Chapter 25

Influence of Metallurgical Parameters on Wear and Impact Characteristics in High Chromium Manganese Irons

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Abstract Nickel chromium irons such as Ni-hard of different grades (high chromium iron) are being employed as wear-resistant materials in thermal power generation applications in view of their excellent inherent material characteristics. They are being deployed in bull ring segments, orifice, rolls, MPO, liners, etc., in thermal power plants and other engineering industries. But, these materials being brittle fail to withstand transient load. To overcome this problem, manganese is added to chromium iron to improve its impact characteristics apart from being wear resistant. In this context, the erosion and abrasion properties affected by metallurgical features are considered important from the point of enhancing its impact energy, without much sacrificing the wear resistance. Considering these aspects, high chromium manganese irons have been prepared in grey cast iron metal mould of section size of 24 mm, followed by heat treatment. The erosion, abrasion and impact energy have been studied using jet erosion, rubber wheel abrasion and drop weight impact test setup for varying manganese content in the range of 5, 10 and 15%. It is very much evident from the metallurgical investigations involving light microscopy that the least Mn

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content sample (5% manganese content) shows the highest wear resistance, whereas on the other hand, the highest manganese addition of 15% exhibits highest impact energy. The hardness and the metallurgical features support these findings as one could visualize the phases and carbide morphological features getting transformed during the heat treatment process, thus favouring the abrasion, erosion and impact properties. These results have been compared and analysed with the results obtained from high chromium iron samples.

Keywords High chromium manganese iron · Erosion · Abrasion · Impact energy · Carbide size · Retained austenite

25.1 Introduction

The family of white irons including cast irons and nickel chromium irons have been investigated and reported [1, 2] extensively in the literature especially the high chromium irons, in view of its possessing good wear resistance property due to the presence of hard carbides in a hard and tempered martensitic matrix [3, 4]. But, there is one drawback with regard to its usage in power, mining, cement and other industries, and it is the brittle nature of it for not taking sudden load. Many researchers [5, 6] have made attempts on the development of wear-resistant high chromium cast iron material to withstand load under impact situations, through the addition of gamma forming elements such as manganese (Mn), copper (Cu) and nickel (Ni). Among them, Mn being cost-effective and productive has been tried up to about 5% by weight, beyond which the literature information is scanty. The influence of microstructure on the wear properties has been studied and reported in [7, 8]. Basak et al. [9] in their work have demonstrated the role of addition of Mn (4% by weight) in high chromium iron for enhanced impact energy but at the same time not sacrificing much on the wear resistance property. Thus, a trade-off between wear and impact characteristics is very much required at this stage. Keeping the literature points in view, the alloying element manganese is added in the range of 5–15% by weight to high chromium iron to improve the load-bearing capacity alongside wear property, as manganese is known to be a strong austenite-stabilizing element. In this work, the manganese concentration has been varied at 5, 10 and 15 weight percent to chromium (16–18 weight percent), and the castings are produced in a metal mould of section size 24 mm in an induction melting furnace, followed by heat treatment. The erosion and abrasion characteristics have been evaluated in a jet erosion and rubber wheel abrasion test rigs, respectively. The impact energy and hardness measurements are carried out using drop weight impact tester and Rockwell hardness tester. The results have been compared with high chromium iron without manganese addition in it. The light microscopy has been taken to examine and interpret the microstructures.

25.2 Materials and Methods

The materials chose are high chromium (16–18%)-alloyed iron and high chromium (16–18%) manganese-alloyed iron with manganese levels of 5, 10 and 15 weight percent. The castings are made by induction melting route by pouring liquid metal into the grey cast iron metal mould of section size 24 mm having the dimensions of 150 × 100 × 25 mm^3. The test coupons are cut to a size of 75 × 25 × 6 mm^3 using abrasive cutting machine from the casting as per the schematic diagram shown in Fig. 25.1 for erosion and abrasion tests and sample size of 55 × 10 × 10 mm^3 for impact energy test.

The test samples are given heat treatment in a muffle furnace with an austenitization soak for 6 h at 950 °C followed by stress relieving treatment for 30 min at 200 °C. The erosion and abrasion tests were carried out in a jet erosion test rig and rubber wheel abrasion, respectively, as per the guidelines given in ASTM standard [10, 11]. The impact energy test is done in accordance with ASTM standard [12] guidelines using drop weight impact tester using an un-notched specimen. The hardness has been measured using Rockwell C hardness tester (conical indenter; with vertex angle 120°; hemispherical tip of radius 200 µm), at a test load of 150 kg. The metallographic procedure has been adopted to arrive at the microstructure and carbide volume using optical microscopy coupled with an image analyser. The retained austenite measurement has been carried out using X-ray stress analyser equipment with chromium as the target material. The details of characterization procedures are reported in [13, 14]. The chemical composition has been determined using optical emission spectroscopy.

