Chapter 1: Introduction

1.1. Introduction

Mill roller shell is usually constructed of a shaft of steel [1] onto which a cast iron shell is shrunk [2]. Sugar mill roller shells are very important surface engineered insert elements, which are manufactured in the Foundry of Hawamdia Machinery & Equipment Factories (H.M.E.F), from grey cast iron. Mill roller shell fractions are fairly common and invariably costly, not only because of the need to replace them, but also due to the downtime that results from their fraction. Moreover, their fraction is usually associated with secondary damage to the bearings and the headstock. The purpose of the mill headstocks is to maintain the working elements in their desired orientation. This orientation needs to be flexible to allow for different roll sizes and setting. The basic mill comprises three mills: the roller number 1 (top roll), which needs to be able to "float" upwards during operation, and the roller number 2 (feed roll) and the roller number 3 (discharge roll) that need to be adjustable sideways.

The company needs a great quantity of mill roller shells (top, discharge and feed), approximately (1200) ton/year and the cost of this production rate is nearly (12) million Egyptian pounds). The Sugar Integrated Industries Company (SIIC) in Egypt adopts a program for annual maintenance for the mill roller shells to prevent failure during the season as failure costs a big pity.

The mean lifetime of mill roller shells in the Sugar Integrated Industries Company (SIIC) in Egypt before the first restoration is approximately one year the main damage occurring to the surface is abrasive wear. For example, the Kawasaki mill roller shells diameter changes by 20 mm each season; from 1120 mm to 1100 mm, 1080 mm and 1060 mm, consecutively, as shown in Figure (1.1). Usually, there are from three to five restoration maintenance repairs conducted when the worn surface reaches about (1.8 %) of the diameter. The restoration or repair includes machining of the worn surface and regrooving of the new surface. This is associated with a decrease in the diameter resulting in a loss in productivity of the mills. For economic purposes, the restoration is done three times till the diameter is drastically reduced and the mill roller shell is put out of the service.

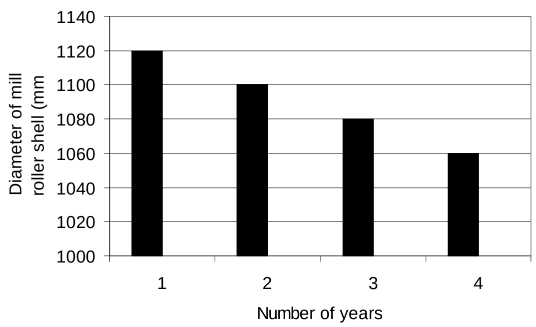

Figure 1.1. Annual wear of mill roller shell.

There are many reasons for wear and corrosion in mill roller shells. such as rust of metal mill roller shells; friction between the top scraper-trash plate-cane- sucker and mill roller shells; and on top of all the high speed of the moving rolls [3], where the wear in the middle of the mill roller shell is greater than their ends. Approximately, the wear is 1.8 % (or 20 mm) annually, and the tool life for mill roller shell is about (3 to 5) years.

The favored specification for mill roller shells used to be "open-grained cast iron", since this produced a rough finish to aid feeding. However, with higher loads and stresses and the development of roll surface roughening techniques such as carbon-arcing and subsequently hard welding; a close grained higher tensile material is now preferred. Wear rate increases with the decrease of angle grooves and the optimum angle for mill roller shell is 45^0: 55^0[3]. Three type of grooving are used on mill roller shells [3][4].

- Pitch of fine grooves 5 to 20 mm.
- Pitch of medium grooves 20 to 50 mm.
- Pitch of coarse grooves above 50 mm.

The fine grooves are best for extraction and the coarse ones are best for crushing. Some engineers adopt identical grooves on all mill roller shells, from the extraction point of view, while others favor differential grooving as by these juice handling capacity increases. The wear and tear, however, in the case of differential grooving is greater than in the case of identical grooving. The angle of grooving is also important. In recent practices, wider angles of (55^0–60^0) are generally employed on the top rollers and (52^0–58^0) on the bottom rollers.

Wear resistance is considered as the most important parameter for proper selection of the material to be used for the manufacturing of mill roller shells. Hardness, microstructure and chemical composition of mill roller shells play a marked role in wear resistance. Although hardness and relative wear are linearly proportional for most of the commercial pure metals, the same simple relation does not hold for a range of mill roller shells where it becomes necessary to consider chemical composition as well.

