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Mechanical and Durability Evaluation of Latex Modified Lightweight Concrete

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Abstract: Modified polymer concretes are popular materials in the construction industry due to their relatively high performance, versatility and stability compared to ordinary cement concrete. In this research, by adding three different latexes, including styrene butadiene rubber, ethylene vinyl acetate and acrylic latex, the mechanical and durability properties of Light weight concrete with Leca aggregates were measured. In this regard, 15 different mixtures are carried out in two laboratory programs. in the first stage, the effect of each latex with 5, 7.5 and 10% percentages with cement are investigated, and in the next stage, the simultaneous effect of latex with Microsilica. It was measured on the properties of lightweight concrete. The results showed that the addition of latex has a significant effect on increasing the durability factors of lightweight concrete several times. With the combination of 7.5% latex and 7% Microsilica, the best compressive strength has been recorded. By using latex, the flexural strength of concrete increased around 30%. Also, the passing charge of the lightweight concrete sample without latex is 4124 coulombs, while the sample containing 10% ethylene vinyl acetate passes 451 coulombs of charge.
Keywords: Lightweight concrete; Polymer modified concrete; Styrene butadiene rubber; Ethylene vinyl acetate; Acrylic latex; Durability.

1. Introduction

Lightweight concrete is considered a versatile material that has generated a lot of industrial interest and demand in a wide variety of construction projects in recent years. This concrete is lighter than normal concrete (normal weight aggregate) and is used in structures to minimize its total dead load. In addition, compared to normal weight concrete, it has low heat transfer and high fire resistance.

Using lightweight structural concrete instead of normal weight concrete can improve the structural efficiency of buildings. Lightweight concrete shows better thermal performance than conventional concrete and its use may significantly reduce energy consumption in buildings. Real et al [1] argued that the use of structural lightweight concrete in buildings can reduce heating energy consumption by 15% compared to normal weight concrete.

Lightweight concrete is classified based on the production method. These types are: a) Using lightweight aggregate with low specific gravity instead of aggregate with normal weight (the specific gravity of lightweight aggregate is less than 2.6. This type of concrete is known as lightweight aggregate concrete.) b) Creating an empty bubble space in Inside the mass of concrete or mortar. This type of concrete is known as aerated, cellular, foamed or gas concrete. c) Removing fine aggregate from the mixture so that coarse aggregate with normal weight is generally used.

Addition of light aggregates causes physical, mechanical and chemical changes in concrete. The most important changes caused by the addition of light aggregates are the loss of strength and durability of concrete. For this reason, in recent years, efforts have been made to compensate this loss of resistance and durability through various methods. To overcome these problems of concrete, both conventional and light, various additives are used to modify the mixtures such as pozzolans or polymer materials such as epoxy resins, natural polymers, etc [2, 3].

The results of past literature show that the use of polymers in concrete improves strength, efficiency, shrinkage and reduces porosity, which increases durability, which has been studied by researchers so far [4-7]. However, there are few studies on the use of polymer on lightweight concrete (LWC) [8]. On the other hand, there is environmental, economic and technical motivation worldwide to encourage the use of lightweight concrete [9, 10]. Lightweight concrete has been used for structural purposes for years. One of the most important things that should be considered in structural lightweight concrete is efficiency [11]. Due to the formation of a three-dimensional polymer network of hard concrete cement-based matrices, polymer concrete has high tensile strength, better plasticity behavior, and the ability to withstand impact and corrosive environments. For this purpose, the use of polymer materials as a replacement for the weight of cement with a suitable percentage can improve the properties of lightweight concrete, which can take advantage of both the lightness of concrete and its acceptable properties [12, 13]. Until now, there have been few articles on the effect of polymer on the properties of lightweight concrete [14-17]. In 2020, mechanical properties and permeability of concrete modified with hydrophobic agent were investigated by Liu et al [18]. In this research, three different polymers including styrene butadiene rubber, polyacrylic ester and organic silicone were used in order to investigate the resistance and permeation properties of chlorine ions. The results showed that the use of these latexes did not have much effect on the compressive strength, but it caused a significant improvement in the permeability properties of concrete.

According to the research of Bahranifard et al [19], styrene butyl acrylate was used as a modifier in the design of polymer modified concrete mix. The results showed that this additive reduced the compressive strength by about 10%, but the flexural strength increased by 30%. Also, SEM photos and microstructural analysis showed that by using this material, the porosity of concrete has been significantly reduced and increased its durability [19].

In 2019, Rezaei et al. [20] investigated the effect of styrene butadiene rubber on the mechanical properties and permeability of structural lightweight concrete. In this study, expanded clay aggregate was used to produce lightweight structural concrete and the specific weight was 1740 to 1780 kg/m3. SBR was added directly and indirectly based on concrete performance. According to the results obtained from this research, the compressive strength of concrete has not changed significantly, but its tensile and bending strength has increased.

In another study, Vahabi et al. [21] investigated the effect of lightweight aggregates with previous coatings in self-compacting concrete modified with latex. In this study, two types of lightweight aggregates, leca and scoria, were used along with a combination of poly vinyl acetate polymers and styrene butadiene rubber. The results of the mechanical and durability tests of this study showed that the use of these polymers significantly reduced water absorption in concrete and the compressive strength of the mixtures containing leca increased by about 21%.

Min Wang et al [22] used SBR and XSBRI latex as conventional alternatives to investigate the mechanism of cement modified with polymer latex. Chemical and physical interactions in cement system modified with polymer latex were investigated using DSC, FTIR, XPS and SEM. The latex layer covers the surfaces of the hydration crystals and fills the cracks and pores of the cement, so it can give better performance to the modified cement. Alternatively, these polymer latexes with functional groups can react with hydration products to form a three-dimensional network structure in the modified cement system, such as styrene butadiene carboxylic latex.

