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STUDY THE CORRELATION OF CLINKER QUALITY, RESIDE, PSD ON THE PERFORMANCE OF PORTLAND CEMENT

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ABSTRACT

This research establishes the correlation between clinker quality, residue, particle size distribution and performance behaviour of cement. Different qualities of clinker were identified to understand the influence of mineralogy on the performance of cement. Chemical and mineralogical evaluation of clinker and gypsum were carried out as per the Indian specified standards, XRD and Optical microscopy. Cement samples were prepared by inter mixing of clinker and gypsum with 95 and 5% respectively for different fineness zones such as 225, 250, 275, 300, 325 and 350 m2/kg. The resultant samples were studied for residue, particle size distribution and performance evaluation as per IS 4031. It was observed that clinker quality plays an important role to achieve the desired performance characteristics in addition to the residue and particle size distribution of the cements.

Key words: Cement, residue, particle size distribution and strength.

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1. INTRODUCTION

It is known that the quality and type of cement are significant factors to determine the strength development of concrete, which is specifically affected by the fineness and mineral composition of cement. The fineness of cement also affects its reactivity with water. Generally, the finer the cement, the more rapidly it will react [1,2]. However, the cost of grinding and the heat evolved on hydration set some limits on fineness.

It is reported in the study that the rate of reactivity and the strength development can be enhanced by finer grinding of cements. It is generally agreed that cement particles larger than 45×10^{-6} m are difficult to hydrate and those larger than 75×10^{-6} m could never hydrate completely. However, an estimate of the relative rates of reactivity for similar cement composition cannot be made without knowing the complete particle-size distribution by sedimentation methods [3–5].

Fineness of grinding constitutes (clinker and gypsum) an important variable in the behavior of portland cement. Everyone is well aware of the opinions that while increasing the fineness of the cement sample increases the strength characteristics [6-19]. Unfortunately, the substantial data is not available to correlate the percentage of performance of improvement while increasing the fineness of the cement. Particularly how much percentage of compressive strength of the cement enhances while increasing the fineness and what is optimum level of fineness for obtaining the better properties. In addition to this, no substantial data were available regarding the parameters which influences the fineness of the material and how the mineralogical aspects influence on the residue or particle size distribution while increasing the fineness of the cement. The behavior of particles of different sizes has a significant effect on such obvious properties of paste as consistency, strength, setting time and durability. In view of the above limitations of the supporting data and to justify the observed findings on the evaluated product, this research work planned systematically for understands the correlation between fineness & performance characteristics and optimum level of OPC. In addition to this, correlation between the residue and particle size distribution on the fineness of the product. It is the aim of this paper to show in a brief way how clinker quality influences reside and particle size distribution and their reactivity and further, to indicate which chemical changes are occurring. This work at present merely touches on the fringes of some significant developments that are increasing our understanding of portland cement and its behavior. Although this work may appear to lack massive amounts of supporting evidence, time and further experimentation will correct this defect.

2. EXPERIMENTAL

Two qualities of clinker samples were collected from the cement plants to establish the correlation between the mineralogical aspects on the performance and residue. Initially both the industrial clinkers were crushed using jaw crusher by passing 100% through 2.8 mm sieve. 8 kg of different cement samples were prepared in laboratory ball by stchiometrically weighment of clinker and gypsum for the target fineness and the details are given in table 1. The obtained cement samples were evaluated for chemical analysis, mineralogical analysis and performance evaluation of setting time, normal consistency and compressive strength as per the relevant Indian standards.

Table 1 Designed proportions of clinker and gypsum along with target fineness

	% of Clinker	**% of Gypsum**	**Target fineness, m2/kg**
SOPC 1	95	5	225
SOPC 2	95	5	250
SOPC 3	95	5	275
SOPC 4	95	5	300
SOPC 5	95	5	325
SOPC 6	95	5	350
COPC 1	95	5	225
COPC 2	95	5	250
COPC 3	95	5	275
COPC 4	95	5	300
COPC 5	95	5	325
COPC 6	95	5	350

2.1. Characterization

Chemical analysis of the clinker and cement samples were carried out as per IS 4032-1985 [20]. The room temperature powder X-ray diffractograms were recorded on Rigaku smart lab XE X-ray diffractometer using Nickel filtered Cu-Kα radiation of wavelength 1.5406 Å for phase confirmation in the 2θ range 10 – 80^o, with step size (2θ) of 0.02^0 and scan step time of 0.15 s. The unit cell parameters and reitviled refinemnt were carried out using JADE software. Morphology and granulometery of clinkers was investigated on their polished sections using NIKON POL 600 reflected light microscope equipped with image analyser. Seive analysis were carried out by using 212, 90, 75, 63, 53 and 45 sieves manually. Particle size analysis of the samples were carried out using

3. RESULTS AND DISCUSSION

3.1. Chemical Analysis

The chemical analysis of Portland clinker samples CL-1 and Cl-4, collected from different cement plants showed presence of usual oxide constituents with free lime content in the range of 0.91-1.77 indicating well burnt clinker samples (Table 1). The moduli value such as Lime Saturation Factor (LSF), Silica Modulus (SM), Alumina Modulus (AM) and potential phases C_3S, C_2S, C_3A and C_4AF as determined on the basis of Bogue' calculations are given in Table 2. The chemical analysis of clinker samples showed their conformity to Indian standard IS:16353-2015 specified for Portland clinker.

