SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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PROCESSING AND PELLETIZING OF HIGH GRADE MALAYSIAN IRON ORE

By

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DECLARATION

I hereby declare that I have conducted, complete research work and written the dissertation entitled **"Processing and Pelletizing of High Grade Malaysian Iron Ore".** I also declare that it has not been previously submitted for the award or any degree or diploma or other similar title of this for any other examining body or university.

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ABSTRAK

Bijih besi bergred tinggi yang diperolehi daripada Honest Sam Pembangunan. Sdn. Bhd, Chaah, Johor, Malaysia telah dikaji. Tujuan kajian ini adalah untuk menyiasat elemen komposisi kimia dan bendasing di dalam sampel ini yang perlu disingkikan, serta teknik pempeletan konsentrat sebelum ia digunakan sebagai suapan ke dalam relau bagas dengan pengikat yang berbeza dan jumlah dos serta ujian kekuatan mekanikal yang telah dikaji. Prosedur eksperimen dan teknikal untuk bijih besi bergred tinggi digariskan, operasi dan proses pempeletan dibincangkan. Hasil daripada ujian dibentangkan. Dua pengikat organik, Peridur 350 dan Peridur 315 serta kesan terhadap sifat-sifat fizikal dan mekanikal pelet telah dikaji. Keputusan yang diperolehi menunjukkan bahawa kesan optimum dos tinggi pengikat 0.1% berat pengikat lebih kuat berbanding dengan pelet dengan jumlah yang berbeza pengikat dos dan keadaan kandungan kelembapan. Dari pencirian mineral dan kepentingan bijih besi, menunjukkan bahawa hampir 62% daripada Fe di dalam sampel semasa penggumpalan adalah silika sebanyak 5%. Oleh itu, sampel dikenali sebagai bijih besi bergred tinggi. Pempeletan bijih besi diperlukan untuk mengelakkan kehilangan berat bijih besi dalam bentuk serbuk semasa penghantaran kepada industri keluli dan semasa pengendalian. Pelet yang diperbuat daripada 0.1% Peridur 350 sebagai pengikat memberi keputusan yang sangat baik dari segi kelembapan dan ketelapan untuk kekuatan mampatan semasa dibakar dan dikeringkan. Peridur 315 meunjukkan keputusan yang optimum bagi kedua-dua ujian kekuatan. Kebanyakan keputusan hasil daripada gabungan kedua-duanya pengikat dengan jumlah 0.1% berat pengikat amat sesuai kerana keputusan memberikan ciri-ciri fizikal dan mekanikal yang terbaik untuk pelet.

PROCESSING AND PELLETIZING OF HIGH GRADE IRON ORE MALAYSIAN

ABSTRACT

Research was conducted on the high grade iron ore was obtained from Honest Sam Development. Sdn. Bhd, Chaah, Johor, Malaysia. The purpose of this study to investigate the chemical composition element and impurities present in this sample, the pelletization technique of concentrate before it was fed to the blast furnace with different binders and amount dosage and mechanical strength tests have carried out. The experimental and technical procedures for high grade iron ore outlined and the pelletizing operations and processes discussed. The result of the tests was presented. Two organic binders, Peridur 350 and Peridur 315 were studied and the effects towards the physical and mechanical properties of the pellets. The results obtained shows that the optimum effect of high dosage of binder 0.1% wt of binder with fired condition are stronger compared to the others with different amount of dosage binder and moisture content condition. From the mineral characterization and iron ore beneficiation, shows that almost 62% of Fe present in the sample while major impurity, silica almost 5%. Therefore, the sample was found to be a high grade iron ore. The result of wet compression strength was lower than that proposed by industry. Pelletizing of iron ore is necessary to avoid some loss of weight of iron ore in powder form during shipping to steel industry and while handling. Result for pellets made of 0.1% wt using Peridur 350 as a binder give out an excellent result for fired and dry compressive strength. Peridur 315 give minimum or can be considered results. Combination of both binder with amount 0.1% shows the excellent results by achieving good physical and mechanical properties of pellet.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Iron ores are metallic rocks and minerals which are economically extracted majority in steel production. The ores are usually rich in iron oxide minerals such as hematite (Fe_2O_3), magnetite (Fe_3O_4), goethite (FeO(OH)), limonite (FeO(OH).n(H_2O)) or siderite ($FeCO_3$) iron combined with oxygen. Greater than 60% Fe in composition known as direct shipping ore meaning can be fed directly into blast furnace for iron-making. Iron ore is the raw material to make 98% steel pig iron. Commonly the colour of iron ore are vary in dark rusty red before it under physical liberation process (Hussain, 1985, Marsden, 1990).

