Beneficiation of Beni-Khaled Limestone Ore for Beneficial Industrial Uses

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Abstract: Limestone ore can be considered as an important source for mineral wealth in Egypt. Using wisdom for extracting these ores supports the national income of Egypt, Where, more than fifty million tons are produced per year. Most of this amount consumes in cement production and iron and steel industry. Beni-khaled quarries El-Menya Governorate, follows the Egyptian Iron and Steel Company, have more than 8 million tons of (-4+1) and (-1+0.0) cm accumulated in the site. Consequently, the main objective of this study is the beneficiation of this piled amount to maximize its beneficial industrial uses. Using crushing and grinding, dry magnetic separation, and calcination techniques produced an ore agrees with the needs of many industries, which increase the national income and solve the current environmental problems in this area.

Keywords: Limestone Industrial Uses, Cement Industry, Limestone Beneficiation

1. Introduction

Limestone is one of the important and common uses industrial ore. In addition to its well-known use in construction and building either as it is or as an aggregate for concrete mixtures and roads paving, it is the main component in the cement industry raw meal [1-8].

Still remain the most important industrial uses of limestone, as it is considered as a necessary material for more than hundred industry such as metallurgical industries, glass, food industries, chemical industries and as a filling material, in addition to its environmental purposes [9-11].

Egypt produces more than fifty million tons per year. Production of these ores by haphazard methods without any identification to their physical and mechanical properties deteriorates the pure types of this ore [4-6].

Beni-Khaled quarries, El-Menya Governorate follows the Egyptian Iron and Steel Company, produces (-8+4) cm, (-4+1) cm and (-1+0) cm of limestone sizes. The largest size (-8+4) cm charges to iron and steel company for melting the iron ores. The two other sizes (-4+1) cm and (-1+0.0) cm are stored in different places beside or near to the crushers. Nowadays, there are more than 8 million tons from the two other sizes accumulated in the site.

Some individual efforts are tired to use (-4+1) cm size in roads paving. The finest size (-1+0.0) cm is tried in cement brick and glass making industries by individual efforts of some contractors. Figure 1 shows the current flowsheet for preparation, crushing and size classification of Beni-Khaled Limestone ore.
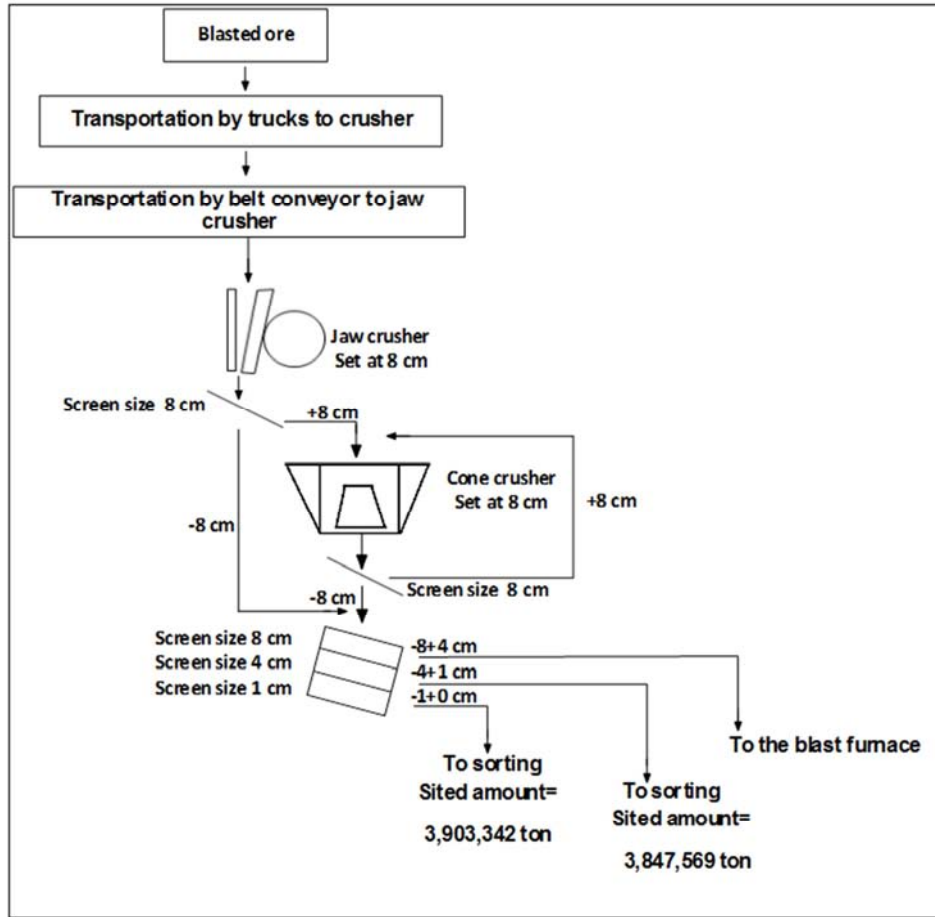
Figure 1. *Current flowsheet for preparation of Beni-Khaled limestone ore.*

Representative samples of these mentioned sizes are obtained from the quarries. Table 1 shows the size distribution of (-4+1) cm and (-4+0.0) cm sizes. Table 2 illustrates the mean chemical composition of the different elements for the three mentioned sizes.

Table 1. *Particle size distribution of (-4+1) cm and (-1+0.0) cm sizes forBeni-Khaled Limestone ore.*

Size (-4+1) cm		Size (-1+0) cm	
Size fraction, mm	weight, %	Size fraction, mm	weight, %
(-80+40)	02	(40+10)	03
(-40+30)	52	(-10+5)	13
(-30+20)	39	(-5+3)	46
(-20+10)	07	(-3+0)	38
Sum	100	Sum	100

Table 2. *Mean chemical analysis for the different elements in the produced size fractions of Beni-Khaled Limestone ore.*

Sample	Size fraction, cm	Chemical Composition							
		SiO_2%	CaO%	MgO%	R_2O_3 ($Fe_2O_3+Al_2O_3$)%	Cl%	S%	P%	LOI%
1	(-8+4)	0.76	54.41	0.59	0.60	0.08	0.03	0.04	43.05
2	(-4+1)	0.96	54.26	0.41	0.64	0.16	0.03	0.03	43.20
3	(-1+0)	0.47	52.68	0.78	2.17	0.12	0.03	0.03	40.56

Consequently:

The main objective of this investigation is to study the possibility of using these piled amounts of limestone ore (8 million tons) of (-4+1) cm and (-1+0.0) cm sizes in suitable industrial uses. (-8+4) cm size is not full charges to the iron and steel company but it depends on the need of the company. Maximization of the benefit of the ore utilization is also intended. These purposes increase the national income and solve the environmental problem of this site.

