Production of Light Weight Foam Concrete with Sustainable Materials

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Abstract- Most of the recent works related to the construction industry in Iraq are focused on investigating the validity of local raw materials as alternatives to the imported materials necessary for some practical applications, especially in thermal and sound insulation. This investigation includes the use of limestone dust as partial substitution of cement in combination with foam agent and silica fume to produce sustainable Lightweight Foam Concrete (LWFC). This study consists of two stages. In the first stage, trial mixes were performed to find the optimum dosage of foam agent. Limestone dust was used as a partial replacement for cement. Chemical analysis and fineness showed great similarity with cement. Many concrete mixes were prepared with the content of lime dust powder being 10%, 14%, and 18% as partial replacement of cement by weight. The results indicate that the compressive strength at 7, 28, and 90 days of age was increased for specimens with 14% limestone dust. The best results in compressive strength show an increase at 7 days and a decrease at 28 and 90 days for concrete specimens with 14% limestone dust. In addition, the results show a decrease in dry density for concrete containing 14% lime dust. In the second stage, different percentages of Polypropylene Fibers were added to the concrete, all mixes, containing a constant content of limestone dust of 14% by weight of cement, were modified using different percentages of Polypropylene Fibers (1%, 1.5 %, and 2% by volume) and the best percentage was found to be 1%. The addition of Polypropylene Fibers enhances splitting tensile and flexural strength at 28 days by 14.55% and 55% respectively.

Keywords-lightweight concrete; foam concrete; sustainable materials; polypropylene fibers ;limestone dust

I. INTRODUCTION

One of the disadvantages of conventional concrete is its high self- weight. The density of normal concrete is in the order of 2200 to 2600kg/m^3. This heavy self-weight makes it, to some extent, an uneconomical structural material. Attempts have been made in the past to reduce the self-weight of concrete in order to increase its efficiency. Light-Weight Concrete (LWC) is a concrete whose density varies from 300 to 1850kg/m^3 [1]. There are many advantages of having low density. It helps in the reduction of dead load, increases the progress of building, and lowers haulage and handling costs. The weight of a building on the foundation is an important factor in design, particularly in the case of weak soil and tall structures. In framed structures, the beams and columns have to carry the load of floors and walls. If floors and walls are made of LWC, this will result in considerable cost decrease. Another important characteristic of LWC is its relatively low thermal conductivity, a property which improves with decreasing density. In extreme climatic conditions and in the case of buildings where air-conditioning is to be installed the use of LWC with low thermal conductivity will produce considerable advantages from the points of thermal comfort and lower power consumption [2]. On the other hand, the cost of natural resources is increasing constantly, leading to the search for alternatives, such as recycled materials like rice husk ash, sawdust ash [3], silica fume, fly ash, coal bottom ash, limestone dust, marble powder, tile powder, millet husk ash, crumb rubber, etc. Also, ordinary Portland Cement (OPC), has been related to several diseases [4-5].

Basically, there are three methods for making LWC. The first way is by using porous lightweight aggregates of low apparent specific gravity. This type of concrete is known as lightweight aggregate concrete. The second way is by introducing large voids within the concrete or mortar mass. These voids should be clearly distinguished from the extremely fine voids produced by air entrainment. This type of concrete is variously knows as aerated, cellular, foamed, or gas concrete. Thirdly, by omitting the fine aggregates from the mix in such a way that a large number of interstitial voids are present. Normal-weight coarse aggregates are generally used. This concrete is called no-fines concrete [2]. Based on the purpose of use, there are three types of concrete. The first type is known as Non-Structural LWC. This is employed mainly for insulation purposes. With low unit weight, seldom exceeding 800kg/m^3, its heat insulation value is high and compressive strength is low, from 0.69 to 6.89N/mm^2 [6]. The second type is Moderate Strength LWC. The use of this concrete requires a fair degree of compressive strength, and thus they fall about midway between the structural and low density concrete. This is sometimes designed as "fill" concrete. Compressive strength varies approximately from 6.89 to 17.24N/mm^2, the insulation values are intermediate, and its density is between 800 to 1300kg/m^3 [7]. The third type is known as Structural LWC. This type can be defined as a concrete with full structural efficiency containing aggregates which fall on the other end of

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the scale. Its minimum compressive strength is 17.24N/mm² [8]. Most of structural LWCs are capable to produce concrete with excessive compressive strength. However, thermal insulation values for structural LWC are substantially better than NWC's. Since the unit weight of structural LWC is considerably greater than that of low density concrete, the insulation efficiency is lower [9]. The compressive strength of insulating LWC increases with increasing density and water-cement ratio [10]. As for polypropylene fibers, research has shown that they increase concrete's resistance to impact loads [11].

