Optimization of Fineness of Ordinary Portland Cement Manufactured in Pakistan

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ABSTRACT

In this paper, investigation regarding impact of fineness of cement on properties of concrete is reported for cement manufactured by five different factories. Clinker was collected from a selected batch of each factory. It was ground along with 4% gypsum in a laboratory ball mill. From each factory, six cement samples with different fineness values were prepared. In order to confirm uniformity of their oxide ratios, their chemical composition was analyzed by XRF-Cement Spectroscopy. Grinding time for each sample was recorded by the built-in timer of ball mills. From the prepared samples, consistency tests of all the samples were performed in the laboratory. Concrete cubes having same mix. and water cement ratios were cast and tested for compressive strength at the age of 3, 7, and 28 days. In order to have an idea of workability, slump test and compacting factor tests were carried out on concrete mixes prepared to cast test cubes. Comparisons were made between fineness of cement versus consistency of cement, compressive strength, slump, compacting factor of concrete, and grinding time. Mathematical relationships between fineness of cement and these parameters were established by using "Least Square Regression Method". Relative study of cost of grinding against desirable properties of cement & concrete at higher fineness levels was also conducted.

Key Words: **Fineness, Grinding, Spectroscopy, Compressive Strength, Workability, Clinker.**

1. INTRODUCTION

Concrete is one of the most commonly used construction materials all over the world. It is a mixture of different ingredients as cement, coarse aggregate, fine aggregate and water. The individual properties of each ingredient have tremendous influence on the properties of concrete. Out of these ingredients, cement act as binding material for other ingredients. It is the most costly material among all constituents of concrete. Its properties also greatly affect the properties of resulting concrete. One of the properties of cement is "fineness" which determines the level of grinding of cement clinker with gypsum in a grinding mill. It can be defined more comprehensively as "the total surface area of the cement that is available for hydration".

The major properties of cement which are affected by change in fineness value are consistency, setting time, expansion and compressive strength [1-3], while properties

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of concrete, which are more respondent to change in fineness of cement are compressive strength and workability [4-11]. Rate of hydration depends on the fineness of cement particles and for a rapid development of strength, high fineness is necessary [4-5]. Although, compressive strength of concrete increases with fineness, this increase ceases at higher finesses values [6-7]. It was also observed that influence of fineness on strength varies with the water cement/ratio and concrete mix proportion [8]. Increase in surface area of cement also slightly increases the tensile strength of concrete [9]. On the other hand, some researchers gave an argument for using coarser cements in high performance concretes [10]. As far as water requirement of cement is concerned, it was concluded that water content of paste of standard consistency is greater for finer cements [1-3].

Various researchers conducted research on effect of fineness of cement on properties of concrete prepared mainly by ordinary portland cements manufactured abroad [4-7, 9]. The trend of locally manufactured cements by using indigenous materials was still demanding a lot of research work. In Pakistan, different factories believe that with an increase in fineness of cement, strength of concrete will also increase. However, due to mutual competition, they unrealistically increase the fineness of cement. The result is a high increase in grinding cost. But previous researchers have showed that gain in compressive strength ceases at high fineness values. The main purpose of this research is to have an optimized study regarding cost of grinding versus gain in compressive strength of concrete. Also, no well-defined relationships exist between fineness of cement and desirable properties of cement & concrete. Therefore, this research work was planned to specify such relationships. Blaine's Air Permeability Apparatus was used for determining fineness of different cement samples.

2. PREPARATION OF TEST SAMPLES

Work was expanded over 5 cement factories. In order to take care of their business interests, the factories have been randomly named as A, B, C, D, and E, in this paper. Cement samples of varying fineness but with uniform chemical composition were prepared in the laboratory. For this purpose, sufficient quantity of cement clinker was collected from each factory, when its kiln was running smoothly. This clinker was mixed with 4% gypsum and finely ground in an Iron-Jar-type Ball Mill at different fineness levels. During grinding of different batches, fineness was periodically measured with Blaine's air permeability apparatus and grinding stopped at different desired levels. Finished cement samples were then sealed in polythene bags and marked accordingly.

3. TEST PROGRAMME

3.1 Chemical Composition

Chemical composition of all samples was analyzed by XRF Cement Spectrometer/Cement X-Ray Analyzer. Results are given in Table 1. The chemical composition confirms the uniform oxide ratio of all samples.