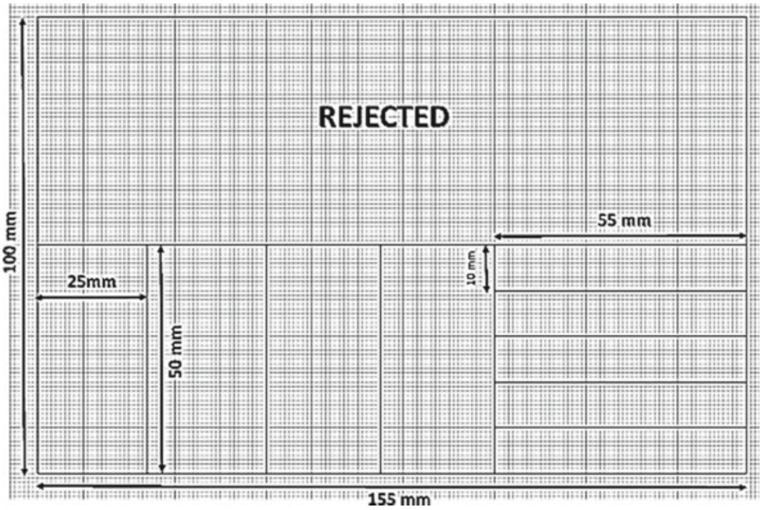

Fig. 25.1 Schematic diagram of casting made, showing the location of test samples for various tests

25.3 Results and Discussions

The sample designation along with its chemical composition is given in Table 25.1, and the hardness, retained austenite and carbide volume are given in Table 25.2, respectively. All the test data provided in this study are pertaining to the heat-treated conditions only.

25.3.1 *Erosion and Abrasion*

The erosion test conducted at 45° and 90° impact angles are shown in Fig. 25.2. It is very well seen from the erosion data that the maximum loss takes place at 45° impact angle and the least at 90° impact angle for HiCr5Mn, HiCr10Mn and HiCr15Mn samples. For HiCr iron sample, the highest erosion is noticed at 90° and the lowest at 45° impact angle. As per the theory [15], the highest erosion loss is reported at 45° for ductile materials and least erosion loss at 90° for brittle materials. In the present case also, the erosion loss of HiCr closely resembles with the data pertaining to the brittle material, and hence, it is exhibiting highest hardness and in turn low erosion resistance. This is on the expected lines as chromium carbide in HiCr which is having highest hardness as well as carbide volume (Table 25.2) and supports the erosion test data. In the case of HiCrMn iron samples, HiCr15Mn is showing the highest erosion loss compared to HiCr5Mn. Accordingly, the erosion data varies

Table 25.1 Chemical composition of HiCrMn iron samples

Sample identification	Composition (wt%)							
	C	Mn	Si	Cr	Ni	Mo	S	P
16–18% Cr (HiCr)	2.87	0.60	0.78	16.50	0.98	1.96	0.042	0.040
5% Mn 17–19% Cr (HiCr5Mn)	2.39	4.60	2.15	18.65	0.92	1.82	0.044	0.090
10% Mn 17–19% Cr (HiCr10Mn)	2.35	9.70	1.85	17.60	0.82	1.80	0.040	0.085
15% Mn 17–19% Cr (HiCr15Mn)	2.43	14.80	1.98	18.15	0.87	1.75	0.042	0.080

Table 25.2 Hardness, retained austenite and carbide volume of HiCrMn iron samples

Sample designation	Rockwell C hardness	Retained austenite (%)	Carbide volume (%)
HiCr	64.7	10	29.0
HiCr5Mn	61.0	50	27.5
HiCr10Mn	53.0	60	25.5
HiCr15Mn	50.9	64	24.0

