Kufa Journal of Engineering
Vol. 10, No. 4, October 2019, P.P. 1-15
Received 11 November 2018, accepted 14 January 2019

IMPROVING PRODUCTIVITY BASED ON THE MOVEMENT OF MATERIALS INSIDE A GRINDING CEMENT MILL

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HTTP://DX.DOI.ORG/10.30572/2018/KJE/100401

ABSTRACT

The problem addressed by this research is how to increase the production of cement mills in the Kufa cement plant when changed the pattern of production and what are the reasons that led to the reduction of productivity. After investigating the research problem, it is found that the change in the pattern of production has led to a change in the size of clinker granules from (15-50 mm) in the case of ordinary cement to (5-15 mm) in the case of sulphate resistant cement. As a result, a change in the behaviour of clinker movement would occur inside the cement mill, that is, the fineness clinker penetrates the grinding balls, and thus reducing the grinding efficiency of the balls, with a diameter of 100 mm, and then productivity. The results of this research have shown that the waiver of balls with a diameter of 100 mm and compensation of smaller balls while maintaining the same weight of the charge led to the increase of the total surface area of the balls increasing as such productivity from 60 t/h to 85 t/h. In conclusion, it appeared that the findings of this study match those of Cleary (2009), which state that the potential energy retained by small balls is greater than that retained by large ones. Thus, the efficiency of the grinding will be increased. In addition, the reduction of the diameter of the balls will prevent the penetration of the clinker between the balls unless they are crushed into soft granules. This will maximize benefit from the kinetic and potential energy of the grinding balls.

KEYWORDS: Critical speed; Grinding media; Blaine; Ordinary cement O.C; Sulphate resistance cement S.R.C.

1. INTRODUCTION

Cement industry in the world is an important aspect in the development of countries and infrastructure. It has lately witnessed significant technological developments with regard to the efficiency and use of the raw materials in order to improve productivity and ensure the good quality of the product.

In general, cement manufacturing passes through four main stages: (1) aggregation and cracking of limestone, (2) wet milling, (3) rotary kiln for burning process to produce of clinker that goes to the final stage, and (4) cement mills for grinding after adding 1 - 3% gypsum (IQS No. 5, 1984).

Grinding is a very common process in the cement industry used to reduce the size of half made material (clinker) to the desired size or fineness. The process of abrasion, attrition, crushing and grinding in the cement tube mill are caused by the interaction of balls among them and the interaction of balls with the lining of the mill. Many milling techniques such as air classifier mills, impact mills and the vertical mill have been developed to achieve the desired size. A large amount of energy is consumed during the grinding process, and much of that energy, like heat and sound, is dissipated, and thus, more energy is consumed during this process (Wang, 2016). According to some studies, cement grinding consumes about 40% of the total energy of the cement production on each phase (Mejeoumov, 2007). According to a study by Longhurst, (2010), the lower grinding efficiency to 5% of the mill of 150 tons / hour and the sale price of 90 dollars / ton, this leads to a loss of 5 million dollars per year. Optimizing milling operations is therefore crucial to reducing the impact of energy in many industrial processes. Thus, a deep understanding of the grinding process is essential in order to achieve the optimal fineness of the final product.

The milling process consists of three stages: feeding, grinding, and separation. Cement is produced by grinding clinker (a semi-made material produced from burning the mix of clay and limestone in rotary kiln) in horizontal mills (containing grinding balls) or vertical or other types of mills with add 1-3% gypsum to reach the desired specific surface (fineness) of cement.

The specific surface of the cement or fineness is expressed as total surface area in square centimeters per gram, or square meters per kilogram, of cement (ASTM C204, 2007). Fineness influenced by a number of factors, including the physical and chemical properties of clinker, mechanical factors and operational factors. Mechanical factors are related to the dimensions of the ball mill and the aerodynamic components, and the physical properties such as the length and radius of the mill, the speed of rotation, shape and type of lining. The physical and chemical factors of clinker are related to the mineral composition of the clinker, especially the C_3S ($3CaO.SiO_2$) and C_2S ($2CaO.SiO_2$) compounds, which affect grindability and thus grinding efficiency. The cement mill is often accompanied by some auxiliary equipment, like the falofon, which gives the operator signal sound about the amount of material inside the mill and thus control it to achieve the appropriate fineness of cement. Fineness can be measured by using *Blain* method is the unit of total area per unit weight (cm^2/ g) or the remaining percentage on a sieve 32-um (Avsar, 2006).

