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Challenges and Developments of Hadfield manganese steel castings based on service life

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ABSTRACT

Austenitic Manganese steel has a high toughness, high ductility, high strain hardening capacity and an excellent wear resistance. This grade of steel is mostly used in the mining industry for crushing and loading equipment. The present paper highlights the challenges and the development of high manganese steel casting based on the service life. Currently the challenge faced among others is the rate of work hardening, which is due to the crushing efficiency of the modern jaw and cone crushers. This limits the rate of work hardening produced on the surface of the metal thus resulting in low wear resistance, loss of material and cost of production for secondary and tertiary crushing equipment. Due to this challenge faced, researchers were motivated to come up with innovative ideas and new development that will increase the hardness and wear resistance of the said steel, resulting in longer service life of the components. These developments include the introduction of a new heat treatment procedure, the addition of micro alloying with Chromium and the use of metal matrix composite on manganese steel casting. However, the introduction of these new developments on high manganese steel casting showed to have a direct increase in wear life and hardness of the steel.

Keywords: Austenitic Manganese steel, Wear resistance, Hardness, Application of manganese steel.

INTRODUCTION

Hadfield steel was invented by Sir Robert Hadfield in 1882. This type of steel with its austenitic matrix at ambient temperature has high toughness, high ductility, high strain hardening capacity and excellent wear resistance. As a result these casting parts have been widely used for many years in a variety of applications such as: earthmoving, mining, railways, quarrying, dredging and oil/gas drilling [3]. Due to this variety of application, there are a number of modified grades for manganese steel. Some application need high impact load and good wear resistance for example, Jaw crushers and cone crushers used for primary crushing equipment, while other applications needs moderate or no impact at all and high resistance to wear for the secondary and tertiary crushing equipment. The table below shows the standard chemical composition of high manganese steel castings used under Gouging abrasion.

Table 1: Chemical composition of Hadfield steel [7]

C	**MN**	**Si**	**Cr**	**P**	**S**
1-1.3	11-14	0.5	-	0.005 max	0.005 max

As mentioned above, that different modified grades of manganese steel castings has been put on place thus this grades of steel are used for different application and these application suffer different kind of wear, this include: erosion or Low-Stress scratching abrasion, high-Stress grinding abrasion and gouging abrasion. The most important feature of wear resistant materials is their ability to prevent abrasive particles from penetrating the wear part surface. The choice of wear resistant material and its key properties will depend upon the application and the properties of the crushed material [4].

CHALLENGES AND FACTORS AFFECTING THE SERVICE LIFE OF HADFIELD MANGANESE STEEL USED FOR CRUSSHING EQUIPMENT

As it is known by now that the only strengthening mechanism for Hadfield steel is its high rate of work hardening. The challenge faced is that, the rate of work hardening is affected due to the crushing efficiency of the modern jaw and cone crushers. This efficiency has been raised by increasing the stroke length and by transforming the crushing by compression alone into a combined effect of compression and shear. In these types of crushing processes, the formerly impact load has largely been replaced by an abrasive wear with a result that the impact loads against the wear parts have not been strong enough to cause the maximum work hardening of the steel and the relative service life of the wear parts have shortened [1].

The situation is the same in the excavator buckets and loader shovels when loading fine grain materials where the impact and compression loads are not always sufficient for the work hardening of the steel. The figures below show some components made from manganese steel and are used in the mining industries.

Figure 1: Worn excavator buckets for fine grained [8]

Figure 2: Jaw crusher [9]

Figure3: Mantle and bowl liner for the Cone crusher [4]

During the crushing cycle, gouging or high stress abrasion is present depending on the particle size of feed material. Between the crushing cycles when particles of feed material are sliding against wear parts, low stress abrasion is present. Several different factors affect the service life of wear parts, these will include the types of wear, environmental factors, crusher operating parameters, feed material and wear part properties are just a few of these.

However one noticeable factor in wearing of crusher parts is the abrasiveness of the feed materials [4]. The table below show abrasiveness for some common feed material

Table 2: Abrasiveness of common material [4]

	French abrasiveness [g/ton]	Abrasive index
Non abrasive	**0-100**	**-0.1**
Slightly abrasive	**100-600**	**0.1-0.4**
Medium abrasive	**600-1200**	**0.4-0.6**
Abrasive	**1200-1700**	**0.6-0.8**
Very abrasive	**1700**	**0.8**

For example, iron ore can have a higher abrasive index as compared to dolomite or coal, thus this means that iron ore will make the manganese wear parts to wear off easier than dolomite when crushed under secondary or tertiary application. Crushability is another important factor which indicates how easily it is for rock material to break down.