Usually, iron ore are extracted to make steel from primary raw metallic ore. Steel is an alloy of iron which unique combination of strength, versatility, formability and low cost function of steel widely in construction industry, machinery, weapon, motor vehicle manufacture, railway construction, bridge building and engineering application (Lu, 2015).

1.2 Origin of Iron Ore

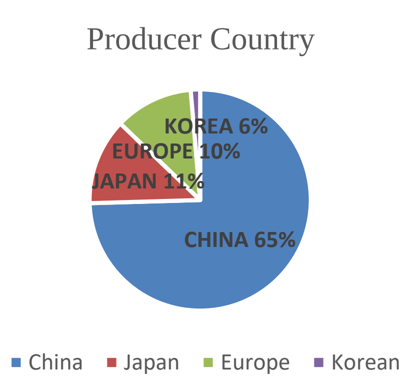
There are two processes involved in formation of iron ore. Physical and chemical, and mechanical processes (Ball et al, 1973). Iron minerals can be concentrated by precipitation from hydrosphere such as rivers, seas and lakes due to chemical or bacterial action. Iron ore might be associated with gangue mineral such as silica then iron rich limestone, sandstone and other rocks formed.

Through mechanical, weathering process may lead formation of iron. The rock may break down into small size particles then carried away by water of rivers or seas and then redeposited at new places. Due to their heavy specific gravity, it deposited sooner later than lighter ones. Examples for this formation are sedimentary hematite deposit and magnetite beach sands (Edwards and Atkinson, 1986).

1.3 World Producer of Iron Ore

Based on the World Steel Association statistics, shown that the demand of iron ore double since 2000. Increase to 94% from 2000 to 2013. Therefore, to maintain sustainability of demand more producer of iron ore is needed in the world. China is one of the largest iron producing country about 1.3Bt in 2012 about 45% of world's iron ore production followed by Australia and Brazil combined production about 919Mt in 2012. Japan (11%), Europe (10%) and Korea (6%). Iron ore consumption increased by year due to increasing international iron ore industry (Elsevier, 2015).

The three largest iron ore producers in world are Vale in Brazil and Rio Tanto and BHP Billiton with operation primarily in Australia.



China is the largest producing country in world. 65% iron producing in China. China exploits wide types of iron ore such as hematite, magnetite, limonite, siderite and other minerals. Magnetite is most predominant ore type. 80% total China's reserves contribute to the world steel associate statistics. 8% production of ore concentrated is generated by 10 producers. China's iron ore deposits low grade and polymetallic nature is required in almost mining operation to produce high grade concentrated ore for sintering and pelletizing to provide raw materials for steel industry (Elsevier, 2015).

Australia almost more than 40 years has been a major iron ore exporter. Outside China, Australia also the largest iron ore producing country, producing and exporting 579Mt in 2013 with crude ore reserves of about 35Bt containing 17Bt of iron. Export industry of iron ore in Australia was started with the lifting of the import in December 1960. Australia's iron ore growth has been increased at an impressive rate since export for lump and sinter reached more than 579Mt in 2013 (Elsevier, 2015).

Brazil is the second largest iron ore producer country in world after China. The deposits are largely located in Amazon basin in the state of Minas Gerais which is wholly owned and operated by Vale. Vale is larger single producer in world with iron reserves 14Bt. Achievement producing about 300Mt of iron ore and 39Mt of iron ore pellets in 2013. Total 80% of Brazil total iron ore export. Vale is high grade resource and reserves with average round 65-66% iron ore content hematite (Elsevier, 2015).

Basically, there are also other countries producing iron ore reserves in world. India, Canada, Iran, United State, and other countries contribute their support in achieving demand in steel iron making industry.

1.4 Producer in Malaysia

Basically, in our country Malaysia there are only a few mining industries which produce iron ore but not international known because mostly of them are private company and associate. Original site of my sample is one of the largest iron ore company, HonestSam Development Sdn. Bhd. Which collaboration with ArasKuasa Sdn. Bhd. This site is located at Chaah, Johor. Almost 40 years its age but the reserves and resources able be achieved until 100 years. Majority 90% of iron content are hematite associated with silica, quartz. Another percent there might be magnetite. Annually production almost 1Mt based on the customer demand. Request from local and mostly export to China and Singapore (Mineral & Geoscience Department Johor).