2. Experimental Work (Methodology)

Samples of (-8+4) cm, (-4+1) cm, and (-1+0) cm were obtained from the site. The following tests were applied on

these specimens:

    a. Petrographical Description.

    b. Crushing operation tests using jaw and roll crushers.

    c. Grinding using hammer and pebble mills.

    d. Low intensity wet magnetic separation using Davis magnetic tube.

    e. High intensity dry magnetic separation using Dry Belt Boxmag Separator.

    f. Calcination processes.

3. Results and Discussions

3.1. Petrographical Description of the Studied Samples

This description has been done by the central laboratories of the Egyptian Geological Surveying authority as follows:

Rock name: Fossiliferous (formaniferal) limestone.

Rock type: Organic carbonate, sedimentary rock.

Texture: Huge amounts of microfossils of different sizes and shapes (mainly foramininfera) are cemented by very fine to fine-grained carbonates (calcite and dolomite).

3.2. Crushing and Grinding Results

3.2.1. Primary and Secondary Crushing Stages

Mineral composition:

The rock is composed of calcite and dolomite as the essential mineral constituents with rare amounts of quartz and traces of iron oxides.

Calcite and dolomite present the matrix of the rock. Quartz presents as very fine grained, anhedral crystals scattered in the carbonates matrix. Microfossils and shell fragments (mostly as foramininfera) are present in huge amount of different sizes and shapes and cemented with micritematrix and/or dolomite (in some parts). Few pores and fractures are observed in the sample. Carbonate minerals are slightly stained by traces of iron oxides in some parts.

Alteration: No significant alteration was observed.

Opaque minerals: Present in rare amount, as very fine grained aggregate and single subhedral crystals of goethite and hematite.

Goethite: Sometimes occurs as staining mineral over carbonate.

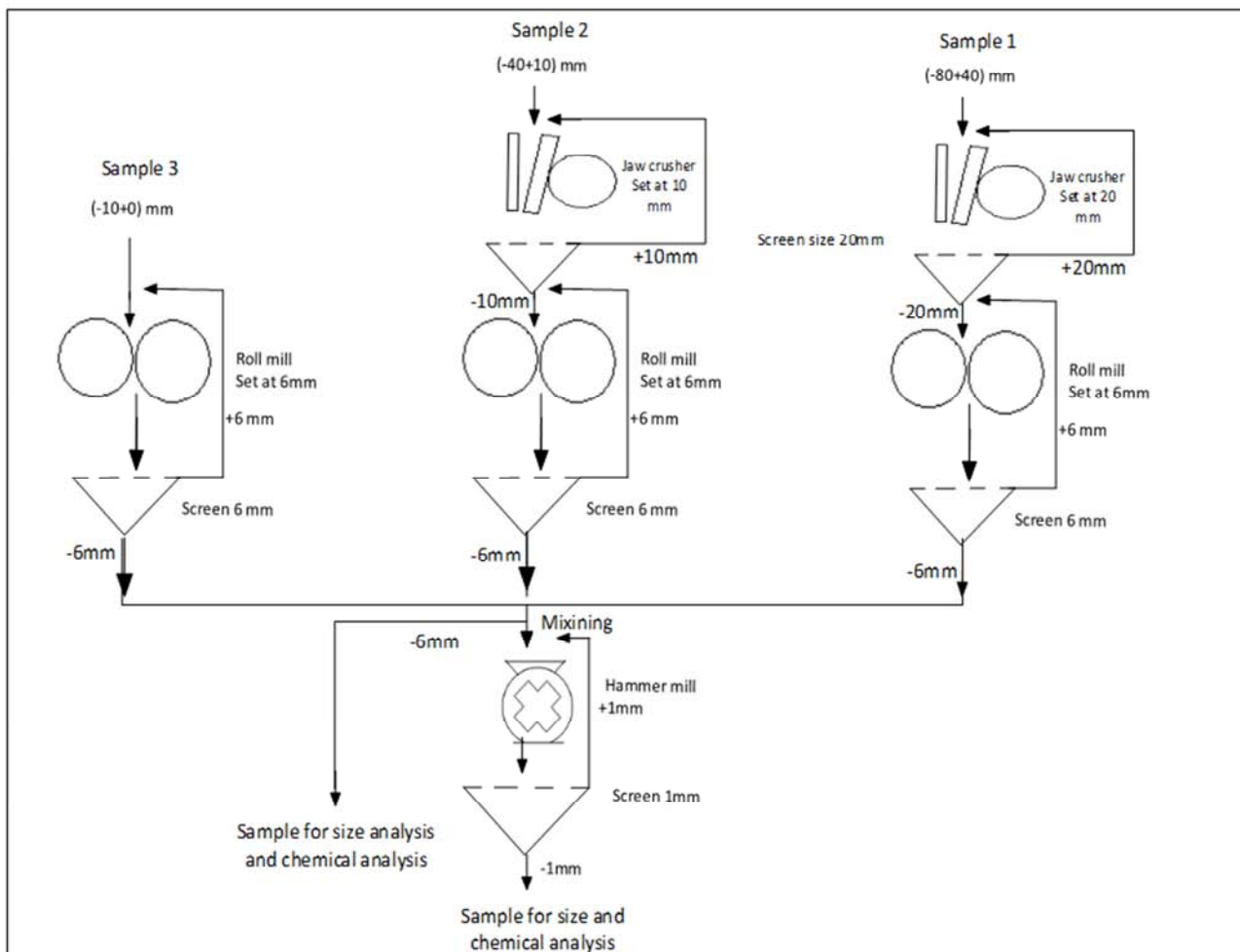Sulphides: (most probably pyrite) present as very fine speaks or tiny spots in carbonate.

Figure 2. Crushing and grinding operations of Beni-Khaled Limestone ore.

The first sample of size (-8+4) cm was crushed using a jaw crusher machine with a set adjusted at 20 mm in a closed circuit with a screen. The product (-20+0) mm was fed to a roll crusher of 6 mm opening in a closed circuit with a screen. The second sample of (-4+1) cm size was crushed using a jaw crusher with a set adjusted at 10 mm in a closed circuit. The product (-10+0) mm was secondary crushed using a roll mill with a set adjusted at 6mm in a closed circuit. The third sample of (-10+0.0) cm was crushed using the roll mill machine to -6 mm product in a closed circuit system.

The same size (-6+0.0) mm were mixed thoroughly. Representative samples of (-6+0.0) mm were fed to a closed circuit hammer mill to obtain (-1+0) mm size as shown in Figure 2.

A representative sample from the product of crushing which has (-6+0.0) mm size was size analyzed using a nest of screens of 4,2 and 1 mm, then a representative sample of each size was chemically analyzed using XRF. Table 3 illustrate the results of size and chemical analyses of the mentioned sizes.

