Abstract

High chromium and nickel-chromium white cast irons are currently being extensively used in a wide range of wear resistant applications. But the cost and scarcity of the alloying elements in the aforesaid irons have led to an increasing interest for the development of substitute alloy irons. To ensure optimum selection and usage of these irons, the form of wear encountered and the loading condition must be known. Very often it becomes essential to develop a structure exhibiting necessary wear resistance and sufficient toughness to resist impact loading. Apart from these two factors the corrosion resistance property is also sometimes taken into consideration for applications involving corrosive wear. In general, for maximum wear resistance a high carbon martensitic matrix is mostly desirable. But the workhardenable predominantly austenitic matrix is better than martensitic matrix, under impact-erosion conditions. With regard to toughness and corrosion resistance properties also, this single phase alloyed austenite is most beneficial. From the review of the literature it appears that the addition of manganese can increase the hardenability when added in restricted amounts and beyond that it produces an as-cast austenitic matrix.
because of its strong austenite stabilizing effect. The matrix can then be transformed into martensite embedded with fine carbides by a suitable heat treatment. The addition of copper strengthens the austenite stabilizing capacity of manganese and moreover it increases the corrosion resistance property of cast irons. In wear-resistant cast irons the primary object of chromium addition is to develop a hard, discontinuous plate-like $M_7C_3$ carbides. A partial replacement of chromium appears to be possible by increasing the amount of silicon because it decreases the solid solubility of chromium in the matrix. Thus greater percentage of chromium would be available for the formation of $M_7C_3$ types of carbides. In view of these, the present investigation was conducted on Cr-Mn-Cu white cast irons to evaluate the following aspects:

a) as-cast properties
b) phase transformation on tempering of as cast and as-quenched alloys, arrested cooling and ausaging treatments
c) wear and corrosion behaviour
d) impact toughness

The object of the present investigation has been to optimise the alloy composition and heat treatments which
because of its strong austenite stabilising effect. The matrix can then be transformed into martensite embedded with fine carbides by a suitable heat treatment. The addition of copper strengthens the austenite stabilising capacity of manganese and moreover it increases the corrosion resistance property of cast irons. In wear-resistant cast irons the primary object of chromium addition is to develop a hard, discontinuous plate-like $M_7C_3$ carbides. A partial replacement of chromium appears to be possible by increasing the amount of silicon because it decreases the solid solubility of chromium in the matrix. Thus greater percentage of chromium would be available for the formation of $M_7C_3$ types of carbides. In view of these, the present investigation was conducted on Cr-Mn-Cu white cast irons to evaluate the following aspects:

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The object of the present investigation has been to optimise the alloy composition and heat treatments which
would offer the best combination of wear resistance, impact
toughness and corrosion resistance.

The studies have been made on alloys melted in an
indirect arc furnace. The alloying additions were made in
several steps so that a wide range of alloy compositions was
available. The experimental techniques adopted to investigate
the aforesaid characteristics included, (i) optical, scanning
and transmission electron microscopy (ii) hardness and micro-
hardness measurements (iii) X-ray diffraction analysis
(iv) electron probe microanalysis (v) potentiostatic measure-
ment of corrosion rate (vi) cup-grinding test for wear rate
measurement (vii) charpy impact test for impact toughness
measurement. The principal findings are summarized below.

A) As-cast properties:

The base iron composition has been selected as 2.5%C,
1.7%Si, 6%Cr to obtain a discontinuous $M_7C_3$ type of carbides
in the as-cast condition. With 1.3% Si and 6% Cr the eutectic
carbides are of mixed $M_3C$ and $M_7C_3$ type. But a totally dis-
continuous $M_7C_3$ type carbides are developed with 1.7%Si.
Further addition of silicon has been restricted to avoid the
formation of free graphite and a reduction in hardenability.
The as-cast base alloy microstructures on addition of manganese
and copper reveal fine pearlitic, pearlito-austenitic or a
predominantly austenitic matrix depending on the manganese (1-5%) and copper (1-3%) contents. With low manganese level (≈ 1%) the as cast matrix becomes predominantly fine pearlitic. Austenite is stabilized in the as cast microstructure only when the manganese percentage exceeds some 3%. The austenite stabilizing capacity of manganese is enhanced in presence of copper when the corresponding manganese content exceeds some 3%. A predominantly austenitic matrix is obtained with about 5% Mn and 3% Cu.

B) Phase transformation characteristics:

With an objective to develop a martensitic matrix embedded with fine alloy carbide precipitates, the as-cast and oil-quenched alloys have been subjected to various heat treatments viz. subcritical tempering, arrested cooling treatment and the ausaging or conditioning treatment and the corresponding phase transformation characteristics have been studied extensively.