In recent years, many important research papers have been implemented to develop the grinding process, which has a great role in achieving economies of scale, reducing energy consumption and improving the cement properties. Yan et al., (2011) focus on the speed of the mill: accelerating the rotation speed of the cement mill is conducive to the increased production, but at the same time, it would increase energy consumption and yet the mechanical corrosion of the grinding balls and lining. However, through a comprehensive assessment, the research leads to the increase of production and profits, with an output improved by 13%.

Longhurst (2010) discusses the continued efficiency of milling by studying the value of the abrasion rate of grinding balls, and compensating this rate every period of new balls. This contributes to improving and continuing productivity, and thus increasing revenue. He also looks in the ability to set a time schedule for the purchase of grinding balls. Jankovic et al., (2004) reaches the conclusion that with the use of crushers for clinker materials, cement production increased by 10-20% on condition there were no energy determinants in other parts of the milling system.

Bian et al., (2017) studied the effect of the speed of rotation and the shape of the lining as well energy consumption on the movement of the balls inside the mill using a laboratory mill designed for this purpose, by using the Discrete Element Method simulation DEM “DEM, which is a simulation method that models particulate systems whose motions are dominated by collisions. This involves following the motion of every particle or object in the flow and modeling each collision between the particles and between the particles and their environment” (Sinnott et al., 2017) and reached several results including:

- The mill speed has a significant impact on the movement of grinding media and trajectories. The laboratory results were very close to the simulation method DEM, especially at the speed of 70-80% of the critical speed. “If the peripheral speed of the mill is very high, it begins to act like a centrifuge and the balls do not fall back, but stay on the perimeter of the mill. That point in the rotation speed is called the critical speed” (Sahoo and Roy, 2008)

- At the specified speed of the mill, the height of the lining lifter affects the path of the fall of grinding media. When the height of the lining is very low, most of the grinding media will move relatively slowly and thus the efficiency of grinding will be reduced. When the height of the lining lifter is very high, the paths fall of particles is very high and many of them will damage the lining. These conditions can accelerate the wear rates of lining, so the acceptable height of the lining lifter is 10-17 mm for this type of mills.
- The number of lifters has a significant impact on cataracting phenomena (It is the movement of the grinding balls from the highest position when the cement mill rotation and its fall downwards) and on particle streams, the number of falling particles and particle streams increases with the increase of the number of lifters.

Kufa cement plant is a one of the factories belonging to the Iraqi Ministry of Industry and Minerals. Since its establishment, it has been specialized in the production of ordinary Portland cement that meets the requirements of Iraqi standard specification No. 5 \ 1984. The production line in the Kufa cement plant consists of three raw mills, four rotary kilns and three cement mills. In the last a few years, the change in the purchasing behaviour of cement users led to the purchase of sulphate resistant cement more than the purchase of ordinary cement. The plant management realized this important change in the customer's behaviour, which had a significant impact on the sales volume and market share. This made the management change the pattern of production of ordinary Portland cement to sulphate resistant cement and succeeded in this change. But that change led to a sharp decline in the productivity of cement mills by almost half.

The aim of this research is to increase the production per hour of the cement mill Z1 by increasing the total surface area of the grinding balls with increasing the number of balls which lead to the reduction of the piece weight of the ball in accordance with the size of the clinker grains fed to the mill.

2. EXPERIMENTAL PART

2.1. The design specifications of cement mills Z1

The cement mill Z1 was designed by the Danish company FL. Smidth, with a design capacity of 110 t /h. It is made of a metal cylinder consisting of two chambers. The first chamber has an effective length of 4.7 m and its effective diameter is 4.02 m. The second chamber has an effective length of 7.75 m and an effective diameter of 4.15 m. The rotary speed of the mill is 15.46 rpm, which constitutes 75% of the critical speed.

Crashing of large volumes of clinker particles is accomplished in the first compartment. The first compartment contains 85 tons of grinding media (balls) with different diameters (100, 90, 80, 70 and 60 mm) distributed in different weight ratios while grinding to the required fineness is done in the second compartment. It contains 145 tons of grinding media type Cylpebs with different dimensions (22*22, 19 * 19 and 16*16 mm) distributed in different weight ratios as well, as shown in Fig. 1.