Table 3. *Particle size analysis and mean chemical analysis for crushed (-6+0) mm.*

Size fraction, mm	wt., %	Grade, %						Purity degree
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
(-6+4)	10.94	55.51	0.33	0.16	0.08	0.18	99.13	High purity
(-4+2)	27.13	55.64	0.32	0.13	0.08	0.16	99.36	High purity
(-2+1)	20.17	54.62	0.75	0.19	0.14	0.2	97.54	Medium purity
(-1+0)	41.76	54.84	0.77	0.22	0.21	0.33	97.93	Medium purity
Head sample	100	55.16	0.55	0.19	0.11	0.22	98.50	Medium purity

A representative sample of the hammer milled ore of (-1+0) mm size was analyzed on 0.5, 0.2 and 0.063 mm nest of screens, then a representative sample of each size was chemically analyzed with XRF. Table 4. clears the results of size and chemical analyses of these samples.

Table 4. *Particle size analysis mean chemical analysis for each size of the ground (-1+0.0) cm product.*

Size fraction, mm	wt., %	Grade, %						Purity degree
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
(-1+0.5)	23.98	55.28	0.40	0.17	0.09	0.16	98.71	High purity
(-0.5+0.2)	30.41	55.04	0.53	0.17	0.13	0.19	98.29	Medium purity
(-0.2+0.063)	28.04	55.17	0.59	0.18	0.11	0.23	98.52	High purity
(-0.063+0)	17.57	55.01	0.55	0.18	0.11	0.22	98.23	Medium purity
Head sample	100	55.14	0.51	0.17	0.11	0.21	98.46	Medium purity

Figures 3 and 4 illustrate the final results of the cumulative weight percent of the crushed and ground products respectively.
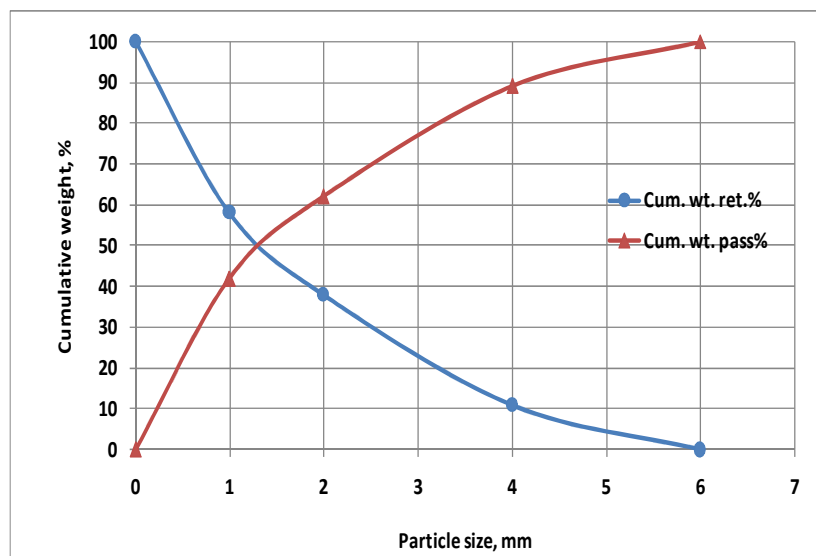

Figure 3. *Final particle size distribution (Cum.wt. % retained and passed) for crushed limestone.*
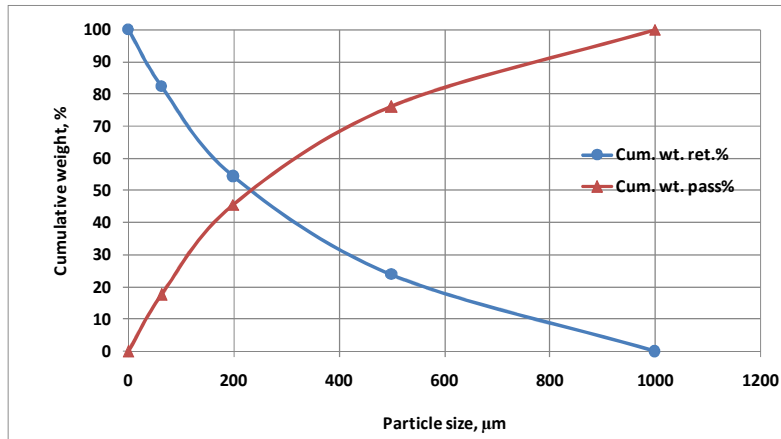
Figure 4. Final particle size distribution (Cum.wt. % retained and passed) for ground limestone.

Table 3 and Figure 5 show the particle size and chemical analysis of each size of the crushed products.
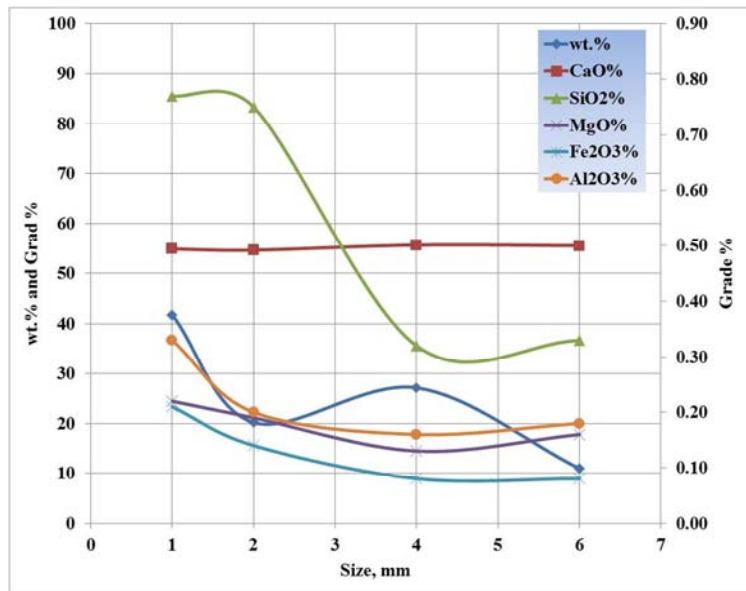

Figure 5. Particle size distribution and mean grade of each element for the crushed limestone size (-6+0) mm.

Table 4 and Figure 6 show the final results of the size and chemical analyses of the ground product.
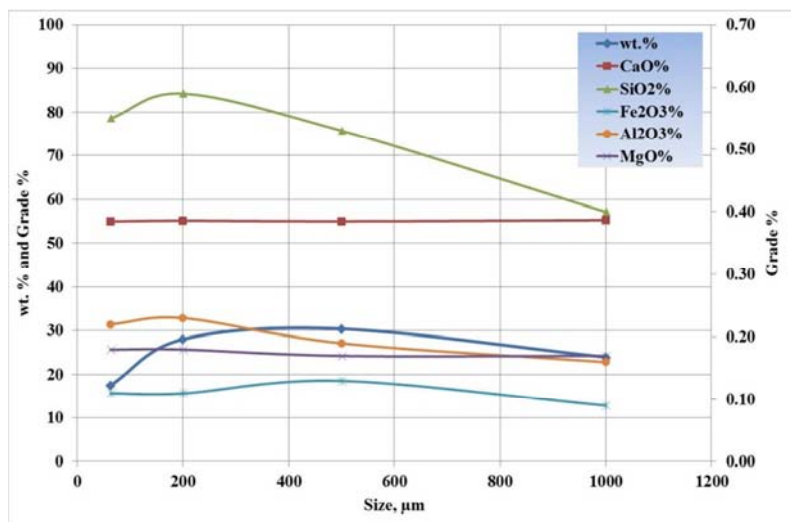

Figure 6. Particle size distribution and mean grade of each element for the ground limestone (-1+0) mm.

