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Effect of limestone on the mechanical properties of concrete containing silica fume and fly ash

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Abstract

In this study, Influence of limestone on the mechanical properties of concrete containing silica fume (SF) and fly ash (FA) has been investigated. Concretes included SF and FA as a cement replacement level of 7% and 15% respectively and contain limestone as a fine aggregate (LF) replacement and cement replacement (LCE). The w/b ratio and total cementitious materials content were kept constant for all mixes at 0.45 and 375 kg/m3 respectively. Concrete mixes were evaluated for compressive strength at 7, 28 and 90 days and tensile strength at 28 days. The results show that the best and worst amounts of limestone as a cement replacement or fine aggregate replacement are approximately 10% and 40% respectively and often until 28 days use of LCE is better than LF in different percents and between 28 days and 90 days LF is better than LCE in compressive and tensile strength.

1. Introduction

Concrete industry, especially Portland cement manufacture is known to be a heavy contributor to the environmental damage and CO2 emissions. European Cement Association reported that cement production was responsible for 2.83 billion tones of CO2 emissions (roughly 2.3% of the total emissions) worldwide in 2008 [1]. The less cement and natural aggregates that are used in concrete production, the lower the impact the concrete industry has on the environment [2]. The materials used in the production of concrete poses the problem of acute shortage in many areas. Thus there are many wastes of some industries and quarries can be used as hundred or partial percent substitutes for concrete materials.

Concrete technology can offer some applications in recycling some industrial wastes, such as, fly ash, silica fume, and ground granulated blast furnace slag. Supplementary cementing materials (SCMs) are often used in concrete mixes to reduce cement contents, improve workability, increase strength and enhance durability through hydraulic or pozzolanic activity.

Silica fume can be incorporated in concrete as partial cement replacement. Silica fume, also known as micro-silica, is a byproduct of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. It contains large proportions of extremely fine amorphous particles of silicon dioxide (SiO2) which usually makes up more than 90% of silica fume constituents. The fineness of silica fume in terms of specific area can range around 20,000 m2/kg. Because of its extreme fineness and high silica content, silica fume is a highly effective pozzolanic material. Silica fume is amorphous in nature and may contain some crystalline silica in the form of quartz or cristobalite. The higher surface area and amorphous nature of silica fume make it highly reactive. The hydration of C3S, C2S, and C4AF are accelerated in the presence of silica fume experiences rapid dissolution in the presence of Ca(OH)2 and a super saturation of silica with respect to a silica-rich phase. This unstable silica-rich phase forms a layer on the surface of the silica fume particles. The layer is then partly dissolved and the remainder acts as a substitute on which conventional C-S-H is formed. Effect of silica fume on the properties of cement, mortar and concrete is well-known, and reported by several authors [3–16].

Also FA as a cement replacement could result in a substantial contribution to reduce the overall CO2 footprint of the final concrete product. Over the years, the use of FA in concrete production has become a common practice worldwide not only to reduce environmental charges but also due to the several benefits. The use of FA in concrete has proven to improve workability and long term strength, reduce permeability, minimize risk of alkali silica reaction, lowering heat of hydration in mass concrete, and enhancing durability performance (resistance to chloride and sulphate attack) [17-20].

On the other hand, the presence of limestone fillers in concrete has been a subject of increasing interest in the literature. Studies generally consist of carrying out tests on mortars in which part of the sand or cement was replaced by limestone fillers. Having a property of physical improvement of the cement paste matrix, limestone filler (LF) is one of the materials that have extensively been studied in the literature [21-28].

In this paper use of limestone as a fine aggregate or cement replacements in concrete containing silica fume and fly ash is studied.

2. Experimental Program

2.1. *Materials and mixture proportions*

Total cementitious materials content and water to binder ratio were kept constant for all mixes at 375 kg/m^3 and 0.45 respectively. Materials utilized included type 2 Portland cement, silica fume, fly ash and limestone. Chemical analysis and physical and mechanical characteristics of these materials are given in Tables 1 and 2 respectively. The results show conformance of the cement, SF with requirements and class F fly ash according to ASTM C150, ASTM C1240 and ASTM C618 respectively. Drinking water was used in carrying out tests and making specimens. The workability of concretes mixes were kept constant in the slump ranges 100 ± 20 mm. The differences in water demand of various mixes were accounted for by use of required amount of a naphthalene formaldehyde sulphonate based superplasticizer (SP). The aggregates used for production of mixes were crushed coarse aggregate (CA) with nominal maximum size of 19 mm and specific gravity of 2.65 g/cm^3 and natural sand (FA) with specific gravity of 2.56 g/cm^3 and satisfied requirements of ASTM C33. Mixture proportions for the control and ternary mixes considered in this study and results are given in Table 3 and 4 respectively.

