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Full Length Article

Influence of the laser pre-quenched substrate on an electroplated chromium coating/steel substrate

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A R T I C L E I N F O

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A B S T R A C T

The chromium coatings were electroplated onto a laser pre-quenched steel substrate to improve the interfacial adhesion properties of chromium coating/steel substrate system. The influence of laser pre-treatment on the substrate, coating as well as interface was investigated by using microstructure characterization, hardness testing, tensile testing and finite element analysis. An apparent boundary line instead of an interlayer was identified between chromium coating/pre-quenched steel substrate. The Vickers hardness and yield strength of steel substrate were significantly improved after laser pre-quenching. The fracture toughness of chromium coating was increased by about 28.6% compared to the un-treated counterpart. The energy release rate for an interfacial crack in the chromium coating/laser-quenched substrate was smaller than that in the untreated specimen. These results may help understand the life prolongation mechanism for the laser pre-quenched chromium/coated steel parts.

1. Introduction

The high hardness, excellent wear and corrosion resistance, and low coefficient of friction have made chromium electrodeposit an ideal coating material for a broad range of applications in engineering parts, including dies [1], engine valves [2], and gun barrels [3]. During the service period, chromium coating usually needs to bear severe squeezing [1,2], high thermal stresses [4] and serious erosion [5]. With repetition of such loading cycles, perpendicular cracks may initiate at the surface, propagate in the thickness direction and eventually kink into the interface causing local delamination [4]. A major concern arises therefore from that the chromium coating is susceptible to cracking and being peeled off the underlying steel substrate. The reason for such failure is closely related to insufficiently good performance of chromium coating and that of the interface in particular [5].

As a well-established method, the technology of laser modification is highly effective and efficient in improving the mechanical properties of metallic materials. It was shown in the experimental work of Soriano et al. [6] that the laser surface hardening was a suitable method for enhancing hardness and wear resistance of austempered ductile irons. Buling and co-authors [7] reported that laser pretreatment of metallic substrates could improve the adhesion of a bearing steel–polymer interface. In the evaluation of laser surface remelting upon a cold work tool steel, Jurci et al. [8] found that laser remelted material was significantly softer than that hardened in a solid state due to the presence of dominant portion of retained austenite in the microstructure. Sturm and co-authors [9] studied the optimal parameters for laser surface melting of powder-metallurgy processed, cold-work tool steel. They found that a crack- and pore-free modified surface was achieved by pre-heating of the steel prior to the laser surface melting. In the work of Varela et al. [10], the dense layers of NiCrBSi alloy powder mixed with WC powder have been produced by laser cladding on stainless steel substrates of AISI 304. Chen and co-authors [11] showed that laser cladding was an efficient method to improve surface properties of Mg–Rare earth alloys.

In a similar manner, two strategies of hybrid processing have been proposed, aimed at enhancing the interfacial adhesion of chromium/steel parts. Either technique consists of two typical processes, i.e., laser quenching and coating deposition, but in different sequences. If the laser was irradiated directly on the chromium-plated steel, the chromium coating was found to exhibit much decreased durability [12]. In contrast, if the steel substrate was laser quenched prior to coating deposition, the load-bearing capacity of chromium electroplates was reported noticeably higher in reference literatures [13] and [14]. By dissolving chromium coatings, Li et al. [15] found that the morphology and microstructure of both steel substrate and chromium coating can be strongly affected by means of laser pre-quenching the steel substrate. In the study of Xu

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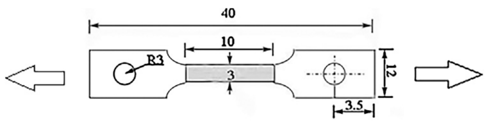

Fig 1. Schematic of the tensile sample (unit: mm). The arrows indicate the load direction.

et al. [16], the microstructure of chromium coating was observed to be dependent on the growth conditions on the steel substrate, which can be altered in an effective way by laser pre-quenching. Zhang and Yao [17] reported that the interfacial shear strength could be increased by 77.7% through laser pre-quenching steel substrate. Yang et al. [18] investigated the effect of a laser pre-quenched steel substrate on the fracture behavior of a coating and found that the crack growth resistance of the bi-material system was enhanced in a pronounced manner.

In the present work, the influence of laser pre-quenching on substrate was characterized for an electroplated chromium coating/steel substrate system. The mechanical properties were investigated, including fracture toughness of chromium coating, Vickers hardness and yield strength of substrate as well as interfacial adhesion properties. Of particular interest is the quantitative evaluation of laser quenching effect on the energy release rate for an interfacial crack by the finite element analysis.