1.5 By Product

Although iron ore are the abundant element in the earth crust but there are a few of impurities associated known as by product or gangue mineral. But it can be another product if extract them out intentionally. About 5% majority bound with silicate or rarely carbonate minerals. These compositions will differentiate the grade of the iron ore. Higher content of impurities by product, lower the grade. The gangue mineral which are intrinsic part of the rock itself. The gangue is separated by physical process and removed as tailings. Mostly are the mineral quartz which is chemically inert (Law and Mudd, 2012)

Silica (SiO_2) almost present in iron ore and removed during smelting process. At temperature 1300^{o}C it reduced and become alloy with iron itself. Amount of silicon content increased as the temperature of furnace increased. The effect of silica on iron it promotes formation of grey iron. Grey iron more brittle than white iron (Turner, 1900).

Phosphorus (P) also can be one of by product of iron. It effects four consequences on iron, increase hardness and strength, lower solid temperature, increase fluidity and cold shortness. Phosphorus can make steel become brittle even at lower concentration. It can be removed by fluxing or smelting (Gordon 1996).

Sulphur also can be a contaminant in iron. Sulphur causes iron to be red or hot short. It can be removed by calcining, roasting and washing. Hot short iron is brittle when hot. This is serious problem in iron making. At hot temperature, steel easily crack and exposed it to oxidized. Large cracks can cause steel to break up. Hot short iron can be worked at low temperatures. Working at low temperatures requires more effort (Gordon, 1996).

1.6 Pelletizing of Iron Ore

Pelletizing is a common agglomeration process for iron ores fine-grained concentrate range size -250um to +45um. This process done by mixing of very finely particles size distribution of iron ore together with help of binders until it become spherical shape pellets 10-13mm in diameter. Types of pelletizer used are organic Peridur 350 and Peridur IT 315-15C with amount per percentage weight of sample used. The pellets were hardened by firing green pellets become dry pellets (sintering process). The mechanical strength of pellets was tested with several techniques to achieve good abrasion and high reducibility pellets (Satyendra, 2013, Technical).

Pellets are balls produced from agglomeration of concentrate and natural iron ores with different chemical composition and properties such as uniform size distribution range in diameter 10-13 mm. High iron content up to 70% iron. Practically moisture content of

13% or less. Uniform mineralogical composition which are reducible hematite or hematite-bearing compounds. Pellets usually high and uniform mechanical strength, low tendency to abrasion and good behaviour during transportation. It is also sufficient mechanical strength even at thermal stress under reducing atmosphere (Meyer, 1911, Berlin, 1980).

1.7 Fundamental of Pelletizing

Pelletizing process enable agglomeration fine iron ores can be used as a substitute into the blast furnace. Pellets have greater porosity 25%-30% after drying it have good reducibility. High porosity help in better metallization in DRI production. Iron ore which undergoes pelletization have uniform size range generally within range 10-13mm can be used as a substitute in the blast furnace. Spherical shape and open pores make pellets have good permeability. Pellets create uneven binder distribution when have low angle of repose which is drawback of pellets (Narayanan, 1964)

Pellets have high and uniform mechanical strength under thermal so that it can be transported for long distance without liberate. Besides, the advantage of pellets is absence of LOI. Pellets offer additional advantages due to good transportability. Usually final product concentrates are very fine-grained and easily dispersed into surrounding during transferring thus, agglomeration is necessary. This agglomeration achieved by sintering and pelletizing.

Already in 1950, the feed into blast furnace was classified in a narrow size range. Therefore, raw ores, coke and other burden were crushed, screened before supplied into blast furnace. The problem arises when raw ores, coke and burden were in narrow size for example in powder state, it may easy lost into surrounding by wind or air. Hence, sintering process needed for increasing amount of fine ores emerged and required strong extension of sinter plant capacity. As the result, the gas permeability of blast furnace burden greatly improved the pig iron capacity increased and coke consumption decreased (Meyer, 1911, Berlin, 1980).

The blast furnace does not work efficiently when there are presence of H_2O and CO_2 in raw ores. Therefore, sintering and pelletizing are required to remove of volatile ballast materials such as H_2O and CO_2 from raw ores before they entering the blast furnace. Such as ore preparation when Minette and limonite must be treated. There are plants in which the blast furnace consists of 100% sinter (Meyer, 1911, Berlin, 1980).

1.8 Principal Process of Pellets

First stage of pelletizing is formation of green balls. Iron ores with fine-grained size distribution are rolled with water, wetting liquid in ball mill drums. As the result, wet balls called green balls are formed. During green balls formation, binder as additives was added act as binding agent such as bentonite for changing metallurgical properties.

