

## Partial Replacement of Limestone and Silica Powder as a Substitution of Cement in Lightweight Aggregate Concrete

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### Abstract

With increasing trends towards the broader usage of concrete and warning depletion of natural resources of aggregates, it seems reasonable to find mineral additives or binding materials of different types as ingredient of concrete. Accordingly, wide usage of light weight concrete lies on some main structural applications as reduction of total dead, seismic loads, environmental pollution, and labour cost. This paper tries to investigate the properties of light weight blended concrete containing lime stone powder (LP), micro-silica (MS), pumice, and leca in various proportioning rateing as a partial replacements of cement. Utilization of these additives on the compressive strength, tensile strength, water absorption coefficient, acid resistance, and impact resistance examined experimentally in various curing conditions at the ages of 7 and 28 days to evaluate the combined effect of micro-silica and lime stone incorporation on strength and durability properties of light weight concrete, along with introduction of optimum replacements. For this purpose, 10 lime-stone based concrete mixtures were prepared with proportions from 0 to 20%, and constant values of 10% micro-silica and w/c ratio. From the results, it was indicated that addition of lime stone powder in concrete reduces short-term properties as well as the compressive strength. Optimum levels of powder replacements can serve as sustainable and durable concrete, also environmental and economic benefits.

*Keywords:* Limestone Powder; Micro-Silica; Pumice; Leca; Structural Light Weight Concrete.

## 1. Introduction

The growing demand for concrete lies on some issues as low costs of constituent materials, construction and maintenance of concrete structures [1]. It was reported that in 2002 about 6.5 billion tonnes of concrete were produced all around the world [2] or annual production of concrete is up to 10 billion tonnes [3]. There may be an estimation to concrete production growing rate up to 18 billion tonnes by 2050 [4]. One of the main reasons of global warming may be attributed to concrete industry by emission a high volume of CO<sub>2</sub> into the atmosphere [5, 6]. In recent years, principal applications of technological advancements have translated into elaborated studies on properties and behaviors of materials, to achieve favorable strength, durability as well as workability. The process of selecting suitable ingredients of concrete and determining their relative amount with the objective of producing a concrete as economically as possible is well known in many studies, the major part of the energy consumption is related to the Portland cement formation [7, 8].

The general term light weight (LW) concrete refers to any concrete which is produced to an oven dry density of less than 2000 kg/m<sup>3</sup> [8]. Any aggregate with a particle density of less than 2000 kg/m<sup>3</sup> or dry loose bulk density of less

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than  $1200 \text{ kg/m}^3$  is defined as light weight [9]. Using lightweight aggregates (LWA) is one of the most typical methods of fabricating structural light weight aggregate concrete [10]. The main advantages of LWA are: reducing dead load, seismic imposed loads, acceleration volume of excavation and construction wastes, concrete demand at bases, and so on. These categories are divided into sub-categories for example, dead load reduction is related to reducing total size of the structure, also columns, beams, foundation, roof thickness, and reinforcements [11, 12]. In another study Akeiber et al. (2016) stated that lightweight floors and walls considerably reduce the interior temperature of the room to make the occupants more comfortable [13]. Lightweight aggregates are broadly classified into two types: natural (pumice, diatomite, volcanic cinders, etc.) and artificial (perlite, expanded shale, clay, slate, sintered PFA, etc.) [14].

There has recently been a trend in literatures to allow supplementary materials or by-products to be used as partial replacements of cementitious materials in concrete production as one way to reduce pollution and environmental disturbances, while offering complementary properties to compensate natural aggregate loss in concrete. Therefore, cement replacements in concrete can be highly beneficial regarding cost, energy efficiency, low permeability, strength and durability [15, 16]. Kasselouri 1977 stated in early works that the use of industrial by-products, such as FA, SF, offers a low-priced solution to the environmental problem of depositing industrial waste. Research works in this regard have proved that inclusion of these pozzolanic materials not only improves the strength and durability of concrete but also can be considered helpful in reducing global warming caused by disposal of waste materials [17].

In some parts of the world lime stone powder has been used for many years, but has received the growing interest globally, especially in Europe in recent twenty years [18, 19]. Addition of limestone possibly reduces the initial and final setting time, also its porosity [20].

Ajay & Rajeev 2012 reported that silica fume possibly increases the strength of concrete up to 25%, while decrease the voids in concrete, capillary, absorption and porosity of concrete due to fine particles of silica fume react with lime present in cement. Silica fume is much cheaper than cement [21] so it reduces the final cost of concrete production. Silica powder (quartz) addition into concrete as a partial replacement of cement has been investigated generally by comparing its performance to that of a similar-sized limestone powder [22-25].

This study aimed to investigate the mechanical and durability properties of light weight aggregate concrete containing limestone and silica powder in different proportions at 7 and 28 days of curing.

## 2. Methodology

With regard to the abovementioned review of the previous literature, consistent interpretation of test data requires a well-defined formation process of samples and test set up. Simultaneous combined effect of lime stone powder and micro-silica as partial replacement of cementitious materials was evaluated experimentally in light weight concrete in different proportions with constant w/c ratio of 0.37. It should be noted that micro-silica addition likely to prevent strength decrease in powdered limestone concrete. Regarding light weight aggregates utilization on concrete performance, five mixtures were provided using an artificial light weight aggregate and five mixtures using a natural light weight aggregate. Samples were designed in cube, cylindrical and beam forms and demoulded after 24 hours, then fully saturated in water tank at  $23^\circ\text{C}$  to have 7 and 28 days compressive strength, impact resistance, water absorption and acid resistance experimentally.