2.2 *Tests carried out*

The aim of the tests performed was to evaluate the compressive and tensile strength of the control and various ternary mixes. Compressive strength test was conducted at the ages of 7, 28, 90 on 100 mm cubic concrete specimens and tensile strength was done at the age of 28 days on 150mm×300mm cylindrical specimens in accordance with BS EN 12390 part 1. After casting, all concrete specimens (cubes and cylinders) were kept at 20 ±3 °C and relative humidity (RH) 65 ±5% for the first 24 h. The specimens were then demoulded and stored in water curing room at 20 ± 3 °C until the time of testing. For each test, three specimens were tested and the average value was reported.

Concrete of different compositions was produced with varying replacement ratios of fine aggregate and Portland cement by limestone. Nine different mixtures with two various replacements were carried out. These nine mixes were named:

- OC: observe concrete with 7% SF and 15% FA only.
- L5CE, L10CE, L20CE and L40CE: observe concrete with 5, 10, 20 and 40% limestone as a cement replacement respectively.
- L5F, L10F, L20F and L40F: observe concrete with 5, 10, 20 and 40% limestone as a fine aggregate replacement respectively.

Table 1: Chemical analysis of cement, silica fume and fly ash

Oxide	Portland Cement	Silica fume	Fly ash
SiO_2	21.57	94.30	52.20
Al_2O_3	4.72	1.22	22.54
Fe_2O_3	3.61	0.75	7.68
CaO	63.22	0.49	5.62
MgO	2.20	0.89	1.83
SO_3	1.50	0.10	0.69
Na_2o	0.18	0.35	0.89
K_2O	0.54	1.25	2.74

Table 2: Physical and mechanical properties of cement,

Property	Portland Cement	Silica fume	Fly ash
Fineness (m^2/kg)	296.2	19200	287
Density (kg/m^3)	3140	2210	2250

Table 3: Mixture proportions for concrete mixture

Mix designation	w/c	SF (%)	FA (%)	LCE (%)	LF (%)	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m3)	Gravel (kg/m3)	SF (kg/m3)	FA (kg/m3)	LCE (kg/m3)	LF (kg/m3)	SP (kg/m3)
OC	0.45	7	15	0	0	293	169	872	1020	26	56	0	0	5.5
L5CE	0.45	7	15	5	0	274	169	872	1020	26	56	19	0	5.7
L10CE	0.45	7	15	10	0	255	169	872	1020	26	56	38	0	6.1
L20CE	0.45	7	15	20	0	217	169	872	1020	26	56	76	0	6.5
L40CE	0.45	7	15	40	0	141	169	872	1020	26	56	152	0	6.6
L5F	0.45	7	15	0	5	293	169	828	1020	26	56	0	44	5.8
L10F	0.45	7	15	0	10	293	169	784	1020	26	56	0	88	6.4
L20F	0.45	7	15	0	20	293	169	696	1020	26	56	0	176	6.8
L40F	0.45	7	15	0	40	293	169	520	1020	26	56	0	352	7.0

Note:
SF: Silica fume FA: Fly ash SP: super plasticizer
LCE: Limestone concrete with cement replacement
LF: Limestone concrete with fine aggregate replacement

3. Test results and discussion

3.1. *Limestone concrete with cement replacement*

Figs. 1-4 show the compressive strength at 7, 28 and 90 days and tensile strength at 28 days for all mixes with 7 % silica fume and 15 % fly ash with different percents of LCE. These results indicate that at 7 days in compressive (7^{cs} days) and 28 days in tensile strengths (28^{ts} days), concretes strength decreases as soon as LCE is added, but this process is inverse for compressive strength at 28 days (28^{cs} days). On the other hand, at 90 days (90^{cs} days) decrease in compressive strength is approximately constant.

