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Effect of molybdenum on mechanical and abrasive wear properties of coating of as weld hadfield steel with flux-cored gas tungsten arc welding

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ABSTRACT

In this study, the variation of microstructure, yield and ultimate strength, strain hardening index, and abrasive wear resistance of the hadfield steel cladded on st40 steel by the flux-cored gas tungsten arc welding process protected by argon gas was investigated. The chemical composition of cladded hadfield Steel contains Carbon, Manganese, and Silicon. Amount of Carbon, Manganese, and Silicon is constant in all experiments, and Amount of Molybdenum ranged from o to 2.2 percent. Hence microstructure of samples with the optical microscope and fractography with SEM as well as the formed phases with X-ray diffraction and energy dispersive x-ray (EDX) were analyzed. To survey mechanical properties, tensile and impact tests were carried out. Abrasive wear resistance was measured by dry sand/rubber wheel apparatus. The results showed that the higher the percentage of Molybdenum is, the higher the yield and ultimate strength will be, while the strain hardening index does not decrease. By increasing the percentage of molybdenum, the impact energy of the specimens and abrasive wear resistance has also increased.

1. Introduction

Austenitic manganese steel, also called hadfield steel, containing Fe-1.2%C-13%Mn has the high intrinsic toughness, the high strain hardening index, and an excellent wear resistance against adhesive and abrasive wear for hard inorganic material [1]. Because of the low yield strength, it is possible to occur distortion and super plastic deformation before activating and hardworking [2].

The yield strength can be increased by adding alloy elements to typical hadfield steel. For example, an addition of vanadium to hadfield steel results in an increase in its yield stress and a decrease in its ductility [3]. G. Moghaddam et al. [4] were studied hadfield steel containing 10%.wt V, ranging its carbon from 2.6%.wt to 3.3%.wt, and then has compared its mechanical properties and microstructure to the standard hadfield steel.

G.Moghdam's observations show that a change in the percentage of carbon leads to a change in morphology and distribution of carbide vanadium in matrix. Increasing the carbon percentage causes an overwhelming increase in metal-to-metal wear resistance and hardness, but decreases toughness and strain hardening index in the same level. This steel is not suitable alternative when high wear resistance and toughness are needed simultaneously.

Abbasi [5] compared standard hadfield steel to the hadfield steel alloying with 1.5%.wt Al in terms of mechanical and wear properties and reported that addition of aluminum enhances the yield stress, primary hardness, and metal-to-metal wear resistance under low stress. Although it decreases the ultimate tensile strength, elongation, strain hardening index, and metal-to-metal wear resistance under high stress.

Smith and Mackay [2] observed that the hadfield steel containing 2%.wt Tungsten has more toughness and hardness than that of typical hadfield steel.

It is also stated that addition of Molybdenum from 0.5%.wt to 2%.wt to a hadfield steel improves toughness, cracking resistance in casting, yield stress, and toughness of cast large component during solution heat treatment and quenching procedure. Molybdenum changes the morphology of primary carbide and turns continuous carbide into discontinuous that around austenite grain. Then carbides in grain boundaries become more spherical and less detrimental, especially in amounts of more 1.5%.wt Mo [3,6].

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Finding an optimum composition of the hadfield steel are of an abundant importance while it is accompanied high strain hardening index and yield strength in the industries where high wear resistance and toughness are needed. In this present paper, to make surfacing properties suitable on low-carbon steel, the flux-cored wire of different amount of Mo was used while composition of surface become that of hadfield. Addition of molybdenum not only increases wear resistance but raises toughness of hadfield steel.

2. Experimental procedure

To fabricate the flux-cored wire, the St12 steel strip was used as a tube in which alloying powders fill. These powders contain pure Fe, graphite, ferromanganese, and ferromolybdenum. To produce the flux-cored wire, first strip was deformed in shape of U by a wire drawing die, and then alloying powders of the suitable percentage were put into U-shape strip. By deforming further, the flux-cored wire seam was completely closed, and consequently powders were compacted with 5 steps of drawing. Fig. 1 shows the procedure of production of the flux-cored wire.

Afterwards the weld wire with size of 4 mm in diameter is made. Therefore one pass of welding dilution of 7% was cladded on St40 steel when using gas tungsten arc welding with argon gas. Specifications of welding are 30 V, 110 A, and speed of 2.13 mm/s. To reduce effect of dilution on composition of weld metal, the second weld pass was cladded on the first weld pass. The chemical analysis of St40 steel is observed in Table 1. In order to obtain the composition of surface of samples, the spectrometric analysis was carried out. As shown in Table 2, five compositions of different amounts of molybdenum were obtained.

