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Laser Cladding for Surface Protection

by

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ABSTRACT

The Laser Institute combines technical and economic feasibility studies with routine cutting, welding, case hardening, and cladding jobs at its affiliated Job Shop. Laser weld overlaying, or cladding, is performed on a production basis at The Laser Institute. Filler metal is deposited into the molten pool created by the partially focused beam of a 5 kW carbon dioxide laser on the metal surface. A variety of different powder and wire feed devices have been developed at The Laser Institute, for adding filler material. The application of this technology to repair the seating surface of diesel engine valves, using procedures developed at The Laser Institute, will be described.

The effect of laser processing conditions on the properties of Stellite 6SF deposits has been determined. Fineness of the microstructure, as quantified by the secondary dendritic arm spacing (SDAS), was measured as a function of the deposition conditions, and showed approximate agreement when compared to a calculation based on the known dependence of dendritic arm spacing on cooling rate.

Laser weld overlays of Nistelle C-276 were produced using a 5 kW carbon dioxide laser and a modified plasma transferred arc welding torch as a means of delivering powder metal overlay material to the weld pool. Low dilution, crack free deposits with a minimum of porosity were deposited on mild steel substrates. Electrochemical measurements in a brine solution saturated with H_2S showed the laser coated sample performed in a similar fashion to a sample of bulk C-276 alloy.

Laser Cladding for Surface Protection

INTRODUCTION

This presentation is about laser cladding for surface protection, and in particular describes the properties and applications of laser produced coatings. First, however, The Laser Institute itself shall be briefly described. At The Laser Institute, technology is developed in the Research and Development division and then transferred to Lasertech, the job shop division. Several examples of this technology transfer will be given, with the main example being laser cladding.

The Laser Institute is a wholly owned subsidiary of the University of Alberta, Canada's second largest university. It is located in approximately 5,700 square feet of laboratory, materials processing and office space, in a light industrial area. It has a number of laboratories devoted to laser applications in materials processing, optoelectronics and optical sensing, metrology and inspection. Lasertech, the job shop, occupies a further 6,000-square feet immediately adjacent to The Institute. Research, development, and engineering activities of the Institute are carried out in two fields of activity, optoelectronics and materials processing.

OPTOELECTRONICS RESEARCH AND DEVELOPMENT

The Optoelectronics Division of The Laser Institute investigates and develops the integration of lasers with other electro-optical devices, such as scanners, modulators, detectors, CCD video cameras, and optical elements, such as filters, monochromators, and optical fibres. Recent projects have involved optical time domain reflectometry, differential absorption, laser induced fluorescence, interferometry, and

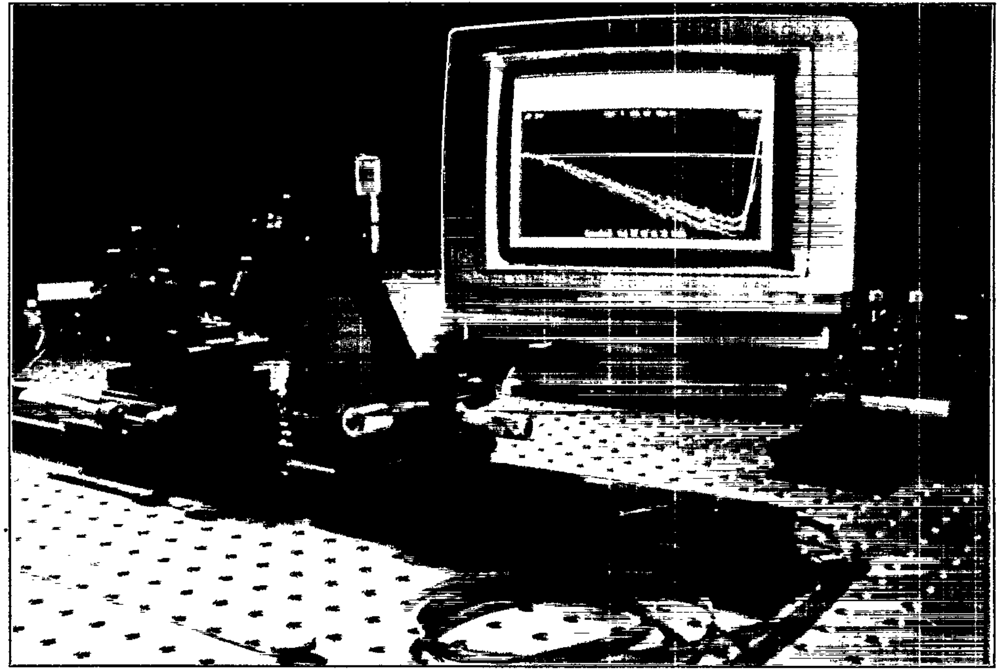

Figure 1 Reflected signal from fibre optic cable, as the fibre is stressed.

fibreoptic sensing, and component inspection using machine vision with feature-enhancing lighting.

