EHLA: Extreme High-Speed Laser Material Deposition

Economical and effective protection against corrosion and wear

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Special coatings protect components against corrosion and wear. However, standard processes such as hard chrome plating, thermal spraying, laser material deposition or other deposition welding techniques have drawbacks. For example, as of September 2017, chromium(VI) coatings will require authorization. Researchers from the Fraunhofer Institute for Laser Technology ILT in Aachen as well as the RWTH Aachen University have now developed an extreme high-speed laser material deposition process, known by its German acronym EHLA, to eliminate these drawbacks in an economical way.

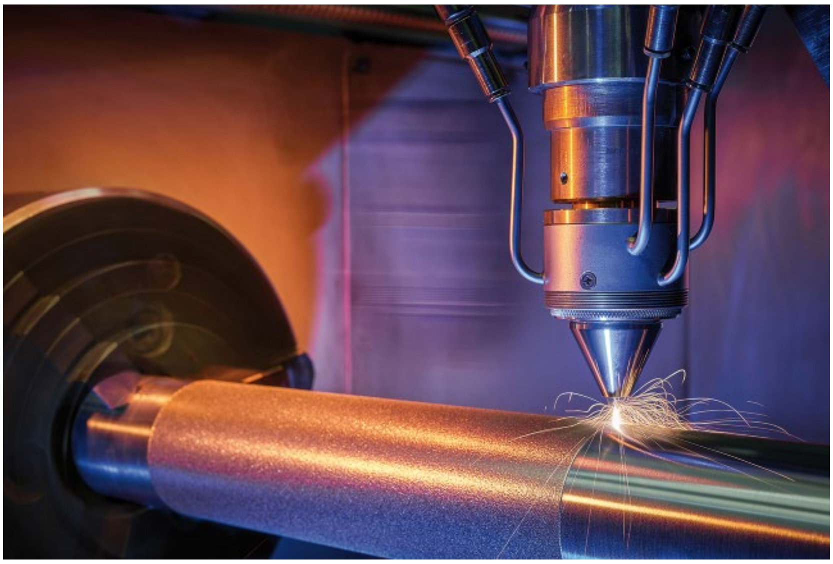

Fig. 1 Using EHLA to coat a piston rod (Source: Fraunhofer ILT / Volker Lannert)

Some components wear out, others corrode. Special coatings are meant to protect them as long and effectively as possible. However, standard processes such as hard chrome plating, thermal spraying and deposition welding are far from being perfect. Even laser material deposition has been used only in specific applications here. A newly developed and patented alternative process now overcomes shortcomings of the conventional processes for coating technology and repair, while improving cost-effectiveness. Layers measured in tenths of a millimeter can thus be flexibly, efficiently and quickly be applied to large surfaces.

An alternative to hard chrome plating

The most common process for corrosion and wear protection is hard chrome plating: Chromium is taken from a chromic acid solution and deposited on a workpiece in an electrochemical bath at process temperatures of 50 to 65 degrees Celsius. However, this process is not optimal: Hard chrome layers are not metallurgically bonded to the base material and they delaminate easily. In addition, the layers show microcracks in the microstructure that reduce their resistance to corrosion and wear. Another disadvantage is that electrochemical processes consume a lot of energy and become less economical as electricity costs rise. Yet the biggest drawback concerns environmental protection. Due to its environmental impact, chromium(VI) has been included in the EU directive EC 1907/2006. Starting in September 2017, it can be used only with authorization or a special permit.

EHLA provides companies the first alternative that is economical. It offers significant advantages over hard chrome plating. The chemical-free application makes the process very environmentally friendly. The resulting layers are non-porous, making pores and cracks a thing of the past. As a result, the layers protect the component much longer and more efficiently. In addition, the coating is firmly bonded to the base material and, unlike hard chrome layers, will not delaminate. Various materials – such as iron, nickel or cobalt base alloys – can be used for these new coatings.

Institute

Fraunhofer Institute for Laser Technology ILT

Aachen, Germany

With nearly 440 employees and more than 19,500 square meters net floor space, the Fraunhofer Institute for Laser Technology ILT, founded in 1985, is one of the most important contracting research and development institutes of its sector worldwide. Its experts develop and optimize laser beam sources and laser processes. In close cooperation with its clients, it uses laser technology to solve tasks for production, measurement technology, environment, energy, medical technology and biotechnology, all done in real life situations.

