ELECTRIC POWER RESEARCH INSTITUTE

Quick Insight Brief: Diode Laser Cladding

RESEARCH QUESTION

Can the diode laser cladding (DLC) process be used to apply high-temperature, corrosion-resistant refractory materials, and when is the technology expected to be available for industry?

KEY TAKEAWAYS

- DLC is being considered for various advanced reactor designs that will be introduced over the next decade. Several of these designs rely on high-temperature alloys that can operate in highly corrosive environments and under cycling conditions. Refractory alloys such as molybdenum or tungsten have been identified as potential alloys that may provide both high temperature and corrosion performance, thereby bridging this gap. Unfortunately, these alloys are difficult to fabricate and are very expensive. One solution may be to clad structural components with a thin layer of refractory materials using DLC technology.
- Small modular reactor (SMR) manufacturers are also considering DLC for cladding of the reactor pressure vessel because the process can be applied in various clad/welding positions.
- DLC results in very low dilution (mixing with a substrate), making it attractive for application of hardfacing materials where wear resistance is required.

KEY POINTS

- Use of DLC technology for cladding in nuclear applications is a relatively new concept that has yet to see its full potential.
- Successful implementation of DLC technology will provide a method for depositing refractory materials or composites to components that are considered impossible to deposit using standard weld cladding techniques. The DLC deposits produce considerably thinner layers than traditional cladding techniques, leading to reduced material costs.
- Having the capability to deposit these high-temperature alloy cladding would provide invaluable enhancements in high-temperature corrosion and wear properties and would significantly increase the design life of advanced reactor components.

WHAT IS THE DLC PROCESS?

Diodes are semiconductor devices that directly convert electrical energy into laser light. Typically, higher power diode lasers output in the near infrared, most commonly at either 808-nm or 980-nm wavelengths. An individual diode laser emitter can produce at most a few watts of output power. Examples of these single diode emitters are shown in Figure 1.

Figure 1. Diode laser emitters [1]

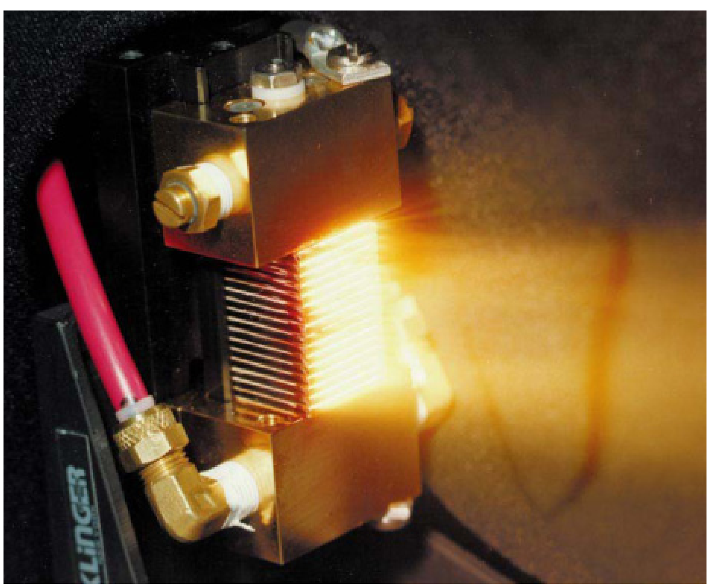

Figure 2. Large array of MCCPs used for delivering diode laser power to the weld head [1]

Numerous diode emitters can be fabricated on a single, monolithic semiconductor substrate or bar with total output power reaching as high as 100 watts. These linear bars can be combined in horizontal and vertical stacks to produce diode laser systems with the necessary output power required to clad substrates with powder or wire alloys. Figure 2 provides an example mounting configuration for the diode laser bars referred to as microchannel-cooled packages (MCCPs). The MCCPs are mounted to a chill plate that contains internal channels for water circulation.

The final step in delivering the diode laser power to the substrate being clad is to use specialized optics to focus the laser as a linear, circular, or rectangular heat source with power density greater than 200 kW/cm^2. Figure 3 provides an image of a diode laser head mounted to a robotic arm in preparation for inside diameter (ID) cladding. The specialized optics are contained within this head and used to focus the diode laser power on the substrate material. Cladding material in the form of wire or powder is introduced and deposited on the substrate surface at the same location where the laser beam is focused. The laser beam heats both the substrate and the cladding material, leading to melting of the wire/powder and metallurgical bonding of the two materials. Figure 4 shows a cross-sectional view of cladding and substrate after DLC.