In the Optoelectronics area, a recent project was an extensive study for the development of fibre optic strain sensors for sensing of mine wall stability. This study investigated the use of optical time domain reflectometry as a means of sensing reflected signals in the fibre optic as a result of lateral subsurface ground movements to a depth of 50 m with a resolution on a millimetre scale. The method has application to other "smart structures".

MATERIALS PROCESSING

The Materials Processing Department performs two types of activities; one is conducting research, development, and engineering projects for a variety of industrial and government clients. One example of the research and development work in laser materials processing is the contract on processing of Nickel Aluminum Bronze that described earlier in this meeting[1]. Another example is the study of Laser Assisted Arc Welding[2,3,4], a process that has been described at previous CRAD meetings. In this process, the relatively expensive but highly controllable power in a focused laser beam is augmented by the inexpensive power from an arc. Welding procedures using the combined processes were developed at The Laser Institute, and coupons submitted to DREA for testing.

The second type of activity pursued by the Materials Processing department is developing procedures for work being conducted by The Job Shop. One example of this is transformation hardening or case hardening of ball bearing grooves in high pressure swivel joints in piping. The processing conditions for these AISI 4140 steel joints were determined. Figure 2 shows the cross-section of the groove, laser hardened with the beam of a 5 kilowatt carbon dioxide laser partially focused by a beam integrator.

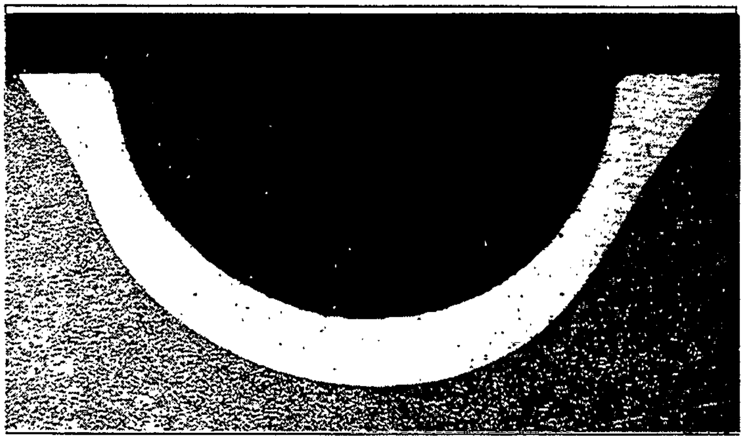
Figure 2 Hardened region in ball bearing race

Laser transformation hardening requires determining the processing conditions such that the material is heated above the phase transition temperature, and held for a dwell period, without melting the material surface. Heat buildup in the material must be controlled, because conduction to the bulk of the material must result in rapid cooling of the surface region, producing a hard Martensitic microstructure. Figure 3 shows how the depth of hardness can be varied by changing