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More efficient use of resources than thermal spraying

Thermal spraying likewise has disadvantages. With high-velocity oxygen fuel (HVOF) spraying, a liquid or gaseous fuel is fed into a combustion chamber, where it is ignited and burnt by adding oxygen. The powdery spray material is guided into the combustion chamber; there, the individual particles are heated, partly melted, accelerated to speeds of 600 to 1000 meters per second, and then sprayed onto the workpiece to be coated. Upon impact, the powder particles are plastically deformed and then bond to the substrate through mechanical clamping. The resulting bond is comparatively weak, which is why the substrate must be pretreated with blasting techniques. In addition, the resulting layers have a porosity of one to two volume percent. This makes it necessary to apply several layers, each some 25 to 50 micrometers thick, atop one another in order to adequately protect the component. HVOF spraying is far from resource-efficient: Several hundred liters of gas are needed per minute and only about half of the material used ultimately coats the surface of the component.

In contrast, the new EHLA process effectively utilizes approximately ninety percent of the material, making it far more resource-effective and economical. Since the layer is dense, one layer already offers adequate protection. In addition, the coating bonds firmly to the substrate, thus dispensing the need for a complex pretreatment of the substrate.

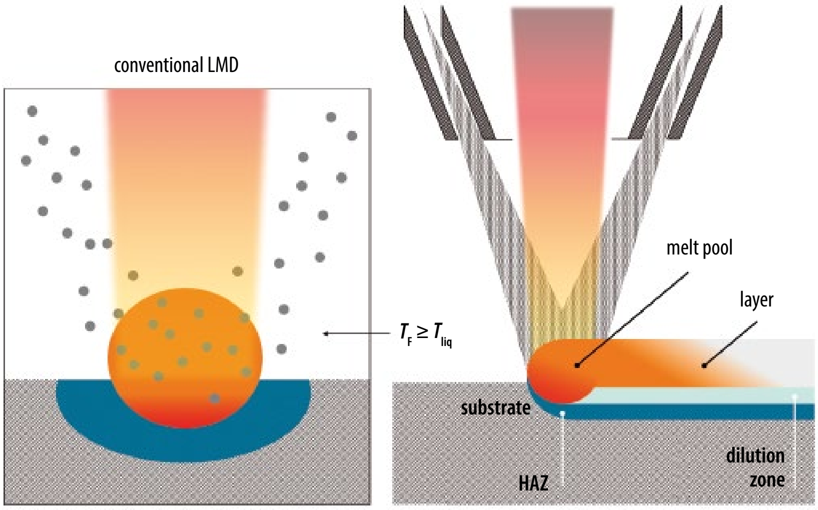

Fig. 2 Schematic representation of the process principle of conventional laser material deposition (Source: Fraunhofer ILT)

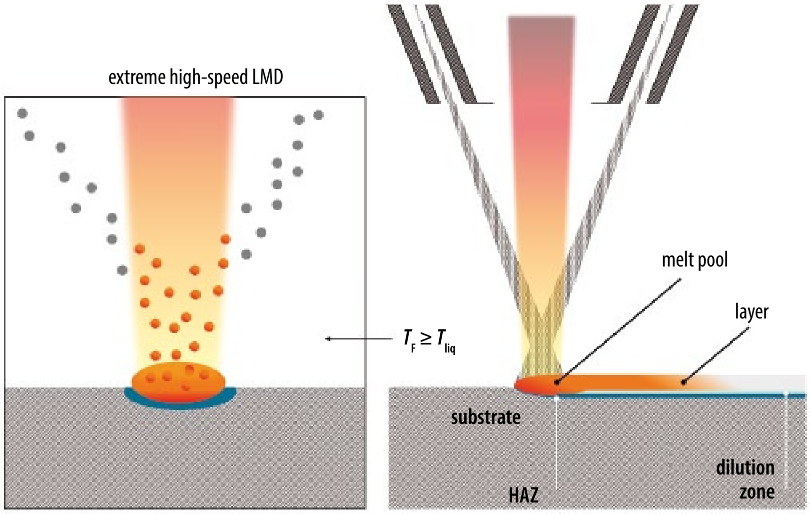

Fig. 3 Schematic representation of the process principle of EHLA (Source: Fraunhofer ILT)