In Table 1, chemical composition of samples prepared from clinkers of different factories is given. Fineness value is different for different samples. However, the actual fineness at dispatching time ranges from 3000-3500 cm^2/g for different factories and even for the same factory.

3.2 Consistency Test

Consistency test of the samples was performed by using "Vicat Apparatus" [12].

3.3 Preparation of Concrete Mixes

Fresh concrete was prepared in the laboratory by using cement samples of different finenesses. Mix ratio was kept as 1:2:4 while water/cement ratio as 0.65 for all the mixes.

3.3.1 Coarse Aggregates

The following three sizes of margalla crush were used:

Batch -1 = Passing through 19.0 mm (¾ inch) and retained on 13.2 mm (½ inch) sieve.

Batch-2 = Passing through 13.2 mm (½ inch) and retained on 9.5 mm (3/8 inch sieve).

Batch -3 = Pan

The three batches were mixed in the ratio of 4:3:1 to get uniform grading [13].

3.3.2 Fine Aggregates

Lawrencepur sand was used in the research. As per sieve analysis results [13], it belonged to "Fine Grading" zone and its Fineness Modules was 2.66.

TABLE 1. CHEMICAL COMPOSITION OF TEST SAMPLES

Factory	Fineness	Chemical Composition (%)									
	(cm^2/g)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	K_2O	TiO_2	Mn_2O_3
A	1525	21.42	5.30	3.14	62.85	1.83	0.24	2.63	0.86	0.31	0.04
	2065	21.58	5.29	3.15	63.28	1.79	0.23	2.67	0.85	0.32	0.04
	2495	21.48	5.26	3.13	62.85	1.77	0.24	2.60	0.84	0.31	0.05
	3048	21.60	5.37	3.20	63.27	1.79	0.24	2.72	0.87	0.32	0.04
	3355	21.54	5.33	3.16	62.85	1.80	0.24	2.64	0.86	0.32	0.04
	3741	21.56	5.31	3.18	62.95	1.82	0.24	2.66	0.85	0.32	0.05
B	1690	20.34	5.28	3.01	62.10	2.64	0.28	2.46	0.98	0.34	0.04
	2083	20.29	5.25	2.97	62.03	2.63	0.28	2.49	0.99	0.33	0.04
	2556	20.32	5.28	2.99	62.17	2.62	0.29	2.46	0.99	0.33	0.04
	2912	20.28	5.28	2.99	62.09	2.64	0.28	2.54	0.99	0.33	0.04
	3315	20.29	5.26	3.00	62.04	2.62	0.27	2.51	0.98	0.33	0.04
	3773	20.27	5.26	3.01	61.89	2.59	0.28	2.58	0.99	0.33	0.04
C	1548	20.72	5.52	3.28	63.55	1.50	0.28	2.69	0.93	0.33	0.04
	2048	20.70	5.50	3.30	63.67	1.52	0.29	2.67	0.93	0.31	0.04
	2468	20.76	5.54	3.32	63.45	1.50	0.28	2.55	0.92	0.34	0.04
	2964	20.78	5.56	3.32	63.65	1.52	0.29	2.51	0.93	0.33	0.05
	3476	20.76	5.54	3.28	63.55	1.50	0.28	2.46	0.93	0.32	0.04
	3883	20.80	5.52	3.26	63.65	1.50	0.28	2.44	0.93	0.33	0.04
D	1661	21.36	5.15	3.34	68.75	1.69	0.28	2.31	0.74	0.32	0.03
	2028	21.48	5.13	3.34	63.85	1.68	0.28	2.32	0.75	0.32	0.04
	2580	21.32	5.12	3.31	63.89	1.67	0.28	2.28	0.75	0.32	0.03
	3033	21.36	5.10	3.35	63.62	1.71	0.28	2.28	0.74	0.32	0.03
	3369	21.32	5.10	3.34	63.48	1.72	0.28	2.28	0.75	0.32	0.04
	3674	21.38	5.10	3.34	63.53	1.71	0.28	2.27	0.76	0.32	0.04
E	1620	20.85	5.64	3.65	62.42	2.44	0.28	2.18	0.85	0.34	0.04
	1945	20.76	5.57	3.70	62.05	2.41	0.26	2.59	0.85	0.33	0.04
	2495	20.89	5.55	3.69	61.89	2.41	0.34	2.58	0.84	0.33	0.04
	2860	20.88	5.51	3.65	61.90	2.43	0.32	2.67	0.84	0.33	0.04
	3380	20.87	5.53	3.63	61.68	2.47	0.31	2.87	0.84	0.33	0.04
	3727	20.90	5.36	3.56	62.13	2.39	0.35	2.74	0.78	0.33	0.04