Second step, the green balls was dried in oven to obtain moisture content then was dried in the blast furnace at 1300^{o}C for an hour for removal of H_2O and CO_2 called sintering process. During heating, crystalline structure and other bonds will changed slag-forming constituent appears (Eisele and Kawatra, 2003).

After heating, the green balls were cooling under room temperature to avoid tension cracks. Maintain crystalline structures and other bonds.

1.9 Binder

Iron ores mostly must be ground into fine particles size to separate all the impurities therefore the iron oxide to be concentrated. But, it must be agglomerated into large enough particles size before it can be processed in the blast furnace. To become large enough in size therefore pelletizing is required. Binder is needed in pelletizing process to hold the fine particles size together so that it can be agglomerated and can be sintered into high strength pellets (Eisele and Kawatra, 2003).

There are two types of binders usually used in steel industry which are organic and inorganic binders. Boron-containing compound and calcium fluoride can be binder additive which is acts to improve preheat pellets strength same goes with organic and inorganic binders. In this experiment, organic binder Peridur 350 was used. Suitable and usually organic binder is carboxymethyl cellulose and binder additive is sodium borate (Basdag and Scmitt, 2002).

The problem when using organic binder is the preheat pellets strength weak due to the weak point in the production of iron pellets. Particularly in the blast furnace. The problem when using inorganic binder is the quality of pellets. As there is no gas emission, metal iron ores easily wet the silica that causes rough surface. The strength of the binders depends on the temperature the binders have been exposed to. At higher temperature the hydrogen bonded disappears, that leads to shrinking and cracking of binders (Steinhauser, 1995).

1.10 Problem Statement

The grade of iron ore deposits majority is not high due to the presence of impurities mainly silica. Therefore, removal of impurities like iron oxide is necessary. Removal of impurities affected by fine particles size. The ores must be ground to fine particles size before inserting into the blast furnace. Blast furnace only accepted certain size so that iron ore must be agglomerate together into large size therefore it can fit into the blast furnace so it can be smelted.

Powder iron ore concentrate might lose of its mass during long transportation. Therefore, pelletizing process is the solution to solve this problem. In mining industry, it is a common practice to agglomerate or pelletize finely ground iron ore concentrate to facilitate during processing and handling/shipping of the ore. Large size of iron ore concentrate enable the blast furnace for smelting.

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1.11 Objectives

The main objectives of this project are:

- ✓ To study the suitable types of binder that can be used to pelletize iron ore concentrate.

- ✓ To investigate the mechanical strength of pellet under certain load through compression tests.

1.12 Scope of Work

This study is concerned only using Peridur 350 and Peridur 315 as binder. It basically can be controlled by percent weight of binder and condition as parameters. This can be done by sintering process. The sintering process consists of combining moist iron bearing fines with solid fuel and igniting the mixture on a traveling grate with a downdraft of air. The temperature in the bed increase to about 1300^{o}C to 1480^{o}C sintering the fines into ore a porous. The bonding between particles is by recrystallization and partial melting, so no additional binder needs to be added in this process. The condition of pellets in fired by firing in the blast furnace until 1300^{o}C and then left for recrystallization. The condition also in dry by heating the pellets inside the oven until 100^{o}C within a day. Wet condition when water sprayed into the mixture of pellets with binders. Hydrogen release, the liquid bridge start forming. The main scope of work to find out the compression strength of load impact on the pellets as mechanical strength measure of the resistance to degradation by breakage due to impacts and abrasion of the pellets have been exposed to in the upper part of the blast furnace.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

World steel production started in the 20^{th} century where Bethlehem Steel was one of the world's largest manufacturers of steel. The risen of production of crude steel approaching level of 800 million tons per year. The consumption of steel increase of 3.3% of average annual rate during the 20^{th} century. 37% of the world's steel was produced by the United State. China, Brazil and India developing countries were provided basic element of steel thus they contribute to the growth of steel production at the end of the last century (O'Hara, 2014).

Steel was made up from iron ore. Iron ore was mined to make steel. Then it smelted in the blast furnaces to remove the impurities and carbon was added. Therefore, steel can be defined as iron alloyed with carbon mostly less than 1%. Steel can differentiate to two types of metals, ferrous and non-ferrous. Ferrous is steel contains iron, while non-ferrous described as metal does not contain iron. Examples of ferrous are mild steel, cast iron, high strength steel and tool steels. Non-ferrous would be copper, aluminium, magnesium and titanium, etc (Henkel, 2012).