Manganese crusher parts increases the work hardening rate due to the high impacts loads. It can be said that for primary crushers such as Jaw, gyratory and impact crushers, the component will have a good work hardening rate thus decreasing the wear rate of the component and intern increase the service life of the component while reducing cost [2]. Figure 4 below show the graph of toughness vs abrasion resistance for manganese steel while figure 5 gives the hardness profile vs distance from the surface for different crushing operation using manganese steel.

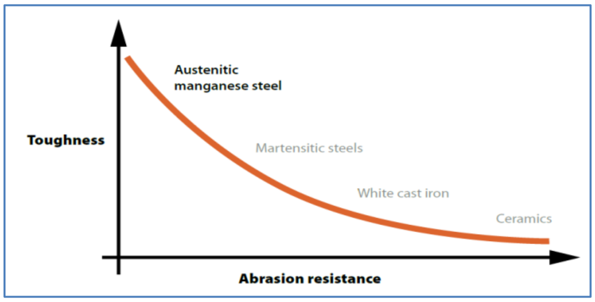


Figure 4: Toughness vs abrasion resistance for Mn steel [4]

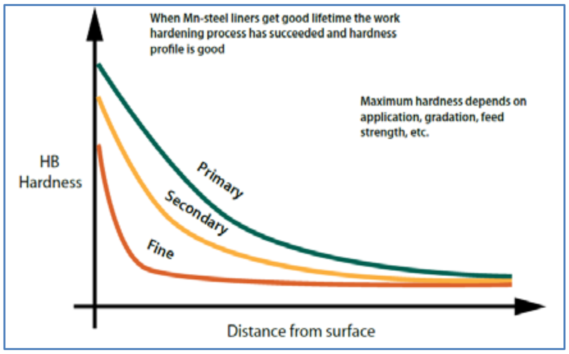


Figure 5: Hardness vs distance from the surface for Mn steel [4]

For secondary crushing equipment where the feed material is abrasive, but the reduction ratio and feed strength are not very high, manganese steel will not be the best material for this application. The reason for this is the fact that the work hardening rate won't be sufficient enough to produce a thick layer of work hardening. Therefore if manganese steel is used for secondary crushing where the impacts load is low, wear resistance of the material will decrease thus resulting in material loss and being uneconomically friendly. For this reason straight manganese steel must be substituted with another grade of steel that is more wear resistance, normally martensitic or the so called boron steel [5].

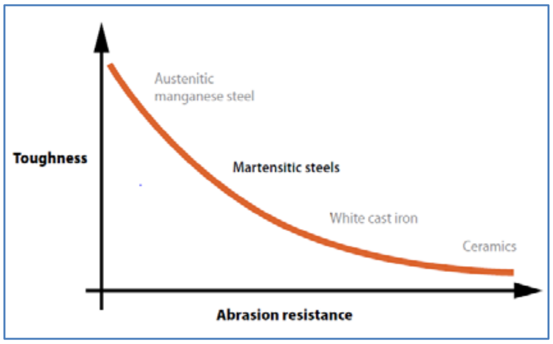


Figure 6: Toughness vs abrasion resistance for Martensitic steel [4]

Tertiary crushing is normally the last stage of crushing. The feed material is abrasive as well, and the reduction ratio and feed strength are very high. Normally this last stage of crushing is used to crush fines material, the impact load is very low and the rate of work hardening is also low thus resulting in material loss when using manganese steel.

Manganese steel will not be a perfect choice for the tertiary crushing equipment thus the suitable steel for this application can be high chrome iron or metal matrix composite [5].

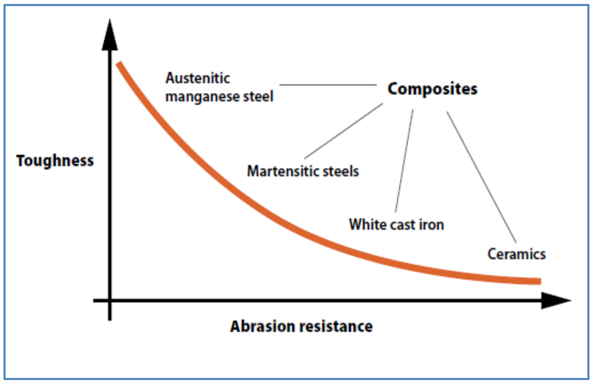


Figure 7: Toughness vs abrasion resistance for a composite material [4]