3.4 Compressive Strength Test

For compressive strength of concrete, it was planned to cast nine 15cm (6") concrete cubes from each test sample by adopting BS:12390: Part-3 [14]. As work was extended over five cement factories and six test samples were prepared for each factory, a total number of (5x6x9) 270 cubes were cast. The compressive strength tests for hardened concrete were performed with the help of a 3000kN Compression Testing Machine and in accordance with BS:12390: Part-3 [14].

4. RESULTS AND DISCUSSION

4.1 Consistency

The results of consistency test on all samples are plotted in Figs. 1-2. Fig. 1 shows comparison of individual trends of samples collected from different factories. All samples show an increase in consistency with an increase in fineness. Factories A, B, C, & D have almost similar pattern while that of factory E is somewhat different. In Fig. 2, an average trend of all the factories is shown. The governing equation is found to be:

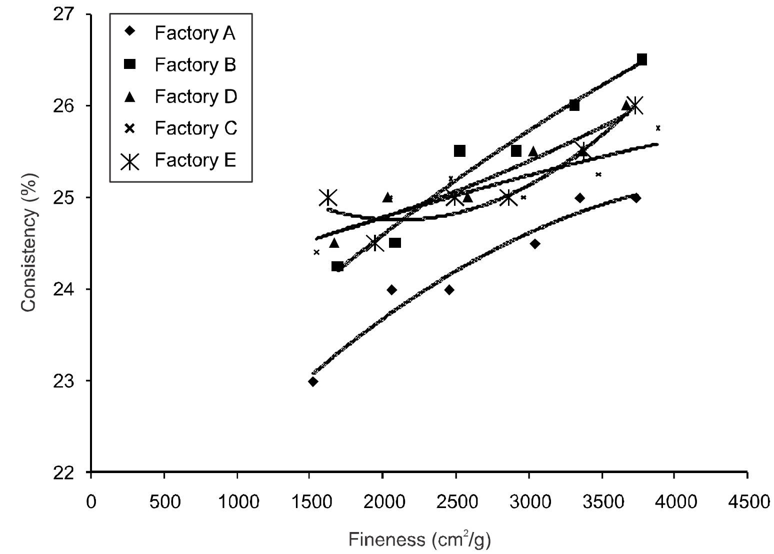

FIG. 1. FINENESS OF CEMENT VERSUS ITS CONSISTENCY (COMPARISON OF DIFFERENT FACTORIES)

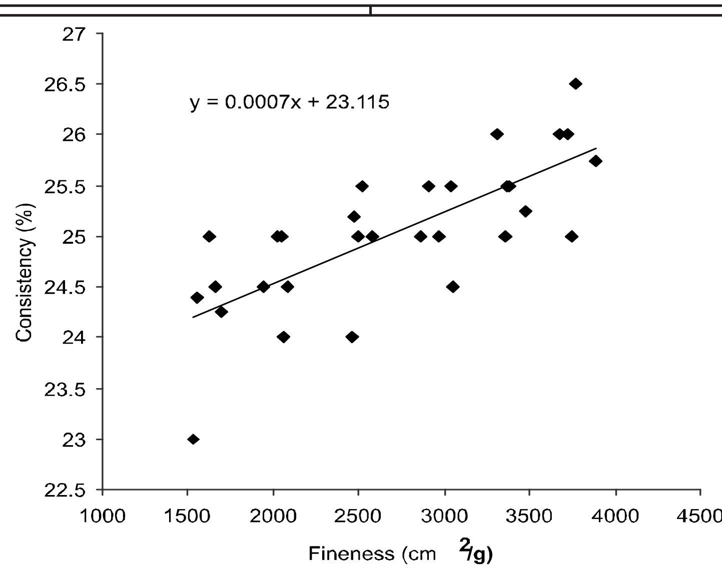

FIG. 2. FINENESS OF CEMENT VERSUS ITS CONSISTENCY (AVERAGE TREND)

$$Y = 0.0007X + 23.12 \quad (1)$$

Where Y stands for consistency (%) and X for fineness value ($cm^2.g$).