These figures show that minimum and maximum amount of growth in compressive strength than observe concrete are at 7 days with 40% LCE (-43%) and 28 days with 10% LCE (12%) respectively. Also Figures.1-3 represent that minimum amount of increase in compressive strength is at 7 days from L20CE to L40CE (-21%) and maximum amount of growth is at 28 days from L5CE to L10CE (4%). This subject often occurs about tensile strength.

All in all, the best and worst amount of limestone as a cement replacement is approximately 10% and 40% respectively.

Totally , the factors that may be responsible for various behavior of compressive and tensile strengths of concrete containing LCE are: (1) difference between thermal expansion of cement and limestone and more effect of this factor at initial ages (2) reduction of porosity by using LCE at 28 days [29]

Table 4: Results

C(kg/m^3)	w/c	MD	SF	FA	LCE	LF	$F_{c(7)}$	$F_{c(28)}$	$F_{c(90)}$	$F_{t(28)}$
375	0.45	OC	7	15	0	0	29.3	46.5	69.5	4.1
		L5CE	7	15	5	0	26.5	50.1	64.3	4.6
		L10CE	7	15	10	0	23.7	52.2	62.6	5.0
		L20CE	7	15	20	0	20.9	51.9	62.1	5.1
		L40CE	7	15	40	0	16.7	46.3	59.5	2.9
		L5F	7	15	0	5	31.5	47.5	67.6	4.3
		L10F	7	15	0	10	32.4	48.3	66.9	4.5

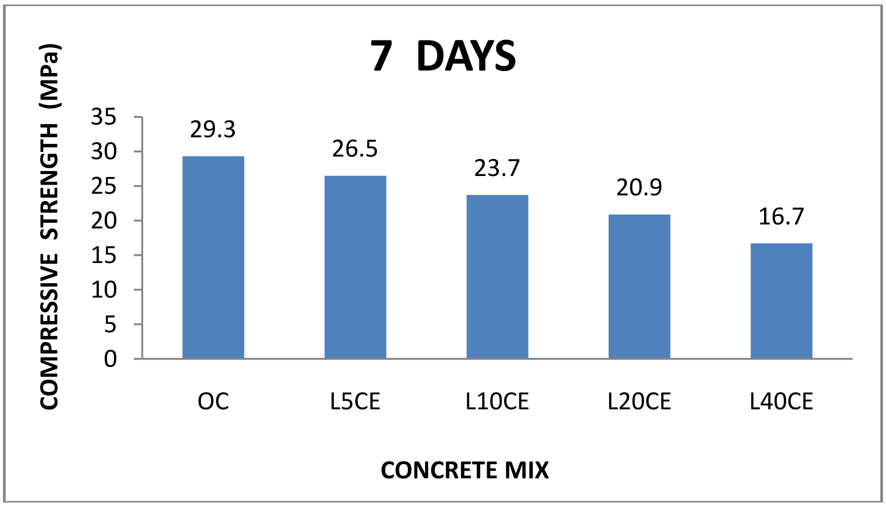


Figure 1: The results of compressive strength of specimens (7days)

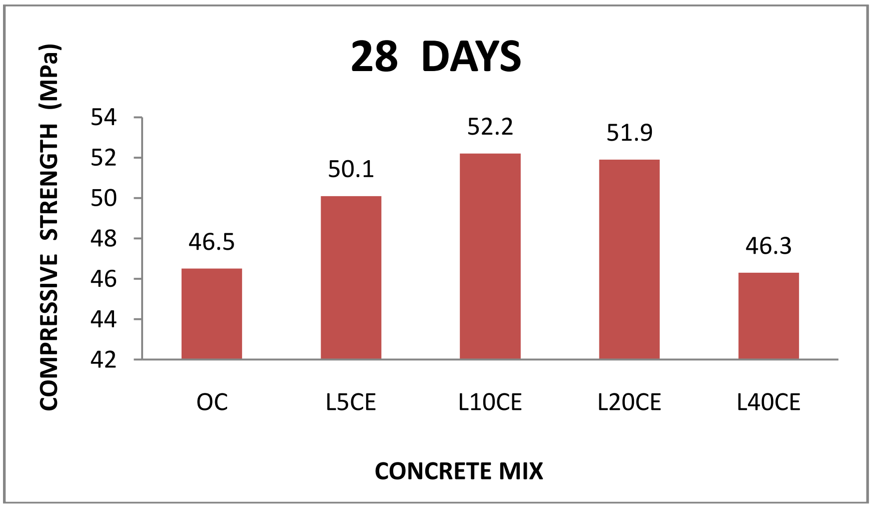


Figure 2: The results of compressive strength of specimens (28days)