The oil-quenched (from 1100°C for 2 hours) low manganese and copper alloy reveal localized accicular martensites along-with retained austenite with globular precipitates of alloy carbides. With increase in manganese and copper contents the as-quenched matrix exhibits mostly austenitic with globular carbide precipitates. A sharp rise in hardness values to about
HRC 56-62 have been observed when these oil-quenched alloys are subjected to a tempering treatment at around 500°C. The effect of time and temperature on this tempering treatment was studied by isothermal and isochronal tempering treatments. At low level of manganese, copper has a potent effect on raising the peak hardness value on tempering but at high level of manganese this effect is not prominent. Increasing manganese content retards the transformation during tempering. The martensite plates are prominent in low manganese alloys whereas in high manganese alloys the martensite plates are not detected even at the peak hardness stage due to tempering. The hardness developed on isothermal tempering depends on several phenomena such as precipitation of alloy carbides from the austenitic matrix, subsequent transformation of the matrix into ferrite carbide aggregates and eventual transformation of the alloy depleted matrix into martensite when the tempering is interrupted by air cooling. From the activation energy data analysis it is concluded that during tempering precipitation of chromium carbide occurs and this precipitation precedes the isothermal transformation of austenite into ferrite-carbide aggregates. As the alloy carbides are precipitated from the austenitic matrix, the depletion of alloying elements raises the $M_s$ temperature of the corresponding matrix. So, if the tempering
is interrupted by subsequent air cooling the austenite gets transformed into martensite because still the corresponding critical cooling rate of the matrix remains low. The response of as-cast high manganese and copper austenitic alloys to the tempering treatment at about 500°C are very much similar to that of as-quenched alloy except a second peak hardness value developed at around 800°C. This temperature is probably just above the A₃ temperature of the alloy under investigation. At room temperature the austenitic matrix is supersaturated with alloying elements and just above A₃ temperature in the γ + carbide phase field the alloy carbides are precipitated from the austenitic matrix. This alloy carbides probably give rise to the precipitation strengthening of the austenitic matrix and resulted in the observed rise in hardness.

The arrested cooling treatment was performed by specimens soaking at 1100°C for 2 hours followed by annealing at 930°C for 1 hour and subsequently air cooled. In the arrested cooled condition, the microstructure reveal fine precipitates of alloy carbides embedded in mostly austenitic matrix alongwith traces of martensite. As the arrested cooled alloy is subsequently subjected to a subcritical tempering treatment, the austenitic matrix is gradually replaced by martensite and ferrite carbide aggregate. During soaking at the highest possible austenitising
temperature a equilibrium stage between the austenite and carbide is attained and the subsequent thermal arrest at the comparatively lower temperature results in the depletion of alloying elements in the form of alloy carbide precipitates, but this precipitation is probably not sufficient enough to deplete the matrix of alloying elements, so that the \( M_s \) temperature is considerably raised above room temperature and hence the corresponding matrix remains mostly austenitic even after air cooling.

Another heat treatment often adopted to destabilize the as-cast austenitic matrix is ausaging or conditioning treatment and the same was also accomplished on as-cast austenitic alloys. An aging treatment just above \( A_3 \) temperature (800° - 850°C in case of alloys under investigation) provokes excessive alloy carbide precipitation from the supersaturated as-cast austenitic matrix. The aging at 800°C for 5 hours led to a rise in hardness to HRC 59 with respect to the as cast hardness value of HRC 48 in case of high manganese and copper alloy. Thin foil transmission electron microscopic observation on this ausaged alloy reveals that the hardness evolution is mainly due to precipitation hardening effect of fine complex chromium carbide precipitates. The depletion of alloying elements is not probably sufficient
enough for the matrix to undergo martensitic transformation during cooling down to room temperature after ausaging.

C) Wear and corrosion behaviour:

The wear test was accomplished in two types of sand slurries, one with plain water and another with 5% NaCl solution to provide corrosive action. In plain water slurry the wear rate is more or less dependent on the hardness of the alloy under the test but the corrosion resistance plays an important role for wear in NaCl slurry. The wear loss data exhibit that in both the slurries the as-cast high manganese and copper austenitic alloys perform comparably with standard Ni-hard 4 alloys. This is probably due to the combined effect of work-hardening effect and improved corrosion resistance. The application of scanning electron microscopy in examining the worn out surfaces provides significant details of the predominating mode of metal loss and a qualitative comparison of the extent of erosive and corrosive wear.

p) Impact toughness:

Some of the alloys which have shown better performance in wear test were subjected to impact testing. As expected, the as-cast austenitic high manganese (~5%) and copper (~3%) alloy exhibits the best impact toughness property of all the alloy-heat treatment combinations studied.