Shells have historically been made of low strength cast iron. The required properties of the shell material include resistance to wear and polishing, suitable strength and good machineability and weldability. Being of a large section, the shell casting requires careful attention to prevent undue porosity and shrinkage cavities. Once the casting has cooled at the correct rate, it is machined for the reshelling of a shaft. Precise machining of the internal through hole is critical to ensure an adequate shrink fit onto the shaft to avoid shell slippage in service [5]. Despite the significance of this issue, there is not much research on this subject. Previous work only studied the surface of grey cast iron rollers arced in traditional ways.

A recent study on eight factories in Jamaica using grey cast iron for their MRS revealed that much more direction and testing of the material specification are required from factories to manufacturers when purchasing mill roller shells. The findings showed that specifications are seldom requested. Later on, researches started to recognize the importance of chemical analysis but research on this subject is still lacking. Good practice, based upon the work carried out by Sare, Constantine, Mason and Thwaite suggested an alloy composition of (3.3-3.5 % C, 1.6-2.0 % Si, 2.0-3.0 % Mn, 0.07-0.10 %S, and < 0.07 % P), with the overriding constraint that the Carbon Equivalent (CE) level = 3.9-4.2 % .

Some studies focused on the hard facing of the grey cast iron rollers using similar welding electrodes. The engineered surfaces were characterized for their abrasion and corrosion wear resistance. The results of the previous studies suggested that the predominant wear mechanism is corrosion associated with porosity and chromium depletion in the weld zone.

The main objective of this study is to bring into focus the significance of the chemical composition of the cast iron used for manufacturing the shells in order to increase juice extraction with minimum wear at the lowest cost. According to Krauss, the addition of each 1.00 percent, silicon reduces the amount of carbon in the eutectic by 0.33 percent [6]. The most common range for manganese in grey iron is from 0.55 to 0.75 percent. Increasing the manganese content tends to promote the formation of Pearlite while cooling through the critical range. It is necessary to recognize that only that portion of the manganese not combined with sulfur is effective. Virtually, all of the sulfur in grey iron is present as manganese sulfide, and the manganese necessary for this purpose is 1.7 times the sulfur content. manganese is often raised beyond 1.00 percent, but in some types of green sand castings, pinholes may be encountered.

Chromium is often added to improve hardness and strength of grey iron. Chromium is generally present in amounts below 0.10 percent as a residual element carried over from the charge materials, and for this purpose, the chromium level is raised to 0.20 to 0.35 percent. Beyond this range, it is necessary to add a graphitizer to avoid the formation of carbides and hard edges. Chromium improves the elevated temperature properties of grey iron. The aim of this experimental study is to study the effect of adding (2.11 % Cr, 3 % Mn and 2.02 % Si) to grey cast iron cast shells in order to improve the wear resistance of the surface. The alloy design is based on adding chromium as carbide former with increased silicon content to approach the upper limit in grey cast iron to act as a graphitizing. Manganese is also raised up to 2% to provide plentiful amounts to stabilize the Pearlite.

Chapter 2: Literature Review

2.1. Description of MRS

The main objective of milling is to separate the sucrose containing juice from the cane. The prepared cane is pushed through a three roller mill and squeezed between the roller number 1 (top roller) and the roller number 2 (feed roller). The juice is extracted and collected in a trough and the bagasse resulting from squeezing is guided by a trash plate to the opening between the roller number 1 (top roller) and the roller number 3 (discharge roller), where it is squeezed once again in the set of the three roller mill. In a three roller mill, three rollers are arranged in triangular pattern for removing sucrose up to 96-97 % max. The arrangement of the rollers is shown in Figure (2.1).

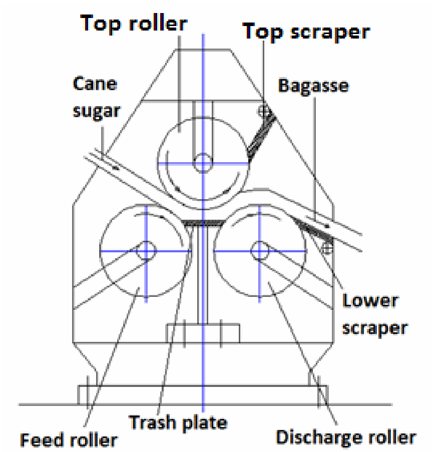

Figure 2.1. Assembly of conventional sugar three roller mills.