II. MATERIALS AND MIX PROPORTIONS

A. Cement

OPC type I, manufactured by Al Kubaisa Cement Factory, was used in 3.1.1 cement in all the mixes throughout this investigation. The chemical and physical properties of this cement are presented in Tables I and II respectively. The test results indicate that the adopted cement, type N 42.5MPa conforms to the Iraqi specification No. 5/2019 [12].

TABLE I. CHEMICAL COMPOSITION OF CEMENT

Oxide composition	Result	Limits of [12]
Lime (CaO)	62	-
Silica (SiO_2)	20.1	-
Alumina (Al_2O_3)	4.24	-
Iron oxide (Fe_2O_3)	4.16	-
Sulfate (SO_3)	2.15	≤ 2.8% if C_3A>3.5 ≤ 2.5% if C_3A<3.5
Magnesia (MgO)	3.65	≤ 5%
Loss on ignition (LOI.)	3.42	≤ 4%
Insoluble residue (IR)	0.71	≤ 1.5%
Main compounds (Bogues eq.) of cement		
Tricalcium silicate (C_3S)		59.02
Dicalcium silicate (C_2S)		29.65
Tricalcium aluminate (C_3A)		4.21
Tetracalcium aluminoferrite (C_4AF)		12.65

TABLE II. PHYSICAL PROPERTIES OF CEMENT

Physical properties	Test result	Limits of [12]
Specific surface area, Blaine method, (m²/kg).	295	≥ 250 m^2/kg
Setting time -Initial setting (min) -Final setting (min)	 1:38 3:45	 ≥ 45 min ≤ 600 min
Compressive strength of mortar (MPa) 2-days 28-days	 20.4 27.5	 ≥ 10 N/m^2 ≥ 42.5 N/m^2
Soundness % (autoclave)	0.35	≤ 0.8

TABLE III. GRADING OF FINE AGGREGATES

Sieve size (mm)	Passing % of sand	Limits of [13]
10	100	100
4.75	100	90-100
2.36	100	85-100
1.18	100	75-100
0.6	67.57	60-79
0.3	36.73	12-40
0.15	4.33	0-10

B. Fine Aggregates

Natural sand supplied from Al-Ekhadir quarry was used in the concrete mixes. The physical and chemical properties of fine aggregates are shown in Tables III and IV. The test results indicate that the sand grading is within the limits specified by the Iraqi Standard No. 45/1984 [13] and lies in Zone 4.

TABLE IV. PHYSICAL AND CHEMICAL PROPERTIES OF FINE AGGREGATES

Properties of sand	Test results	Limits of [13]
Fineness modulus	2.16	-
Specific gravity	2.61	-
Absorption	0.8%	-
SO_3	0.23 %	≤ 0.5%
Dry rodded density	163.7 kg/m³	-
Materials finer than 75μm %	2.6	≤ 5.0

C. Foaming Agent

Foaming agent for cellular concrete ASTM C796-97 [14] from Dr. Foamcrete was used to produce LWC by entraining a controlled amount of air bubbles to concrete mix. Table V indicates the technical description of the foaming agent used throughout this investigation.

TABLE V. TECHNICAL DESCRIPTION OF FOAMING AGENT (DATA TAKEN FROM MANUFACTURE PRODUCTION REPORT)

Appearance	Liquid
Color	Yellow
Specific gravity	1.1
Nitrate content	Nil
Compatibility with cement	All types of Portland cement
Point	Below 0ºC
Flash point	Water base
LOI	3.5

D. Mixing Water

Water was used for mixing and curing of all concrete mixes conforming to standard Iraqi specification 1703 [15].

E. Fibers

Polypropylene fibers bought from Belgian Fibers Manufacturing were used for reinforcement. The specifications and properties of the fibers used throughout the experimental work are illustrated in Table VI according to the supplier.

TABLE VI. TECHNICAL PROPERTIES OF POLYPROPYLENE FIBERS

Length of Fiber	6 mm
Diameter	34μm
Density	0.91gr/cm^3
Young modulus	3750MPa
Melting point	>164Cº
Elongation	200%
Spinning oil	1%
Moisture	Max 3%
Tenacity	30Cn/tex
Alkali resistance	Excellent
Conductivity	Very low

F. Silica Fume

Silica fume commercially known as Mega Add MS(D) from the chemical company Conmix was used as partial replacement of cement throughout this investigation. Tables VII and VIII illustrate its physical and chemical properties. The results show that the used silica fume satisfies the requirements of [16].

