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Materials Chemistry and Physics 92 (2005) 340–347
MATERIALS CHEMISTRY AND PHYSICS
www.elsevier.com/locate/matchemphys

Investigation on multi-element Ni–Cr–Mo–Cu alloying layer by double glow plasma alloying technique

Xu Jiang[a,*], Xishan Xie[b], Zhong Xu[c], Wenjin Liu[a]

[a] *Laser Processing research Center, Mechanical Engineering Department, Tsinghua University, Beijing 10084, PR China*
[b] *University of Science and Technology Beijing, Beijing, 100083, China*
[c] *Taiyuan University of Technology, TaiYuan, 030024, China*

Received 2 April 2004; accepted 22 October 2004

Abstract

This paper describes an investigation of double glow surface alloying of low-carbon steel with Hastelloy C-2000 nickel-based surperalloy. Emphasis is placed on the effect of the source electrode voltage, cathode voltage, working pressure and parallel distance between source electrode and cathode on the chemical composition and physical qualities of surface alloying layer. The results show that the total content of alloy elements, thickness of alloying layer and absorbing alloy element rate have closely related with technological parameters. The combination of SEM and XRD is used to investigate morphology and structure of the multi-element Ni–Cr–Mo–Cu surface alloying layer. The thermodynamic calculation was performed to predict the mole fraction of phase in the alloying layer as function of temperature. The calculated results is in agreement with the observation of microstructure of alloying layer. The corrosion experimental results indicated that the corrosion resistance of alloying layer formed on the stainless steel was super to that of alloying layer formed on the low-carbon steel.

Keywords: Double glow; Technological parameters; Ni–Cr–Mo–Cu multi-element alloying

1. Introduction

It is well known that the reason of damage for most of metallic components is relative to the surface properties of materials. Technique of surface treatments that result in special properties have stimulated much interest for increasing hardness, corrosion resistance etc. Professor Xu Zhong from TaiYuan university of technology invented a new technique for surface treatment, the double glow plasma surface alloying technique, known as Xu-Tec/Xu-Loy process. Worldwide patents for Xu-Tec process have been granted in the United States, Canada, United Kingdom, Australia, Belgium, France and Sweden [1]. The double glow surface alloying technique is unique and hybrid plasma surface treatment technique which is the evolution of both plasma nitriding and sputtering techniques and develops in response to the need for higher quality alloy layer on the surface of cheap materials. This technology employs low temperature plasma produced by a glow discharge to drive source materials atoms of one or more element to be sputtered and then diffuse into the substrate's surface. The depth of the alloying layer could vary form several microns to 500 μm, with alloying elements in a concentration of few percent to 90% or more. Mono-element alloying of alloying-element of Ni, Cr, Mo, W, Ta, Al, Ti, etc. [2] and multi-element alloying of alloying elements of Ni–Cr, W–Mo, W–Mo–Cr–V, etc. have been studied [3–6]. Comparing to ion implantation or laser surface alloying, the double glow plasma technique is cheaper for many potential users. In order to achieve a high quality surface alloying process, the glow discharge parameters must be selected carefully. There are four parameters relating the glow discharge in the double glow process, i.e., source electrode voltage, cathode voltage working pressure and distance between the source electrode and cathode. This work introduces the effect of technological parameter on the composition and thickness of multi-element

* Corresponding author. Tel.: +86 13311212937; fax: +86 10 62772353.
E-mail address: xujiang73@sina.com.cn (X. Jiang).

0254-0584/$ – see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.matchemphys.2004.10.050

Ni–Cr–Mo–Cu surface alloying layer by double glow plasma process.

2. Experimental method

The Xu-Tec process is performed in a vacuum chamber. Fig. 1 indicates the general principle of Xu-Tec process. There are three electrode:the anode and two negatively charged members, the cathode (workplace) and the source electrode. The source electrode is made up of the desired alloying elements. With the two power supplies turned on both cathode and source electrode are surrounded by glow discharge. One glow discharge heats the substrate to be alloyed while the second glow strikes the source electrode materials for supplying desired alloying elements. The desired alloying elements travel toward the substrate and diffuse into the substrate materials surface forming alloying layer.