The three roller mills used for extraction of juice consist of roller number 1, 2 and 3 (top, feed and discharge rollers). Sugar cane is fed into the top and feed rollers, then further pass through the top and discharge rollers along with trash plate. This trash plate has a downside such that 25% of the total hydraulic load is shared by this trash plate in overcoming friction and the remaining 75% only is useful, i.e. 25% of the hydraulic load is shared by feed roller and 50% is shared by the discharge roller, as shown in Figure (2.2). The crushing rolls are designed to have high coefficient of fraction and are operated at very low rotational speeds up to 4 to 7 rpm.

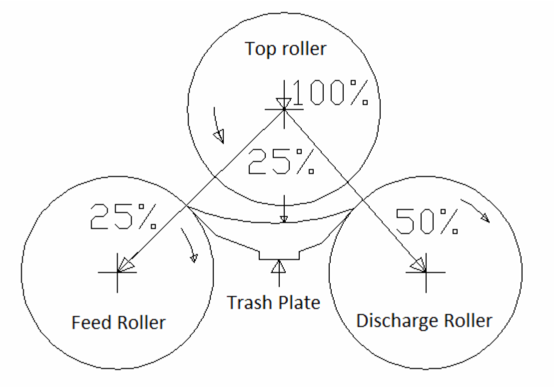

Figure 2.2. Conventional Roller mill Hydraulic load details.

The power needed for crushing the sugarcane is applied on to the top roller which rotates the feed and discharge rollers, with pinion arrangement attached on one side of roller. The roller number 1 (top roller) is the most critical component amongst all, as the drive torque, hydraulic load and crushing load all act on it. The forces acting on the mill roller shell gives rise to shearing, bending, torsion and compressive stress. The top roller is the most highly stressed, since it consumes about half of the mill torque. Out of total power 50 % is taken by top roller, 35 % is taken by discharge roller, 15 % is taken by feed roller. Figure (2.3) shows the worn roller surfaces, from which it can be deduced that the main wear mechanism is abrasive wear by forming large grooves across the surface of the rolls. The chemical composition of the current working mill roller shell is (3.2-3.5% C, 1.5-2.5%Si, 1.5-2.5% Mn, 0.5% max. P and 0.15% max. S).

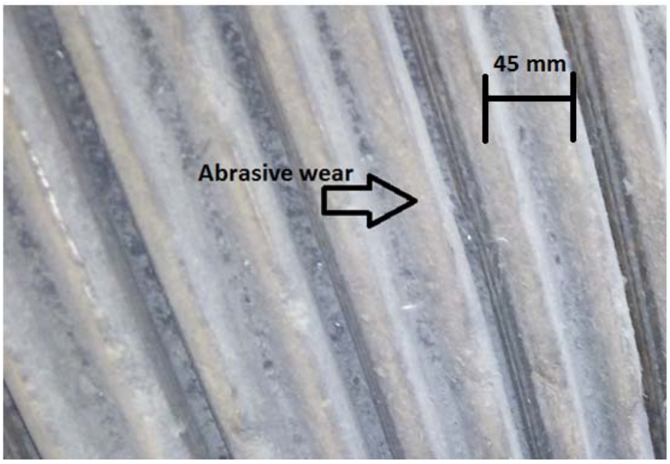

Figure 2.3. Image of worn roller surfaces.

Analyzing operational conditions

The pressure acting on the mill roller shell is very large, and it ranges from 550 to 600 ton and the mill driving power ranges from 650 to 850 HP. These conditions result stresses in the range of approximately 2.2 Kgf/mm^2, at a speed range of 4 to 7 rpm. The diameters of mill roller shells range from 1070 to 1165 mm all depending on the production rate. Based on the working conditions, the lab wear test was selected to simulate those conditions during the operation.

During the rotation of the mill roller shells, friction is generated between the top and feed rollers; as well as between the top and discharge rollers. Leading to abrasive wear in the mill roller shells. The testing conditions in this work were selected to represent the working conditions.

2.2. Grey Cast Iron

Cast iron is iron which has been heated until it liquefies, and is then poured into a mould to solidify. It is usually made from pig iron. It is a cheap alloy. Ordinary cast iron is an alloy containing a total of up to 10% of the elements C, Si, Mn, S and P; the balance being iron. Alloy cast irons; contain also varying amounts of Ni, Cr, Mo, V and Cu.