Table 2 Chemical anlysis of clinker, gypsum and cement samples

Constituents	CCL-1	SCL-2	Gyp	SOPC-1	COPC 2
LOI	0.86	0.6	21.76	1.66	1.91
CaO	62.3	62.65	30.89	61.06	60.73
SiO2	20.9	19.8	4.31	19.03	20.07
Al2O3	5.99	4.94	0.77	4.73	5.73
Fe2O3	3.91	3.36	0.56	3.22	3.74
MgO	2.32	4.25	0.56	4.07	2.23
SO3	2.33	0.87	44.18	3.04	4.42
Na2O	0.45	0.21	0.03	0.20	0.43
K2O	0.57	0.29	0.03	0.28	0.54
IR	0.41	0.56		0.53	0.39
Cl	0.02	0.005	0.015	0.01	0.02
f-CaO	1.77	0.91		0.86	1.68
CW			18.61	0.93	0.93

*Silica & acid insoluble, IR: Insoluble residue, CW: combined water

3.2. X-ray Diffraction

XRD analysis of Portland clinker samples showed presence of usual clinker mineral phases; alite [$Ca_{54}MgAl_2Si_{60}O_{90}$], belite [$Ca_2SiO_4$], calcium aluminate [$Ca_3Al_2O_6$] and calcium alumina ferrite [$Ca_2(Al,Fe)_2O_5$] along with periclase [MgO] in small amount as shown in Figures 1 and 2. Semi-quantitative estimation of clinker mineral phases, in clinker samples CCL-1 and SCL-2, carried out by considering the integral intensity of diffraction line d=1.76Å corresponding to alite and intensities of lines d=2.70 and 7.24Å corresponding to C3A and C4AF. Alite and belite contents of clinker samples CCL-1 and SCL-2 were found to be in between 51 and 55 % and 26 and 22 % respectively as given in Table 3 indicating their good quality.