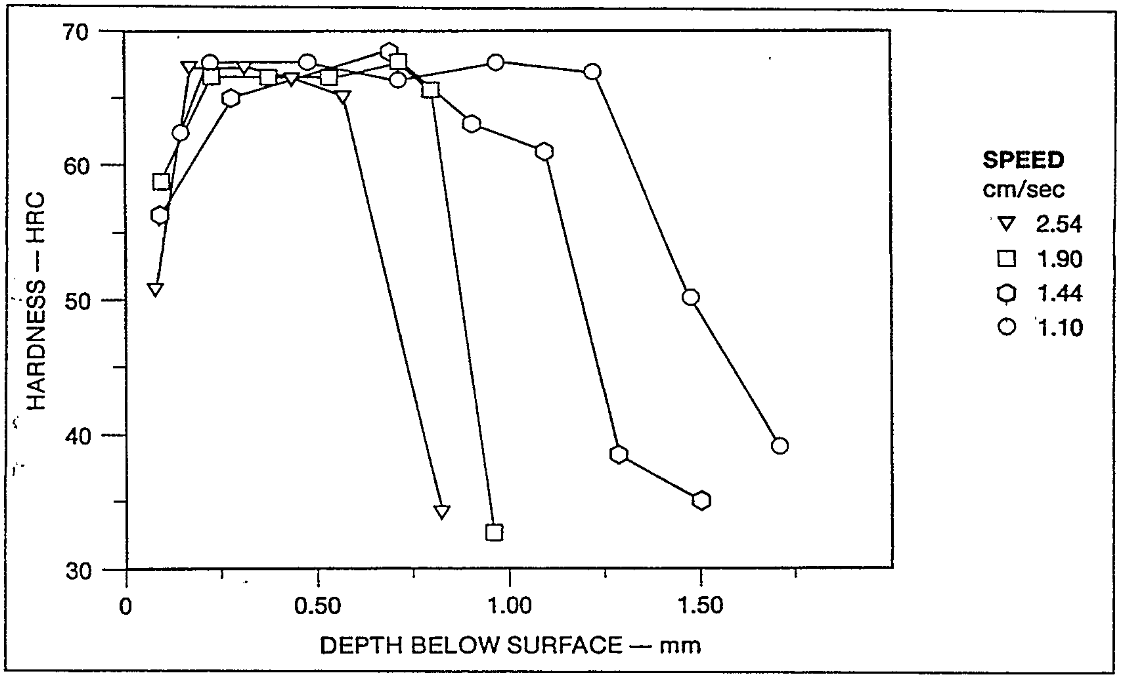

Figure 3 Case Depth in laser transformation hardening of AISI 1070 steel

the laser processing conditions, in AISI 1070 steel. For these measurements, a 3 kW beam concentrated with beam integrator to a width of 12.5 millimetres, was scanned at speeds ranging from 0.6 to 1.5 meters per minute, producing depth of hardening that varied from 0.75 mm to 1.5 mm. The metal became fully hardened, although a less hard region occurred on the surface due to partial decarburization of the steel during prior treatment.

LASERTECH

Lasertech, a division of The Laser Institute, serves a wide range of industrial clients. In the materials processing area, noteworthy equipment includes:

- a 5000 watt carbon dioxide laser coupled to a 5 axis work-station
- a 700 watt Nd:YAG laser, coupled to the same workstation
- a 1600 watt carbon dioxide laser coupled to a 4x8 foot flatbed cutter,
- a 1700 watt carbon dioxide laser coupled to a rotary cutter. Various pipe sizes, in lengths up to 8 meters, can be cut.
- a 50 watt carbon dioxide laser on a flatbed cutting work-station, used for cutting plastics and other non-metallic materials

All of the CNC work-stations are linked to an AUTOCAD system to facilitate rapid parts programming. The rotary cutter, shown in Figure 4, was used to cut about 60,000 meters of pipe in 1994, with many different hole patterns and spacings, for use in perforating guns. Besides cutting, job shop activities include welding, transformation hardening, and cladding. In a recent welding job, 1250

