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Microstructure and properties of the laser cladding ODS layers on CLAM steel

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ABSTRACT

In this study, oxide dispersion strengthened (ODS) layers with different Y_2O_3 addition were cladded on China Low Activation Martensitic (CLAM) steel to improve its mechanical strength, micro-hardness and high-temperature behavior. The results show that fine surface morphologies can be observed in cladding zones. In cladding layers, the Fe, Cr, W, Y, Ti elements was discriminated by the scanning electron microscope (SEM) with energy-dispersive spectrometer (EDS) and the most stable Y-Ti oxide complexes $Y_2Ti_2O_7$ phase were analyzed by X-ray diffraction (XRD). The micro-hardness of ODS layers are higher than that of CLAM steel. The CLAM steel with 2 wt% Y_2O_3 addition ODS layer possesses an average tensile strength of 840 MPa which is 166 MPa higher than that of CLAM steel. It is suggested that the dispersion strengthening of oxide particles in ODS layer contributed to the increased strength.

1. Introduction

China Low Activation Martensitic (CLAM) steel is a kind of reduced activation ferritic/martensitic (RAFM) steel which is chosen as candidate for structural materials in future fusion reactor applications considering their excellent swelling resistance [1–3]. The ton-scale CLAM steel can be produced by casting and rolling [4]. However, CLAM steels exhibit a low strength during the long-term thermal exposure in operation temperature around 550 °C [5]. Oxide dispersion strengthened (ODS) steel was developed to improve its high temperature properties. The Y–Ti–O rich nano-scale clusters play key roles in ODS steels by pinning dislocation which can improve its thermal stability behavior [6–7]. ODS steels are fabricated by mechanical alloying, hot extrusion and spark plasma sintering (SPS) generally [8]. However, it is difficult to produce ODS steel by casting, because the oxide particles will agglomerate in the casting process, which results in the decrease of mechanical properties [9]. Recently, some researches about ODS coating on different substrate to improve the substrate properties have been done. Y.-H. Koo et al. [10] had coated Y_2O_3 layer on Zircaloy-4 by laser beam scanning to increase its strength. With the formation of Y_2O_3 coating, the tensile strength increase by 20% at room temperature. Fu et al. [11] investigated the effect of La_2O_3 content in ODS cladding layer on 316 L steel. The corrosion resistance and the micro-hardness of ODS coated 316 L can be improved when the addition amount of La_2O_3 is 0.4%, too much La_2O_3 cause inclusion and other defects which is unfavorable to the improvement of the performance. Laser cladding is a dominating and popular surface technology to fabricate coatings on substrate which has more advantages in large scale samples [12].

In this paper, ODS layers was cladded on the CLAM steel surface by laser cladding to increase its mechanical property and operating temperature. The effects of Y_2O_3 addition on the microstructure, micro-hardness, tensile strength of the ODS coated CLAM steel were investigated.

2. Experimental procedures

The CLAM steel (Fe-8.93Cr-1.43W-0.48Mn-0.19V-0.1Ta-0.09C-0.05Si) was used as the substrate material with a thickness of 1.5 mm. The chemical composition of ODS layers are shown in Table 1. The predeposit powders are prepared by elemental blended. The micromorphology and XRD results of powders are shown in Fig. 1. Y_2O_3 exist in the XRD results of 2 wt% Y_2O_3 and 5 wt% Y_2O_3 addition ODS powders. No peak of Y_2O_3 was detected in XRD results of 1 wt% Y_2O_3 addition powders due to its low content. The powders are mainly spherical and the average diameter of the powders is about 5 μm. In order to obtain clean substrates, the CLAM steel was sanded with metallographic

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Table 1
Chemical composition (wt%) of pre-deposit powders.

Specimen	Fe	Cr	W	Ti	Y_2O_3
1	88.7	9	2	0.3	0
2	87.7	9	2	0.3	1
3	85.7	9	2	0.3	2
4	83.7	9	2	0.3	5

sand paper, cleaned with acetone solution, alcohol successively and then dried. To form a pre-deposit layer, ODS powders were added in an agate bowl, mixed with distilled water and Carboxyl Methyl Cellulose (CMC).The mass ratio of ODS powders to water to CMC is 50:25:1. The ODS powders were wet-coated on the CLAM steel by a doctor blade and dried in an oven at 80 °C for 40 min to form a 200 μm thick paste. In order to ensure the reliability and reproducibility of the test results, three specimens of every parameter were tested for analysis.

A 1000 W pulsed Nd:YAG laser system was used for laser cladding. According to previous study and our great deal of tests, the laser power of 150 W, 170 W and 190 W were chosen to discuss in this article. The scanning speed is 3.5 mm/s. The diameter of laser spot is 0.6 mm, pulsed frequency is 25HZ, pulse width is 2 ms, overlap rate is 50%, the defocusing distance was 0.5 mm. 12 L/min Ar gas continuously blow on the samples' surfaces to prevent oxidation.

