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# EROSIVE WEAR BEHAVIOUR OF HARDFACING AUSTENITIC MANGANESE DEPOSIT

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***Abstract***
*The solid particle erosion wear behaviors of hardfacing austenitic-manganese deposited layers on the low carbon steel surface were experimentally studied at intermediate and normal impact angles. The specimens were surfaced with single, double and triple pass bead on-plate welds using SMAW with austenitic-manganese electrode, respectively. Erosion tests were conducted at impact angles of 30, 60 and 90$^o$ using angular hard erodent. The results showed that the erosion rate varied as a function of the impact angles, and that the highest wear occurred at 90$^o$. All layers had relatively higher erosion resistant at oblique impact than those of normal impact. The first layer exhibited the highest resistance to erosion, because of intensive martensitic microstructure. The repeated impacts caused plastic flow in relatively softer surface of the second and third layer and material removal occurs by microcutting and microploughing. During the erosive wear progress for samples with multilayer pass welding, in just below eroded surface, remarkable plastic deformation were simultaneously observed with work hardening and strain-induced martensitic transformation from austenite. This also increased the hardness of the layer.*

**Key words:** *Solid particle erosion, hardfacing austenitic manganese electrode, impingement angle*

## 1. INTRODUCTION

Properties of a surface can be also modified and improved in an even more sophisticated way by covering it with a number of different or similar surface layers. There are three main reasons why it may be advantageous to use layered coatings:
1) Interface layers: these are increasingly used to improve the adhesion of a coating to substrate and to ensure a smooth transition from coating properties to substrate properties at the coating-substrate boundary. Additional effect may be to inhibit the substrate materials from influencing the coating deposition process, to add a substrate wear-protecting layer or to decrease the probability of pinholes in coating system.
2) Large number of repeated layers: By depositing several thin layers with various mechanical properties on each other the stress concentration in the surface region and conditions for crack propagation can be changed.
3) Diverse property layers: The properties of the surface can be improved by depositing layers of coatings that separately have different kinds of effects on the surface, such as corrosion protection, wear protection, thermal isolation, electrical conductivity, diffusion barrier and adhesion to the substrate. Another effect of the interface layer can be to reduce the internal stresses in the interface region. By the use of at least two layers on each other the probability of pinholes or defects going from the surface to substrate is decreased [1]. Hardfacing may be broadly defined as the application of a wear-resistant material, in depth, to the vulnerable (or worn) surface of a component by a weld-overlay orther mal spray process[2,3].

Weld-overlay coatings, sometimes referred to as "hardfacing" offer unique advantages over other coating systems in that the overlay/substrate weld provides a metallurgical bond that is not susceptible to spallation and can easily be applied free of porosity or other defects. Welded deposits of surface alloys can be applied in thickness greater than most other techniques, typically in the range of 3 to 10 mm. Most welding processes are used for application of surface coatings and on-side deposition can be more easily carried out, particularly for repair purposes. Weld overlays are very versatile because a large number of commercially available alloys can be selected to provide protection from a wide range of environmental degradation mechanism. That's why, welding is also a solidification method for applying coatings with corrosion, wear and erosion resistance [4].

Especially, erosion resistance of materials is very dependent on the erosion conditions, the effects of which are dominated by a number of variables including particle size, shape, composition, and velocity; angle of incidence; and temperature. Unlike wear properties, the erosion rate of weld–overlay coatings generally increases with increasing hardness. However, the erosion resistance of weld-overlay alloys depends on whether the coating can be classified as a brittle or ductile materials [5] those materials that can be deformed plastically (ductile) produce a large plastic zone beneath the eroded surface, and the increased plastic zone size can be directly correlated to an improved steady-state erosion resistance. For those materials that cannot deform plastically (brittle), an increase in coating hardness sometimes may lead to a decrease in volumetric erosion rate.

Thus, materials that can dissipate particle impact energy though plastic deformation exhibit low erosion rates. However, for materials that do not deform plastically (no plastic zone) and do not undergo plastic deformation, the ability to resist brittle fracture (i.e, cracking) becomes a major factor that can control the erosion resistance [4].

