AN EXPERIMENTAL STUDY FOR THE IMPROVEMENT OF SOME PROPERTIES OF THE LOCALLY AVAILABLE CAST IRON

BY

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A thesis submitted to the Department of Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dacca, Bangladesh in partial fulfillment of the requirements for the degree of Master of Science in Engineering (Metallurgical).

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CERTIFICATE

This is to certify that this thesis work has been done by the author under the supervision of Dr. M. Ibrahim, Professor and Head, Department of Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dacca and it has not been submitted elsewhere for the award of any other degree or diploma or for publication.

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SYNOPSIS

With the growth of industries in Bangladesh the demand of high duty cast iron is increasing day by day. Cast iron locally available is of inferior quality and does not satisfy the requirement wanted by the industry concern. None of the local foundries maintains any chemical or physical laboratories to check up the qualities of their products. As a result, is inferior in their product.

Some local cast iron were physically and chemically tested. By varying the compositions specially the metalloids, it was found that the good quality cast iron can be produced. It was also found that by adding alloying elements the physical properties of cast iron can be enhanced and may be made suitable for the requirements of different industries concerned.

GLOSSARY OF SYMBOLS

A_3	Upper critical transformation temperature line
C	Carbon
C. E.	Carbon Equivalent value
C. E. F.	Carbon Equivalent value based on Fluidity
Cr	Chromium
Fe-Cr	Ferro-Chrome
Fe_3C	Iron Carbide
Fe-Mn	Ferro-Manganese
Fe-Si	Ferro-Silicon
HN	Hardness
Mn	Manganese
P	Phosphorus
S	Sulphur
Si	Silicon
T.C.	Total Carbon

CHAPTER - I

INTRODUCTION

There are a good number of local foundries who are producing cast iron. Due to the lack of definite specifications of composition and physical properties the quality of the castings is very inferior. None of the foundries producing cast iron is using any alloying elements. Recently high duty cast iron, nodular cast iron, and ductile iron are abundantly produced and used in advanced countries. The aim of this project is to use alloying elements in the form of ferro-silicon, ferro-manganese, ferro-chrome etc. in order to popularize the use of high quality cast iron and to improve its physical and other properties.

CHAPTER - II

LITERATURE REVIEW

CAST IRON

Most metal products originate from castings. Casting is essentially a remelting process, accomplished in a furnace especially designed for the quality and type of metal to be cast.

Cast iron is a general term applied to a wide range of iron-carbon-silicon alloys in combination with smaller percentages of several other elements. It is an iron containing so much carbon, or its equivalent, that is not malleable. The carbon content is usually between 2.0 to 4.0%. Quite obviously, cast iron has a wide range of properties, since small percentage variations in its composing elements may cause considerable change. Cast iron should not be thought of as a metal containing a single element, but rather as one with at least six elements in its composition. All cast irons contain iron, carbon, silicon, manganese, phosphorus and sulphur. The silicon content is 0.90 to 2.80%, manganese from 0.50 to 1.00%, phosphorus from 0.07 to 0.60% and sulphur from 0.05 to 0.10%.

CLASSIFICATIONS

There are four major kinds of cast iron. These are

(1) White cast iron

(2) Malleable cast iron

(3) Grey cast iron

and (4) Ductile or Nodular cast iron

(1) White cast iron is so called because the fracture has a light colour. White cast iron has no free graphite; all of its carbon is combined as cementite or as pearlite -

a laminated structure of cementite and ferrite.Because it has no free carbon, white cast iron is hard, brittle, wear resistant, non-machinable, and impractical to weld.

(2) Malleable cast iron is made by heating white cast iron for a long time below the critical temperature (1700°F for 50 hours). Most of the cementite (iron carbide) then decomposes, leaving a structure of ferrite and nodules of graphite. Ferrite becomes the continuous phase and, since ferrite is ductile, the alloy is ductile. The impact strength of malleable iron is low, but higher than that of white or gray cast iron. Malleable cast iron is used for making machine parts such as axles and steering gear linkages, and for hardware. When welded, malleable iron tends to develop a very brittle layer of carbon-free iron.

The normal base structure of malleable iron is ferrite; for which this metal is sometimes called "ferritic malleable iron". By a variation in the processing, but with the same chemical composition, an appreciable amount of combined carbon can be developed in the form of pearlite, martensite, and spherical carbides distributed through the ferrite. Since pearlite is the dominant constituent in this type of malleable iron, the term "pearlitic malleable iron" is used. This leads us to a generalized statement of the fact that the structures of cast irons of the same chemical composition may vary greatly. A specific carbon-iron-silicon alloy can be either white cast iron, malleable iron and gray cast iron, depending on the rate of cooling.

(3) Gray cast iron which contains carbon in the form of graphite flakes. The graphite is embedded in a matrix of either ferrite (weakest and softest), or pearlite and ferrite

mixed (intermediate strength) or pearlite (strongest). The nature of the matrix depends mainly upon the chemical composition of the iron. The greater the carbon and silicon content, the softer the iron and more graphitic it tends to be. The carbon in solution, as in pearlite, is often referred to as combined carbon. The carbon in graphitic form is called free carbon. The ratio of combined carbon to free carbon greatly effects mechanical properties of the alloy. The lower the ratio, the lower the hardness. Gray cast iron has a dark fracture resulting from the free graphite.

(4) Ductile or Nodular cast iron is produced by addition of magnesium and/or cerium. These alloying elements cause the carbon to precipitate as tiny balls or spheres of graphite within a matrix that is basically pearlite, although usually some ferrite and some free cementite are also present. These higher priced irons possess higher tensile strength and greater ductility than the plain gray cast irons. They also have excellent machinability, shock resistance, thermal shock resistance, and rigidity.

EFFECTS OF CHEMICAL ELEMENTS ON CAST IRON

Most commercial cast iron castings contain from 2.70 to 3.60% total carbon. This carbon may exist as free carbon (graphite); as combined carbon(cementite) as found in free massive cementite, and in the cementite lamellae of pearlite; or in solution in molten iron and in austenite.

Graphitic carbon is soft and not tenacious, and in gray iron is found as black flakes.

Cementite is very hard and possesses little ductility. Under certain conditions it may be decomposed into iron and carbon (graphite).

At sub-critical temperatures iron can hold only a few hundredths of a percent of carbon in solution. This solubility increases rather abruptly to about 0.85% or less at the A_3 transformation temperature (approximately 1350°F, depending on composition) and the solubility increases further as the temperature is raised.

The structure of a given cast iron depends largely on the amount, size and distribution of the various forms of carbon. The amount depends both on the percentage in the charged metal and on the melting process. The size and distribution of the various forms depend on the temperature, time and other factors involved in the melting process, and on the rate of cooling of the metal from the molten condition, as well as on the composition and on the presence of inoculants.

SILICON

Because of the relation between the carbon and silicon contents, silicon is a very important element in the metallurgy of gray iron. Silicon promotes the decomposition of the combined carbon (in pearlite and massive cementite) to ferrite and graphite. Irons that contain no silicon usually have a white (cementite) fracture. In changing white iron to gray, silicon makes commercial production of gray iron practicable. For strong irons, just enough silicon should be used to ensure decomposition of all massive cementite, but not enough to cause decomposition of the cementite in the pearlite. Excessive decomposition of the pearlite to graphite and ferrite, gives a weak, soft metal.

Silicon also reduces the carbon content of the eutectic by about 0.30% for each percent of silicon. This means that higher-silicon pig irons are often lower in carbon than lower-silicon irons. It is easier to produce low-carbon cupola metal with

higher silicon contents. Silicon raises the eutectic temperature slightly.

An increase in silicon content lowers the percentage of carbon in the eutectoid approximately 0.07% for each percent of silicon.

MANGANESE

Manganese in small amounts does not have an appreciable effect, but in amounts over 0.5% it combines with sulphur to form a manganese sulphide. The mixture has a low specific gravity and is eliminated from the metal with the slag. It acts as a deoxidizer as well as a purifier and increases the fluidity, strength, and hardness of iron. If the percentage is increased appreciably over the usual amounts, it will promote the formation of combined carbon and rapidly increase the hardness of the iron.

