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The Effects of Lime Addition and Fineness of Grinded Clinker on Properties of Portland Cement

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Abstract

Two types of Portland Cement Clinker "PCC" were used in this study: high fineness grinded and low fineness grinded , and after grinding of PCC, hydrated lime was used in 5%,10% and 15%; by weight, as a replacement of the blend cement with a constant 3% addition of gypsum by the blend weight. The importance of this study is to show the influences of different fineness on the physical properties of the blended cement, and to find the probability of using hydrated lime (that could be a by-product) in cement and declare its effects on the blend, so the solid waste "lime" and air pollutant of cement factories will reduce. In this research, the low fineness blend exhibited about 87% from compressive strength of high fineness blend at 28 days age. The results show that the using of hydrated lime up to 10%; by weight, as a replacement of cement will give good compressive strength and workability, and will reduce moderately the setting time, but the use of hydrated lime by more than 10% will reduce the compressive strength and increase the unsoundness of the blend (from 3mm expansion at 10% hydrated lime to 29mm expansion at 15% hydrated lime).

Keywords: Hydrated Lime, Fineness, Clinker, Compressive Strength.

تأثير اضافة النورة ونعومة الكلنكر المطحون على خواص السمنت البورتلاندي

الخلاصة

تم استعمال نوعان من كلنكر السمنت البورتلاندي في هذه الدراسة : مطحون بنعومة عالية ومطحون بنعومة قليلة ، وبعد عملية الطحن للكلنكر تم استعمال النورة المطفأة بنسب 5% ،10% و15% كنسب تعويضية وزنية من السمنت المخلوط مع اضافة نسبة وزنية ثابتة 3% من الجبس. تتجلى اهمية هذه الدراسة هي لايضاح تأثيرات الفرق بالنعومة على الخواص الفيزيائية للسمنت المخلوط، وكذلك لإيجاد احتمالية استخدام النورة المطفأة (قد تكون كنواتج عرضية) في السمنت ولبيان تأثيرها على الخليط، وبذلك يتم تقليل الفضلات الصلبة "النورة" وتقليل التلوث الهوائي الناتج من معامل السمنت. تبين في هذا البحث ان مقاومة الانضغاط للخليط قليل النعومة تمثل نسبة 87% من الخليط العالي النعومة بعمر 28 يوم. أظهرت النتائج ان استعمال النورة المطفأة الى حد 10% كنسبة تعويضية وزنية من السمنت يعطي مقاومة انضغاط وقابلية تشغيل جيدة وكذلك يقلل وقت التماسك بشكل متوسط، ولكن اذا ما تم استعمال النورة المطفأة بنسبة اعلى من 10% سوف تقلل من مقاومة الانضغاط ويزيد خاصية عدم الثباتية للخليط (من تمدد 3مم عند نسبة 10% من النورة المطفأة الى تمدد 29مم عند نسبة 15% من النورة المطفأة.

الكلمات الدالة: النورة المطفأة، النعومة، الكلنكر، مقاومة الانضغاط.

Introduction

Portland Cement (PC) concrete is the most popular and widely used building material, due to the availability of the basic raw materials all over the world, and its ease of use in preparing and fabricating all sorts of shapes[1]. Portland cement is made by heating a mixture of limestone and clay, or other materials of similar bulk composition and sufficient reactivity, ultimately to a temperature of about 1450°C. Partial fusion occurs, and nodules of clinker are produced. The clinker is mixed with a few percent of calcium sulfate and finely ground, to make the cement. The calcium sulfate controls the rate of set and influences the rate of strength development[2]. Calcium Sulfate is a material composed essentially of calcium sulfate in one or more of its hydration states: anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), or calcium sulfate hemihydrates ($CaSO_4 \cdot 1/2H_2O$)[3]. The amount of calcium sulfate added depends on the target sulfate level for the cement and therefore also on the sulfate in the clinker. The latter is derived from the sulfur in the raw materials and fuel[4]. However, due to the restriction of the manufacturing process and the raw materials, some inherent disadvantages of Portland cement are still difficult to overcome. One of the major drawbacks with respect to sustainability: About 1.5 tons of raw materials is needed in the production of every ton of PC, while, at the same time, about 1 ton of carbon dioxide (CO_2) is released into the environment during the production. The world's cement production has increased from 1.4 billion tons in 1995 to almost 3 billion tons by the year 2009. Therefore, the production of PC is an extremely resource- and energy-intensive process [1].