Welding processes used to apply hardfacing materials range from the traditional (for example, oxyacetylene torch) to new and sophisticated (for plasma transferred arc, PTA, and laser methods). The processes can be grouped as torch process, arc welding process, and high-energy beam techniques [6,7]. The torch process, oxyacetylene welding, is oldest and simplest hardfacing process and involves simply heating the substrate with the flame and then melting the filler rod to get the hardfacing to melt. High-energy-beam techniques use laser beam welding or electron beam welding to alloy the surface by adding alloy powders to the weld pool. In arc welding, the heat is generated by an arc between an electrode and the workpiece. To accommodate these different overlay processes mentioned before, the hardfacing materials are available in a variety of forms. Hardfacing materials fall into six categories: built-up alloys, metal-to-metal wear alloys, metal-to-earth abrasion alloys, tungsten carbides (for extreme earth sliding and cutting wear), nonferrous alloys, stainless steels [8]. The built-up alloys are used as wear-resistant materials under mild wear conditions, and to return worn parts back to, or near, its original dimensions and to provide adequate support for subsequent layers of true hardfacing materials. These type alloys fall into two categories: alloys steels and austenitic manganese steels. Alloys steels built-up materials are used with carbon steel and alloy steel substrate; austenitic manganese steels are used for the joining, repair and/or protection of manganese steels components. Typical examples of applications where built-up are used include tractor rails, railroad rail ends, steel mill table rolls, and large slow-speed gear teeth [8]. Austenitic manganese steel [9] containing about 1.2 mass % C and 12 mass % Mn is known for a high resistance to impact wear caused by rapid cold work hardening. It is well known that metastable austenitic manganese steels, in comparison with Hadfield steel, appear to have a higher work-hardening capacity and a better wear resistance under low stress abrasive wear condition [10], but there is little work reported on the mechanism leading to this behavior. In general, it is known for the formation of numerous strain-induced martensites and twins [10,11]. Furthermore, a fragmentation of grains was seen as a reason for work hardening [12,13].

In another study on standard hadfield steel, however, magnetic measurements showed alfa-martensite in tensile specimens above 30 % of elongation, amounting to 0,43 % near the fracture face [14],which is hardly enough to enhance much of a TRIP strengthening. Recently a stainless type of hadfield steel was also developed [15-18] to resist corrosion in pit mining, where a slightly acid environment is encountered. However, solid particle erosion of hardfacing hadfield steel has not been studied in detail.

The purpose of this study is to investigate the effect of hardfacing layers deposited with arc welding using an austenitic manganese electrode on the erosive wear behaviour of low carbon steel and that of the number of weld-overlay coating deposited on the steel surface.

## 2. EXPERIMENTAL

### 2.1. Material

Low carbon steel plates (SAE 1020) measuring 150x30x10 mm were prepared for hardfacing. The specimens were surfaced with single, double and triple pass bead on-plate welds using the manual shield metal arc weld (SMAW) with austenitic-manganese electrode (DIN 8555: E 7 UM-200K) having 4 mm diameter. After the welding was performed, the welded part was immediately cooled with water to prevent the possible formation of manganese-carbide precipitation. The welding parameters are given in Table 1 and the weld metal compositions given by producer firm and obtained in the present study are given in Table 2.

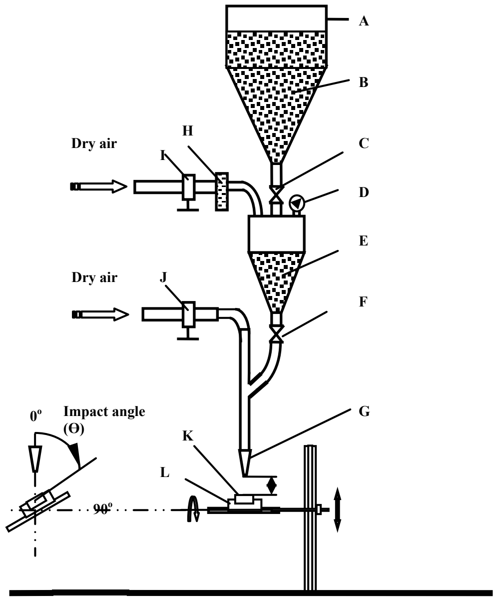
**Table 1.The welding parameters used in this study**

| *Parameter* | *Value* |
|---|---|
| Voltage | 24V |
| Travel speed | 1,1 mm/sec |
| Current | 160 A |