SULPHUR

Sulphur occurs largely as manganese sulphide, and rarely as iron sulphide. Under proper operating conditions, sulphur does not seem to exert harmful effects on grey iron in amounts upto 0.16 or 0.18%, provided manganese is present in amounts sufficient to prevent chill. In the absence of enough manganese, sulphur has a marked stabilizing action on the cementite and promotes chill. It promotes the formation of combined carbon, with accompanying hardness, and causes the iron to lose fluidity, with resultant blow-holes.

PHOSPHORUS

Phosphorus increases the fluidity of the molten metal and lowers the melting temperature. For this reason phosphorus upto 1% is used both in small castings and in

those having thin sections. Large castings should have low phosphorus content since additional fluidity in the iron is not required.

Phosphorus also forms a constituent known as "steadite", a mixture of iron and phosphide, which is hard, brittle, and of rather low melting point. Steadite appears as a light, structureless area under the microscope but may appear as a network if sufficient phosphorus is present.

THE CARBON EQUIVALENT VALUE

The cast irons contain several constituents. The presence of these modifies the compositions and temperatures at which the various reactions occur. Thus the solid solubility of carbon in iron is affected by the presence of silicon, the limiting solubility being about 1.5 instead of 2 percent, in the presence of 2 percent of silicon. Again, in pure iron-carbon alloys containing, when molten, more than 4.3 percent of carbon (hyper-eutectic irons), graphite gradually separates from the melt during cooling to the temperature of solidification, being seen as a layer on the surface of the metal after tapping. This graphite, known as 'kish' by the foundryman, arises from the separation from the melt of Fe_3C, and its simultaneous decomposition into iron and carbon. The amount of carbon which can be retained in solution in the molten state is reduced by the presence both of silicon and phosphorus; while the temperature of solidification of the eutectic may also vary. To determine whether graphite will separate from molten iron, it is thus necessary to apply a correction to the actual carbon content of the iron. The formula most generally used to determine the 'carbon equivalent' of the iron is :

Carbon Equivalent (C.E.)[1] =

$$\text{Total Carbon percent} + \frac{\text{Silicon percent} + \text{Phosphorus percent}}{3}$$

Thus the carbon equivalent of an iron containing 3.5 percent carbon, 1.5 percent silicon and 1.5 percent phosphorus is 4.5 percent, showing that graphite will separate as kish before solidification. Irons with which this effect is found give rise to weak and porous castings. It should be noted, however, that light castings — i.e. those ranging from 1/8 inch to about 3/8 inch in thickness, in which the surface area is large in relation to the weight — are more likely to crack when of low than of high C.E. value[2]. For castings of 1/4 inch and less in thickness, C.E. values should be kept at or about 4.6.

The relation of the carbon equivalent value to the fluidity of molten cast iron has been studied by Evans[3]. Using the commonly accepted formula for carbon equivalent, C.E. = T.C + (Si+P)/3, the fluidity of hypo-eutectic cast irons at any temperature increases with carbon equivalent. When the C.E. value is exceeded, fluidity continues to increase until, at some critical C.E. value, it is rapidly reduced. The usual C.E. value is not entirely satisfactory when considering fluidity and solidification temperatures, and a new carbon equivalent value based on fluidity (CEF) and calculated from the formula :

CEF=T.C.+Si/3 + P/2 was evolved. Fluidity varies directly with CEF values of irons of similar phosphorus contents at similar temperatures. All irons of similar CEF value upto 4.74 at similar temperature have the same fluidity. The CEF value of irons showing the maximum fluidity at any temperature varies with phosphorus content. The CEF value applies only upto 4.74 in low-phosphorus irons or about 5.0 in phosphoric irons. In practice, irons with CEF values upto 4.70 can be used satisfactorily.

NORMAL DEFECTS OF COMMERCIAL CAST IRON

Casting defects are usually not an accident; they occur because some step in the manufacturing process is not properly controlled. Melting, casting, and solidification of metal comprise many intricate operations, and perfect control is impossible; it is not surprising that castings are afflicted with a greater variety of defects than the products of other fabricating methods. It is important to producers, designers, consumers, and engineers that such defects as do occur in castings be recognized and their origin and control be properly understood.

SURFACE IMPERFECTIONS

Surfaces of castings are sometimes rough or pebbly because the molding sand is too coarse, or the pouring temperature of the metal too high. Sometimes penetration of metal between and around sand grains is a serious problem. Surface reactions sometimes cause sub-surface porosity or pinholes.

BUCKLES AND SCABS

These are defects which, when present, usually appear in cope surfaces of castings. A buckle is a relatively extensive overlapping of metal; that is, a layer of metal is separated from the casting proper by a layer of sand which has sheared from the cope surface. Buckles and scabs are alike in appearance, the only difference being that scabs are relatively small. Usually these defects are caused by cope surfaces becoming preheated too rapidly by radiation from the rising metal. The non-uniform expansion of sand at and immediately behind the cope surface, caused by rapid preheating, develops stresses sufficient to shear layers of sand from the cope

surface. These sheared layers then extended into the mold cavity and are surrounded by rising metal. The development of high gas pressure in a region of too low permeability can also produce excessive stresses in the cope and cause scabbing. Often cope surfaces preheated by metal actually rain sand down upon the rising liquid, causing sand spots. Buckles and scabs may be prevented by using sands with high hot-plasticity or low expansion characteristics, like chromite, or by using an expansion buffer such as wood flour mixed with sand; the wood flour burns and leaves space for surface sand grains to expand without shearing from the mold. The problem may also be minimized by rapidly filling the mold.

Surface Laps, Seams, and cold shots result from pouring metal too cold. Usually these imperfections occur in castings with relatively light sections where two surfaces of flowing metal meet and do not fuse properly; they can be distinguished by clean appearance and lack of sand or other impurity to account for poor surface finish. In cold shots, small shotlike spheres of metal are almost completely distinct from the casting. These defects can usually be prevented by using higher pouring temperatures or by using streamlined sprues to give smoother flow, or a combination of these expedients.

Entrapped air, dross, and slag inclusions are usually found on the cope surfaces of castings. Entrapped air is recognized as small, internally oxidized holes just beneath the cope surface. Dross and slag inclusions are oxides or other reaction products of the metal being cast (or the slag may be other non-metallics from the melting operation). These defects can be caused by improper control of (1) melting

and pouring, (2) gating design, or (3) molding sand practice. To prevent slag or dross inclusions entering from the ladle, they should be skimmed before pouring, or teapot or bottom-pouring ladles should be used. Pouring basins should be employed so that any slag or dross entering from the ladle will rise and not pass into the runner system. The runner system itself should be designed to exert additional skimming action on the flowing metal. Streamlining the runner system will minimize any tendency to entrap air or form dross or slag inclusions during the mold-filling operation. Careful control of mold permeability and gas content reduce the danger of entrapping air (or mold gases) and minimize any tendency to form dross from mold-metal reactions.

Sand spots are caused by the metal washing particles from the runner system or mold walls. They appear as small irregularly shaped depressions in the finished casting and may be spaced randomly or gathered in clusters where the impurities have been collected at one or more vortices developed by the metal. Sand spots sink or float depending on the density of the metal cast; they may also become entrapped by growing dendrites along the sidewalls of the casting. Excess turbulence in the gating system, "Spurting" of metal into the mold, and poor molding sand properties are causes of this defect.

DEFECTS RESULTING FROM INCOMPLETE FEEDING

It is not widely appreciated that many of the more prevalent defects of castings result directly from solidification shrinkage; often the blame is laid erroneously elsewhere. Shrinkage of castings is noticeable in many forms.

