Wear 297 (2013) 1006–1015

Contents lists available at SciVerse ScienceDirect

Wear

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

Slurry erosion resistance of boride-based overlays containing boride crystals oriented perpendicularly to the wearing surface

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A R T I C L E I N F O

Article history:
Received 16 February 2012
Received in revised form
1 October 2012
Accepted 21 November 2012
Available online 5 December 2012

Keywords:
Slurry erosion
Microstructure
Hardfacing
GMAW overlays
Iron boride

A B S T R A C T

Components exposed to the flow of liquid solutions containing hard particles experience significant material loss. For defined slurry conditions, the extent of damage to the components depends upon their microstructure and the slurry particle impingement angles. This paper presents the research work carried on to develop a gas metal arc welding (GMAW) clad overlay that resists slurry erosion at both low and high particle angles. GMAW overlays containing hard primary Fe_2B crystals in a supporting matrix enriched in molybdenum, carbon and silicon have been considered. Cored wires of specific compositions deposited with adapted welding parameters produce weld overlays presenting a peculiar microstructure. These iron boride-based overlays contain fine elongated boride crystals aligned mainly perpendicularly to the wearing surface. This peculiar microstructure is responsible for the outstanding slurry erosion resistance observed at both impinging angles of 30° and 90°. These iron boride-based overlays present a slurry erosion resistance at low and high impinging angles far beyond that observed with known materials including chromium carbide overlays.

1. Introduction

Slurry erosion is strictly defined as a mechanical interaction in which material is lost from a surface (which is in contact with a moving particle-laden liquid) exposed to a high-velocity stream of particle-laden slurry [1]. In many industrial applications ore is ground and mixed with a liquid to form slurries for handling, conveying and further processing. Components that are in contact with aqueous (or liquid) solutions containing hard particles that impact against the surface experience significant material loss. The extent of damage depends upon the quantity, size, speed and type of solid particles present in the effluent as well as the mechanical properties of the surface. For defined slurry conditions, the erosion resistance of materials greatly depends upon their microstructure and the slurry particle impingement angle [2–5].

High-Cr white cast iron parts and carbide weld overlays are largely used in heavy industry as they offer large wall thicknesses, synonymous with long life protection. However, their protection is often limited to low impact angles. Cast irons and weld overlays are composed of carbides bonded in a ferrous matrix. The erosion mechanisms of these materials are known to involve both plastic deformation of the ductile matrix and brittle fracture of the carbides. At lower impact angles plastic deformation of the ductile matrix is the dominant erosion mechanism and the carbides fracture is negligible, which leads to a small erosion rate. At high angles gross fracture and cracking of the carbides are the main erosion mechanisms in addition to indentation with extruded lips of the ductile matrix [5].

The erosion mechanisms of ductile materials such as low carbon steel depend also on the particle impact angles. For impact angles $\leq 15°$, shallow ploughing and particle rolling are the dominant erosion mechanisms. For impact angles comprised between 15° and 75° microcutting and deep ploughing are observed and for impact angles $\geq 75°$, indentations and material extrusion prevail [5].

Alterations in the microstructure of chromium-rich irons and hardfacing alloys through alloying additions [6–12], modifications in casting and cooling methods and heat treatments [9,10,13,14] have resulted in surface distribution of carbide and ductile phases more prone to resist to particle impacts. However, no cast iron and carbide hardfacing alloys developed so far have presented slurry erosion resistance exceeding a 50% improvement.

This work presents the research work carried out to develop a gas metal arc welding (GMAW) clad overlay that resists slurry erosion at low and high particle angles. The welding deposition parameters as well as the composition range in the Fe–Mo–B–C–Si system that lead to improved performance are exemplified.

2. Gas metal arc welding and process variables

Gas metal arc welding, also referred to as metal inert gas (MIG) welding is a semi-automatic or automatic arc welding process in

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0043-1648/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2012.11.059

which a continuous and consumable wire electrode is fed through a welding gun. An inert gas is also continuously injected to ensure current flow and to prevent the melt pool from oxidation. A constant voltage power source is most commonly used with GMAW. Since a cored wire without flux is used as filler metal, the main method of metal transfer is globular. GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation.

A successful combination of arc voltage with wire feed rate is required to ensure complete melting of the wire. In automatic GMAW the traverse speed of the torch, its oscillation width and the number of cycles per oscillation control the overlay thickness. All the parameters must be set accurately in order to obtain weld overlays presenting even surfaces. Obviously, the deposition parameters determine the microstructure for given wire diameter and composition. In this work, the angle between the torch and the work-piece should be fixed and the contact tip-to-work distance (*stick out distance*) should be kept constant.