### 2.2. Erosion test procedure

Samples with sizes of 2 x 2 x 1 $cm^3$ used for erosion tests were cut from the welded specimens. The surfaces of the layers were ground and polished before the tests. The erosion tests were conducted at impact angles by changing the orientation of the sample with respect to the stream of the impinging particles, using erodent particles of nominal diameter of 420µm.

The impact angles were set at three different values, $30^o$, $60^o$ and $90^o$. The particles were angular steel grits (SAE No: G40), with hardness of 55 Rc and uniform martensitic microstructure, at a density of 7.2 g $cm^{-3}$. The steel grits were blasted onto the surfaces through a blast rig shown in Fig 1. The impact angle was defined as “θ” in the figure.




***A:** Mean reservoir; **B:** Erodent; **C, F:** Valve; **D:** Manometer, **I, J:** Pressure Regulators, **H:** Powder filter, **E:** Pressured particle tank, **G:** Nozzle; **L:** Holder, **K**: Specimen*

**Fig.1:** *Schematic illustration of the test rig*

**Table 2.The chemical compositions of the layers**

| | *C* % | *Si* % | *Mn* % | *Ni* % |
|---|---|---|---|---|
| First layer | 0.35 | 0.97 | 4.9 | 1.20 |
| Second layer | 0.49 | 0.98 | 8.10 | 2.10 |
| Third layer | 0.61 | 0.99 | 11.42 | 2.75 |
| Weld metal* | 0.70 | 0.10 | 13.0 | 2.80 |

**The composition of the weld metal was given by the producer*

Particle velocity was controlled utilizing the gas pressure regulators and measured through double-discs method, as described in Ref [19]. Dried air was used for accelerating these particles. Each specimen was approximately eroded at particle velocity of 30 m/s, and exposure times until 27 minutes. The nozzle diameter was 7 mm, the distance between the nozzle and the specimen was 10 mm. After completion of the tests, the samples were cleaned with low-pressure air afterwards with alcohol and weighed to an accuracy of $10^{-4}$ g.

To compare the wear-resistance of the specimen, erosion rate is used. The mass losses are firstly calculated by the differences of the specimen weights before and after the experiments. The erosion rate is defined as the mass loss per unit impact solid particle weight. In order to examine erosion mechanism and failures, top view of the eroded surfaces and cross-section of the specimen structures are observed after the experiment. Variation in surface hardness as a function exposure time was determined in RB and RC to be taken an average hardness of four points in the surface and the ones from bottom of the wear crater occurred after completion of the test. Hardness distribution of the wear crater in depth was further detected by vickers indentor under loading of 40 g.

## 2.3. Metallography

The specimens were prepared using standard metallographic techniques, involving grinding with successive silicon carbide papers to 1200-grit finish. The polishing was carried out with diamond paste to obtain a surface finish of 1 µm. The polished specimens were subsequently etched with 2 % Nital.

SEM back-scattered electron imaging and optic microscopy were used to differentiate the various phases in the microstructures of the weld overlays. Additionally, because eliminating metallographically cutting probably effects on the microstructures of the samples to be eroded, the cross-sectional investigation were carried out in that the samples were cut by half prior to the erosion test and grounded, polished and afterwards subjected to the erosion test by together face to face again.

## 3. RESULT AND DISCUSSION

### 3.1. Microstructure characterization

Increase in the number of the deposited layer led to variety and enrichment of chemical composition in the surface, especially, C and Mn, and thereby microstructural and hardness differences revealed each occasion. Figure 2 shows microstructure of first overlay deposited on the steel substrate. As seen from the figure, typical lath-martensite phases are predominant in the microstructure of layer. The preferred oriented microstructure of interface between the first and the second layer provide a good bonding as seen in Fig.3. The second layer composed of austenite and martensite in general. Hard martensitic structure appears in the form of a precipitation island grown in the austenite matrix as *dark spots* in figure 4. The microstructure of the third layer is given in Fig.5. As can be seen in this figure the microstructure consists of fully austenite. From the results of the microstructural examination, it can be seen that the microstructures are in good agreement with the composition given in table 2.