In fig. 1 are shown typical defects due to shrinkage. The most prevalent type is localized cavities which appear at unfed hot spots in the castings. Whenever feeding is grossly inadequate, internal unsoundness is usually indicated by some external imperfection: either the wall punctures or deforms by dishing at the weakest point, or elongated wormholes appear at the base of the riser, at internal angles, or sometimes on cope surfaces. Sometimes shrinkage defects resemble collections of dross where cope surfaces are wrinkled and drawn inward. Often small voids which appear to be pinholes are really caused by imperfect feeding. If unusual surface imperfections, or depressed regions on cope and upper surfaces, are encountered, it is wise to consider shrinkage as a possible cause. Gross shrinkage, center-line shrinkage, and microporosity are internal manifestations of solidification shrinkage. Gross shrinkage is a localized cavity most likely to occur in isolated sections called hot spots: i.e., the last regions of the cavity to solidify. Centre-line shrinkage is a narrow, more or less continuous void sometimes found along the centre line of castings with extensive plate-like sections. The shrinkage may actually be in a continuous line or may appear as a line of fine shrinkage chevrons with the tips pointing away from the main direction of feeding.

A less obvious defect resulting from imperfect feeding is internal hot tearing. Internal hot tears are radially disposed discontinuities inside castings, more commonly steel castings, which can be disclosed non-destructively only by radiography. The discontinuities resemble external hot tears, except that they are

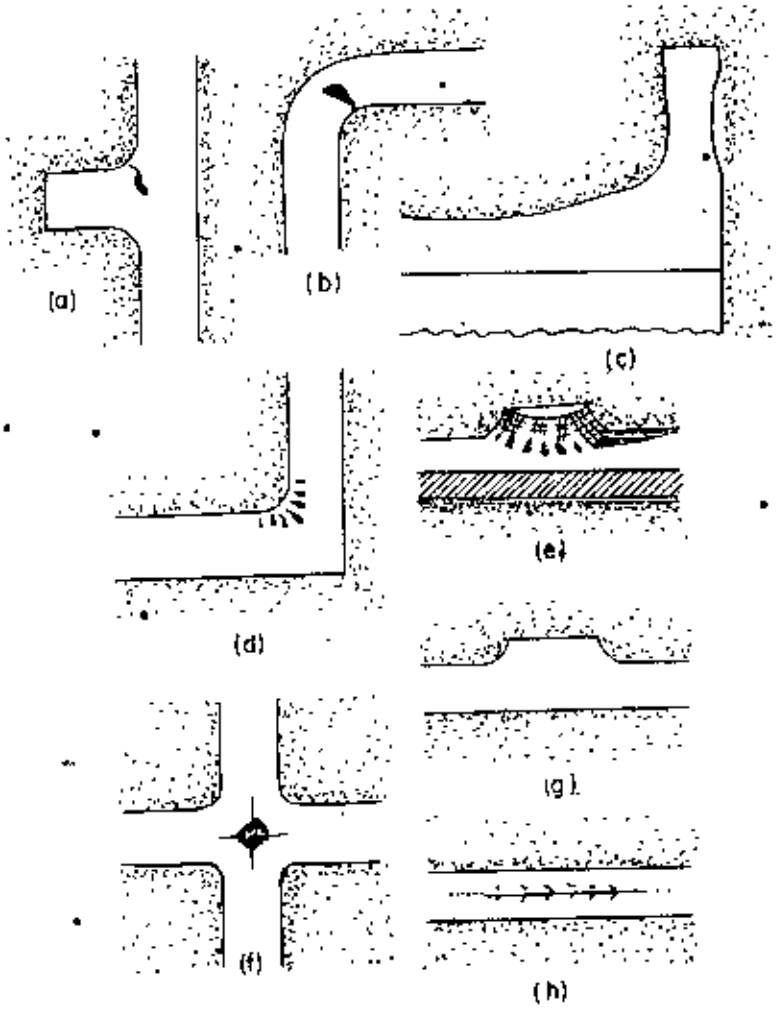

FIG. 1 TYPICAL DEFECTS RESULTING FROM SHRINKAGE

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radial rather than roughly parallel (Fig. 2). The tears emanate from a low-density area, giving the radiograph an octopus-like appearance. It is usual to associate any form of hot tears with contraction stresses and to correct the fault by measures to give mold relief. The cure for internal hot tears is improved feedings; it has been found very difficult to tear a sound casting internally by stresses developed in normal casting procedure.

GAS POROSITY

Voids in a well-fed section must be caused by gas. Rounded voids with smooth walls are generally due to gas, while angular voids, perhaps with dendrite arms protruding into voids, are usually caused by imperfect feeding. Often, as in the case of the fine microporosity seen occasionally in non-ferrous castings, the distinction is not simple, and both gas content and metal shrinkage must be regarded with suspicion when such microporosity is observed.

EXTERNAL HOT TEARS, COLD CRACKS AND WARPAGE

Unless castings can contract relatively freely in the mold as they cool from the temperature of solidification to room temperature, external hot tears, cold cracks, or warpage may occur. These defects result from (1) stresses developed in the casting by resistance of the mold, Fig. 3a, 3b or (2) resistance of thinner parts of the casting to normal contraction upon them of heavier sections which cool more slowly, Fig. 3c, 3d. External hot tears are jagged, roughly parallel tears generally visible to the unaided eye but usually found by X-ray, magnetic powder, or Zyglo testing; tears are often deep and are formed by surface rupture near the temperature at which the casting is completely solid. The appearance of an external hot tear on a radiographic film is shown in Fig. 2 — 2a.

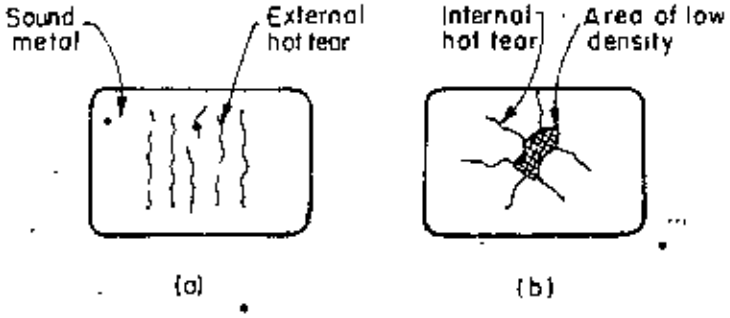


FIG. 2 APPEARANCE OF EXTERNAL AND INTERNAL HOT TEARS ON RADIOGRAPHIC FILM.

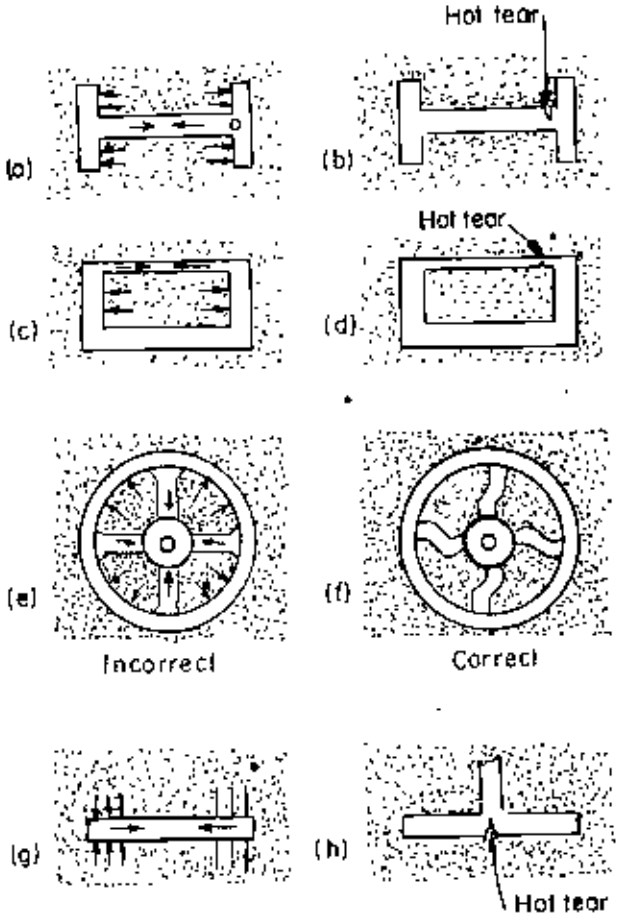


FIG. 3 HINDERED CONTRACTION IN SOLIDIFYING CASTINGS

Cold cracks are somewhat similar to external hot tears. Usually a cold crack is continuous, less jagged than hot tears, and forms in the cold casting from stresses imposed during cooling or heat treating.

