures as required by the materials used. The removal of such large components, the thermal requirements, and the resulting distortion can greatly increase the cost for refurbishment.

The Navy Manufacturing Technology Office (MANTECH) of the Office of the Assistant Secretary of the Navy has been funding two major programs through Mare Island Naval Shipyard, Naval Sea Systems Command (NAVSEA 5142), and the Applied Research Laboratory, The Pennsylvania State University (ARL Penn State) to decrease such high refurbishment costs. The first program is the development of high powered laser cladding processes for the refurbishment of components that can be removed from the ship and into a laser materials processing facility. The second, and the primary topic of this paper, is the development of a shipboard laser materials processing system that utilizes fiber optics.

INTRODUCTION

As the age of the U.S. Navy fleet increases and efforts are being made to prolong the life of surface ships and submarines, the cost for refurbishment has increased substantially. One source of this increased cost is due to the refurbishment of worn and corroded parts. These parts must be refurbished or replaced, both of which are expensive and time consuming. In a refurbishment, the worn/corroded areas must have material added so that the part can be machined to meet the dimensional requirements. Examples of such parts include valve seats (Figure 1), bearing areas shafts, hatch seals, and through hull penetrations. Many of these parts have very stringent dimensional requirements which are difficult to meet if conventional arc welding processes are used due to the thermal distortion characteristic of the process. Also, many of the cladding materials and the base materials require pre-, interpass, and post weld temperature controls (MIL-STD-278) which are not always possible during shipboard refurbishment. It is therefore very common for parts to be removed from the ship for refurbishment. This removal can be very costly, especially for submarines, where many of the components that require refurbishing do not fit through existing openings.

Figure 1.
Example of valve component that is candidate for laser cladding operation. Base materials are carbon steel and 416 stainless steel. Clad material would be Stellite 6.

In addition to the problems related to the distortion of the parts, some of the cladding materials that are used are not very weldable. Such materials include cobalt based alloys (e.g, Stellite 6) which are used to hardface valve seats. The weld cladding of the valve seats with such materials can become very expensive if repeated cladding and machining is required to remove defects. Many of the problems with these types of cladding materials are related to the high temperature ductility which is related to the segregation, dilution, and/or cooling rate of the process used.

The implementation of lasers in industry has occurred in the last twenty-five years. Industrial lasers are normally one of two types gaseous (e.g., CO_2) or solid state (e.g., Nd:YAG) (1,2,3,4). Each type of laser may differ in design and/or operation based on the power required and the type of process that is to be performed. In both laser types the coherent, collimated, infrared light that is produced can be focussed to a very small diameter and therefore very high power densities can be achieved (10^5-10^8 w/cm^2). Such high concentrations of energy results in low total heat input to accomplish the desired material processing (e.g., laser cutting, cladding, or welding). For example, 12.7 mm thick HY- and HSLA steel plates have been laser welded without filler metal at approximately 20 kJoules/in of heat input. The interaction characteristics between the laser beam and the material are very similar to electron beam processing, however, laser processing normally occurs in air and is more flexible to manipulate using lenses and/or mirrors instead of magnetic coils. There are numerous examples of laser materials processing in industry to date. They range from the drilling of vanes and blades of jet engines, to the laser welding of the recuperators for the Abrams MlAl Army main battle tank (11) (Figure 2) using low power lasers, to the welding of locomotive engine components, and the cladding of aircraft carrier catapult components with multi-kilo Watt lasers. Lasers have been used in these applications because the low heat input of the process results in minimal amounts of distortion and small Heat Affected Zone (HAZ's).

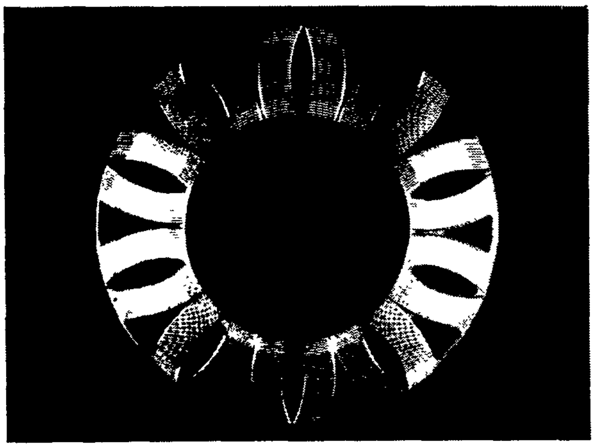

Figure 2.
Abrams AGT-1500 recuperator plate that is laser welded. Laser welds join plates along the ID's of the "footballs" and "triangles". Material is Inconel 615; 0.0081" thick.