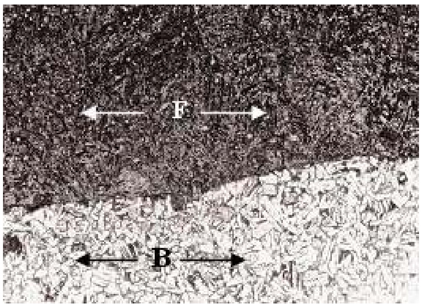



**Fig.2:** *Microstructure of the first layer (F: First layer, B: Base metal). (X 100)*

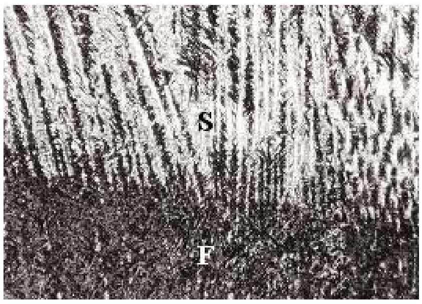



**Fig.3:** *Microstructure of second layer (F:First pass, S: second layer) (X 100)*

As the contents of C and Mn increased, the microstructure changed from martensite to austenite.

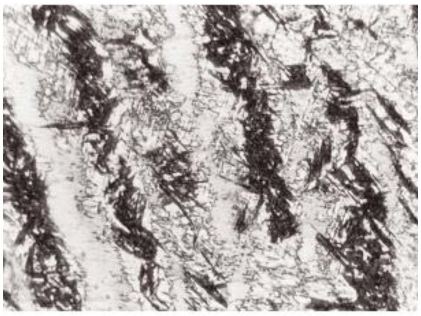


**Fig.4:** *Microstructure of deposited layer for the second pass hardfacing (X 375)*

**Fig.5:** *Microstructure of deposited layer for the third pass hardfacing(X 100)*

### 3.2 Hardness Measurement

Table 3 shows the hardness of first, second and third weld overlays and the substrate, the hardness of surface with single layer was much higher than those of the substrate and the others. The increase in the hardness for the first pass layer is related to the martensitic microstructure. As C and Mn increased in the layer, the hardness decreased. This decrease in hardness can be related to the austenitic microstructure.

**Table 3. Initial hardness values**

| *First layer* | *Second layer* | *Third layer* | *Substrate (AISI 1020)* |
|---|---|---|---|
| 48 RC | 92-95 RB | 80-82 RB | 90 RB |

### 3.3. Erosion behavior

Fig.6 shows the variation in erosion rate with impact angle for the weld hardfacing layers. The erosion rates as a function of time at 30, 60 and 90$^o$ impingement angles. The figure indicates that the hardfacing layer can enhance the erosion resistance of AISI 1020 steel substrate, rates of which are 1.8, 1.5 and 1.2 mg/kg at each impact angle respectively. Each layer reached the highest value at the 90$^o$ impact angle and the lowest value at the 30$^o$ low impact angle. They exhibited an intermediate behavior at 60$^o$. This shows that all weld overlay exhibited brittle behavior during erosion loss, although the erosion loss rate of the hardfacing layers at high impingement angles were comparable to the base material and presents the feature of brittle material.