Warpage is misalignment caused by stresses set up by conditions of cooling, improper design, or mold resistance; warpage does not involve any discontinuities such as is the case with cold cracks and hot tears.

ALLOY CAST IRONS

They are numerous and have varied properties. By proper alloying, one or more of the following properties may be improved: tensile strength, strength at elevated temperature, machinability, wear resistance, and many others. Alloy combinations called inoculants cause the graphite to separate in shapes that give the iron higher mechanical properties. The inoculant forms nuclei for separation of the graphite as the cast metal solidifies, resulting in fine and well distributed graphite instead of larger and weakening graphite flakes in the more common cast iron.

Alloy cast iron is cast iron that contains a specially added element, or elements, in sufficient amount to produce a measurable modification of the physical and mechanical properties of the iron in the section under consideration. Silicon, manganese, sulphur and phosphorus, as normally obtained from raw materials, are not considered as alloy additions.

EFFECTS OF ALLOYING ELEMENTS

Alloying elements are added to cast iron for improvement of mechanical properties or for development of a special characteristic; such as resistance to corrosion, heat or wear. The alloying elements that have important effects on the structure of the metal, should be added to well-made cast irons in order to improve them. Such additions to poorly made cast irons are not economical. Additions of alloying elements have a marked effect on graphitization. Some alloying elements will accelerate graphitization while others will retard this transformation. The control

of graphitization is one of the important reasons for the use of alloying elements in cast iron. The elements copper, nickel, aluminium, titanium, vanadium, molybdenum, chromium and magnesium are added to provide special properties to certain grades.

CHAPTER - III

RAWMATERIALS AND EFFECTS OF FERRO-ALLOYS

PIG IRON USED:

1. Grade 1

Percentages of silicon	-	2.65% (before casting)
Percentages of silicon	-	1.84% (after casting)
Percentages of manganese	-	0.77% (before casting)
Percentages of manganese	-	0.58% (after casting)

2. Grade 2

Percentages of silicon	-	1.55% (before casting)
Percentages of silicon	-	1.16% (after casting)
Percentages of manganese	-	0.69% (before casting)
Percentages of manganese	-	0.59% (after casting)

FERRO-ALLOYS USED:

Percentages of silicon, manganese and chromium in Fe-Si, Fe-Mn and Fe-Cr are given below:

3. Fe-Si	-	Si - 65%
	-	Fe - 35%
4. Fe-Mn	-	Mn - 70%
	-	Fe - 30%
5. Fe-Cr	-	Cr - 42%
	-	Fe - 58%

Grade 1 - Pig iron used from the Met. Engg. Department.

Grade 2 - Pig iron used from "Essential Products", Dacca.

FERRO-ALLOYS

There is a considerable number of various ferro-alloys and alloying metals in the iron and steel production. As far as the volume of production is concerned, the leading role among the ferro-alloys belongs to the alloys of manganese and silicon. Each of these alloys or groups of alloys possesses certain foundry characteristics that necessitate giving them special consideration beyond that possible in a discussion of general principles. The common ferro alloys are ferro-silicon, ferro-manganese, ferro-chrome, etc.

FERRO-SILICON

Ferro-silicon an alloy of iron and silicon used as an alloying element in the experiment contained 65% Si, the remainder being iron. If silicon is low in the cast iron, all the carbon is present as Fe_3C. Silicon increases the instability of iron carbide; in most cast irons, which contain considerable silicon, some of the iron carbide dissociates into iron and carbon (graphite). By regulating the silicon content and other variables, such as the size of the section and the cooling rate, the amount of dissociation of the carbide can be controlled. Silicon is a very important element in the metallurgy of gray iron. Silicon promotes the decomposition of the combined carbon (in pearlitic and massive cementite) to ferrite and graphite. Silicon is a good graphitizer.

FERRO-MANGANESE

Ferro-manganese used as an alloying element in this work was an alloy of iron and manganese containing manganese upto 70%, the remainder being iron. Manganese may be present in the carbide phase in gray iron or may occur as manganese sulphide in small slate-coloured inclusions throughout the metal. About 0.3% more Mn than is required theoretically for combination with sulphur (which is 55/32 times the sulphur percentage) is necessary for mitigating the effects of sulphur. Mn increases the hardness and strength.

FERRO-CHROME

Ferro-chrome is an alloy of iron and chromium also used in this work containing 42% Cr, the balance being iron. Chromium, is a powerful carbide former, increases the combined carbon and intensifies the chilling properties of cast iron. When added to cast iron, chromium forms complex iron chromium carbides, which are more stable than Fe_3C. The chromium irons graphitize less readily than plain cast iron.

Because of the effect of chromium on structure, small amounts of chromium increase strength, hardness, depth of chill, and resistance to heat and wear, but decrease machinability. For general improvement in mechanical properties, 0.15 to 1.00% chromium is used with or without other alloying elements. To ill

elements. To illustrate carbide-forming characteristics of chromium additions, the following effects on a soft gray iron may be cited[4].

Percentage of Chromium	Structure
0	Ferrite and coarse graphite
0.3	Less ferrite, some pearlite and finer graphite
1	Fine graphite, pearlite and small carbide
3	Disappearance of graphite
5	Much massive carbide
10 to 30 ...	Fine carbide

Chromium strengthens ferrite slightly compared to its strong effect on increasing hardenability in those alloys which are hardenable by heat-treatment.

CHAPTER - IV

DETAILS OF EXPERIMENTS

INVESTIGATION OF A FEW LOCALLY MADE CASTINGS - THEIR COMPOSITIONS, MICRO-STRUCTURES AND PHYSICAL PROPERTIES

Many complaints have been received from the local foundries about the quality of the cast iron they produce. A few investigations have so far been made from the local foundries "Essential Products", Bayeer Bazar, Dacca and "People's Ceramics", Tongi, Dacca. It has been observed that the quality of the cast irons they produce are not good. A few castings were made in the Foundry Shop of our Department. Their hardness values were taken, chemical analysis done and their structures were also seen under the microscope. It was observed that their quality with respect to their other properties were inferior.

No analysis was conducted in these foundries. After analyzing the quantities of the different metalloids in pig iron before and after casting in our departmental laboratory, it was observed that the metalloids which had great effect in controlling the different properties and structure of cast iron were less in quantity. So attempts were made to increase the amounts of these metalloids by adding different alloying elements to cast iron in the molten condition. The alloying materials containing metalloids used in our research works are ferro-silicon and ferro-manganese. The percentages of Si and Mn were varied in different castings by controlling the amount of the respective alloy additions. Their properties and structures were studied. The alloying element ferro-chrome

was used to vary the percentage of chromium. Structural, physical and other properties of cast iron were found to be improved due to the addition of these alloying elements. Accordingly, good quality cast products by melting pig irons were possible to be produced.

EXPERIMENTS TO ENHANCE THE PROPERTIES BY VARYING THE COMPOSITIONS OF METALLOIDS AND ALLOYING ELEMENTS DURING CASTING

For melting pig iron, the crucible furnace of the foundry shop was used. The furnace was not in a good working condition. The linings of the furnace were done by the refractory bricks. The gas and air valves were adjusted so that a proper air and gas mixture was maintained to raise the temperature. The graphite crucible was placed at the centre of the furnace. Coke of different size was put around the crucible.