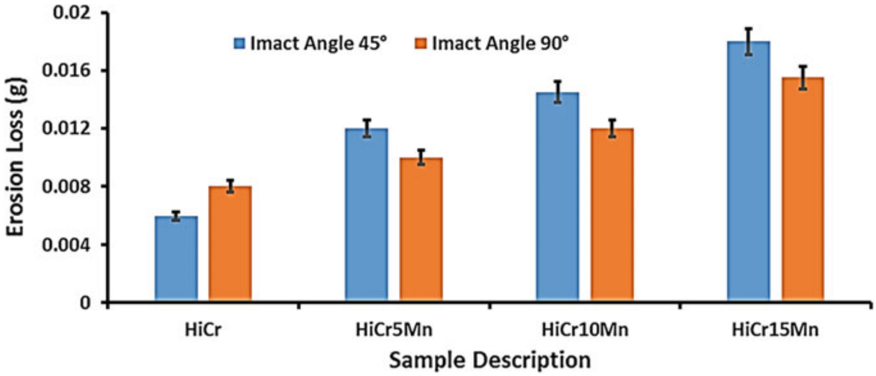

Fig. 25.2 Erosion loss at 45° and 90° impact angles

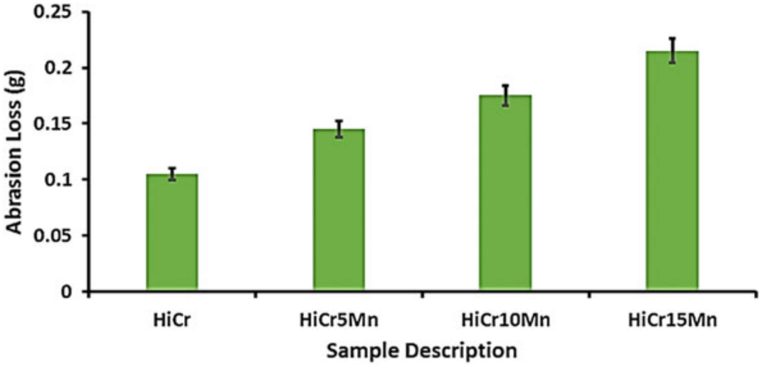

Fig. 25.3 Abrasion loss

with respect to hardness and carbide volume. Thus, it is seen that the addition of manganese content from 5 to 15% lowers the hardness and carbide volume and in turn increases the erosion loss.

The trend in abrasion loss (Fig. 25.3) remains the same like in the case of erosion loss with respect to the manganese addition. Higher the manganese level, higher the abrasion loss and vice versa. The highest abrasion loss is obtained for HiCr15Mn and least for HiCr5Mn as the hardness and carbide volume values support these trends (Table 25.2). The HiCr iron samples exhibit the least, as it is hard and brittle.

25.3.2 *Impact Energy*

It is very well known that higher is the austenite content, lower is the carbide volume and better is its toughness characteristics. In the present case also, higher manganese

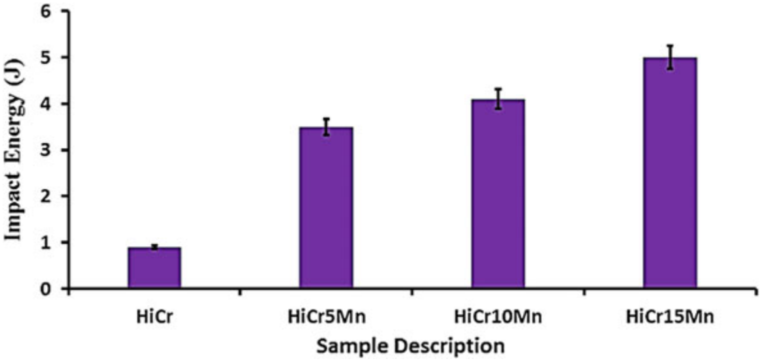

Fig. 25.4 Impact energy

content sample (HiCr15Mn) has yielded higher impact energy and vice versa as can be seen from Fig. 25.4. HiCr iron sample being brittle is showing very low impact energy, and hence, it cannot take any sudden shock. The retained austenite values also give credence to the data, i.e., retained austenite content of HiCr iron is about 10%, whereas HiCr15Mn sample is possessing retained austenite content in the range 50–64%. The results obtained are in line with the published reports [16–18], wherein with increase in manganese content, the wear resistance decreases. But, the impact energy increases due to the higher concentration of manganese present in it which acts as austenite-stabilizing agent. Hence, the reported data and the present results pertaining to the impact energy are in good agreement with each other. Thus, the main objective of obtaining higher impact energy in HiCr iron samples has been achieved by the addition of manganese to chromium iron at three levels. Further, it is envisaged that increase in manganese concentration beyond 15% would yield enhanced impact energy levels, which is not attempted in this work.

The impact energy value obtained in the present work is about 50% better than the value reported [9], whereas the wear property decreases by 20%. Thus, the use of HiCr15Mn seems to be beneficial to withstand the sudden load and at the same time not forgoing wear resistance.

