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Review of Laser Cladding Technology

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Abstract

Laser cladding technology uses non-contact laser to melt the coating material and the substrate surface at the same time to form a cladding layer. The coherent laser used has the characteristics of good directionality, monochromaticity and high energy density. The formed cladding coating has the advantages of low dilution rate and good combination with the base material, and can significantly improve the wear resistance, corrosion resistance, heat resistance, oxidation resistance and other characteristics of the surface of the base material. As an efficient remanufacturing method, laser cladding has been widely used in the manufacturing, surface modification and repair of components in aerospace, water conservancy and hydropower, mold, automobile and other fields.

Keywords

Laser Cladding; Repair; Self-fluxing Alloy Material; Composite Material.

1. Introduction

Laser cladding process has many advantages, such as: 1) Under the condition of reasonable cladding parameters, high energy density laser can melt the materials with high melting point in a very short time, so the dilution ratio between the cladding material and the substrate can be controlled in a small range. At the same time, a small heat input can significantly reduce the impact on the thermal sensor, and will not introduce too large thermal residual stress, so it will not produce large deformation, The scrap rate is reduced. 2) The rapid cooling of the molten pool may produce metastable phase. The amorphous phase and supercritical phase refine the grains of the solidified structure, reduce the dendrite spacing, and reduce the number of micropores, resulting in low porosity of the coating. 3) The spot size of the laser beam is small, which can selectively process the parts of complex surfaces and precision parts that cannot be processed by conventional processing, reducing the unnecessary waste of cladding materials and parts and the cost of reprocessing.

Laser cladding technology has many of the above advantages, and is widely used in the surface strengthening and repair of industrial components. Laser cladding technology can cladding a layer of coating with good physical and chemical properties on cheap metal or non-metal substrate, reduce the use of precious metals, repair the defects such as small cracks and wear formed after a long time of work, significantly improve its service time, save resources and reduce costs.

2. Application of Laser Cladding Technology

2.1 In Aerospace, Water Conservancy and Hydropower

Steam turbine is an important equipment in aerospace, water conservancy and hydropower. When the high-pressure superheated steam leaves the turbine blade, the erosion caused by the condensation of steam into water droplets due to the reduction of pressure will reduce the service efficiency and

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service life of the turbine blade. Many people have studied the blade repair using laser cladding technology:

Kathuria Y P[1] used cobalt-based alloy powder (Stellite 6L) with high chromium content to carry out laser cladding on the 12Cr-Ni steel sample labeled SUH600-N as the base material of turbine blades. It was found that compared with the longer cladding time, in the short time, the fabric in the cladding coating was finer and the dilution rate was lower, thus having higher hardness and longer service life.

Brandt M[2] et al. realized the in-situ laser cladding repair of steam turbine blades by synchronously cladding cobalt-based alloy powder (Stellite 6L) with fiber laser, and inspected the blades repaired by laser after a long time of operation. The blades showed good performance and no signs of damage.

Shepeleva L[3] and others used a CO_2 laser to carry out laser cladding on In713 alloy which is similar to the material of gas turbine blades. The results were compared with the finished products of metal wire plasma cladding, which showed that the microhardness value (650-820HV) of the laser cladding coating was higher than that of the plasma cladding sample (420-440HV) due to the significant reduction of the grain size, and the laser cladding sample did not find micro-pores and micro-cracks.