### 2.1. Materials

Materials used in this study consists of ordinary cement, sand, coarse aggregates of leca and pumice, powdered limestone, and micro-silica, brief definitions of each are presented below.

#### 2.1.1. Cement

Among different types of cements, locally available Shahrekord type II cement for our evaluation used, with physical properties and chemical analysis composition given in the following tables:

**Table 1. Physical properties of cement used in the present study**

Property	density ( $\text{g/cm}^3$ )	Characteristic surface blain ( $\text{cm}^2/\text{g}$ )	28 days compressive strength (Mpa)	Bulk density ( $\text{g/cm}^3$ )
Value	3.19	3420	40.3	1.13

**Table 2. Chemical analysis of cement**

Cao	Arts,	Mgo	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	So <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	Tio <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	LOI
61.2	21.7	4.78	3.47	2.53	2.58	0.98	0.14	0.04	0.65	1.68

### 2.1.2. Micro-Silica

The initial interests considering the evaluation of concrete performance containing micro-silica as a partial replacement of cement has been prompted by strict enforcement of air-pollution controls in various countries mostly aimed to stop release of the material into the atmosphere. Silica fume is typically known to produce a high-strength concrete which can be used in two different ways, one as a cement replacement to reduce the cement content (usually for economic reasons); and as an additive to improve concrete properties [26].

The main influences of micro-silica super plasticizer incorporation into concrete can be summarized in to: less mechanical strength, less permeability, improving paste-to-aggregates bond due to reduction of weak transition zone between paste and aggregates, reduction of chloric ions movement, prevention from reinforcement corrosion in reinforced concretes, reduction of internal exothermic rate, providing high early strength and durability, and decrease air pollution.

Micro –silica differs with other plasticizers whose efficiency relative to unit weight is 2-4 times more than that of cement, while partial replacement of cement by low percentage of micro-silica leads to internal heat reduction. Any change occurs in the mechanical properties of concrete means to the changes in long-term service of the binder hydration. The cement hydration caused by chemical reactions of Portland cement and water leads to the formation of hydrated cement paste that can be effective on the concrete strength.

**Table 3. Mechanical and chemical properties of micro-silica pozzolan**

Particle size (µm)	Density (kg/m <sup>3</sup> )	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	CaO	MgO	SiO <sub>2</sub>
0.6-00.45	550-650	0.89	1.32	0.21	0.26	0.71	96.6

### 2.1.3. Lime Stone Powder

The grey and black stone, formulated with accumulation of volcanic ashes and gradual cooling along with expansion due to bubbles caused by vapor and going gases. It is found in various ingredient sizes of about fly ashes to larger particles of size beyond 100µm, per with different beneficial effects. Limestone powder is a kind of super-fine material with size normally smaller than 5 µm, which is produced by grinding of limestone. Limestone powder can react with hydration products of cement in the hydration process of cement-based material, producing C<sub>3</sub>A·3CaO·3H<sub>2</sub>O and C<sub>3</sub>A·CaO·11H<sub>2</sub>O. S.H.[27].

Two decades elapsed since the development of lime stone – filler blended cement. Owing to large numbers of stone cuttings in Iran, and considering substantial increase in generated wastes from the industry, this huge amount of powdered limestone could rather to be used as by-product or partial replacement of cement, even to satisfy local requirements. The results of chemical analysis of stone powder are tabulated in Table 4.

**Table 4. Chemical analysis of stone powder**

CaO	SiO <sub>2</sub>	MgO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	LOI	Blaine	Specific gravity
54.02	1.5	0.36	0.25	0.26	0.06	0.08	0.04	0.05	0.01	41.07	334	2.75

When the content of limestone powder is 10%, the strength of ultra-high performance concrete decreased little, which indicates that we can reduce the cost of the ultra-high performance concrete [28]. In an article, it was also reported that filler blended cements with the content of 10% powdered limestone showed less strength compared to the reference sample that even increased in later ages. In another study, it has been revealed that concrete contains 10% limestone powder as a partial replacement of cement may have compatible properties (durability and compressive strength) in comparison with ordinary Portland cement [29].

### 2.1.4. Super Plasticizer

Poly- carboxylic super plasticizer was used with relative solid components of 47%, was produced by Panta Company. Super plasticizer based mixes benefits in lower water demand, more followability of concrete particles, and hydration improving at different ages.

### 2.1.5. Light Weight Aggregate Leca

A part of this investigation allocated to expanded clay coarse aggregate (leca) with rounded and rough appearance, brown pores on microscopic surface, and black cellular inner part. In general, the procedure of mix design containing leca fall in to the stage of clay expansion in rotatory kilns with 1200°C, with the sizes were between 0 to 32 mm. Benefits

of coarse aggregates leca such as light weigh, low thermal conductivity, enough acoustic loss, chemical long lasting was made this type of artificial aggregate more and more functional in building, agricultural, environmental and road pavement sections. Regarding cohesion and resistance, light weight concrete leca may be used for the following applications as space filler, insulator or load bearing by in-site casting or to be used as blocks or prefabricated elements.