Samples from imported pig iron were prepared to see the microstructure under a microscope. Thick and elongated graphite flakes were observed under the microscope. Ten kg of pig iron were taken for each individual casting. Microstructures of cast irons were studied without alloy additions. Graphite flakes were observed to be smaller in the cast iron than those in the pig iron from which they were obtained before melting. After annealing at a temperature of 850°C, the structures of the graphite flakes were observed and seen to be thick and elongated than the structures seen before annealing. Castings were conducted in three different molds, keeping the molds in the same mold box. Pouring temperatures were varied.

It was observed that the graphite flakes differ due to the rate of cooling and differences in pouring temperature.

Decision were taken to make castings in separate mold boxes. The percentages of silicon in pig iron before and after castings were ascertained. The percentages of silicon in pig iron before and after castings were found to be 2.65% (before) and 1.84% (after) and 1.55% (before) and 1.16% (after) respectively. The ferro-silicon was found to have 65% Si. After proper ferro-silicon addition a few castings were made. It was observed that the graphite flakes increased in number and became more elongated than in the previous castings. After annealing the samples it was found that the graphite flakes increased in size than that in the castings without annealing. The samples were seen under a microscope before and after etching. Graphite flakes and ferrite were observed before etching, and graphite flakes, ferrite and pearlite were observed after etching.

The percentages of manganese were found to be 0.77% (before) and 0.58% (after) and 0.69% (before) and 0.59% (after) respectively before and after castings. A few castings were performed with the addition of ferro-manganese. The percentage was varied and changes of properties were observed. The structures were observed under a microscope. In this case fine pearlitic structure with a few lines of cementite was seen. Ferrite and graphite flakes were also detected in the micro-structure study.

A few castings were prepared with the addition of ferro-chromium. Chromium was used in the cast iron as a new addition. The percentages of chromium were varied from 0.3% to 1.22%. The samples were seen under a microscope. Pearlitic structure with small graphite flakes was the result. Carbides appeared to be more in quantity than in the samples with ferro-manganese addition. When the percentages of chromium was increased it was found that each structure consisted of pearlite, carbides and ledeburite. Ledeburite was found to be prominent in each structure and hardness also increased than the previous samples had with low chromium.

CHAPTER - V

RESULTS AND DISCUSSIONS

RESULTS:

ADDITION OF FERRO-SILICON IN PIG IRON

The ferro-silicon used in the experiments contain silicon = 65%

After chemical analysis, percentage of silicon in the pig iron used in the experiments were found as follows:

Before casting = 2.65%

After casting = 1.84%

So, loss of silicon due to casting = 30% (approx.)

Total pig iron taken in each individual casting = 10,000 gram (10 kg)

After casting, amount of silicon in 10 kg of pig iron = 10,000 x 0.0184 = 184 gm

Fe-Si at the rate of 1% of the weight of pig iron used was added in the molten bath to raise the percentage of silicon upto 2.5% :

Total silicon present in the molten bath containing 10 kg pig iron

= (100 x 0.65 + 184) = (65 + 184) gm = 249 gm = 250 gm (approx.)

Percentage of silicon actually found after Fe-Si alloy addition on chemical analysis in the pig iron = 2.4% instead of 2.5% silicon.

SAMPLES FROM "ESSENTIAL PRODUCTS", DACCA

After chemical analysis, percentage of silicon, in the pig iron of "Essential Products" used in the experiment were found as follows:

Before casting = 1.55%

After casting = 1.16%

So, loss of silicon due to casting = 25% (approx.)

After casting, amount of silicon in 10 kg of pig iron = 10,000 × 0.0116 = 116 gm

Enough silicon in the form of Fe-Si used to increase the percentage of silicon upto 2.03% :

Silicon present in the casting (in 10,000 gm molten iron) = 116 gm

Total silicon required in the casting (after addition) = 203 gm

So, silicon to be added = 87 gm

Therefore, Fe-Si (containing 65% Si) required = 134.12 gm

Fe-Si required including the 25% loss = 134.12 × 1.25 = 167.54 gm

Percentage of silicon actually found after Fe-Si additions = 1.76%

ADDITION OF FERRO-MANGANESE IN PIG IRON

The ferro-manganese used in the experiments contain manganese = 70%

After chemical analysis percentage of manganese in the pig iron used in the experiments were found as follows:

Before casting = 0.77%

After casting = 0.58%

So, loss of manganese due to casting = 25% (approx.)

Manganese was used to increase the percentage of Mn from 0.58% to 1.0%

Manganese present after casting = 58 gm
(In 10,000 gm molten iron)

Manganese required in the casting = 100 gm
(after addition)

So, Mn to be added in the molten bath = 42 gm

Therefore, Fe-Mn required = 42/.7 = 60 gm

Fe-Mn required including the 25% loss = 1.25 x 60 = 75 gm

By analysis, the percentage of manganese was found to be 0.9% instead of 1% Mn

After one casting, the molten metal of 10,000 gm iron reduced to some extent. It was considered to be 9,000 gm

Now 40 gm Fe-Mn was added to 9,000 gm molten metal keeping the crucible in the furnace.

Therefore, Mn in 40 gm Fe-Mn = 40 x 0.7 = 28 gm

Considering the 25% loss

Therefore, Mn required = 28 x 0.75 = 21 gm

So, total Mn were increased in 9,000 gm molten bath of iron = (90+21)= 111 gm

= 1.23% Mn

After chemical analysis the percentage of Mn actually found in the pig iron = 1.05%

For 1.5% Mn in the product:

Presence of Mn in the molten bath of 10,000 gm iron = 50 gm

Total Mn required in the casting after addition = 150 gm

Therefore, Mn to be added = 92 gm

So, Fe-Mn (containing 70% Mn) required = 131.4 gm

Fe-Mn required including the 25% loss = (1.25 x 131.4) gm = 164.25 gm

After chemical analysis, the percentage of Mn actually found to be 1.34% in th
pig iron.

After two castings, the molten metal of 10,000 gm iron reduced to some extent. It was considered to be 8,000 gm

Now in molten bath of 10,000 gm iron (after addition) Mn present = 150 gm

So, in molten bath of 8,000 gm iron (after addition) Mn present = 120 gm

For 2% Mn in the product:

Now, Mn was increased from 1.5% to 2% in the molten bath of the crucible.

Therefore, Mn required for 8,000 gm molten iron (after addition) = 160 gm

Mn to be added = (160-120)= 40 gm

So, Fe-Mn required (containing 70% Mn) = 40/.7 = 57.14 gm

Therefore, Fe-Mn required including the 25% loss = 57.14 x 1.25=71.37 gm=72 gm (approx.)

By analysis, the percentage of Mn actually found to be 1.7%

ADDITION OF FERRO-CHROME IN PIG IRON

The ferro-chrome used in the experiments contain 42% chromium.

For 0.5% Cr in the product:

42 gm of Cr present in 100 gm Fe-Cr

So, 50 gm of Cr present in 119.04 gm Fe-Cr

So, remaining iron = (119.04-50)= 69.04 gm

For 0.5% Cr

In 10,000 gm iron Cr required = 50 gm

So, for 69.04 gm iron Cr required = 0.345 gm

Again 0.345 gm Cr is contained in 0.90 gm Fe-Cr

Therefore, total Fe-Cr required in 10,000 gm iron = (119.04+0.90)= 119.94 gm
= 120 gm (approx.)