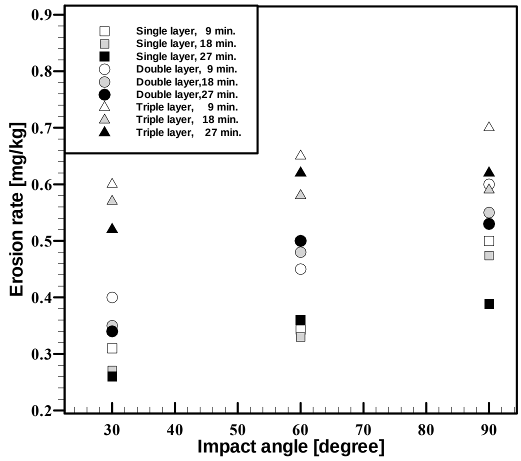



**Fig.6:** *Erosion rates versus the impact angles*

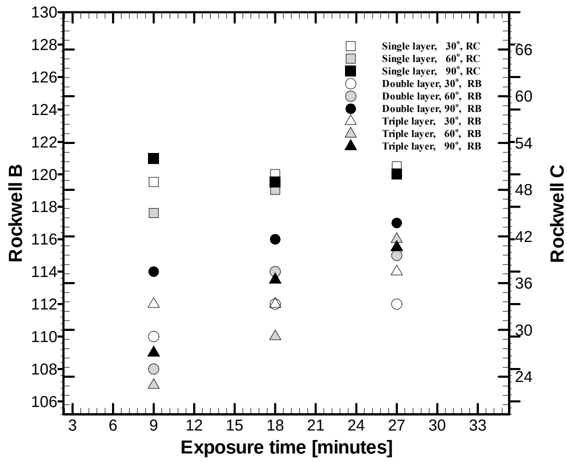



**Fig.7:** *Change in surface hardness with exposure time.*

This can be explained by the multiphase structures of the overlays. The repeated impacts increased the surface hardness by work-hardening, strain-induced martensite transformation just below the eroded surface, especially at the second and third hardfacing layer, and also fatigue resistance increasing the consequent brittleness. Further identification of whether ductile or brittle erosion loss in the layers could be obtained by observing the work hardening on the eroded surface. Fig. 7 shows the surface hardness of the weld hardfacing layers at different impact angles. The increasing rate of hardness slightly increased with the impact angle. Although the first layer exhibited higher hardness and lower mass loss, for third layer, the surface hardness increment was relatively higher because of work hardening. Fig. 8 also summarizes the hardening response of each layer. Initial hardness values and hardness after completion of the erosion tests for each layer was given in the figure. Due to a higher work-hardening rate, the hardness increment of the second and third layers at all impact angles was higher than that for than the first layer. At a normal impact, rather, removal of material from the surface goes on by surface fatigue apart from that of the first layer. Because the first layer composed of martensitic phases in general, it is considered that stresses resulting from repeated impacts induced during the erosion process also may be causes the brittle fracture in erosion mass loss and this leads to wear debris broken off the eroded surface as shown Fig 9. However, at oblique impact angles, the erosion loss was due mainly to deformation by subsequent cutting and ploughing. The surface was plastically deformed and the material was gradually removed by cutting and ploughing (Fig.10). The deformation was also observed interlayers for sample with triple layer (Fig. 12). Such a multilayer absorbs high impact energy and simultaneously gains strength by virtue of strain-induced martensite transformation shown in Fig 11.

