CONTROL MEASURES FOR CLAD CRACKS OF LASER CLADDING REMANUFACTURING

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Abstract

The causes and preventive measures for clad cracks of laser cladding remanufacturing were discussed in this paper. The controlling crack is very importance to laser remanufacturing. The cracking formation depends mainly on residual stress and mechanical performance of layer itself. The influence of cracking formation factors is very complex. The preventive measures consist of three aspects, namely cladding materials, optimization laser process parameters and pretreatment and post-treatment technique.

Key words: remanufacture; laser cladding; crack; control measures

1 Introduction

A high energy laser beam is used to melt the substrate and powder is injected into the molten pool simultaneously, and it can provide good metallurgical bonds, minimal dilution and low distortion of substrate which is called as laser cladding processing. Laser cladding processing is a surface modification technique for improving wear resistance, corrosion resistance, heat resistance, anti-oxidation etc. surface properties of metals [1, 2]. It is an advanced surface modification and maintenance and remanufacturing waste parts technology with high economic benefits which can improve cheap steel surface performance, save cost and rarely precious metals materials [3-5]. But there are still many key problems need to solve in laser cladding processing, such as residual stress and deformation, elimination and inhibition of the crack etc., forming accuracy and surface quality and so on. The crack is the most important factor among them. Once crack generated, it will spread to the laser cladding and lead to scrape the whole part. So it is very important to control crack. Therefore, many scholars at home and abroad did a great research to the problem of cracking [6, 7]. The paper point out the mechanism and control measures for cracks of laser cladding remanufacturing.

2 Reasons of cracking formation

There are a lot of reasons on cracking formation. In generally, it depends on residual stress and mechanical performance of layer. The cracking formation is very complex. It always appears in layer internal or layer interface.

2.1 Characteristics of the effects between laser and metal material

We always do not consider the refraction during interaction between laser and metal material. When laser beam interact with the metal material, a part of laser beam was reflected and others were absorbed by metal surface. When the laser irradiated the metal material surface, as long as the energy density was big enough and the interaction time was long enough, the absorbed energy may exceed latent heat of fusion of the material and melt material. At the same time, high temperature liquid will transfer energy to neighboring solid through interface between liquid and solid, which make solid temperature high and the temperature gradient was formed. When laser beam moves away, molten pool will solidify and form laser cladding coating [8].

2.2 The effects of the residual stress

There are several reasons for crack forming. The main reason is related to the big residual stress of coating, which comes from three part: thermal stress、phase transformation stress and constrained stress. The thermal stress was caused by the temperature gradient. The phase transformation stress was caused by the phase transformation which was produced by melting metal. And the constrained stress was caused by substrate and the surrounding cladding layer. The thermal stress was the main cause，it can be expressed by [9]:

$$\sigma_{th} = \frac{E\Delta\alpha\Delta T}{1-\upsilon} \qquad (1)$$

Where, the E、υ are elastic modulus and poisson ratio of the cladding, respectively. $\Delta\alpha$ is the difference of the cladding layer and the thermal expansion coefficient. ΔT is the difference of the cladding temperature and the room temperature. Apparently, the residual stress's magnitude and whether it was the tensile stress or compressive stress was determined by the difference of the thermal expansion. There is small crack sensitivity of the cladding, when expansion coefficient of the coating is closed to or smaller than that of substrate.

2.3 Effects of the cladding materials

Self-fluxing alloy powder or self-fluxing alloy powder with some ceramic particles are the basic laser cladding materials now. These materials are not designed according to the feature of the laser cladding metallurgy, so there will be cracks in the forming process. The laser molten pool life is very short, some borosilicate cannot float on the surface of the laser pool and leave in it. So in the cooling process they will be formed liquid film and accelerate the cracking. Another borosilicate can float on the surface of the laser cladding layer, which cover the surface after cooling. If there is only single cladding layer, it is good to prevent molten or high temperature laser cladding from oxidation. But when the depositing cladding is forming, these impurities which cover the surface will lead to crack at the next layer forming process [10].

2.4 Forming mechanism of the crack [11-13]

When the force exceeds ultimate load capacity of material, the materials will from cracking. So cracking depends on force and mechanical properties of laser cladding. The influence of interaction between them leads to crack. The force mainly comes from residual stress in laser rapid forming, which is caused during laser forming. The mechanical properties of laser cladding consist of ductility and strength and defect etc., which depend on powder material and forming technology. Generally speaking, laser cladding region have different force performance and magnitude of stress, which will form crack in different region. It always appears in laser cladding layer and interface. The cracking in laser cladding layer will generate during solidification process, which spread through surface or internal of cladding layer to interface between substrate and cladding layer. The forming mechanism is that the well dendrites mutual connection to form network lead to close liquid between the dendrite during the solidification temperature range. The solid metal can deform freely, but the existing liquid in crystal cannot flow freely. Therefore there will be not enough liquid to supply. In addition, some low melting point impurities which have low crystal temperature, come into dendrite structure easily. This will make cracking sensitivity high. The cracking formed between the dendrite with the increase of stress under continuous cooling. The cracking in interface is caused in interface between substrate and layer and layer by layer. Once the crack forms it will spread through layer or cross the whole layer. This will appear macroscopic crack. The forming mechanism is that residual stress exceed interface bonding strength. This phenomenon always appears in multi-stacking process.

3 The preventive measures for cracks

The crack can be eliminated from material, process parameters and pretreatment and post-treatment technique etc. aspects.