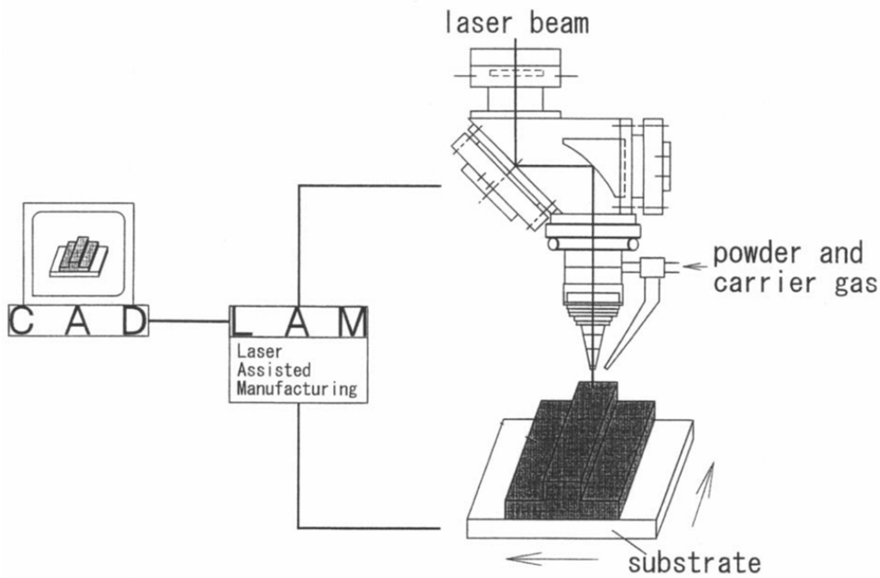

Fig 1. Schematic diagram of laser cladding

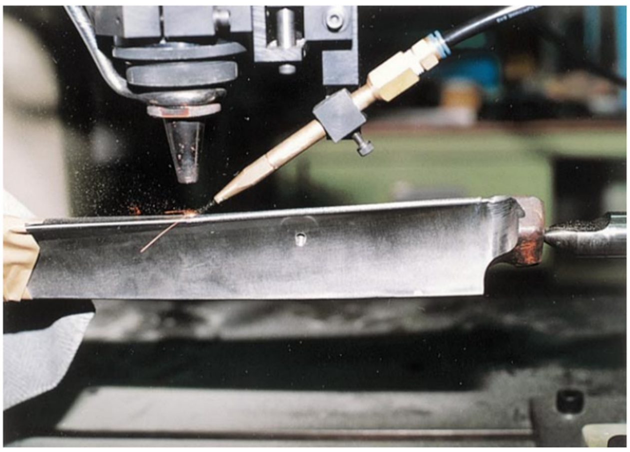

Fig 2. Laser cladding technology for repairing turbine blades

2.2 In Mold Repair, Automobile and Mining

Under cyclic thermal load, local fatigue, corrosion, wear and other damages often occur on the surface of the die. Kattire P[4] and others use CO_2 laser to synchronously coat tool steel alloy powder (CPM 9V) with high vanadium content on the common die steel plate material (H13). Hard vanadium carbide increases the hardness of the cladding layer by three times compared with the substrate.

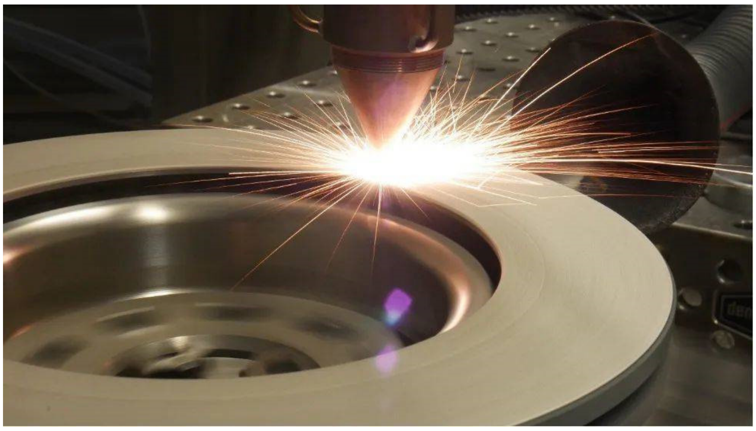

Fig 3. Laser cladding repair mold

Molybdenum-based alloys and composites are commonly used toroidal coatings for automobile engines. Rajput D[5] et al. deposited eutectic Cr- CrB_2 chromium coating and eutectic Mo-MoB molybdenum coating on AISI 4130 steel substrate in a preset way using a fiber-type laser. In this continuous coating, the boride phase of the chromium layer and the solid solution strengthening of chromium, iron and boron in the molybdenum layer make its hardness reach 1050 ± 50VHN and 1100 ± 50VHN respectively, At the same time, the wear resistance of the chromium layer and the molybdenum layer relative to the substrate are increased by 2.5 and nearly 10 times respectively, and the corrosion resistance of the chromium layer is also increased by 3 times.

In the oil production industry, crude oil mixed with corrosive media is easy to corrode the stainless steel parts in drilling and production equipment. Zhang D W[6] and others used type CO_2 laser to pre-coat the mixed powder of Ni alloy and Cr_3C_2 wrapped in Ni-Cr alloy on a stainless steel substrate similar to AISI 410 steel. Under the condition of acidic mud containing quartz sand, the corrosive wear rate of the coating was reduced by 50% compared with that of the stainless steel substrate due to the formation of austenite and hard compound M_7C_3.