The term (fineness or fineness of grinding) refers to the average size of the cement particles. A higher fineness means a more finely ground cement, smaller particles. The significance of fineness lies in the fact that it affects several technically important properties of cement and concrete. For instance, the higher the fineness, the higher compressive strengths are developed at early ages. Also, finer cement bleeds less than a coarser cement, contributes to better workability, and shows less autoclave expansion as well. For these reasons the fineness of cement was steadily increased until about the middle of this century. Since then this increase has leveled off, partly because higher fineness is more expensive, and partly because an overly fine cement (Blaine specific surface over 500m²/kg, that is, 5000cm²/g) has certain technical disadvantages, such as higher shrinkage tendencies, stronger reaction with alkali-reactive aggregates, higher water demand, and poor storability[5]. In particular, cements ground in high-pressure roller mills hydrate and set faster than those ground in ball mills, even for an equal particle size distribution and fineness. This appears to be due to a higher reactivity of the C_3A and C_3S phases, a reduced rate of decomposition of calcium sulfate dihydrate to hemihydrate and a less favorable distribution of calcium sulfate in cements ground in high-pressure roller mills[6].

Over the past thirty-four years, many studies have been conducted on improving the physical and mechanical characteristics of mortars by means of adding or substituting mineral fines[7]. So the bad compatibility of Portland cement with some aspects of restorations requirements, such as the aggression to the stones due to the high amount of salts, the low flexibility, and the scarce compatibility with old materials have been reported. On the other hand, the slow settings of lime mortars, as well as their low mechanical strengths have also been discussed. This situation leads to the study of blended binding materials, which could share in the advantages of lime and cement mortars, avoiding or reducing their disadvantages. These blended materials will be characterized by faster setting than lime and better compatibility with the old materials and the stone than cement mortars[8]. Lime most widely-used alkali. The global production of lime products is believed to be over 200 million tpa (tones per annum)[9]. Slaked lime is produced by reacting, or "slaking" quicklime with water, and consists mainly of calcium hydroxide. The term includes hydrated lime (dry calcium hydroxide powder), milk of lime and lime putty (dispersions of calcium hydroxide particles in water). Slaked lime is widely used in aqueous systems as a low-cost alkali. However, lime can be use with cement, and aggregate addition to be called 'Cement-lime mortars', these mortars gave significant improvements in both the "soft" and "hard" characteristics[9].

In the literature, Antiohos[10] found that the addition of industrially produced quicklime on flyash–Portland cement pastes had a positive influence mainly on the strength development and reaction rate of high lime fly ash. It was demonstrated that replacing a small amount of a Class C fly ash with quicklime resulted in a notable acceleration of the fly ash degree of reaction throughout the curing period. It seems that apart from the physical effect of lime and the creation of CH bonds among ash particles, quicklime addition increased the solubility of SiO_2 leading to a greater release of soluble silica into the hydrating matrix. Conversely, when quicklime replaced an ash of lower lime content, activation was limited to the early stages of hydration. Arandigoyen[11,12] added lime in different percentage to cement and he discovered Inverse proportion between percentage of lime addition and pore size and as a cause of that the porosity will reduce. Sébaïbi and Dheilly[13], added lime (0-10)% as a replacement of cement and they found that higher lime substitution percentage, the replacement of cement with fine lime particles induces modification of the mortar microstructure, which is revealed either by the presence of microcracks in the matrix or by an alternative hydrate development in the case of calcium hydroxide with a significant specific surface area.

The objectives of the present research project were, first to enhancing properties of local cement by using traditional material that could be produce as by-product from local industrial processes, and second to reduce the air and solid pollutant of the regional environment.

Experimental Work

Materials

Portland Cement (PC)

Ordinary Portland Cement Type I (Badoosh factory); which satisfy to the Iraqi standard specification No. 5/1984 [14]. It possesses 346.4m²/kg fineness, this cement used in the reference mortar mix, as a comparative to the rest mixes. The chemical composition of the Portland cement and physical properties are shown in Table (1) and Table (2), respectively.