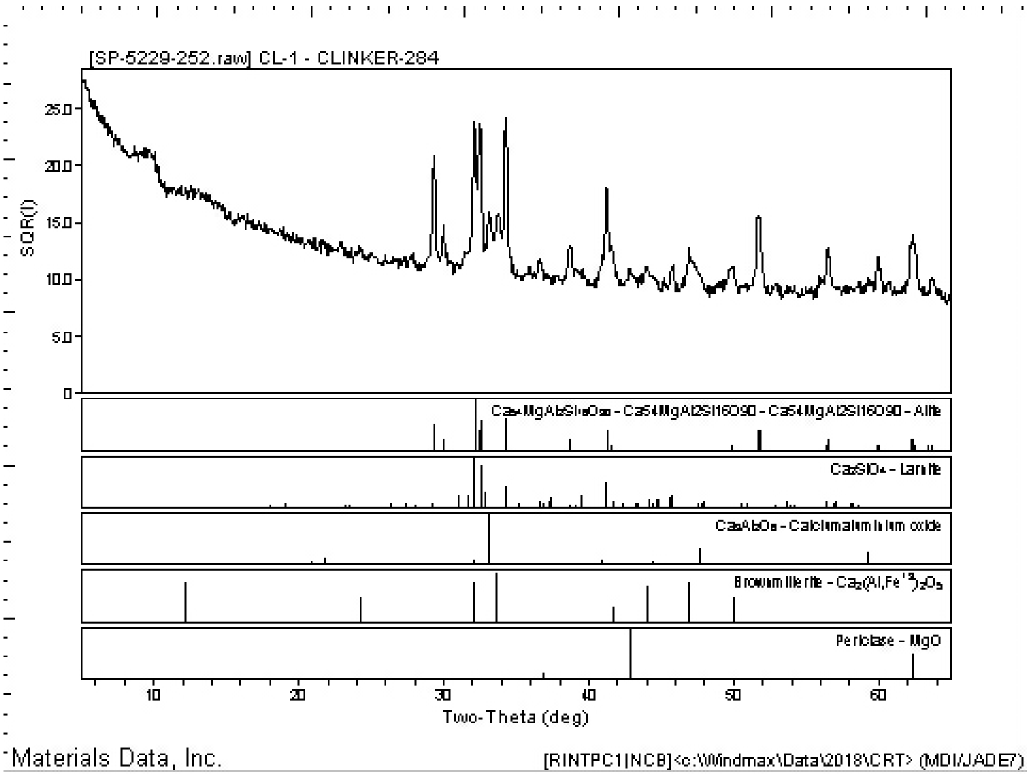

Figure 1 X-ray diffractogram of CCL-1

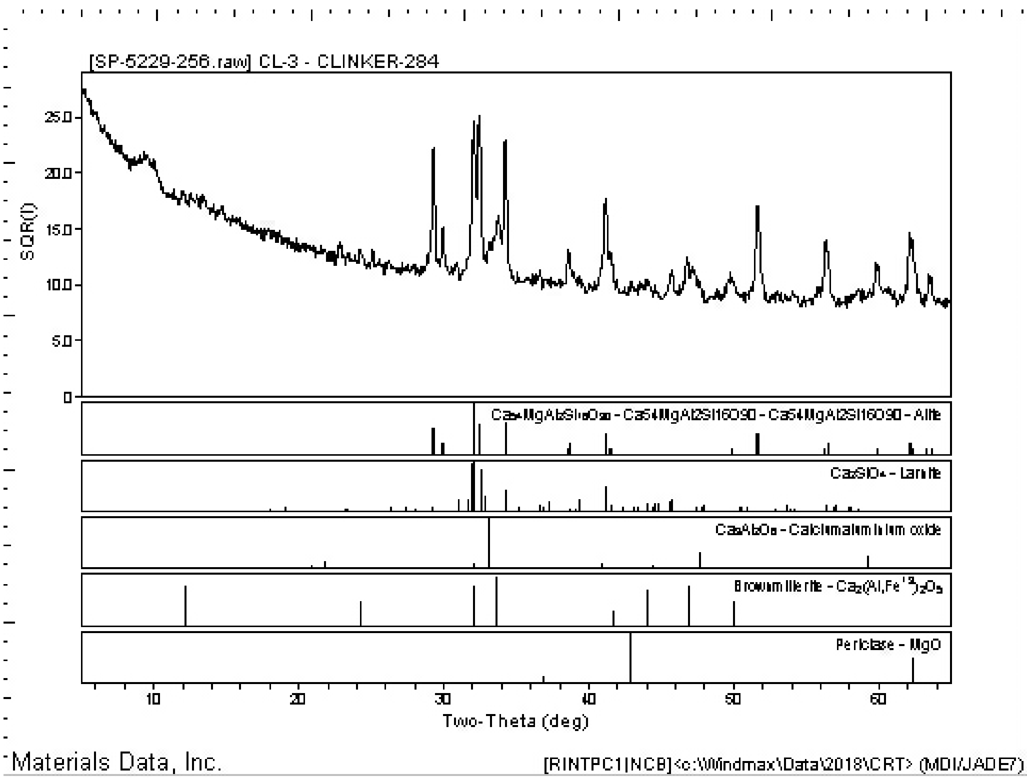

Figure 2 X-ray diffractogram of SCL-2

Table 3 Potential mineral phase by Boague method and semi quantitaive mineral phases by XRD

Potential clinker minerals			**Obtained clinker minerals by XRD**	
Minerals	CCL-1	SCL-2	CCL-1	SCL-2
C3S	42.0	59.97	51.0	55.0
C2S	28.0	11.53	26.0	22.0
C3A	9.0	7.41	5.0	4.0
C4AF	12.0	10.23	13.0	14.0
Others	-	-	5.0	5.0
LSF	0.89	0.97		
AM	2.11	2.38		
SR	1.53	1.47		

4. MICROSTRUCTURE

Clinker CCL-1

Clinker phases were moderately developed and in homogeneously distributed.

Majority of alite grains are pseudo-hexagonal to hexagonal in shape with sharp grain margins along with development of very fine alite grains on the margins of alite phenocrysts. Few alite grains were partially broken on the margins. Bleb shaped belite grains were also observed in the alite grains. Fused alite grains were also observed in clinker. Transformation of belite into alite did not reach equilibrium conditions. Majority of alite grains were in the size range of 25 to 35 µm. Most of belite grains were sub rounded to rounded in shape with corroded margins. Radiating needles and one and two set twinning was observed in belite grains. The Majority of belite grains were in the size range of 15 to 20 µm. Porosity of the clinker was high with pores of various shapes and sizes (20-680 µm). The average grain size of alite and belite grains were found to be 32 and 16-µm respectively. The percentage of alite and belite were 53 and 28% respectively with 19% interstitial matter.

Clinker SCL-2

The clinker phases were moderately developed and in-homogeneously distributed. Majority of alite grains were pseudo-hexagonal to hexagonal in shape with sharp grain margins. Bleb shaped belite grains were detected in the alite grains. Fused alite grains were also very commonly developed in the clinker. Grain size variation in alite is too large. Transformation of belite into alite did not reach equilibrium conditions. Majority of alite grains were in the size range of 30 to 40µm. Most of the belite grains were sub rounded in shape with corroded margins. Radiating needles were also observed in the belite grains. Majority of belite grains are in the size range of 20 to 30 µm. Porosity of the clinker was high with pores of various shapes and sizes (40 to 690-µm) were uniformly distributed. The percentage of alite and belite were 59 and 25% respectively with 16% interstitial matter. The average grain size of alite and belite grains were found to be 37 and 26-µm respectively.

