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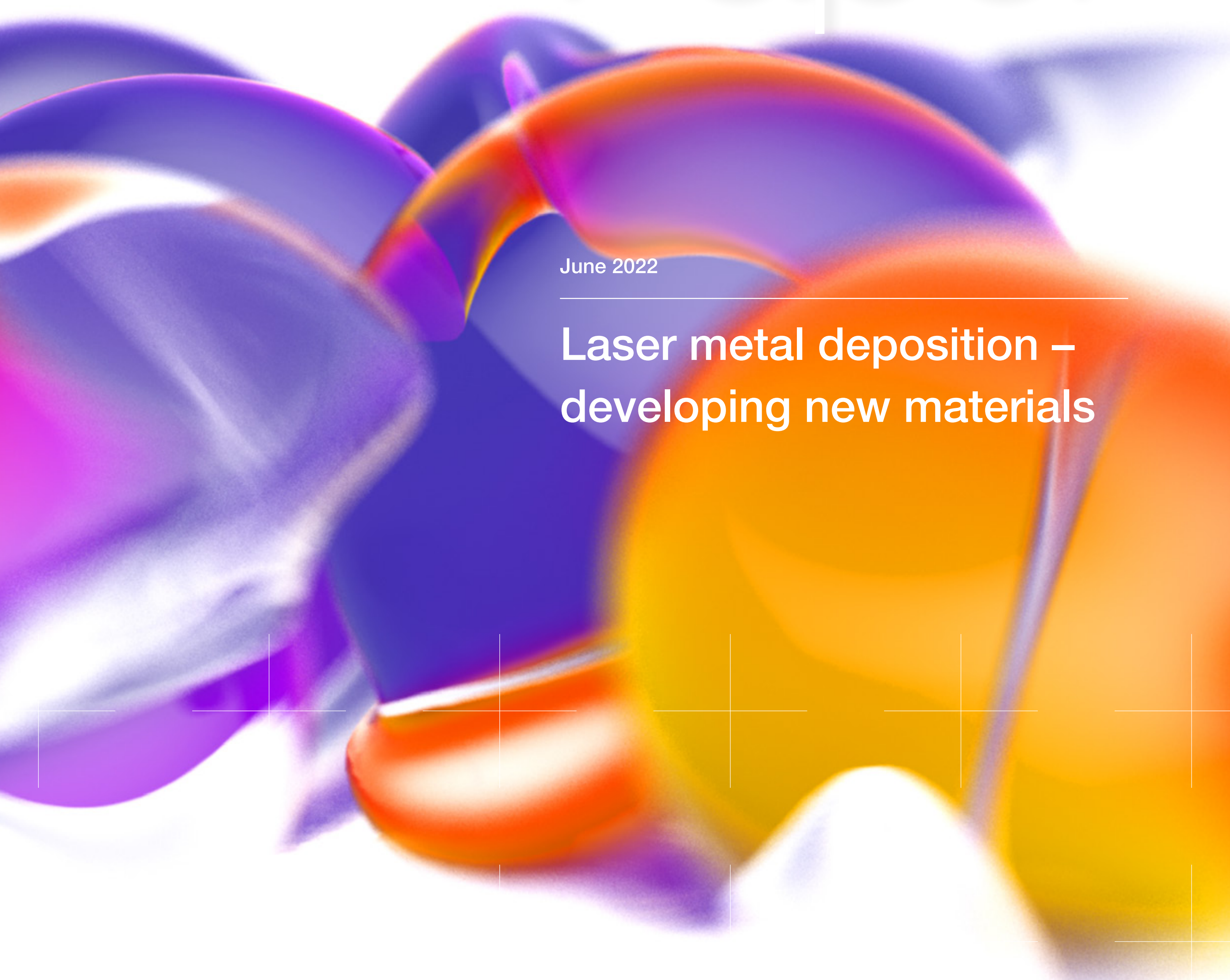
White Paper



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Laser metal deposition – developing new materials

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Many industries rely on precision, hard-wearing components for everyday operations. From pumps to turbines, compressors to gearboxes, rotating equipment is central to maintaining productivity. Continuous operation leads to progressive wear and tear that is, ideally, resolved during planned maintenance periods. However, one truth often applies: Time is of the essence, and operators are always looking for better and more cost-effective solutions. When it comes to rebuilding worn surfaces, improving wear resistance or recovering dimensional tolerances, there are several options. Over recent years, laser metal deposition (LMD) has increased in prominence, offering a number of benefits over more established technologies such as submerged arc welding and thermal metal spray, or high velocity oxidized fuel (HVOF).