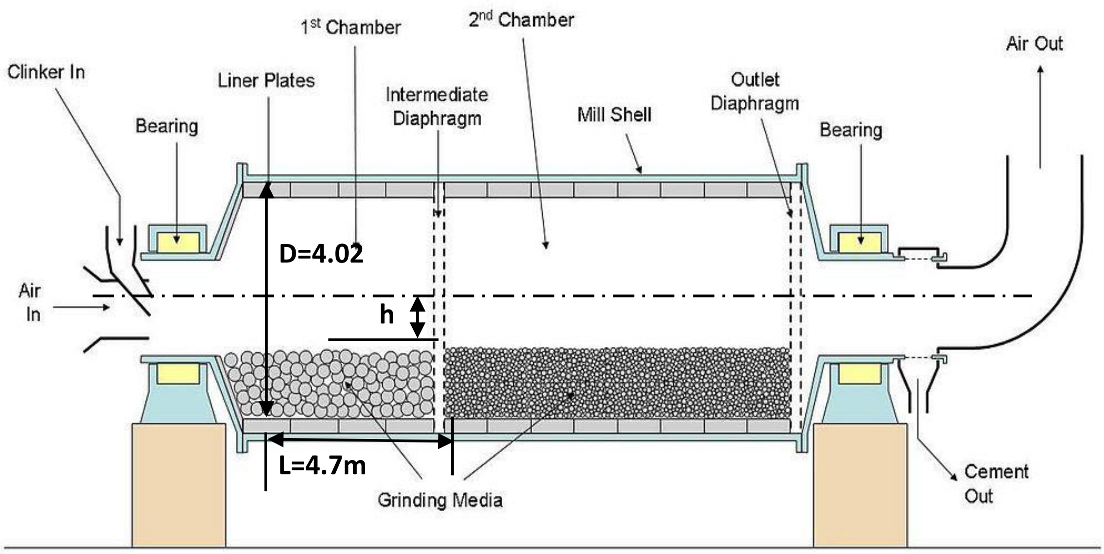

Fig. 1. Illustration of the cement mill Z1 in kufa cement plant.

2.2. The principle of grinding process

The idea of grinding clinker and turning it into cement with a certain specific surface is based on the principle of the centrifugal force that lifts the grinding balls to a certain level and descends down again while the mill rotates. These movements of grinding balls of different sizes produce the forces of shear and compression as well shocked forces lead to crushing and fragmenting clinker in the first compartment to fineness about 2000 cm^2/g Blain. When the material moves to the second compartment, it grinds to fineness (Blain) of 3000 cm^2/g or more.

Fig. 2 shows the grinding process in the first chamber, with the rotation of the mill, the balls rise to a certain level (shoulder) by the centrifugal force and separated at the detachment point, and fall some of the balls towards the toe (impact zone) which causes the clinker granules (material) to break into very small parts. The other balls revolve around the center of circulation. Those small parts of the material will penetrate the balls in the abrasion and attrition zone, which grind into very soft granules due to the shear and compression forces produced between the balls in this zone (Powell and McBride, 2004 and Katubilwa, 2008).

The grinding efficiency depends on several factors, some of these factors are the ratio of (D/L) of the mill, the capacity of the mill, the distribution of grinding media, the speed of the mill and the shape of lining. Here, the rise level of the balls when the mill is in rotation depends on two main factors: the speed of mill rotation and the lining shape. Both factors cannot be changed without significant cost losses.