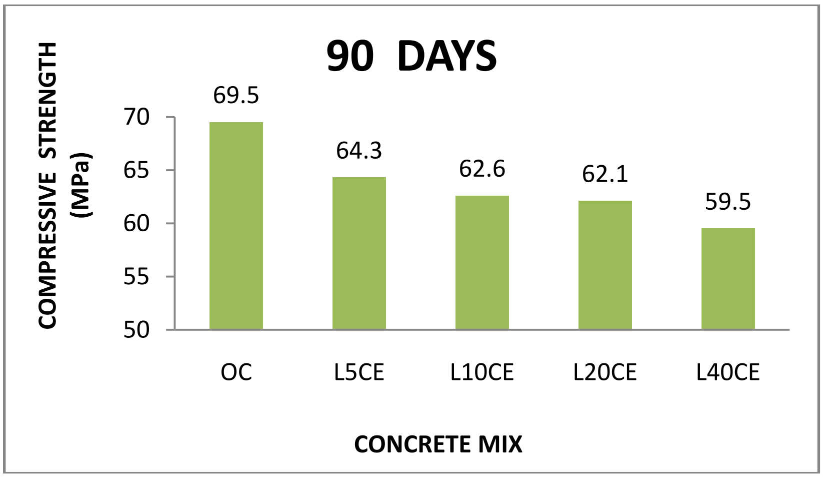


Figure 3: The results of compressive strength of specimens (90days)

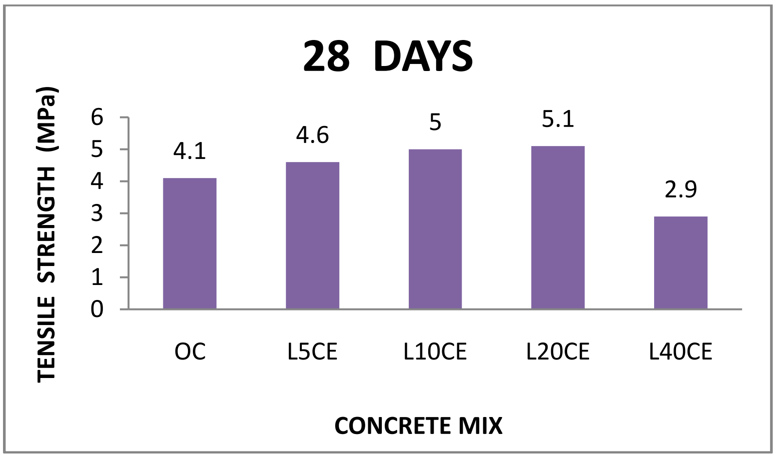


Figure 4: The results of tensile strength of specimens (28days)

3.2. *Limestone concrete with fine aggregate replacement*

Figs. 5-8 show the compressive strength at 7, 28 and 90 days and tensile strength at 28 days for all mixes with 7 % silica fume and 15 % fly ash with different percents of LF. These results represent that in compressive at all ages, concretes strength decreases as soon as LF is added, but On the contrary, this process is inverse for tensile strength at 28 days (28^{cs} days) until L20F.

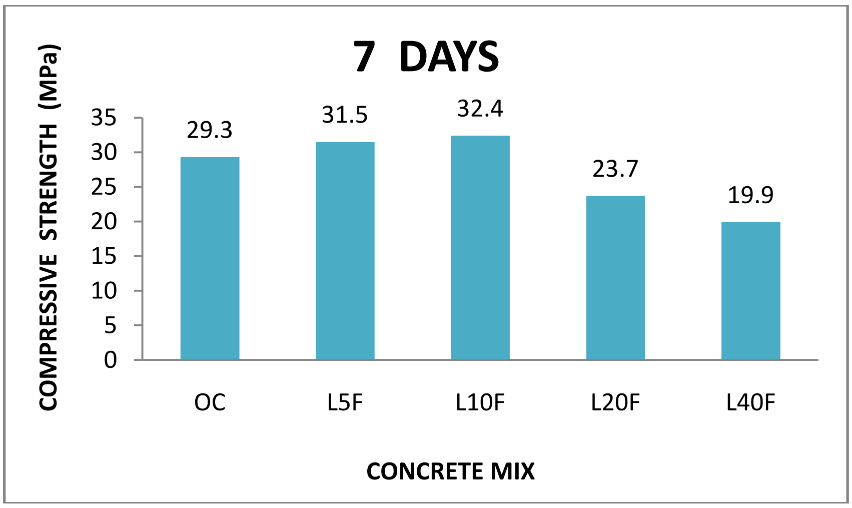


Figure 5: The results of compressive strength of specimens (7days)