TABLE VII. PHYSICAL ANALYSIS OF SILICA FUME

Physical Properties	Results	Requirements of [16]
Color	Grey	-
Percent retained 45μm (No.325)	10	≤ 10
Bulk density (kg/m3)	500 to 700 kg/m3	
Specific surface are (m²/gm)	>15	> 15
Specific gravity	2.2	> 105

TABLE VIII. CHEMICAL COMPOSITION OF SILICA FUME

Oxides	Oxide content	Requirements of [16]
Sio_2	89	Min. 85%
Al_2o_3	0.4	-
Fe_2o_3	1.2	-
Mgo	2.5	-
Cao	1.4	-
So_3	1.0	-
Na_2o	1.2	-

G. Limestone Dust

The limestone dust (Figure 1) was obtained from a limestone quarry in Karbal. It is finely ground in the form of a dust, most of it passing sieve No.100. The chemical composition of the lime dust conforming to [17] is given in Table IX.

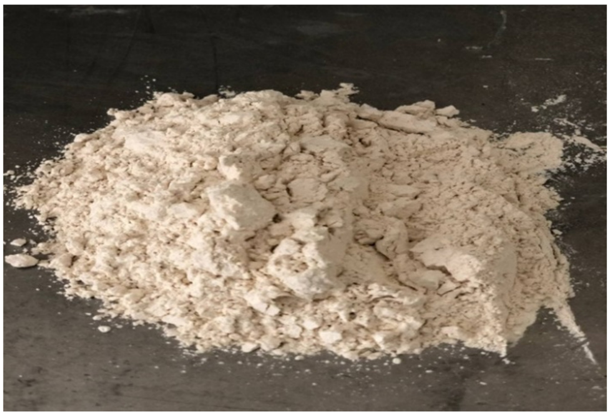

Fig. 1. The limestone dust used in the current research.

TABLE IX. CHEMICAL ANALYSIS OF LIMESTONE DUST

Chemical composition	Constituent(%)	IQS 807 (%)
Silicon dioxide (SiO_2)	5.0	5 (max)
Calcium oxide (CAO)	52.2	80 (max)
Aluminium oxide (Al_2O_3)	0.66	5 (max)
Ferric oxide (Fe_2O_3)	0.08	5 (max)
Magnesium oxide (MgO)	0.51	5 (max)
Sulphur oxide (SO_3)	0.0	-
LOI	41.49	-

H. High-Range Water Reducing Admixture(HRWRA)

The HRWRA Master Glenium 51 produced by BASF Company, satisfying the ASTM C 494/C 494M-17 [18] was used. The type F was used as concrete superplasticizer. The technical data of this type of admixture are shown in Table X.

TABLE X. TECHNICAL DESCRIPTION OF THE SUPERPLASTICIZER

Properties	Technical description
Appearance	Viscous liquid.
Color	Light brown
Density	1.1kg/lt.
pH	6.6

III. MIXING, CASTING, AND CURING

The mixing procedure is important in order to obtain the required workability and homogeneity. Mixing was performed with an electric mixer. The fine aggregates used were in Saturated Surface Dry (SSD) condition. The mixing sequence was the following: the required quantity of dry cement was added to the fine aggregates, the mixing continued for one minute, then the two thirds of the required quantity of water were added to the dry materials. The remaining water and the required quantity of foaming agent were mixed. Drill was used and in the head of the drill it was put the so-called mesh or paddle which rotates at high speed, 14000rpm, with a power supply of 220-240V/50Hz. Then the foam agent was added to mix. The mixer was stopped when a good homogeneous mix was produced. Before casting, the mould sides and the base were oiled slightly to prevent mortar sticking to the surfaces. The casting was carried out to two layers. Each layer was compacted by using a large vibrating table. The specimens were left under polyethylene sheets in the laboratory for one day after casting, then they were removed from the molds and kept in closed polyethylene bags for 7, 28, and 90 days until testing time.

TABLE XI. MIX SYMBOLS

Symbols	Type	Content
MR	Cube	Mortar + foam agent+ silica fume+ HRWRA
ML1	Cube	Mortar + foam agent+ silica fume+ HRWRA + lime dust 10%
ML2	Cube	Mortar + foam agent+ silica fume+ HRWRA + lime dust 14%
ML3	Cube	Mortar + foam agent+ silica fume+ HRWRA + lime dust 18%
MF1	Prism	Mortar + foam agent+ silica fume+ HRWRA + lime dust 14% + polypropylene fiber 1%
MF2	Prism	Mortar + foam agent+ silica fume+ HRWRA + lime dust 14% + polypropylene fibe1.5%
MF3	Prism	Mortar + foam agent+ silica fume+ HRWRA + lime dust 14% + polypropylene fiber 2%
MF4	Cylinder	Mortar + foam agent+ silica fume+ HRWRA + lime dust 14% + polypropylene fiber 1%