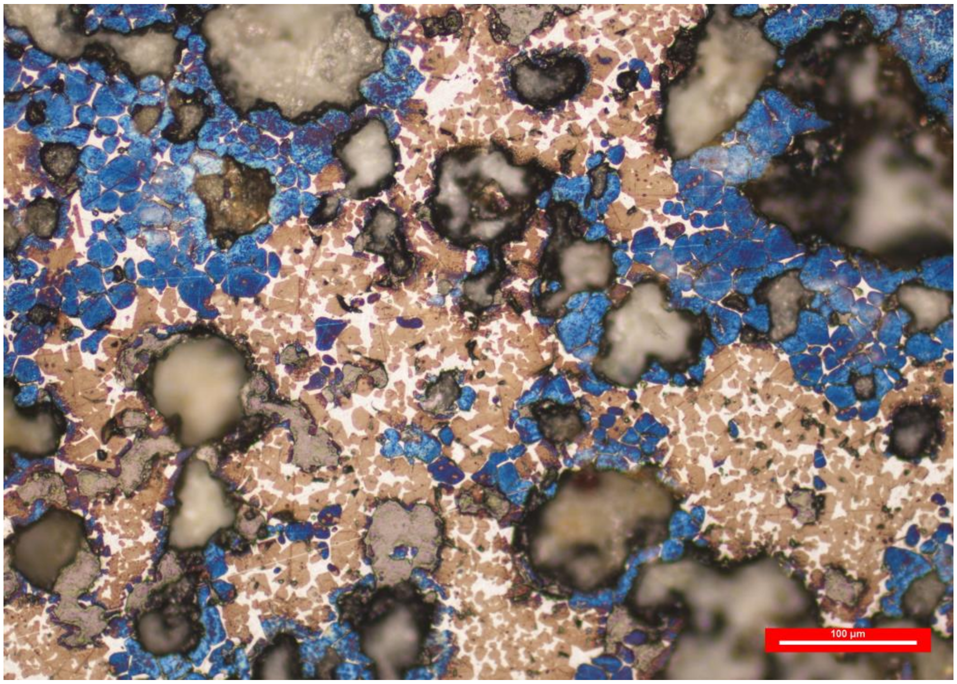

Figure 3 Distribution of alite and belite grains in the clinker (CCL-1). (10X)

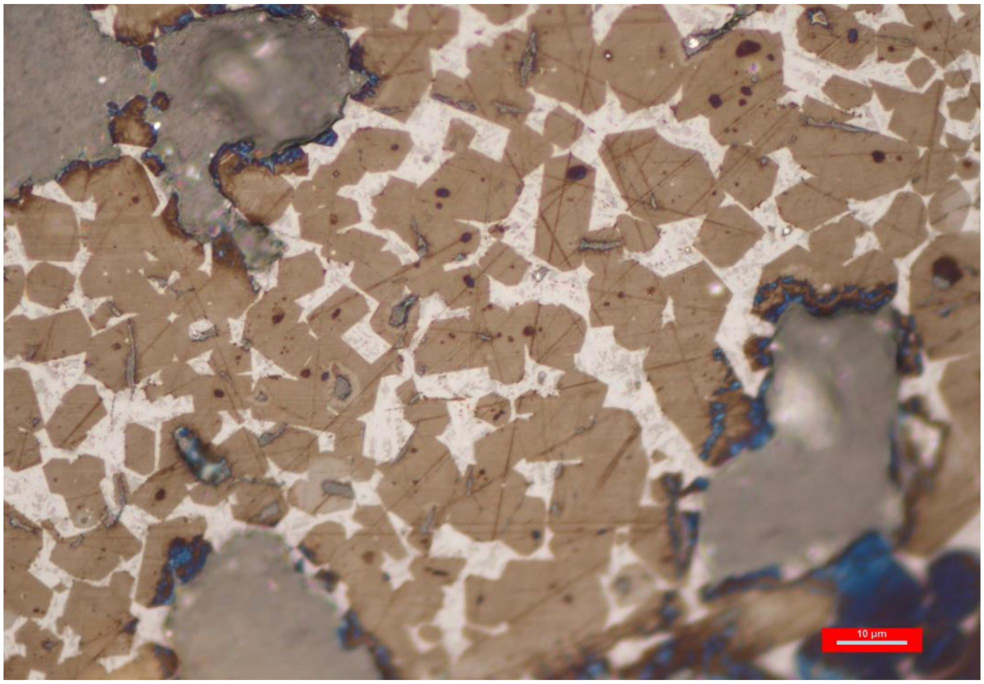

Figure 4 Development of hexagonal to pseudo hexagonal alite grains in the clinker (CCL-1). (50X)