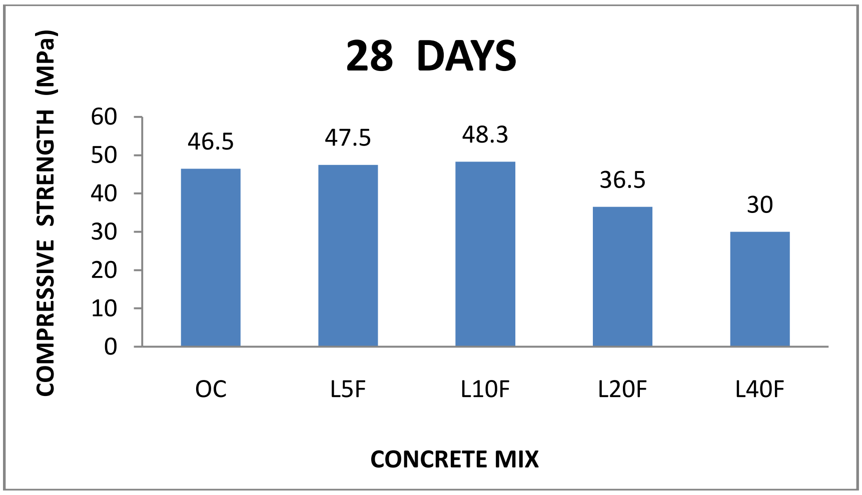


Figure 6: The results of compressive strength of specimens (28days)

These figures show that minimum and maximum amount of growth in compressive strength than observe concrete are at 90 days with 40% LF (-39%) and 7 days with 10% LF (11%) respectively.
Also Figures.5-7 represent that minimum amount of increase in compressive strength is at 7 days from L10F to L20F (-27%) and maximum amount of growth is at 7 days from OC to L5F (8%). On the other hand minimum amount of increase in tensile strength is from L20F to L40F (-39%) and maximum amount of growth is from L10F to L20F (13%).

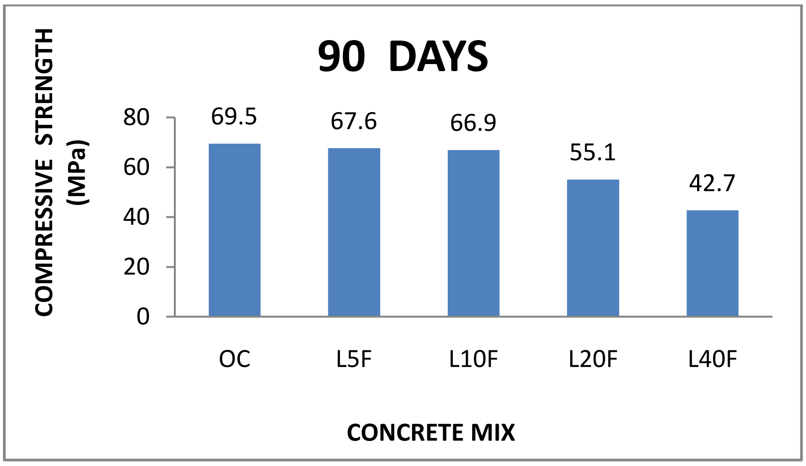


Figure 7: The results of compressive strength of specimens (90days)