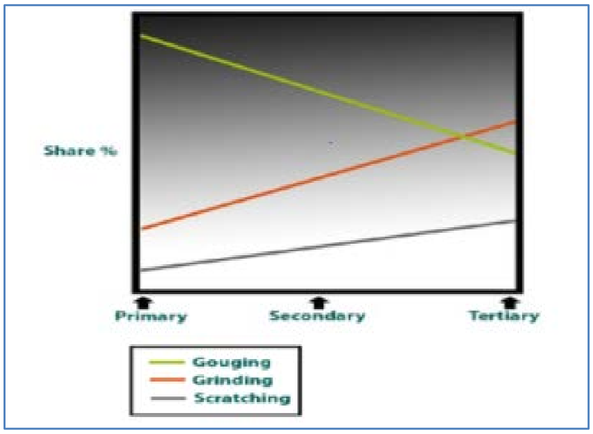


Figure 8: Share (Wear resistance) vs different application for different abrasion [4]

DEVELOPMENT OF HADFIELD MANGANESE STEEL BASED ON THE CHALLENGES FACED

Although wear parts produced by forging and hot rolling already have enough hardness to withstand the wear action, however most parts used in the above applications are produced by casting. This has led to new development of adding alloying elements such as chromium so as to increase the hardness and wear resistance of the steel as well as the manufacture of metal matrix composite as to increase the hardness and wear resistance of manganese steel.

Aribo and Alaneme added that, the conventionally heat treatment for austenitic manganese steel is solution annealing followed by quenching, which is performed by heating the steel between the temperature range of 1000°C to 1100°C, held for enough time depending on the size of the steel and then cooled rapidly by quenching in water. This gives the steel a brinell hardness number of 200 to 250, which is low for effective wear resistance [1].
Therefore an additional form of heat treatment has been found, which can be used to increase the hardness of the steel and thereby increase the wear resistance and in turn the service life of the components working under low impact and high wear rate.

Table 3: chemical composition of the new developed Hadfield steel alloyed if Chromium [1]

C%	Mn%	Si%	Cr%	P%	Ni%	S%
1.27	13.8	0.583	2.25	0.03	0.03	0.02

The treatment involves austinizing at 1000°C before quenching in water. Thereafter the components are subjected to a second stage heat treatment which involves ageing at temperatures between 600°C and 700°C for holding time of two hours before air cooling. This treatment has a direct influence on the hardness and wear resistance of Hadfield steel as illustrated by the figure below.

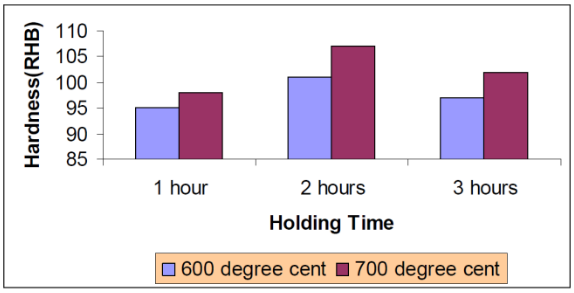
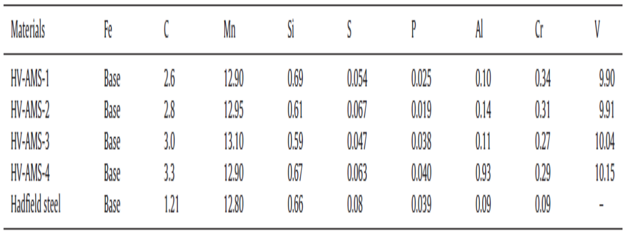


Figure 9: Hardness vs holding time at different aging temperature [1]

Moghaddam & Varahram also investigated the effect of vanadium and varying carbon content on Hadfield steel. The treatment also showed to have a direct influence on the wear resistance and hardness of manganese steel. According to the demands in upgrading the productivity and quality of products as well as to pursuit the optimum economy in wear industries; in the past decade the powder metallurgy approach has been replaced with the in situ ceramic–steel matrix composite. This is a synthesis technique to increase the life of the wear parts. The technique involves adding hard ceramic material in to molten steel as alloy elements and a more thermodynamically stable reinforcing phase will be formed during solidification. The process occurs by the nucleation and growth mechanism in the parent iron matrix that has a coherent interface with the iron matrix.