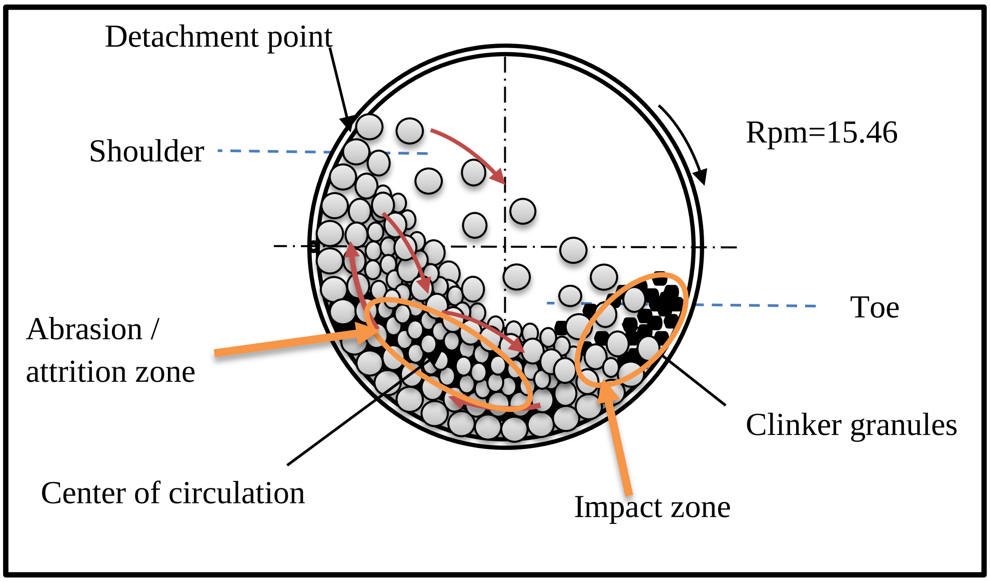

Fig. 2. The grinding process in the first compartment when producing O.C. according to (Powell and McBride, 2004 and Katubilwa, 2008).

2.3. Calculation of charge when producing ordinary cement (O.C)

The company designing cement mills has developed a number of mathematical equations for the purpose of charge calculations based on the dimensions of the mill as well the speed of mill rotation and the fullness percentage, in order to reach the weight required to be added from the grinding media in each compartment (FL. Smidth, 2007):

$$F = 0.01\, q \;\; .\, W \,.\, V \qquad (1)$$

Whereas:

F Required weight of charge measured in tons (t)

q Specific charge from the Table A1 which depends on (*h/D*)

h Centre distance (m)

D Effective diameter of compartment No.1 (m)

W Bulk weight measured in tons per cubic meter (t/m^3) from Table A2

V Volume of compartment No. 1 = $\frac{\pi}{4} . D^2 . L$ (m^3)

L Effective length of compartment No.1 (m)

The first step in the charge calculation is to select the *q* value from Table A1, depending on the design requirements of the designing company and then conduct the rest of the calculations according to the equations mentioned, to get the results as shown in the Table 1.

It should be noted that we can use q and *h/D* mutually. That means if we need to know *q*, this can be measured by the *h* distance inside the mill divided by *D*, and we can consult Table A1 to get the value of *q*. On the other hand, if we aimed desired specific charge assume 33% we can use this value to know *h/D* inside the mill when we complete charging and comparison it on Table A1.

Table 1. Charge calculation for compartment No. 1.

		Value
Specific charge (target)	q	33
From Table A1	h / D	0.134
Centre distance (When charging complete)	h	0.54 m
Effective length	L	4.7 m
Effective diameter	D	4.02 m
Volume	V	59.6 m^3
Bulk weight for balls from Table A2	W	4.3 t/m^3
Weight of charge	F	≅ 85 t

After reaching the required weight of the charge, which is 85 tons, we start the second step, which is the distribution of the balls according to the size. There are two methods for the distribution of the charge according to the different sizes of balls. In terms of the first method, there is an equal number of balls of each size. The second is the distribution of the grinding media in the first chamber with diameters (100, 90, 80, 70, and 60) according to the ratios established by the designing company (FL. Smedth Company) on constructing the Kufa cement plant. Taking into account the hardness and size of the clinker feed particles. Fig. 3 shows the grinding ball sizes and hardness of three types of feeding. This requires the addition of large sized balls when the feed size is increased (Duda, 1976).

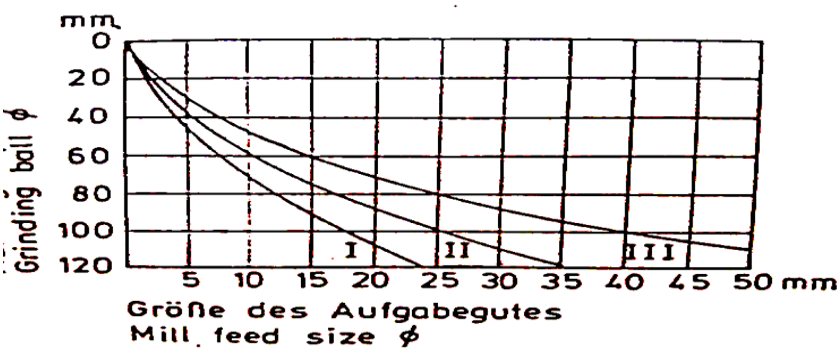

Fig. 3. Grinding ball and feed size ,(I) Hard material ,(II) Medium hard material , (III) Soft material , (Duda, 1976).

Where the size of clinker feed to the mill in the case of ordinary cement is (15-50) mm and this was the size of balls (100 - 60) mm in the first compartment distributed designed by FL. Smidth company as shown in Table 2:

Table 2. Standard distributions of balls in compartment No.1 when producing O.C (before modification).