In this paper, we examine the advantages, as well as the considerations, of LMD and explore the process of qualifying a material like Super Duplex, which is commonly used in the oil and gas industry as well as power generation and petrochemicals.

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What is LMD

Laser metal deposition is a technique that can be selected for the repair of many components used in rotating equipment and is similar to methods such as conventional welding and HVOF. The range of repairs that can be achieved using LMD is extensive. From restoring worn bearing journals and seal areas to renewing the leading edges of steam turbine blades and the impeller vane tips of pumps.

To ensure a uniformity, an automated application system is required

LMD is a technique that uses a laser-based directed energy deposition process to add layers of material onto the component under repair. The new material is supplied either in a powder form or as a wire and a fiber laser melts it together with the base material into a melt pool. The nozzle is moved across the workpiece, usually by an automated robotic arm to ensure a uniform depth, until the desired profile is achieved.

Commonly used for rebuilding worn shafts, bearing journals and gear hubs, precise control of the workpiece and the LMD nozzle is required to deposit consistent layers of material approximately 0.2 - 1.0 mm thick. The metallurgical bond that is formed with the base material is essential for a high-quality repair that is almost indistinguishable from the original component. Once the LMD process is complete, final machining is used to achieve the precise dimensions of the finished component.

How is it supporting industry

Modern industry relies on a vast amount of rotating equipment that needs to perform reliably for many years to repay its initial investment costs. Unplanned downtime can have very significant consequences for the business, so most will have a preventative maintenance program that addresses any issues before they cause greater problems. The methods available to complete any repairs are wide-ranging but it is important to select the most appropriate one for each situation.

In the past, parts with complex geometries would have to be replaced with new components because the technology to effect the repair was not available. As new methods are developed, the range of materials that are qualified for the process is initially quite restricted, but as more research is completed, so a wider selection is presented.

Maintenance specialists and fabricators also have the opportunity to make changes to the original design of a component to accommodate alterations in the application. Reliability can be extended by adding higher quality materials to reduce wear, erosion or corrosion. Repairs can be delivered more quickly and, more importantly, without affecting the microstructure of the component.

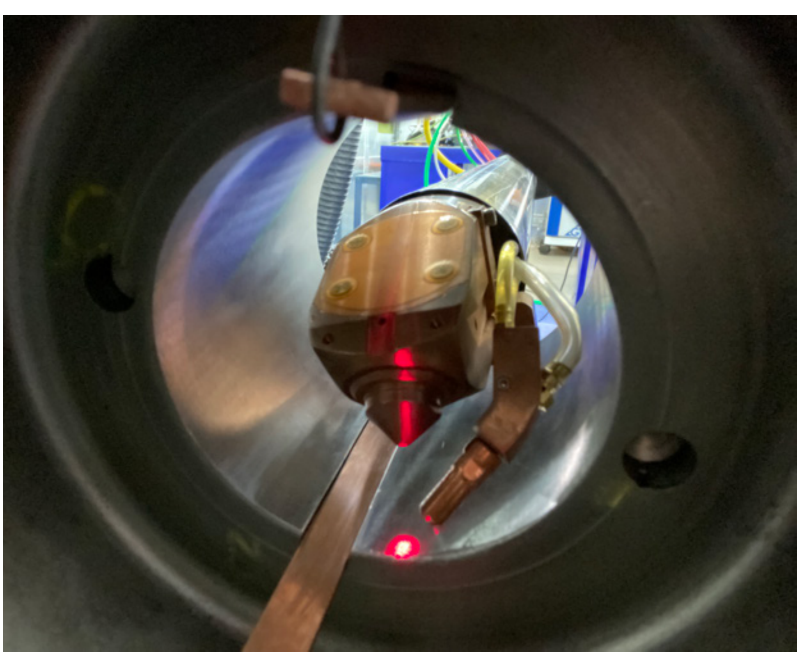
All of these benefits enable businesses to minimize any downtime and achieve the most cost-effective solution for important assets.

Advantages in detail

The laser in the LMD repair process offers benefits beyond what both HVOF and submerged arc welding (SAW) provide. The most obvious is the reduced heat input, which minimizes distortion, reduces the heat-affected zone (HAZ) and almost eliminates the need for post-weld procedures. At the same time, the metallurgical bond of LMD assures excellent consistency in material density and perfect adhesion with the parent material of the component, making it stronger than traditional welds or plating techniques.

It can produce fully customized, functionally-graded parts for demanding applications, or restore existing components to their original strength. LMD is both highly precise and fast, allowing for the creation of rough to very fine structures with quicker build rates in comparison to other processes. As a result, it is a multi-purpose manufacturing process that is effective for fabrication, repair, welding, and cladding.