Figure 1. Light weight aggregate leca

Table 5. Chemical analysis of leca and pumice aggregates

Chemical compounds	Leca aggregates	Pumice aggregates
SiO <sub>2</sub>	66.05%	60.8%
AL <sub>2</sub> O <sub>3</sub>	16.57%	17.0%
Fe <sub>2</sub> O <sub>3</sub>	7.10%	3.40%
CaO	2.46%	3.5%
MgO	2.99%	2.5%
TiO <sub>2</sub>	---	0.49%
P <sub>2</sub> O <sub>5</sub>	0.21%	0.47%
MnO	---	0.04%
SO <sub>2</sub>	0.03%	---
Na <sub>2</sub> O	0.69%	3.8%
K <sub>2</sub> O	2.69%	2.31%
L.O.I	0.84%	5.62%

**2.1.6. Light Weight Aggregate Pumice**

Using pumice with different workability can be found on account of some properties as low specified weight, compaction strength, elastic coefficient, resistance and insulation toward the action of fire up to 760°C without any considerable change in form and volume, and suitable thermal coefficient allowing addition of this material in concrete production, prefabricated components, and using as a fine filler. Primary addition of pumice in manufacturing process of prefabricated components is likely to reduce structural weight, concrete and ironware consumption, and minimizing human casualties in earthquake events.



Figure 2. Light weight aggregate pumice

**Table 6. Comparison the properties of aggregates**

Type	Aggregates	Form/ Plan	Production Method	Raw Materials	Water absorption (mass ratio)			Bulk Density	Granular Density
					24 H	60 Min	30 Min		
Natural	Pumice	Irregular	Mechanical	Pumice	20-40	20-30	10-20	500-800	900-1900
Artificial	Leca 700/ Iran	Rounded	Rotatory kiln	Expanded clay	6.8	5.5	-	580-700	1300-1500

### 3. Casting, Testing and Curing of Specimens

Using a mixer of 50 litres capacity, initially dry materials were added for two minutes' rotation, then 50% of water and all of the cementitious materials were added for another 3 minutes mixing, finally remained water and the superplasticizer were added, the amount of which determined by the required workability to establish a favorable mixture. Proportioning rates by percentage are summarized in Tables 7 and 8. After 24 hours of casting, the specimens were all demoulded and then were immersed in cold water tank by 23 °C.

**Table 7. Light weight concrete blended with leca  $kg/m^2$** 

Mix plan	W/b	Lime stone powder (%)	Cement	Micro-silica (%)	Water	Coarse aggregates	Ordinary sand	Super- plasticizer
LM0=CTL		0	450					
LM5		5	430					
LM10	0.37	10	410	10	184	360	540	10
LM15		15	390					
LM20		20	370					

**Table 8. Light weight concrete blended with pumice  $kg/m^2$** 

Mix plan	W/b	Lime stone powder (%)	Cement	Micro-silica (%)	Water	Coarse aggregates	Ordinary sand	Super- plasticizer
PM0=CTL		0	450					
PM5		5	430					
PM10	0.37	10	410	10	184	360	540	10
PM15		15	390					
PM20		20	370					

#### 3.1. Mixture Proportions

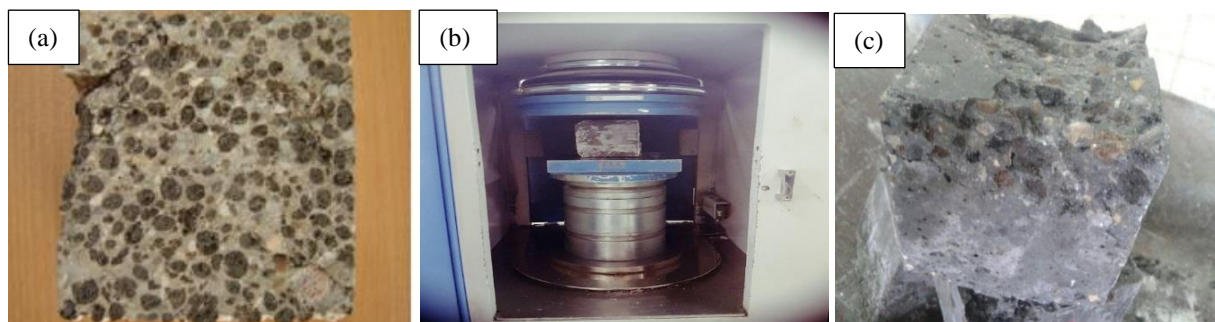
Ten series of mix proportions of which one control and nine with different proportions of mineral additives were prepared here, the amount of w/b ratio was kept constant at 0.37 in all mixes. Of each mix plan, 6 cube specimens of  $10 \times 10 \times 10$  mm size were prepared, and the compressive strength, bending strength, impact resistance, water absorption ratio, chloride ions penetration, and tensile strength measurements were made on them. After hardening state by half an hour, each three of the specimens were cured at 7 and 28 days, respectively. Tensile strength test performed at 7 and 28 days of curing on two concrete columns ( $10 \times 10 \times 50$  mm) obtained from each mix plan.

#### 3.2. Compressive Strength Test

Several attempts were made to evaluate the compressive strength in various ages of concrete. After cold water curing at 23°C, then specified dry weight and short term water absorption calculations were calculated. Using hydraulic jack, as it can be seen in Figure 3, compression strength is obtained. Loading protocol is according to the hydraulic jack specification (ELE ADR-Auto V2.0 2000 standard compression). The results are presented in Table 9. The results can be interpreted that increase in lime-stone powder incorporation at 7 and 28 days of curing subsequently decrease the compressive strength of both types of leca and pumice concretes by 10%, after that progressive increase could be observed (except for 20% incorporation of limestone powder in leca based concrete that cause higher levels of the compressive strength compared to the reference sample and a growing rate may be expected for this type of concrete).