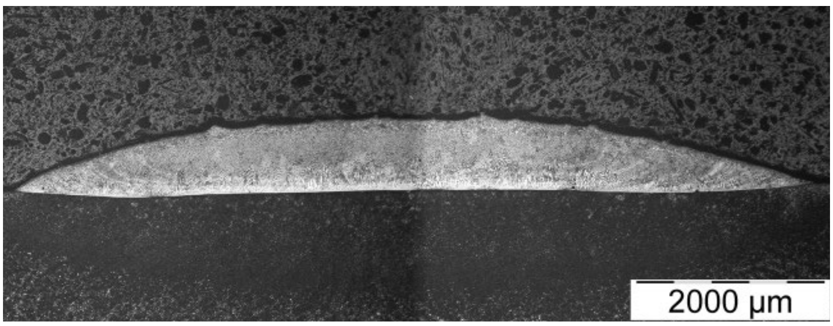

Fig. 4 Cross-section of a laser material deposition layer (Source: Fraunhofer ILT)

Faster and more broadly applicable than deposition welding processes

Deposition welding processes are used to produce high-quality and firmly bonded coatings. With conventional processes such as tungsten inert gas (TIG) welding or plasma powder deposition, however, the layers of 2 to 3 millimeters are often far too thick and too much material is used as a result. As much of the coating material mixes with the base material, multiple layers often must be applied. Laser material deposition already allows for far thinner layers – between 0.5 and 1 millimeter (Fig. 4, left). Since laser material deposition requires considerably lower heat input compared to conventional processes, even a single layer can provide protection. One such example is wear protection for agricultural blades. Laser material deposition is, however, too slow for large components. Because the surface rate is only ten to fifty square centimeters per minute, it is used only for specific corrosion and wear protection applications. In summary, there has been no solution anywhere for coatings between 25 and 250 micrometers in thickness.

In the past, increasingly powerful laser beam sources and optical systems as well as wide-beam powder

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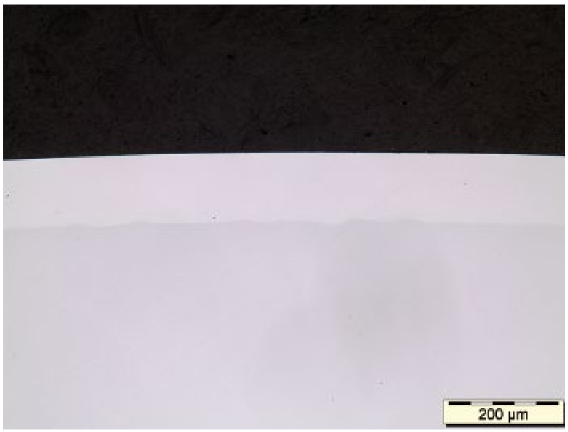

Fig. 5 Cross-section of an EHLA layer (Source: Fraunhofer ILT)

Fig. 6 EHLA coated and partially post machined piston rod (Source: Fraunhofer ILT)

feed nozzles were developed to achieve larger surface rates during laser material deposition. Although these efforts resulted in improved surface rates and especially deposition rates, their use for industrial coatings was insignificant. Key drawbacks are the relatively high energy input, insufficient dimensional accuracy and the subsequent need for time-intensive reworking. In addition, lasers are expensive compared to competing energy sources, such as arcs or plasma. That is why conventional material deposition processes are usually more cost-effective for thick layers. In short, a flexible, resource-efficient and economical process for applying high-quality, metallurgically bonded thin coatings does not exist.

The EHLA process fills this gap. It eliminates the drawbacks associated with deposition welding processes and conventional laser material deposition. EHLA increases the feed rate from 0.5 to 2 meters per minute to between 50 and 500 meters per minute, thus coating a component 100 to 250 times faster than before. It also solves the problem of layer thickness. Until recently, a layer could not be thinner than 500 micrometers at elevated deposition rates. EHLA allows for layers that measure just 25 to 250 micrometers. In addition, the layers are smoother; roughness is now a mere tenth of that typical of laser material deposition (Fig. 4, center left).

A significant advantage lies in the heat input. Unlike laser material deposition where the powdery additive is melted in the melt pool, EHLA uses the laser beam to melt the powder particles while they are still above the melt pool. Since drops of liquid material fall into the melt pool instead of solid powder particles, less material must be melted – a few micrometers suffice instead of hundreds of micrometers. Using EHLA shrinks the heat-affected zone by a factor of one hundred: from between 500 and 1000 micrometers in conventional laser material deposition down to just 5 to 10 micrometers. New is also the EHLA powder nozzle, which can operate ten times longer than in conventional laser material deposition.

Innovative strength of EHLA

The innovative strength of EHLA is highlighted by the principle behind standard laser material deposition: A laser melts the component locally, resulting in a comparatively large melt pool on the component's surface (Fig. 2). A powder nozzle feeds a powdery additive into the melt pool, where it then melts. A non-porous and metallurgically bonded layer forms once the melt has solidified. If the layer is to be defect-free, the powder particles must melt completely. This requires a relatively large melt pool, which requires a lot of energy and high heat input – which can thermally damage the component. Because the powder particles must first be heated to their melting point in the melt pool, conventional laser material deposition cannot be executed very quickly.