Table 1. Chemical composition of the Portland cement and clinker as percent by weight

Physical properties			Iraqi standard specification No. 5/1984
Fineness (Air permeability) (m²/kg)		346.4	230 min
Time of setting	Initial (minutes)	237	45 min
	Final (minutes)	277	600 max
Autoclave expansion (%)		0.2	0.8 max
Water for normal consistency (%)		25	----
Compressive strength (MPa)	3 days	23.66	15 min
	7 days	30.24	23 min

Table 2. Physical properties of Portland Cement

Constituent	Iraqi standard specification No. 5/1984	Cement	Clinker
SiO_2	----	21.14	21.65
Al_2O_3	----	5.66	5.92
Fe_2O_3	----	2.54	2.68
CaO		62.62	63.54
MgO	Max 5%	3.7	3.64
SO_3	Max 2.8%	2.01	1.71
C_3S	----	38.93	39.54
C_2S	----	31.24	32.24
C_3A	----	10.7	11.15
C_4AF	----	7.73	8.16
Loss on ignition	Max 4%	1.16	0.18
Insoluble residue	Min 1.5%	0.2	------
Free CaO	----	1.95	1.5
L .S .F.	66-102	90.5	89.75

Portland Cement Clinker (PCC)

Type I Portland Cement Clinker was obtained from (Badoosh cement factory) in about 10 mm average particle size, and the clinker had been crushed and grinded in a grinder and treated by sieving to produce PCC with two fineness; high fineness 298 m²/kg and low fineness 233 m²/kg. And the chemical composition of the Portland cement clinker has shown in Table (1).

Gypsum

Gypsum rocks were brought from Batnaya area on the outskirts of Mosul city; the Material was converted to a fine powder with 385m²/kg fineness by using a grinder machine. And the chemical composition of the gypsum has shown in Table (3).

Table 3. Chemical composition of the gypsum as percent by weight

CaO	32.12
SO_3	45.57
H_2O	20.16
Impurities	2.15
$CaSO_4.2H_2O$	97.85

Hydrated lime

Hydrated lime was brought from Alnoora factory in Karbala city, and it is produced according to Iraqi standard No. 807/1988 [15], and it has high surface area about 587m²/kg.

Fine aggregate

Natural sand used, with 2.51 specific gravity, which satisfy to the Iraqi standard specification No. 45/1984 [16]; Table (4) shows the sieve analysis of sand.

Table 4. Sieve analysis of sand

Sieve Size B.S. (mm)	Weight Passing (%)	Total Limits Passing zone No. 3 (Iraqi standard specification No. 45/1984) (%)
4.75	100	90 – 100
2.36	100	85 – 100
1.18	91.05	75 – 100
600µ	70.4	60 – 79
300µ	18.6	40 – 12
150µ	2.3	0 – 10

Mixes

Two types of mixes were made: high fineness with 298 m²/kg of ground clinker, and low fineness with 233 m²/kg of ground clinker. The two types have different percentages of hydrated lime as replacement, by weight of the blend cement. All the mixes have a constant addition with percentage 3% of gypsum powder; by the blend weight. The first part composed of three different mixes A1, A2 and A3, and they contained hydrated lime with 5%, 10% and 15%, respectively. The second part with low fineness included three mixes A4, A5 and A6 and also contained 5%, 10% and 15% hydrated lime, respectively, and A is the reference mix, as shown in Table (5). The X-ray Diffraction "XRD" method was used to determine the chemical composition of PC, PCC and gypsum. The mixes were tested in compressive strength at different ages 1, 3, 7 and 28 days with (50*50) mm cubes. The mortar mixtures were prepared using a 0.55 constant water-to-cement ration with 1:2.75; blend cement to natural sand.

Table 5. Proportions and properties of the blend

Sample	Gypsum %	Hydrated lime %	PCC (ground clinker) %	Normal consistency W/C	Setting time min.		soundness mm	Blain Fineness m²/kg
					Initial	Final		
A	reference	reference	reference	0.25	237	277	1	346
A1	3	5	92	0.253	164	222	0	341
A2	3	10	87	0.266	177	219	3	380
A3	3	15	82	0.272	159	216	29	400
A4	3	5	92	0.247	178	211	0	331
A5	3	10	87	0.251	167	203	2	364
A6	3	15	82	0.259	175	229	22	371

Tests

Normal Consistency of Hydraulic Cement according to ASTM C 187 – 98[17].