**Table 9. Results of the compressive strength test**

Mixtures	Compressive strength at 7 days of curing (Mpa)	Compressive strength at 28 days of curing (Mpa)	Density (kg/m <sup>3</sup> )
PM0	48.82	54	1870
PM5	36.52	44.87	1778
PM10	26.62	36.61	1788
PM15	34.48	40.6	1832
PM20	35.26	42.3	1846



**Figure 3. a) The compressive strength test; b) Specimen's failure caused by loading was applied by standard hydraulic jack (ELE); c) Cracked section of light weight leca based concrete**

How the compressive strength vary by the dimensions of specimens is of importance, the compressive strength of cylindrical specimens at the age of 28 days reached 80% of that of a cube specimen by 150 mm dimension and 83% of cube specimens with 200mm diameter. It should be bore in mind that the compressive strength of light weight aggregate concrete specimens did not vary substantially related to size variations. The results of compressive strength tests can be observed in Table 10.

**Table 10. Results of the compressive strength test**

Mixture proportions	Compressive strength at 7 days of curing	Compressive strength at 28 days of curing	Density
LM0	24.47	35.74	1570
LM5	23.39	33.82	1434
LM10	20.62	28.21	1446
LM15	22.36	30.71	1502
LM20	25.97	37.23	1558

Excess limestone powder addition (optimal level obtained here by 20%), is the reason that the amount of fine particles increases up to the level that cement paste lose its capacity to coat all fine and coarse particles leads to drop in the reactive clinker component and significant physical modifications of the material [30].

### 3.3. Specified Oven Dry Weight

The major features of light weigh concrete contains durable ingredients in spite of mass degree less than 2000 kg/m<sup>3</sup> Is the compressive strength beyond 17 MP. Combination of light weigh aggregates- as leca or pumice at different proportions possibly compensate this weight problem. Oven dry test conducted by putting the first three cube specimens in oven dry, to be weighted precisely after that, as it can be seen in Figure 4. Necessary care was taken to specimens with predetermined size, volume and shape that can be established using calipers. The results clearly indicate significant weight loss in leca and pumice concretes when cement partially replaced by lime-stone powder, whereby dry weight increased with an increase in replacement levels of lime stone (in percentage), by average. Slight changes in dry weight can be traced in replacement of cement by 20% lime- stone powder compared to the reference sample

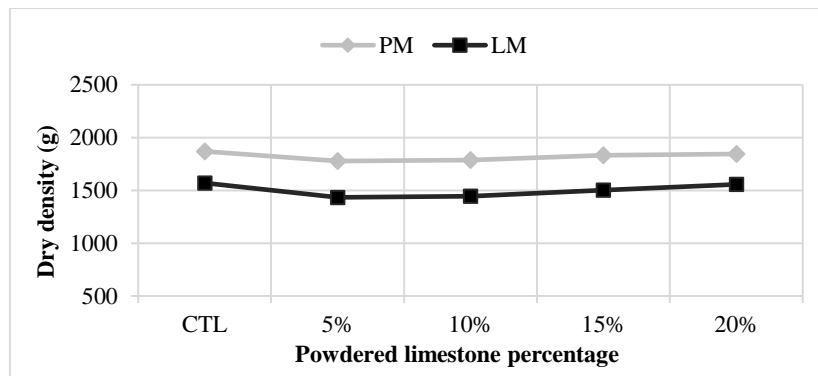


Figure 4. Oven dry weight calculations for pumice and leca based concrete (g)

### 3.4. Three - Point Bending Test

For experimentally evaluating concrete tensile strength in tensile due to bending condition, a simple standardized test can be conducted. The test set up consists of a concrete column of dimensions 10× 10×50 mm adjusted to be placed on the surface of two supports, then two identical loads were imposed in an interval of one third of the length of the beam from the support until crack occurrence. It was indicated that the tensile strength measurement corresponds to the relation of stress/tension due to bending. Bending strength defined by fracture modules. The results are presented in Figure 5.

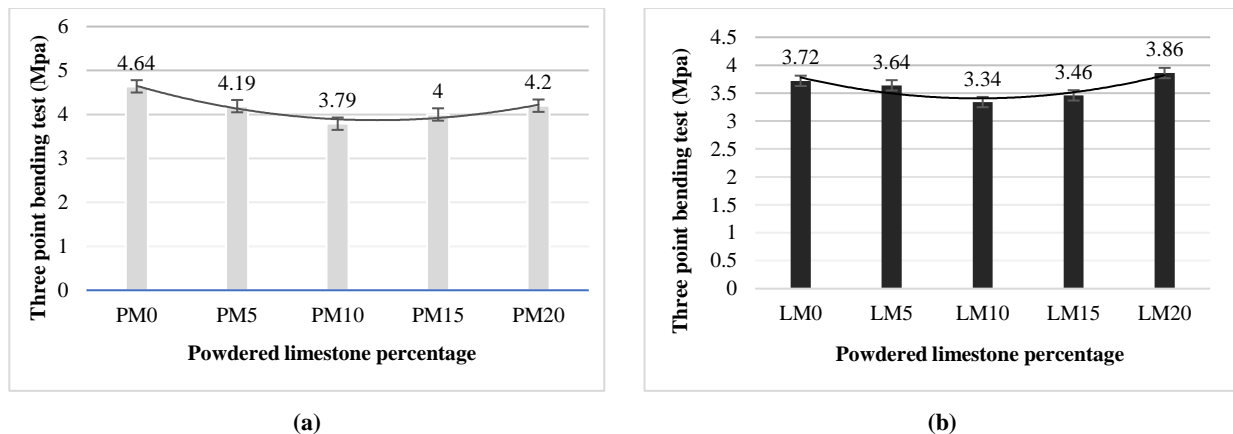


Figure 5. a) Results of the three-point bending test on pumice based concrete at 28 d of curing (Mpa); b) Results of the three-point bending test on leca based concrete at 28 d of curing (Mpa)

As it can be seen from the figures, when lime-stone powder addition increased by 20%, thereby, the three-point bending strength of pumice based concrete samples decreased up to 9.5% than that of reference sample. This is opposed to the results obtained by leca concrete whose given strength initially decreased, then an increase by to 3.7 was observed in LM20 contains 20% lime stone powder, compared to the reference sample. In the following figures the relation between three- point bending strength and the compressive strength of specimens is provided for both types of concrete samples.