With EHLA, on the other hand, the laser melts the powder particles while they are still above the melt pool (Fig. 3). Since the powder particles no longer need to be melted in the melt pool, the processing speed of 0.5 to 2 meters per minute can be increased by orders of magnitudes to 500 meters per minute despite minimal heating. EHLA thus makes it possible to coat heat-sensitive components, which excessive heat input had made impossible up to now. This new process can also be used for entirely new material combinations, such as coatings on aluminum base alloys or cast iron.

Steps towards EHLA

The following systematically derived steps were used to develop EHLA. A system for the powder-gas jet was developed and patented that accurately measures the number of particles, the position and diameter of the powder focus, as well as the speed of the powder particles layer by layer. The data obtained then serves as basis for an in-house particle propagation model, which describes three-dimensional particle distribution: the position, direction and average velocity of the particles. Fraunhofer ILT used the measured data to model the interaction of powder particles and laser radiation – which had never been done before. Based on the results, powder feeding nozzles were optimized so that they produce a small powder focus – making it possible to adjust particle velocity and trajectory and thus the interaction time.

A good alternative in additive manufacturing

EHLA provides many advantages for coatings. But that is not all. This process also offers several other innovative and promising possibilities – in the manufacturing of new parts, for example. This is because conventional manufacturing methods such as casting or forging can be combined with EHLA to manufacture added volumes. Traditional manufacturing techniques are often characterized by a subtractive approach. Forged or cast blanks must be extensively reworked: As much as ninety percent of the original workpiece is machined and goes unused. This increases resource consumption as well as material and manufacturing costs.

The advantages of EHLA here are best explained using an example: A rotary shaft must be machined for several hours to manufacture flanges or seal seats by conventional means. If the same component is produced using

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Fig. 7 EHLA: Protection against wear and corrosion, repair and additive manufacturing – all with only one system technology (Source: Fraunhofer ILT)

a hybrid-additive approach – which is the additive manufacturing of volume elements on existing components – production time can be reduced to a few minutes.

EHLA is already proving beneficial for industry

Some companies are already using this new process, such as the Dutch firm IHC Vremac Cylinders BV. They use EHLA to coat their hydraulic cylinders – which exhibit a diameter of up to fifty centimeters and a length up to ten meters – for off-shore applications. Moreover, in close cooperation with ACunity GmbH from Aachen which is a spin-off of the Fraunhofer ILT, the Dutch company Hornet Laser Cladding BV will deliver the first EHLA system to China in the near future. It shall be used for research purposes and industrial applications at the Advanced Manufacture Technology Center of the China Academy of Machinery Science & Technology CAMTC in Beijing. Thus, EHLA improves the service life of existing products and creates innovative component functions for new ranges of applications.

Sustainable as well as good for the environment and job security

EHLA's application potential is enormous, not just in coating technology but also in additive manufacturing. In 2015, the worldwide market for hard chrome plating was estimated at 13.64 billion dollars, while the market for thermal spraying amounted to 7.56 billion dollars. If EHLA could capture a ten-percent share of the surface refining market – and that is a conservative estimate – this new process could account for an annual market volume of 2 billion euros. Another advantage of EHLA: It could be used for the large-scale coating of components nowadays used without coatings. This would make it possible to produce innovative components that do not wear out during a product's lifecycle. Moreover, EHLA could ensure that coating jobs remain in Europe – countering the trend of such jobs being outsourced to low-wage countries.

The process also bears considerable potential for additive manufacturing methods, which have grown some thirty percent on average since 2011. EHLA can contribute significantly to this growth, particularly in the manufacturing of large components.

Joseph von Fraunhofer Prize 2017

At the Fraunhofer General Assembly Meeting, held on May 30 in Dresden, Dr. Andres Gasser, Thomas Schopphoven and Gerhard Maria Backes received the Joseph von Fraunhofer prize, which carries a reward of 50,000 euros, in recognition of their work.

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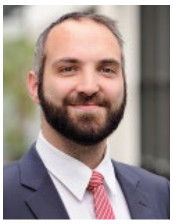
Authors



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Gerhard Backes studied physical technology at the FH Aachen in Jülich, Germany. His main work today is in the field of Laser Material Deposition. He is responsible for development and repair of aero-engine components with LMD and layed foundations for the EHLA process and its patent.

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