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Hardfacing using ferro-alloy powder mixtures by submerged arc welding

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ABSTRACT

In this study, we investigated the microstructure and properties of hardfacing coatings produced using Submerged Arc Welding (SAW) process. Powder mixtures of ferro-chrome powder, cast iron chip or stainless steel shot were used as alloying source to form Fe–Cr–C coating. Modified alloys were also produced by the addition of boron-containing powder to partially or fully replace carbon in the carbide-based coatings. Microstructural examination of produced samples showed the formation of carbides and borides of different morphologies which were best interpreted as microstructures of undercooled alloys. Abrasive wear and impact testing were also performed on the coatings as a measure of process effectiveness. By adjusting the amount of powder input and process variables, hypoeutectic, eutectic and hypereutectic alloys were successfully produced.

1. Introduction

Hardfacing ground engaging tools using superior material coatings has been widely used to achieve longer service life [1–3]. Protective coatings can be applied to the surface of base materials using thermal spraying, cladding and welding [4]. Among all methods, welding is considered as an economical choice as a variety of processes can be utilized to deposit the desired coatings. In most cases, a solid or cored wire is used as an electrode or filler to form a protective material on the surface of a base metal using processes such as Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW), Submerged Arc Welding (SAW) or Flux Cored Arc Welding (FCAW). When a mixture of fine powders is prepared for direct feeding to form an alloy or make a composite, plasma arc or laser beam welding is preferred to avoid melting of hard phase materials through controlled heat input [5].

Iron-based hardfacing alloys and Ni–WC alloy powders are the most common coating types being utilized in the mining and oil-sand industries [5]. Due to low cost and acceptable performance, iron–chromium coatings are being widely preferred over tungsten carbide coatings in many applications such as the pipeline slurry transport, crusher teeth, hydro transport screens and centrifugal pumps. These alloys are based on the high chromium white cast irons of hypoeutectic and hypereutectic compositions. In alloys of the hypoeutectic composition, the microstructure of the coating consists of primary dendrites of austenite surrounded by eutectic mixture of austenite and finer carbides. In alloys of the hypereutectic composition, primary carbides grow as rods or needles and are embedded in the eutectic matrix. The main type of carbides that can be formed with the common commercial composition being used is M_7C_3. Other forms of carbides such as M_3C or $M_{23}C_6$ can be formed depending on the Cr and C levels and process conditions. At low Cr and high C levels near eutectic composition, M_3C carbides can form a shell around solidified M_7C_3 eutectic as a result of a peritectic reaction of liquid and eutectic M_7C_3 [6,7]. At high Cr levels, $M_{23}C_6$ was found to form a shell around M_7C_3 type through a destabilization and solid-state diffusion heat treatment [8,9]. Nonetheless, majority of commercial chromium carbide coatings possess Cr/C ratios that aim at the formation of M_7C_3 carbides in the deposits.

The microstructure of Fe–Cr–C systems undergoes noticeable changes upon alloying addition and rapid solidification. These changes subsequently affect the mechanical and wear properties of these alloys. Boron is one of the alloying elements than can be added to the system or replaced with carbon to form chromium and iron borides instead of carbides [10]. Previous studies on alloys of various boron and carbon compositions showed that different microstructures containing chromium carbides and borides (M_2B, M_3B, M_3B_2 and $M_{23}B_6$) are developed using GTAW hardfacing [11]. Among all alloys, those having M_3C carbides and $M_{23}B_6$ borides showed the lowest abrasion resistance based on a pin-on-disc abrasion test. Enhanced wear resistance was observed in microstructures containing mixed types of M_7C_3, M_3B and M_3B_2 hard phases. Ni and Mn are also added to hardfacing alloys to improve toughness as these elements remain in the matrix to stabilize the austenite and prevent the formation of martensite or secondary carbides [12].

In high chromium white cast irons, besides alloying elements, rapid and directional cooling can affect their properties and produce anisotropic microstructures. This anisotropic behavior has been reported for the columnar zone in the exterior of cast parts close to the mold which showed a higher wear rate compared to the interior of thicker equiaxed sections with randomly oriented carbides and eutectic colonies [13]. When M_7C_3 rods in the columnar zone are aligned

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perpendicularly to the wear surface, the abrasion resistance is lower [14,15]. On the other hand, the impact testing on individual carbide by indentation [16] or on directionally cooled bulk by shot blasting [17] pointed out to the fact that vertically aligned rods to the surface resulted in better impact-wear performance. Additionally, rapid cooling can create large undercooling which is believed to be the root cause of different microstructural features observed in rapidly cooled casting samples [18–20] and weld deposits [21]. When undercooled, the microstructure of Fe–Cr–C hypereutectic casting alloys showed a wide variation compared to near equilibrium condition. Complex regular carbides of equilateral triangles, austenite halos and branched carbides were all explained as a result of such undercooling. Similar microstructural features have been found in the weld deposits [21], which usually involves fast cooling rate [22]. Nonetheless, no significant microstructural changes were observed in the microstructure of hypoeutectic and eutectic undercooled compositions.