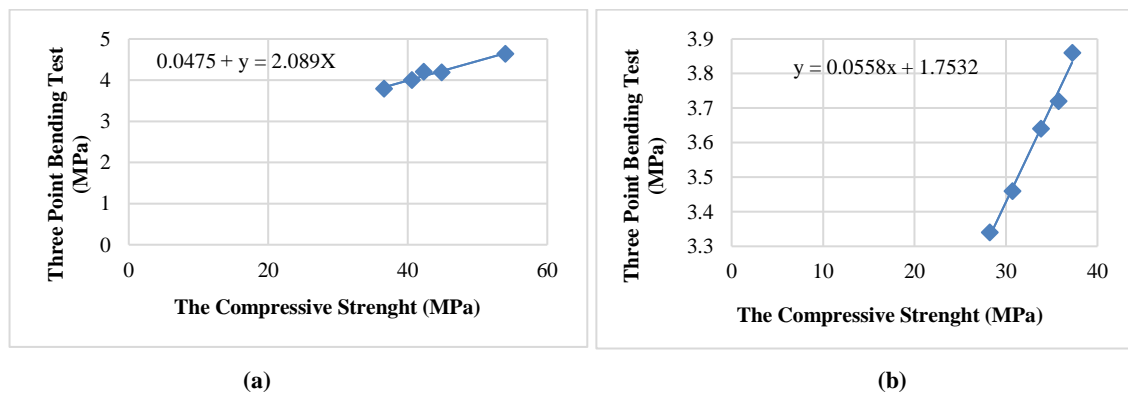


Figure 6. a) The relation between bending and compressive strength of pumice based concrete; b) the relation between bending and compressive strength of leca based concrete

### 3.5. Durability Test (Short Term Water Absorption)

The material gets more vulnerable in hardening phase once the porosity of specimen is closed or residual water gets evaporated, especially in permanent water placements. After water curing, the moulded specimens transferred to an oven at 105°C for 72 h, and then were fully immersed in cold water tank for 30 m. Water absorption is calculated by measuring the increase in mass as a percentage of dry mass [31]. The weight of the specimen in fully saturated condition was compared to weight of dried specimen, by average to determine water absorption coefficient. It was found that water absorption is compatible with the quality of concrete faced with harassment or unbound conditions and corrosion, especially those permanently immersed in water, the obtained results in this experiment can be seen in Figure 7.

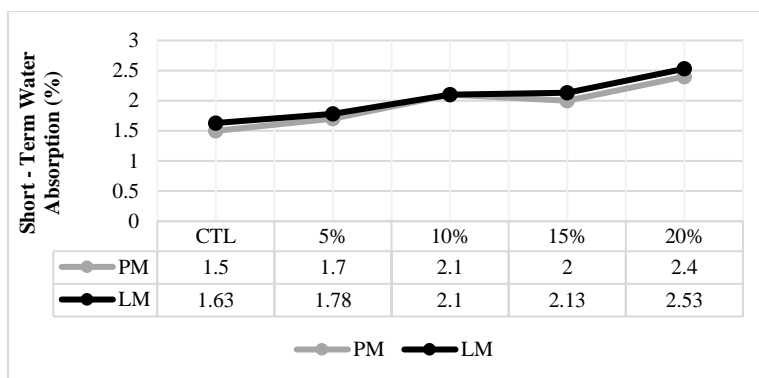


Figure 7. The average water absorption values for concrete blended with pumice and leca

The total water absorption values for mixtures without silica-fume are greater than that of the reference mixture. This result may bring out the opinion that lime stone powder cannot sufficiently block capillary pores and increase water absorption, also can be attributed to more porosity of leca and pumice aggregates. The lowest water absorption ratio caused by the improved aggregate-matrix bond resulting from the formation of a less porous transition zone in the silica fume concrete [32].

### 3.6. Rapid Chloride Ion Penetration Test (RCPT)

One of the most usable methods for evaluation of concrete permeability in contact with chloride ions is methods of RCPT (Rapid Chloride Permeability Test) established according to the provisions of ASTM C1202 standard test method. It is now a well-established method of quality control in Iran [33]. Simple- to conduct is assumed to be the main reason of broad usage of RCPT test method. In this test, the total amount of charge passed by a concrete cube sample under the effect of a 60 V electric field was measured for 6h to show the specimen's permeability. To ensure saturation, all samples were placed in an mmhg1 vacuum chamber.

The samples generally placed in a 3 % (or 1.5%) NACL-solution. The electrical current through the system is automatically recorded. According to Ohm’s law this voltage drop is converted to a current:  $V = R.I = 1.I$ , as it can be seen in Figure 8 [34].