After chemical analysis percentage of Cr in the iron was found to be 0.3% instead of 0.5% Cr

After a few castings, the molten metal of 10,000 gm iron reduced to some extent in quantity, and it was considered to be 7,000 gm

For 0.75% Cr in the product :

42 gm Cr present in 100 gm Fe-Cr

Therefore, 75 gm Cr present in 178.5 gm Fe-Cr

So, remaining iron = (178.5-75)= 103.5 gm

In 10,000 gm of iron,Cr required (after addition) = 0.75 gm

So, in 103.5 gm iron,Cr required = 0.776 gm

Now 0.776 gm Cr contained in 1.8 gm = 2 gm (approx.) Fe-Cr

Therefore, total Fe-Cr required = (178.5+2) = 180.5 gm

In the molten bath of the crucible, the required Fe-Cr to raise the percentage of Cr from 0.5% to 0.75% = (180.5-120) = 60.5 gm Fe-Cr

Therefore, Fe-Cr required for 7,000 gm iron = 42.35 gm

But we added 60.5 gm Fe-Cr

Therefore, exact percentage of Cr found = (0.75 x 60.5) / 42.35 = 1.07% Cr

After chemical analysis the percentage of Cr actually found to be 0.55%

For 1.5% Cr in the product :

42 gm of Cr present in 100 gm Fe-Cr

Therefore, 150 gm of Cr present in 357.14 Fe-Cr
(after addition)

So, remaining iron = (357.14 - 150) = 207.14 gm iron

In 10,000 gm of iron Cr required (after addition) = 150 gm

So, for 207.14 gm iron, Cr required = 3.10 gm

Therefore, 3.10 gm of Cr contained in 7.38 gm = 7.4 gm Fe-Cr (approx.)

So, total Fe-Cr required = (357.14+7.4) gm = 364.54 gm Fe-Cr

After chemical analysis the percentage of Cr actually found after addition in the pig iron = 1.01%

For 2% Cr in the product:

After a few castings the molten metal of 10,000 gm of iron reduced to some extent in quantity and it was considered to be 7,000 gm

42 gm of Cr present in 100 gm Fe-Cr

So, 200 gm of Cr present in 476.19 gm Fe-Cr

Therefore, remaining iron = (476.19-200) = 276.19 gm

In, 10,000 gm of iron, Cr required (after addition) = 200 gm

So, for 276.19 gm of iron, Cr required (after addition) = 5.52 gm

Now, 42 gm of Cr present in 100 gm Fe-Cr

Therefore, 5.52 gm of Cr contains = 13.14 gm Fe-Cr

Therefore, total Fe-Cr required (after addition) = (476.19+13.14) = 489.33 gm

Therefore, the required Fe-Cr to raise the percentage of Cr from 1.5 to 2% Cr

In 10,000 gm iron = (489.33-364.54) = 124.79 gm

So, the exact Fe-Cr required for 7,000 gm molten iron = 87.35 gm

After analysis the percentage actually found to be 1.22% Cr

ROCKWELL HARDNESS OF CAST IRON AS FOUND IN 'B' SCALE

(Load 100 kg, ball dia 1/16")

Hardness of cast iron

Sample No.	Position of the Sample	Hardness
1.	Centre	91.0
	Side	94.8
	Side	97.0
2.	Centre	92.0
	Side	95.0
	Side	95.8

Average HN = 94.26

HARDNESS WITH FERRO-SILICON ADDITIONS with 2.4% Si

Sample No.	Position of the Sample	Hardness
1.	Centre	90.0
	Side	90.0
	Side	88.00
2.	Centre	87.2
	Side	89.0
	Side	89.5

Average HN = 88.95

SAMPLES FROM ESSENTIAL PRODUCTS

with 1.76% Si

Sample No.	Position of the Sample	Hardness
1.	Centre	85.0
	Side	84.0
	Side	83.0
2.	Centre	86.0
	Side	84.0
	Side	84.0

Average HN = 84.30

HARDNESS WITH FERRO-MANGANESE ADDITIONS

With 0.9% Mn

Sample No.	Position of the Sample	Hardness
1.	Centre	87.0
	Side	85.5
	Side	85.0
2.	Centre	87.0
	Side	85.5
	Side	85.0

Average HN = 85.6

With 1.05% Mn

Sample No.	Position of the Sample	Hardness
1.	Centre	83
	Side	84
	Side	84
2.	Centre	83
	Side	84
	Side	84

Average HN = 83.67

With 1.34% Mn

Sample No.	Position of the Sample	Hardness
	Centre	90.0
1.	Side	86.0
	Side	85.0
	Centre	88.0
2.	Side	84.0
	Side	85.0

Average HN = 86.3

With 1.7% Mn

Sample No.	Position of the Sample	Hardness
	Centre	88.0
1.	Side	89.0
	Side	89.0
	Centre	88.0
2.	Side	89.0
	Side	89.0

Average HN = 88.2

HARDNESS WITH FERRO-CHROME ADDITIONS

With 0.3% Cr

Sample No.	Position of the Sample	Hardness
1.	Centre	76.0
	Side	79.0
	Side	79.5
2.	Centre	78.5
	Side	78.5
	Side	79.0

Average HN = 78.30

With 0.55% Cr

Sample No.	Position of the Sample	Hardness
1.	Centre	84.0
	Side	85.0
	Side	86.0
2.	Centre	84.0
	Side	86.0
	Side	85.0

Average HN = 85

With 1.01% Cr

Sample No.	Position of the Sample	Hardness
1.	Centre	89.0
	Side	95.0
	Side	95.5
2.	Centre	89.0
	Side	96.5
	Side	95.5

Average HN = 94

With 1.22% Cr

Sample No.	Position of the Sample	Hardness
1.	Centre	96.5
	Side	97.5
	Side	97.3
2.	Centre	96.0
	Side	97.8
	Side	98.0