2. Experimental

2.1. Materials

The steel 30CrNi2MoV was used as substrate material, whose informative chemical composition was given in Table 1. The substrate was quenched on surface by using CO_2 laser of power 600 W, with a spot diameter of 5 mm and a scan speed of 10 mm/s. The quenched steel plate was then tempered in vacuum at 200 °C for 2 h to remove the existing residual stresses. The chromium coating, of thickness ranging from 100 to 150 μm, was electroplated onto steel substrate at an operating temperature 85 °C and a current density of 60 A/dm^2. The standard chrome plating solution was used with chromic acid (250 g/L) and sulfuric acid (2.5 g/L). The detailed preparation process on chromium electroplating can be found in Ref. [15].

Table 1
The average chemical composition of substrate material (wt.%).

Element	C	Cr	Ni	Mo	V	Fe
Content	0.28	0.7	2.27	0.2	0.21	balance

2.2. Microstructure characterization and hardness test

The specimens with a final size of 17 mm × 10 mm × 5 mm were prepared by electro-discharge machining device. The cross-section was mechanically grinded and polished with the 2000 grit SiC paper, and then ultrasonically cleaned in an ultrasonic bath for 5 min. The Nital 4% in volume was used to reveal the microstructure of laser-quenched zone. The microstructure and morphology in the immediate neighborhood of the interface were characterized by optical microscope (OM), scanning electron microscope (SEM) (Zeiss Auriga FIB, Germany) and transmission electron microscopy (TEM) (Tecnai G2 F30, USA). The hardness of substrate was measured on a Vickers micro-hardness tester (MH-6, China) with a load of 0.1 kg and dwell time of 15 s.

2.3. Tensile test

The dog-bone shaped specimen was represented schematically in Fig. 1, and was produced from chromium-electroplated samples using electro-discharge machining process. The grey area indicates the chromium layer. The coating thickness and the substrate thickness are ∼140 μm and ∼860 μm, respectively. The systems

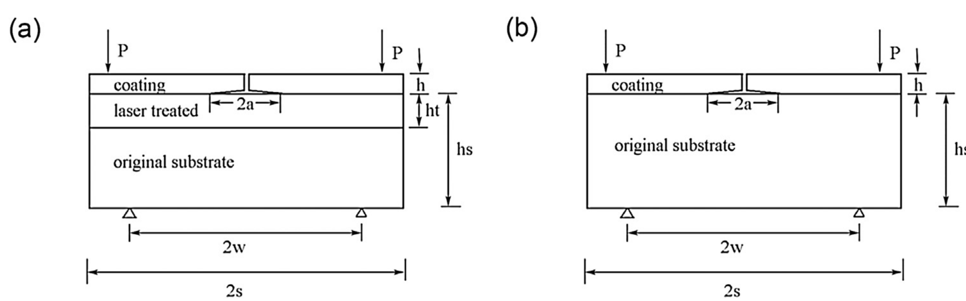

Fig. 2. Schematic representation of the four-point bending specimen (a) laser-treated specimen; (b) untreated specimen.

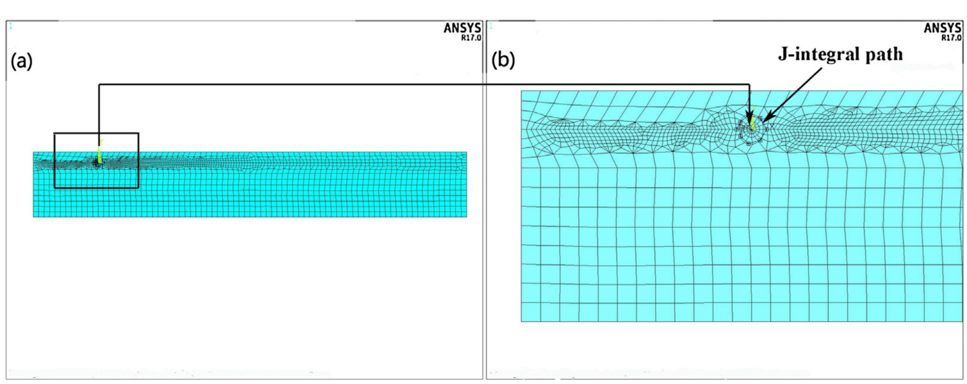

Fig. 3. (a) Schematic of finite element mesh; (b) the zoomed view around the crack tip.