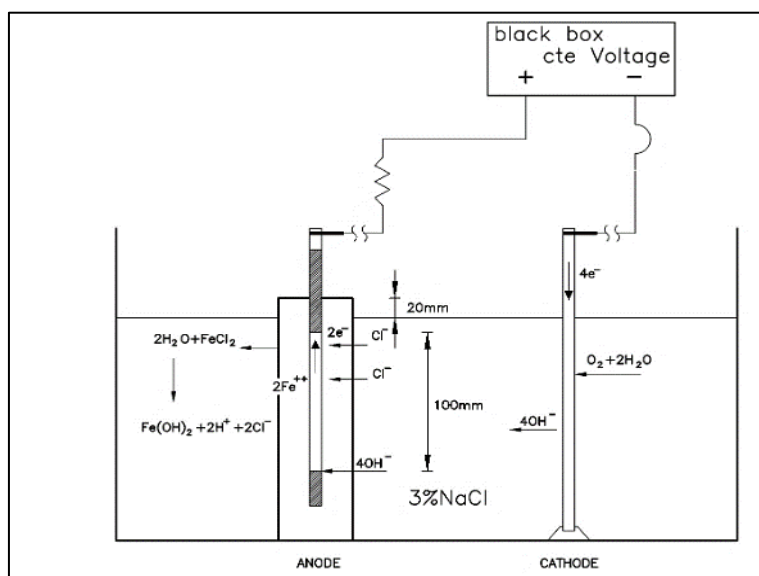


Figure 8. Electronic circuit of the test [34]



Corrosion progress in concrete is broadly attributed to chloride ions penetration in to the aggregates from contaminated materials, soils or even caused by external impacts from sources such as sea water. In Figure 9. the total amount of electrical charges measured for 6 mixes by Columbus can be seen. It is thought that CPT tests can be conducted align with diffusion test on the same mixes to ensure reliability of the relationship between the diffusion coefficients. Validity of CPT relies on its ability to allow comparative tests to be conducted on different concrete mixes or on hydrophobic factors based on the diffusion coefficient and chloride penetration times.

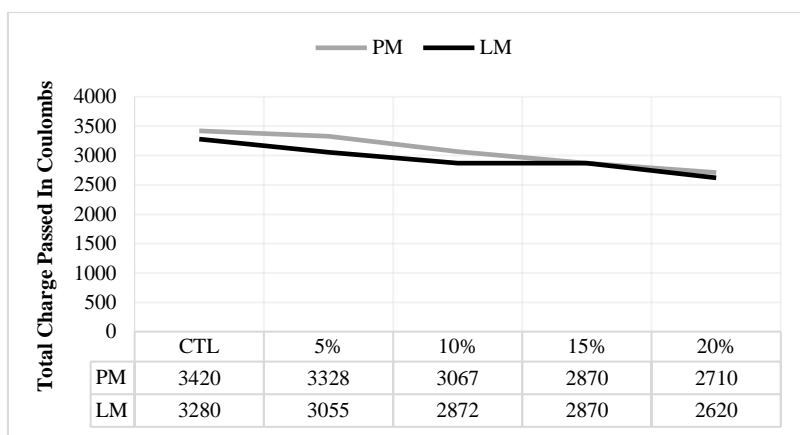


Figure 9. Test results of RCPT for concrete blended with leca and pumice

Table 11. Concrete permeability categorization in contact with chloride ions based on the (ASTM C1202)

The chloride permeability of concrete	Passing electric flux (Coulomb)
Much	>4000
Average	2000~4000
Little	1000~2000
Very little	100~1000
Negligible	<100

### 3.7. Impact Resistance Test

Impact resistance is the evaluation of partial or whole material’s ability to resist toward iterative impacts or high-rate loadings. Impact resistance is of parameters considered to be the most difficult to quantify. To the author’s knowledge there may not be a clear relationship between this parameter and the compressive strength. Impact resistance corresponds to concrete resistance subjected to impacts and energy absorption percentage, for example, the number of tolerable beats until returned conditions occur. In this case, the most common test type is falling weight test. Simple- to conduct is the main reason of broad usage of this test to evaluate the behavior of cement-based materials. The number of impacts was recorded until crack at about 2.5 cm width was observed on lateral surface of specimen in accordance to provisions of ASTM G544 impact resistance test standards. The results are shown in Table 12 and 13.

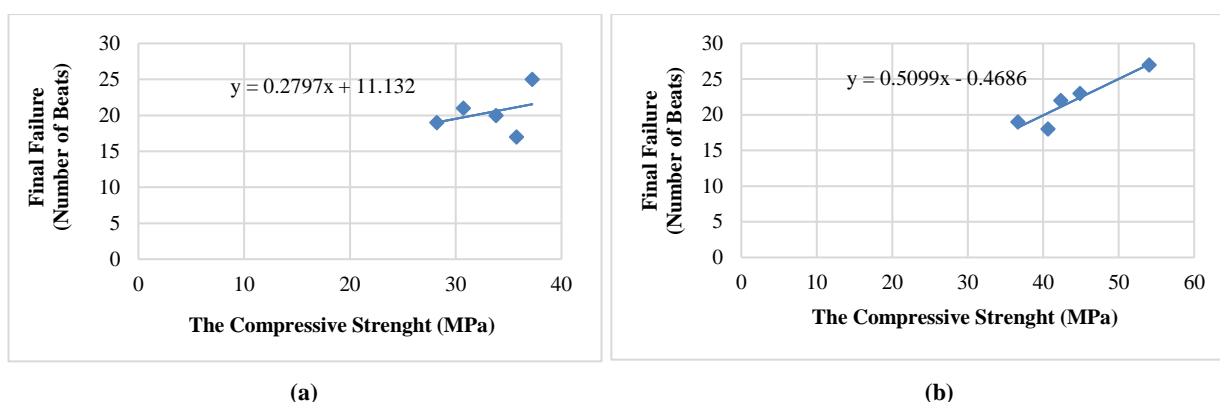
Table 12. Impact resistance results of the leca samples