The material range for LMD is extensive, offering single component metal powders, tungsten carbides, alloy powder, and even custom powder blends to create sandwiched bimodal structures or new alloys. Many material properties and hardness ratings can be achieved using LMD for cladding or re-building components. These materials include nickel-based alloys such as INCONEL® and HASTELLOY®, cobalt-based alloys such as Stellite®, carbides, stainless steels, and titanium alloys. Furthermore, the material is also used very economically, as it is only added as required.



Precision working ensures faster repairs

LMD reduces the heat-affected zone (HAZ)

Considerations

The development of LMD and the equipment that is required to deliver the repairs mean that its use is predominantly seen in areas where high-value assets are in operation. The manufacture of the metal powders for this process is limited to a few suppliers and the quality of these materials are crucial to the overall performance of the finished components.

In addition, the number of maintenance providers that can deliver this type of repair can be limited because of the considerable amount of metallurgical knowledge required to deliver high-quality solutions that will bond properly with the base material. Coupled with the need for automated application systems that can provide a uniform layer of metal with pinpoint accuracy on a rotating element, operators of rotating equipment should engage with vendors that have a proven record in this field.

Applications

Currently, the most common applications of LMD technology include the repair of tooling surfaces, high-value parts, engine components and turbine blades. It has been used for the surfacing of oil and gas drills as well as the repair of sintered tools and precision metal components. As new alloys are developed, so this range will widen to include more specialist parts, although it is not expected to be employed for low-cost machinery in the near future.

As an additive manufacturing process, LMD is also being used to construct medical implants and for the rapid prototyping and fabrication of high-value or bespoke parts for aerospace, oil and gas, power generation as well as tooling applications.

Where protective materials are required, such as for the deposition of vanadium carbide tool steels and titanium alloys onto high-stress components, LMD offers a fast and efficient process.

Qualifying materials - Super Duplex

Super Duplex is used in arduous applications where corrosion and/or erosion are particular challenges. The material itself is a premium product and it is most commonly found in the oil & gas, aerospace, petrochemical and pharmaceutical industries. When components, such as pump impellers, are found to be damaged after long periods in service, it is more cost effective and timely to repair the part rather than investing in a new one.

Super Duplex stainless steel has two phases, austenite and ferrite, and the balance of these two needs to be maintained during any repair process to ensure the continued performance of the material. However, it is not very tolerant of heat and welding can cause this balance to shift from 50:50 to 30:70 in favor of ferrite, which will seriously affect corrosion resistance. In addition, excessive heat can cause distortion of the metal, so this eliminates tungsten inert gas (TIG) welding from the list of options.

In this situation, LMD would offer an ideal solution due to the low heat input and the very small HAZ. In addition, cooling rates can be managed to obtain much improved phase balance and eliminate intermetallic phases.

However, introducing a new process, such as LMD, to components that operate in such crucial applications, requires considerable investigation and development before it will be sanctioned by any standards organization such as ASME, BSI or Lloyds Register. The research covers all aspects of the material's characteristics to ensure that they are unaffected by the repair process.

In the case of Super Duplex, Sulzer extended the testing scope beyond the standard requirements to better understand the material's behavior. A combination of various standards was used to establish the acceptance criteria, with the majority coming from Norsok M630.

Visual

On a macro scale, visual as well as liquid penetrant tests and volumetric ultrasonic testing were carried out on a sample, but they did not reveal any flaws. The chemical composition of the base metal, HAZ and the weld metal were examined and all were found to have a carbon content below 0.03% and a pitting resistance equivalent number (PREN) above 40. In addition, the weld areas were macro etched in hydrochloric acid to highlight the macro structure of the material. Close examination revealed no cracks, porosity or lack of fusion in either the longitudinal or transverse directions.

Moving to the microstructure, where the intermetallic phase balance was assessed according to ASTM A923 Method A, examining the structure at 100x – 500x magnification. The ferrite content of the base metal, HAZ and weld metal were assessed and found to be 46%, 47% and 59% respectively. Although the global phase balance met the target, it was proposed to reduce the significant local variation by using smaller weld passes.

Further testing

Qualifying a new material means that all aspects of its structure must be assessed including its hardness, which has a direct effect on durability and resistance to galling. The metal deposition process should not make any significant changes to the hardness of the material, ensuring that the original properties are retained.

Tests carried out as part of the qualification for Super Duplex included 10 measurements at three locations spanning the new material layer, from the base material to the top of the new layer. Using procedures laid out in BS EN ISO 6507-1, the highest hardness value observed was 332 Hv, which was within tolerance and below the maximum value of 350 Hv.