If silicon content is high and the cooling rates during solidification are low, complete graphitization takes place and the resulting structure will contain graphite flakes only. Then it is called grey cast iron, the fracture surface may be dull and grey. The important engineering properties of grey cat iron are;

1. High compressive strength.
2. Moderate tensile strength.
3. Good wear resistance.
4. High damping capacity.
5. Good machinability.

The shortcoming of grey iron is the brittleness due to the flake form of graphite which introduces sharp notches at the edges. The most important applications of cast iron are machine beds, ingot moulds, lamp spots and others[7][8].

2.3. Effect of Alloying Elements on Grey Cast Iron

- **Carbon**

Carbon is the most effective, most widely used and lowest in cost alloying element available for increasing the hardness and strength of the metal. Although carbon is desirable alloying elements, high levels of it can cause problems; therefore, special care is required when welding high carbon steels and cast iron. The primary source for graphite and/or carbide in any cast iron[9].

- **Silicon**

Silicon is a graphitizing element, high silicon irons, over about 1.6%Si, tend to be graphitic, while low silicon irons are mottled or white. Silicon contents of grey iron are generally around 2.0%. Silicon is needed for two reasons. A minimum amount of silicon is necessary to improve fluidity of the melt and to produce a fluid slag, but of equal importance is its effect on as-cast hardness. Increased levels of silicon, in the range of 1 to 1.5%, have been found to increase the amount of martensite and the resulting hardness.

- **Manganese**

Manganese is necessary to neutralise the effect of sulphur in iron. Without sufficient Mn, iron sulphide forms during solidification and deposits around grain boundaries where it renders the metal hot-short and likely to produce cracked castings. the hardness increases with increasing the manganese. It has high negative graphitizing potential. Manganese is a pearlite stabiliser and it increases the hardness of the iron. However, it is not primarily used for strengthening because it can affect nucleation adversely[10][11][12].

- **Chromium**

Chromium, in combination with carbon, is a powerful hardening alloying element. In addition to its hardening properties, chromium increases corrosion resistance and the strength. Added in small amounts, Cr suppresses the formation of free ferrite and ensures a fully pearlitic structure, so increasing hardness and tensile strength. Too much Cr causes chill at the edges of the casting, reducing machinability seriously. Cr up to about 1% may be added to grey irons used for special purposes, such as camshafts, where chills are often used to create wear resistant white iron on the cam noses[10].

- **Sulphur**

Numerous investigators have shown that sulphur plays a significant role in the nucleation of graphite in grey iron. It is important that the sulphur content of iron be balanced with manganese to promote the formation of manganese sulphides. This is normally accomplished by using %Mn > 1.7 times sulphur content + 0.3% [11].

- **Phosphorus**

It is rarely added intentionally but tends to come from pig iron or scrap. To some extent, it increases the fluidity of iron. P has limited solubility in austenite and so segregates during solidification forming a low-melting phosphide phase in grey iron that is commonly referred to as steatite. At high levels, it can promote shrinkage porosity, while very low levels can increase metal penetration into the mould [12].

2.4. Wear Phenomena of Testing

Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of the mechanical action of the opposite surface. The study of the processes of wear is part of the discipline of tribology. The complex nature of wear has delayed its investigations and resulted in isolated studies towards specific wear mechanisms or processes. Some commonly referred to wear mechanisms (or processes) include: abrasive wear, adhesive wear, surface fatigue, fretting wear, erosive wear and corrosion and oxidation wear.

2.4.1. Abrasive Wear

Abrasive wear occurs whenever a solid object is loaded against particles of a material that have equal or greater hardness. A common example of this problem is the wear of shovels on earth-moving machinery. The extent of abrasive wear is far greater than may be realized. Any material, even if the bulk of it is very soft, may cause abrasive wear if hard particles are present. For example, an organic material, such as sugar cane, is associated with abrasive wear of cane cutters and shredders because of the small fraction of silica present in the plant fibers. A major difficulty in the prevention and control of abrasive wear is that the term 'abrasive wear' does not precisely describe the wear mechanisms involved. There are, in fact, almost always several different mechanisms of wear acting in concert, all of which have different characteristics.

The corrosion is one of the problem that may be occur to mill roller shells but in this investigation will be studied dry abrasive wear.