Iron ore and other bearing material such as coke and limestone are charged into the furnace from the top. When the materials becoming hotter, they sink in the body of the furnace called stack. In the top, oxygen from the iron ore was removed by the gas from burning coke. Slag was formed about halfway down when limestone begins to react with impurities in the ore. Then, slag was absorbed by the ash from the coke. Some silica is reduced to silicon and dissolves in the iron same does carbon in the coke.

The temperature at the bottom of the furnaces risen over 3000 Fahrenheit, thus molten slag formed and floats on a pool of molten iron. In the summary, there are several processes need to be taken before iron ore introduced into the blast furnace for better operations.

2.2 Quality of Green Pellets

Quality of pellets depending on several factors including the green pellets quality, physical and metallurgical properties, firing conditions and mechanical strength. In turn, quality of green pellets depends on several parameters like initial feed seed size, moisture content and porosity. Physical and metallurgical properties depend on the types and amount of binders used to agglomerate the fine iron ore concentrate particles (Lingxiao, 2012).

Green pellets formed by interlocking between wetted particles depending on the shape of particles. Adhesion and cohesion forces due to the presence of a liquid phase. The strength of green agglomerates results from the physical forces that hold the particles together. Seed pellet known as the added moist feed fines and was made to enhance the formation and/or growth of well-formed species.

The “well-formed species” are defined to be those with finite size and those which undergo changes in their number and size by the occurrence of any of the growth mechanisms. In industrial balling systems, the balling devices are continuously operated to formed seed pellets.

Nucleation defined as any formation of new pellets from an extra supply of moist feed. Snowballing or layering is the common mechanism to form new pellets. ‘Snowballing’ or layering known as whenever new moist feed is supplied to a system of pellets, the pellets act as seeds and tend to collect the newly added moist fines.

The pellets change their mass by snowballing mechanism. The dry iron ores were layering the moist seed feed until the diameter of pellets reach +1.0cm. Pellets then taken and measured their diameter. Thus, snowballing causes change in pellet size resulting in an increase in the total mass but does not change the total number of pellets.

Porous ore like goethite and hydrated iron oxide behave differently as compared to massive ores like hematite and magnetite. Porous ores need more water for pelletizing compared to massive ores and the later are more sensitive to moisture content and binder addition. Some of the water added to the porous ore penetrates the pores.

Excess water may be stored in the pores, becoming less sensitive to moisture content. At given moisture content, porous ores exhibit higher drop numbers and compressive strength as compared to massive ores. The effects of these properties are reflected in the amount of moisture needed for proper pelletizing and particle size distribution of the feed.

Firing condition important in determining the suitable temperature and time. Mechanical strength after firing dry pellets to determine the resistance of pellets towards pressure. In process technology of pelletizing, there are four stages involved in production of pellets. Most of the blast furnaces requires feed with definite structure and size besides chemical specification for crushing and screening essential.

Many furnaces now specify maximum sized 6.35cm as the top size and such ore have minimum sized of -0.95cm with high chemical content more than 62% Fe. In the steel plant, high grade ores only necessary the ores to be reduced in size and graded. At the mine, the ores crushed to maximum size range 10-20cm, further crushing and screening before export terminal then at the steel plant, only have taken ores size range -3.81cm + 0.635cm; the larger size to be removed.

Low grade ores, the iron content must be upgraded by gangue removal. Low grade ores are not amenable to be concentrated by mineral processing. When the iron ore was agglomerated into large particles is blown out the furnace as the flue dust.

2.3 Physical and Metallurgical Properties

The growth of green pellet was controlled by addition of binders. Addition of binders include the types and amount of binders. The amount of binder addition in the agglomerate varies at least 0.01 wt%, preferably at least 0.02 wt%, most preferably 0.03 wt%, and generally at most 1.0 wt%, preferably at most 0.8 wt%, and most preferably at most 0.5 wt%, based on the total weight of the agglomerated particles (Schmitt, 2005).

The binding addition enhanced the binding strength of the pellets as they transported from the furnace to the kiln. The binder additive containing boron and/or calcium fluoride found has been preheat strengthening activity. For many years, bentonite clay most popular in choice inorganic binding agent in pelletizing process for mineral ore concentrate. By using bentonite as binding agent comes up with pellets having good preheat strength, very good wet and dry strength. Bentonite also desired degree of moisture control.

The presence higher amounts of silica have several disadvantages. When bentonite was added to pellets contains of silica, the efficiency smelting operation of the blast furnace decreases. The use of bentonite as binding agent can cause alkalis presence. The presence of alkalis in the blast furnace causes pellets and the coke to deteriorate and form scabs on the furnace wall, which increase fuel consumption and decreases the efficiency of smelting operation.