1- Time of Setting of Hydraulic Cement by Vicat Needle according to BS EN 196-3: 2005[18].
2- Soundness (Le Chatelier) according to BS EN 196-3: 2005[18].
3- Fineness of Hydraulic Cement by Air-Permeability Apparatus according to ASTM C 204 – 00[19].
4- Flow of hydraulic cement mortar according to ASTM C 1437 – 01[20].
5- Compressive Strength of Hydraulic Cement Mortars according to ASTM C 109/C 109M – 02[21].

Results and Discussion

Six mixes were prepared in specific percentages of materials, the water-cement-ratio, normal consistency, vicat setting time, end time, soundness test and specific surface area shown in Table (5).

The results in Table (5) for the normal consistency test shows that the water-cement-ratio increase with increasing the percentage of lime replacement, that indicates workability of 15% lime replacement is more than 5% & 10% due to high surface area of lime 587.2 m^2/kg. As shown in Figure (1), the water-cement-ratio of normal consistency decreased in low fineness mixes A4, A5, and A6 as compared to the high fineness mixes due to the low specific surface area of the PCC that used in A4, A5 and A6 and because the large particles that absorbed less water in low fineness mixes. Lime-based mortars have excellent workability and plasticity, a high degree of cohesiveness and spread easily under the trowel. These properties help to increase productivity and minimize wastage by droppings. They are eminently suitable for use with mechanical spraying equipment [9].

Table (5) shows that the setting time decrease in most mixes with lime dosage increasing as compared to the reference mix A, as illustrated in Figure (2). The mixes A4 and A5 which they have low fineness PCC, they sat before the other mixes and may be because of large particle size of low fineness PCC, which blocked the Vicat needle penetration.

The soundness test was performed by using (Le Chatelier) method, and should be less than 10 mm, and from Table (5), it's clear to see that only the 15% lime replacement was unsatisfied with both high and low PCC fineness, the rest mixes were satisfied, so it's obvious from that the optimum replacement of lime is up to 10%. The PCC mixes with high fineness were slightly more than PCC with low fineness in expansion, but may be the difference will be large if the lime replacement more than 15% as shown in Figure (3).

