Fusion Cladding Prevents Pipeline Wear and Corrosion

Corrosion costs $2.2 trillion annually to the global economy, with nearly $1.2 trillion to the oil and gas industry alone. To satisfy the ever increasing demand for energy, oil and gas companies continue to move further offshore and into deeper waters to produce fuel from challenging reserves using highly corrosive processes. These difficult conditions demand corrosion-resistant pipes, components, and equipment that can withstand an assault of caustic fluids at very high temperatures and pressures. Parts made from corrosion-resistant clad steel are an optimal solution given the economic risk and safety concerns involved.

However, popular cladding technologies such as mechanical lining and roll bonding suffer from major concerns involving integrity and supply. These matters are further aggravated by the need for thick-walled and large-diameter pipes in heavy demand in the Gulf of Mexico and Asia-Pacific regions.

To confront these issues, MesoCoat Inc. developed a new cladding technique. The company’s CermaClad high-energy-density fusion cladding process addresses most of the concerns associated with current technologies: The process enables application of metallurgically bonded cladding over large areas at high production rates, and without the size, thickness, and reeling/installation limitations of other methods.

Central to the CermaClad process is a high-intensity arc lamp that melts and fuses corrosion- and heat-resistant materials onto the interior walls of pipes that carry abrasive slurries, high-sulfur crude oil, and similar products. This article describes the equipment, operation, materials, and coating characterization involved.

CermaClad is based on a Vortek quartz plasma lamp that radiates high-energy-density infrared light. Its power ranges from 350 to 3500 W/cm², with total power output scalable from 150 kW to 1 MW. The plasma arc thermal source functions at a temperature of 10,000K (17,500°F), approximating conditions in the sun’s corona. It is designed to emit roughly 80% of its energy in the infrared spectrum: Just over 18% is emitted in the visible light range, and only 1-2% is in the ultraviolet.

Fig. 1 — (a) Spectral distribution for the irradiance of the quartz plasma lamp. (b) 3D representation of irradiance on a 4 × 20 cm target plane surface (200 kW input power to lamp).

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convection) heat transfer and stirring. As a result, weld dilution is significantly reduced, enabling more through-thickness control over microstructures than is possible with traditional laser and weld overlay processes.

The CermaClad arc lamp system (Fig. 2) is designed so that the light energy can be focused on a relatively wide path as the substrate moves beneath it. Substrates can be coated at a rate that enables coverage of 75 to 580 sq ft/hr, and 100 to 500 lb/hr application rates with a single system. This compares to 1 to 20 sq ft/hr and 5 to 15 lb/hr application rates for lasers. A typical 350 kW, 10-in. arc lamp setup is shown in Fig. 3(a), while a pipe ID fusion cladding system is shown in Fig. 3(c).

Cladding materials
Feedstock materials for CermaClad are engineered to control wetting and melt viscosity, enabling the fusion process to produce pinhole-free, smooth, uniform coatings as thick as 15 mm. Generally, these feedstocks are similar to welding filler metals, but are engineered with highly efficient, clean-burning binders and shear-thinning agents to be applied as thick coatings or paints. Materials developed or in development include nickel-base alloys, stainless steels, metallic glasses, metal matrix composites (WC and SiC), titanium, tantalum, tungsten, and copper. Claddings are available as corrosion-resistant alloys (CRA), wear-resistant alloys (WRA), and high temperature (HT) and low thickness (LT) varieties:

- **CRA claddings** are made of alloy 625, 825, 316, Monel 400, and titanium. Cladding thickness is typically between 0.5 and 4 mm.
- **WRA claddings** are made of ceramics such as chromium carbide, structurally amorphous metal (SAM) alloys, and tungsten carbide. Cladding thickness is typically between 3 and 15 mm.
- **HT claddings** are made of nickel-chromium and metal-chromium-aluminum alloys for high temperature applications in the energy, pulp and paper, nuclear, and marine industries. Cladding thickness is typically between 0.05 and 6 mm.
- **LT claddings** are made of stainless steel or metallic glass, and are typically between 0.05 and 0.5 mm thick.