2.5. Previous Trials to enhance the performance of MRS

Johnson O. Agunsoye, Talabi S. Isaac, Olumuyiwa I. Awe, Afemefuna T. Onwuegbuzie [13] studied the effect of silicon Additions on the Wear Properties of grey cast iron. The effects of sliding speed, applied load, time and percentage of ferrosilicon additions, on the wear rate of grey cast iron were studied.

Table 2.1. Process parameter for the wear test.

Levels	Speed (m/s)	Time (sec)	Load (N)
1	1.18	60	6
2	2.36	120	12

Table 2.2. Design parameter for the wear process.

Factor	Name	Units	Low level (-)	High level (-)
A	Speed	m/s	1.18	2.36
B	Time	Sec	1	2
C	Load	N	6	12
D	Rein forcer	Wt %	2	4

Table 2.3. Chemical composition experimental of grey cast iron (wt %).

Samples	Elemental composition (wt %)					
	C	Si	Mn	P	S	Fe
Batch 1	3.52	2.04	0.55	0.11	0.16	92.90
Batch 2	3.25	2.41	0.39	0.08	0.12	92.90
Batch 3	3.17	2.85	0.38	0.09	0.11	92.60
Batch 4	3.53	3.2	0.35	0.09	0.07	92.00
Batch 5	3.17	3.33	0.35	0.09	0.07	92.20

The study showed that the wear coefficient with respect to increasing load, speed and time decreases with increase in silicon additions for the grey cast iron. A wear transition occurred at 3.2 % silicon addition irrespective of the varied wear parameters (speed, load and time). The location of the transition zone (3.2%) with respect to the operating parameters is important to design engineers to save proper materials selection and design.

The morphology and size of the soft graphite flaks has a domineering effect on the hardness and consequently wear resistance of the grey cast iron.

Factorial design of the experiment can be successfully employed to describe the wear behavior of grey cast iron and the developed linear equation models can be used in predicting the wear rate of the materials within the set experimental conditions.

The singular effects of silicon additions, load and speed variables are more pronounced on the wear behavior of the grey cast iron, while time has a less significant effect. The sliding speed – time interactions effect has the most significant effect on the grey cast iron. Inverse variation between hardness and impact resistance of the grey cast iron was observed. From the result of the experimental work, although improved wear was observed with increase in silicon content, it can be concluded that grey cast iron is suitable for application where the impact load is considered low.

G.D. Oliver & B. Wilson [14] studied the effect of roughening the surface of Sugar Cane mill roller shell as Practiced in Jamaica. All eight (8) sugar factories in Jamaica use grey cast iron for their mill roller shells. The findings showed that much more direction and testing of the material specification are required from factories to manufacturers when purchasing mill roller shells. The findings show that specifications are seldom requested. The Chemical Compositions for the same two shell samples taken from Appleton and St. Thomas are shown in Table to amplify this point.

Table 2.4. Chemical Analysis of grey cast iron within two of the Sugar factories in Jamaica.

%	Appleton	St. Thomas
C	3.09	1.79
Si	1.73	2.23
Mn	0.50	0.48
S	0.078	0.087
P	0.256	0.342
Cr	0.23	0.14
Mo	0.03	0.28
Ni	0.12	0.11
Al	< 0.005	< 0.005
Co	< 0.01	< 0.01
Cu	0.26	0.23
Sn	0.02	0.02
Ti	0.014	0.017
V	0.03	0.03

Good practice, based upon the work carried out by Sara, Constantine, Mason, Thwaite suggests an alloy composition of that shown are 3.3-3.5% C,1.6-2.0% Si, 2.0-3.0% Mn, 0.07-0.10% S and< 0.07% p , with the overriding constraint that the Carbon Equivalent (CE) level, completed by the formula:

$$C.E. = T.C. + 1/3\ (\%Si + \%P)$$

Should be in the range of 3.9 – 4.2%. This alloy composition has a slightly lower Phosphorous and significantly higher manganese than those found in the study and reported herein.