Average HN = 97.2

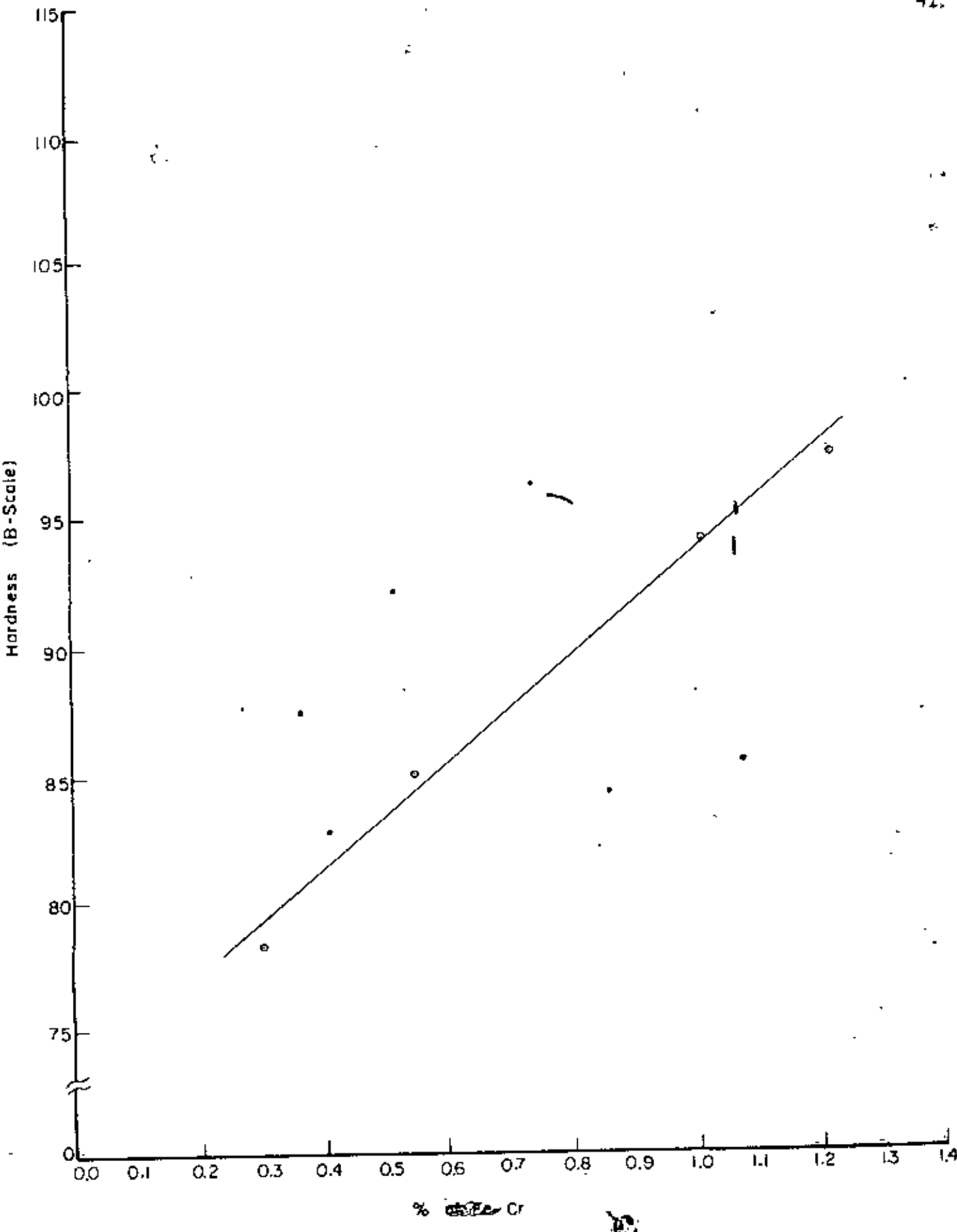


FIG.4 ROCKWELL HARDNESS CURVE WITH Fe - Cr ADDITIONS

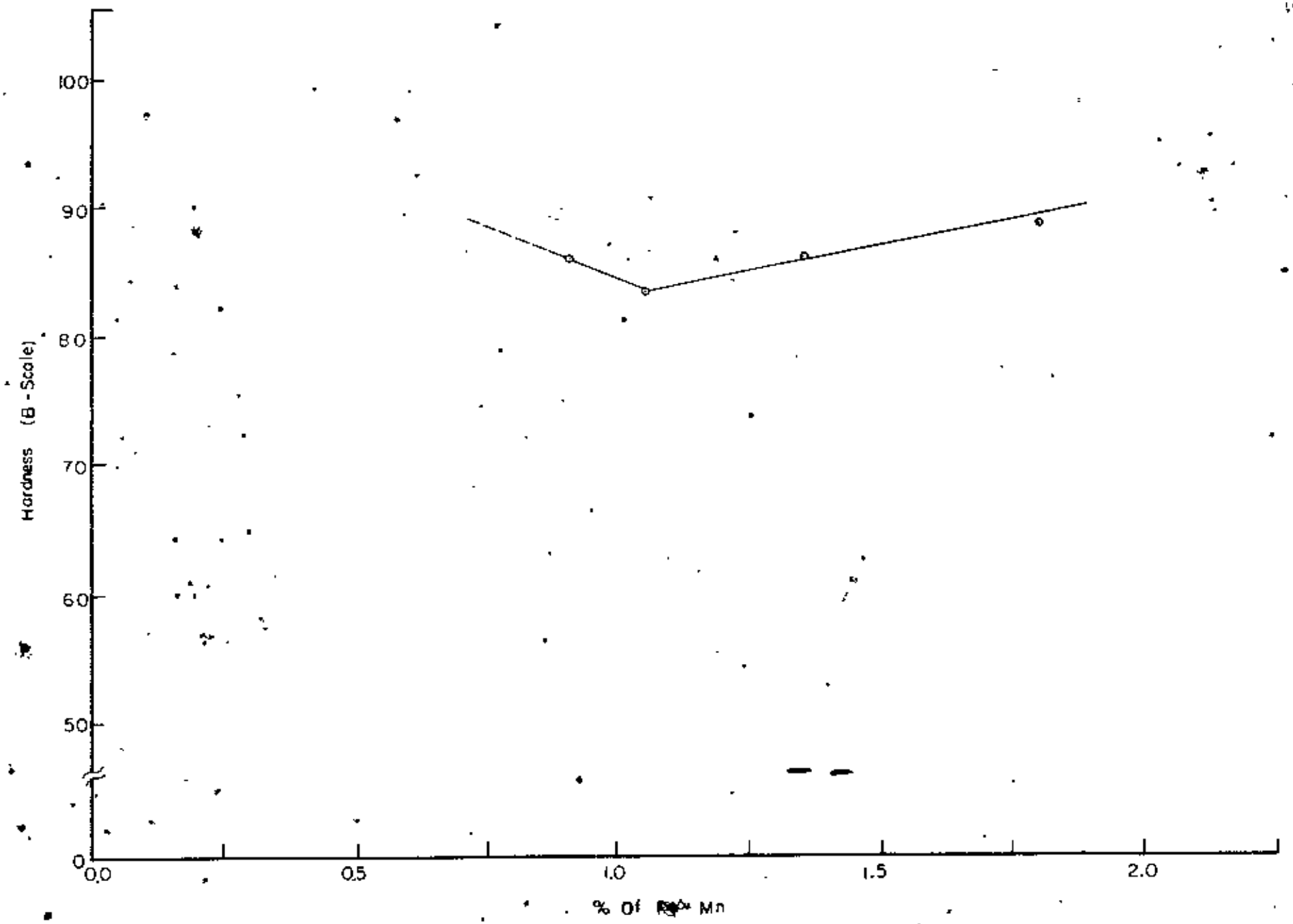
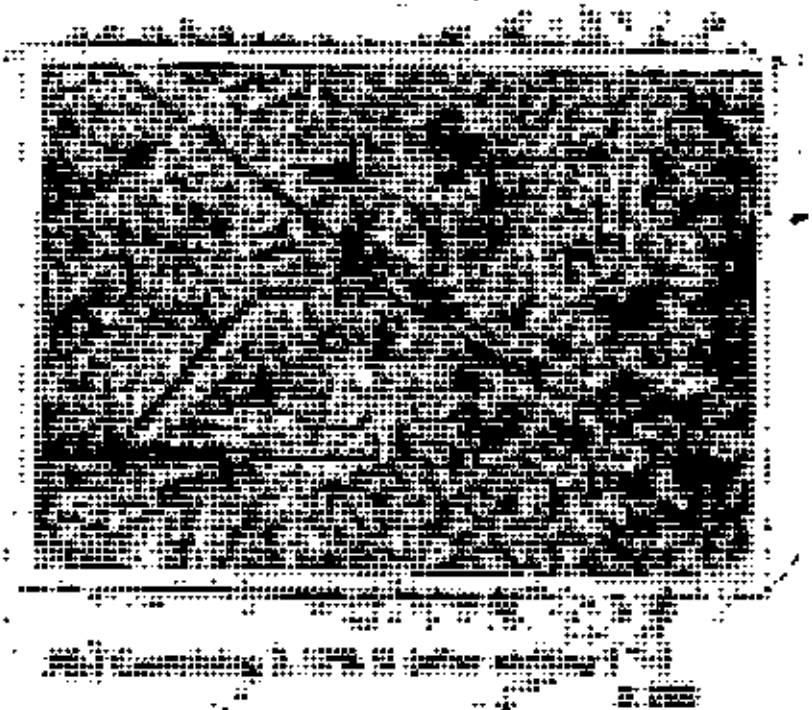


FIG. 5 ROCKWELL HARDNESS CURVE WITH Fe-Mn ADDITIONS

(9(a) Containing 3.12% Si (before etching)

X 200



9(c) Containing 2.63% Si (before etching) X 200

9(d) Containing 2.63% Si (after etching) X 200

9(e) Containing 1.6% Si (before etching)

X 200

9(f) Containing 1.6% Si (after etching)

X 200

Fig. 9(e) & 9(f) shows – the change of structures with the variation of Silicon in Cast iron.