Most industrial gaseous lasers are CO, lasers. This type of laser produces a beam of light at 10.6 microns at power levels from tenths of a Watt to 25 kilowatts. It can be used for welding or cutting on circuit board components at low power levels or for the welding of 12.7 mm thick steel plates using 10 kilowatts of power. The beam is delivered from the laser to the work piece using a series of mirrors and/or lenses in a beam duct. An example of a complex beam delivery system is the Laser Articulating Robotic System (8) (LARS) (Figure 3). Because of the high precision of the beam delivery, the LARS and similar systems (8, 9) are very complicated and expensive.
limited the use of CO, lasers to assembly lines and work stations.

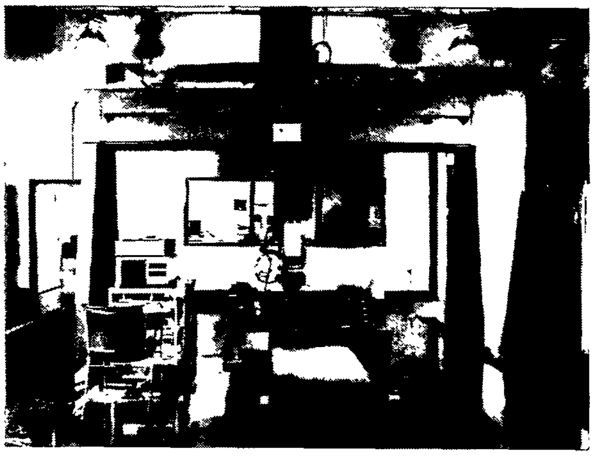

Figure 3.
Laser Articulating Robotic System (LARS)

Some efforts have been made to use CO, lasers for in-situ operations. An example of this is the use of a low power (less than 1 kW) CO, laser to make heat exchanger repair welds (10). The system used a complex robot and "smart", self aligning mirrors to deliver the laser beam to the work piece.

The solid state laser has not changed dramatically since the first ruby lasers of the 60's. Today's industrial solid state lasers primarily use crystals of yttrium, aluminum, and garnet (YAG) or this combination doped with small amounts of neodymium, forming Nd:YAG glass (1). Most of these lasers are powered by flash/quartz lamps and have an average maximum output of 600 watts. In the past, these lasers have been used primarily for drilling and cutting in a pulse mode operation. An advantage that the Nd:YAG laser has over the CO_2 laser is that its beam can be delivered through a flexible fiber optics cable. This allows for more flexible work stations and the possible use of conventional robots.

The Navy MANTECH office is funding a research program with the goal of developing, qualifying, and demonstrating a laser cladding process that is targeted for the refurbishment of submarine components which require hardfacing and corrosion protection. The laser cladding operation consists of depositing a powder directly in front of the laser beam which is at or near focus. The laser beam is oscillated perpendicular to the travel direction melting the powder and a minimal amount of base plate material (Figure 4). This results in a minimal amount of distortion due to thermal gradients. Also, because the heat input is minimal, the molten pool solidifies rapidly with little or no segregation. The result is low dilution clad with minimum distortion.

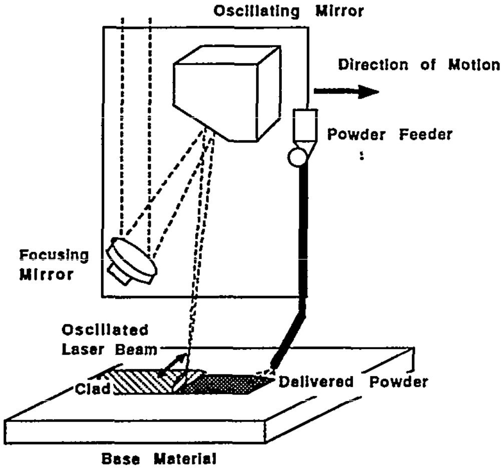

Figure 4.
Diagram of laser cladding system used with the high powered CO_2 laser.