As it is clear from the mentioned materials, the examination of the resistance characteristics and durability of concrete modified with latex is one of the things that has not been investigated yet. Therefore, in this study, an attempt has been made to modify light weight aggregated concrete using three types of polymers: styrene butadiene rubber, polyvinyl acetate, and acrylic latex and check its properties. In the first phase of this study, the optimal percentages of each latex were obtained based on mechanical and durability tests. In the next phase, the effect of adding microsilica to mixtures with the optimal percentage of latex was also investigated.

2. Experimental design

2.1 Materials

2.1.1 Cement

In this study, type 1 Portland cement with a strength class of 42.5 MPa made by Tehran Cement Factory was used. The method of making and producing cements is based on ASTM 150 [23]. The chemical analysis of cement is shown in Table 1.

2.1.2 Microsilica

Due to having more than 90% silica in a non-crystalline state and in the form of fine particles with an average diameter of 0.1 micron, this material is highly pozzolanic and is very suitable for use as a cementitious material in concrete and complies with the ASTM C1240 [24]. The microsilica used in this research is manufactured by Vand chemistry Company, that chemical and physical properties are listed in Table 1 and Table 2.

Table 1. The chemical compositions of Cement and Microsilica

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	L.O.I
Cement (%)	20.35	4.6	3.5	65	1.94	2.45	0.8	0.35	0.95
Microsilica (%)	91.64	0.5	0.81	0.66	0.71	0.36	0.79	2.52	1.56

Table 2. Physical characteristics of used microsilica

Color	White
Specific surface($m/^2gr$)	23
Particles dimension(nm)	229
Particles shape	Spherical
Density (gr/cm^3)	1.9

2.1.3 Aggregate

Aggregate prepared from Tehran mines has been used for the laboratory program. The maximum dimension of aggregate is 9.5 mm with density and modulus of elasticity equal to 2600 kg/m3. Natural aggregates are graded according to ASTM C33 [25]. The grading curve of the natural aggregates mixture (green curve) according to the regulation limit is shown in figure 1.

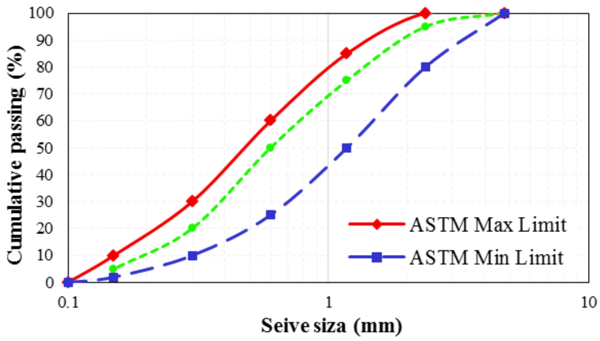

Figure 1. Aggregate grading used according to ASTM C 778 [26].

2.1.4 Lightweight Aggregate

The lightweight aggregate used in this research is of Leca type with 2 different grading in the range of 0 to 4.75 mm and 4 to 9.5 mm. The mass specific gravity of Leca is about 500-700 kg/m3. The technical specifications of these aggregate by the manufacturer are as follows. The specific gravity of Leca sand is between 911 and 1171 kg/m3. At the same time, the water absorption of Leca according to the ASTM C 127 [27] for 30 minutes, one hour and 24 hours is about 5.5, 5.8 and 9.4 percent.

2.1.5 Latex

In this research, three different latexes were used, namely styrene butadiene rubber, acrylic latex and ethylene vinyl acetate. These latexes, which have a liquid and milky appearance, are manufactured by the Armani Chemical Company, and their physical and chemical characteristics are specified in Table 3.

Table 3. Physical characteristics of latexes

	Styrene Butadiene Rubber	Acrylic latex	Ethylene vinyl acetate
Appearance	White milky liquid	White milky liquid	White milky liquid
PH	55.5	5.4-6.7	4.5-5.5
Density (Kg/m^3)	970-990	670-820	430-50
Film formation temperature	0	less than 5 degrees Celsius	less than 5 degrees Celsius

2.1.6 Superplasticizer

Usually, super-plasticizer is used when either the ratio of water to cement in the sample is low, or when additives are used that reduce the fluidity of mortar or concrete. The use of latex in concrete by itself causes a certain amount of fluidity due to the chemical reaction, but the samples without latex because the fluidity decreases and the appropriate amount of water does not reach all the samples, the cement hydration reaction is not complete and the materials it is not made of good quality. Therefore, super plasticizer was used to achieve a more homogeneous mixture with better performance [28]. The type of water reducer used in this research is carboxylic polymer based super plasticizer

2.2 Mix Proportions, mixing, casting and curing

The laboratory program has been carried out by making 15 mixtures. The first mixture was ordinary concrete with common aggregates, the second mixture was concrete without latex, but 50% of the aggregates were replaced with Leca aggregates. Next, 9 mixtures were made in order to investigate the effect of various latexes on structural light weight concrete and to find the optimal mixture considering the added value. In the next step, by making 5 mixtures and using microsilica as pozzolan, the effect of using pozzolanic materials and latex at the same time was investigated. It should be noted that the latex used as a substitute for cement with 5, 7.5 and 10 percentages, as well as light aggregates with 50% of the total aggregate used. The details of the mixtures produced are specified in Table 4.

