Study of mechanical properties of wear resistant chromium alloy coated mild steel by semi-automatic welding method

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Abstract. In this study, changes of mechanical properties of low carbon steel, which widely used in steel structure, were studied after coating by Wear Resistant High-Chromium White Cast Iron (HCWI). The coating process were carried out by semi-automatic welding method using powder materials with particle size of 0.7, 0.6 and 0.5 mm. The coating materials were prepared by casting small pieces of HCWI and machining into chips, then hand crushing the chips and sieving them according to appropriate sizes. Before the welding process, the coating material was glued on the steel surface with size of 0.3, 1.0 and 1.5 mm thickness.

Electrical current for welding was selected in three modes, namely 80, 100 and 120 A.

Changes in mechanical properties after coating were evaluated by surface hardness measurement and abrasive wear testing. Analyzing chemical composition of the coating performed with relation to surface hardness. The hardest and most wear resistant layer is formed when the chromium content was around 2.4-2.6%.

Keywords: Hardness, Low carbon steel, Material, Wear, Mechanical property, Abrasive wear

1. Introduction

The majority of equipment in Mining, Soil treatment industry and Construction material production are failed and delayed by abrasive wear process of their parts [1]. In order to reduce the abrasive wear losses, the following two main methods are used at present [1].

1. Production of parts from abrasive wear-resistant material.
2. Coating the work surface of parts with wear-resistant material.

The first method is expensive, whereas the second one is cheap and simple as for production technology. So it is widely used in operational conditions. There are many

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experimental and research works to reduce the rate of wear and increase the service life by coating low-cost material surface with wear-resistant materials.

The welding method is widely used to coat wear resistant materials on steel surface. All types of welding methods including electric arc welding, gas shielded automatic welding, oxygen acetylene gas welding and semi-automatic welding are used in the coating process.

Traditionaly, hand electric arc welding method is commonly used for making coats on any shaped steel surface made of low carbon steel. Special designed wear resistant electrodes are used for the electric arc welding process [2]. Also, there is a research that prepared hollow shaped wire electrode filled with wear-resistant powder material [2].

Mechanical properties of coating are depended on number of coating layers. There is a research which compared the mechanical properties of single and triple coating layer in comparison [3]. This study showed that the triple coating layer has higher hardness and better wear resistance than single coating. Because by making triple layer coating, the new coating is laid on the top of previous coating, thus reducing its surface defects.

High chromium white cast iron is a metal alloy widely used in production of equipment that works in the abrasive wear environment in mining, mineral processing, and cement industry. It is a iron-chromium-carbon (Fe-Cr-C) ternary alloy containg 2.4-2.8% carbon, 12-28% chromium, and up to 3 % elements such as nickel, molybdenum, copper, and manganese.

2. Method and materials

Totally, 24 specimens are made from mild steel with dimension of 60x30x5mm with chemical contents shown in **Table 1**.

Table 1. Chemical composition of St3 steel

№	Fe,%	C,%	Ni,%	Mn,%	Si,%
1	97	0.14	0.3	0.4	0.05

High chromium white cast iron which melts at the Repair Mechanics Plant of "Erdenet mining company" was used as a wear-resistant material for the experiment. Chemical composition of the white cast iron shown at **Table 2**.

Table 2. Chemical composition of cast iron.

№	C,%	Cr,%	Si,%	Mn,%	Ni,%
1	2.5-3.0	28-30	0.7-1.4	0.5-0.8	1.5-3.0

A piece of white cast iron was mechanically machined into chips then crushed and separated into 3 different particle sizes: 0.7, 0.6, and 0.5 mm. The powder material was mixed with liquid glass and glued to the surface of the test specimen with a thickness of 1, 1.5 and 2 mm.

The coating process was carried out with a semi-automatic welding machine of EWN brand. The welding wire is G3S11, and the welding current is chosen in 3 modes: 120, 100 and 80A. The hardness of the coated surface was measured by Rockwell method. Abrasion experiment were performed on equipment prepared according to ASTM G65.

The experimental work was carried out according to the design of full factorial experimental planning. According to this plan, 8 experiments were conducted with 3 repetitions each. Factors are the followings.

- Particle size of powder material
- The thickness of the adhesive layer of the coating material
- Welding current

Table 3 shows the matrix of the 2^3 plans of the full factor experiment design.

Table 3. A table of the 2^3 plans of the full factor experiment design

Testing and testing frequency	Characterization of factors		
	Particle size of the material, mm	Thickness of glued material, mm	Electric current, A
	X_1	X_2	X_3
Upper (+)	0.7	2	120
Basic (0)	0.6	1.5	100
Lower (-)	0.5	1	80

3. Results

Steel samples with glued particle on its surface are shown in **Fig 1**.