The Silicon levels accords with that practice by the local manufacture of sugar mill roll shells while the higher manganese content was included to ensure that a uniform pearlitic microstructure throughout the Casting cross-section. Most importantly, the specification for mill roller shell material should take into consideration that arcing is performed upon the surface. The process limits the amount of Phosphorous level to <0.07%. If this level is exceeded a formation of a network of iron phosphide eutectic would result, providing a self-roughening surface. This previously was considered advantageous when throughput of the mills was lower and where arcing was not carried out. The self-roughening mechanism resulted by way of abrasion and corrosion of the relatively soft pearlitic matrix, which is worn away, resulted in the hard iron phosphide eutectic standing in protrusion. Best practice for arcing mill roll shells requires that the Phosphorous level be kept below 0.07% and multiple layers be used in order to obtain the desired result. The standardization of the grey cast iron mill roll shells to the ASTM Type a size 3 is recommended. Courses designed specifically to train welders for mill arching should be pursued.

GD Oliver, VE Buchanan and KO Cooke [15] studied a critique on the wear mechanism of surface engineered sugar mill roller shells. The desired effects of the engineered surface on the sugar mill roller shells. The desired effects of the engineered surface on the sugar mill roller shells (SMRS) are: to increase friction between the sugar mill roller shells and the shredded sugar cane, to enhance the extraction of sucrose juice, to minimize the wear and to potentially enhance bagasse comminution. The engineered surfaces were characterized for their abrasion and corrosion wear resistance by using shield metal arc welding (SMAW) in which the surface of the cast iron mill roller shell is roughened by an arc hard facing process.

Table 2.5. The chemical compositions (%) of electrode and cast iron.

Elements	Electrode		Cast Iron
	Wire	Coating	
C	-	8.74	3.45
Si	0.02	3.90	2.41
S	0.049	< 0.005	0.076
Mn	0.30	1.90	0.38
Cr	0.060	41.8	0.14
P	< 0.005	< 0.005	0.095
Ni	0.071	0.11	0.081
Mo	0.006	0.007	0.028
Cu	0.20	-	0.22
Al	-	0.52	-
Ca	-	1.10	-
Mg	-	0.24	-
Ti	-	0.67	-
V	-	0.053	-
Fe	Balance	-	Balance

The results showed that: (1) both chromium and carbon increase as the distance from the base metal increases. (2) The Vickers micro hardness of the deposit on the cross section of the sample as well as on the surface. Hardness increases from the substrate to the surface of the deposit. (3) The hardness sharply increases within the first layer, levels off at the interface between the layers and then increases or decreases as it approaches the surface.

Although the electrodes used in this study had an overall hypereutectic composition, that enhances the formation of primary or pro-eutectic M7C3 carbides, dilution of carbon and chromium can shift the composition of the deposit to the hypereutectoid composition. The structure in this study is clearly hypereutectic with rod-shaped proeutectic M7C3 carbides.

The depletion of chromium in the 'weld matrix' combined with the pores, contributes to an increase in corrosion rate. Apart from the depletion of chromium caused by dilution in the weldment it is postulated that some amount of chromium is lost by air borne movement during the welding operation. This air borne loss can lead to health problems to the welder and should be further investigated. The rate of wear of sugar mill roller shells contributes significantly to the complex mix of tribomechanisms and corrosion mechanisms affecting a typical sugar mill roller shells. In this study, however, investigation honed in on the corrosive mechanism in which it was shown that the rate of corrosion is dependent on the ratio of carbide to matrix in which the larger the ratio the larger the corrosion rate.

J. O. Agunsoye, E. F. Ochulor, S. I. Talabi and S. Olatunji [16] studied the effect of Mn additions and wear parameter on the tribological behaviour of grey cast iron.

Table 2.6. The chemical compositions of experimental grey cast iron are.

Elements	C %	Si %	Mn %	P %	S %
Batch 1	3.32	1.90	0.31	0.12	0.11
Batch 2	3.30	1.94	0.43	0.11	0.09
Batch 3	3.26	2.00	0.73	0.08	0.06
Batch 4	3.24	2.10	1.02	0.09	0.05
Batch 5	3.20	2.07	1.71	0.09	0.05

The samples were sand cast with a 40 kg capacity crucible furnace. The wear parameters studied are sliding speed, applied load, time and percentage of Ferro-manganese additions. The wear test was carried out with variable sliding speed, time and load as shown speed 125 and 250 rpm, time 60 and 120 sec, load 10 and 15 N and Mn 0.31 % and 1.71 %. The result showed that:

(1) The wear coefficient with respect to increasing load, speed and time decreases with increasing Mn additions for the low alloy grey cast iron.
(2) The improved wear resistance of the samples with increasing manganese additions is due the formation of hard carbide phase with in the matrix structure of the low alloy grey cast iron.
(3) Increasing Mn additions leads to decrease carbon equivalent (CE). This will guarantee lower mould solidification resulting of hard and brittle inter-metallic second phase Fe_3C and improved toughness.
(4) The main effect of manganese additions, load and speed variable are more pronounced on the wear behavior of the low alloy grey cast iron compare with main effect of time.