Table 4. Mix Proportions

Mix Code	Latex Type	Cement	Latex	Water	Natural Aggregate	Lightweight Aggregate	Microsilica	Super Plasticizer
NC	-	500	0	200	1570	0	0	2.5
LWC	-	500	0	200	577	515	0	2
S5	Styrene Butadiene Rubber	475	25	200	577	515	0	0
S7.5		462	37.5	200	577	515	0	0
S10		450	50	200	577	515	0	0
E5	Ethylene-vinyl acetate	475	25	200	577	515	0	0
E7.5		462	37.5	200	577	515	0	0
E10		450	50	200	577	515	0	0
A5	Acrylic Latex	475	25	200	577	515	0	0
A7.5		462	37.5	200	577	515	0	0
A10		450	50	200	577	515	0	0
M7-L5	Ethylene-vinyl acetate	440	25	200	577	515	35	0
M8.5-L5		432	25	200	577	515	42.5	0
M10-L5		425	25	200	577	515	50	0
M7-L7.5		427	37.5	200	577	515	35	0

2.3 Test methods

2.3.1 Slump test

The slump test has been recorded according to ASTM C143 [29]. Due to the presence of variable parameters such as the type of aggregate, variable latex and the percentage of microsilica, it is difficult to control the slump and keep all mixtures stable, but it has been tried that the slump of the mixtures is above 10 cm. Table 5 shows the amount of slump as well as the fresh and 28-day specific weight of the mixtures.

Table 5. Fresh properties of mixtures

Mixture	Slump (mm)	Fresh density (Kg/m ^{3})	28 days density (Kg/m ^{3})
NC	165	2489	2354
LWC	155	1701	1633
S5	165	1686	1621
S7.5	175	1580	1501
S10	180	1610	1571
E5	170	1674	1590
E7.5	170	1621	1574
E10	185	1679	1602
A5	165	1736	1658
A7.5	180	1701	1627
A10	185	1680	1600
M7-L5	145	1740	1650
M8.5-L5	145	1794	1680
M10-L5	130	1825	1710
M7-L7.5	135	1796	1700

2.3.2 Compressive Strength

After Constructing and curing of the samples, in order to calculate the compressive strength at different ages of 1, 7 and 28 days, the compressive samples with dimensions of 150x150x150 mm have been tested according to the EN 12390-3 [30] by a 20-ton compressive strength machine which is shown in figure 2. For each mixing plan, the loading direction of the samples is in the direction of pouring the materials into the mold, and the method of calculating the compressive strength of the samples is obtained by dividing the amount of load on the surface of the sample.

Figure 2. Compressive strength device

2.3.3 Flexural strength

After making the Flexural beams in the dimensions of 100x100x500, the flexural strength at the age of 28 days with dry and wet processing was calculated using the following formula [31]. The flexural test apparatus is shown in the figure 3.

$$f_t = \frac{pl}{bd^2} \quad (1)$$

where F_t is the flexural strength in MPa, P is the maximum applied force shown by the device in newtons, L is the effective length of the beam in millimeters, b is the width of the beam in millimeters, and d is the height of the beam in millimeters.

Figure 3. Flexural strength device

2.3.4 Porosity

According to ASTM C642 [32], based on the Archimedes method a water batch containing the boiling water was used to measure concrete porosity. For this purpose, the saturated weight of the sample with dry surface ($W_{boiling}$) and the apparent weight of the sample immersed in water (Wa) have been measured. Then, the dry weight (Wd) of the sample was determined after being in the oven for 24 hours at a temperature of 100 ± 5 degrees Celsius. Sample porosity (P) is obtained using the following equation. The figure 4 Show the Porosity test device.

$$P = \frac{W_{boiling} - W_d}{W_{boiling} - W_a} \times 100\% \quad (2)$$

Figure 4. Porosity Test

2.3.5 Water absorption

This test is done to check the short-term water absorption of concrete. As can be seen in figure 5, first the samples for the durability tests are cored and then the samples are kept for 24 hours in a greenhouse at 100°C to evaporate the water inside. Then the samples are immersed in water for 30 minutes and then the water absorption rate is calculated by calculating the percentage of added weight with the sample.

Figure 5. Preparing samples for water absorption test

2.3.6 Electrical resistivity

In order to measure the surface resistance or specific resistance of conductors or semiconductors, a four-point probe device is used. Since resistance can affect series resistance, threshold voltage, capacitance and other parameters, measuring the resistance of semiconductor materials is one of the most common electrical tests. In this device, four probes with equal distances from each other are placed in contact with a sample whose resistance is unknown. The probes are located in a straight line and the first and last two probes are used as current sources and the middle two probes are used to measure voltage. Each probe is supported by an elastic spring that minimizes damage to the sample during measurement. In this device, a constant current is applied to the sample through the two farthest probes, and the middle two probes measure the potential difference or voltage drop between the two probes. The accuracy of measuring with a four-point probe device depends on factors such as the type and hardness of the sample, the type of probe, the surface of the sample, and the pressure of the probe [33]. The test method is shown in the figure 6.