2.3 In Biomedicine

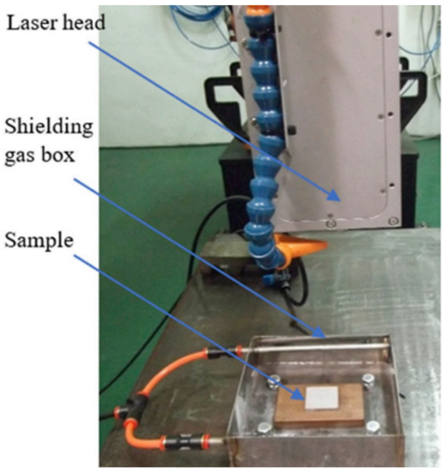

Fig 4. Preparation of biomedical materials by laser cladding [8]

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Ni-free stainless steel is a common biomedical equipment and implant material, but its wear resistance is still not ideal. This problem can be solved by improving the surface hardness of nickel-free stainless steel to improve the wear resistance. Ibrahim MZ[7] et al. prepared the Fe-based amorphous FeCrMoCB coating on nickel-free stainless steel (Cronidur 30) by using a semi-conductor laser in a preset way, with 87% amorphous content α- Fe phase makes its microhardness 1.6 times higher than that of the matrix.

3. Types of Materials Used in Laser Cladding

The commonly used cladding materials can be divided into two categories: self-fluxing alloy materials and composite materials.

3.1 Self-fluxing Alloy Material

Self-fluxing alloy powder with strong deoxidation and self-melting effect includes Fe-based, Ni-based, Co-based alloy powder, etc. For example, B and Si can form borate and silicate film with slagging effect and low melting point to cover the surface of the molten pool, prevent excessive oxidation of liquid metal, and increase the wettability of the coating [9]; Ti and Al form intermetallic compounds to produce precipitation strengthening; C generates carbide with high hardness and forms dispersion strengthening.

The composition of Fe-based alloy powder is mainly Fe-C-X (X is Cr, W, Mo, B, etc.), which is strengthened by metastable martensite and carbides [10], commonly Fe60, Fe50, etc. It can form a layer of good metallurgical bonding for steel parts, such as cast iron and low carbon steel, and has a large elastic modulus, good wear resistance and high hardness. In addition, it is cheap, and is the largest amount of cladding material at present. However, compared with Ni-based and Co-based alloy powder, the Cr element contained in it is easy to be oxidized and cause spheroidization pollution on the surface during the cladding process, with slightly poor self-solubility, weak corrosion resistance, and more pores and slag inclusions in the molten layer.

Ni-based alloy powder contains Ni, Si, B, Mo, W, Cr, Zr, Co, Fe, W and other elements, in which Cr, Fe and Ni form a solid solution to improve the wear resistance and oxidation resistance of the cladding layer, Cr, Fe, W, Mo and other elements are easy to combine with C to form carbides Cr_7C_3 , $Cr_{23}C_6$ and other elements to improve its hardness and wear resistance, and B, Zr, Co and other elements are added to achieve grain boundary strengthening. Ni-based alloy can also produce a second phase, the second phase will produce reverse grain boundaries to prevent related dislocation movement[11]. Ni-Cr-B-Si-Ci base alloy powder (Ni60, Ni55, etc.) is the most widely used in laser cladding technology, mainly used for wear-resistant, heat-resistant corrosion and thermal fatigue resistant components.

The elements contained in the Co-based alloy powder are mainly Co, Cr, W, Mo, Ni, Si, B, C and other elements. Among them, Ni can reduce the thermal expansion coefficient and melting temperature range of the cladding layer, effectively prevent cracks in the cladding layer, and improve the wettability of the cladding layer to the substrate. The Cr_7C_3 and $Cr_{23}C_6$ carbides generated by Co and Cr elements provide good high-temperature mechanical properties, and CrB and other borides improve the hardness, wear resistance and corrosion resistance of the coating, W element is often used to improve the high-temperature mechanical properties of coatings. It is widely used in valve seats in nuclear power plants, fuel nozzles and blades of steam turbines that are resistant to high temperature and wear[12], but its high price limits its application range.

3.2 Composite Materials

3.2.1 Metal-based Ceramic Materials

Metal-based ceramic materials refer to the materials that add ceramic materials as strengthening phases on the basis of metals and their alloys. The coating after laser cladding has both the high hardness of ceramic materials and the toughness of metal materials.

Ceramic materials are widely used in the fields of mechatronics, aerospace, medical and chemical industry, national defense and military industry with excellent wear resistance, high temperature resistance, high hardness, corrosion resistance and other characteristics. Generally, they can be divided into oxide, composite oxide ceramics, non-oxide ceramics, cermets and silicate ceramics. The most widely used oxide ceramics and non-oxide ceramics are introduced in detail below.

In common oxide ceramics, Al_2O_3 ceramics have excellent wear resistance, high hardness and light weight. They can be used as grinding balls, crucibles, spark plugs, thermowells, sealing rings, etc. in ball mills. They can also have a good protective effect on the matrix in high-temperature corrosive environments. They can also be combined with other oxides to synthesize composite oxide ceramics to meet specific performance.