2.4 Pelletization Technology Process

There are several technologies available for iron ore pelletizing process. Some of them are Shaft Furnace Process, Straight Traveling Grate Process, Grate Kiln Process, Cement Bonded Process, (Grangcold Process, MIS Grangcold Process, Char Prosess and Hydrothermal Process) etc. However currently, Grate Kiln Process (GK) and Straight Traveling Grate (STG) process are more popular processes. The Grate Kiln Process was developed by Allis Chalmer and the first plant on this technology was constructed in 1960 (Sarna, 1965).

In this process, the traveling grate is used to dry and preheat the pellets. Materials moves until temperature of 800^{o}C to 1000^{o}C the magnetite gets converted into Fe_2O_3 in exothermic reaction. The liberated heat hardens the green pellets which is helpful to withstand the tumbling impact in the rotary kiln. The Straight Traveling process developed by former Lurgi Metallurgie accounts. This process double deck roller screen ensures right size of green pellets is evenly distributed across the width of the traveling grate (Sarna, 1965).

2.5 Types of Binders Used

There are two types of binders usually used in pelletizing process; organic binding agent and inorganic binding agent. Binding agent is added to the wetted iron ore concentrate to hold or bind the iron ore together, so that agglomerates can be transported without losing particles for further processing. Binder system is substantially free of hydrophobic liquid and comprises; (1) an inorganic binder (2) organic binder and (3) a binder additives from boron-containing compounds, calcium fluoride.

The boron-containing compound is selected from boron oxide, calcium borate, sodium borate, boric acid, and boron nitride. The organic binder comprises a carboxymethyl cellulose (Basdag, 2005). However, the pellets preheat strength has always been problem with organic binders. It is weak point in the production of iron ore pellet in Grate kiln or shaft furnace. Organic binders include polyacrylates, polyacrylamide, partially hydrolyzed polyacrylamide, copolymers, cellulose derivatives such alkali metal salts of carboxymethyl cellulose, guar gum, dairy wastes, starches, alginates, pectins, and the like are the commonly used organic binders because it does not increase the silica content of the ore and impart the physical and mechanical properties comparable to those of bentonite (Basdag, 2005).

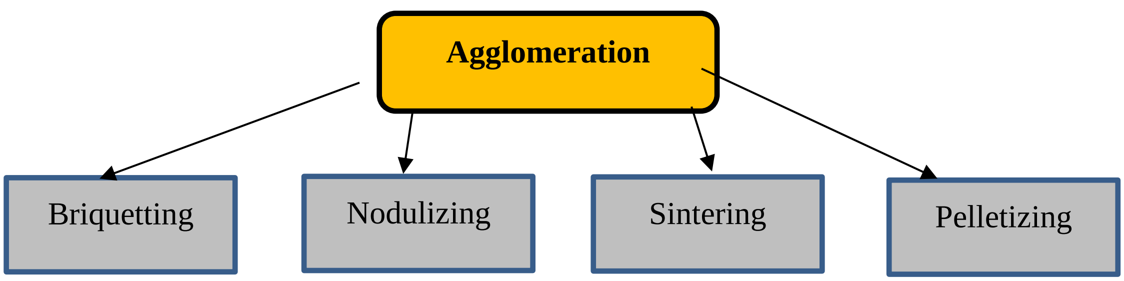
Organic binder burns out during the firing operation thus increases the micro porosity of the pellets. When the surface area become larger, the permeability of pellets produced increase. The reduction of iron oxide is more efficient than the pellets prepared with bentonite.

2.6 Concentrated Fine Iron Ore

Concentrated fine iron ore are defined as high grade quality iron ore in powder form. This kind of form need to be agglomerated before it entered the blast furnace. Fine size iron ores are not suitable to be fed into the blast furnace. Therefore, the powders must be agglomerated into larger size particles that will be improve permeability of the furnace burden, increase the rate reduction and reduce amount of materials blown out of the furnace as dust because fines tend to be carried away as dust by the high gas flow rates (Blhaj, 2009).

2.6.1 Agglomeration

For agglomeration, there are four types of agglomerating processes. They are briquetting, nodulizing, sintering and pelletizing.



(a) Briquetting

Briquetting is the cold binding process. Usually fine grained iron ore are pressed with or without binder with addition of some water under high mechanical pressure. Fine iron ore shaped briquettes and then subjected the briquettes to a hardening process. Usually, briquetting was used for some direct production due to the reason of metal produced is ductile enough to bond together by mechanical deformation without the need for binder. However, the production of briquettes for use in the blast furnace decrease after 1950 because of briquetting of unheated iron ores has not been successful due to the available binders do not develop sufficient strength (Blhaj, 2009).