After laser cladding, metallographic samples were cut perpendicular to the cladding direction. The samples were grinded on emery papers and polished, then etched in Villella's reagent for 35 s. Optical microscope (OM, HT630CN), scanning electron microscope (SEM, JSM-6490LV), energy dispersive X-ray spectroscopy (EDS, Oxford Inca Energy350) and X-ray diffraction (XRD, D/MAX2500V) were used to analyze microstructure, element distribution and phases in the cladding zone. Vicker's micro-hardness was measured by Warnway VTS401 at the cladding zone from top to substrate on depth direction of every laser track with a load of 50 g and a holding time of 10 s. Tensile strength was evaluated on CMT5150 Universal tester with a constant displacement rate of 1 mm/min. The sample size and macroscopic morphology of samples after tensile test are shown in Fig. 2.

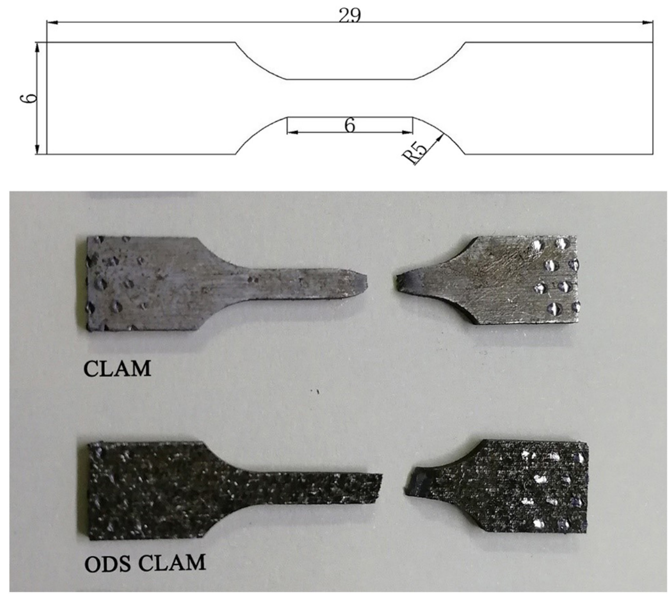

Fig. 2. Tensile sample size and appearance of ODS CLAM specimens.

3. Results and analysis

3.1. Surface and cross-sectional morphologies

Fig. 3 shows the top surface and cross-sectional morphologies of cladding zone with 2 wt% Y_2O_3 addition under different laser power. The fine ripple patterns on the surface of cladding zone were observed. With the increase of laser power, cladding zone present incremental tendency in thickness. The certain depth of cladding zone is important to ensure the impact on the performance of CLAM steel [10]. At the power of 150 W, the top surface of cladding zone shows relatively smooth while the cross-sectional morphologies indicate that the depth is very shallow. Too shallow depth of ODS layer make it difficult to affect its mechanical property and high-temperature strength of CLAM steel. At the power of 190 W, the cladding zone exhibit a deeper depth while the spatters bring out a large number of ODS powders pointed out with an arrow in Fig. 3. Too high laser energy leads to many powders burning out. The top surface of cladding zone is relatively smooth with little burning loss at the power of 170 W. The cross-sectional morphologies of cladding zone shows metallurgical bonding between ODS layer and CLAM steel. Take these two factors into account, laser power of 170 W was selected in our subsequent experiments.

In order to ensure the good metallurgical combination of cladding material and substrate, a certain amount of matrix must be melted in the process of laser cladding, and the melted matrix will dilute the cladding layer. Proper dilution rate is a key to ensure the effective bonding of cladding and matrix [13]. The schematic diagram of dilution rate was shown in Fig. 4. The area of deposit (A_d) and molten area (A_m) under different laser powers were calculated by Image Pro-plus. The dilution rate can be approximately calculated by the following

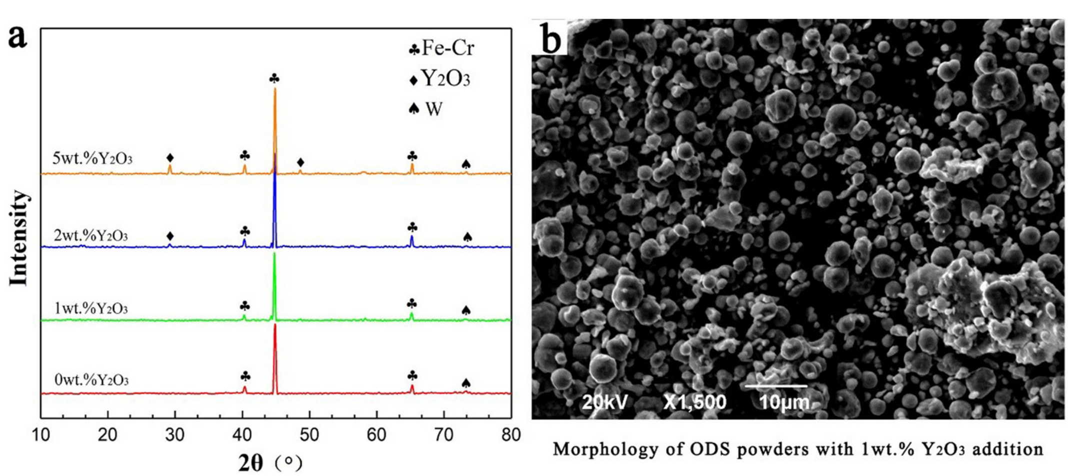

Fig. 1. The XRD result and micromorphology of ODS powders.