Laser cladding procedures have been developed for a number of material combinations. The Navy MANTECH program has concentrated on cobalt/tungsten alloys (e.g., Stellite 6) for hardfacing material on a number of stainless and low carbon steels. The program is also in the process of developing laser procedures for the corrosion cladding of nickel-copper (e.g., Monel), nickel-chrome (e.g., Inconel 625), and nickel-chrome-molly-tungsten (e.g., C-276) on HY- and HSLA- 80 steel alloys. This development work is being accomplished using a 14 kW CO_2 laser. The goal is to develop, qualify, demonstrate, and transfer the technology for the laser cladding of submarine components. The targeted components, such as main steam and sea water valves, can be removed for this operation.

To date, the Navy MANTECH CO_2 laser cladding program has been very successful. Laser parameters have been developed and optimized for the cobalt-tungsten hardfacing material on 316L and 416 stainless steels and 4140 and DH-36 carbon steels. Metallurgical specimens have been made of the clads to measure the amount of dilution (Figure 5), evaluate the interface between the clad and the base materials (Figure 6), and to determine the microhardness of the HAZ and clad (Figures 7-9). Special "donut" shaped specimens were clad to determine the crack sensitivity of the process (Figures 10-12). Using optimized parameters, qualification clads have been produced and evaluated according to MIL-STD-248C. All of the clads have been made with no preheat to the substrate.

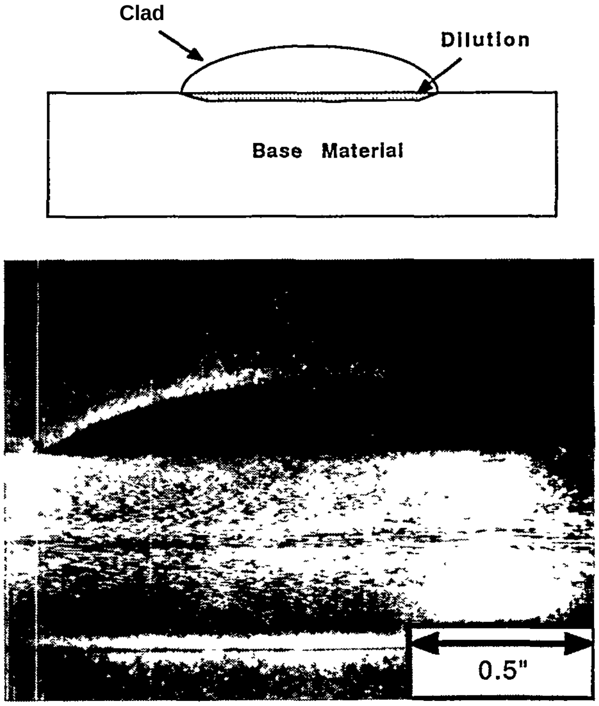

Figure 5.
(Top) Diagram of laser clad showing the base material, clad, and dilution material. (Bottom) Photo-macrograph of laser clad with Stellite 6 on 316 stainless steel.

The high powered CO_2 laser cladding development program was well suited for a number of components that can be removed. But not all of the components that may require refurbishment can be easily removed and some components must be removed from the ship/sub through openings made in the hull of the vessel. This is extremely time consuming and

Figure 6.
Photo-micrograph of interface between Stellite 6 clad (top, white region) and 416 stainless steel (bottom, dark material).

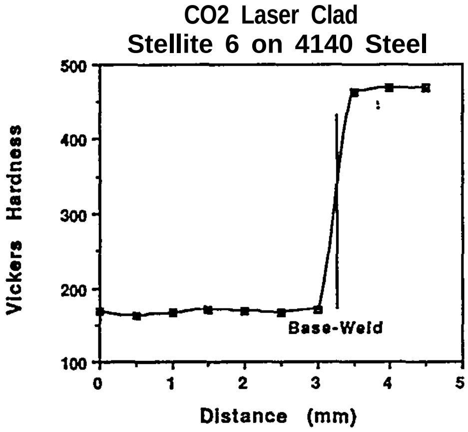

Figure 7.
Microhardness profile for laser clad of Stellite 6 on 316 stainless steel.