Table 4: Chemical composition of the Austenitic Manganese Steel alloyed with vanadium and having different carbon content [3]



Materials	Fe	C	Mn	Si	S	P	Al	Cr	V
HV-AMS-1	Base	2.6	12.90	0.69	0.054	0.025	0.10	0.34	9.90
HV-AMS-2	Base	2.8	12.95	0.61	0.067	0.019	0.14	0.31	9.91
HV-AMS-3	Base	3.0	13.10	0.59	0.047	0.038	0.11	0.27	10.04
HV-AMS-4	Base	3.3	12.90	0.67	0.063	0.040	0.93	0.29	10.15
Hadfield steel	Base	1.21	12.80	0.66	0.08	0.039	0.09	0.09	-

The experiment showed that, carbon content has an effect on the carbide morphology of high manganese steel alloyed with vanadium. As the molten metal solidifies, vanadium carbide nucleates and grows in the melt, it crystallize as coarse primary vanadium carbides between liquidus and solidus temperature. It has been found that as the carbon content increases; the amount of vanadium carbides increases and primary VCs change from rod, strip into bulk, spherical shape [3]

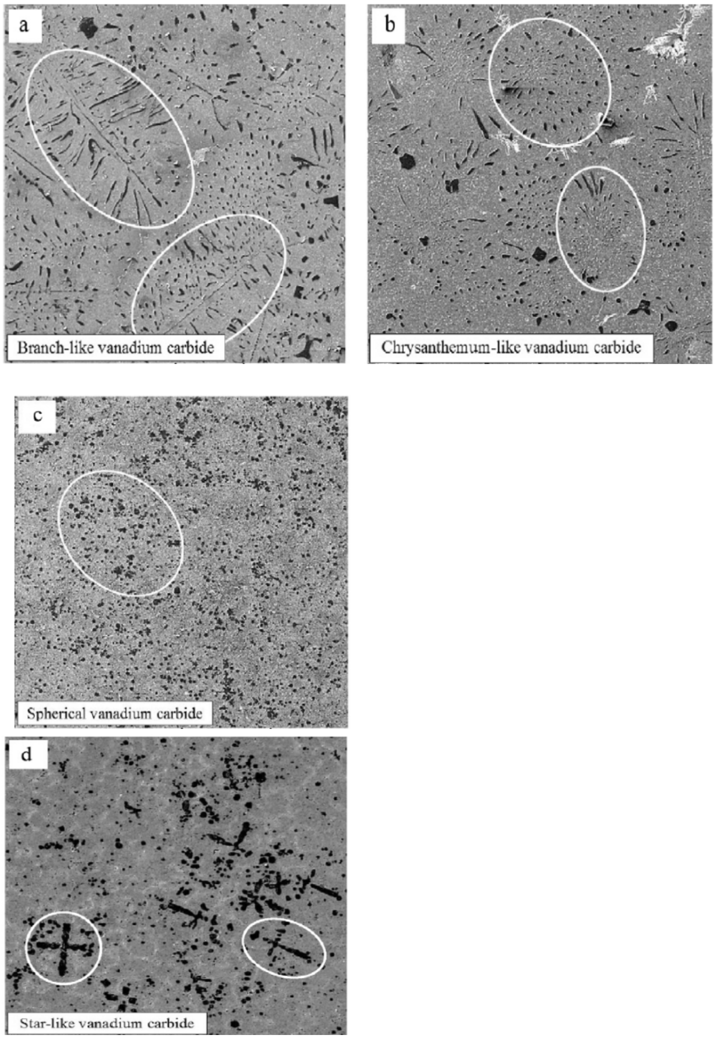


Figure10: Scanning electron microscope (SEM) micrograph of high-vanadium austenitic manganese steel materials in the as-cast condition: (a) branch-like VC distribution (alloy1), (b) chrysanthemum-like VC distribution (alloy2), (c) homogenous VC distribution (alloy 3) and star like VC (alloy 4) [3]

However, microstructural observations showed that solution annealing at 1100 ◦C for 90 min followed by a water quench does not have a significant effect on vanadium carbide morphologies or distribution. As said before that the presence of the vanadium carbide will bring forth an increase in hardness value, decreasing the wear rate of said steel. The figure below illustrate the difference in hardness for original

Hadfield steel compared to the one alloyed with vanadium at different carbon content [3].