Weight of charge F	t	85				
Diameter (size) of ball	mm	100	90	80	70	60
Contribution Ratio	%	22	32	22	13	11
Weight of size	t	18.7	27.2	18.7	11.1	9.4
Surface area of one ton	m^2 / t	7.7	8.5	9.6	11.0	12.8
Surface area of size	m^2	144.0	231.2	179.5	121.6	119.7
Total Surface area	m^2	796				
Weight of one ball	kg	4.100	2.989	2.099	1.406	0.886
Number of balls per size	No.	4561	9101	8910	7860	10554
Total number of balls	No.	40,985				

Now we need to calculate values of piece initial weight and specific initial surface; these values can be obtained from the following equations:

$$\text{Piece initial weight} = \frac{\text{F}}{\text{Total number of balls}} \qquad 2$$

$$= \frac{85(10^6)}{40985} = 2074 \text{ g}$$

$$\text{Specific initial surface} = \frac{\text{Total Surface}}{\text{F}} \qquad 3$$

$$= \frac{796}{85} = 9.364 \text{ m}^2/\text{t}$$

2.4. Calculation of charge when producing sulphate resistant cement (S.R.C)

The Kufa cement plant has planned to change the pattern of production from ordinary cement to sulphate resistant cement. This trend is a sort of adaption to conform to the developments of local needs and competition in the cement market. The management of the plant has noticed that that the customers have begun to prefer (S.R.C) on the ordinary cement (O.C). They think that the S.R.C is better than the O.C in all properties. In fact, the S.R.C is better in resistance to the sulphate in the soil only; the other characteristics of O.C may outperform S.RC. Anyway, of the final purchase decision is the buyer's himself. The plant then should adjust its policy to the customer's new preferences and needs.

As a result of the successful idea of producing S.R.C at the level of the characteristics of the physical and chemical product, the plant faced a situation of low production of cement mills to about 60t/h or less. After studying this problem, it appeared that producing S.R.C led to a transformation in the size of the distribution of clinker granules from 15-50 mm in the case of O.C to 5-15 mm in case of S.R.C as shown in Fig. 4.

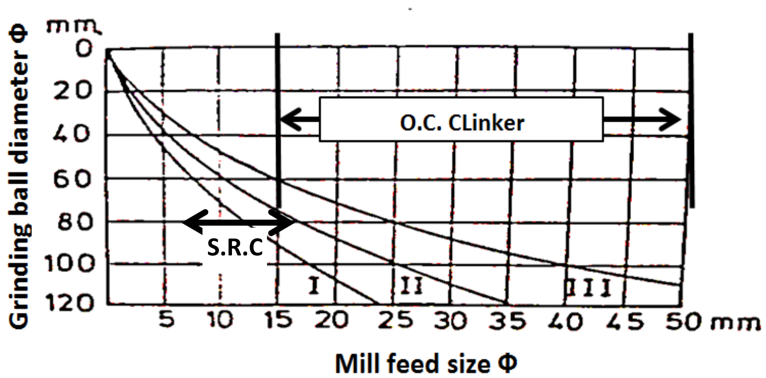

Fig. 4. Comparison between clinker size distribution in O.C and S.RC.

This means that the relatively small size of the feed allows it to infiltrate into the gaps between the balls without subjected to the crushing process in the impact zone. The clinker moves directly to the abrasion - attrition zone between the small balls. Moreover, a large quantity of clinker will penetrate the first chamber with minimal exposure to the shear and crushing forces. This leads to a decrease in *Blain* of output to less than 3000cm^2/ g when attempting to increase the amount of feed to more than 60t/h. This requires keeping productivity at about 60t/h to maintain the desired level of *Blain* because the increased feed-in such circumstances will increase the filling rate in the first chamber, and thus, will increase the proportion of materials not grinded and crushed. This leads to lower efficiency in the first compartment.

According to that analysis the balls whose size is 100mm in the first chamber do not have a significant impact on the grinding process because the materials are small in size and do not settle in the impact zone as shown in Fig. 5.