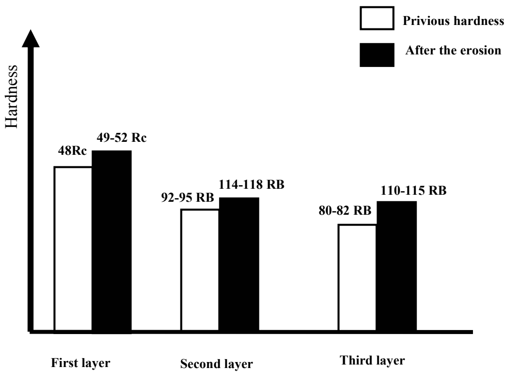



**Fig.8:** *Variation in surface hardness of each hardfacing layer*

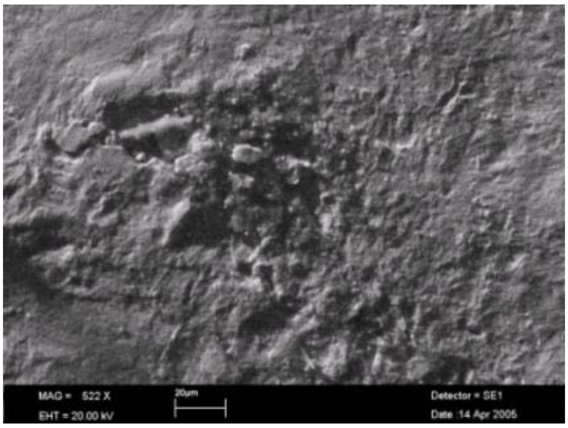



**Fig.9:** *Surface topography of eroded first layer (Impact angle: 90°)*


**Fig.10:** *Top view of eroded surface the belonging of third layer deposited. (Impact angle: 30°)*

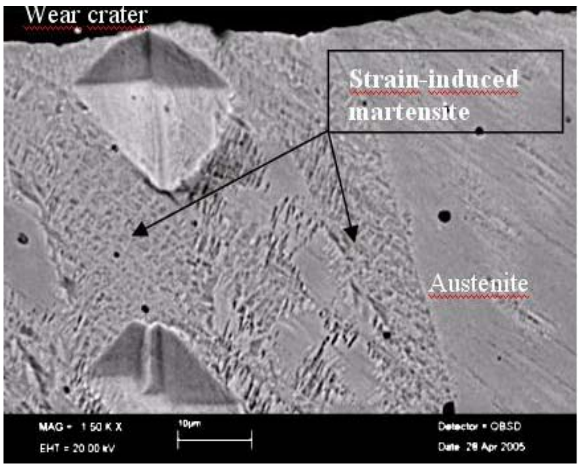



**Fig.11:** *Cross sectional view of the wear crater (Just below the surface for third layer, the angle:90°)*

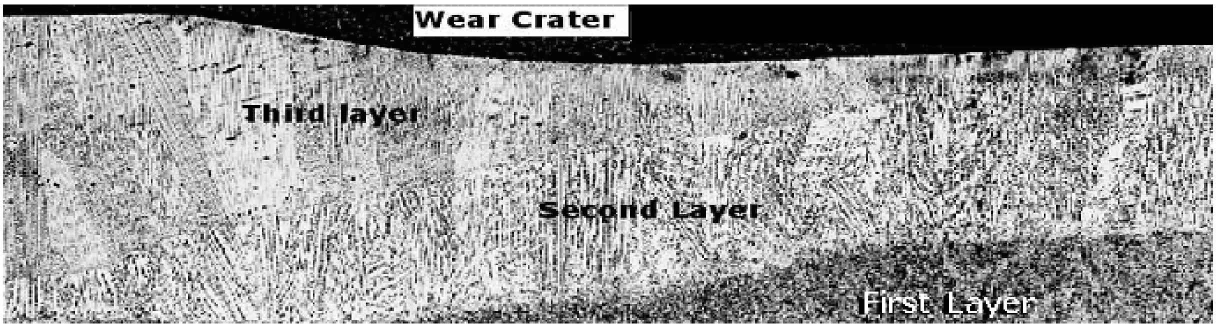



**Fig. 12:** *Cross sectional view of eroded surface for sample with triple layer (Impact angle: 30°, Mag: x20)*

## 4. CONCLUSION

(1) Under the condition of erosive wear, the wear resistance of the first layer is about 1.5 times as high as that of the others. However, as the wear resistance of second and third layers tends toward arising.
(2) Increase in the number of the deposited layer leads to variety of chemical composition in the surface, especially, C and Mn, and thereby microstructural and hardness differences revealed each occasion.
(3) There also existed work hardening and strain-induced martensite phases produced while impact erosive wearing.
(4) The formation of numerous strain-induced martensites, the additional pressure stress caused by martensitic transformation in surface layer of worn specimens, the obstruction of the lattices in the movement of dislocations on slip planes, and the dynamic strain aging are the major causes for the high work-hardening rate in the hardfacing austenitic manganese steel.
(5) It can be suggested that the hardfacing austenitic steels occurred by arc welding is useful for local repair, reinforcement, recoating applications of mild steel surfaces to erosion, regardless of multilayer coatings.

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