Table 5 and Figure 7 show the cumulative weight % passed of particles and cum.% of chemical analysis for each element in the crushed of (-6+0) mm product.

Table 5. Cum.wt. % passed of particles and their chemical analysis for each element in the crushed limestone.

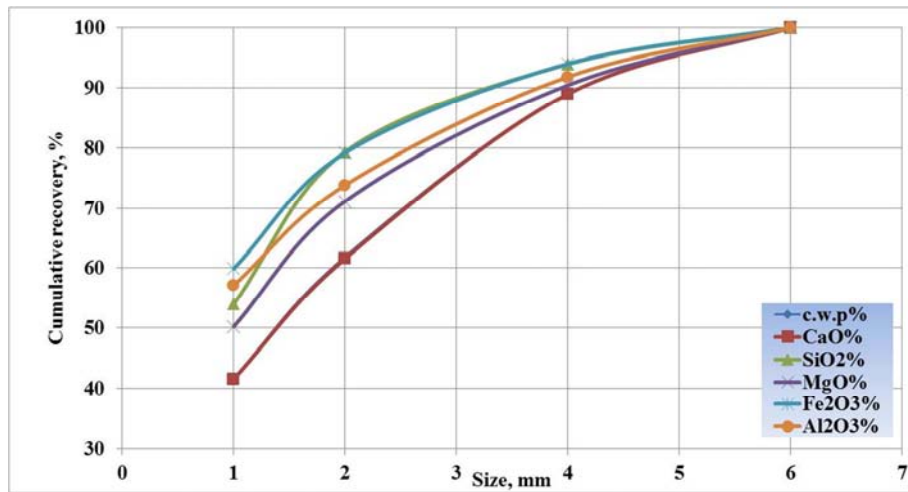| Size fraction, mm | c.w.p.% | Cumulative recovery, % | | | | |
		CaO%	SiO₂%	MgO%	Fe₂O₃, %	Al₂O₃, %
(-6)	100	100	100	100	100	100
(-4)	89.06	88.98	93.94	90.44	94.02	91.84
(-2)	61.93	61.57	79.37	71.16	79.20	73.85
(-1)	41.76	41.57	53.98	50.21	59.91	57.12

Figure 7. Cum.wt. % passed of particles and their chemical analysis for each element in the crushed limestone.

Figure 8 and Table 6 show the cumulative weight % passed of particles and Cum.wt.% passed of each element in the ground limestone.

Table 6. Cum.wt. % passed of particles and their chemical analysis for each element in the ground limestone.

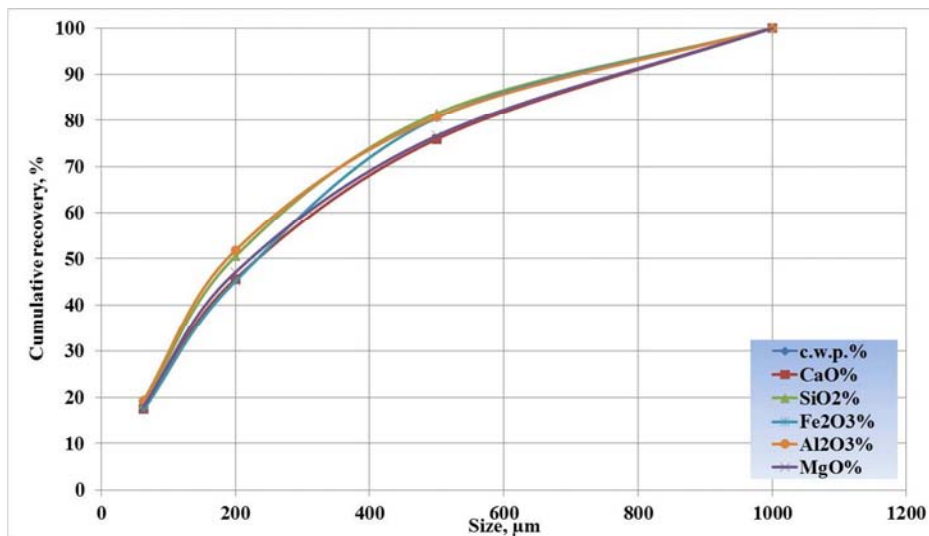| Size fraction, μm | c.w.p.% | Cumulative recovery, % | | | | |
		CaO%	SiO₂%	MgO%	Fe₂O₃, %	Al₂O₃, %
(-1000)	100	100	100	100	100	100
(-500)	76.01	75.95	81.52	76.64	80.60	80.74
(-200)	45.61	45.59	50.48	47.03	45.08	51.75
(-63)	17.57	17.53	18.61	18.11	17.36	19.39

Figure 8. Cum.wt.% passed of particles and their chemical analysis for each element in the ground limestone.

From the results of Table 3 it is clear that, it is possible to add the high purity sizes (-6+4) mm and (-4+2) mm which represent 38.07% from the head sample to obtain a product suitable for some industrial beneficial uses. These results are shown in Table 7.

Table 7. Mean chemical composition for the most important elements that produced from adding (-6+4) mm and (-4+2) mm sizes.

| Size fraction, mm | wt., % | Grade, % | | | | | | Purity degree |
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
(-6+4) & (-4+2)	38.07	55.60	0.32	0.14	0.08	0.17	99.29	High purity

According to the Egyptian General Authority of Mineral Wealth classification [1]. the chemical composition from adding these two sizes Follows to super high purity (98.85 CaCO$_3$), but according to the British Geological surveying Authority [13] it follows the high purity classification due to occurrence of little high contents of Fe$_2$O$_3$ and Sio$_2$. Consequently, adding these two products makes the mixture suitable for paints, paper, plastic, rubber, Adhesives and sealants, and Agriculture and animal feed industries [12-13]. The same results of Table 7 clear that this product can not be used in food industry due to the high ratio of Sio$_2$, where the permissible ratio ranges between 0.10 and 0.12%. It can not be used also in ceramics industry due to the ratios of Sio$_2$ and Fe$_2$O$_3$ are higher than the required ones.