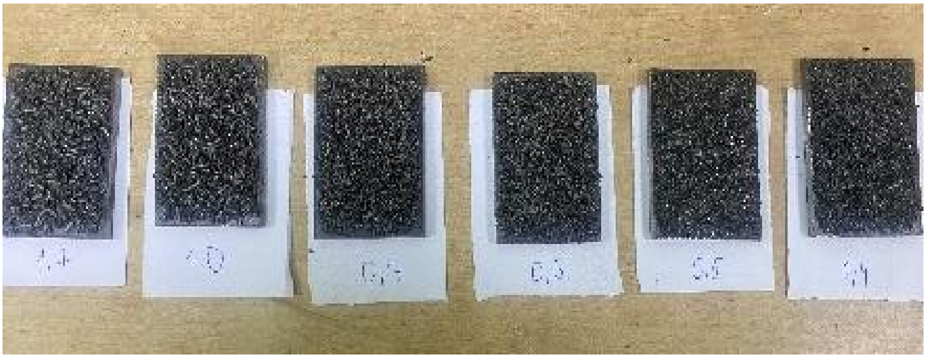

Fig 1. Experiment specimen

After drying the glued particles, the samples were welded then cut for next treatment. The welded and cut work specimens for next polishing treatment and investigation are shown in **Fig 2**.

Fig 2. Coated test specimen

The welding process was carried out by appropriate welding mode given in **Table 3**. The chemical composition of the welded surface of each 24 samples of 8 groups were measured and showed **Table 4**.

Table 4. Chemical composition of 8 coated specimens

№	C, %	Cr, %	Mn, %	Ni, %	Fe, %
1	0.371	3.778	1.054	0.163	93.71
2	0.333	2.426	1.013	0.112	95.11
3	0.36	3.001	1.041	0.133	94.45
4	0.404	3.540	1.052	0.155	93.78
5	0.301	2.323	1.030	0.106	95.2
6	0.414	3.199	1.010	0.143	94.16
7	0.296	1.997	0.949	0.094	95.73
8	0.323	2.503	1.072	0.116	95.00

As main component of the surface carbon and chromium contents are shown in **Fig. 3** and **Fig. 4**.

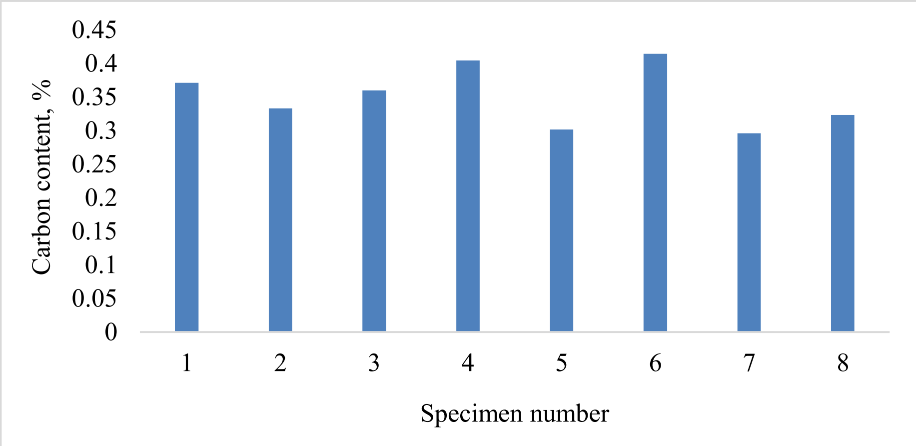

Fig 3. Carbon content

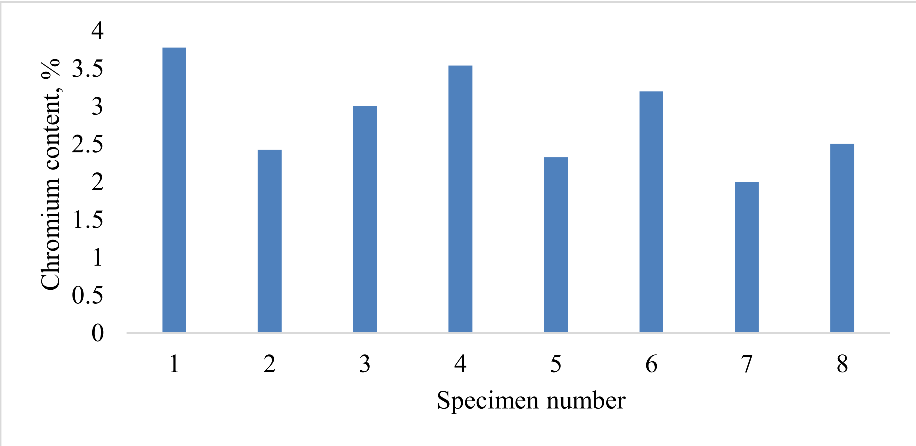

Fig 4. Chromium content

Carbon content of cladded surface of mild steel is increased from 0.14 to 0.4% while chromium content up to 3.5%. In the result of the cladding the mild steel surface turns into chromium alloyed steel.