Table 1
Chemical composition of substrate to weld.

Fe	C	Mn	Si	S	P	Al	Cr	Mo
Bal	0.18	1.5	0.4	0.015	0.025	0.02	0.3	0.08

Table 2
Chemical composition of weld metal after cladding.

Sample.no	Fe	C	Mn	Si	S	P	Al	Cr	Mo
1	Bal	1.38	12.9	0.07	<0.005	<0.05	0.002	0.04	–
2	Bal	1.41	13.1	0.06	<0.005	<0.05	0.003	0.02	0.75
3	Bal	1.36	12.8	0.07	<0.005	<0.05	0.002	0.04	1.22
4	Bal	1.39	12.7	0.05	<0.005	<0.05	0.004	0.03	1.65
5	Bal	1.42	13.2	0.05	<0.005	<0.05	0.002	0.03	2.22

2.1. Microstructure

Because of high hardness and harden ability, the samples were cut with wire-cut apparatus and then were grounded and polished with alumina suspension. To etch samples and observe the optical microstructure, samples were first suspended in naital reagent of 2% within 20 s and later in ferric chloride (Fe_3 Cl) within 60 s.

Olympus BX51 optical microscope was applied for studying the section that recognizes surface. To distinguish the phases with the same chemical composition and calculate volume fraction of carbides, seven images were taken from surface of each sample using scanning electron microscope, Tescan VEGA 2. Meanwhile, energy dispersive x-ray and x-ray diffraction were used to obtain chemical composition of carbides. The x-ray diffraction analysis was done with specification of Cu−Kα radiation ($\lambda = 1.5406$ Å) at 2ϴ-step of 0.02° and scanning duration of 0.5 s from 10 to 100.

2.2. Impact and tensile test

To fabricate specimens for the charpy impact test and tensile test, two plates with bevel of 30° were used while gap distance was 7 mm, and a backing material of St40 steel was applied as it was welded to two plates in spot weld with GTAW. The root of V-shape bevel is filled by two passes with GTAW process. As observed in Fig. 2, three specimens for impact test and two specimens for tensile test were made from each of the welded samples.

The subsize specimens for tensile test were made by wire-cut apparatus according to E8M-O4ASTM standard. Based on ASTM E23-96, the specimens for impact test were prepared with a specification of 3.8 mm × 55 mm × 10 mm and notch of 45° with 2 mm depth. Impact test was carried out using AVERY apparatus.

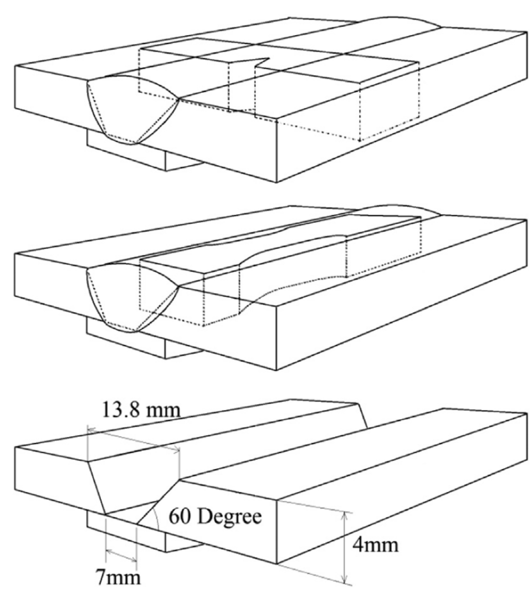

Fig. 2. Procedure of making specimens for tensile test and impact test after welding.

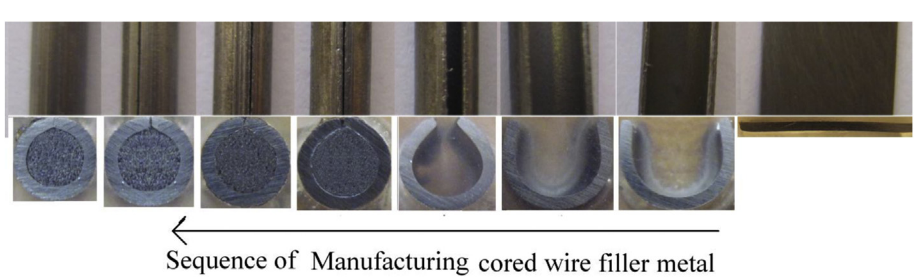

Fig. 1. Sequence of production of flux-cored wire.