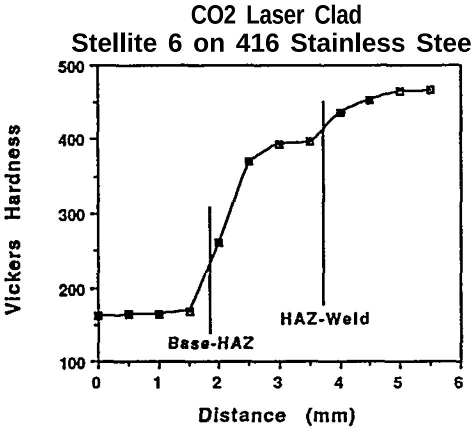

Figure 8.
Microhardness profile for laser clad of Stellite 6 on 416 stainless.

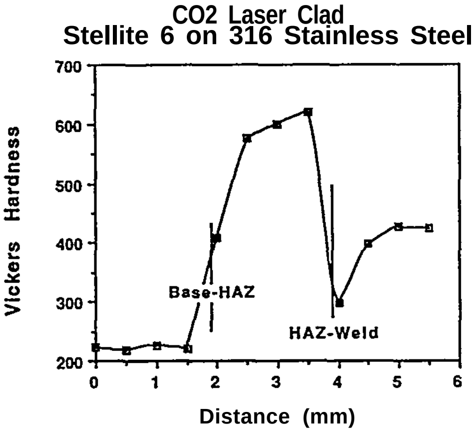

Figure 9.
Microhardness profile for laser clad of Stellite 6 on 4140.

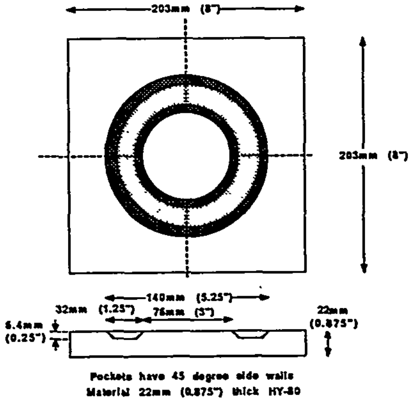

Figure 10.
Diagram of "Donut" test specimen that was used to determine the crack sensitivity of the laser cladding process.

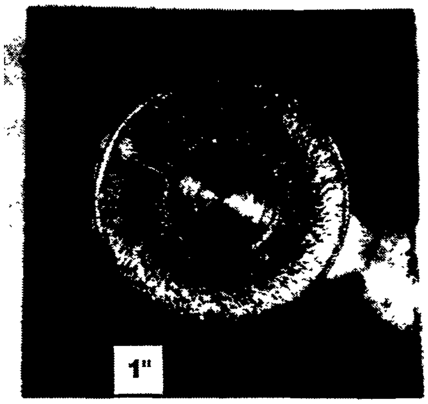

Figure 11.
Photograph of laser clad "Donut" specimen.

Figure 12.
Cross section of "Donut" specimen showing the Stellite clad in the pocket;

expensive. However, special tooling exists that allow for many of these components to be machined in-situ.

The second Navy MANTECH laser program has the objective of developing a method by which the laser cladding process can be accomplished on-board the ship. The use of such a laser system could minimize the dilution of the clad, decrease distortion, and eliminate the need for preheating and controlled cooling of the part. The program has centered on recent developments in the power output of Nd:YAG lasers and the use of fiber optics to deliver the Nd:YAG laser light. The goal of the program is to acquire advanced laser technology and develop laser processing techniques that can be qualified for the refurbishment of components in-situ.

As stated before, the maximum average power output for a single Nd:YAG crystal has been approximately 600 Watts of power. A number of companies in the USA and Japan have been developing ways to cost effectively combine the power from a number of different crystals at the work piece. One method is to independently deliver the beams to the work niece by fiber optics (1, 12). The beams can be-delivered simultaneously or overlapped. The fiber optics also allow the beam to be redirected to a number of work stations as demanded. A second method of producing high powered Nd:YAG laser beams is to pass the laser beam through a number of crystals to form a single laser beam that has the power of the combined crystals. Some manufacturers have accomplished this using six standard crystals and the existing cooling methods (13). Power outputs averaging over 2 kW have been achieved for short periods in a pulse mode. Such high power levels have been delivered through fiber optics as well. This system has been used to make field repair welds in heat exchangers in power plant facilities. In this case (14) a 2 kW Nd:YAG laser beam is delivered to the weld by fiber optics. This is an alternative to the use of the CO, laser based system mentioned earlier that used reflective optics to deliver the beam. However, the six crystal configuration used to produce the 2 kW in this system is very large, prone to alignment problems, and very expensive.