From the results of Table 3 it is clear also that the two sizes of medium purity (-2+1) mm and (-1+0) mm shown in Table 8, which represent 61.93% of the head sample produces a beneficial product. The Egyptian General Authority of Mineral Wealth classified this product in a purity degree (CaCO$_3$ 97-98.5%), but the British Geological Surveying Authority classified this product as a medium purity due to the occurrence of little high ratios of Sio$_2$ and Fe$_2$O$_3$. Chemical analysis of the final product clears that; it can be used in some industries after reducing the Fe$_2$O$_3$ from 0.19% to 0.10% by using high intensity magnetic separator such as paint, rubber, adhesives and sealants, and Agriculture and animal feed industries [12-15].

Table 8. Mean chemical composition for the most important elements in the mixture of (-6+4) mm and (-4+2) mm sizes.

| Size fraction, mm | wt., % | Grade, % | | | | | | Purity degree |
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
(-2+1) & (-1+0)	61.93	54.77	0.76	0.21	0.19	0.29	97.80	Medium purity

But it can not be used in paper, plastic, and foods due to the higher value of Sio$_2$ content. It can not be also used in ceramic industry due to the higher ratio of Sio$_2$ and Fe$_2$O$_3$ and the lower ratio of Cao and CaCO$_3$ content [13].

From the results in Table 4. it is clear that it is possible to add the two sizes of high purity (-1+0.5) mm and (-0.20+0.063) mm which represent more than the half of the head sample (52.03%) to obtain a product proper for some industries [13]. The final results are shown in Table 9.

Table 9. Mean chemical composition for the most important elements produced from adding the (-1+0.5) mm and (0.2+0.063) mm two sizes.

| Size fraction, mm | wt., % | Grade, % | | | | | | Purity degree |
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
(-1+0.5) & (-0.2+0.063)	52.03	55.22	0.50	0.18	0.10	0.20	98.61	High purity

According to the Egyptian General Authority of Mineral Wealth classification [1], the chemical composition of the mixture produced from blending these two sizes follows the super purity category (98.5% CaCO$_3$), But according to the British Geological Surveying Authority considered as a high purity category due to the little higher ratios of Sio$_2$ and Fe$_2$O$_3$ contents.

The chemical composition of the mixture (Table 9) clears the possibility of its use in paints, plastic, rubber, adhesives and

sealants, and agriculture and animal food industries [15-16].

This product can not be used in paper or food industries due to the high percentage of Sio$_2$ (0.10-0.12%). It can not be also used in ceramics industry due to the higher ratio of Sio$_2$ and the lower ratio of Cao and CaCO$_3$ [16]. The results of Table 4. clears that, it is possible to add the two size (-0.5+0.2) mm and (-0.063+0) mm which represent 47.97% of the head sample. Chemical analysis of this mixture is shown in Table 10

Table 10. Mean chemical composition for the most important elements produced from (-0.5+0.2) mm and (-0.063+0) mm two sizes.

| Size fraction, mm | wt., % | Grade, % | | | | | | Purity degree |
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
(-0.5+0.2) & (-0.063+0)	47.97	55.03	0.54	0.17	0.12	0.20	98.27	Medium purity

According to the Egyptian General Authority of Mineral Wealth classification and from the chemical composition of adding these two sizes, it is clear that this mixture follows the high purity category (CaCO3 ranges from 97% to 98.5%),

but according to the British classification it follows the medium purity due to the little high percentage of Fe$_2$O$_3$ (0.12%) than the permissible (0.10%).

From the chemical composition and after lowering the

Fe_2O_3 to the acceptable limit by using the high intensity magnetic separator, it can be used in paints, plastic, rubber, adhesives and sealants, and agriculture and animal feed industries [17-19].

This mixture can not be used in paper and food industries due to the higher ratio of Sio_2 than the required. It can not be also used in ceramic industry due to the higher ratio of Sio_2 and Fe_2O_3 and the lower ratios of Cao and $CaCO_3$ than the required ratios.

3.2.2. Grinding of the Crushed Samples in the Pebble Mill

A representative sample of (-1+0) mm size that produced from hammer mill was fed to the pebble mill with different sizes fillent as a grinding media.

The operating parameters were kept constant at a mill speed of 60 rpm, 20 minutes grinding time and the ratio of the fillent weight to the ore weight was 2:1.

A sample of the product was screened on a 800, 630, 500, 315, 200, 160 and 63 μm screen nest. The results of screening are illustrated in Table 11 and Figure 9.

Table 11. *Cum.wt.% retained and passed for pebble milled ground product.*

Size fraction, μm	wt., gm	wt., %	c.w.r.%	c.w.p.%
(-1000+800)	7	2.86	2.86	100.00
(-800+630)	26	10.63	13.49	97.14
(-630+500)	18	7.36	20.85	86.51
(-500+315)	35.5	14.51	35.36	79.15
(-315+200)	13	5.31	40.68	64.64
(-200+160)	20	8.18	48.86	59.32
(-160+100)	58	23.71	72.57	51.14
(-100+63)	52.5	21.46	94.03	27.43
(-63+0)	14.6	5.97	100.00	5.97
∑	244.6	2.86	2.86	100.00

c.w.r.% = cumulative weight retained percent
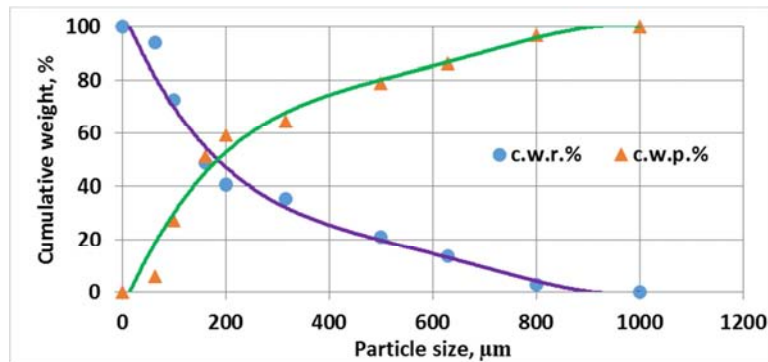c.w.p.% = cumulative weight pass percent

Figure 9. *Cum.wt.% retained and passed for pebble milled ground product.*

The size greater than 200μm of the product was ground again in the pebble mill in a closed circuit with a 200μm screen. From the represented results in Figure 9. the grinding efficiency of the pebble mill is calculated to be 1.17. The pebble milled product of -200 μm size was agitated in cold and hot waters under conditions shown in Table 12.

Table 12. *Agitation conditions of -200 μm pebble milled product.*

Condition	Cold water	Hot water
Weight of the sample before leaching (gm)	247	248
Volume of water, (cm^3)	1000	1000
Speed of agitation, (rpm)	1200	1200
Time of agitation, (hr)	2	1

The product of agitation was filtered, dried and weighed. It is found that the dried material did not leach either in cold in hot water.

3.3. Magnetic Separation

Low intensity wet magnetic separator (Davis magnetic tube) and high intensity magnetic separator (Dry belt boxmag) were applied on the ore.