Weld hardfacing of hypo or hypereutectic composition is mainly applied to the surface of the base metal using wires, rods or compact powder mixtures. This requires preliminary processing of rolling or compressing [23,24] which can be time consuming and costly. As an alternative, powders mixture can be easily mixed and placed on a surface for flat applications. In such a case, the SAW welding technique makes a good economical choice in which the powder mixture as the main source of alloying is melted to form a hard coating under a flux coverage [5]. In this study, we aim at investigating the effectiveness of the SAW process to produce coatings using low cost ferro-alloy powders as the main source of alloying elements. The powders contain Fe, Cr, C and B as the major elements with trace amounts of Si and Ni. Microstructural characterization was performed to determine the type of the alloys. Wear and impact testing were chosen as tools to measure the effectiveness of the hardfacing process.

2. Experimental

Ferro-alloy powders used in this study along with their composition are listed in Table 1. A Lincoln Electric AC/DC 1000 SD power source was used to perform welding (34–45 V, 350–600 A, travel speed 3.8–6.8 mm/s, direct/constant current mode). Lincoln L-61 wire and Lincoln Electric 880 M were utilized as electrode and flux, respectively. Coatings were deposited on 30 × 5 × 1.9 cm mild steel substrates. The single layer coatings were 23 to 25 cm long using stringer bead technique. Powder mixture amount varies between 4.9 and 9.8 g/cm depending on the welding condition employed.

Hardness measurement was done on the longitudinal or transverse surface of coating, using Rockwell C scale (150 kg load, diamond cone indenter, 7 indents). Microscopy analysis was performed on the same surface. Optical images were obtained after etching in a 75% HCl–25% HNO_3 solution. A JEOL Auger Microbe (JAMP 9500F) was used to obtain the mean composition of individual phases containing light elements of carbon and boron. Before any analysis, sample surfaces were cleaned using an Ar^+ ion source gun at working condition of 2 kV and 20 mA. A SEM (Vega-3 Tescan) equipped with EDS was also utilized to perform microscopy and chemical analysis on the wear and impact tested samples.

Abrasive wear test was performed on the ground surface of coatings and 75% down the coating thickness (75% depth) using the dry sand rubber wheel abrasive wear tester (ASTM G65, procedure A). In one sample, only 75% depth test was done due to bead geometry limitations which did not provide enough flat area at top of the coating. Volume loss was reported for each coating. The density of each coating was calculated based on the alloy chemistry.

Impact testing was also performed on the coatings using an impact tester unit built at the Alberta Innovates Technology Futures research center [25]. In this test, a hammer with a ball bearing head (D-2 tool steel, 52–60 HRC) spins at 150 rpm (rotational speed) to hit the surface of the coating at an impact energy of 8 J. Sample size is specified as 18 × 6.4 × 1.3 cm and required no surface preparation. The mass loss after each 4 minute test period for a total of 24 min was reported as the impact wear result for each sample. Detailed information can be found in Ref. 25. After the testing, metallographic examination was performed on each sample at the impact site.

The different mixtures tried in this study are listed in Table 2. Uniform mixtures were achieved by mixing powders using a ball mill for a period of 1 h. Powder mixture compositions were selected to form hypoeutectic, eutectic or hypereutectic of Fe–C or Fe–B systems with alloying element additions such as Cr, Si, Ni and Mn. Approximate chemical composition of each alloy was analyzed on the wear surface by an Optical Emission Spectroscopy machine (OES Spectro MAXx). Since the machine was incapable of reading high concentration of boron, the estimated boron content was calculated based on the ratio of ferro-boron powder melted.

3. Results and discussion

3.1. Effects of welding conditions on coatings dimension and type

The observation on coatings bead shape revealed that higher voltage creates wider bead and higher current has more effect on the penetration depth. However, it was not only the welding condition that influenced the bead shape and geometry but also the alloy chemistry. Among all alloys studied, those with high Cr content such as Hyper FeCrC tend to form narrower beads with higher thickness at the same welding condition and amount of powder per inch used.

The microstructure and type of alloys produced depend on a few factors. Powder mixtures containing higher ratios of cast iron chips and stainless steel shots in the mixture resulted in formation of hypoeutectic or eutectic microstructure given the same welding condition. The reason for this change is the lower amount of carbon and boron in the mentioned powders. The light elements such as carbon have a more significant influence on the type of alloy than the transition metals of iron and chromium [26]. Another factor that influences the type of alloy is the amount the powder input. At the same welding condition, a lower powder input resulted in formation of hypoeutectic, e.g. FeCrCB sample. This was accompanied with higher dilution level, another unavoidable factor resulting in the increase of the iron content in the weld pool. A change from hypoeutectic to hypereutectic microstructure in the FeCrCB coating occurred by increasing the powder amount from 4.9 to 9.8 g/cm. In the case where the amount of powder input or the mixture was kept the same, welding conditions influenced the type of

Table 1
Powder chemical composition (wt.%).

Powder	% Cr	% C	% B	% Mn	% Ni	% Si	Particle size (mm)
Ferro chrome powder	58–60	10				3–5	0.2–0.8
Ferro boron powder			17–19			4	0.2–0.8
Stainless steel shot	16–20	0.2		1.2	8–10	2	0.15–0.2
Cast iron chip		3.7–4.5				4	1.5–3
Welding wire		0.05–0.15		0.8–1.2		0.1–0.3	–

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