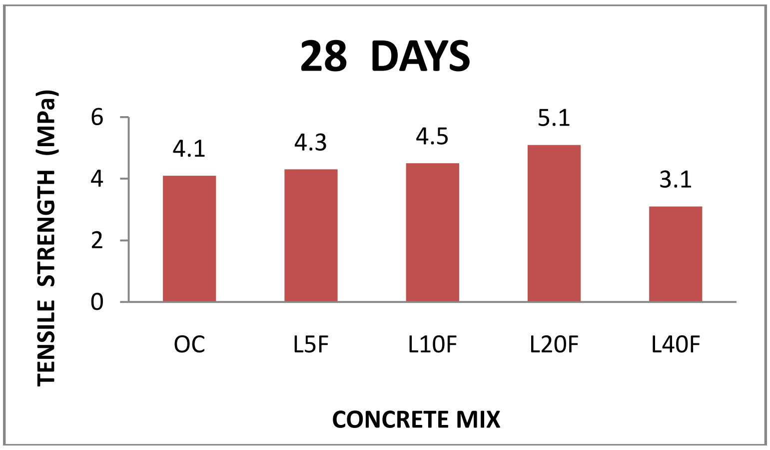


Figure 8: The results of tensile strength of specimens (28days)

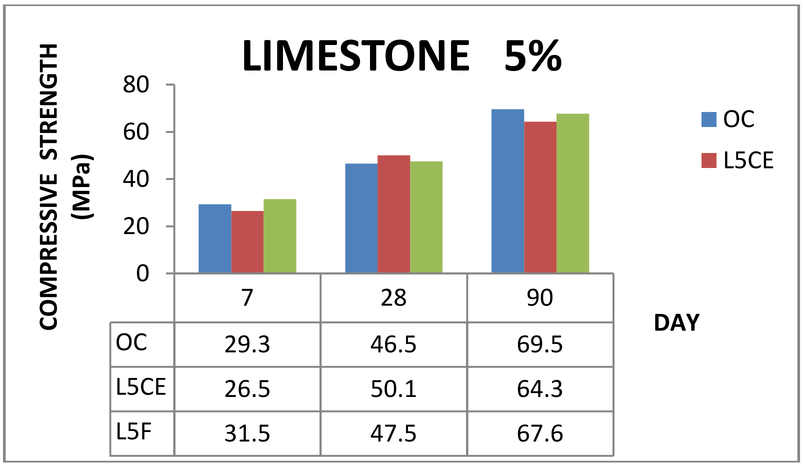


Figure 9: The results of compressive strength of specimens (5% Limestone)

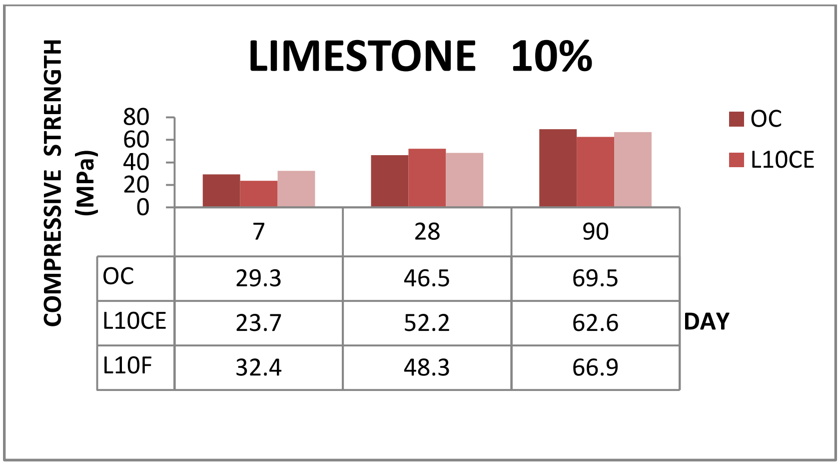


Figure 10: The results of compressive strength of specimens (10% Limestone)

All in all, the best and worst amount of limestone as a cement replacement is approximately 10% and 40% respectively. Totally, the reduction in the compressive strength of concrete is probably due to the large amount of calcium hydroxide resulting from the hydration process of the cement and limestone. Moreover, the loss of the compressive strength at a replacement level 20% and 40% can be related to the increasing of relative of powder for limestone as a replacement from sand [30].