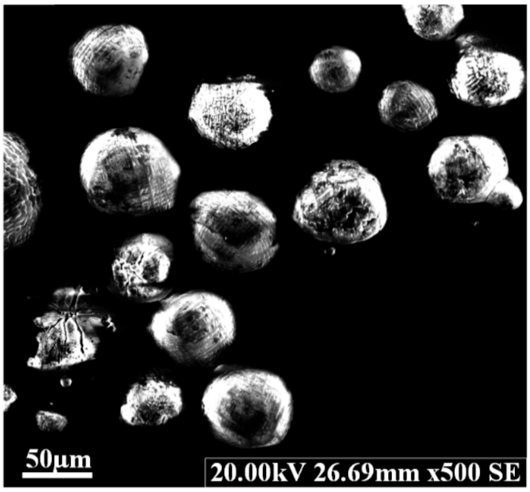

Fig 5. Ceramic material Al_2O_3

Hong Qin [13] and others successfully prepared alloy samples with various Al_2O_3 ceramic powders ratios using laser cladding technology. When the weight ratio of Al_2O_3 ceramic powders is 5%, the microstructure of the alloy is significantly improved and the grain size is significantly refined; Ceramic materials can also be laser cladding separately. For example, Gnanamuthu D S[14] used the preset method to cladding the Al_2O_3 ceramic coating on 2219 aluminum alloy plate. It was found that the cladding area without cracks has high hardness, which provides hope for the preparation of the subsequent high-performance dense ceramic coating.

Carbide, titanide and nitride ceramics (WC, TiC, TiN, TiB_2) are common in non-oxide ceramics. The contact between carbide and molten metal was first studied by Engri[15]. The metal was fused with hot-pressed TiC, and the mesophase was studied by metallographic method. Then WC, SiC, B_4C and other strengthening phases have been developed and used in succession. In laser cladding applications, coating methods (such as cobalt-coated and nickel-coated tungsten carbide) are often used to reduce the excessive melting, burning loss, carbon loss of WC powder and reduce its precipitation at the bottom of the molten pool to enhance the coating hardness and other characteristics. Among them, better wear resistance is used to manufacture special cutting tools. The face-centered cubic titanium carbide ceramic TiN can be used as an excellent wear-resistant and fusion-resistant material.

For example, Li Leichang [16] and others carried out laser cladding excitation experiments on the surface of hot work die steel 4Cr5MoSiV1 with Ni50A nickel-base self-fluxing alloy powder mixed with 10wt.% cast WC powder to study the mechanism of WC on the cracks of the cladding layer. Yamaguchi T [17] and others carried out laser cladding of WC-12wt.% Co powder on the surface of 304 stainless steel and studied the effect of ambient oxygen concentration on the properties of the cladding layer during cladding.

3.2.2 Metal Base Rare Earth Materials

Rare earth refers to scandium, yttrium and 15 lanthanide elements. The common rare earth materials used for laser cladding include yttrium aluminum garnet powder materials.

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In the process of laser cladding, rare earth element alloy is mainly added to improve the wear resistance and corrosion resistance of the cladding coating. This material has many advantages, such as: 1) large atomic radius (0.713-0.204 nm) leads to extremely strong electronegativity, and it is easy to form high-melting point positive ion rare earth oxides and sulfides. Unlike rare earth elements, which require harsh storage environment, rare earth halides and sulfides are very stable, It can produce good dispersion and strengthening effect. 2) Rare earth elements can narrow the columnar crystal area, expand the equiaxed crystal area and refine the grains. 3) Rare earth elements reduce the dendrite segregation of liquid alloy during rapid cooling, and form more uniform dendrite structure with chemical composition. At the same time, the rare earth fills the distortion zone and vacancy on the grain boundary, reducing the diffusion rate of the grain boundary of the matrix atoms, which hinders the grain boundary sliding controlled by diffusion, reduces the generation of cracks, and plays a role in grain boundary strengthening. 4) Lanthanum and cerium can obviously improve the creep strength of heat-resistant steel. 5) Strong hydrogen absorption capacity can reduce the adverse effects of hydrogen.

Fig 6. Rare earth material YAG: Ce

Figure 5 shows the rare earth material YAG: Ce. At present, laser cladding materials focus on adding ceramic materials or rare earth materials to metal-based alloy powder to achieve the purpose of surface modification.

4. Conclusion

This paper systematically introduces the advantages of laser cladding technology, the current application fields and the types of laser cladding materials. Laser cladding technology is mature, and the range of materials used is wide. Metal or non-metallic materials such as powder, wire and plate can be cladding, and different alloy powder types and proportions can be designed to meet the required performance. In addition, the laser cladding process is controlled by a predetermined program and the process parameters are easy to adjust, with high degree of automation and industrialization and high efficiency. By selecting appropriate process parameters and materials, the cladding coating and the base material can achieve a good metallurgical combination. At present, laser cladding is widely used, and it will be used in more and more aspects of people's daily life in the future.

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