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ARTICLE

Improvement of the Corrosion Resistance of Steel Wires by Manufacturing Continuous Bulk Metallic Glass-Coated Steel Wires

Zhang Baoyu[1], Guo Xinge[2], Chen Xiaohua[3], Yang Wenzhi[1], Chen Ziming[1], Huang Wei[1], Shang Fujun[1], Shi Honggang[1]

[1] Ningbo Branch of China Academy of Ordnance Science, Ningbo 315103, China; [2] Institute of Solid State Physics, Chinese Academy of Sciences, Hefei 230031, China; [3] State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, China

Abstract: To improve the corrosion resistance of steel wires, a uniform thin layer of bulk metallic glass alloy with different compositions of $(Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5})_{100-x}Nb_x$ (x=0, 3, 5, 8 at%) was coated on the surface of Q195 steel wires by a newly developed continuous coating process. Phase analysis results show that the coating is mainly composed of metallic glass alloy and some other intermetallics. The potentiodynamic polarization tests indicate that the steel wires with metallic glass coating show passivation behavior, and have higher pitting potential and lower corrosion current density than Q195 steel wires. With the increment of Nb content, the passivation region of the metallic glass-coated steel wires become wider while pitting potential is increased. As shown in composition analysis results, it may be attributed to the addition of Nb which has properties of easy passivation and stabilizing the passivation elements of Zr and Ti.

Key words: steel wires; bulk metallic glasses; coatings; pitting corrosion resistance

Bulk metallic glasses (BMGs) are of great interest for their excellent mechanical, physical and chemical properties [1-3]. Compared with their crystalline counterparts, BMGs possess disorder structure, homogeneous components, more easily passivation nonferrous metal elements and eliminate grain boundaries as well as composition segregation, etc. So BMGs show better corrosion resistance than metallic crystal materials counterparts in corrosion environment.

Zr- [4,5], Cu-[6,7], Ti-[8] and Fe-[9] based BMGs possess excellent glass forming ability (GFA), high mechanical properties and high passivation ability in halide-free electrolytes. In contrast, these alloy systems show poor pitting corrosion resistance in aqueous solution containing chlorides ions[10-14]. Many methods have been reported to improve the anti-pitting corrosion ability of metallic glass alloys, such as ion implantation[15], shot peening[16,17], addition of Nb or Ta[18,19].

Recently, more and more attention is paid to the applications of BMG alloys as corrosion resistant coating. On one hand, new systems of bulk BMG have been trapped into difficulty; On the other hand, metallic glass is an ideal candidate for anticorrosion coating because of its excellent wear or corrosion resistance. Fe-[20-24], Zr-[25-27], Ti-[28,29], Cu-[30] based metallic glass alloys are coated on bulk alloy plates by pulse magnetron sputtering, shroud plasma spraying, or pulse laser deposition, thermal spraying, or electrospark deposition. However, only a few studies[31] have been reported on coating metallic glass on metallic wires, which play a key role in transferring loads and power. In our early works[32-37], a newly developed continuous coating technique was developed, which can achieve both higher coating efficiency and lower preparation cost than any other coating process. In order to improve the corrosion resistance of steel wires, a series of

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Corresponding author: Zhang Baoyu, Ph. D., Assistant Researcher, Ningbo Branch of China Academy of Ordnance Science, Ningbo 315103, P. R. China, Tel: 0086-574-87017901, E-mail: byzhang@outlook.com

$(Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5})_{100-x}Nb_x$ (x=0, 3, 5, 8 at%) BMG-coated Q195 steel wires were prepared by the newly developed continuous coating process. And their corrosion behavior in 3.5 wt% NaCl aqueous solution was studied using potentiodynamic polarization tests combined with scanning electron microscopy and energy dispersive spectrometer.

1 Experiment

Master alloy ingots with nominal composition of $(Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5})_{100-x}Nb_x$ (x=0, 3, 5, 8, at%) were synthesized by arc-melting pure metal blocks under a Ti-gettered argon atmosphere. Nb and Zr were first melted as master alloy and then were remelted with other metallic elements for four times to ensure the homogenization of the refractory Nb in the alloy. The surface of Q195 steel wire with diameter of 0.5 mm was polished using 12 μm SiC sandpapers and then cleaned in the solution of acetone and ethanol. Then the metallic glass alloy was coated on the surface of the Q195 steel wire by the continuous coating process. A Q195 steel wire was firstly drawn through a crucible filled with the melting metallic glass alloy, and then quickly entered the cooling unit to obtain metallic glass coating. More details of this coating process can be referred to Refs. [32-37].

