Ceramic metal composite approach for the advanced Hadfield steel

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Abstract. This work is aiming at attaining the highest wear abrasion resistance of Hadfield steel, through using ceramic metal matrix approach. The metal matrix composite structure was attained through using honey comb method. Then, microstructure observations, wear abrasion resistance of the metal matrix composite structure were well tracked by using optical microscope, SEM, XRD, and wear test. Comparing with the reference Hadfield steel, it was found that wear abrasion resistance has been multiplied through using ceramic metal matrix composite structure, adding to the great enhancement of strain hardening property. These results refer to the possibility of using this new technique for producing the crusher components to be applied under severe mining conditions.

1. Introduction
Wear abrasion is the most significant parameter that can be in the charge of losing millions of tons of metal through crushing, milling, and other mining activities. It is believed that many tons, and much energy can be saved through control the wear abrasion resistance of the steel, and cast iron that are being applied in the crushers. Hadfield steel is one of the famous material that is being used for manufacturing many components of crusher and milling machines. This category of steel is designed as A128 according to ASTM [1]. Its wear abrasion resistance is mainly based on its strain hardening character, where γ-austenite accommodates the plastic strain generated from the wear mechanism and transforms into hard alpha martensite phase [2]. In fact, the strain hardening property is common insufficient to act against the wear abrasion of the abrasive particles. Then, it is believed that strengthening the metal matrix through metal matrix ceramic composite structure should be sufficient on multiplying the wear abrasion resistance of Hadfield steel. Certainly, many research have tried this new technique in reinforcement of chromium cast iron metal matrix [3]. However, the using of this technology for Hadfield steel is still vague. Thereby, this manuscript has been designed for studying the optimum methodology for reinforcement of Hadfield metal matrix with ceramic structure, and monitoring the effect of the new composite structure on the wear abrasion resistance, and strain hardening property of Hadfield steel.

2. Experimental works
Two heats of Hadfield steel have been melted in open air magnesite crucible induction furnace and afterward they have been ladle treated with Mg, and Ca-Si through inoculation process. Then, they have been poured into different molds, while one of them has a ceramic insert (corundum) bonded with 5% of ferrotitanium powder to enhance the wettability of the molten steel to the ceramic material, as given
in Figure 1. Table 1 shows the chemical composition of the molten steel after ladle treatment inoculation process. Samples have been cut by EDM, and subjected for microstructure observations by optical and scanning electron microscope. Wear abrasion resistance has been determined by using Pin on Disc method. Finally, worn samples have been monitored by using X-Ray Diffractometer with Cu-source.

**Table 1.** The chemical compositions of Ladle treated Hadfield steel.

| Heat         | Chemical compositions, Wt% |
|--------------|----------------------------|
|              | C  | Mn  | Si  | Cr  | S   | P   | Mg  | Ca  | Ce  |
| Hadfield steel| 1.02| 13.2| 0.8 | 1.2 | 0.035| 0.03| 0.045| 0.1 | 0.01 |

3. Results and discussions

3.1. Microstructure observations

**Figure 2.** Microstructure observations of as cast ladle treated Hadfield steel. a- reinforced with ceramic; b- without ceramic.
Microstructure observations as being observed in figure 2, shows that the no of nucleation has been multiplied in the metal matrix that has been reinforced with ceramic material. In fact, this observation prove the effect of ceramic material in promoting the cooling of molten metal, and therefore induce the nucleation throughout austenite matrix [4]. On contrary, it was observed the normal ladle treated Hadfield steel with no much nucleation site as being observed in figure 2b. No doubt, the increment in the no of nucleation sites can multiply the strength of the austenite, in one hand with increasing its strain hardening ability as being discussed later.

3.2. Wear abrasion resistance

Alumina disc has been used through monitoring the wear abrasion resistance of the two heats by using pin on disc method. It was observed that the wear abrasion resistance is highly enhance in Hadfield ceramic matrix composite structure in comparing with the ordinary Hadfield steel. By determining the weight loss of the two heats through wear abrasion test, it was found that the weight loss is decreased with time either in Hadfield steel reinforced with ceramic or not, as shown in figure 3. However, after 14 minutes the weight loss is again increasing with time in ordinary Hadfield steel. While the decline of weight loss is continuously established with time at Hadfield steel reinforced with ceramic composite structure. This observation should refer to the cutting mechanism can be established after 14 minutes at ordinary Hadfield steel. While the surface can accommodate much plastic strain in Hadfield steel reinforced with ceramic. Certainly, this observation should be attributed to the strain hardening capability of the two steel. Then, it is believed that XRD of the worn samples can explain the change in crystal structure owing to the plastic strain of the wear mechanism. In addition, figure 4 shows that
friction coefficient change has been observed early in the ceramic Hadfield matrix structure, which should also indicate to the change in the strain hardening mechanism among the two steel [5].

3.3. Worn surface observations

SEM with the aid of EDS was used to identify the wear mechanism among the worn surface of the two steel studied. Micro-cutting mechanism is widely established among the worn surface of the ordinary Hadfield steel, as shown in figure 5. On contrary, Micro-ploughing is widely observed among the surface of Hadfield ceramic composite structure which proves that the strain hardening has been greatly affected
by the reinforcement with ceramic. However, micro-cutting is observed at the interface between the ceramic and the metal matrix, which should refer to the low wettability character of the ceramic by the molten steel. Actually, it was much proved that the wettability of alumina to molten steel is commonly very small with high wetting angle around 160° [6]. So, it is clear that 5% of wetting alloy as ferrotitanium is not sufficient to attain the optimum wettability of molten Hadfield steel to the corundum.

![Image](image_url)

**Figure 5.** The worn surface of the steel studied.

- a. Worn surface ordinary Hadfield steel
- b. Worn surface of Hadfield ceramic composite structure
3.4. XRD observations
As mentioned before, the most significant character of Hadfield steel is its ability for strain hardening, while fcc γ-austenite is accommodate the plastic strain through transforming into bcc hard martensite structure. The ability of Hadfield steel for strain hardening is explaining its behavior against wear [7]. As increasing the strain hardening ability of Hadfield steel, the wear abrasion resistance increases. The worn samples have been tracked by using X-ray diffractometer, and it was observed that the transformation of austenite into alpha martensite is exclusively observed at Hadfield ceramic composite structure sample, while there is no transformation has been observed at the worn sample of ordinary Hadfield steel, as shown in figure 6. This observation confirms the ability of Hadfield steel with ceramic composite structure on strain hardening. In fact, XRD assures the observation of friction force that has been mentioned before.

![Figure 6. XRD patterns of the worn steel, a- Ordinary Hadfield steel; b- Hadfield steel ceramic composite structure.](image)

4. Conclusions
(1) Reinforcement of Hadfield steel with ceramic constituents has a great effect on enhancing the nucleation of new eutectoid structure throughout the austenite matrix.

(2) Ceramic Hadfield steel composite structure has a great performance against wear abrasion mechanism.

(3) Based on friction coefficient, and XRD, Ceramic Hadfield steel composite structure has high capability of strain hardening against the plastic strain generated through wear.

(4) High fraction of alpha martensite has been generated as a result of strain hardening of Ceramic Hadfield steel composite structure.
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