Hardness test

A hardness test was performed on the 30x60x0.5mm prepared specimen, and the following results were obtained by measuring the hardness with WOLPERT multi-functional hardness tester "DIA-TESTOR 2". The hardness values were shown in **Table 5** and **Fig. 5**.

Table 6. Hardness of the coated specimen

№	1	2	3	4	5	6	7	8

HRC	58	56	55	57	53	54	53	57

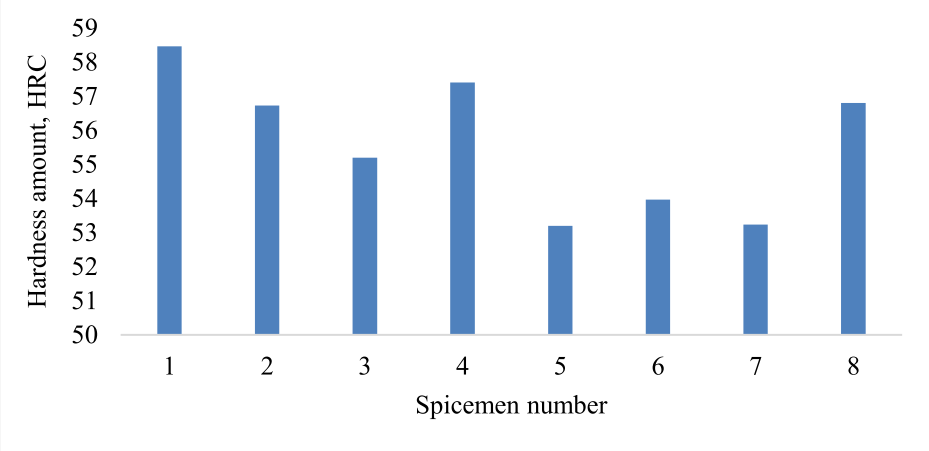

Fig 5. Hardness of coated surface of samples

The result shows that the hardness of sample №1 seems as the highest. The reason for the high hardness is due to the good penetration of the powder material Fe-Cr-C to base material, the high melting depth, and the large weld beam thickness. Also, the particle size and electric current were 0.7mm and 120A respectively. Also, the hardness of specimen 4 and 8 is higher. The lowest hardness was obtained in samples 5 and 7.

Micro-structure analyses

Microstructure analysis was carried out using a "OPTION" brand microscope with a magnification of x50-1000. The specimens are etched by 2% of HNO_3, 98% of ethyl alcohol solution. A total of 8 microslices were studied for microstructure. The microstructure analysis of the specimens coated by various methods is shown in the **Fig. 7**.

The base metal has a ferritic and pearlitic structure and has poor wear resistance. The widmannstätt structure exists on the sample 7. Martensitic structures developed in samples 1, 4, 8 and others.

Also, the following graph shows the relation of the melt depth and the seam thickness between the coating material and the base material.

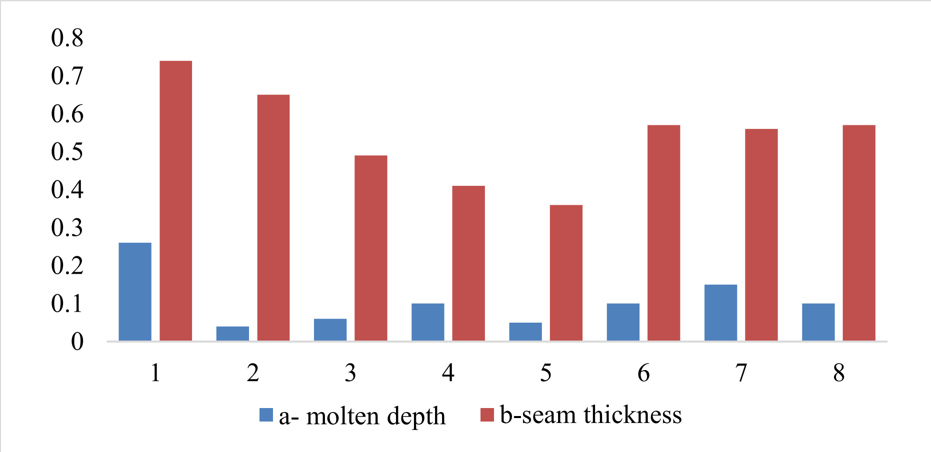

Fig 6. Comparison of depth of melting and seam thickness of all specimens

Here, the penetration of powder material into the base metal, the depth of melting, and the thickness of the seam were the largest as for specimen №1. It can be seen that good permeability increases hardness and wear resistance.