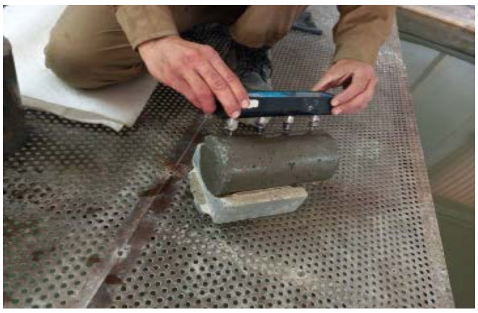

Figure 6. Electrical resistivity test

2.3.7 Rapid Chloride Penetration Test (RCPT)

This test, which is based on the ASTM C1202 [34], is a method for measuring the concrete resistance to chloride ion penetration. This test includes monitoring the amount of electric current passing through a 50 mm thick slice of the core or uses with a nominal diameter of 100 mm during a period of 6 hours. A potential mixing with a direct current of 60 V is passed through two ends of the specimen that one end of the specimen is immersed in sodium chloride solution and the other in sodium hydroxide solution. The total charge, in coulomb units, determines the resistance of the sample against chloride ion penetration.

$$Q = 900\ (I_0 + 2I_{30} + 2\ I_{60} + \ldots + 2\ I_{300} + 2\ I_{330} + 2\ I_{360}) \tag{3}$$

In this equation Q is the amount of charge passing through the device (Coulombs) and I is the amount of current (mA) at different time intervals of 30 minutes. The rapid chloride penetration test setup is shown in figure 7.

Figure 7. Chloride ion penetration measuring device

2.3.8 Capillary water absorption

Capillary water absorption test is a method to determine the rate of water absorption in concretes containing hydraulic cement, which is done by measuring the mass increase of the concrete sample whose one surface is exposed to water as a function of time. According to the figure 8, the sample is placed in an environment with standard relative humidity to provide constant humidity conditions in the capillary pore system. The desired surface of the test sample is immersed in water and mainly due to capillary suction, water infiltration occurs in unsaturated concrete in initial contact with water. This test was conducted according to the ASTM C1585[35].


Figure 8. Capillary water absorption Test

3. Results and discussions

3.1 Compressive strength

Figures 9 to 12 show the compressive strength of samples cured in the humidity room with a temperature of 25% and a humidity of 60% at the ages of 1, 7 and 28 days. Lightweight concretes made with light weight aggregates and polymer materials have lower compressive strength than normal concrete. According to the American Concrete Association standard, lightweight structural concrete must withstand a minimum compressive strength of more than 18 MPa at the age of 28 days. Results showed that approximately all designs containing polymer materials and light weight aggregates are in this range. For example, figure 9 shows the compressive strength of samples made with styrene butadiene rubber. The 28-day strength of normal concrete is 50 MPa and lightweight concrete without polymer materials is 25 MPa. The best compressive strength was recorded at the age of 28 days with the addition of 7.5% of the weight of styrene butadiene rubber at 26.7 MPa, which is an acceptable compressive strength.

As can be seen in figure 10, the best compressive strength of lightweight concrete containing polymer materials with the addition of 5% ethylene vinyl acetate is equal to 27.5 MPa, which is a 10% increase in compressive strength compared to the lightweight sample without polymer. On the other hand, the use of acrylic latex in lightweight concrete has caused a very small decrease in compressive strength. However, this reduction in resistance in the lowest state is equal to 22.3 MPa, which still is acceptable.

Due to the nature of polymer materials and the small effect they have on compressive strength, if these materials are mixed with pozzolanic materials such as Microsilica, they can improve the compressive strength. Considering that ethylene vinyl acetate has given the best results compared to other polymer, in this research, this polymer material was combined with different percentages of microsilica and the results are shown in figure 12. As it is known, the compressive strength has increased significantly by adding microsilica to concrete containing 5% latex. In this way, the compressive strength has reached 29, 30.3 and 35 MPa from 25 MPa with the addition of 7, 8.5 and 10% Microsilica. On the other hand, with the combination of 7.5% latex and 7% Microsilica, the best compressive strength has been recorded, which is equal to 37.5 MPa, which has increased the compressive strength by about 50%. Of course, it is necessary to mention that at the age of 1 and 7 days, this composition has shown a lower compressive strength than other compositions, although its strength is insignificant, which can be due to the different processing of polymer materials and pozzolanic materials.