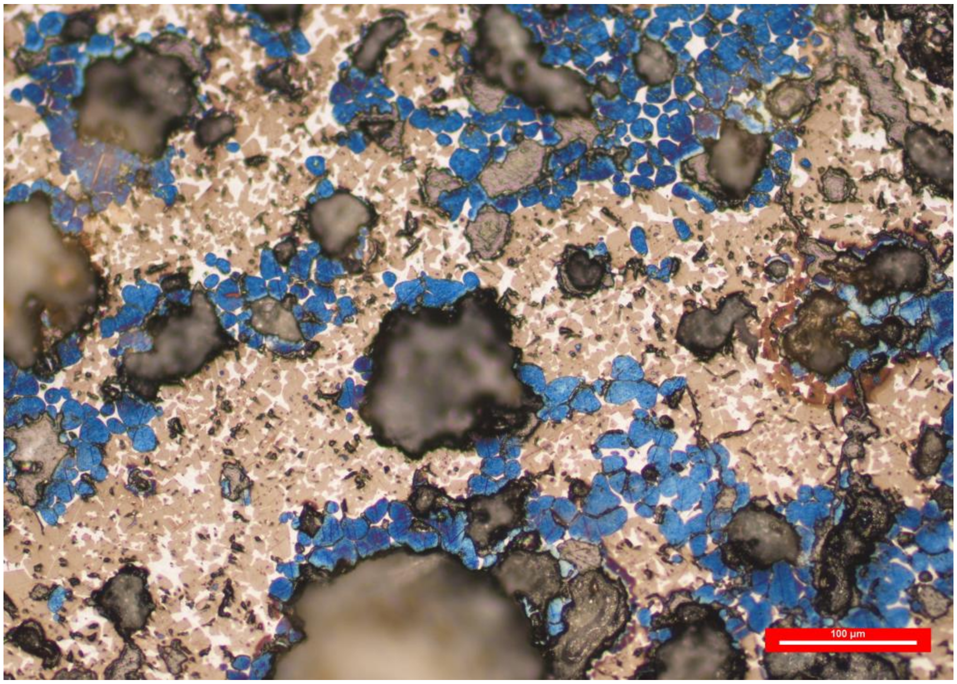

Figure 5 Distribution of alite and belite grains in the clinker (SCL-2). (10X)

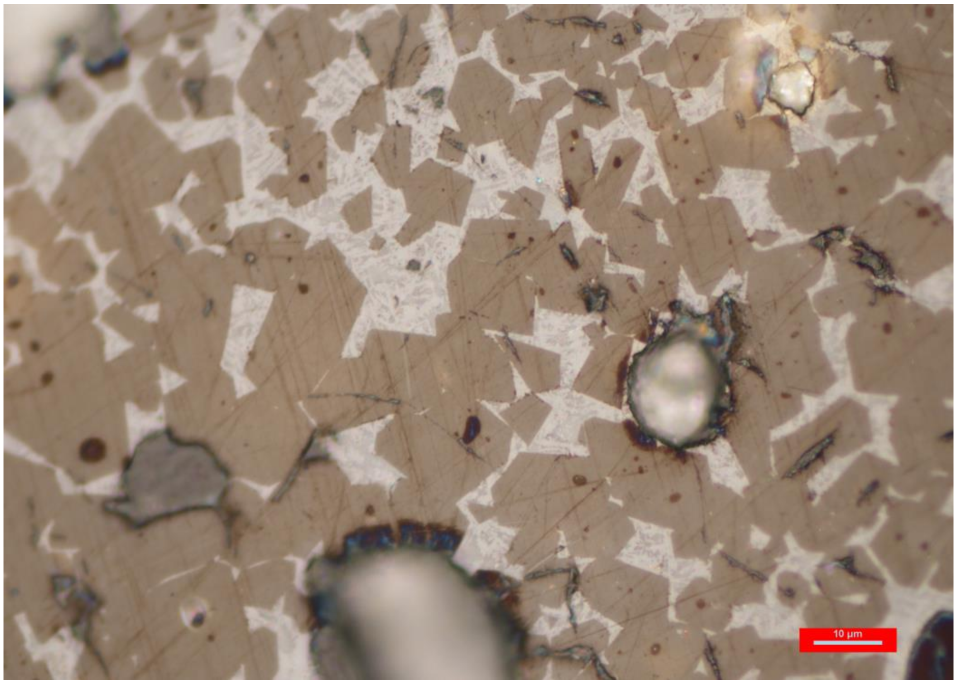

Figure 6 Distribution of alite grains in the clinker (SCL-2). (50X)

5. RESIDUE

Residue of all the cement samples were carried out using 212, 90, 75, 63, 53 and 45 sieve manually. The obtained results are given in table 4. While incresing the fineness of cement samples from 225 to 350 m2/kg, residue on 212 microns decrases slightly from 0.97 to 0.36 and then the remaing samples shows 99.9% passing. The remaining sieve analysis shows decrases in the residue while increse the fineness of cement samples. Significant changes with all the seives interms of residue was observed of samples contains the fineness level of 250 and 275 m2/Kg sample. Clinker 1 containg samples shows significant diffrence around 50% of the residue with all the seives between the fineness level of 225 to 250 m2/kg. After that gradual decrement was obseved of the residue with all the seives. Clinker 2 containg samples shows significant diffrence around 50% of the residue with all the seives between the fineness level of 250 to 275 m2/kg. It is observed that the percenatge of passing of SOPC samples was significantly more at all the seives compared to COPC sample. It may be due to the more percenatge of C_2S percent in the CCL-1 than the SCL-2.