L. Collini, G. Nicoletto, R. Konecna [17] studied the Microstructure and mechanical properties of pearlitic grey cast iron. The material under examination is a lamellar grey cast iron with fully pearlitic matrix of GJL 300 grade and chemical compositions of grey cast iron produced by foundries A – C are reported in table.

Table 2.7. Chemical compositions (% in weight) of grey cast iron.

Foundry	C	Si	Mn	P	S	Cr	Mo	Ni
A	3.29	1.52	0.79	0.055	0.030	0.150	0.005	0.029
B	3.20	1.92	0.64	0.031	0.068	0.290	0.006	0.039
C	3.15	1.98	0.85	0.086	0.086	0.086	0.012	0.068

Foundry	Cu	Sn	Ti	V	Al	Pb	Mg	E. C.
A	1.34	0.009	0.013	0.011	0.002	0.003	0.001	3.815
B	0.07	0.110	0.017	0.005	0.004	0.002	0.001	3.850
C	1.10	0.018	0.012	0.014	0.005	0.002	0.001	3.839

In terms of mechanical and microstructural properties, of three pearlitic gray cast irons, which were nominally of the same grade but produced by three different foundries. Specimens used in the experimental activity were machined from industrial casting. The first part of the experimental activity was the static and fatigue mechanical characterization of the three materials; the second was a quantitative metallographic analysis that has been conducting with the aim of correlating microstructure and mechanical properties.

The main conclusions of this work are the following:

- Mechanical properties of grey cast iron show high variability ; they depend not only on the microstructure heterogeneity but also on the local point of extraction in the casting and, especially, from foundry to foundry;
- A direct and precise correlating between all microstructure features and mechanical performance in grey casting iron was not established because interrelation and the overlapping of different effects especially when graphite morphology is nearly the same .However the following partial results were found : (1) no direct correlating is always found between static and fatigue performance ;(2) graphite content is detrimental with respect to mechanical properties ;(3) a fine structure of eutectic cells increases the fatigue limit ;(4)phosphorus has a damaging effect on tensile strength while improves the fatigue behavior of grey casting iron ;
- The quantitative metallographic analysis is a useful tool to estimate or explain difference in mechanical properties of grey casting iron
- Only an in-depth study of the casting process of grey casting iron could bring to a greater control of the microstructure and consequentially of the obtained mechanical properties

G. L. Rivera, R. E. Boeri, J. A. Sikora [18] studied solidification of grey cast iron, the solidification of hypo, eutectic and hypereutectic grey cast iron. Melts were cast in resin bonded sand moulds to produce round bars of 20, 30 and 46 mm diameter. Table lists the chemical composition of the alloys used. The melts were alloyed with Cu and Ni in order to provide enough austemperability to carry out the DAAS (Direct Austempering after Solidification) macrograph technique.

Table 2.8. Chemical composition of hypo, eutectic and hypereutectic grey cast iron.

Melt	Chemical composition (wt %)					
	CE	C	Si	Mn	Cu	Ni
Hypoeutectic	3.94	2.99	2.84	0.23	0.96	0.46
Eutectic	4.27	3.28	2.95	0.22	0.93	0.65
Hypereutectic	4.64	3.61	3.11	0.18	1.05	0.68

The study showed that the Direct Austempering After Solidification (DAAS) micrographic technique has been successfully applied to reveal the macrostructure of hypo, hyper and eutectic flake gray cast irons. The macrostructure of sand cast hypo, hyper and eutectic GI show relatively large grains in all cases. Color metallography techniques were used to reveal the austenite dendrites locations and its interaction with graphite flakes. Graphite flakes frequently cross austenite dendrite stems, suggesting that such flakes can continue growing after they have been enveloped by austenite.

This study proves that austenite dendrite growth is predominant not only for hypoeutectic but also for hypereutectic gray irons. The units usually called ‘‘eutectic cells’’ are not solidification grains, as it is commonly accepted. A great number of them are present into each grain.