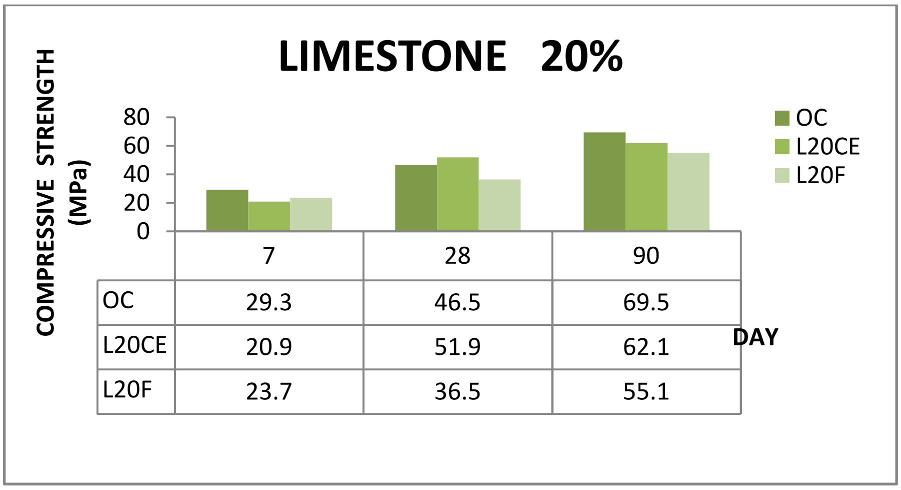
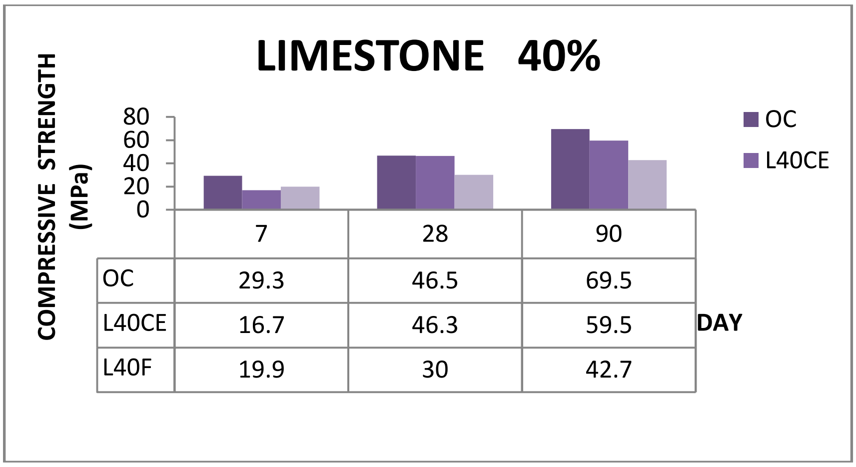


Figure 11: The results of compressive strength of specimens (20% Limestone)



	7	28	90
OC	29.3	46.5	69.5
L40CE	16.7	46.3	59.5
L40F	19.9	30	42.7

Figure 12: The results of compressive strength of specimens (40% Limestone)

3.3. *Comparing strength of LCE and LF*

Figs. 9-16 show the compressive strength at 7, 28 and 90 days and tensile strength at 28 days for all mixes with different percents of LCE and LF. Results indicate that approximately use of LF is better than LCE at 7 days and on the other hand at 28cs days utilization of LCE is better than LF in all percents.

But at 90cs and 28ts days various behaviors is received. At 90cs days in 5 and 10% LF is better than LCE and in 20-40% this subject is inverse. On the other hand, at 28ts days in 5, 10 and 20% LCE is better than LF and in 40% this subject is not true.

Totally, until 28 days use of LCE is better than LF and between 28 days and 90 days LF is better than LCE.

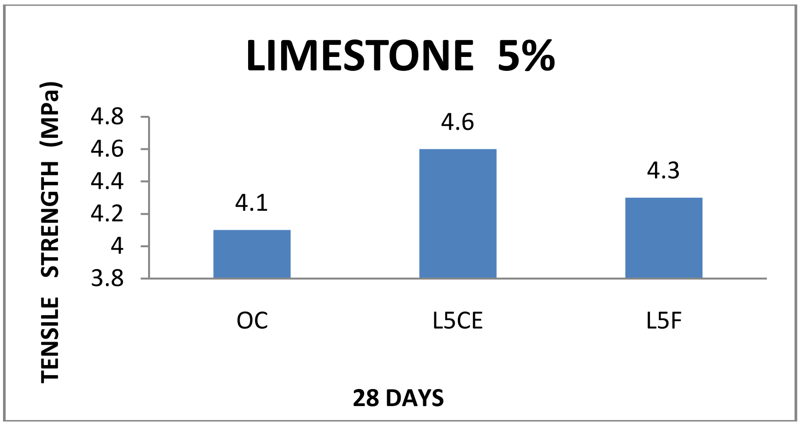


Figure 13: The results of tensile strength of specimens (5% Limestone)