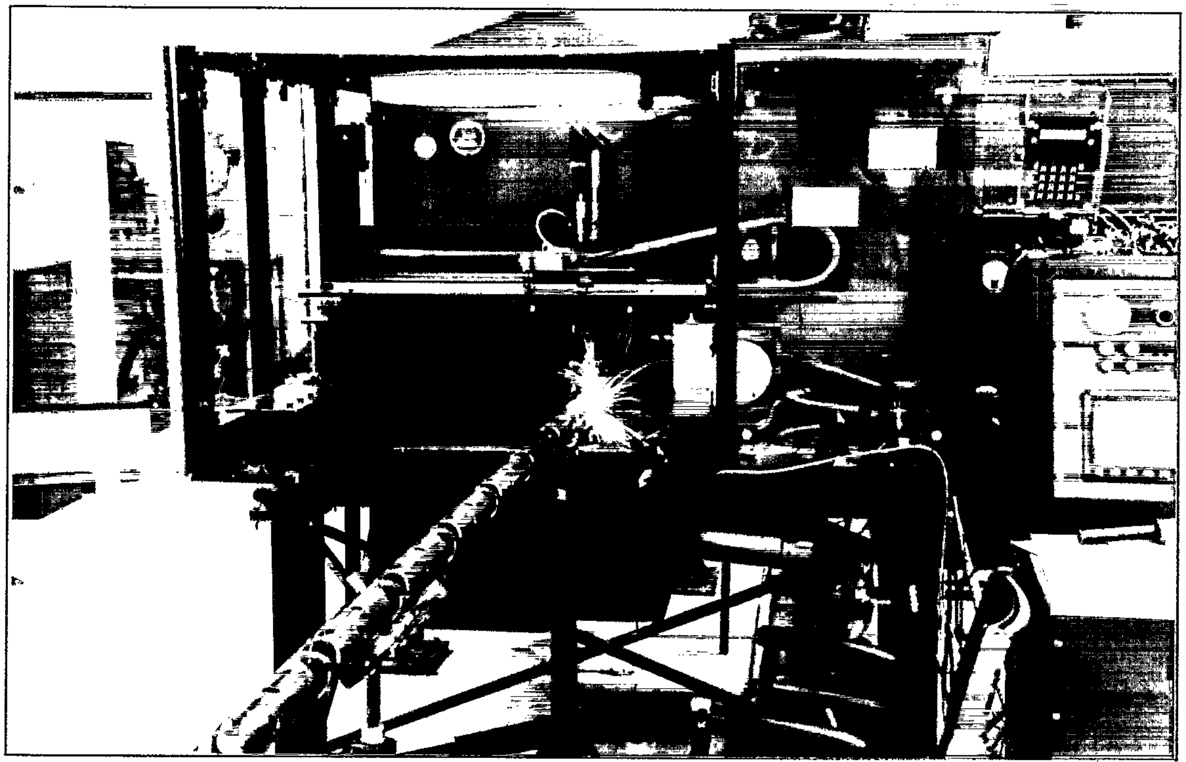

Figure 4 Rotary cutter at Lasertech, cutting pipe

condenser tubes of ASME 310 stainless tubes with wall thickness 0.083" were joined with a welding process approved to the specifications of the ASME Boiler and Pressure Vessel Code, Section IX. The technology for laser Transformation Hardening has been transferred from the R&D Materials Processing group, to LASERTECH, which is now pursuing this activity on a job shop basis. Personnel from the Materials Processing group are available to establish processing conditions on an as-needed basis. Processing of the swivel joints referred to above is one example of an ongoing transformation hardening job.

LASER WELD OVERLAYING, OR CLADDING

The essence of laser cladding is deposition of filler metal into the molten pool created by the partially focused beam on the metal surface. The work at The Laser Institute has used the beam from the 5 kilowatt CE-5000 laser. Filler metal is added using either a powder feed or a wire feed. Wire feed is accomplished using either a Hobart 2210 Wire Feeder or a custom built wire microwire feeder. The Hobart wire feeder was designed for use with gas metal arc welding, but was adapted by using a custom designed torch and integrating the wire feeder controls with the Computer Numerical Control programs of the laser system. The microwire feeder is similar to one designed at Sandia National Laboratory[5] in the United States. This unit uses a high speed stepper motor to drive rubber coated wire drive units, with a hypodermic needle to collect the wire as it is ejected from the drive wheels and guide it into teflon lined tubing. A personal computer is used to program the stepper motor controller, but motion is initiated by a signal from the CNC controller of the laser workstation.

A CCD camera is used with the microwire feeder, to aid in relative positioning of the wire, the seam, and the beam. The camera is mounted off to the side of the focusing column, and views the workpiece through a mirror mounted at 45°. The workpiece can be viewed only during the set-up to welding, with the mirror withdrawn out of the beam path during actual welding. Figures 5 and 6 show the wire feeder and the torch respectively.

Use of the microwire feeder allows control over the rate at which the weld pool cools. A standard wire feeder, using coarser wire, requires higher laser energy input and hence a slower cooling rate. The microstructure of the weld can be controlled because of the range of cooling rates that are accessible. For example, in forming weld overlays of Nickel-Aluminum-Bronze, a weld overlay with a largely single phase microstructure was created, as discussed in Reference 1.

Two different torches have been used to deliver powder to the weld pool. One feeds powder into the leading edge of the weld pool. The other feeds powder collinear with the beam and allows multi-directional operation. This is a modified nozzle for cladding by plasma transferred arc (PTA) welding. The centre electrode of the PTA nozzle has been removed, and the laser beam directed along the centerline of the torch. The laser beam was focused inside the