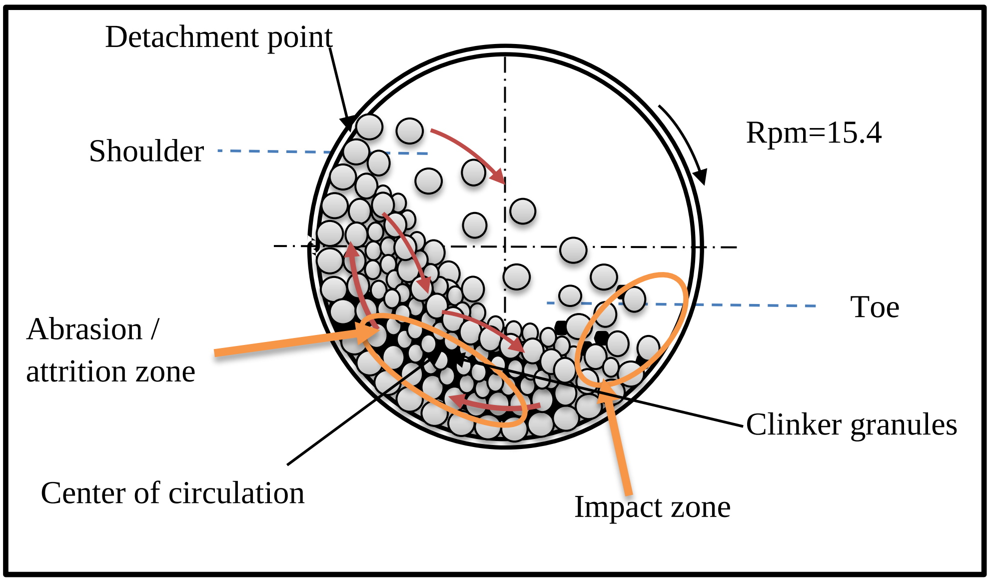

Fig. 5. The grinding process in the first compartment when producing S.R.C.

Cleary (2009) employed the DEM simulation models to discover that small balls absorb nearly twice of energy of collisions compared to large balls per unit of mass. The dissipated energy increases linearly along with the increasing the size of balls. Thus, this work aims to adjust the size of balls in the first chamber by adjusting the range sizes from (100-60 mm) to (90-50 mm) in order to increase the number of small balls. These adjusted balls lead to the increase of the total surface area of charge as well as reducing the energy dissipation while increasing the efficiency of energy absorption. The charge calculations according to this analysis is shown in Table 3.

Using equation (2) and (3) we get the following:

$$\text{Piece initial weight } = \frac{\text{F}}{\text{Total number of balls}} = \frac{85(10^6)}{63217} \cong 1345\text{g}$$

$$\text{Specific initial surface } = \frac{\text{Total Surface}}{\text{F}} = \frac{911.3}{85} = 10.72\ \text{m}^2/\text{t}$$

Table 3. Distributions of balls in compartment No.1 when producing S.R.C (after modification).

Weight of charge F	t	85				
Diameter (size) of ball	mm	90	80	70	60	50
Contribution Ratio	%	22	32	22	13	11
Weight of size	t	18.7	27.2	18.7	11.1	9.4
Surface area of one ton	m^2 / t	8.5	9.6	11.0	12.8	15.4
Surface area of size	m^2	159.0	261.1	205.7	141.4	144.0
Total Surface area	m^2	911.3				
Weight of one ball	kg	2.989	2.099	1.406	0.886	0.513
Number of balls per size	No.	6257	12959	13301	12473	18227
Total balls number	No.	63,217				

3. RESULTS AND DISCUSSION

The process of modification in this study is based on the behavior interpretation of the movement of material inside the mill. It draws on personal experience and yet consulting relevant studies that have dealt with the effect of the size of the materials used on the size of the grinding balls as well as the principles of energy absorption. Some research papers have shown that the small balls are more efficient in absorbing the energy than large ones.

As mentioned above, the size of clinker granules (clinker fed) in the case of producing O.C ranges between (15-50) mm, which makes it settle in the impact zone and thus break down into small parts by falling balls on them as shown in Fig. 2. This can be deduced by calculating the largest diameter of the gap generated between three balls with a diameter of 100 mm. On the assumption that the clinker granule is very similar to the spherical shape, it is possible to use the following equation to obtain the gap diameter (clinker diameter) as shown in Fig. 6:

$$d_{clinker} = 0.3094\ (D_{ball}/2) \tag{4}$$

$$d_{clinker} = 0.3094\ (100/2) = 15.47\ mm$$

As can be seen, the largest diameter can be composed of three ball size (100 mm) is 15.47 mm so that most of the clinker grains will not be able to penetrate the balls unless exposed to cracking to become small granules. These small grains will move to the abrasion - attrition zone to be grinded into smaller particles.