10(a) Containing 0.9% Mn (before etching)

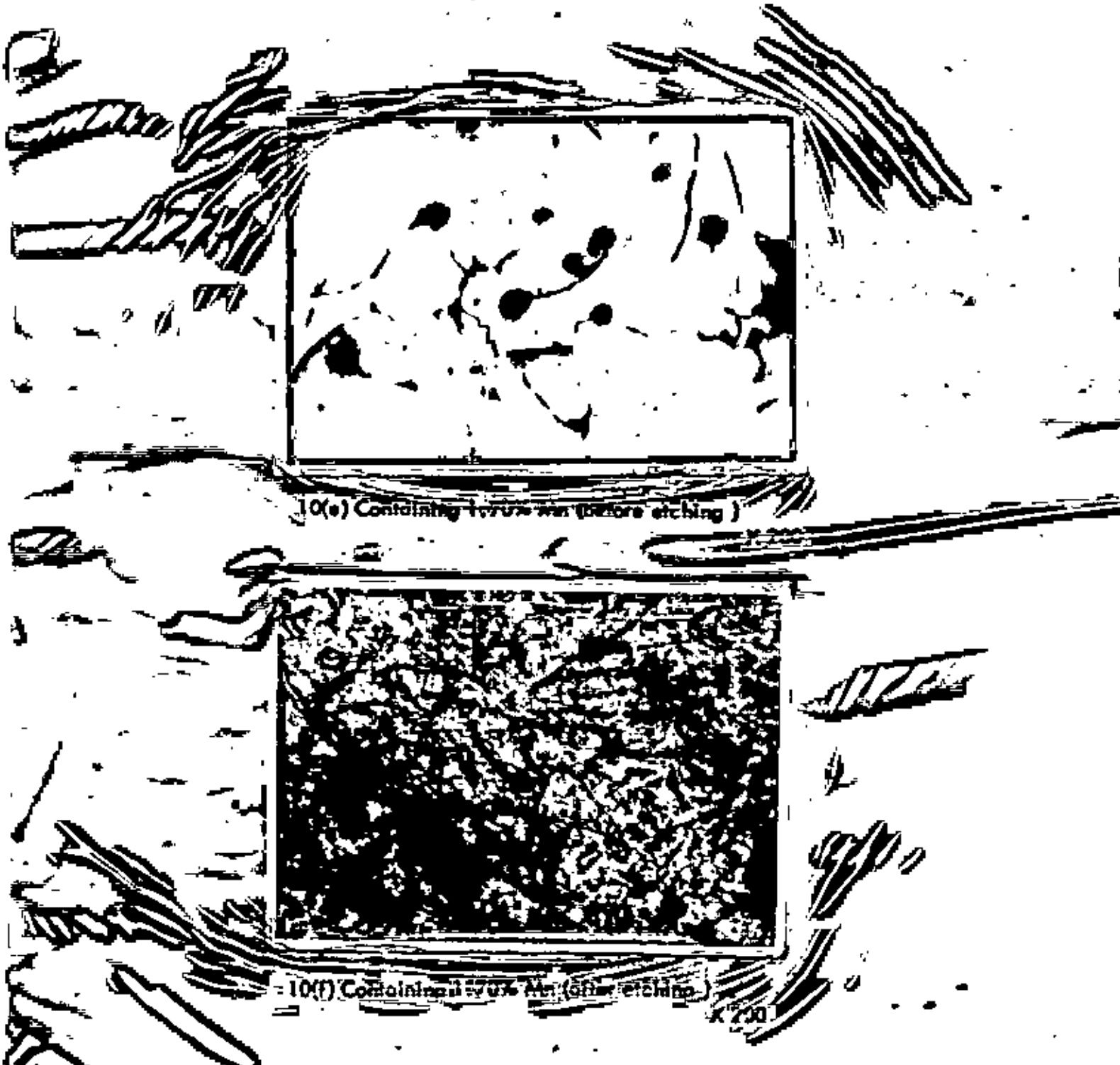
X 200

10(b) Containing 0.9% Mn (after etching)

X 200

10(c) Containing 1.34% Mn (before cooling) X 200

10(d) Co[illegible] 1.34% Mn [illegible] X 200



10(e) Containing [illegible] Mn (before etching)

10(f) Containing [illegible]% Mn (after etching)

X 200

Fig. 10(a) to (f) shows – the change of structures with the variation of Manganese additions in Cast Iron.

11(a) Containing 0.4% C (before etching)

X 200

11(b) Containing 0.4% C (after etching)

X 200

11(c) Containing [illegible]

11(d) Containing 1.01% Cr (other [illegible])

x200

Fig. 11(e) to (f) show the change of structures with the variation of Chromium additions to Cast Iron.

DISCUSSIONS

Deficiency of metalloids was observed in the locally available cast iron. No data of the standard physical properties was available. It was observed after some experimental works that the usual physical and other properties could be increased by adding a limited quantity of metalloids and alloying elements. Sound casting may thus be possible.

The chemical analysis showed that the loss of metalloids was between 15 to 25%. It was observed that the loss of alloying elements was considerably large when ferro-alloys were added in the crucible. The reason might be that the quantity of metal in the crucible was not sufficient and it was kept heated during the addition of ferro-alloys and this was thought to be responsible for the increased oxidation of the alloying elements in the molten bath of iron in the crucible. Due to this excessive loss of the alloying elements as well as metalloids, metalloids and alloying elements were added including the probable loss during casting. The alloying elements were Fe-Si, Fe-Mn and Fe-Cr.

It is seen in the hardness curve shown in fig.5.4 that hardness of cast iron with Fe-Mn addition first decreases slightly and then increases gradually. The hardness curve of cast iron with Fe-Cr addition increases linearly. The hardness increases due to the increase in amount of cementite in the structure of cast iron after solidification. Pouring temperature and holding time were found to have

greater effect in controlling the structure of cast iron. When the pouring temperature was high, it was seen that the casting was softer. The metal was observed to be less fluid at a lower pouring temperature. Graphitization was affected due to the difference in holding time of the molten metal. A number of castings were included in a single mold box. Due to this the rate of cooling of subsequent castings were slower than that obtained with the one which was poured earlier. To avoid this variation of temperature separate mold boxes were used for separate castings in the later investigations. By this method, structures of the castings were found to be same in every case. It is thought that after alloy addition the molten metal should not be held in the furnace for a longer time. If the holding time is longer, then the loss due to oxidation is, more which is substantiated by experiment. So pouring of the molten metal into the mold box should be done as quickly as possible after the alloy addition. Alloy addition can be done either by keeping the crucible inside or outside the furnace. The slag should be removed before the additions.

In ordinary gray cast iron the amount of ledeburite is not very much conspicuous due to the dissociation of austenite and cementite into the ultimate products of ferrite and graphite. In the case of cast iron containing chromium, the cementite gets stabilized and helps the formation of eutectic cast iron, which does not get dissociated even at temperature below the lower critical line

of iron-iron carbide equilibrium diagram. Hence cast iron containing chromium or other alloying elements shows the conspicuous presence of ledeburite. Fig.11.j shows a good amount of ledeburite what is generally known as eutectic cast iron.

In ordinary cast iron no etching is necessary to know the size and quantity of graphite it contains. But etching becomes necessary when a knowledge of the constituents such as pearlite, cementite or even ledeburite is necessary. Fig. 9 shows the structure of unetched specimens of cast iron giving an idea of the size and quantity of graphite in the specimen. Some specimens when etched with 5% nital solution, reveal the structures of pearlite and graphite flakes. The edge of the graphite flakes are widened due to the attack of the etching reagents.

From the tensile test of the specimens the following data were obtained.

TENSILE STRENGTH FOR CAST IRON AS FOUND:

Material	Aver. Max. Load in Lbs.	Max. Tensile Strength in Tons/Sq.in.	
Cast iron:	4780	12.00	
With 2.4% Si	3460	8.66	Diameter=(7/16+5/128)
" 1.7% Si	4200	10.50	=(0.437+.0395)
" 0.9% Mn	3750	9.40	=0.4765 inch
" 1.05% Mn	4100	10.10	
" 1.34% Mn	4380	10.97	
" 0.3% Cr	3280	8.20	Area= $\pi D^2/4$
" 0.55% Cr	3400	8.50	= 0.178236 Sq.in.
" 1.01% Cr	4340	10.87	
" 1.22% Cr	4720	11.82	

Observations of the micro-structures and the physical properties such as tensile strength and hardness, clearly show that with a little compositional control, a significant improvement of cast iron products can be obtained.

Industries in Bangladesh dealing with cast iron products may therefore be urged to give some serious consideration regarding this matter.

Follow-up research work on this line with other similar alloy additions for further improvement of locally available cast iron may thus be suggested.

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