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Characterization of phases and defects in chromium carbide overlays deposited by SAW process

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ABSTRACT

Owing to their enhanced wear resistance, chromium carbide overlay (CCO) plates deposited by submerged arc welding (SAW) process have been widely used in various branches of the mining industry. Defects in the deposited CCO directly determine the wear performance of this material. Several characterization techniques, including optical microscope (OM), optical emission spectroscopy (OES), and field emission scanning electron microscope (FESEM) equipped with an energy dispersive spectroscopy (EDS) and electron backscatter diffraction (EBSD), have been used to identify the most common defects and phase distribution in the SAW-deposited CCO. The main phases are consist of primary carbide, secondary Cr_7C_3 and $Cr_{23}C_6$ carbides, austenite, and a small amount of ferrite. Defects in CCO, such as cracks, porosity, and clusters of particles known in the industry as "rice crispies" are observed near the top surface of the CCO. The undissolved Cr_7C_3 particles with surrounding porosity seem to have provided the preferential nucleation sites for the initial micro-cracks. These initial cracks are observed to propagate along the interface between the austenite and Cr_7C_3 carbides.

1. Introduction

Chromium carbide is one of the highest impact and abrasion resistant materials. Chromium carbide overlay (CCO) can be applied typically on hardfacing for earth-cutting tools, for machine parts exposed to abrasive materials and for chutes and slides that convey ores and other materials that do not impose considerable impact loads [1]. Chromium carbide overlay can also provide oxidation and corrosion resistance at high temperatures because of its high concentration of chromium in the austenite matrix [2]. Various welding processes, such as plasma transferred arc welding (PTAW), laser beam welding (LBW), and submerged arc welding (SAW) can be used to deposit chromium carbide overlay. Plasma transferred arc (PTA) deposition may lead to the enrichment of alloying elements in the matrix because carbides tend to melt in the plasma arc and dissolve in the leaner, thus more plastic matrix [3]. Laser re-melting techniques have been applied to eliminate micro-cracks and pores, which significantly increase the wear resistance of the coatings, but the high cost of equipment and a lower deposition efficiency have limited laser deposition to high value, smaller-sized, components for Ni-based WC coatings [4]. Submerged arc welding is the most commonly used welding process because of its high operational simplicity and deposition productivity [5]. For SAW deposition, CCO is often preferred over tungsten carbide overlays owing to its lower price. The CCOs are based on the high chromium white cast irons of hypoeutectic or hypereutectic compositions [6]. Deposited by SAW, the CCO consists primarily of iron, chromium, carbon, and a small amount of manganese, silicon, molybdenum, nickel, and copper. Chemical composition and microstructure of Fe-based

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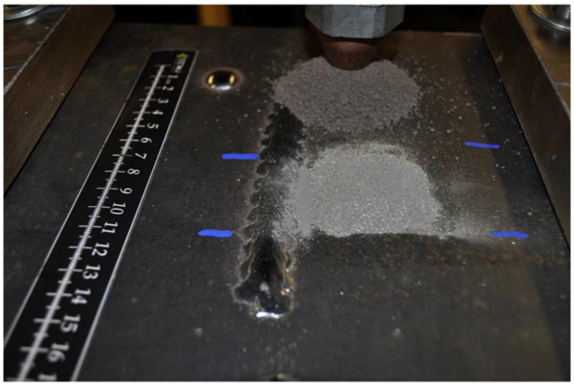

Fig. 1. Addition of alloying elements on CCO's by submerged arc welding.

alloy coatings were studied through the addition of alloying elements such as W, Co and Mo, to generate a defect-free layer after solidification and to meet the expected service conditions. It was observed that those alloying elements increase the hardness of the different phases without a significant increase in the brittleness [7]. The metallurgical microstructure of a CCO is generally composed of M_7C_3 carbides and austenite matrix [8]. CCO belongs to the Fe-rich corner of C–Cr–Fe ternary system, and a liquidus projection [9] of the system is available for compositions of commercial interest (up to 40 wt.% Cr and 6 wt.% C).

There are also a number of problems associated with the welding deposition that limit the designed properties and applications of CCOs. The featured defects in the deposit that may contribute to the loss of properties include gas porosity, oxide inclusions, oxide filming, and solidification (hot) cracking or hot tearing [10]. For instance in the presence of cracks, exceeding a critical load which is determined by fracture toughness of the wearing material, wear severity increases with both increasing volume fraction of pores and micro-cracks [12]. Engineering evaluation and optimization may be useful to avoid unnecessary expenditures of resources to repair a defective deposition [11]. Cracks, porosity, and granular agglomerates of particles commonly called in the industry “rice crispies” are often observed in CCO. These structures, despite its frequent occurrence in industrial processes, are barely characterized or studied in the literature. It is paramount to characterize those defects to clarify the formation and propagation mechanisms of pores and cracks. Advanced characterization methods, such as high-resolution scanning electron microscopy and electron backscatter diffraction (EBSD) technique is helpful to conduct a detailed characterization on the defects above, which contributes to understanding the formation mechanism of them in the deposition and solidification processes. EBSD technique has been a powerful and reliable tool to analyze grain orientation, grain boundary and phase identification and distribution [13].

In this work, several characterization techniques, including visual inspection, optical microscopy (OM), optical emission spectroscopy (OES), field emission scanning electron microscopy (FESEM) with energy dispersive spectroscopy (EDS) and electron backscatter diffraction (EBSD) are used to identify the microstructure and phase distribution of an industrial CCO deposited by SAW. The main defects in CCO are examined to evaluate the wear performance of CCO.

1.1. Experimental procedure

The CCO analyzed in this study was deposited on a plain carbon steel plate (2440 mm × 6100 mm × 6.35 mm) by submerged arc welding (SAW) process using a low carbon steel wire (Lincoln L-61) of 32 mm in diameter. The single-layer weld bead is applied using a weaving technique with 44.4 mm oscillation amplitude, 3.17 m/min oscillation speed and 6.35 mm overlap on each pass. To obtain CCOs using SAW, a powder mixture with a proprietary composition of high ferroalloys is placed down on top of the base plate surface in front of the welding head, as shown in Fig. 1. The employed flux (OK Flux 10.71) is a neutral flux in regard to alloying weld metal. This flux shouldn't add alloy to the overlay [14]. Because the flux should have the ability to solidify after the weld bead and its density should be smaller than the weld pool, which enables isolation in the molten material and later on can be separated easily from the CCO after complete solidification of the weld bead. The SAW welding parameters are shown in Table 1. After the deposition process, the plate was cooled in ambient air without a post-weld heat treatment.

Table 1
The SAW process parameters for CCOs.

Welding parameters	Values
Contact tip to workpiece distance	31.75 mm
Travel speed	245 mm/min
Wire feed speed	1.63 m/min
Voltage	33 V
Current	450 A
Pounds of alloying powder per pounds of wire ratio	2.4