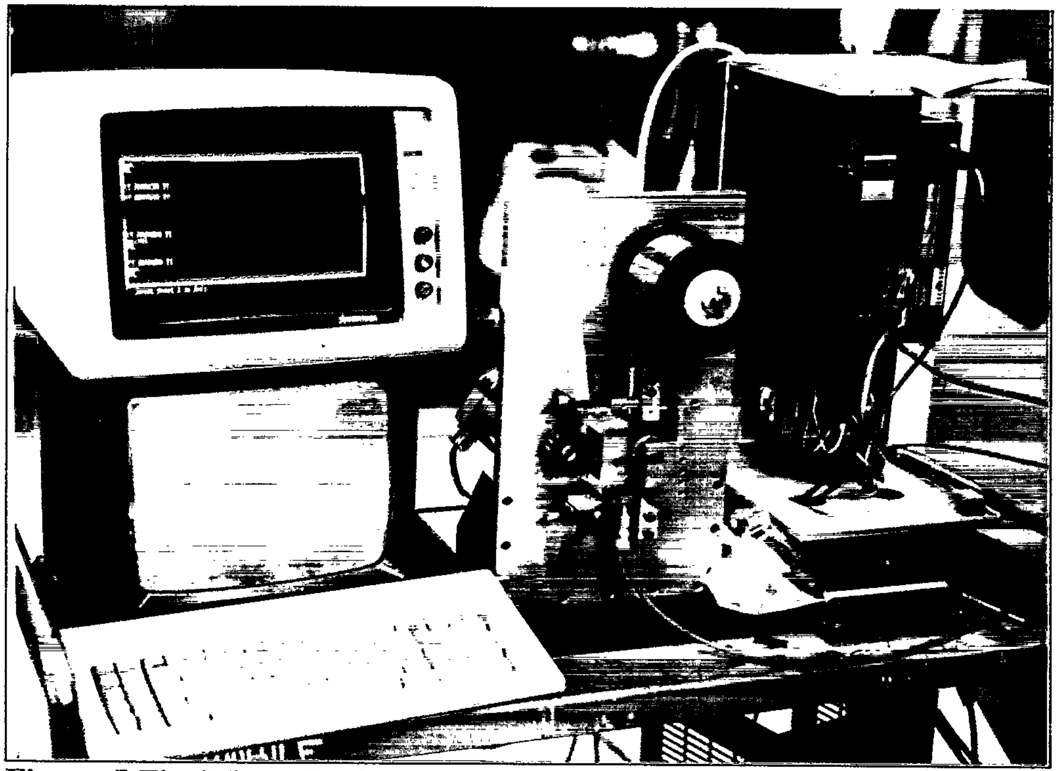

Figure 5 The Microwire feeder designed and constructed at The Laser Institute.

nozzle, so that it diverged as it emerged from the nozzle. This required judicious machining of the inside surface of the nozzle, to match the taper to the conical path of the converging laser beam.

The beam is brought inside overhead beam tubes from the laser to the workstation, then deflected by a 45° mirror downwards through either a 38 cm focal length antireflection coated zinc selenide lens or a 50 cm focal length mirror system. The converging beam passes through the nozzle and is diverging as it strikes the workpiece. An overhead powder feeder, integrated with the CNC control of the laser system, supplies a metered flow of powder into the beam-workpiece interaction area. The position of the workpiece below the nozzle is chosen so that the diameter of the beam approximately matches that of the powder distribution flowing from the nozzle.