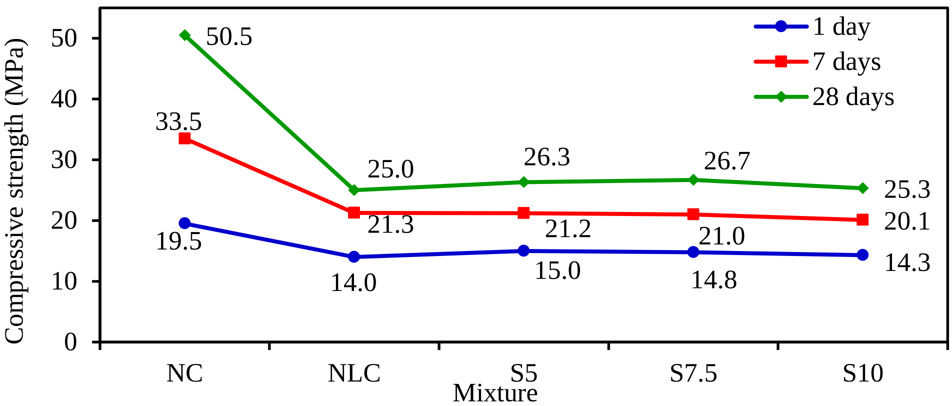

Figure 9. Compressive strength of samples made with styrene butadiene rubber

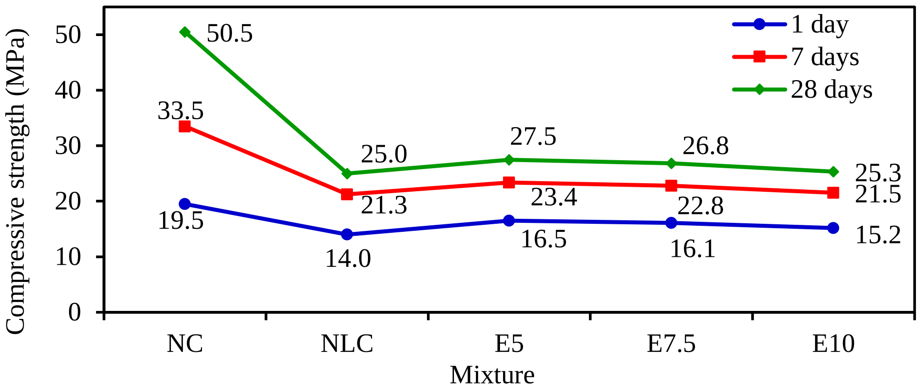

Figure 10. Compressive strength of samples made with Ethylene vinyl acetate

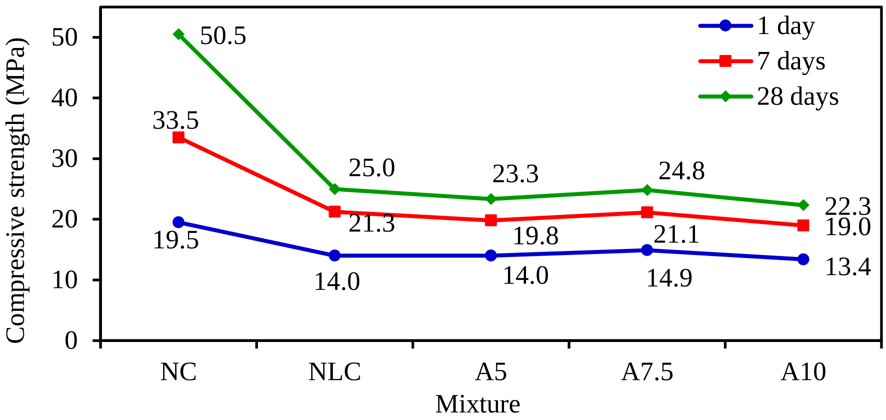

Figure 11. Compressive strength of samples made with acrylic latex

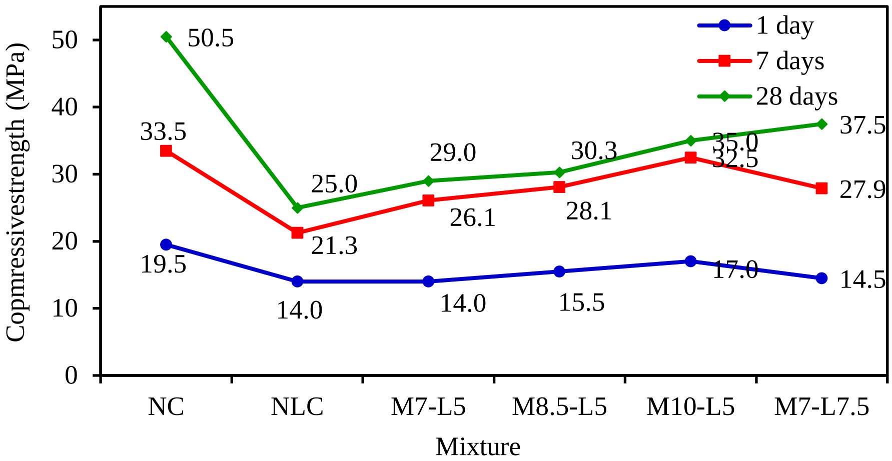

Figure 12. Compressive strength of samples made with combination of Microsilica and latex

3.2 Flexural strength

Flexural strength is one of the most important properties of concrete structures. This feature is especially important in members like roofs and beams. The results of bending strength of 28-day samples using flexural beams are shown in figure 13. The results showed that the use of polymer materials (latex) in the concrete mixtures significantly improves the flexural strength. The samples of normal concrete and lightweight concrete without additives have shown bending strength equal to 2.4 and 1.8 MPa, respectively. While the use of latex has improved at least 30% compared to normal concrete and 70% compared to lightweight concrete. Ethylene vinyl acetate was obtained the best result in compressive strength, the use of this additive had the greatest effect on flexural strength, so that the use of 5, 7.5 and 10%, respectively, flexural strength was 3.8, 4 and 4.8, which due to the lightness of concrete and specific weight of about 1700 kg/m3, these resistances are excellent and suitable for prefabricated structures [36].

The results of figure 11 show that the use of latex and micro silica together in concrete improves the compressive strength. This increase is less than the samples containing only latex, which do not contain microsilica. Although microsilica improves the hydration reaction, using it together with latex causes the latex to not fully react and set.

3.3 Water absorption and porosity

The durability factor is one of the most important factors in concrete structures, especially in corrosive environments where concrete is destroyed quickly and the structure must be rebuilt, which involves huge costs, or the structure must be repaired. Therefore, building a structure with high durability can significantly reduce the cost of reconstruction or maintenance. The most important factor that causes the destruction and corrosion and as a result the weakening of concrete structures is the penetration of water or corrosive factors into it. This penetration is done through the pores in the concrete. The reaction of hydration and water present in concrete before setting causes porosity and holes in concrete. In addition to the presence of holes in concrete, the channels that connect these holes are also important and the cause of concrete failure sooner. Therefore, by reducing the porosity and as a result, reducing the permeability of the fluid in concrete, its durability can be significantly reduced. One of the ways to reduce surface porosity and prevent fluid penetration into concrete is to use epoxy on the surface of the structure and its so-called waterproofing.