Concrete specific gravity Kg/m <sup>3</sup>	Impact resistance First crack/ final failure	Compressive strength (Mpa)	Age of concrete (days)
LM0 1570	6 17	35.74	28
LM5 1434	7 20	33.82	28
LM10 1446	4 19	28.21	28
LM15 1502	11 21	30.71	28
LM20 1558	17 25	37.23	28

**Table 13. Impact resistance results of the pumice samples**

Concrete specific gravity Kg/m <sup>3</sup>	Impact resistance First crack/ final failure	Compressive strength (Mpa)	Age of concrete (days)
PM0	14 27	54	28
PM5	10 23	44.87	28
PM10	9 19	36.61	28
PM15	11 18	40.6	28
PM20	8 22	42.3	28

From the results it can be interpreted that a direct relationship exists between compressive strength and impact resistance of samples. The results show that resistance of pumice concrete increased due to its relative delay of failure in strong impacts compared to that of a leca concrete sample. In the following a comparison made between the compressive strength and final failure of given concretes.



**Figure 10. a) The relationship between the compressive strength and failure of the concrete contains leca; b) The relationship between the compressive strength and failure of the concrete contains pumice**

According to the provisions of ACI 544, the final rupture corresponds to complete separation of elements and therefore, complete loss of concrete load bearing capacity. Figure 10. shows linear regression relation between the compressive strength of samples and final rupture at the age of 28 days. Final rupture measurement being performed with a 4.54 kg hammer and the compressive strength was evaluated in Mpa. As it can be seen from the Figure 10a,  $y = 0.2797x + 11.132$  defined for leca lightweight concrete presenting that, there was not found any direct relation between strength and number of impacts. For example, the least strength of 28.21 Mpa didn't resulting in the lowest strength of 17 in samples. In general, the more the compressive strength at the age of 28 days, the more the probability of deletion of concrete final rupture. It is opposed to pumice light weight concrete results presented in Figure 10b, in which  $y = 0.5099x - 0.4686$ , shows the linear direct relation between the compressive strength and final failure at the age of 28 days. For example, the highest compressive strength of 54 Mpa could yield the highest impact resistance by 27. Comparison of two figures show that the correlation coefficient of pumice light weight concrete  $R^2 = 0.8663$  is much larger. There was not found any clear relation between addition of limestone powder and impact resistance. A concrete limestone powder disk is separated from the cylindrical sample. The impact causes dent which could be observed at the center of the disk and initial cracks evolving in 60° sectorial form through the disk. There is a decreased possibility to find significant differences between the number of final impacts in the reference sample and powdered limestone concrete samples. It can be interpreted that energy absorption capability and concrete ductility did not change considerably. It seems that light weight concrete with the capability of impact resistance being achieved by using various fibers.

**3.8. Weight Alterations of the Specimens Immersed in Sulphuric Acid**

Sulphuric acid corrosion in structures and concrete sewer pipes after a few years of construction is yet to be resolved satisfactorily by weighting the effects of these solutions on concrete in terms of mass change, residual compressive strength and duration of placement. In this case, a research by looking the ways of improving acid resistance of Portland cement based concretes evaluated the effects of using some binders and supplementary materials such as limestone conducted by [35]. Weight changes and the residual compressive strength of two 10 cm cube specimens was calculated

by passing 28 d of immersion in PH= 3% sulphuric acid solution. The acidic ratio of the solution was controlled by PH meter device, to keep it by PH=3. The results are presented below:

**Table 14. Weight alterations of the specimens immersed in sulphuric acid for concrete blended with leca**

Mix plan	Specimens' weight before acid immersion	Specimens' weight after acid immersion	Reduction of Weight at an age of 28 d (%)
LM0	1570	1556	0.89
LM5	1434	1419	1.04
LM10	1446	1424	1.52
LM15	1502	1481	1.39
LM20	1558	1537	1.34

**Table 15. Weight of the specimens immersed in sulphuric acid for concrete blended with pumice**

Mix plan	Specimens' weight before acid immersion	Specimens' weight after acid immersion	Reduction of Weight at an age of 28 d (%)
PM0	1870	1856	0.74
PM5	1778	1760	1.01
PM10	1788	1771	0.95
PM15	1832	1812	1.09
PM20	1864	1843	1.6

Tests was conducted on two 10 cm cube specimens (from each mix plan two specimens were fully immersed in acid solution). The results show that, addition of limestone powder increases acid resistance, thereby increasing the weight loss and compressive strength. It was concluded that partial replacement of cement by 15% limestone powder leading to a decrease in compressive strength up to 10% in both types of blended light weight concretes.

### 3.9. The Compressive Strength of Specimens Immersed in Sulphuric Acid

Pumice and leca based concrete samples immersed in sulphuric acid at an age of 28 d, to be compared to normal 28 d tap water curing. The results can be observed below.