In the case of producing S.R.C, the size of the clinker grains ranges between (5 - 15) mm, so most of the grains will enter between the balls without exposure to the crushing in the impact zone as shown in Fig. 5, thus reducing the productivity of the cement mill when converting from producing of O.C to S.RC. In order to address this problem, two actions are taken:

First: Exclude balls with a diameter of 100 mm from the mill because it does not make any important effort in the process of milling and replace them by balls of a less diameter. Thus, to calculate the largest diameter of the gap generated between balls with a diameter of 90 mm according to the equation (4), we find:

$$d_{clinker} = 0.3094\ (90/2) = 13.92\ mm$$

Because of $d_{clinker}$=13.92 mm is located between (5-15mm), so, a part of the clinker granules will settle in the impact zone, thus increasing the milling efficiency.

Second: Increase the number of balls by using the range (90 - 50 mm) instead of (100 - 60 mm) in order to increase the total area of balls as well as the contact area between the balls and clinker, thus optimization of utilization of shear and compression forces is produced between the balls in abrasion - attrition zone.

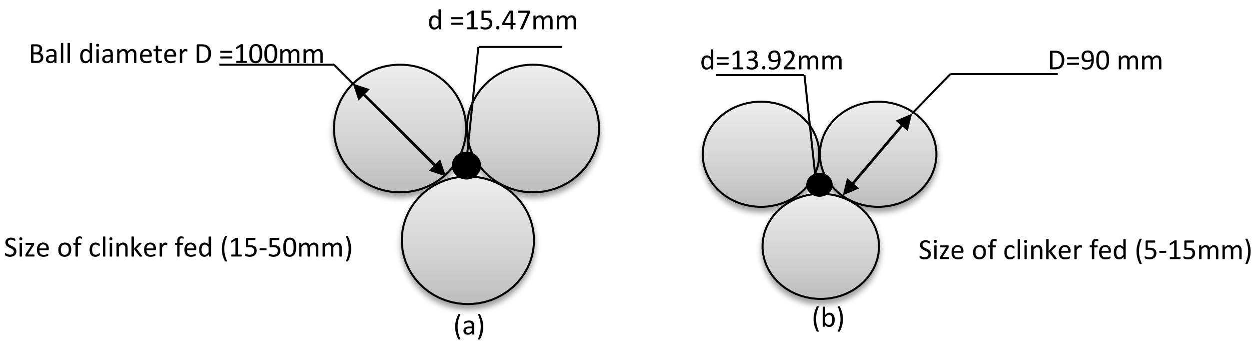

Fig. 6. Maximum ball diameter vs. maximum clinker diameter, (a) before modification, (b) after modification.

The results of this notion shown in Table 4 reveal that there is an increase in the number of grinding balls, more than 22000 new balls added with a same charge whose total weight is 85 tons. These lead to a decrease in the piece initial weight from 2074 g to 1345 g and an increase in specific initial surface 14.5% as well as an increase in the total surface of charge to 115 m^2.

Deeply understanding the milling process has a significant role in achieving production efficiency and thus increases revenue through increasing production. This research has achieved an increase in production by 41%, equal to 25 t /h. If we take into account that the average working time per month is 500 hours when the selling price is 80,000 ID/t, the value of increase is 1,000,000,000 ID/month, through the process of modifying the charge in the first compartment of cement mill No. 1 in the Kufa cement plant.

Table 4. Results of charge change before and after modification.

	after modification (1)	before modification (2)	Result (3)	Result %
Total balls number (ball)	63,217	40,985	+22,232	54
Total Surface (m^2)	911	796	+115	+ 14.5
Production (t/h)	85	60	+25	+ 41
Weight of charge (t)	85	85	constant	constant
Piece initial weight (g)	1345	2074	- 729	-35
Specific initial surface (m^2/t)	10.72	9.364	+1.356	+14.5

4. CONCLUSION

It has been concluded so far that:

- The size of the clinker granules has a very large impact on the amount of production of cement mill per hour and this is not because of the shape of grains only, but because of the changing behavior of movement between the grinding balls, thus effect on the efficiency of grinding.
- The total surface area of the grinding balls has a very large impact on the efficiency of grinding and thus increases productivity because this will increase the area of contact between the balls and the clinker granules, which leads to very fine particles.

- The increase in the number of balls in the first compartment leads to a reduction in the piece initial weight and this led to increasing the surface area of one ton of balls, thus increasing the efficiency of milling.
- The results of this research open up the possibility of increasing production without incurring significant additional costs.

Therefore, it is recommended to take into account the precise understanding of the movement of materials inside the mill and the appropriateness of the grinding ball distribution to the size of the clinker granules fed.