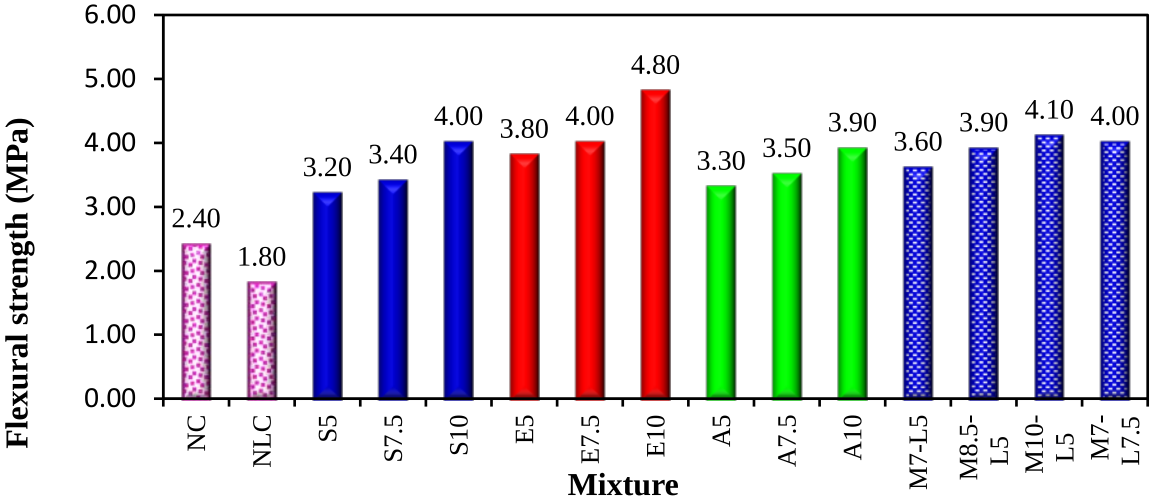

Figure 13. Flexural strength of samples made with latex and Microsilica.

Figures 14 and 15 show the results of porosity and water absorption for half an hour of samples containing latex and Microsilica, respectively. The results of the porosity test with the Archimedes method show that the use of latex has significantly improved the porosity and reduced it. Normal concrete and normal lightweight concrete show porosities of 9.2 and 12.2, respectively. While the use of ethylene vinyl acetate latex has reduced this porosity to a third and even less, so that the use of 5, 7.5 and 10% of this latex has the porosities of 4.81, 4.15 and 73, respectively. On the other hand, the simultaneous use of Microsilica and ethylene vinyl acetate has further reduced the porosity, and the use of 10% Microsilica along with 5% latex has shown a porosity of 3.15, which can have a constructive effect on durability.

When concrete is placed in the presence of a fluid such as water or sea water, the rate of water penetration is higher in the first hour because the concrete surface has more porosity and water penetrates the surface more easily. Although the water does not penetrate into the center of the concrete structure, it causes damage and corrosion in the surface layer of the structure and penetrates into the depth of the structure layer by layer until the structure loses its function. Therefore, if water absorption can be reduced in the early hours, this damage can be stopped or postponed. According to the code of recommendations for concrete reliability in the Persian Gulf, the short-term water absorption (half an hour) of concrete in a corrosive environment should not be more than 2%. figure 15 shows the results of this experiment. Ordinary concrete and lightweight concrete without latex have water absorption of 3.54 and 12.4%, respectively, while samples containing latex or a combination of latex and micro silica, except for a few mixtures, all show water absorption of less than 2%. This requirement of the regulation has been fulfilled. On the other hand, as the results show, the use of micro silica along with latex has improved short-term water absorption and reduced it by 1.57%, which will have a great effect on the durability of concrete structures, especially in corrosive environments.

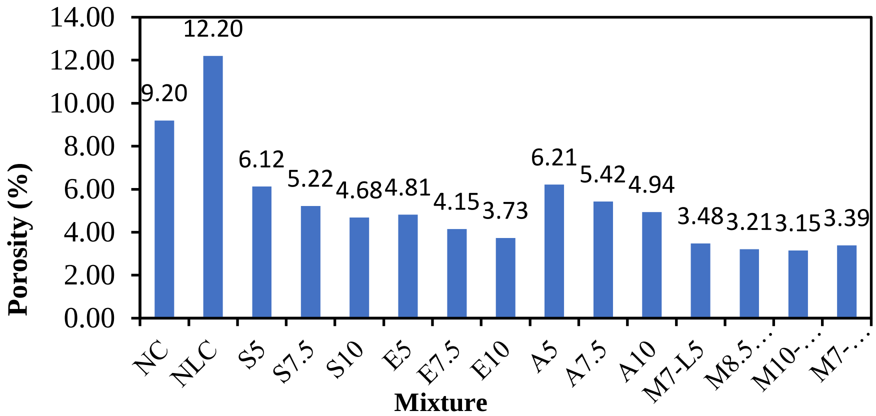

Figure 14. The effect of polymer materials and Microsilica on the porosity of lightweight concrete.