Consistency indicates the degree of density or stiffness of cement. It is the amount of water content required for a given cement to get a cement paste of standard consistency. With the increase of fineness, specific surface of cement increases. As a result, more surface area is available for hydration from the same weight of cement. So, more water will be required to produce the cement paste of same standard consistency. It can be better understood with the fact that the increase in fineness is associated with increased cohesion and reduced bleeding. Also, very fine cements produce a fat and sticky concrete, thus, increasing overall water demand [6].

4.2 Compressive Strength

Figs. 3-5 show effect of fineness of cement on 3, 7 and 28-days compressive strength of concrete cubes for five factories respectively. All Graphs show an increase in the compressive strength with increase in fineness. With the increase in surface area, hydration accelerates; setting time decreases and cement paste hardens in less time. As a result, with increasing fineness, the early age compressive strength is improved.

(i) For 3-days compressive strength, all the curves except that for factory D show a higher rate of increase in strength at lower fineness levels while after about 3200 cm^2/g the rate of gain of strength declines (Fig. 3).

(ii) For 7-days Compressive strength, all the curves except that for factory D show a higher rate of increase in strength at lower fineness levels while after about 3200 cm^2/g the rate of gain of strength ceases (Fig. 4).

(iii) For 28-days compressive strength, the curve for factories A, C, D and E are convex while that of factory B is concave upward (Fig. 5). It shows that increase in 28-days compressive strength for factories A, C, D and E ceases with increasing fineness while that for factory B, it increases.

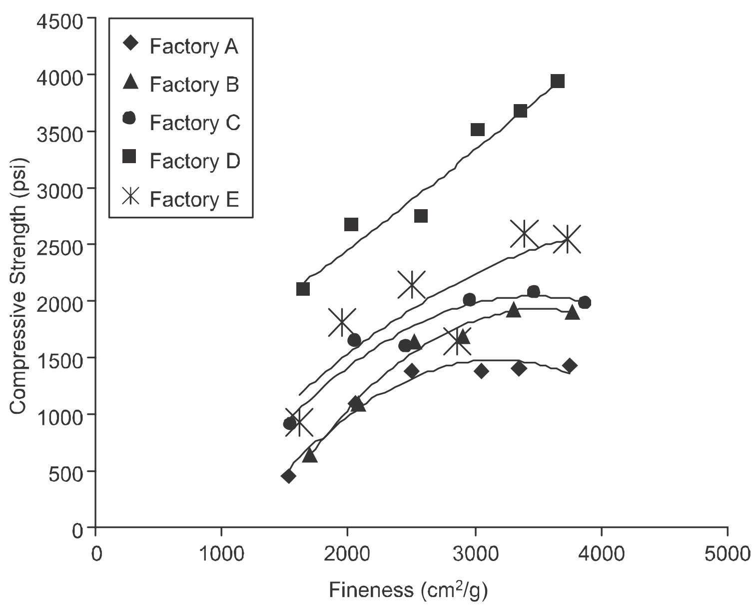

FIG. 3. FINENESS OF CEMENT VERSUS 3-DAYS COMPRESSIVE STRENGTH OF CONCRETE (COMPARISON OF DIFFERENT FACTORIES)

The different trends obtained in Figs. 1,3 and 5 even for the same age is due to different sources of raw materials for different factories and different controlling conditions in respective kilns.