It was obseved that while incrasing the fineness from 225 to 350m2/kg, more number of more than 63 microns size particles were ground about 85% of 90 microns, 81% of 73 microns, 71% of 63 microns, 61% of 53 microns and 50% of 45 mirons were ground.

Table 4 Residue of all the OPC samples

Sample	+212µ	+90 µ	+75 µ	+63 µ	+53 µ	+45 µ	-45 µ
COPC 1	0.85	12.35	19.99	28.37	34.68	40.43	59.57
COPC 2	0.15	4.98	10.61	18.52	25.91	32.46	67.54
COPC 3	0.13	4.41	9.57	17.14	24.42	30.97	69.03
COPC 4	0.12	3.16	7.05	13.75	20.28	27.01	72.99
COPC 5	0.13	2.38	5.82	12.30	18.64	25.02	74.80
COPC 6	0.10	1.82	3.61	7.70	13.35	20.20	79.80
SOPC 1	0.97	13.89	21.43	29.57	35.16	40.70	59.30
SOPC 2	0.37	11.27	18.30	26.28	32.43	37.90	62.10
SOPC 3	0.12	5.35	11.42	19.08	25.02	31.02	68.98
SOPC 4	0.11	3.46	8.09	14.89	21.17	27.14	72.86
SOPC 5	0.10	2.34	5.89	12.26	17.96	24.12	75.88

5.1. Particle size distribution

Particle size analysis of all the cement samples were carried out by using microtrac S3500 and the obtained results are giben in the below table. Portland cements COPC1 and SOPC 1 of Blaine fineness about 225 m2/kg respectively contains about 52 and 50 percent on + 33 µ particles and 11.32 and 15.37 percent of - 10 µ particles respectively. While increasing the fineness from 225 to 350 m2/kg, reside on 33 microns decreased from 52% to 40%, 37%, 37% and 33% of COPC 2, COPC 3, COPC 4, COPC 5 and COPC 6 respectively. Similarly, increasing the fineness to 350 m2/kg increases the - 10 µ from 11.32 to 15.52, 16.12, 16.86, 18.76 and 21.45 of COPC 2, COPC 3, COPC 4, COPC 5 and COPC 6 respectively. Average mean size of the cement particles of COPC 2, COPC 3, COPC 4, COPC 5 and COPC 6 are 21.24, 17.57, 18.07, 16.68, 15.86 and 14.76 respectively.

SOPC samples also show the similar chrematistics by increasing the fineness of the samples from 225 to 350 m2/kg. Reside on 33 microns decreased from 50% to 49%, 43%, 39% and 37% of SOPC 2, SOPC 3, SOPC 4 and SOPC 5 respectively. Similarly, increasing the fineness to 350 m2/kg increases the - 10 µ from 15.37 to 16.10, 17.32, 19.01 and 21.35 % of SOPC 2, SOPC 3, SOPC 4 and SOPC 5 respectively. Average mean size of the cement particles are 18.01, 17.14, 16.77, 15.80 and 14.88 of SOPC 2, SOPC 3, SOPC 4 and SOPC 5 respectively.

Table 5 PSD studies of COPC samples

	COPC 1	COPC 2	COPC 3	COPC 4	COPC 5	COPC 6
%Tile	**Size(um)**	**Size(um)**	**Size(um)**	**Size(um)**	**Size(um)**	**Size(um)**
1.0	4.11	3.89	3.85	3.80	3.40	3.30
3.0	5.76	5.22	5.22	5.06	4.65	4.43
5.0	6.95	6.17	6.21	5.97	5.53	5.23
10.0	9.40	8.08	7.89	7.78	7.27	6.78
50.0	34.97	26.15	25.46	24.05	23.95	21.75
60.0	44.30	33.65	34.85	30.42	30.62	27.96
70.0	54.74	42.02	43.38	37.90	38.10	35.23
80.0	68.23	51.99	54.12	47.45	47.49	44.32
90.0	91.71	66.50	72.61	63.39	63.26	59.68
95.0	119.1	80.17	93.36	80.95	81.97	77.94
MV(um):	45.11	32.83	35.65	31.31	31.53	29.46
MN(um):	6.46	6.37	6.28	6.29	5.50	5.41
MA(um):	21.24	17.57	18.07	16.68	15.86	14.76