(b) Nodulizing

Nodulizing is the cold binding process of passes of fines along with carbonaceous materials through inclined rotary kiln heated by gas or oil. The temperature inside the kiln are hot enough to soften but not enough to fuse the ore. The nodules are very dense, slaggy and lack required porosity therefore this process not a great favor. Mostly used for the recycling recovered iron ore wastes in the steel plant. Nodulizing not required the addition of binders.

Nodules formed are bonded together by the liquefied portion of the melted fines. The advantages of this process, insensitivity to feed moisture and particles size and high strength of the nodules. However, it is also has disadvantages which this process consumes high fuel, operating and difficult to control (sensitive to charge in fusion point), non-uniform nodules size and poor reducibility in the blast furnace make this process uncompetitive, and no longer use (Ban, 1985; Blhaj, 2009; Eisele 2003).

(c) Sintering

The production of blast furnace iron and direct reduce recorded 1183 Mt and 73Mt during 2014, as per World Steel Association. Most of iron ore in the form of sinter and pellet. The origin of sintering process started 1887 when F. Harbelein and T. Huntington of England invented the agglomeration process for sintering of sulphide ores. Middle 19^{th} century, small sintering pot was constructed in England.

The sintering was carried with the sintering bed being blown with air from bottom upwards and known as up-draft sintering process. In 1902, W. Job invented the sintering of pyrite cinder and dusty iron ores with addition of coal and air blowing. In 1906, EJ Savelberg developed a development in sintering process by using sintering mixture containing coal and coke breeze. A belt type sinter machine for vacuum sintering was invented by AS Dwight and RL Lioyd in 1906 and same type machine but the operation with air blowing by (W. Barth, 1913).

A rotary type of sintering machine was invented by Von Schlippenbch in 1909. Rectangular tilting pans for vacuum sintering was granted by JE Greenawait in 1914. While, the circular type sintering machine was invented by Sakharnov in 1930. The Huntington and Haberlein was the best method for sintering process prior to Dwight Lloyd patent number 882517 of 17^{th} March 1908. This process capable producing sintering materials but the composition and cost of handle was unsatisfactory for the product of mass. But it produced in great pots which tons of ore were mixed with lime and burned under draft force upward. However, uniform product could not be produced.

This process consists of combination moist bearing fines with a solid fuel and igniting the mixture. The temperature increases about $1300^{o}C$ to $1480^{o}C$ sintering fines into porous which suitable for use as blast furnace feed. No additional binder needs to be added in this process because the bonding recrystallization and partial melting. Sinter perform well in the blast furnace, which fluxes added before sintering and sized to 6-40mm before charging to the furnace. Mostly used for processing ore from mines to the blast furnace operation and recycling iron bearing fines such as furnace dust and mill scale (Blake and Komarek, 1985; Eisele and Kawatra, 2003; Ball et al, 1973, Blhaj, 2009).

(d) Pelletizing

Pelletizing is a process at which a green unbaked pellet or ball formed and hardening by heating. This process is the further improved for using micro fines ores besides development of sintering process which is alternative ways. First phase of the development in the pelletizing process applied in Sweden and Germany use major quantity of fines in the sinter mix led to limit productivity. The first patent of pelletizing was granted in 1912 to AG Andersson of Sweden (Patent number 35124) and in 1913 to CA Brackelsberg in Germany. 120 tons per day capacity was constructed by Rheinhausen Steel Plant in 1926 for Krupp. In 1937, the plant was dismantled for making to large sinter plant.

The second phase of development of pelletizing process was developed in USA, the technique and source studied in the Mines Experiment Station of the University of Minnesota, USA. At this phase, the problem of utilizing low grade iron ore was examined by Dr. EW Davis and his associates in Minessota. Low grade ores (25% to 30%) Fe are quite hard and abrasive. These ores originate from high grade and have been evolved by natural leaching and oxidation. The recovery of these low grade ores about 80% of size – 325 mesh for liberation, concentrate containing about 65% Fe and 8% silica (Narayanan, 1964).

In 1945, the usage of very fine concentrate was investigated by researchers and development at the station and evolved a promising concentration technique. The concentrated was balled in rotating drum and hardened by heating using suitable heat treatment in a shaft kiln. The hard pellets about 15mm to 25mm in diameter were thought to be a suitable feed of the blast furnace. By 1949, USA and Sweden were generally agreed that the best way to prepare balls from the concentrate in a rotating drum. But, the opinion was divided on the heat treatment method.