(iv) Figs. 6-8 indicate the average trend at almost all ages of concrete. An increase in compressive strength with fineness is observed. After Regression Analysis, the governing equations are found to be as under:

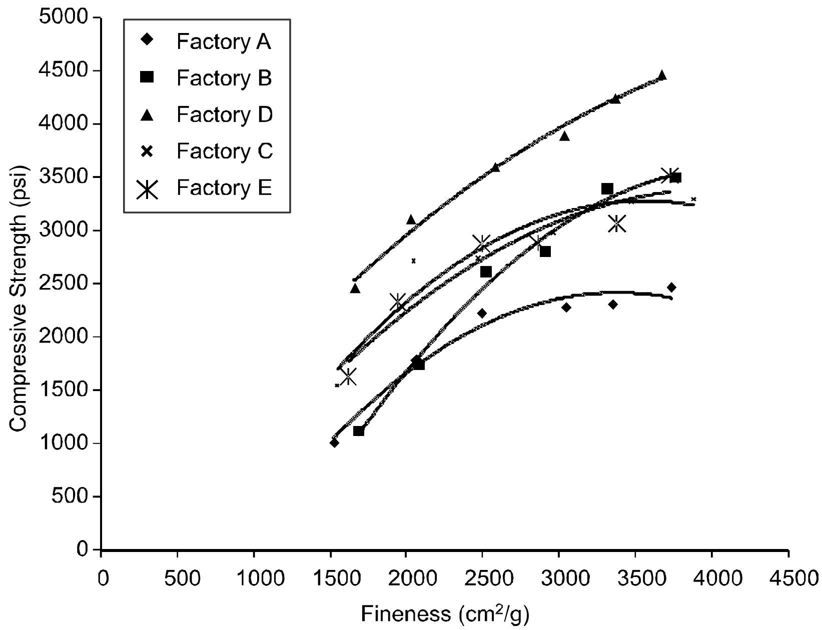

FIG. 4. FINENESS OF CEMENT VERSUS 7-DAYS COMPRESSIVE STRENGTH OF CONCRETE (COMPARISON OF DIFFERENT FACTORIES)

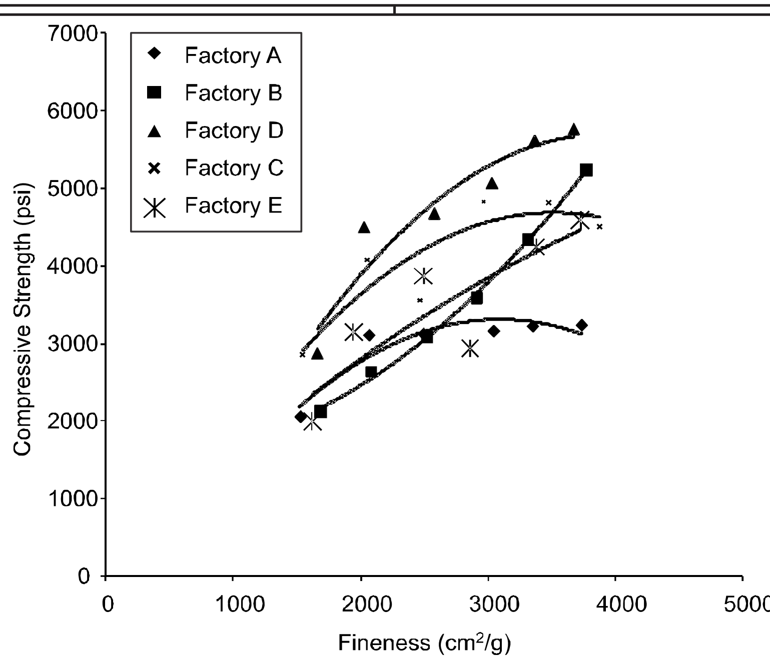

FIG. 5. FINENESS OF CEMENT VERSUS 28-DAYS COMPRESSIVE STRENGTH OF CONCRETE (COMPARISON OF DIFFERENT FACTORIES)

For 3-Days Compressive Strength

$$Y = 0.6\,X^{1.01} \quad (2)$$

For 7-Days Compressive Strength

$$Y = 2.08\,X^{0.9} \quad (3)$$

For 28-Days Compressive Strength

$$Y = 13.59\,X^{0.71} \quad (4)$$

Where Y stands for compressive strength of concrete (psi), while X stands for fineness of cement (cm^2/g). Keeping in