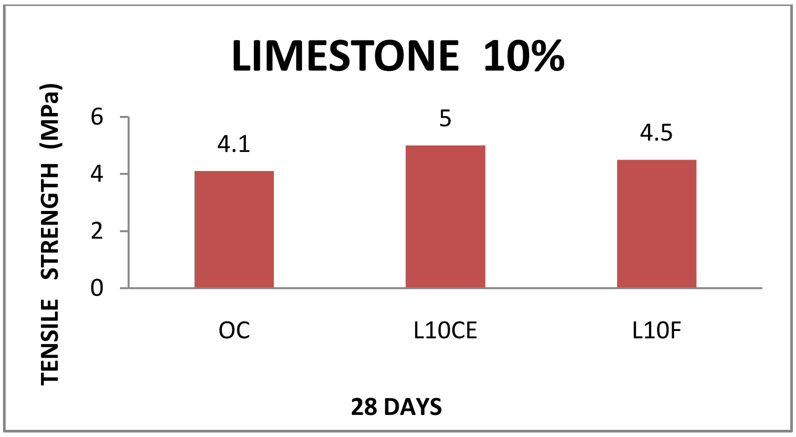


Figure 14: The results of tensile strength of specimens (10% Limestone)

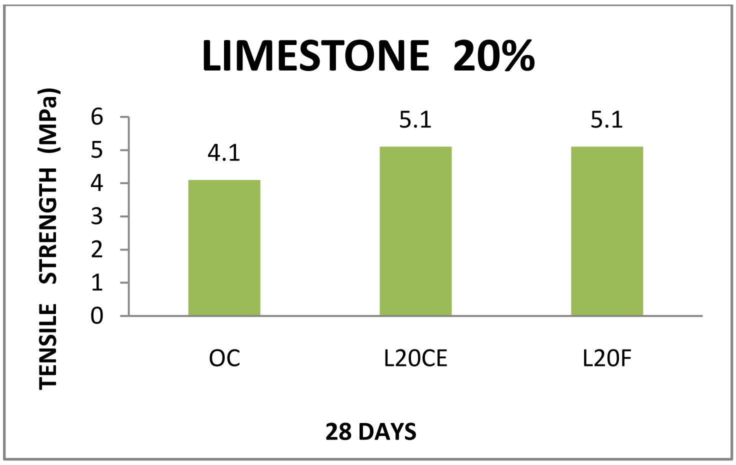


Figure 15: The results of tensile strength of specimens (20% Limestone)

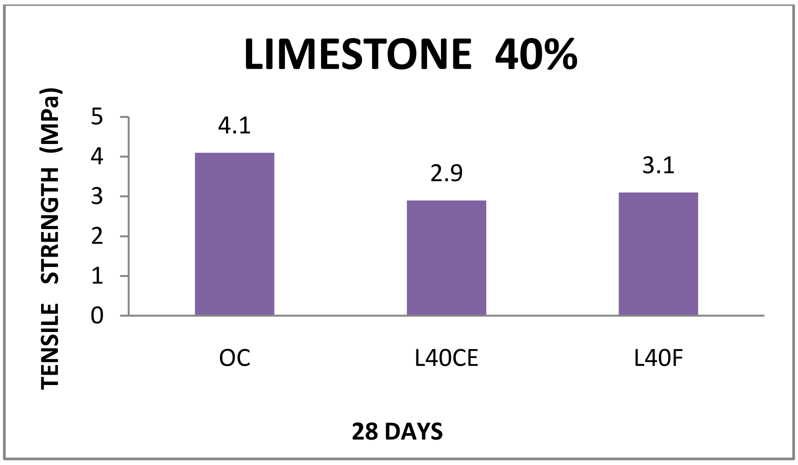


Figure 16: The results of tensile strength of specimens (40% Limestone)

Conclusions

Based on the findings of the experimental program presented above, the following conclusions can be drawn:
– In LCE and LF: the best and worst amounts of limestone as a cement replacement or fine aggregate replacement are approximately 10% and 40% respectively.
- Often until 28 days use of LCE is better than LF in different percents and between 28 days and 90 days LF is better than LCE in compressive and tensile strength.
- All in all, use of limestone as LCE or LF in 10% is advantageous and it can help to environmental pollution reduction and use of cement in industry.

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