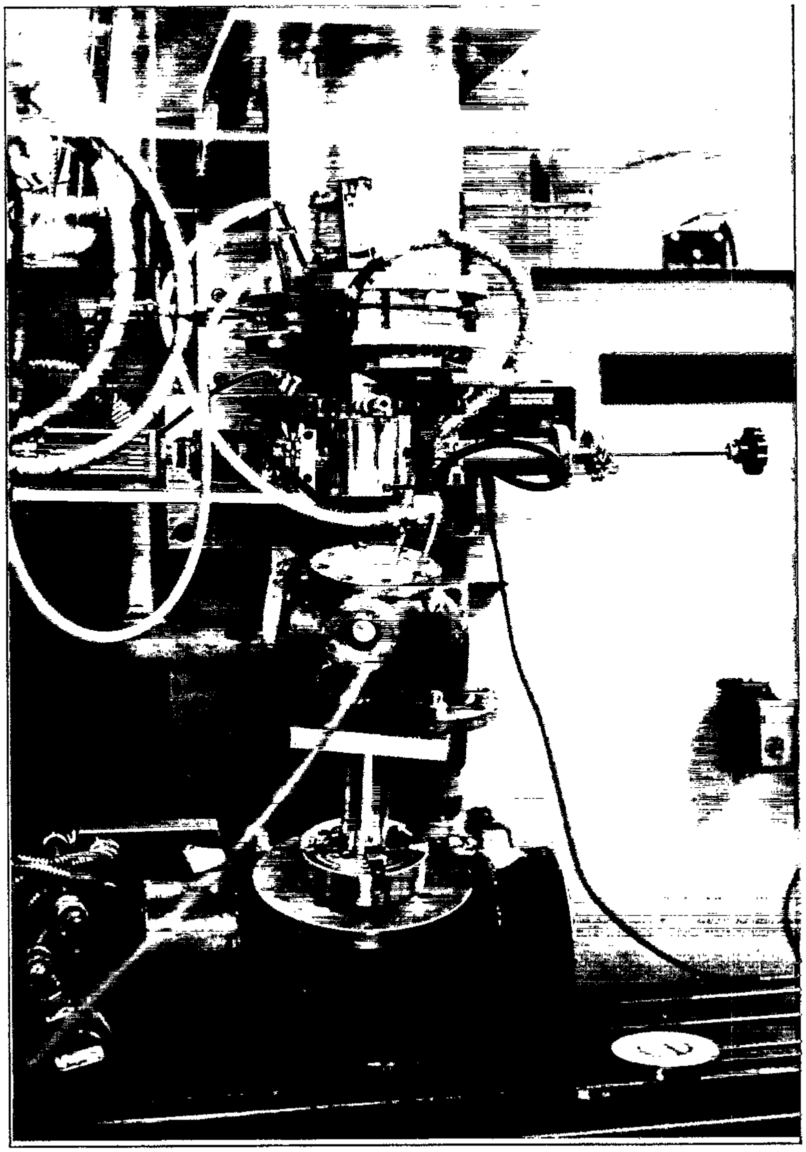

Figure 6 The focussing head, showing the wire feed nozzle attached. The CCD camera is visible to the left of the focusing head; a knob to the right of the focusing head is used to adjust the position of the viewing mirror.

The laser beam does not directly impinge on the base metal, but only on the powder being deposited, as shown in Figure 7. The base metal is heated primarily through conduction through the partially solidified build-up, and not directly. This allows control of the dilution, or mixing, of the base metal with the deposited material. Figure 8 shows a cross-section, and part of the upper bead, of a weld overlaid track on mild steel, in which the low dilution is particularly evident. Figure 9 shows the cross-section and upper bead of a series of side-by-side passes in which C-276 alloy is deposited on a coupon of AISI 4140 steel.

Figure 7 Deposition of Powder During Laser Cladding

PROPERTIES OF LASER PRODUCED COATINGS

An extensive study of the microstructure of laser deposited coatings was undertaken. In this work, a partially focused beam was scanned over preplaced powder, rather than using a powder feeder. This experimental procedure resulted in the ability to control the deposit thickness and scanning speed independently. Figures 10 shows the microstructure of a Stellite* 6SF deposit created by a set of parameters producing a low heat input. There is a narrow region in which planar solidification occurs; the dendritic microstructure above this region are much finer than when high heat input was used. The secondary dendritic arm spacing (SDAS) was measured for coatings created under a variety of conditions; the results are plotted against the deposition conditions in Figure 11. Clearly, the linear heat input doesn't uniquely determine the SDAS; there is some dependence on power and speed individually. The cooling rate in deposits created as described above was calculated using the Rosenthal 3-dimensional model[6] for heat flow in the material. The cooling rate was then translated into a predicted SDAS, using the measured[7] dependence of SDAS for Stellite 6; the results are also shown in Figure 11.

In spite of the approximations inherent in this calculation[8], this approach was shown to result in rough agreement between the calculated values for SDAS and the measured values. The Rosenthal equation assumes a point heat source and results in a cooling rate that

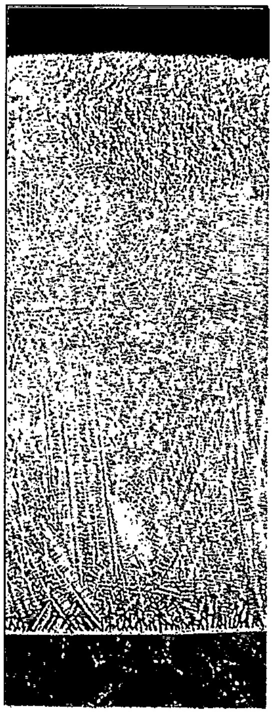

Figure 10 Solidification Microstructure of preplaced powder fused with a heat input of 112 J/mm (400X)