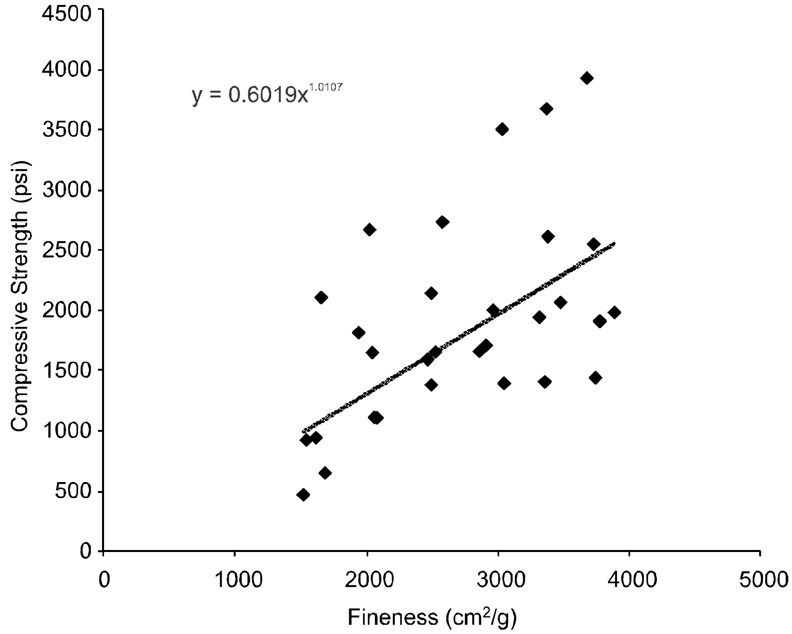

FIG. 6. FINENESS OF CEMENT VERSUS 3-DAYS COMPRESSIVE STRENGTH OF CONCRETE (AVERAGE TREND)

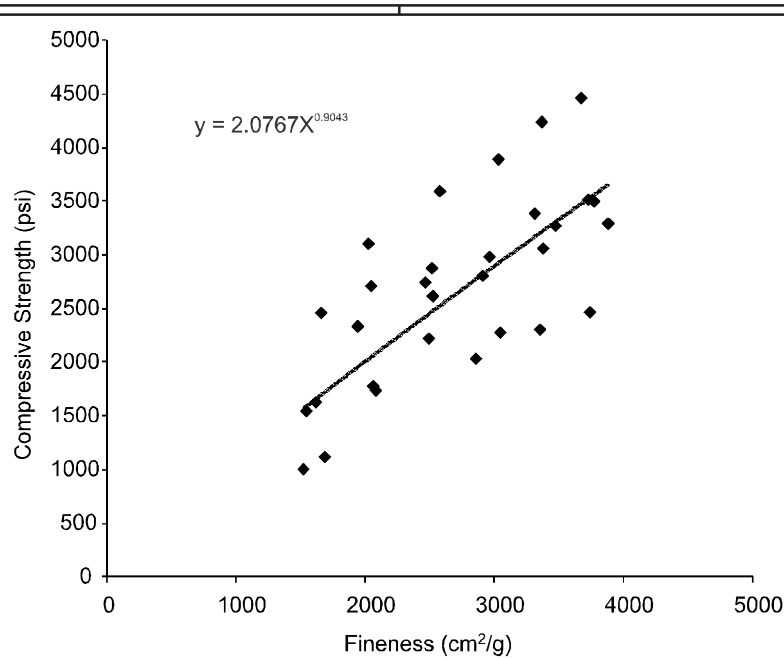

FIG. 7. FINENESS OF CEMENT VERSUS 7-DAYS COMPRESSIVE STRENGTH OF CONCRETE (AVERAGE TREND)

view the limitations of our work, the Equations (2-4) may be applied only up to a fineness level of 4000 cm^2/g.

As far as compressive strength of cement is concerned, a fineness of 3200 cm^2/g may be considered as optimum value. Up to this value, increase in strength is more and grinding cost is less. After this value grinding cost increases while rate of gain of strength ceases.

4.4 Grinding Cost

(i) Fig. 9 shows variation of grinding time involved in preparation of test samples with increasing fineness of samples for factories A, B, D and E respectively. All Graphs show an increase in the grinding effort with increase in fineness values.