3. Development of overlay composition

Many works have demonstrated that coatings and weld overlays containing iron boride and iron can replace carbide-based coatings and overlays. Arc-sprayed coatings and weld overlays have been found to possess superior erosion and abrasion resistance [15–17]. However, GMAW overlays containing primary Fe_2B crystals in a Fe_2B–Fe eutectic supporting matrix [18] have presented a slight improvement in slurry erosion resistance compared to chromium carbide overlays. The microstructure of these overlays containing a large amount of hard Fe_2B crystals supported by a relatively soft matrix composed of fine Fe_2B crystals dispersed in iron responds to particle impingement the same manner as chromium carbide overlays or cast irons do.

Important additions of molybdenum, carbon and silicon have been considered for improving the wear resistance of the Fe_2B–Fe eutectic supporting matrix. Molybdenum and carbon could form molybdenum carbides with enhancement in slurry erosion resistance of the supporting matrix. Silicon was also added to favour bainite transformation upon cooling. This transformation could toughen the supporting matrix by limiting ferrite known to be ductile. Finally, GMAW deposition parameters have been varied to obtain refinements in microstructure required to enhance the slurry erosion resistance at low and high impingement angles.

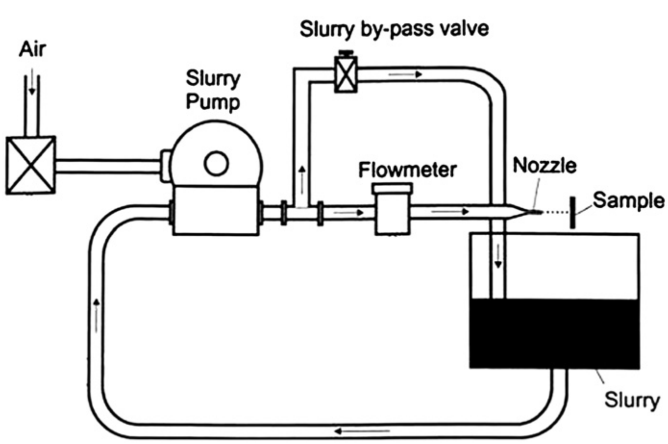

Fig. 1. Schematic of the slurry jet erosion device.

4. Experimental procedure

The cored wires for weld overlays were first produced on a laboratory scale from flat metal strips bent to form a U-shape into which powders were introduced. The U-shape was then closed and cold drawn through successive dies to 1.6 mm diameter.

The cored wires were deposited using the GMAW process with a Miller INVISION 456P DC Inverter Arc Welder. Wires were fed with a Miller 60 Series 24 V wire feeder and displacements and oscillations of the welding torch were carried out with a GULLCO OSCILLATOR KAT. Overlays were deposited on hot rolled steel (A36) in two successive passes to form a 6.5 mm thick deposit. The angle between the torch and the work-piece was fixed at 90°and the contact tip-to-work distance was fixed at 19 mm. 98% Ar -2% O_2 was used as the welding gas. After cooling to room temperature, the overlays were sectioned with a water jet cutting system so as to obtain specimens 25.4 mm wide $\times$ 191 mm length. This procedure avoids changes in overlay microstructure contrary to other processes such as arc or plasma cutting. The specimens were thereafter diamond ground (250 grit) to obtain flat and parallel surfaces. Test samples 50 mm in length were extracted from specimens by cutting with a diamond saw.

Slurry erosion tests were carried out using a slurry jet erosion device (Fig. 1). Not being a standardized procedure, the test consists in circulating 12 L of prepared slurry during 2 h using an air-powered double-diaphragm slurry pump. The re-circulating slurry, consisting of filtered 15–20 °C tap water with 15 wt% 212–300 μm quartz sand particles, was pumped from a tank and forced to impinge on the test surface located at 10 cm from the exit of a 5 mm diameter alumina tube. The velocity of the slurry was measured to be 13 ms^{-1}. Specimens were maintained at 90° and 30° and exposed to the slurry jet for 2 h. After each test, the slurry was replaced.

Wear damage and volume loss were evaluated with a National Research Council Canada in-house built profilometer, based on optical coherence tomography, setup in a common-path mode. This time-domain system includes an interferometer, an optical probe and a XY displacement system for moving the probe over the sample. Measurements steps are 50 μm in both axes (X–Y) while axial (along the depth) precision is about 1 μm and resolution about 0.125 μm [19]. Volumes of defects on a surface can be easily computed and three-dimensional pictures of the scanned surface can be produced with imaging software. Computerised cross sections along chosen positions can be also obtained to show wear scar depth profiles [20].

In the course of the development of slurry erosion resistant Fe–Mo–B–C–Si overlays, some reference materials were also slurry erosion tested. These are hot rolled A36 steel, AISI 304

Table 1
Chemical composition of reference materials.

	C	Cr	Ni	Mn	Cu	Si	P	S	Fe
A36 hot rolled	0.26			0.75	0.3		Max 0.04	Max 0.05	Balance
AISI 304	Max 0.08	18–20	8–10.5	Max 2		Max 1	Max 0.045	Max 0.03	Balance
White cast iron	2.75	25	0.6	0.75	0.6	0.6	0.002	0.03	Balance
CrC overlay	4	30							Balance