The surface alloying experiments were performed in Double Glow Plasma Surface Alloying Devise. Hastelloy C-2000 (the composition is Ni 59, Mo 16, Cr 23, Cu 1.6, C <0.01 in weight percent) plate (130 mm × 50 mm × 4 mm) was used as the source electrode for supplying alloying elements. Low carbon steel 1020 plate (80 mm × 25 mm × 3 mm) were used as substrate. Orthogonal test is given in Table 1 for choosing the process parameters such as source electrode voltage, cathode voltage, working pressure, distance between source electrode and cathode as experimental factor, and every factor has four levels (treatment time 3 h). The content of alloy elements of alloying layer on surface, thickness of alloying layer and absorbing alloy element rate (the ratio the increasing mass of workpiece to the mass loss of source materials) are selected as evaluating target from the principle and demand of the double glow discharge plasma alloying process. The chemical compositions in the surface layer are analyzed by X-ray Energy Dispersive Spectroscopy (X-EDS).

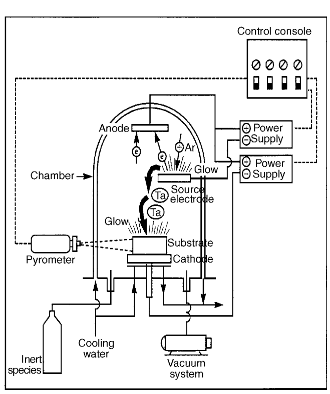

Fig. 1. Schematic diagram of the Xu-Tec unit.

Table 1
Factor and levels

Factor	Levels			
	1	2	3	4
Source electrodevoltage (V)	1050	1000	950	900
Workpiece electrode voltage (V)	275	250	350	300
Working pressure (Pa)	35	30	45	40
Distance (mm)	15	20	25	22.5

Potentiodynamic anodic polarization curves were obtained at a sweep rate 20 mV min^{-1}, starting form a moment when the open circuit potential become steady after immersion of the specimen for about 10 min. A saturated calomel electrode and a platinum sheet were used as reference and counter electrodes, respectively. An electrolyte used was 3.5% NaCl, 5% HCl and 5% H_2SO_4 solution open to air at 25 °C.

3. Results and discussion

3.1. Source voltage

The effect of source voltage on the content of alloy elements on surface, thickness of alloying layer and absorbing alloy element rate are shown in Figs. 2–4. From Figs. 2–4, the content of alloy element of surface of alloying layer, thickness of alloying layer and absorbing alloy element rate increase with increasing of source electrode voltage. Because of the energy of ion bombarding relating with sputtering voltage, the higher source electrode voltage, the higher energy of ion bombarding on the target is offered. As shown in Fig. 5, when increasing source electrode voltage from 900 V to 1050 V, the source electrode current increases linearly from 6.97 A to 7.4 A. Since the increasing of a amount of output power density and sputtering coefficient, which help especially to form high supplying desired alloy element from the source electrode materials and gradient concentration of alloy elements in surface alloying layer. Correspondingly, the process of the

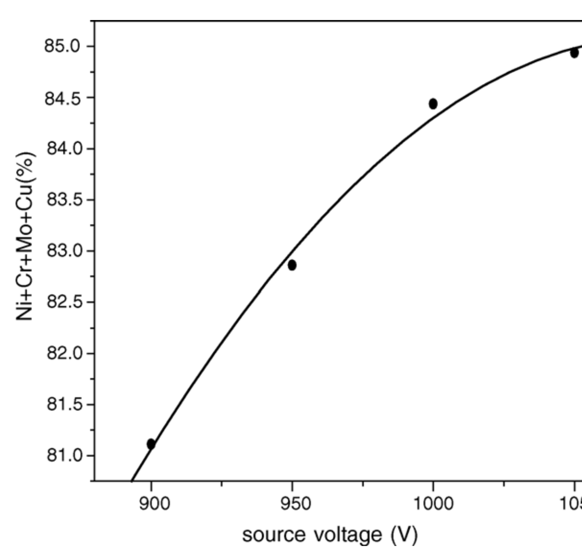

Fig. 2. Effect of source voltage on the content of alloy elements on the surface of alloying layer.