A. Mix Proportions

Several mixes were tried in order to find the best mixing of cement to sand, and several ratios were used (1:2.25,1:2,1:3,1:1.5,1:2.5). The optimal ratio of 1:2 was used. Experimental mixtures were then made by adding different amounts of foam agent to the water allocated to them (1, 3, and

5ml) where it was found that adding 3ml to the water gives the required consistency of the mortar. A reference mixture was made as described in Table XII, three limestone dust ratios (10%, 14%, and 18%) were used. The best replacement rate of the weight of cement was found to be 14%. This percentage was used in a mixture in which three different ratios of polypropylene fiber (1%, 1.5%, 2%) were used. It was found that best fiber percentage was (1%). 10% silica fume was used as a partial replacement of cement and 1% of HRWRA.

TABLE XII. DETAILS OF CONCRETE MIXES

Mixes	Cement (Kg/m^3)	Sand (Kg/m^3)	w/b	Silica fume (gm)	Foam agent (ml)	HRWRA (ml)	Fiber (gm)	Lime dust (gm)
MR	300	600	0.4	30	3	1.5	-	-
ML1	300	600	0.4	30	3	1.5	-	30
ML2	300	600	0.4	30	3	1.5	-	42
ML3	300	600	0.4	30	3	1.5	-	54
MF1	300	600	0.4	30	3	1.5	17	42
MF2	300	600	0.4	30	3	1.5	26	42
MF3	300	600	0.4	30	3	1.5	34	42
MF4	300	600	0.4	30	3	1.5	17	42

IV. RESULTS AND DISCUSSION

A. Determination of the Consistency of Mortar (Flow Test)

The amount of water required for standard consistency of plain mortar or foamed mortar was determined by the flow test. The flow table was prepared according to [19]. The amount of mixing water was sufficient to produce a flow of 110±5mm expressed as a percentage of the original base diameter of the flow mould. The required amounts of water for standard consistency of mortars, expressed in terms of w/c ratio, are shown in Table XIII.

TABLE XIII. DETAILS OF THE MORTAR MIXES WHEN USING 1:2 MIX

Foaming Agent (ml)	w/c	Flow 110 ± 5mm
1	0.4	106
3	0.4	112
5	0.4	117

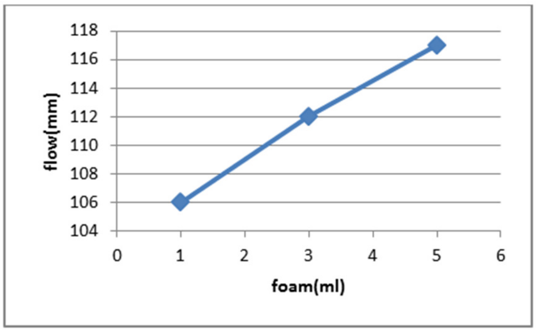

Fig. 2. The relationship between foam and flow.

B. Compressive Strength Test

This test was conducted on 50×50×50mm cubes using an electrical testing machine with a capacity of 2000KN at fixed load according to [20] .The average of three cubes was recorded for each test conducted at ages of 7, 28, and 90 days as shown in Table XIV.

TABLE XIV. COMPRESSIVE STRENGTH RESULTS

Mixes	Compressive Strength (MPa)		
	Age (days)		
	7	28	90
MR	10.45	15.77	20.32
ML1	8.95	12.32	19.93
ML2	10.73	20.86	25.58
ML3	7.41	12.71	17.14

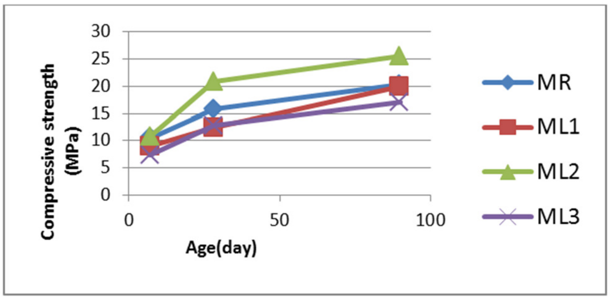

Fig. 3. Compressive strength at 7, 28, and 90 days.

C. Dry Density Test

Dry density was determined from the dried weight (105°C for 24 hours) and the measured volume by a ruler. Three cubes were measured in each tested sample. The density was found by weighting the specimens and dividing the weight by their measured volume. The dry density was tested at 7, 28, and 90 days as shown in Table XV.