It was found that the results of low intensity magnetic separation on -63μm either cold leached or hot leached were unreasonable. A representative sample of magnetic and non-magnetic products were chemically analyzed using XRF

apparatus. Table 13 and Figure 10 clears the results of recovered ratios for the most important elements in the sample.

From the results that tabulated in Tables 13 and 14 and represented in Figures 10 and 11 it is clear that:

The Cao percent is increased from 55.13% to 55.28% with a recovery of 51.60% and weight recovery of 51.46%. At the same time the Cao percent is decreased to 54.97% with a recovery of 48.4% in the magnetic product. With respect to Fe_2O_3 its ratio is decreased from 0.11% to 0.05% with a recovery of 23.77%.
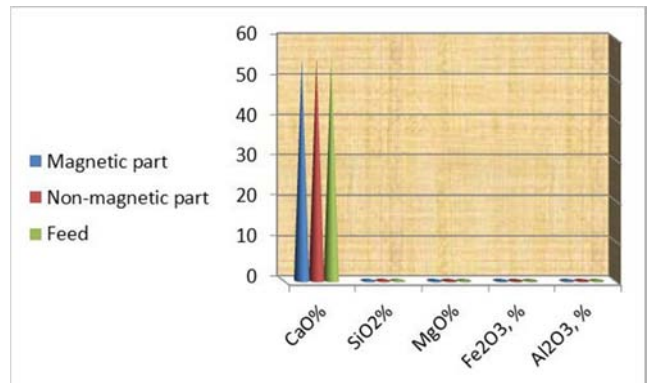

Figure 10. *Chemical analysis of the most important elements in the products of dry magnetic separation process using Dry belt Boxmag Rapid Apparatus.*

Table 13. *Chemical analysis of the most important elements in the product of dry magnetic separation process using Dry belt Boxmag Rapid Apparatus.*

Sample	wt., %	Chemical Composition						Purity degree
		CaO %	SiO$_2$ %	MgO %	Fe$_2$O$_3$, %	Al$_2$O$_3$, %	CaCO$_3$, %	
Magnetic Part	48.54	54.97	0.53	0.21	0.17	0.23	98.16	Medium purity
Non-magnetic Part	51.46	55.28	0.54	0.18	0.05	0.19	98.71	High purity
Head sample	100	55.13	0.54	0.19	0.11	0.21	98.45	Medium purity

In the non-magnetic part. In the same time this ratio increased to 0.17% with a recovery of 76.23% in the magnetic part. This means that the Dry Belt Boxmag magnetic separator reduced Fe$_2$O$_3$ to one quarter of its value in the magnetic product. Pertaing to the other elements, it was no change in the recovery ratios of Sio$_2$, Al$_2$o$_3$, and Mgo either in the magnetic or non-magnetic products.

Table 14. *Recovery ratios of the most important elements in the product of dry magnetic separation process using Dry Belt Boxmag Rapid Appratus.*

Sample	wt., %	Component Recovery				
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %
Magnetic Part	48.54	48.40	48.07	52.39	76.23	53.31
Non-magnetic Part	51.46	51.60	51.93	47.61	23.77	46.69
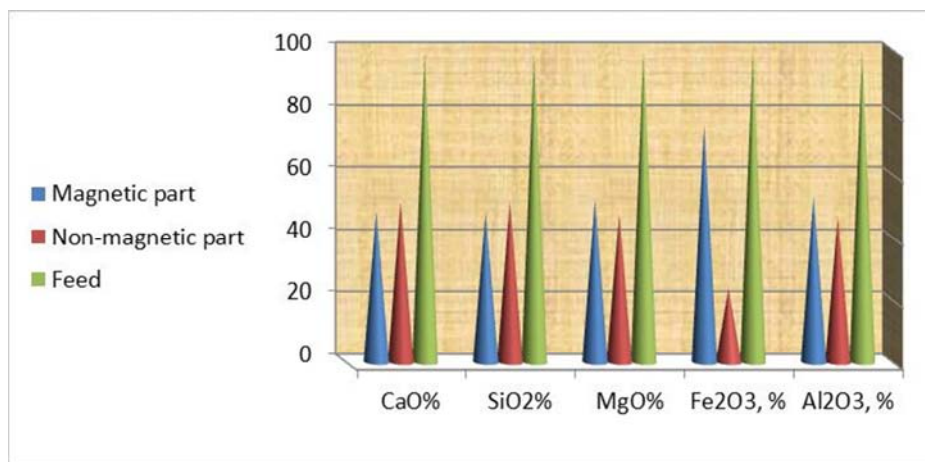
Figure 11. *Recovery ratios of the most important elements in the product of dry magnetic separation process using Dry Belt Boxmag Rapid Appratus.*

According to the Egyptian general Authority of Mineral Wealth classification the chemical composition of the non-magnetic product follows the super-high purity (98.5% CaCO$_3$), but according to the British Geological Surveying classification it follows the high purity category due to the high percent of Sio$_2$. The non-magnetic part of the product can be used in paints, plastic, rubber, adhesives and sealants, and agriculture and animal feed industries [16-19].

This product can not be used in paper and foods due to the high ratio of Sio$_2$. It can not be also used in ceramics industry due to its higher ratios of Sio$_2$ and Fe$_2$O$_3$ and lower ratios of Cao and CaCo$_3$ than the required limits.

3.4. Calcination Process

Calcination of limestone at 1000°C produces a quick lime that can be used in many industries such as iron and steel, paper, sugar production, preparation of some dyes, as an acidic modifier for soil acidity and as assistant for fertilizer analysis in the soil (5). It is also used to inhance the analysis of the anthrax dead animals, as a constructional material, glass making, furnaces lining industry and as a modifier for soil alkilily [12].

3.4.1. Calcinations of -500μm Size

Samples of -500μm size taken from the pebble mill product were calcined for three hours at different temperatures (900, 1000 and 1050°C). The loss due to calcination was calculated as:

$$\text{Loss due to calcination} = \frac{weight\ of\ the\ sample\ before\ calcination - weight\ after\ calcination}{weight\ of\ the\ sample\ before\ calcination} \times 100$$

Results of (-500+0)μm size calcination are shown in Table 15 and Figure 12.