Phase analysis of the metallic glass-coated steel wires was performed using Rigaku D/max-rB type of X-ray diffraction (XRD) with Cu Kα radiation. A row of metallic glass-coated steel wires with length of 16 mm were arrayed on the groove of glass slide, and the XRD patterns reflected the structure information of both the BMG coating and the Q195 steel wire. The pitting corrosion behavior of all BMG-coated steel wires in the 3.5 wt% NaCl aqueous solution was evaluated using model Gill AC manufactured by ACM Instrument. A symbolic three electron cell using a platinum counter electrode and a saturated calomel reference electrode (SCE) was used in the electrochemical polarization tests. The open circuit potential (OCP) measurement was maintained until the potential value change was no more than 2 mV/5 min. The potentiodynamic polarization tests were performed from –100 mV (*vs*. SCE) to +700 mV (*vs*. SCE) with a scanning rate of 10 mV/min. The corrosion potential (E_{corr}), the corrosion current density (I_{corr}) and the pitting potential (E_{pit}) were calculated by Tafel equation method. The surface morphology of the metallic glass-coated steel wires after potentiodynamic polarization tests was observed by scanning electron microscopy (SEM) and the elements distribution in the pitting holes were analyzed by Energy Dispersive Spectrometer (EDS) using a Carl Zeiss Auriga Crossbeam Workstation.

2 Results and Discussion

2.1 Microstructure of the metallic glass-coated steel wire

The cross-section image of $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$ (Vit 1)-coated Q195 steel wire is displayed in Fig.1. The metallic glass with thickness of 5~7 μm is uniformly coated on the

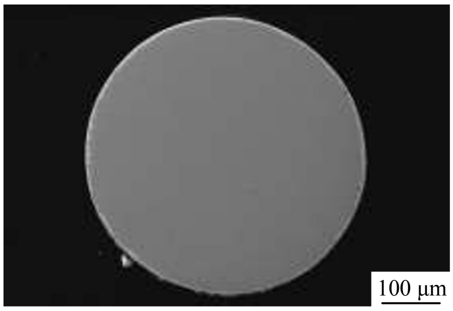

Fig.1 Cross-section photograph of $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$ BMG-coated Q195 steel wire

surface of Q195 steel wire. It is also noticed that most metallic glass coatings strongly bond with the surface of Q195 steel wire. In the left section of Fig.1, there are some micropores near the interface between metallic glass coating and Q195 steel wire, indicating that some gas molecules are trapped during solidification of metallic glass. These gas voids can be eliminated through optimizing the preparation process in further research.

2.2 Phase structure analysis

The XRD patterns of Q195 steel wire and $(Zr_{41.2}Ti_{13.8}Cu_{12.5}$-$Ni_{10}Be_{22.5})_{100-x}Nb_x$ (x=0, 3, 5, 8, at%) BMG-coated steel wires are shown in Fig.2. The patterns of metallic glass-coated steel wires show a wide dispersion of the diffuse scattering peak, which is the characteristic of amorphous structure, superimposed by crystalline diffraction peaks of the Q195 steel wire and some other phases ($Fe_{37}Nb_9Zr_{54}$, Ni_2Zr_3 and NiZr). With the increment of Nb content, the peak intensity of Q195 steel wire decreases while the peak intensity of $Fe_{37}Nb_9Zr_{54}$ increases notably. It is also noticed that the $(Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5})_{95}Nb_5$-coated Q195 steel wire contains crystalline phase NiZr.

2.3 Electrochemical analysis

Fig.3 shows the potentiodynamic polarization curves of $(Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5})_{100-x}Nb_x$ BMG-coated steel wires

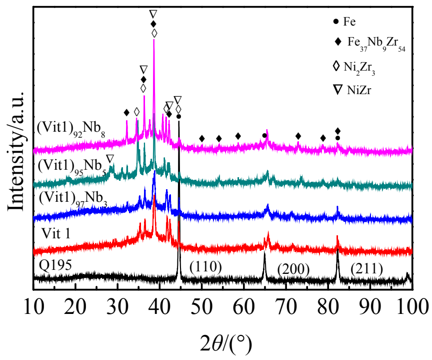

Fig.2 XRD patterns of Q195 steel wire and $(Zr_{41.2}Ti_{13.8}Cu_{12.5}$-$Ni_{10}Be_{22.5})_{100-x}Nb_x$ (x=0, 3, 5, 8, at%) BMG-coated Q195 steel wires