Optics and Laser Technology 108 (2018) 480–486

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Microstructure and properties of Cu/TiB_2 wear resistance composite coating on H13 steel prepared by in-situ laser cladding

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ARTICLE INFO

Article history:
Received 13 April 2018
Received in revised form 4 July 2018
Accepted 16 July 2018

Keywords:
Cu/TiB_2 composite coating
Laser cladding
Wear resistance
Abrasive wear testing
H13 steel

ABSTRACT

In this paper, microstructure and properties of Cu/TiB_2 composite coating from Ti, B, Cu pure powders on H13 steel prepared by in-situ laser cladding were studied. The experimental results showed that, in laser cladding process to manufacture coatings, Ti and B powders react to form dispersed TiB_2 phase in the Cu matrix. The Energy Dispersive X-ray Spectroscopy (EDS) analysis showed that, a high-strength metallurgical bond is formed between coating and substrate. The surface microhardness of coating is found to reach 650 HV0.5, which was significantly higher than that given by the substrate, and gradually decreases with the depth into the substrate. When abrasive wear testing at temperature of 500 °C, the wear resistance of the Cu/TiB_2 coating was higher than that of the substrate by many times, and it significantly reduces with increasing (Ti + B) content. This implies that the in-situ synthesis of Cu/TiB_2 composite coating prepared by laser cladding can improve the friction and wear properties of H13 steel. This coating can be applied for manufacturing die and mold, especially hot working die and high pressure die casting die.

1. Introduction

In industrial production, the dies and molds play an important role in the production process. Because of working under extreme environmental conditions, the dies and mold surface generally have to meet high performance requirements, especially for hot and cold working dies. In the process of processing, dies and metal blanks contact frequently and have relative movement to each other. This leads to increased friction and wear on the die surface. Therefore, at some moment it is necessary to stop the production line to repair or replace dies, that will cause economic losses to manufacturers.

Surface treatment for hot working dies by creating wear and thermal resistant coatings is the most popular solution to improve utilization efficiency of the dies. Recently, one of the most advanced surface techniques is laser cladding. Laser cladding widely uses a high power industrial laser beam to melt material onto a substrate creating an overlay with true metallurgical bonding. The main advantage of laser cladding is the low heat input into the substrate.

Copper is a soft metal with very low solubility in iron. The two elements do not react, but the solved Cu causes a slight lattice distortion and hardens the material. Alloys that contain enough Cu can be precipitation hardened. The inclusions of Cu can then act as a lubricant when the steel is abraded, forming a protective tribo-layer [1–3]. Recently, the inclusions that play a role reinforcing copper and form self-lubricating coatings are often hard ceramic particles, such as NiB, h-BN, MoS_2, WS_2, ZrB_2, Al_2O_3, TiO_2, Ni_3P, TiC, TiB_2 [4–13]. For example, Cheng and his co-workers [4] have studied the effect of h-BN addition on the friction coefficient of SiC coating at room and evaluated temperature. Ružić and his co-workers [7] have studied copper matrix composite reinforced with ZrB_2 particles. Moreover, in order to strengthen the surface of pure copper, the nanocrystalline Ni-B has also been synthesized experimentally.

Among those various ceramic particles, TiB_2 is expected to be one of the best reinforcements for steel matrix materials due to its high hardness, high melting temperature, high elastic modulus, good electrical conductivity, good wear resistance and good thermodynamic stability [5,12,14–22]. For instance, the authors [5,12] indicated that the TiB_2/Fe coating on steel can enhance its wear resistance of mechanical components by laser cladding. Meanwhile, the authors [14] showed that a Cu matrix composite with 5 vol% TiB_2 particles by powder metallurgy through ECAP for 4 passes at 513 K can increase strength of the Cu matrix. Gu et al. [19] showed that the electrical conductivity of the TiB_2/Cu composite, prepared by an in situ laser remelting was reduced with

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https://doi.org/10.1016/j.optlastec.2018.07.036
0030-3992/

increasing TiB_2 content, but its wear resistance was 10 times higher than that of the copper sample. However, in all of the above works, in-situ laser cladding technology to generate TiB_2/Cu coatings from Ti, B and Cu powders has not been studied sufficiently.

It is well known that laser cladding technology has some advantages, such as rapid cooling rates (up to 10^6 °C/s), reaching non-equilibrium solidification state, generating fine grained size, even pseudo phases, dispersed superhard phases and non-crystalline solids, small heat affected zone (HAZ), formation of high-strength metallurgical bond between coating and substrate. This technology can coat with a wide variety of metallic materials and alloys, generating coatings of refractory metals and its alloys in low melting temperature substrates with minimum loss of material and easy to control automatically manufacturing process of coatings. However, laser cladding method has recently some limitations such as high expensive price of the equipment, especially of the equipment with high power laser generator, and the lack of fully theoretical basis system about laser cladding to apply for the different practical requirements. However, to date, laser cladding still is used widely as one of the most advanced surface techniques.