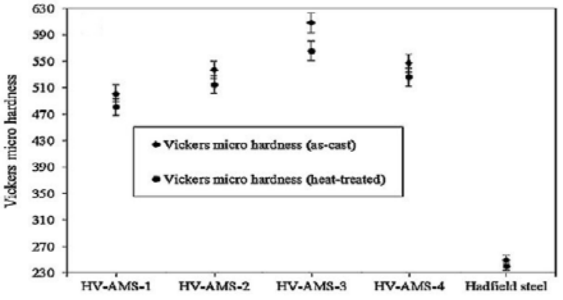


Figure 11: Vickers micro hardness of materials in both the as-cast and heat-treated conditions before the abrasion test [3]

It is clear that, the addition of vanadium to Hadfield steel will increase the hardness by approximately 60% as compared to the standard Hadfield steel. The explanation of increasing in hardness as carbon content increase can be due to the different vanadium carbide morphology as carbon content increase. Directly from this increase in hardness value, it can be assumed that the wear resistance of the component alloyed with vanadium will increase as well, but the impact toughness will definitely decrease since impact strength is indirectly proportional to the hardness and wear rate [3]. The figures below show the weight loss and impact strength respectively for components alloyed with vanadium as compared to the standard Hadfield steel.

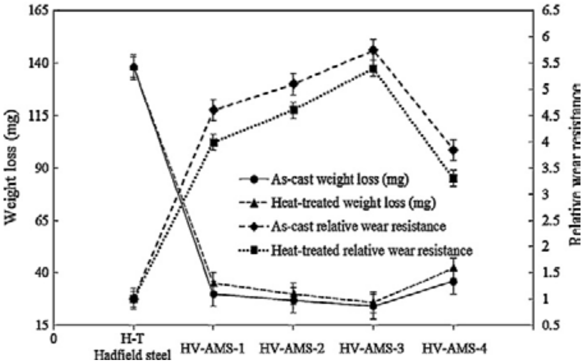


Figure 12: Weight loss and relative wear resistance of manganese steel alloyed with vanadium, related to the heat-treated Hadfield steel sample [3]

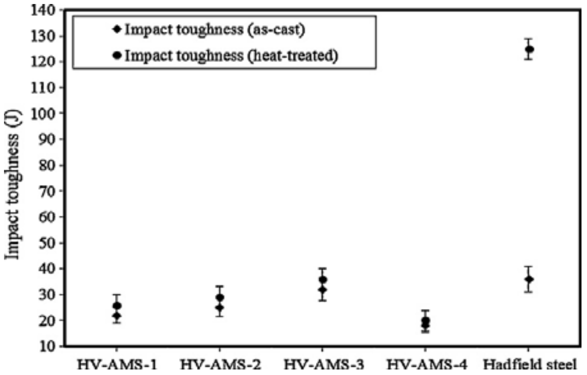


Figure 13: Impact toughness of manganese steel alloyed with vanadium in it's as- cast and heat-treated condition, relating to the standard manganese steel [3]

So Many considerations are involved in the selection of the proper grade of abrasion-resisting steel. For example: the type of service, the type of material being handled, the type of abrasion, and the economics of operation.
Wear problems can best be solved by selecting a grade of steel for trial, shaping it into an experimental part and observing the wear rate. However, the following generality can be stated: as the hardness increases, the resistance to abrasion increases. However excessive hardness should be avoided so that problems can be avoided when forming, or in premature failure owing to lack of impact strength [6].

Therefore, the development was based on improving the hardness of manganese steel using vanadium carbide second phase, thus enhancing the wear resistance of the said steel. Due to the decrease in impact strength, the following material cannot be used where high impact loads are used. Application that are recommended for this steel is where, wear resistance is of out -most importance and impact toughness is of less importance.

CONCLUSION

For a given application, the correct material is needed so that it can yield the correct properties and increase product life for that component. The challenges and factors affecting high manganese steel casting was discussed, this includes the feed material to be crushed, the abrasiveness of that material and the kind of wear experienced during the crushing cycle. Due to this common challenges, innovative ideas and development where introduced and they have shown to have a direct impact on the properties of high manganese steel used for secondary and tertiary crushing equipment. The development discussed include the introduction of Chromium as an alloy element aging at a given temperature and the second development include the formation of round to semi round vanadium carbide that are small, evenly dispersed and coherent with the austenitic matrix. However both of this development has shown to have a direct impact on the hardness and wear resistance of Hadfield manganese steel used in the secondary and tertiary crushing equipment.

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