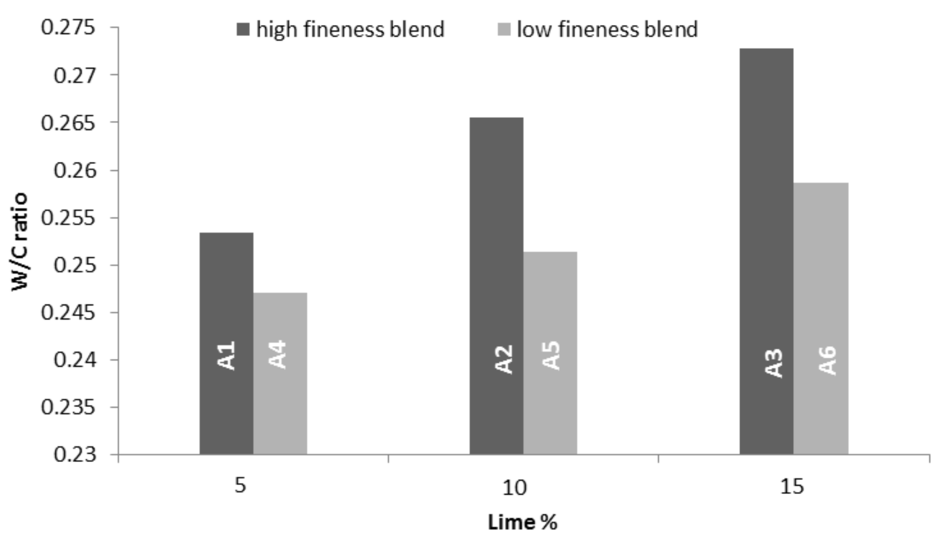

Fig. 1. Relation between W/C ratio and percentage of lime

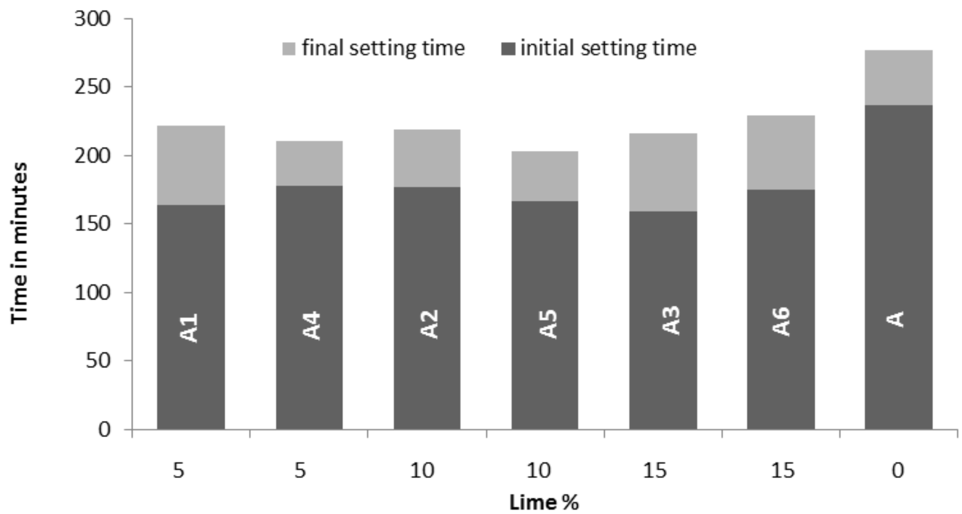

Fig. 2. Relation between setting time and percentage of lime

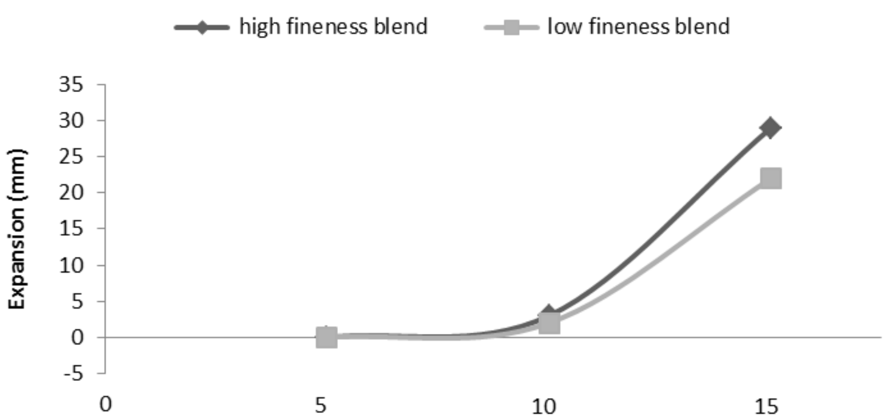

Fig. 3. Relation between expansion and lime replacement percentage

The surface areas of all mixes were tested by blain method. Two types of PCC with high fineness 298m²/kg and PCC with 233m²/kg low fineness were used and the lime fineness and gypsum were 587.6 m²/kg and 385.11m²/kg, respectively, so it's sure the addition of gypsum and lime will increase the surface area of the mixes, as shown in Figure (4).

The flow test as in Table (5) shows when increase lime replacement, there is a slight increasing in water demand to satisfy flow 105%-115%, due to high surface area of lime. Lime and the increment of water play a good rule in enhancing the workability of the mortar.

The compressive strength of lime-cement mortars can be adjusted to the required level by the selection of the mix design. Incorporating lime in mortar is reported to improve adhesion (or bond strength) and reduce rain penetration. There is evidence that the presence of lime can increase the resistance of mortar to attack by sulfate [9]. Table (6) shows the compressive strength of the mixes in different ages 1, 3, 7and 28 days as illustrated in Figure (5).