Table 15. *Effect of the temperature on the calcination of (-500+0)μm size.*

Temp., °C	Weight of sample before calcinations	Weight of sample after calcinations	% Loss in weight
900	100.5021	58.6847	41.61
1000	103.2108	58.6226	43.20
1050	112.9843	64.0347	43.32

The results of Table 15 and Figure 12 show that the loss in weight due to calcination process increased from 41.61% to 43.20% as the temperature increased from 900 to 1000º c. Increasing the temperature to 1050°C led to a tough increase in the loss weight. This means that the optimum temperature of calcination is 1000°C.
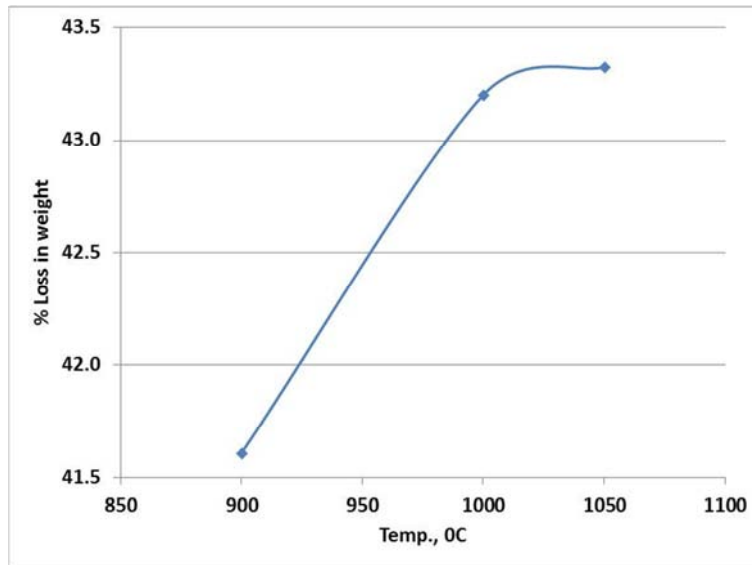

Figure 12. *Effect of the temperature on the calcination of (-500+0)µm size.*

Representative calcined samples at the different studied temperatures were chemically analyzed using XRF and shown in Table 16 and Figure 13.

Table 16. *XRF chemical composition for the most important elements for (-500+0)µm calcined product at different temperatures.*

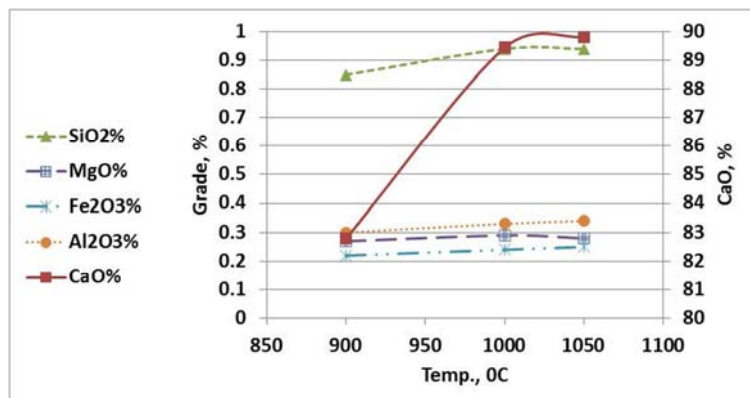| Temp., °C	% Loss in weight	Chemical Composition				
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %
900	41.61	82.79	0.85	0.27	0.22	0.30
1000	43.20	89.44	0.94	0.29	0.24	0.33
1050	43.32	89.82	0.94	0.28	0.25	0.34

Figure 13. *Chemical analysis of the most important elements using XRF for (-500+0)µm calcined product.*

Results of Table 16 represent the chemical composition for the most important elements for the calcined product. These results are represented in Figure 13. From this Figure it is clear that the Cao% increased from 82.79% to 89.44% by increasing the temperature from 900 to 1000°C. Increasing the temperature to 1100°C increased the Cao% slightly. Consequently, 900°C can be considered as the optimum calcination temperature for (-500+0)µm.

Table 17 clears the component recovery of the most important constituents for (-500+0) µm calcined product at the different studied degrees of temperature. From the results of Table 17 and Figure 14 it is clear that the recovery of Cao, Al$_2$o$_3$, Fe$_2$o$_3$ in the calcined sample increased with increasing the temperature up to the optimum temperature (1000°C). the recovered ratios of Mgo and Sio$_2$ increased to a certain limit (up to 1000°C) then decreased, These results clear also that calcination process of (-500+0)µm size did not get red of enough amounts of harmful elements. Most of the lime in the specimen is recovered at 1000°C with a recovery ratio 89.44% and a weight recovery of 56.80%.

Table 17. *Component recovery for the most important elements in the calcined product of (-500+0) µm.*

Temp., °C	% Loss in weight	Component recovery				
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %
900	41.61	87.69	85.57	82.98	91.76	83.41
1000	43.20	92.15	92.06	86.69	97.37	89.26
1050	43.32	92.35	91.86	83.53	99.19	91.77
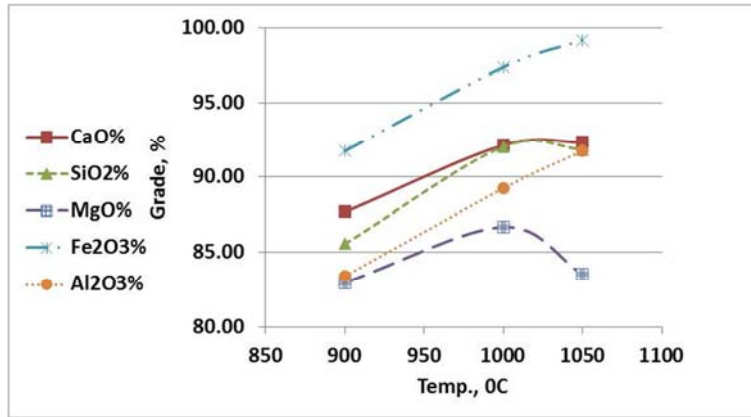
Figure 14. *Recovery ratios of the most important elements for (-500+0) µm calcined product.*

3.4.2. Calcinations of (-200+0) µm Size

Final results of (-200+0) µm calcination process are shown in Table 18 and Figure 15. From these results it is clear that the loss in weight due to calcination increased from 11% to 41.19% with increasing the calcination temperature from 800° to 900°C. The results show also that the optimum calcination temperature is 1000°C.

Table 18. *Effect of the temperature on the calcination of (-200+0)µm size.*

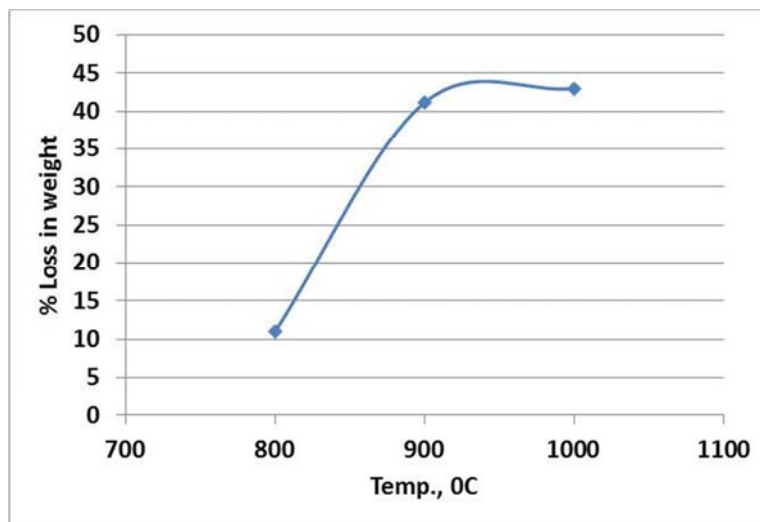| Temp., °C	Weight of sample before calcinations			Weight of sample after calcinations			% Loss in weight
	Sample A	Sample B	Mean	Sample A	Sample B	Mean	
800	79.54	80.88	80.21	70.86	71.91	71.38	11.00
900	85.04	84.56	84.80	50.62	49.13	49.88	41.19
1000	78.29	88.42	83.36	44.72	50.33	47.53	42.99