Recent advances have been made in the U.S. to modify the design of the multi-crystal laser system to make it more compact, reliable, and less expensive. The result has been a continuous wave laser using three crystals with a constant power output of 1.8 kW. This was achieved by decreasing the diameter of the Nd:YAG crystals and increasing the cooling water flow rate. Because this system is based on three crystals, it is rather compact and can be hardened for shipboard use. To deliver the laser beam to the work piece, the laser beam can be directed into a flexible, hardened fiber optic cable. There is combined power loss from the entering and exiting of the fiber optic cable of approximately 10%. The loss per unit length of cable is dependent on the quality of the fiber and the amount of bend and torque placed on the fiber. However, the 10% loss 'from the ends represents the majority of the power loss. At the work piece end of the fiber optic cable, a set of lenses refocus the laser beam for processing.

The results from the preliminary process development stage for the program indicate that the Nd:YAG can successfully be used to make clads. To date, a series of single and multiple layer laser clads of various material combinations have been successfully made with the 1800 Watt Nd:YAG system. These include cobalt-tungsten on 416 and 316 stainless steels and HY-80 and 4140 carbon steels (Figures 13 & 14). The clads have very low dilution rates as was the case for the high powered CO_2 laser clads and very shallow HAZ's in the base materials. The microhardness values were very similar to those obtained from the CO, laser cladding operation (Figures 15-17). Clads have also been made on previous laser passes. Minor imperfections must be corrected such as inclusions or pores in the overlap areas of the clads. A similar problem occurred in the CO_2 cladding but was corrected through modifications in the powder and power distribution.

The microhardness results from the Nd:YAG clads are very comparable to those of the high powered CO, clads. There appears to be minimal or no softening of the previous HAZ or clad regions.

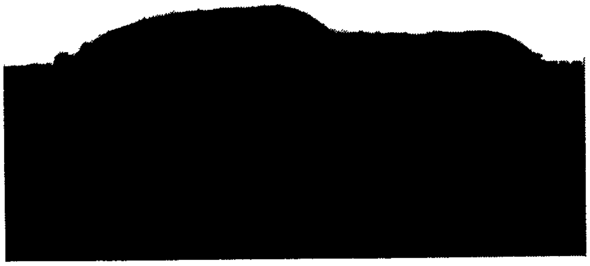

Figure 13.
Nd:YAG laser clad of Stellite 6 on 316 stainless steel.

Figure 14.
Nd:YAG laser clad of Stellite 6 on 416 stainless steel.

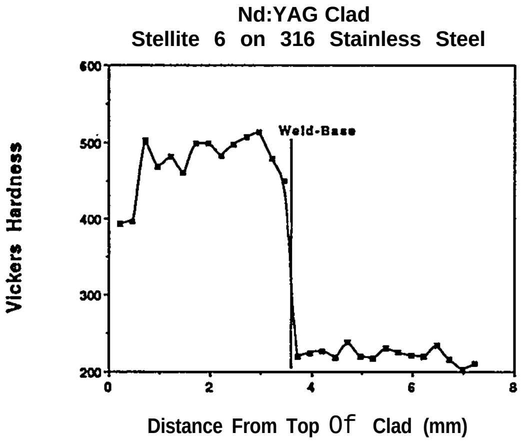

Figure 15.
Microhardness profile for Nd:YAG laser clad of Stellite 6 on 316 stainless steel.

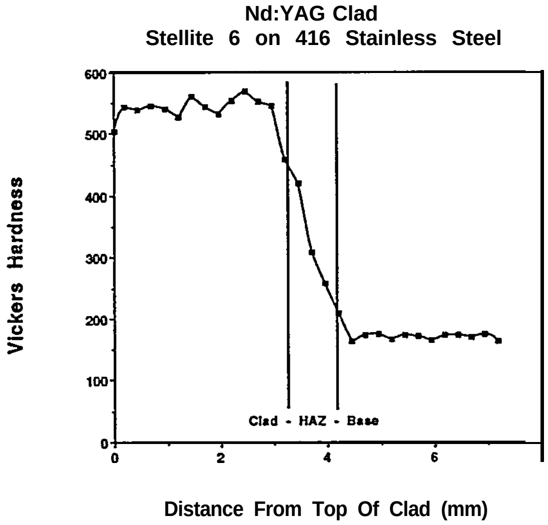

Figure 16.
Microhardness profile for Nd:YAG laser clad of Stellite 6 on 416 stainless steel.