Considerable metallurgical knowledge is required to deliver high-quality bond with the base material

One of the attributes of Super Duplex is its excellent corrosion resistance, and considering the applications this material is used for, it is essential that this property is not diminished by the LMD process. Test were carried out at 35°C, 40°C and 50°C for 24 hours as per ASTM G48 Method A corrosion testing routine. The samples included the base material, the HAZ and the weld material. In all cases there was no evidence of pitting when observed at 20x magnification.

Having completed the comprehensive array of tests and been satisfied that all the requirements and criteria set by commonly used overlay standards had been met, Sulzer was confident that the defined process for Super Duplex LMD was a complete success. As such, it has significantly widened the scope of parts that can be repaired using this process.

Examples

Lean amine impeller

Lean amine is used to absorb hydrogen sulfide (H2S) and carbon dioxide (CO2) constituents from sour natural gas, creating rich amine, which is circulated to a regeneration unit where the gases are stripped from the liquid. As in the below outlined repair project carried out for Equinor, the whole process is driven by a high-pressure pump, an important asset on the platform.

Due to the nature of the application, the lean amine contains gas in saturation, entrained gases and with limited suction pressure to the pump, it wasn't a surprise to discover cavitation damage on the suction impeller.

The options for the impeller were to either repair it or to replace it with a new component, but the latter option would have a longer lead time. In parallel, Equinor and Sulzer had been in discussion about additive manufacturing (AM) technologies and this naturally lead on to a request to repair the impeller using AM, rather than waiting for a replacement to be manufactured.

After final machining parts can be quickly returned to operation

The impeller was manufactured from Super Duplex stainless steel. Careful selection of consumables, control parameters and techniques enabled the best method to be established. In this case, for greater flexibility and access, a semi-automated process using a manual wire feed and automated control of the laser head across the area being repaired was selected. In between each pass of the LMD head, a cooling period was required to ensure the temperature of the repair site did not exceed 100°C (212°F).

Once the damaged areas had been built up, a process of manual blending using abrasive hand tools and templates was employed to establish the final dimensions of the vanes. Again, using the same methods as the original manufacturing process and minimizing any heat build-up ensured the original properties of the impeller were retained. The finished impeller was checked for any flaws using dye penetrant inspection (DPI), with the whole repair process was completed in two weeks.

A second impeller from a sister pump was subsequently repaired, but now that the process had been qualified, the repair time could be reduced to only one week.

Compressor and turbine shafts

LMD was used to rebuild the shaft from a compressor where the thrust bearing had come into contact with the bearing journal, causing grooving in the surface and heat damage to the surface of the shaft. A number of solutions were open to the operator including welding, thermal metal spray, LMD and replacing the component.

For each option, it was important to consider the depth of the repair, the shaft geometry and the overall heat input from the repair process. LMD was selected because it posed no risk of distortion and also offered a shorter lead time as well as a lower cost, especially when compared to the purchase of a new shaft.

Similarly, the same options and considerations were in play for a gas turbine shaft that had suffered from multiple J-strip seal failures. The surface needed to be built up by 0.100 inches (2.5 mm) and machined back to the final dimensions. Due to the tight tolerance pin holes, no distortion could be permitted and LMD offered the best solution. Again, it also delivered the most cost-effective and timely resolution.

On another machine, the low-pressure coupling hub had suffered from corrosion and some galling on its internal diameter. The standard approach would be to coat the internal surface with Inconel 718 and grind it to the final dimensions. However, the internal diameter is a taper fit and it had two keyways, which posed additional challenges for the suggested repair process.

As a result, Sulzer recommended to apply Inconel 625 using LMD which can be done without affecting the keyways. The taper can then be machined to final dimensions leaving a high-quality repair that did not affect the base material or the keyways.

Conclusions

Laser metal deposition is one of several repair technologies that offer high-quality solutions that can be quickly delivered to extend the service life of important components. Parts can be rebuilt using LMD to almost as-new condition making use of only a fraction of the energy and raw materials that are required to create a replacement.

In situations where high specification materials, such as Super Duplex, are used, considerable time savings can be made in component repairs, once the process has been qualified. In industries where downtime has significant financial implications, and the lead-time for new components is extended, LMD offers an ideal solution.

Combined with precision machining facilities, Sulzer provides a fast and effective repair service for all types of rotating equipment using the most effective solutions available. LMD is just one of the techniques Sulzer uses to help operators minimize downtime and extend the working life of important assets.

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