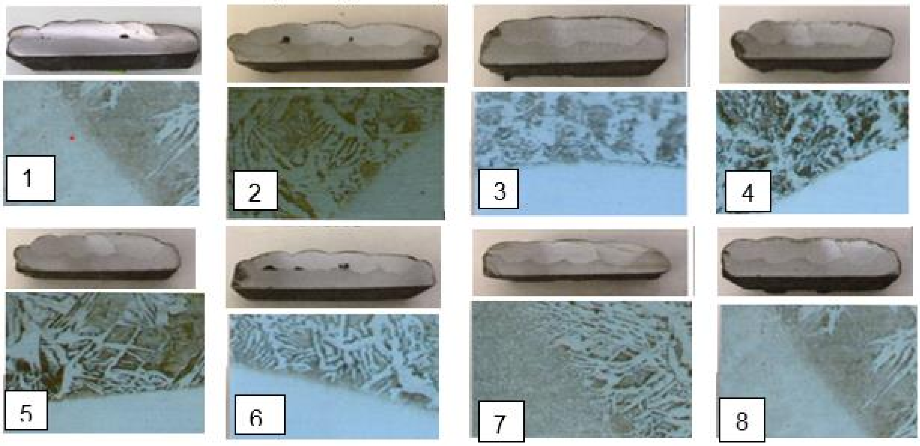

Fig 7. Microstructure images of coated surface of samples

Abrasive wear experiment

For the abrasive test of any materials the ASTM G65 standart is the most widely used. In abrasive test 8 coated mild steel samples (1 to 8), 3 arc welded samples by using T-620 electrode (9 to 11) and base steel (12) were analyzed. Wear test was conducted for 3 minutes each, and the following results were obtained (**Fig. 8**).

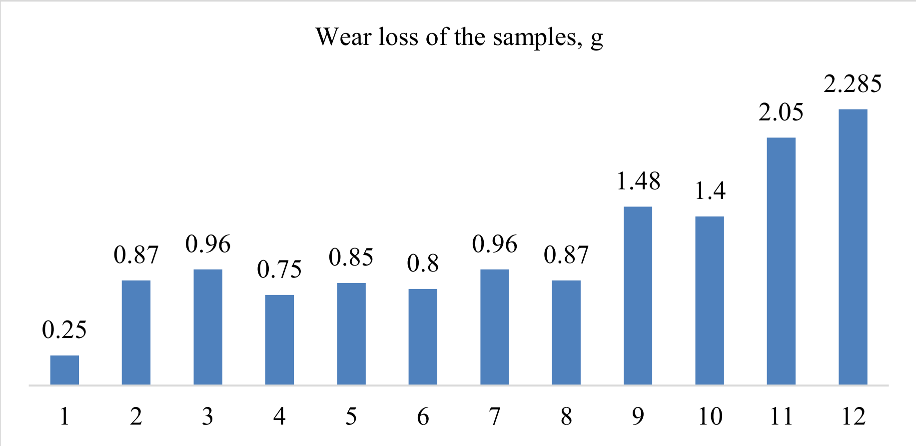

Fig 8. Result of abrasive wear test

The wear amount was measured individually on an electronic scale before and after the wear. As can see from the graph above, the 8 specimens coated with wear-resistant chromium alloy, and the weight loss is between 0.25-0.87g. The wear loss is 2 times less compared to the specimens coated by T-620 electrode and 2.5 times less than the base steel.

4. Conclusion

1. It is possible to increase 2 times the surface hardness and wear resistance of low-carbon steel by coating with chromium alloy. As a result of the coating, the surface of the steel is obtaining property of alloyd steel, forms a martensitic structure and hardened. As the main body of the steel remains mild, so it will retain its ability to function against of impact environments.
2. When coating by chromium alloy, the coating layer thickness is highest at the electrical current 120A, the grain size 0.7mm, and the thickness of the layer 2 mm. Higer values of hardness and wear resistance are obtained in such mode of coating process.
3. It is possible to use the high chromium white cast iron as a surface property improver for low-carbon steel.

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