25.3.3 Light Microscopic Features

The light micrographs of HiCr, HiCr5Mn and HiCr10Mn at a magnification of 500× and 1000× are shown in Figs. 25.5 and 25.6, respectively. The microstructure of HiCr iron reveals primarily eutectic carbides of different sizes in a matrix of predominantly martensite. Further, the carbides are distributed non-uniformly in the matrix. The retained austenite content obtained in this case is about 10%. The HiCr5Mn (Fig. 25.5b) shows fine carbides and is more or less uniformly distributed in the matrix of austenite. The occurrence of hexagonal carbides along with fine carbide

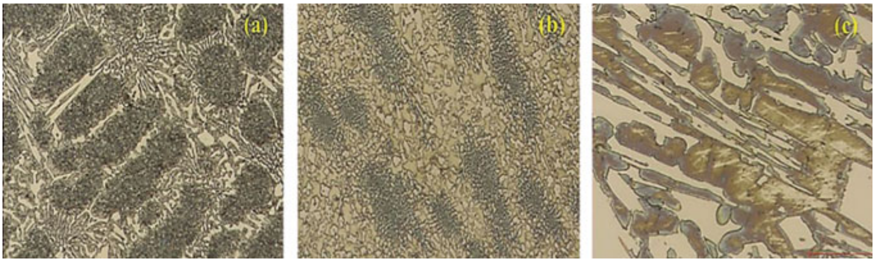

Fig. 25.5 Light microstructure of **a** HiCr, **b** HiCr5Mn and **c** HiCr10Mn samples at a magnification of 500×

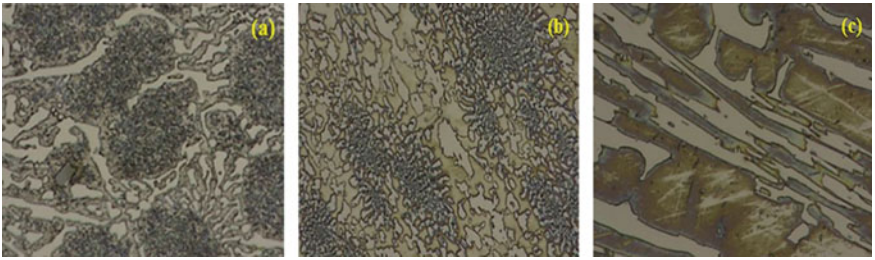

Fig. 25.6 Light microstructure of **a** HiCr, **b** HiCr5Mn and **c** HiCr10Mn samples at a magnification of 1000×

network is observed in the matrix. The addition of 10% manganese (HiCr10Mn) reveals long carbides with hyper-eutectic carbides in the matrix of austenite. Thus, all these micrographs help to discourse the erosion, abrasion and impact energy results in a meaningful way. It is quite logical about the fact that by considering the micrographs of HiCr iron, HiCr5Mn and HiCr10Mn, the carbide morphological features, i.e., size, its distribution and matrices decide its properties. In fact, microstructure dictates the characteristics of HiCr family. The literature reports [19–21] give more information on high chromium manganese irons regarding the impact energy aspects influenced by varied manganese levels, mould type, size as well as the heat treatment effect.

In summary, the results pertaining to the wear and impact properties of HiCr5Mn have yielded best wear resistance compared to HiCr10Mn and HiCr15Mn, whereas HiCr15Mn exhibited highest impact energy level compared to HiCr5Mn and HiCr10Mn. HiCr although has shown very poor impact energy, but its wear resistance is much superior compared to high chromium manganese iron samples. HiCr sample has exhibited brittle behaviour, i.e., the erosion loss is higher at 90° impact angle and lower at 45° impact angle which are in line with the reported predictions in the literature [15]. Thus, in the HiCrMn samples, wear resistance is in between brittle and ductile behaviour in view of the fact that for ductile samples, the wear is the lowest at normal impact angle (90°) and highest at shallow impact angles (30° and 45°)

as reported in [15]. Further, supporting experimental values, viz., hardness, retained austenite content, carbide volume and microstructures compiled, lend credence to the above findings.

Thus, the work may summarize that the dual objectives of obtaining best wear resistance and highest impact energy in high chromium manganese iron samples have been achieved based on different manganese concentrations in high chromium iron.

25.4 Conclusions

Based on the work carried out on HiCrMn iron samples, the following conclusions are drawn:

- HiCr sample shows the best erosion and abrasion resistance, but poor impact resistance in view of its material and metallurgical characteristics.
- HiCr5Mn iron samples exhibits the highest wear resistance compared to HiCr10Mn and Hicr15Mn samples.
- Impact energy of HiCr15Mn shows the highest among the high chromium manganese iron and high chromium iron samples investigated.
- A trade-off between wear and impact properties is desirable by choosing 10% Mn addition to HiCr in industries requiring good wear resistance property coupled with higher impact energy level.

All these test results have been substantiated with the supporting evidences such as hardness, retained austenite and carbide morphological features. It is inferred from this study that the addition of 15% of Mn to chromium iron is preferred for application involving impact load, whereas HiCr is best suited for erosion and abrasion resistance properties.

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