**Table 16. The compressive strength alterations of the specimens immersed in sulphuric acid for concrete incorporated with leca at an age of 28 d.**

Mix plan	Compressive strength at an age of 28 days of tap water curing	Compressive strength at an age of 28 days of acid immersion	Reduction of compressive strength at an age of 28 days (%)
LM0	35.74	33.7	6
LM5	33.82	30.54	10
LM10	28.21	27.33	5
LM15	30.71	25.41	11
LM20	37.23	32.69	12

**Table 17. The compressive strength alterations of the specimens immersed in sulphuric acid for concrete incorporated with pumice at an age of 28 d.**

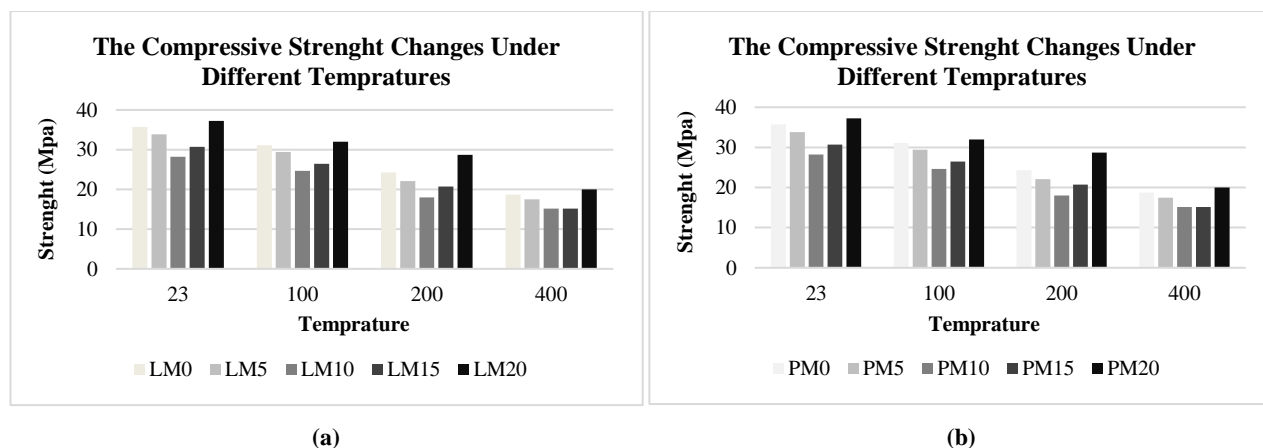
Mix plan	Compressive strength at an age of 28 days of tap water curing	Compressive strength at an age of 28 days of acid immersion	Reduction of the compressive strength at an age of 28 days (%)
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LM20	37.23	32.69	12

It can be observed from the results that immersion of this type of concrete in to acid solutions lead to a slight improved compressive strength as a function of sulphuric acid penetration into specimens to be reacted with cement paste and coarse aggregates. When the strength of different mixes is compared it can be concluded that this variation depends on mixture type and limestone powder amount. Partial replacement of cement by powder limestone yield suitable strength properties that can be interpreted from slight changes in samples' weight were immersed in acid solutions.

### 3.10. The Compressive Strength Under High Temperature

Compressive strength test was carried out on cube specimens of LM and PM (basic mixtures) at an age of 28 days. The residual compressive strength measurement made after specimens were exposed to elevated temperatures ranging from 800-100°C, then gradual cooling in laboratory environment. Figure 11. shows the residual compressive strength of light weight concrete blended with leca and pumice in a variety of temperatures, respectively. It can be interpreted from the results that elevated temperatures is the reason of strength loss. Above 400°C, strength drop is faster by about 52.21% and 53.59% by the initial strength, respectively, while strength loss is not sharp at lower temperatures.

The replacement of cement by limestone powder increase the decrease in compressive strength after exposure to elevated temperature, this resulted by the dense micro structures which led to the build-up of high internal pressure during heating [36].



**Figure 11. a) Compressive strength variations at different temperatures for leca concrete (Mpa); b) Compressive strength variations at different temperatures for pumice concrete (Mpa)**

In presence of different temperatures, both types of concretes exhibit the similar strength loss, for concrete contains leca this amount is slightly more than that of a pumice based concrete in similar situations, which can be attributed to more fire resistance of its light weight aggregates. Care should be taken that in elevated temperatures more than 200°C, deviation from structural behaviour may be observed in both types of concretes specifically in leca concrete. Incorporation of powder limestone and micro-silica in concrete assumed to increase the compressive strength compared to the reference sample in high temperatures.

## 4. Conclusion

The following conclusions can be drawn from this study:

- High stable light weight concrete contains lime stone powder and micro- silica fitted to achieve as economic and environmental benefits as possible.

- Simultaneous partial replacement of cement with 5% powdered limestone combined with the same amount of micro- silica provide suitable mechanical and durability properties. While the optimal level of replacement in terms of durability properties of leca based light- weight concrete obtained 20%.
- Water absorption coefficient of specimens incorporated with 20% powdered limestone and w/c ratio of 0.37 was between 1.5 to 2.5%.
- The compressive strength of compounded concrete containing micro-silica and up to 20% powdered limestone decreased by 21% in pumice concrete, while increased up to 4% in leca concrete.
- Chloride ions penetration results found to be correlated with increased amount of powdered-limestone, such that 20% decrease in chloride ions penetration observed comparing to the reference sample.
- Durability tests results claimed that strength of concrete did not change significantly in contact with acidic solutions, such that the maximum strength loss obtained up to 12% comparing to normal solutions.
- Compressive strength appraisal of specimens exposed to temperatures over 200 °C indicated that the more the temperature was elevated, the more the strength decreased even up to 50% comparing to normal temperature (23 °C).
- Ideally, experiments and related studies regarding industrial wastes or supplementary materials have tried to prompt cement industry applying clean energy, and establishing sustainable development.
- Field experience with water absorption coefficient of specimens contains 20% powdered limestone and w/c ratio of 0.42 was between 1.63 to 2.53%.

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