Table 6 PSD studies of COPC samples

	SOPC 1	SOPC 2	SOPC 3	SOPC 4	SOPC 5
%Tile	**Size(um)**	**Size(um)**	**Size(um)**	**Size(um)**	**Size(um)**
1.0	2.928	3.48	3.34	3.21	3.17
3.0	4.26	4.90	4.58	4.36	4.25
5.0	5.30	5.97	5.50	5.21	5.04
10.0	7.57	8.22	7.40	6.98	6.63
50.0	33.27	32.74	27.34	24.63	22.80
60.0	43.45	43.20	35.04	32.05	29.96
70.0	55.10	55.20	43.56	40.91	38.29
80.0	70.28	70.65	54.15	52.3	48.72
90.0	96.48	95.48	72.22	72.32	65.83
95.0	126.6	119.7	92.22	96.02	85.44
MV(um):	45.25	44.11	35.19	34.53	31.51
MN(um):	4.35	5.34	5.30	5.17	5.17
MA(um):	18.01	19.14	16.77	15.80	14.88

5.2. Perfomance Evaluation

The Blaine's fineness of cement blends, determined by air permeability (Blaine's apparatus) method, as per IS: 4031(2)-1999. The water requirement to prepare cement paste of normal consistency was measured according to IS: 4031(4)-1998. The initial and final setting times, determined as per IS: 4031(5)-1998 of cement blends. The compressive strengths at different aging, measured as per IS: 4031(6)-1989 on 1:3 cement-sand mortar of cement blends [21]. The obtained results of COPC and SOPC are given in Table 8 and 9 respectively. The strength of cement is the most important of all the cement properties. The compressive strength of cement cube specimens of COPC and SOPC samples in Figure 6. From the obtained results, it can be observed that an increase in cement fineness of both the cements reduces the intial and final setting times as well as increases in the initial age compressive strength of the cement mortar. This is due to the fast kinetics of hydration of the mineral C3S (tricalcium silicate) and C2S (dicalcium silicate). These two mineral phases are the two principal constituents in the cement which ensure the development of the strength. Thus, it can be concluded that the fineness of cement is a significant characteristic during the hydration of the mix, more the particles are fine, more the cement surface in contact with water is large and more the hydration is fast and complete (shortening of set times). Generally, most of the literature reported that higher alkali content, present in the form of hydroxide or sulfate, result in quick setting.

In the case of COPC samples, strength increase due to the increase of the reactivity of C_3A and C_3S with the presence of alkali content in the cement. Generally, the evidence points out to the increase of initial hydration. However, it is possible that the nature of the reaction products is impacted rather than just the reaction rate itself; also, the role of alkalis on the hydration process greatly depends on the sulfate levels in cement. it is very clear from the literature that alkalis impact the hydration and kinetics of hydration of Portland cements. That is, the dependence of the hydration process on many factors, especially sulfate content, and the dependence of this on alkali content as well as the cement composition appear not to be clearly considered.

The later strength development of COPC samples shows different results. Up to 250 m2/kg fineness, samples shows strength gain from 7 Days to 28 days. But, beyond the 250 m2/kg fineness level samples doesn't show strength improvement from 7D to 28 D. This may be due to the presence of alkalies in the clinker (CCLK-1) samples as well as average belite size is lower comparing to SCLK-2 (i.e. 16 micro meters). The alkali hydroxide favors the formation of crystalline monophase around the C_3A grains, and the sulfate, mostly in the form of potassium, leads to the precipitation of syngenite. These effects are strongly dependent on the content of these ions. For strength development, most of the evidence pointed to an increase in the early strength and a decrease in the 28-day strength. This is due to lowering of the gel in the presence of alkalis compared to that of calcium which enhances the gelatinous properties of the hydrates. It was concluded that the effect of the alkalis on late strength is caused by something happened during the early hydration and not governed by the conditions of the pore liquid at later ages.

Residue on 45 microns and passing percentage of COPC samples at different fineness respectively low and more compare to SOPC samples. Strength development at later ages depends mainly on the particle size between 10 to 30 microns. The 50 passing particle size in the case of COPC samples is lower than the SOPC samples. Based on the above observations, in addition to the sulfate optimization according to the fineness for optimum performance characteristics, mineralogy of the clinker plays an important role for optimizing the fineness, residue and PSD for desired performance cement characteristics.

Table 7 Performance characteristics of OPC prepared by CCL-1 at different fineness levels

		Fineness	Setting Time, min		Compressive Strength, Mpa			
Name	**N.C**	**m2/kg**	**IST**	**FST**	**1D**	**3D**	**7D**	**28D**
COPC-1	25.0	225.0	175.0	220.0	16.5	35.5	41.5	49.0
COPC-2	25.2	247.0	165.0	215.0	17.5	38.0	43.0	49.0
COPC-3	25.5	267.0	140.0	180.0	25.5	42.0	52.0	52.0
COPC-4	25.8	308.0	130.0	170.0	29.0	46.0	54.0	50.0
COPC-5	26.0	321.0	110.0	160.0	28.5	48.0	52.5	49.5

Table 8 Performance characteristics of OPC prepared by CCL-1 at different fineness levels