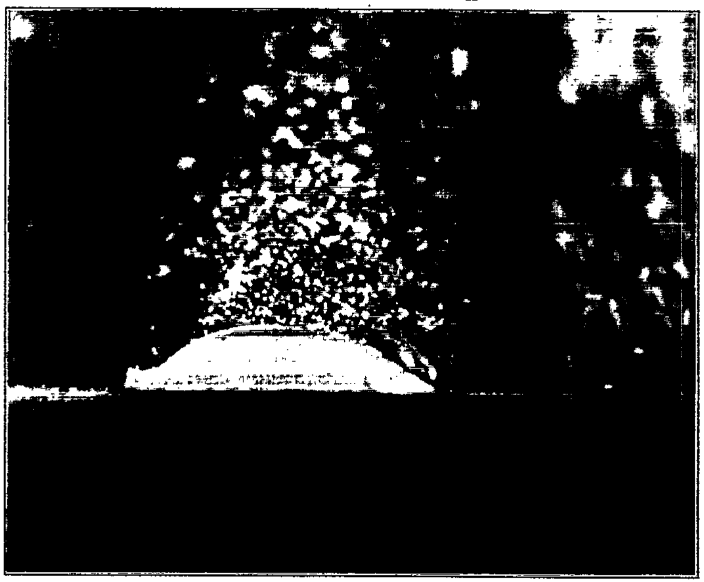

Figure 8 Laser clad track on mild steel

depends only on the linear heat input, not on the power and speed independently. Hence, the calculated cooling rate is a single valued function of the heat input.

Figure 9 Photographs of upper bead and polished and edge surface of laser clad C-276 alloy.

Electrochemical corrosion tests were conducted on a coupon of weld overlaid C-276 material, and compared to that of bulk material. Slugs were cut from the samples, the surfaces were ground and polished, and corrosion tests were conducted on the overlaid deposits. Electrochemical measurements used a three-electrode configuration within an electrochemical cell containing a brine solution saturated with hydrogen sulphide, at room temperature. The electrodes included the weld overlay sample and a bulk C-276 sample along with a reference electrode, in order to corrode the two sample electrodes under the same conditions. Polarization measurements were obtained with a computer controlled potentiostat. From this, a polarization curve was plotted, as in Figure 12. Corrosion rates for the laser weld overlaid C-276 and the bulk sample were 4.4mpy and 5.8mpy respectively. Although the results from this one test can only suggest a general trend, the hysteresis curve shown in Figure 12 indicates that the laser weld overlayed material appears to react similar to a bulk

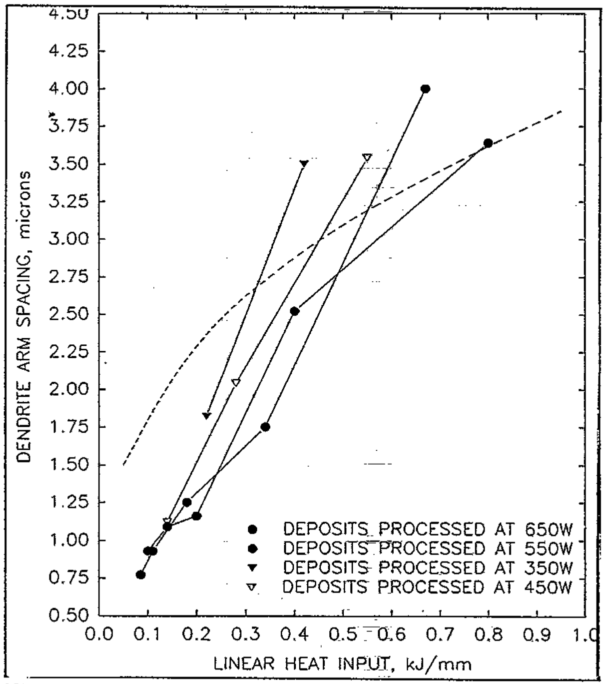

Figure 11 Dependence of Secondary Dendrite Arm Spacing on Linear Heat Input

C-276 under the given conditions. In other words, the properties of the C-276 material are apparently not altered by using this deposition process, and the low dilution should allow the same corrosion resistance through most of the thickness of the deposit.