Vertical shaft kiln was used in pilot research plant, by fed moist balls of concentrate into the top moving downwards against flow of hot gases which first dried and then elevated the temperature to the hardening region. In 1943, experimental work was conducted by Davis which the pellets were fired in the blast furnace and the similar experimental was built in Sweden after World War II.

The pelletizing is an economically feasible method of agglomerating fine grained concentrate become most practicable and it became evident in 1950s. The first pelletizing plant was built and operated in Sweden where pellets were fired in shaft furnace with capacities 10 to 60 tons per day. Fine ores concentrate usually pelletized at the mine and shipped as pellets to steel company. Then, the pellets fed into the blast furnace. Usually, high grade ores were pelletized and the size about 90 µm. The fired pellets are durable and easy to handle. The pellets also perform well in the blast furnace with good permeability and reducibility (Blhaj, 2009).

The concentrate is thickened and wetted to provide material with desired moisture content (around 10%). Binder as Peridur mixed with the moist concentrate in small quantity where the moist concentrate is pelletized by passing it through a drum or disc which rotates at about 25 rev/min. The green pellets are hardened by three processes; drying, firing and cooling. Three different types of firing equipment generally commercial use; the vertical shaft, the traveling grate and the grate kiln (Forsmo, 2006). Pelletizing is a process which the concentrate is rolled in wet condition with binder into balls using either pelletizing disc or pelletizing drum then dried and hardened usually heating to 1300^{o}C (Firth and Manuel, 2005).

However, this process has some difficulties. First, the difficulty of securing gas distribution. Second, the difficulty of securing stock descent, uniform pellet treatment and trouble free discharge of product. Third, the difficulty of securing a high output from one unit. And uncertainty appropriate kiln shape (Andersson, 2010).

2.7 Pellet Criteria

To make the pellets there are some criteria must follow:

i. The concentrate must in fine grained size

ii. Sufficient moisture is needed to make ore are sticky enough to pelletize.

iii. A binder is necessary to hold particles grain together after the pellets is dried and before it finally hardened and tested.

The determination of pellets must (1) good resistance to breakage during shipping or handling; (2) good resistance to weathering; (3) uniformly high grade chemical composition; (4) good reducibility in furnace and (5) resistance from swelling and disintegration during reduction. The earlier investigation state that the pellets must be a good shipping product, an excellent blast furnace feed and high grade composition (Ghosh and Chatterjee, 2008; Devaney, 1985).

2.8 Mechanical Strength

Physical properties of the pellets must be paid great attention to measure of their ability to withstand load tending to reduce size during handling and transporting over the pellets from the mine to the steel company industry. Hence, the pellets received by the customer in good condition. There are several tests carried out by earlier research to determine the physical properties of pellet;

i. Wet drop strength
ii. Compression strength
iii. Plastic deformation
iv. Resistance to tumbling and abrasion

2.8.1 Wet Drop Strength

Moist pellets are dropped from 90 cm height onto a steel plate until the first sign of failure seen. The number of drops required to produce breakage is recorded (Pietsch, 2002, Forsmo, 2006). Drop number shows the green or wet pellet strength during a fast impact for example the impact which occurs during loading and unloading from a conveyor belt. The drop number must be high enough for the green pellets to survive the transportation from the pelletizing to the blast furnace.

The drop number influence by the moisture content in both plasticity and elasticity with increasing moisture content and increasing binder dosage (Forsmo, 2006). Wet strength is a measure how well the pellet particles holding together can resist a force expressed as ratio of wet to dry force at break. The particles mainly held together by hydrogen bond. To improve the wet strength usually binder is commonly use. The use of chemical binder can retain 10% to 30% of the original strength by hydrogen bond (Neimo and Leo, 1999).

2.8.2 Compressive Strength

Compressive strength can be described as the ability of pellets to withstand loads tending to reduce size which load to break and failure. Pellets fracture when exceed their compressive strength limit. The amount of deformation of shape and size can be considered as the limit of compressive load.

Compression strength usually test by using Instron Machine or Universal Testing Machine. Load are impacted the pellets until it starts to fail or break to reduce it size. Measurement of compression test are affected by the moisture content of the pellets itself. When the moisture content increase, the strength of compression decrease.

2.8.3 Plastic Deformation

The deformation of pellets is usually observed and recorded during the compression test. Plastic deformation can be described as the changes of size or shape and cannot return to the original shape after certain load are given. Plastic deformation test are most accurate rather than drop number test. This is because the load impact on the pellets more accepted compared to the load given by human.