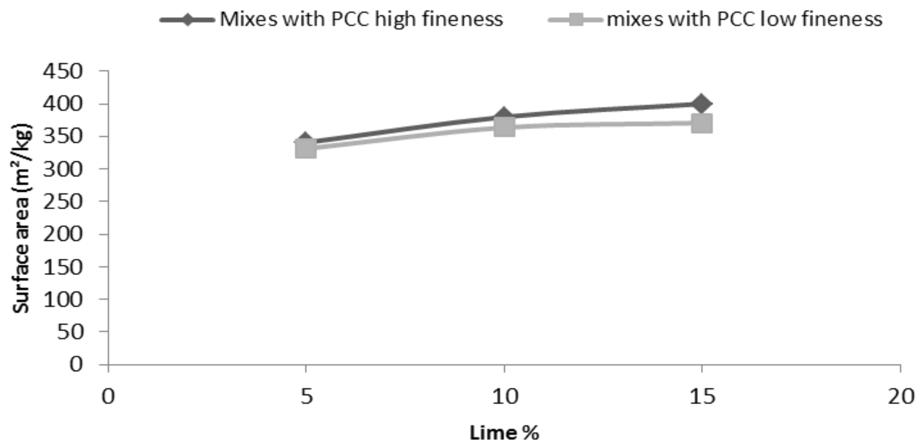

Fig. 4. Relation between surface area and lime replacement percentage

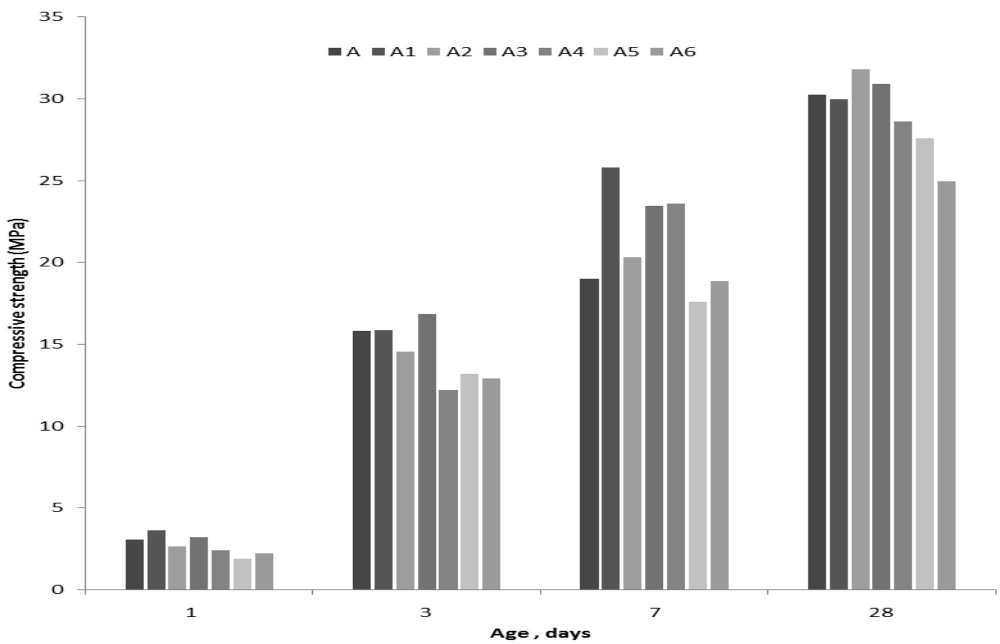

Fig. 5. Relation between compressive strength and test age

Table 6. Compressive strength of the mixes

Sample	Compressive strength MPa				Water percentage according flow test %
	1 day	3 day	7 day	28 day	
A	3	15.8	19	30.3	100
A1	3.6	15.9	25.8	30	104.2
A2	2.6	14.6	20	31.8	105.2
A3	3.2	16.9	23.5	30.9	105.5
A4	2.4	12.2	23.6	28.6	101.2
A5	1.9	13.2	17.6	27.6	104.9
A6	2.2	12.9	18.9	25	107.5

It's clear from Table (6) that the specific surface area of the cement will affect significantly on the compressive strength, and the surface area of cement is directly proportional to compressive strength. The mixes A1, A2 and A3 with high fineness gave high compressive strength than A4, A5 and A6 with low fineness as shown in Figure (6). The effect of hydrated lime on strength show that the mixes A1,A2 and A3 have little difference in strength at the ages of 1 day and 3 day as compared to the reference mix A, but at ages of 7 day and 28 day show more significantly differences to the reference mix A , as shown in Figure (7), the effect of lime replacement 5%,10% and 15% on compressive strength at different ages are illustrated in Figure (8), in spite of the fact that the reference mix A comprise pure cement with 346.3 m^2/kg fineness and the mixes A1,A2 and A3 have less than 93% of cement fineness with 298 m^2/kg PCC fineness and still give the same or more strength as compared to the reference mix A, so it can conclude that, if the fineness of cement can be reduced to about 298 m^2/kg and add from 5%-10% lime, it can produce a blended cement with a good fresh and hardened properties and more energy saving during the cement production processes.