Figure 3. Fiber-coupled diode laser head mounted to robotic arm at the Nuclear Advanced Manufacturing Research Centre facility in preparation for ID cladding [2]

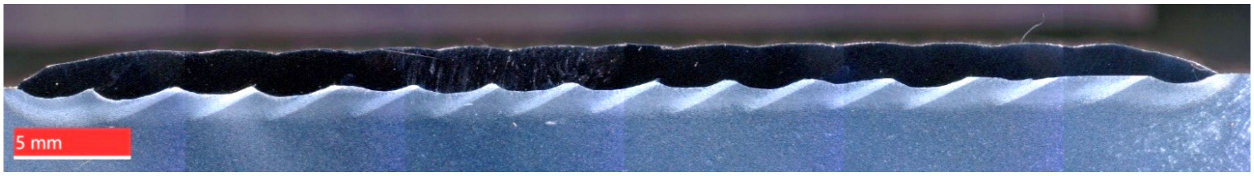

Figure 4. Cross section of 308L stainless steel one layer cladding onto low-alloy steel [3]

As with all cladding investigations using new alloys, there is a potential for metallurgical incompatibility between the cladding material and the underlying substrate. However, an advantage of DLC technology is that it applies minimal heat input to the substrate during deposition, resulting in extremely low mixing (dilution) of the substrate with the cladding material. Because of this minimal mixing and low heat input, the risk of metallurgical incompatibility is reduced substantially. Furthermore, minimal mixing allows the cladding layer thickness to be reduced by 50% or greater relative to conventional arc-based cladding processes, providing the potential for significant material and cost savings.

Although powder deposition is not practical for out-of-position cladding applications, the use of wire-fed deposition with DLC technology is a potential option that can be used to address this issue. This is typically accomplished using a hot wire system to preheat the wire close to melting temperature prior to deposition onto the substrate. Preliminary research has been completed by the Electric Power Research Institute (EPRI) to determine the effectiveness of hot wire diode laser welding [1]. This investigation involved using robotic DLC to perform cladding in the 2G (horizontal) welding position, and additional studies are planned to further investigate DLC technology for out-of-position cladding.

WHICH INDUSTRIES ARE CURRENTLY USING DLC TO MANUFACTURE COMPONENTS?

DLC technology has been applied to a vast number of aerospace, power generation, and petrochemical applications. Specific examples where DLC is being used include turbine blades, superheaters, valve seating surfaces, water walls, and many other coating applications requiring high corrosion and wear resistance. Because DLC has benefited a wide range of industrial applications, it is anticipated that this technology can also be successfully developed for many nuclear applications.

WHERE WILL DLC BE USED TO MANUFACTURE NUCLEAR COMPONENTS?

DLC technology could be used during fabrication of essentially all nuclear components that require corrosion and/or wear resistance. Example components that could potentially benefit from the use of DLC technology include the reactor vessel ID, valves, pump housings, tubing, and piping. The technology is particularly attractive to the industry in that it may provide an avenue to apply high-temperature, corrosion-resistant materials such as molybdenum, tungsten, or other composite structures. The technology is also being explored under a U.S. Department of Energy (US DOE) project (DE-NE0008629) that is investigating DLC for cladding both the inside and outside surfaces of the reactor vessel (see discussion in the following sections). Lastly, because of its low dilution (mixing with substrate), DLC is being considered for application of hardfacing alloys for improved wear resistance.

EMERGING ADVANCED MANUFACTURING TECHNOLOGIES

Investigation of DLC for Generation IV Reactor Components

A two-year project, initiated in early 2020, has been funded by EPRI to evaluate use of DLC technology for advanced non-light water reactor components. This effort includes a comprehensive evaluation of cladding materials with superior high-temperature corrosion resistance. Primary candidate materials that will be investigated include molybdenum, tungsten, and composite powders. These materials will be clad to candidate substrates using the DLC process to demonstrate the feasibility for use in advanced reactor applications.

DLC of SMR Vessel Surfaces

Under US DOE project DE-NE0008629, EPRI and the United Kingdom-based Nuclear Advanced Manufacturing Research Centre are investigating advanced manufacturing and fabrication technologies for SMRs. The project is investigating a wide range of advanced technologies, including powder metallurgy-hot isostatic pressing to produce reactor pressure vessel components, electron beam welding to join these components, and DLC to clad the reactor vessel. In the project, DLC is being investigated because of its ability to be used out of position (welding position) and because it can reduce the overall thickness of the corrosion-resistant cladding required by >50%. The NuScale Power reactor application that is being investigated requires cladding on the interior and exterior surfaces. The total surface area is estimated at an area greater than two Olympic-sized swimming pools; therefore, if one can reduce the volume of material required, significant savings can be achieved.

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