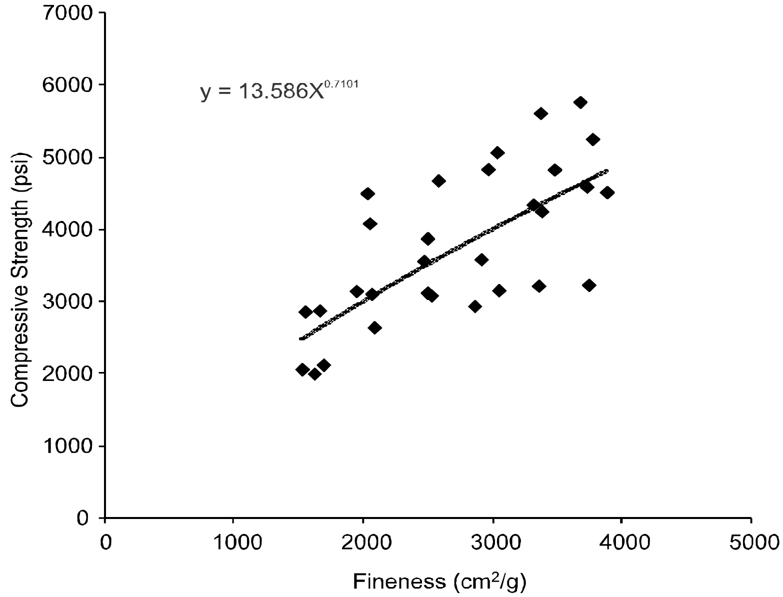

FIG. 8. FINENESS OF CEMENT VERSUS 28-DAYS COMPRESSIVE STRENGTH OF CONCRETE (AVERAGE TREND)

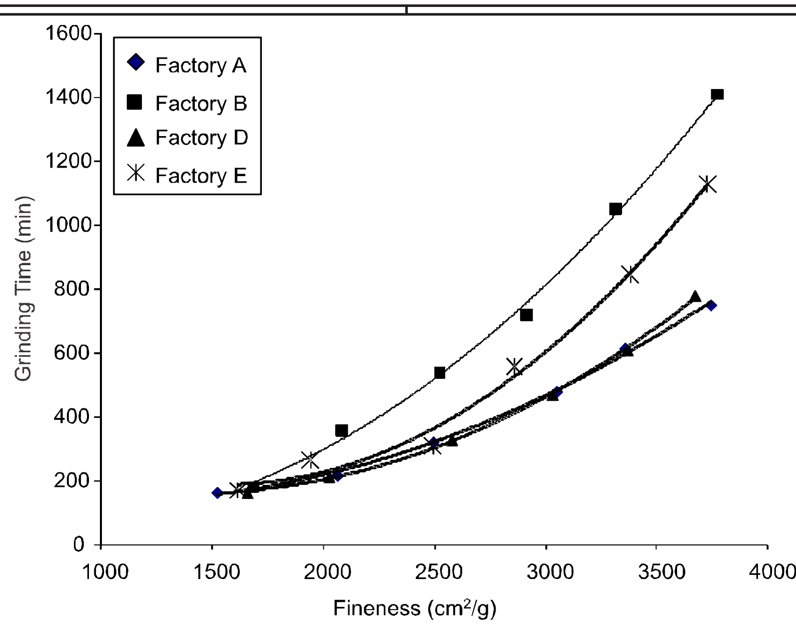

FIG. 9. FINENESS OF CEMENT VERSUS GRINDING TIME (COMPARISON OF DIFFERENT FACTORIES)

(ii) All the curves are somewhat flat at lower fineness levels and show a gradual steepness towards increasing finesses indicating increasing grinding requirement and hence increased cost. However, clinker of factory B required more grinding as compared to that of A and D. It is most probably due to presence of reducing atmosphere in the kiln. Due to shortage of oxygen in the kiln, the crystal size of C_3S grew larger; resulting in increased grinding effort to gain the same fineness.

5. CONCLUSIONS

(i) Compressive strength of concrete increases with increasing fineness of constituent cement. However, this increase in strength is prominent up to 3200 cm^2/g. After 3200 cm^2/g, rate of increase of strength is slowed down.

(ii) Consistency of cement increases with an increase in fineness of cement.

(iii) The governing equations obtained after regression analysis may be applied only up to a fineness level of 4000 cm^2/g.

(iv) As fineness values go higher, grinding effort and ultimately the grinding cost increases.

(v) As far as strength of cement is concerned, a fineness of 3200 cm^2/g may be considered as optimum value. Up to this value, increase in strength is more and grinding cost is less. After this value grinding cost increases while rate of gain of strength ceases.

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