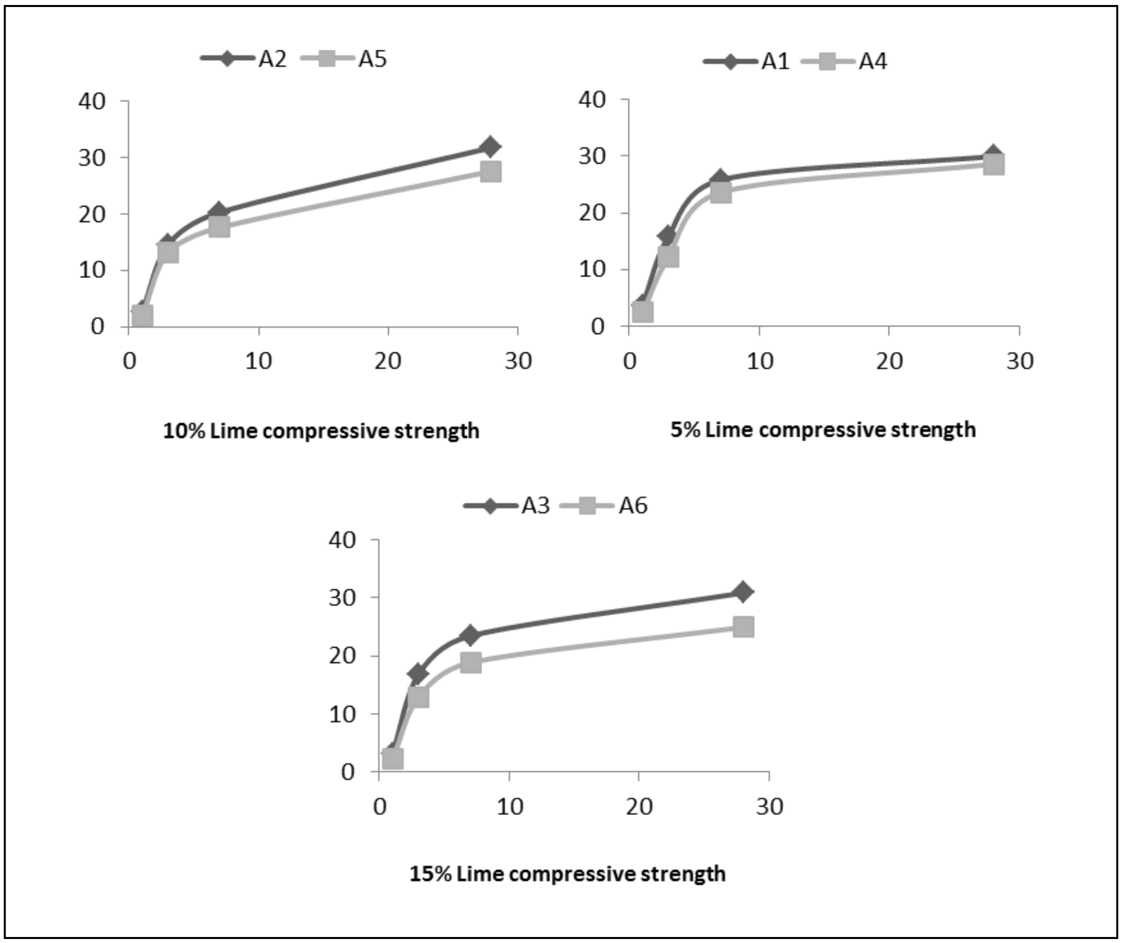

Fig. 6. Effect of fineness and lime replacement percentage on compressive strength at different ages