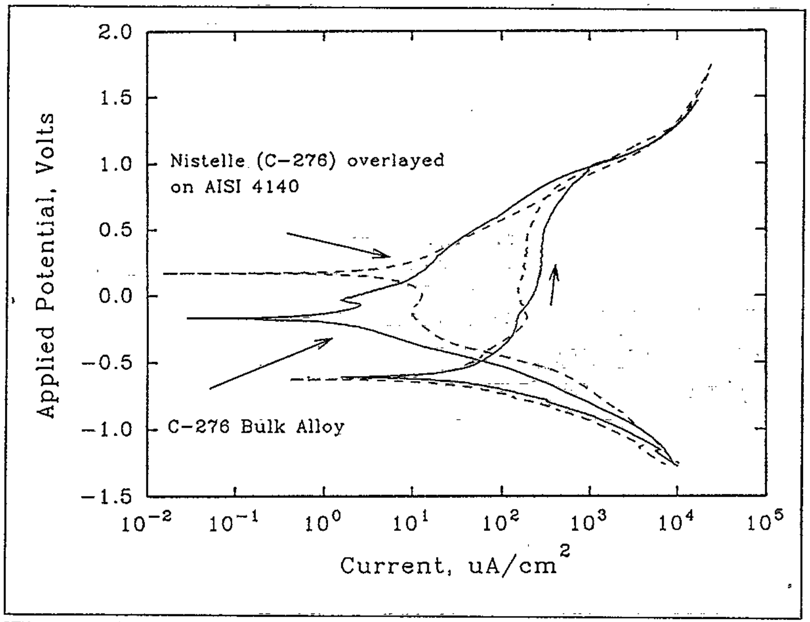

Figure 12 Polarization curves showing similarities between laser weld overlayed and bulk C-276.

APPLICATIONS OF LASER CLADDING

Applications of laser cladding have recently been reviewed, and the results are reproduced in Table 1. The table also indicates the state of the application, whether it is still in a research phase or it is being used in a production environment. Laser cladding is used predominantly either in the aircraft industry, or in valve applications.

Figure 13 Laser cladding of a valve

An application that has been pursued at The Laser Institute is cladding for reconditioning of diesel exhaust valves. This is another example of technology transfer from the research and development group, in which the processing conditions were developed, to Lasertech, the job shop division. Lasertech is now cladding of the order of 1000 valves per month;

Figure 13 shows a valve being processed.

Each valve is manually preheated by an oxy-acetylene torch prior to cladding; preheating processes more amenable to mass production are currently being investigated. Two side-by-side passes cover the valve sealing area on each of the six different valve sizes that are treated.

TLI engineers worked closely with the customer during cladding procedure development to ensure that the clad deposits met his quality requirements. The customer performs pregrinding of the valves prior to material deposition, and postgrinding to ensure the valves have the correct finished profile. Figure 14 shows the cross-section of an as-clad valve, prior to grinding. The customer also chrome plates the valve stems to complete the reconditioning process.

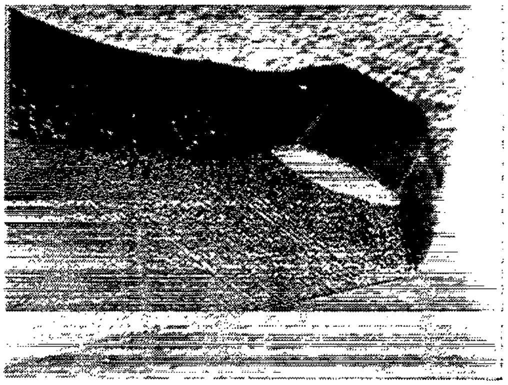

Figure 14 Polished and etched cross section of a clad valve

ACKNOWLEDGEMENTS

The corrosion tests were performed by the Linda Gray at the Alberta Research Council in Edmonton. The analysis of the microstructure of laser clad Stellite and its dependence on cladding conditions was performed by Chris Green.

Table I. Laser Weld Overlaying Applications[9]

Organization	Application	Status
Westinghouse R&D	Near net shape casting of cylindrical bosses	Development
Westinghouse	Steam generator blades Internal pipe surfaces	Production Development
Westinghouse	Electrical contactors	Development
General Electric	Gas turbine engine components	Production
Tinkler Air Force Base (USAF)	Turbine blades	Repair
Mare Island Naval Ship Yard/ARL	Submarine steam chests	Development
Stardyne Inc.	Valves Aircraft carrier catapult Turbine engine components Drive shafts	Repair
Quantum Laser	Gas Turbine Parts	Production Repair
Rofin-Sinar Inc.	Die components	Development
Huazhong University	Exhaust valves	Research
Fiat Auto	Exhaust valves	Production
Toyota	Exhaust valves Moulds	Production
Sulzer AG	Exhaust valves	Development
Rolls Royce	Turbine blade interlocks	Production
Pratt and Whitney	Turbine blade interlocks	Production
GEC-Alsthom	Turbine blades	Production
The Welding Institute	Alloying bronzes	Research
Combustion Engineering	Offshore drilling components Boiler firewalls	Research
Komatsu Ltd.	Overlaying copper onto steel	Research
IIT Research Institute	Refractory materials onto steel	Research
Exxon Research and Engineering Co.	Oxidation resistant materials onto steel	Research
Imperial College	ceramic/metal composites onto steel	Research

* Stellite is a registered trademark of Deloro Stellite, Inc.

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