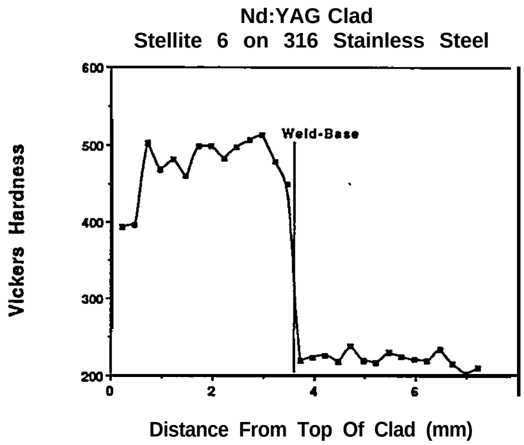

Figure 17.
Microhardness profile for Nd:YAG laser clad of Stellite 6 on 4140 carbon steel.

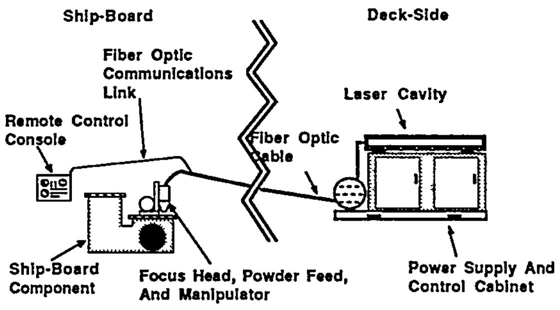

Figure 18.
Diagram of portable Nd:YAG laser system.

All of the results to date have been accomplished in the simplest configuration using standard optics. The cladding has been accomplished in the "down-hand" position using gravity fed powder. Final application for the process will require that out-of-position processing methods be developed. The laser beam used was defocused (not at minimal spot size) which does not give an optimized power distribution during laser cladding. An oscillated and/or linear power distribution of the laser beam is better suited for cladding and is planned for later stages in the program.

The final stage of the Nd:YAG laser materials processing program will be the deployment of a portable laser system to the shipyard. The entire system--laser, chiller, and fiber optics--will be hardened for use on the water front (Figure 18). The planned procedure for utilization of the portable laser system in the shipyard is to position the laser and chiller on the dock or on deck. The fiber optics, laser processing head, and control panel will be passed through hatches and openings to the part that is being processed. The processing head will be attached to a manipulator and the area secured for operation. The manipulator can take the form of a simple linear motion device, modified portable machining equipment, or a small robotic system. The operator will control the laser and the processing through a communication box. The method for delivery of the cladding material has not been finalized. It may take the form of pre-placed powder, compacted powder, sprayed powder or solid inserts.

Future work is already being planned for the fiber optic Nd:YAG laser system. The development of parameters and procedures for laser cutting and welding is planned. A higher powered laser system, at the 2.4 kW level, is under development and is to be bench tested in late FY-91.

SUMMARY AND CONCLUSIONS

There have been a number of successes in the development of a laser cladding system that utilizes a fiber optic delivery system. Some of these accomplishments have been achieved as part of the CO_2 laser cladding program, however, many of the lessons learned there will be applicable to the Nd:YAG laser system. Listed below are a number of the accomplishments to date.

1) Parametric studies have been conducted using high power (14 kW) CO_2 lasers and Nd:YAG lasers for a variety of hardfacing/corrosion clad substrate combinations.

2) Both CO_2 and Nd:YAG laser clads have been found to have very low dilution rates (<10%). For hardfacing materials, this has resulted in high surface hardness values.

3) Both CO_2 and Nd:YAG laser clads have been made with no preheating of the substrate.

4) Qualification clads (MIL-STD-248C) have been accomplished with a high powered CO_2 laser for a Number of hardfacing/substrate material combinations.

5) A portable laser system with fiber optic delivery system is scheduled for delivery for process development by mid FY-91 and with a demonstration in early FY-92.

Based on the rate of success to date, the technology transfer and implementation of the laser cladding process will occur rapidly. This will occur on two fronts; the application of the high power CO_2 laser for the initial cladding of new components and the refurbishment of worn on&s that can be easily removed from a structure. The second front will be in the area of in-situ laser processing and machining for the refurbishment of parts that can not be economically moved and/or refurbished by conventional processing.

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