It is recommended that the DEM simulation method is used in Kufa Cement Plant for the purpose of reaching the optimal composition of charge, as well as the use of the scientific method in modifying the charge due to the mechanical corrosion loss during the continuous operation process by calculating the piece initial weight as well specific initial surface and comparing it with the weight and surface required for equilibrium.

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Table A1. Specific charge (FL. Smidth, 2007).

h/D	a	q	h/D	a	q
0.000	0.424	50.0	0.200	0.647	25.2
0.005	0.430	49.4	0.205	0.653	24.6
0.010	0.435	48.7	0.210	0.659	24.1
0.015	0.441	48.1	0.215	0.665	23.5
0.020	0.446	47.5	0.220	0.670	22.9
0.025	0.452	46.8	0.225	0.676	22.4
0.030	0.457	46.2	0.230	0.682	21.8
0.035	0.462	45.5	0.235	0.688	21.2
0.040	0.468	44.9	0.240	0.693	20.7
0.045	0.473	44.3	0.245	0.699	20.1
0.050	0.479	43.6	0.250	0.705	19.6
0.055	0.484	43.0	0.255	0.711	19.0
0.060	0.490	42.4	0.260	0.717	18.5
0.065	0.495	41.7	0.265	0.722	17.9
0.070	0.501	41.1	0.270	0.728	17.4
0.075	0.507	40.5	0.275	0.734	16.8
0.080	0.512	39.9	0.280	0.740	16.3
0.085	0.518	39.2	0.285	0.746	15.8
0.090	0.523	38.6	0.290	0.751	15.3
0.095	0.529	38.0	0.295	0.757	14.7
0.100	0.534	37.4	0.300	0.763	14.2
0.105	0.540	36.7	0.305	0.769	13.7
0.110	0.546	36.1	0.310	0.775	13.2
0.115	0.551	35.5	0.315	0.781	12.7
0.120	0.557	34.9	0.320	0.786	12.2
0.125	0.562	34.3	0.325	0.792	11.8
0.130	0.568	33.6	0.330	0.798	11.3
0.135	0.574	33.0	0.335	0.804	10.8
0.140	0.579	32.4	0.340	0.810	10.3
0.145	0.585	31.8	0.345	0.816	9.86
0.150	0.591	31.2	0.350	0.822	9.41
0.155	0.596	30.6	0.355	0.828	8.95
0.160	0.602	30.0	0.360	0.833	8.51
0.165	0.608	29.4	0.365	0.839	8.07
0.170	0.613	28.8	0.370	0.845	7.64
0.175	0.619	28.2	0.375	0.851	7.21
0.180	0.625	27.6	0.380	0.857	6.80
0.185	0.630	27.0	0.385	0.863	6.39
0.190	0.636	26.4	0.390	0.869	5.98
0.195	0.642	25.8	0.395	0.875	5.59

Table A2. Torque factors (FL.Smidth, 2007).

Material	Grinding	Lining	Internal fittings	Media Type	Media w [t/m³]	Torque μ
Cement and raw meal (dry)	Coarse and medium	Steel	None	Balls	4.3	0.73
			None	Rods	6.0	0.55
			Danula	Balls	4.3	0.75
			Sonex	Balls	4.3	0.66
	Fine	Steel	None	Balls	4.5	0.69
			None	Cylpebs	4.7	0.73
			None	Minipebs	4.7	0.64
			Danula	Balls	4.5	0.71
			Danula	Cylpebs	4.7	0.75
			Danula	Minipebs	4.7	0.66
	All	Steel Silex	None	Ceramic	1.9	0.75
			None	Stone	1.5	0.75
Slurry (wet)	Coarse and medium	Steel	None	Balls	4.3	0.66
			None	Rods	6.0	0.50
			Danula	Balls	4.3	0.67
			Sonex	Balls	4.3	0.59
	Fine	Steel	None	Balls	4.5	0.66
			None	Cylpebs	4.7	0.66
			Danula	Balls	4.5	0.67
			Danula	Cylpebs	4.7	0.67
	All	Steel Silex	None	Ceramic	1.9	0.85
			None	Stone	1.5	0.85
Wash drum			Lifters	Stone	1.5	0.85
Coal	Coarse	Steel	None	Balls	4.3	0.69
	Medium		None	Balls	4.5	0.69
	Medium		None	Cylpebs	4.7	0.69
	Medium		Danula	Cylpebs	4.7	0.71