		Fineness	Setting Time, min		Compressive Strength, Mpa			
Name	**N.C**	**m2/kg**	**IST**	**FST**	**1D**	**3D**	**7D**	**28D**
SOPC-1	25.0	225.0	150.0	215.0	22.5	33.5	42.5	53.0
SOPC-2	25.2	256.0	145.0	210.0	23.5	33.5	43.0	52.5
SOPC-3	25.5	285.0	130.0	185.0	28.5	34.5	45.0	55.0
SOPC-4	25.8	307.0	125.0	180.0	28.5	35.0	42.5	54.0
SOPC-5	26.0	335.0	110.0	170.0	32.0	35.0	43.5	52.5

6. CONCLUSIONS

Clinker quality is an important parameter to consider the set points for target fineness. Quality of the clinker plays an important role on the residue and particle size distribution of the cements. Clinker (CCL-1) contains high C2S shows drastic diffrence on the residue while incresing the fineness from 225 to 250 m2/kg. SCL-2 shows significant diffrence on the residue at the finess level of 275 m2/kg. Particle size distribution studies shows incraesing the percentanage of pass after 33 microns while incresing the fineness from 225 to 350 m2/kg. Clinker contains more C2S around 26% shows significant passing percentaile diffrence between 225 to 250 m2/kg as 90 percenatge on 91.71 microns to 90 percent on 66.50 microns. Clinker contains more C2S around 22% shows significant passing percentaile diffrence between 250 to 275 m2/kg as 90 percenatge on 95.48 microns to 90 percent on 72.22 microns. The setting times are shortened as the cement particle fineness increases. This is due to the fact that the coarse cement particles require less hydration to achieve equivalent set than a finer cement particle. The compressive of cement increases as cement particles increase in fineness from 225 to 350 m2/kg. Also, the finer the cement, the high the reactive ness of its particle. Based on the above observations, in addition to the sulfate optimization according to the fineness for optimum performance characteristics, mineralogy of the clinker plays an important role for optimizing the fineness, residue and PSD for desired performance cement characteristics.

REFERENCES

[1] Liaqat A Q and Saeed A Optimization of fineness of Ordinary Portland Cement Manufactured in Pakistan Mehran University Research Journal of Engineering & Technology. 2011, 30: 549-558.

[2] Ali M A, Arif E S, Burak F and Kambiz R, Effect of Cement Fineness on Properties of Cementitious Materials Containing High Range Water Reducing Admixture Journal of Green Building. 2017, 12: 142-167.

[3] Abla Z Effects of Portland Cement Particle Size on Heat of Hydration (Pampa, Florida). 2013, 27-48.

[4] Hu J, Ge Z and Wang K Influence of cement fineness and water-to-cement ratio on mortar early-age heat of hydration and set times Construction and Building Materials. 2014, 50: 657-663.

[5] Mtarfi N H, Rais Z and Taleb M Effect of clinker free lime and cement fineness on the cement physicochemical properties Journal of Materials and Environmental Sciences. 2017, 8: 2541-2548.

[6] Chen J J and Kwan A K H Superfine cement for improving packing density, rheology and strength of cement paste Cement and Concrete Composites. 2012, 34: 1-10.

[7] Celik A B The Effects of Particle Size Distribution and Surface Area Upon Cement Strength Development Powder Technology UK. 2009, 188: 272-276.

[8] Bentz D P, Sant G and Weiss J Early Age properties of Cement based materials: Influence of cement fineness ASCE Journal of Materials in Civil Engineering. 2008, 20: 502-508.

[9] Liaqat A Q Variation in Properties of Different Pakistani Cements and Its Effect on Properties of Concrete. 2010, 81-132.

[10] NIS 444 2003 Standard for Cement. Standard Organization of Nigeria, Lagos.

[11] BS 12 1996 Specification for Portland Cement. British Standard Institution, London.

[12] BS EN 1008 Mixing water for concrete - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete. 389 Chiswick High Road London, 2002.

[13] BS 882:1992 Specification for aggregates from natural sources for concrete. British Standard Institution, London.

[14] BS EN 12350: Part 2: 2000 A method for Determination of Slump. British Standard Institution, London.

[15] BS EN 12350-6: 2009 Testing Fresh Concrete Density of Test Specimens. British Standard Institution, London.

[16] BS EN 12390-3: 2009 Testing Hardened Concrete. Compressive Strength of Test Specimens. British Standard Institution, London.

[17] BS EN 12390-6: 2009 Testing Hardened Concrete. Tensile Splitting Strength of Test Specimens. British Standard Institution, London.

[18] Tsivilis S, Batis G, Chaniotakis E, Grigoriadis G and Theodossis D Properties and behavior of limestone cement concrete and mortar Cem. Concr. Res. 2000, 30: 1679–1683.

[19] Stark J, Freyburg E and Lohmer K Investigation into the influence of limestone additions to portland cement clinker phases on the early phase of hydration. In. Dhir RK, Dyer TD (cds) International conference on modern concrete materials: binders, additions and admixtures, London, 1999, Thomas Telford.

[20] IS 4031 Method of physical test of hydraulic cement

[21] IS 4032-1985 method of chemical analysis of hydraulic cement