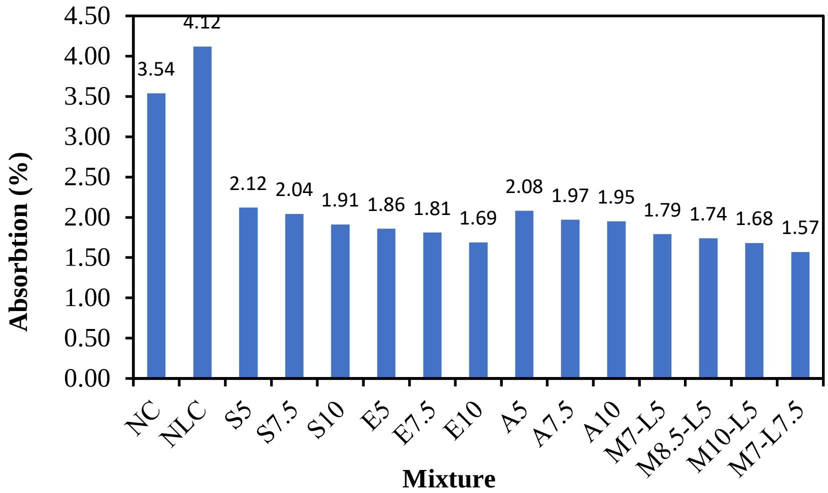

Figure 15. The effect of polymer materials and Microsilica on half-hour water absorption of lightweight concrete

3.4 Capillary absorption of water

In most corrosive environments, the performance of concrete is largely a function of its capillary permeability. In unsaturated concrete, the penetration rate of water or any other liquid is often controlled by fluid absorption due to capillary rise. This test is to determine the rate of water absorption (capillary absorption) in concrete containing hydraulic cement, which is done by measuring the increase in mass of a concrete sample with one surface exposed to water as a function of time. According to ASTM C1585 standard, the rate of water absorption in the samples that are in the corrosive environment should be less than one millimeter per squared time (per hour) of capillary absorption. figures 16 to 19 show the capillary water absorption rate of samples containing latex and the combination of latex and micro silica. As can be seen in the graphs, concrete samples include two primary and secondary absorption rates, which can be obtained from the diagram. As you can see, the primary absorption rate is much higher than the secondary rate and its importance is also high. According to the obtained results, it was demonstrated that the light weight concrete without latex has the highest capillary absorption rate, followed by normal concrete, compared to the rest of the designs. But with the use of polymer latexes, this rate is greatly reduced. The lightweight concrete sample has shown a high absorption rate due to the presence of Leca aggregates, but when latex is added to this concrete, this material covers the surrounding aggregates, especially light aggregates with high absorption, and prevents absorption. They are above the water, which is sealed from the inside by modifying the concrete. Among the three types of latex used, ethylene vinyl acetate has the best positive effect on capillary absorption rate, and the design containing 7.5% of this latex recorded the lowest rate compared to other designs. The noteworthy point is that the use of more than 7.5% latex has a negative effect on capillary absorption, which shows that excessive use of latex can reduce its positive effect on durability properties. Figure 19 shows the capillary absorption of samples containing micro silica and latex, which, as expected, due to the synergistic effect of latex and micro silica, capillary absorption is more improved than the use of latex alone.

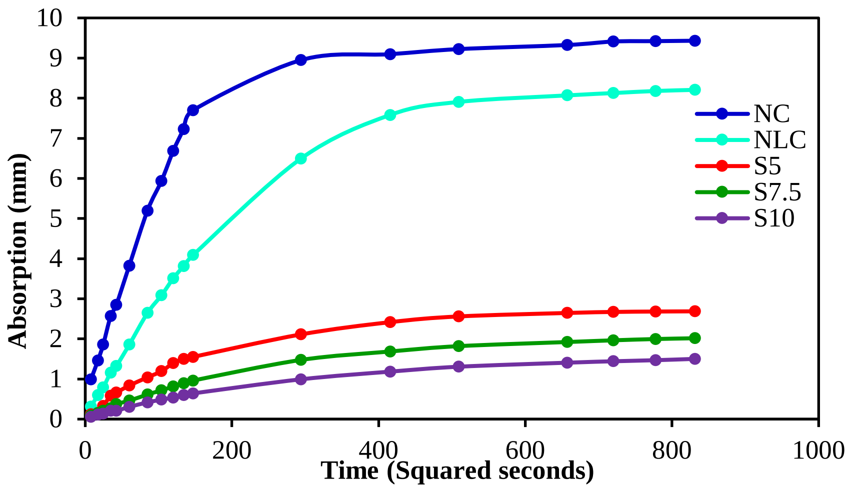

Figure 16. Water absorption of samples made with styrene butadiene rubber.

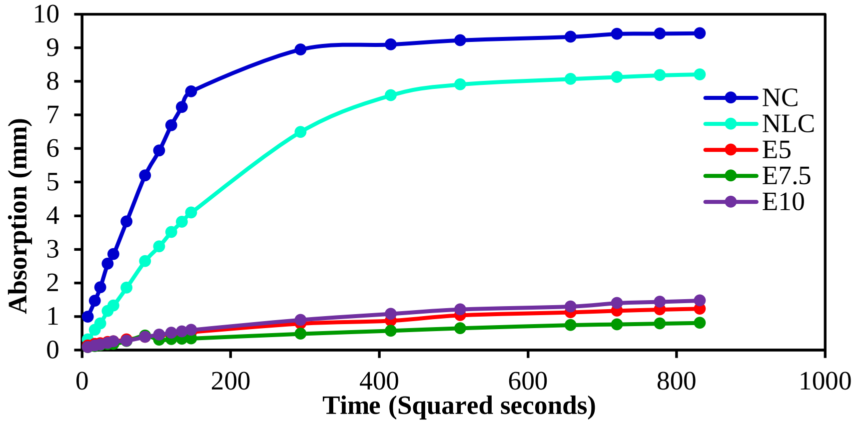

Figure 17. Water absorption of samples made with ethylene vinyl acetate.