TABLE XV. DRY DENSITY RESULTS

Mixes	Dry density (kg/m^3)		
	Age (days)		
	7	28	90
MR	1484	1623	1730
ML1	1478	1601	1679
ML2	1460	1572	1722
ML3	1354	1429	1620

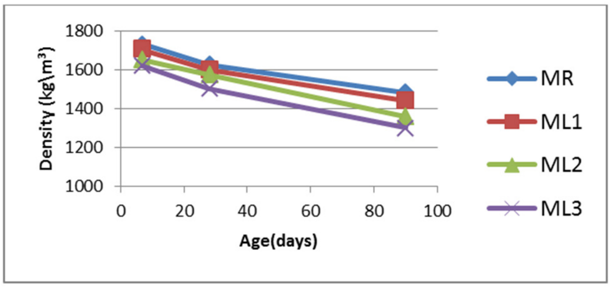

Fig. 4. Density-age relationship.

D. Splitting Tensile Strength Test

Splitting tensile strength test was performed according to [21] in which 100×200mm cylindrical specimens were used. They were tested using an electrical testing machine with a capacity of 2000KN. This test was conducted at 7, 28, and 90 days as shown in Table XVI.

TABLE XVI. SPLITTING TENSILE STRENGTH RESULTS

Mix	Splitting tensile strength (MPa)		
	Age (days)		
	7	28	90
ML2	0.82	1.65	2.04
ML4	1.01	1.89	2.21

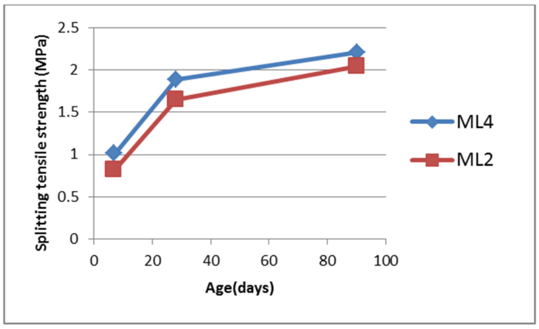

Fig. 5. Splitting tensile strength at 7, 28, and 90 days.

E. Flexural Strength Test

The flexural strength was determined according to [22] by using the center point method. The prism-shaped specimens with dimensions of 70×70×380mm were simply supported with 300mm span and were tested at the age of 7, 28, and 90 days as shown in Table XVII.

TABLE XVII. FLEXURAL STRENGTH RESULTS

Mix	Flexural Strength(MPa)		
	Age (days)		
	7	28	90
ML2	1.6	2.45	2.94
MF1	3.1	3.8	4.77
MF2	2.33	2.7	3.69
MF3	1.75	2.34	2.83

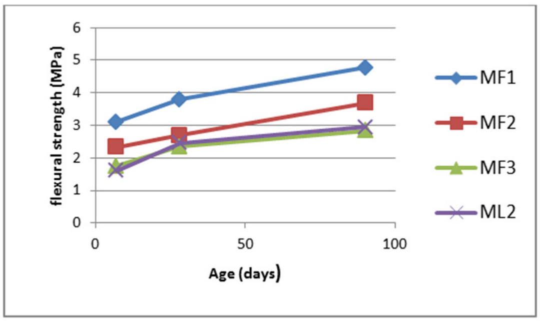

Fig. 6. Flexural strength at 7, 28, and 90 days.

V. V. CONCLUSION

Based on the results obtained from the experimental investigation, the following conclusions can be drawn:

- The water requirement for LWC is decreased as the percentage of foaming agent increases and the maximum decrease in water for all concrete mixes was 0.4 as a percentage of cement weight.
- LWC with 3ml foam agent gave better results of density and compressive strength.
- Compressive strength, flexural strength, and splitting tensile strength of LWC with limestone dust is slightly lower than those of normal concrete at all ages.
- The added foam leads to an increase in the flow. Three amounts of foam were added (1, 3, 5ml) and the flow rate was 106, 112, 117mm respectively. Three percentages of foam (10%, 14%, and 16%) were added to concrete as partial replacement of cement to produce sustainable LWC.
- Flexural strength and splitting tensile strength of LWC with 1% polypropylene fiber are higher than those of LWC without fiber at all ages.
- The best results were for specimens of LWC having a combination of polypropylene fibers (1%) and limestone dust (14%) due to the further physical effect of micro steel fibers in addition to the effect of limestone dust.

The results of this research confirm that we can use limestone dust to produce green LWC and enhance its properties with polypropylene fibers.

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