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ORIGINAL ARTICLE

Long term study of mechanical properties, durability and environmental impact of limestone cement concrete

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Abstract In this study, properties of limestone cement concrete containing different replacement levels of limestone powder were examined. It includes 0%, 5%, 10%, 15%, 20% and 25% of limestone powder as a partial replacement of cement. Silica fume was added incorporated with limestone powder in some mixes to enhance the concrete properties. Compressive strength, splitting tensile strength and modulus of elasticity were determined. Also, durability of limestone cement concrete with different C_3A contents was examined. The weight loss, length change and cube compressive strength loss were measured for concrete attacked by 5% sodium sulfate using an accelerated test up to 525 days age. The corrosion resistance was measured through accelerated corrosion test using first crack time, cracking width and steel reinforcement weight loss. Consequently, for short and long term, the use of limestone up to 10% had not a significant reduction in concrete properties. It is not recommended to use blended limestone cement in case of sulfate attack. The use of limestone cement containing up to 25% limestone has insignificant effect on corrosion resistance before cracking.

1. Introduction

During the oil crisis (1974–1980), cement manufacturers who had a long experience of blending of Portland clinker with blast furnace slag, pozzolans and fly ash decreed that inert finely ground mineral materials "such as limestone" were also allowed as secondary constituents in composite Portland cements [1,2].

Limestone cement can be produced by inter-grinding, blending or by addition at the time of concrete mixing. Inter-grinding of limestone has several benefits. Limestone is a softer material than clinker and therefore takes less energy to grind to the same fineness [3]. The environmental effect of using limestone in cement manufacturing as an ingredient in blended cements is less clinker has to be produced for an equivalent amount of cement, and therefore less energy is consumed and CO_2 emissions and other greenhouse gases are reduced [4].

The strength of concrete produced with limestone cement is strongly influenced by the quality of the limestone used, the manufacturing process (blending versus inter-grinding) and

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the final particle size distribution of the cement. Most of the previous work in this topic concluded that limestone cement replacement has a negative effect on concrete compressive strength. The negative effect of limestone powder replacement may be due to cement content dilution effect [5–8]. Also, for modulus of elasticity and tensile strength, the behavior is the same as that observed for compressive strength and predictive equations [2,9,10].Additionally, the previous researches indicated that generally when the content of limestone increases, the sodium sulfate resistance and corrosion resistance of concrete decrease [5,6,11–15].

On another hand, some researchers found that the replacement of 10% limestone does not significantly alter the compressive strength at any age. In fact the limestone cement replacement improves the compressive strength till 10%. This improvement of strength is essentially due to the acceleration effect of limestone filler related to the formation of calcium carboaluminates hydrate, which may be contributed to the overall increase in the rate of hydration [16–18]. Additionally, the previous researches indicate that generally when limestone is increased, the expansion and the strength loss decrease. This effect may be due to the fact that when limestone powder replaces some cement, the hydration products, i.e. gypsum and $Ca(OH)_2$, decrease, and then the expansion of gypsum and the loss of $Ca(OH)_2$ and other hydration products of cement decrease subsequently [19].

This work aimed to study the mechanical properties of limestone cement concrete. Also, the durability in terms of sulfate resistance and corrosion in addition to environmental impact are studied.

Table 1 Chemical composition and physical properties of limestone powder.

Properties	Value
Blaine	3400 cm^2/gm
Specific gravity	2.55
Calcium carbonate content	94%
Gypsum	4%
Calcium oxide	54%
Total sulfate	3.3%
Chlorides	0.10%
Total silica	3.5%
Magnesium oxide	0.80%
Loss on ignition at 950 °C	38.20%

2. Experimental program

Portland cement, limestone (LS) and silica fume (SF) were used in the experimental study. Type I, Type II and Type V complying with ASTM C-150 were used in this work. The chemical composition and physical properties of limestone powder are presented in Table 1. Natural siliceous sand with 2.67 fineness modulus and crushed pink limestone with 20 mm nominal maximum size meeting ASTM C-33 were used. The slump was kept constant using different dosage of Type F superplasticizer complying with ASTM C-494. The used cement content was 400 kg/m^3.

For mechanical properties, twenty-one concrete mixes were prepared using Type I Portland cement, limestone powder (as cement replacement). In order to enhance the mechanical properties of limestone cement 5%, 10% and 15% of silica fume were studied. These contents were used as an addition of limestone amount with water cementitious ratio of 0.425, 0.41 and 0.391 in various proportions as summarized in Table 2. Concrete compressive strength was obtained at 3, 7, 28 and 365 days using cubes of 150 × 150 × 150 mm. Splitting tensile strength and modulus of elasticity were obtained at

Table 2 Mix proportions for mechanical properties (kg/m^3).

Mix No.	Cement	Lime stone	Silica fume	Coarse aggregate	Fine aggregate	Water	Admixture
Control	400	0.0	0.0	1050	714	183	4.00
1	380	20.0	0.0	1048	713	183	4.00
2	360	40.0	0.0	1046	711	183	4.00
3	340	60.0	0.0	1044	710	183	4.00
4	320	80.0	0.0	1041	708	183	4.00
5	300	100.0	0.0	1039	707	183	4.00
6	380	20.0	20.0	1032	702	183	5.4
7	360	40.0	20.0	1029	700	183	6.1
8	340	60.0	20.0	1026	698	183	6.9
9	320	80.0	20.0	1023	696	183	7.1
10	300	100.0	20.0	1021	694	183	7.1
11	380	20.0	40.0	1016	691	183	7.4
12	360	40.0	40.0	1013	689	183	7.6
13	340	60.0	40.0	1011	687	183	7.7
14	320	80.0	40.0	1010	687	183	6.4
15	300	100.0	40.0	1008	685	183	6.6
16	380	20.0	60.0	1002	681	183	7.7
17	360	40.0	60.0	998	679	183	8.6
18	340	60.0	60.0	994	676	183	9.7
19	320	80.0	60.0	992	674	183	10.0
20	300	100.0	60.0	989	672	183	10.4