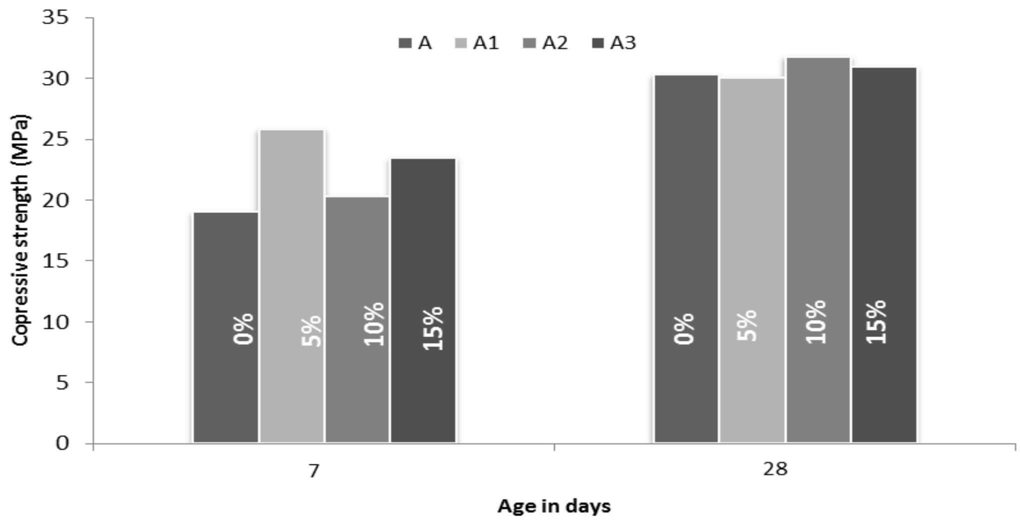

Fig. 7. Relation between compressive strength of blended cement and age with lime replacement percentage

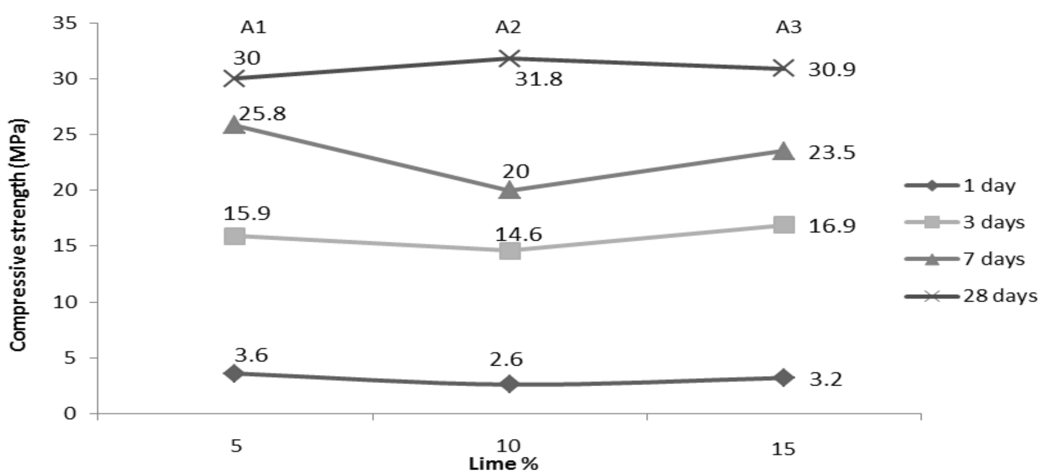

Fig. 8. Relation between lime replacement and compressive strength with different ages

Conclusions

From the data developed in this study, the following conclusions could be drawn:

1. Increasing the fineness of cement will raise the compressive strength at all ages, where at 1 day age, the increasing of high fineness compressive strength was 144% from low fineness, at 3 days was 124%, at 7 days was 115% and at 28 days was 114%.
2. In this study found that; the low fineness cement (233 m²/kg) will set faster than the high fineness cement (298 m²/kg), may be due little different in fineness.
3. Adding hydrated lime up to 10% as a replacement of cement will increase the workability and compressive from 30.3 MPa to 31.8 MPa, and decrease the setting time of the blended cement.
4. Adding hydrated lime more than 10% as replacement of cement weight will reduce the compressive strength especially in late times, and increase the unsoundness property of cement (from 1mm to 29mm according to Le Chatelier test).
5. When use hydrated lime as replacement up to 10% in cement, it will reduce the annual

production of cement, and that will lead to increase energy saving and reduce the emission of the gas pollutants in cement factories during the cement production.

6. Whenever there is lime that produced as a by-product from other industries, two major benefits can be obtained: (1) enhance cement industry, (2) reduce solid waste of lime.

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