Figure 15. *Effect of the temperature on the calcination of (-200+0)µm size.*

The representative samples of the products calcined at 800°, 900°, and 1000°C for three hours were chemically analyzed using XRF. These results are shown in Table 19 and Figure 16. From these results it is clear that the percentage of Cao increased from 60.75% to 79.69% with increasing the temperature from 900°C to 1000°C. Increasing the temperature to 1000°C increased the Cao% to 85.32%. Consequently, 1000°C can be considered as the optimum one.

Table 19. *Chemical composition for the most important elements for (-200+0) µm calcined product at different temperatures.*

Temp., °C	% Loss in weight	Chemical Composition				
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %
800	11.00	60.75	0.57	0.20	0.14	0.20
900	41.19	79.69	0.66	0.27	0.17	0.23
1000	42.99	85.32	0.71	0.25	0.20	0.25
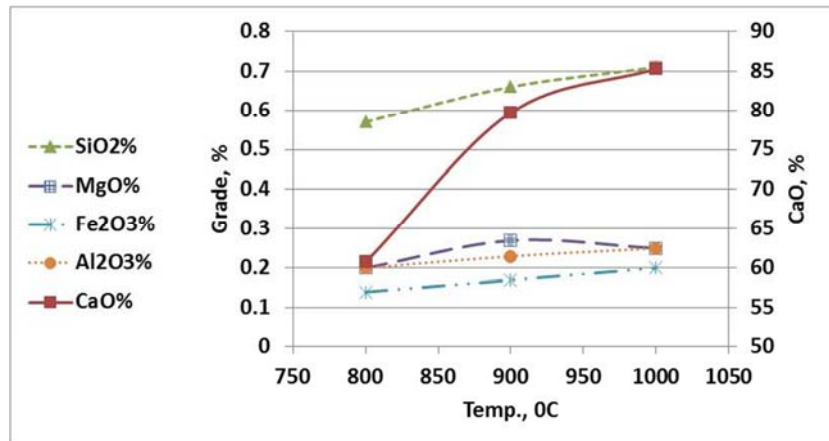
Figure 16. *Chemical analysis for the most important elements for (-200+0)µm calcined product.*

From the results of Table 20 which represented in Figure 17 it is clear that the component recovery of Cao, Al$_2$o$_3$ and Fe$_2$o$_3$ in the calcined sample decreased with increasing the temperature up to 900º (the optimum temperature) then increased. The component recovery of Mgo decreased absdutly with increasing the temperature. These results show also that the calcinations process at 1000°C dismissed about one third of the harmful elements (Al$_2$o$_3$ and Sio$_2$) and a quarter of Mgo and fifth of Fe$_2$o$_3$ from the calcined ore of size (-200+0)µm. Most of the lime in the calcined specimen (88.23%) is recovered at a temperature of 900°C.

Table 20. *Component recovery for the most important elements in the calcined limestone of size (-200+0)µm at different temperatures.*

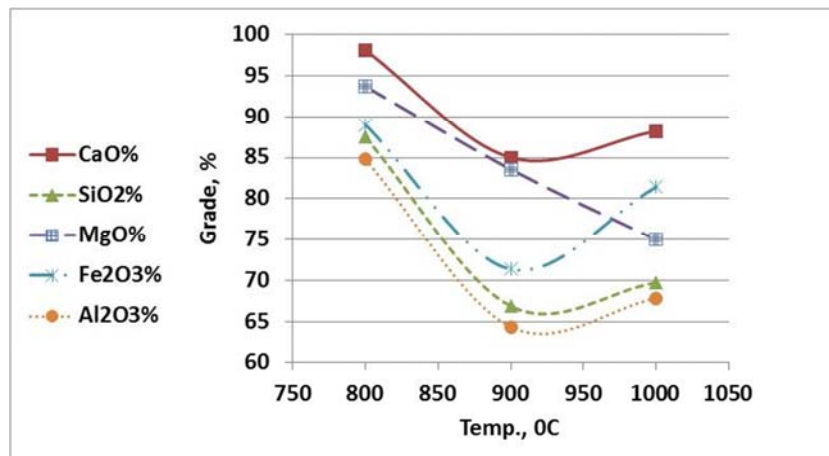| Temp. °C	% Loss in weight	Component recovery				
		CaO%	SiO$_2$%	MgO%	Fe$_2$O$_3$, %	Al$_2$O$_3$, %
800	11.00	98.07	87.47	93.68	89.00	84.76
900	41.19	85.01	66.92	83.57	71.41	64.41
1000	42.99	88.23	69.79	75.01	81.44	67.87

Figure 17. *Recovery ratios of the most important elements for (-200+0) µm calcined product at different temperatures.*

4. Conclusion

From the obtained results and their discussions, the following conclusions can be drawn:

1. The limestone deposits located in Beni-Khaled, El-Minya Governorate can be considered as a potential high-grade calcium carbonate.
2. Results of crushing the limestone ore cleared that, adding (-6+4)cm and (-4+2)cm sizes which represent 38.07% of the head sample produces a proper mixture

for different industrial uses such as paints, paper, plastic, rubber, adhesive and sealants, agriculture and animal feed. This product can not be used in food and ceramics industries.

3. The high quality sizes (-1+0.5)mm and (-0.2+0.063)mm ground ore which represent 52.03% of the head sample can be added to produce a mixture proper for different industries such as paints, plastic, rubber, adhesive and sealants and animal feed. This mixture can not be used for paper, food and ceramics industries.

4. Low intensity magnetic separation process is not able to purify the ore from its iron traces.

5. Dry Belt Boxmag Rapid separator succeeded to purify the ore from its iron traces. A non-magnetic product liable for some important industries such as paints, rubber, adhesive and sealants, agriculture and animal feed was produced. This product does not agree with the requirements of paper, food and ceramics industry,

6. Calcination of the ore produced a lime proper for many modern industries such as iron making, paper, sugar, tanning and treatment of sewage sludge and tailings of industrial operations. It can be also used in the preparation of some types of dyes and bleaching, as a modifier for soil acidly, and as accelerator for analyzing the animals buried cadaver that died by anthrax.

7. Uses of limestone ore should be oriented to the beneficial industries instead of using it as a building material (brick).

Acknowledgements

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