Ganwarich Pluphrach [19] study of the effect of solidification on graphite flakes microstructure and mechanical properties of an ASTM a-48 GCI using steel molds (SKD 11 tool steel, S45C medium carbon steel and SS400 hot-rolled steel molds). These three steel molds are important for heat conduction and different from other works. This analysis involving thermocouples immersed in the molten cast alloy is convenient to quickly obtain solidified ingot data on the behavior of solidification processing.

Table 2.9. Chemical composition (in wt %) of an ASTM A-48 grey cast iron and three different cylindrical steel molds.

Elements & carbon equivalent	grey cast iron	Mold 1 SKD 11 Tool steel	Mold 2 S45C Medium carbon steel	Mold 3 SS400 Hot-rolled steel
C	3.25	1.42	0.44	0.23
Si	1.52	0.33	0.20	0.23
Mn	0.75	0.34	0.62	0.43
P	0.15	0.022	0.012	0.012
S	0.10	0.007	0.005	0.005
Cr	0.15	11.44	0.05	0.01
Mo	0.006	-	-	-
Ni	0.029	0.15	0.04	0.4
Cu	0.07	0.05	0.05	0.04
Sn	0.11	-	-	-
Al	0.004	-	-	-
Mg	0.001	-	-	-
C.E.	3.807	-	-	-

The study showed that material under examination is a lamellar gray cast iron with fully pearlitic matrix. Pearlite, characterized by high strength and hardness, is a product of eutectoid transformation and it is made up of alternate lamellar planes of ferrite and cementite. Ferrite, which has low strength and high ductility, is the Fe phase with low carbon content; its formation is favored by graphitizing elements, such as Si or by low cooling rates, characteristic of thick cast walls. Cementite is hard and brittle intermetallic. The formation of Fe–C compound is favored in zones of castings characterized by high cooling rates, such as thin wall sections, corners, or at the external surfaces. Properties of pearlite strongly depend on spacing between ferrite – cementite planes: the mechanical strength of pearlite increases when the interlamellar spacing decreases.

The carbon equivalent content for this material is 3.807%, a typical pearlitic microstructure of gray cast iron. Casting solidification simulation process is used to identify the defective locations in the castings from the generated time-temperature contours. It is used to determine the cooling rate influenced by the grain structure of castings. The time-temperature plot explains the effect of under cooling of solidifying castings which reflects more on the inside microstructure responsible for material properties. Thermal analysis of solidification is a technological complex procedure. The measured cooling curves collected from simple shape castings test cylinders have to be treated carefully. The number of thermocouples introduced in eight thermal fields of a solidifying cast alloy has significance on the quality of the interpreted results. A solidification simulation of the test cylinder has been done by a simulation code including kinetic models for calculation of the release of latent heat.

The main objective of this study is to bring into focus the significance of the chemical composition of the cast iron used for manufacturing the shells in order to increase juice extraction with minimum wear at the lowest cost. According to Krauss [20], the addition of each 1.00 percent, silicon reduces the amount of carbon in the eutectic by 0.33 percent. The most common range for manganese in grey iron is from 0.55 to 0.75 percent. Increasing the manganese content tends to promote the formation of pearlite while cooling through the critical range. It is necessary to recognize that only that portion of the manganese not combined with sulfur is effective. Virtually, all of the sulfur in grey iron is present as manganese sulfide, and the manganese necessary for this purpose is 1.7 times the sulfur content. manganese is often raised beyond 1.00 percent, but in some types of green sand castings, pinholes may be encountered. Chromium is generally present in amounts below 0.10 percent as a residual element carried over from the charge materials. Chromium is often added to improve hardness and strength of grey iron, and for this purpose, the chromium level is raised to 0.20 to 0.35 percent. Beyond this range, it is necessary to add a graphitizer to avoid the formation of carbides and hard edges. Chromium improves the elevated temperature properties of grey iron. The aim of this experimental study is to study the effect of adding (2.11 % Cr, 3 % Mn and 2.02 % Si) to grey cast iron cast shells in order to improve the wear resistance of the surface. The alloy design is based on adding chromium as carbide former with increased silicon content to approach the upper limit in grey cast iron to act as a graphitized. Manganese is also raised up to 2% to provide plentiful amounts to stabilize the pearlite.