3.1 Control cracking according to the feature of materials

(1) The thermal expansion coefficient and heat capacity matching principle of the laser cladding and substrate

One important reason of laser cladding layer crack is the different thermal expansion coefficient between cladding alloy and substrate alloy. When the difference of expansion coefficient decreases, the thermal stress of laser cladding layer will decrease. So the small difference of the thermal expansion coefficient between cladding alloy and substrate alloy is helpful to control the crack. The matching principle between the cladding materials and the substrate materials was given the following formula in reference [14].

$$\sigma_2(1-\mu)/(E\Delta T) < \Delta\alpha < \sigma_1(1-\alpha)/(E\Delta T) \qquad (2)$$

Where, the E、υ are elastic modulus and poisson ratio of the laser cladding, respectively. $\Delta\alpha$ is the difference of the cladding layer and the thermal's expansion coefficient. ΔT is the difference of the cladding temperature and the room temperature. σ_1 and σ_2 are the tensile strength of the laser cladding and the substrate materials, respectively. In addition, the heat capacity of the substrate materials is another factor. Due to there is big heat capacity for materials, the heat quantity will be larger and the temperature gradient will be bigger too. This is easy to form macroscopic crack.

2) Alloying increase tough phases

The tough phases are increased in the laser cladding layer by means of adding certain or some alloy elements under satisfying the service performance condition. Increasing the toughness of the cladding layer is a good method to control cracks. A.N.Grezev etc. [15] added 3% (mass fraction) of FeV, FeTi and FeSi to the Ni-Cr-B-Si alloy, respectively. The results showed that the tough phase γ were increased in the laser cladding layer. At the same time the cracking sensitivity of laser cladding layer was decreased significantly. The research of SONG etc. [16] showed that adding Ni, Co to the Fe-based alloy can improve the plasticity and toughness of layer. The angle between the crack direction and the laser scanning direction decreased as Ni content in the cladding layers was increased. Adding rare earth elements or rare earth oxide to the laser cladding, it may refine grain, purify tissue, improve materials' toughness and decrease the cracking sensitivity of laser cladding layer, which is helpful to control crack formation [17].

(3) Alloying change tissue morphology

Hot crack of laser cladding layer is certain similar to welding hot crack. There is one traditional theory for Ni, Cr stainless steel—there is single γ phase in the alloy steel welding seam, by adjusting Ni, Cr alloy content, γ phase and δ phase are generated. It is helpful to decrease crack. The main reason is that δ phase has more solid solubility for harmful impurities P and S which reduce harmful impurities P and S precipitate on the grain boundary. Meanwhile it reduces hot cracking for inclusion and segregation. Secondly the dispersed δ phase limits the development of γ phase dendrite, so it refines the tissue.

4) Using intermediate transition layer

It is helpful to improve the strain compatibility ability between cladding layer and substrate using a transition layer between the substrate and the cladding layer, namely using materials with strong cracking resistance and match well with substrate as bottom layer. Ni-based alloy was always used as transition layer. Because Ni-based alloy has well toughness, thermal conductivity and thermal expansion coefficient which is close to Fe-based alloy. It is helpful to reduce thermal stress which is induced by temperature gradient. Meanwhile Ni and Fe may form solid solution at the interface and improve combining strength.

3.2 Optimization laser process parameter

Once cladding material composition was fixed, laser cladding layer structure mainly depends on laser power, laser beam diameter, laser scanning speed and powder feeding rate. Xinlin Wang etc. [18] have done some experiments on increasing power density and slowing scanning speed. The purpose is that prolong the life of molten pool to increase energy input. But it should be moderate controlled considering dilution and tissue morphology. The laser remelting shows that it is a good method to form layer with homogeneous tissue composition, smooth surface and eliminate defect. Shihong Shi etc.[19] found that when the specific energy input was relatively low, there is no good metallurgical bonding between the laser cladding and substrate; when the specific energy input was relatively high, there is serious mutual diffusion between laser cladding and substrate, high dilution rate and coarse grain. Chunfang Xue etc. [20] found that sintering width was affected mainly by laser facular dimension (namely defocusing amount). When laser power density was fixed, sintering width increase with the increment of defocusing amount; When laser power and defocusing amount are fixed, sintering thickness decrease with the increment of laser scanning speed. Literature [21] has made use of MSC/NASTRAN Finite Element Analysis Software to analysis planar residual stress in laser cladding layer cross section. The authors obtained the residua stress distribution to explain laser cladding crack phenomenon. This is a good method to optimize process parameters and material parameters. So it may also reduce crack effectively.

3.3 Optimization pretreatment and post treatment technique

The substrate preheating before laser treatment and slow cooling after treatment is one of the effective methods. The essence of preheating and slow cooling is that they decrease temperature gradient. This is helpful to decrease residual stress. But this will lead to weak the technical advantage of laser rapid heating and fast cooling. LUAN etc. proposed a concept of critical overlapping amount, that is different materials may avoid crack in critical overlapping amount. But in practical operation, there was a certain limitation that the accuracy of overlapping amount was hard to control. It is better to remain certain width between two laser traces when large area laser cladding must adopt multi-track overlapping. This is good to control the generation and transmission of cracking. In addition, we can increase tempering process to decrease stress value after laser cladding. Besides there are other methods to decrease cracking, such as electromagnetic stirring and laser remelting .etc.

4 Application examples

Our investigative group presently is using laser cladding technology to repair high speed heavy load gear. We can decrease or eliminate cracking significantly through improvement of material composition and optimization of process as well as preheating process. Gear is one of the parts most widely used. That remanufacturing has economic effect significantly.

5 Conclusions

There is still no perfect method to inhibit cracking now, because the influence factors of laser cladding cracking are complex. Laser clad cracking is related to internal stress of laser cladding layer, which is necessary condition for cracking forming. The main reason on cracking forming is bonding strength and plasticity and toughness of the laser cladding. At present, the three main aspects such as materials, process parameters and pretreatment/post-treatment technique can eliminate and inhibit cracking.

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