Cladding characterization
As a representative system, alloy 625 was applied to samples and pipe IDs (10-in. X65 line pipe), and compared to wrought and weld overlay materials. The fusion-clad materials exhibited properties between those of wrought and weld overlay materials, with corrosion and microstructural properties closer to wrought than weld material. Figure 4 shows microstructures of weld overlay 625, wrought 625, and CermaClad fusion clad 625.

One of the advantages of the CermaClad process is that there is no electrode stirring and limited Marangoni convective mixing. This results in metallurgical bonding, but with low dilution of the cladding with the base metal. This can improve corrosion resistance as well as enable use of thinner coatings at a given iron dilution concentration. Figure 5 is an EDX line scan showing both a metallurgical bond (interdiffusion zone) and low coating dilution.

The reduced iron dilution and fast cooling rates of the 625 alloy overlays resulted in higher corrosion pitting resistance than weld overlay, approaching annealed wrought alloy. Typically, CermaClad 625 samples have G28 corrosion rates roughly 50 to 70% lower than comparable weld overlay, and well below the acceptable American Petroleum Institute API 5LD (governing standard) requirements for metallurgically bonded clad pipe.

Metallurgical bonding was observed through both interdiffusion zones (Fig. 5) and shear testing. Bond shear strengths were consistently above 30,000 psi, with measured values ranging from 31,475 to 32,480 psi shear.
strength. This is comparable to the shear strength of the base X65 pipe and is more than 50% higher than API 5L standards requirements for metal- lurgically clad pipe. API 5L standards require 20,000 to 24,000 psig typical of roll-clad product, and 20,000 psi shear.

Figure 6 illustrates guided bend test results from a CermaClad pipe section. The fusion clad alloy 625 shows excellent ductility and bonding, and passes all API 5L requirements for metallurgically clad oil and gas line pipe.

Alternate materials

Figures 7 and 8 show different materials clad by the fusion cladding process. These include stainless steel, WC-Ni/Cr metal matrix composites (MMCs), 50:50 Ni:Cr, Ti, structurally amor-

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phous metals, and nanocomposite Cr$_3$C$_2$ overlays. Figure 7 (right) shows one version of a nanocomposite coating, specifically a structurally amorphous metal (SAM). These nanocomposite coatings contain high volume percents of either hard (Cr$_3$C$_2$) or amorphous (SAM) phases with a highly refined microstructure. This fine microstructure imparts very high hardness while maintaining the micron-scale toughening of a ductile metallic phase. The microstructure also provides very high corrosion resistance, while enabling high polish and low frictional properties.

Hardness up to 1600 VHN was achieved in nanocrystalline fusion overlays with good impact resistance and with abrasive wear resistance approaching WC MMC levels. Figure 9 shows a comparison of wear data with conventional tungsten carbide and illustrates the performance of various nanocomposite and MMC fusion clad overlays. MMC claddings achieved state-of-the-art wear resistance of 0.036 g (G65, 5000 rev), while eutectic carbides also performed well. Figure 8 shows the lack of decomposition and dissolution of the eutectic carbides, which rapidly degrade in alternate processes such as laser or PTA weld overlay procedures due to the higher temperatures.

Fig. 6 — Guided mandrel bend test of clad pipe sections with iron dilution measurements; wrought alloy 625 contains 2% iron (left). Close-up of bend edge-on bend (right); cladding appears on right of bend.

Fig. 7 — Left, alloy 316 cladding on carbon steel. Right, structurally amorphous metal alloy NC8.

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<tr>
<th>Sample</th>
<th>Spot 1</th>
<th>Spot 2</th>
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<tr>
<td>P014A</td>
<td>2.19</td>
<td>0.18</td>
</tr>
<tr>
<td>P014B</td>
<td>0.94</td>
<td>0.13</td>
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Spot 1: Middle of beam
Spot 2: Overlap region
P014A: Surface
P014B: Ground to middle of cladding

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MMC coatings and composites that have kinetic or dissolution limitations hindering microstructural control may be advantageously applied using the lower temperature (compared to laser or transferred arc) and more uniform heat flux of the CermaClad plasma arc cladding torch. Optimizing MMC overlay cladding involves enhancing the binder (for corrosion resistance, hardness, and distribution), as well as the hard particle packing density. This is sensitive to the application technique for the MMC precursor matrix and requires further study to achieve the best results.

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Bibliography