For hot die, the Cu/TiB_2 composite coating has a good thermal conductivity and self-lubricating property, improving the wear resistance of dies at high temperature. Therefore, in this study, we study the microstructure and properties of the Cu/TiB_2 wear resistance composite coating on H13 steel prepared by in-situ laser cladding. In fact, both the direct method (using TiB_2 particles and Cu powder) and in-situ method (using Cu, Ti and B powders) are used to manufacture the coating layers. Our results show that when TiB_2 particles were directly used to generate the coating, the coating easily formed dendritic structure. TiB_2 particles melted incompletely and formed TiB_2 rich areas, especially in the overlapping areas between two coating layers. Whereas, with in-situ methods, based on in-situ laser energy source, the Ti and B powders turned into uniform dispersed fine TiB_2 particles in coating substrate and thus, coating has a more uniform distribution. These results could provide useful information for improving surface properties and repairing the worn-out dies, shortening manufacturing time for new dies.

2. Experimental procedure

In this study, the chosen substrate is H13 steel plate with thickness of 10 mm and cladding materials used in synthesis process by in-situ laser cladding consist of Ti, B and Cu powders. All powders have the purity of 99.5% and provided by Beijing Changsha Tianjiu Company (China).

The cladding powder compositions was designed with two components: 25%wt (Ti + B) + 75%wt Cu and 30%wt (Ti + B) + 70% wt Cu, in which the mole ratio between Ti and B in (Ti + B) mixture was 1:2 (weight ratio of approximately 24:11). The powder materials were mixed by Ball Mill Mixing Machine with the milling parameters as follows: rotation speed of 350 rpm, ball - powder mass ratio of 20:1, milling time of 24 h. The morphology of powders before and after milling is shown in Fig. 1.

Experiments were conducted with basic parameters as follows: laser-cladding power (P), laser scanning speed (V) and laser defocusing amount (D). The specimens with dimensions of 20x20x5 mm (length x width x thickness) were cut from Cu/TiB_2 coated H13 steel plate by in-situ laser cladding to observe microstructure, XRD, SEM, measure microhardness and carry out high temperature friction and wear test. In this work, we used a fibre laser source with 1000 W maximum power, and a gaussian energy distribution. The laser beam with a diameter of about 2.5 mm was focused with a 210 mm focal length lens. Argon was used to protect from oxygen or other gases in laser cladding process with flow rate of 10 l/min.

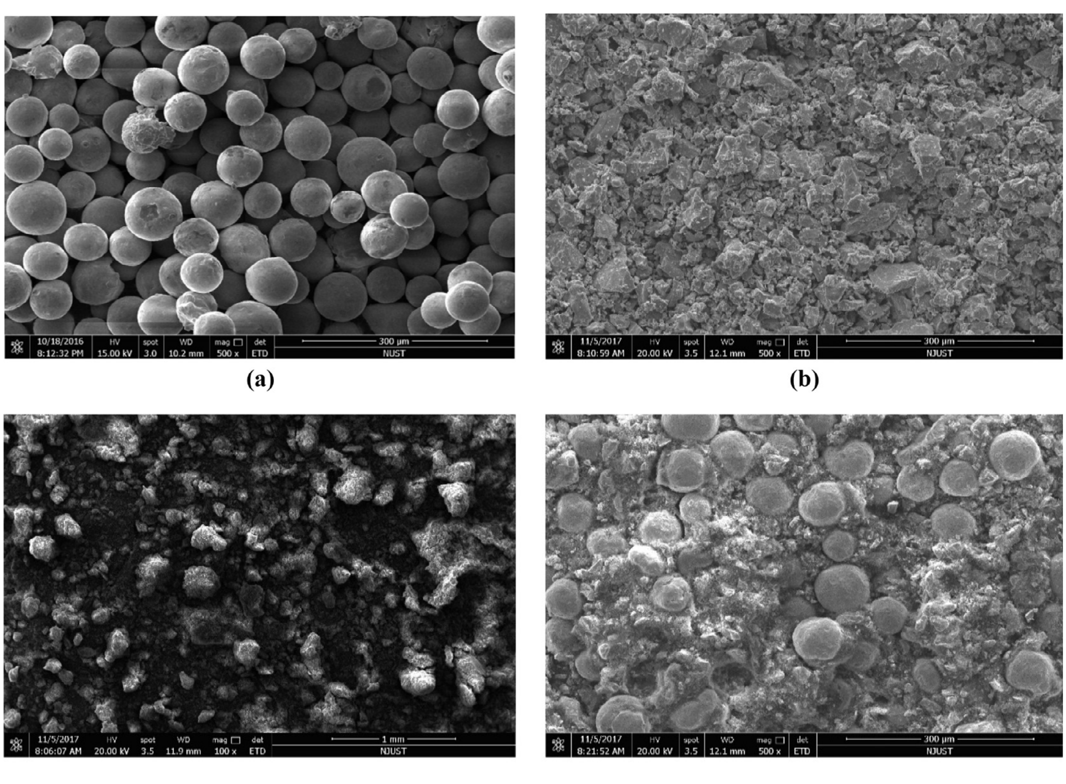

Fig. 1. The morphology of powders: a. Initial morphology of Cu powder; b. Initial morphology of Ti powder; c. Initial morphology of B powder; d. Morphology of mixed powder after milling.