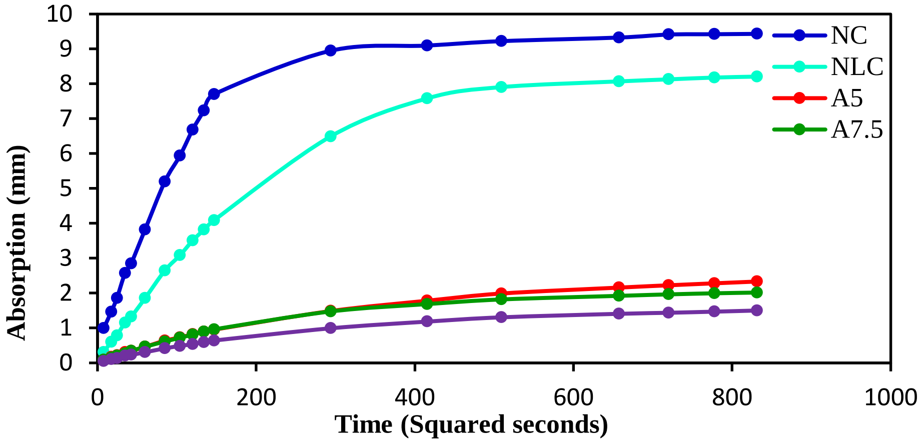

Figure 18. Water absorption of samples made with acrylic latex.

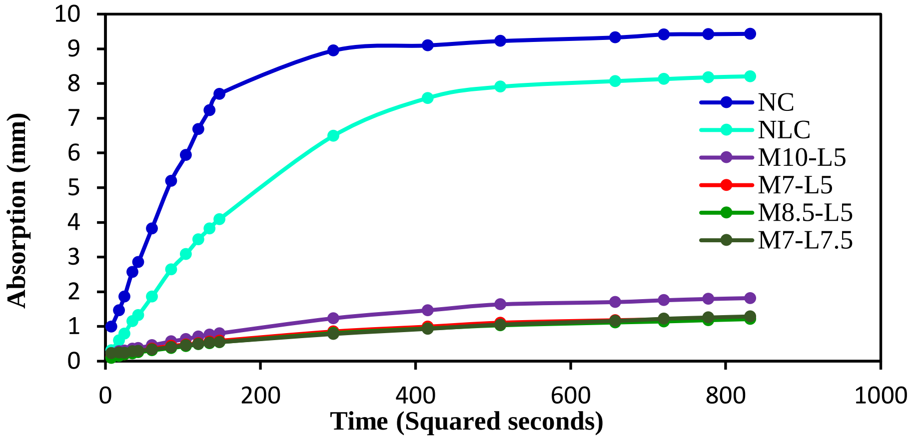

Figure 19. Water absorption of samples made with latex and Microsilica.

3.5 Electrical resistivity of concrete and RCPT

Concrete deterioration may be caused by chemical, physical and environmental effects on the concrete itself or damage caused by the corrosion of rebar in it. The characteristics of materials and conditions that are resistant to this damage, or effective in its extent, should be investigated. The main causes of concrete disintegration are: sulfate attack, alkaline reaction of aggregates, melting and freezing, wear and fire. Armature corrosion is an electrochemical process that requires the presence of moisture and oxygen. Therefore, the presence of moisture and its ability to enter concrete and move in it are important characteristics, because both sulfate and chlorides need moisture to carry out reactions and cannot be effective in dry concrete, so tests that measure water absorption and permeability are evaluated, considering the durability and reliability of concrete, they are very important. The electrical resistance of concrete is a suitable indicator for evaluating the permeability of concrete and its resistance to chloride ion penetration. This test is performed by passing an electric current through the concrete sample and measuring the resistance of the sample. Since this test is performed for saturated samples with a dry surface, if the electrical resistance is low, it indicates that there are many holes and connections in the sample, and there is water in these holes. But if the electrical resistance is high, it indicates the presence of less water, which is caused by the low porosity and holes inside the sample. The American Concrete Association has proposed values for the amount of electrical resistance and its relationship with the possibility of concrete corrosion, which can be seen in Table 6.

Figure 20 shows the electrical resistance of the mixtures. As the results show, the use of latex has increased the electrical resistance several times, which indicates a significant reduction in the probability of failure in corrosive environments. Also, the use of Microsilica and latex at the same time has increased the electrical resistance up to 512kΩ.cm [37].

In addition to the electrical resistance test, it is possible to measure the amount of passing charge in the presence of chlorine ions in concrete by using the chlorine ion penetration test (RCPT). The results of this test should be different from the electrical resistance test, because in this test, the amount of charge passing through the concrete sample is measured. The lower the charge, the lower the porosity and the better durability of the sample. Based on Table 7, the resistance of concrete against chloride permeability can be determined.

The results of chlorine ion permeability test for the samples are shown in figure 21. As can be seen, the results of this test have an opposite relationship with the electrical resistance test, which means that the higher the electrical resistance, the lower the amount of charge passing through the sample. As expected, the addition of polymer materials to lightweight concrete samples has significantly reduced the penetration of chlorine ions. For example, the passing charge of the lightweight concrete sample without latex is 4124 coulombs, while the sample containing 10% ethylene vinyl acetate passes 451 coulombs of charge, which according to Table 7, the permeability of chlorine ions is very small. On the other hand, mixing latex and Microsilica has improved the permeability even further, to the point where the charge has decreased up to 264 coulombs.

Table 6. Correlation between electrical resistance of concrete and possibility of corrosion.

Surface Resistivity Test($_{k\Omega\text{-}cm}$)	< 12	$12 - 21$	$21 - 37$	$37 - 254$	$254 <$
Chloride Ion Penetration	High	Moderate	Low	Very Low	Negligible

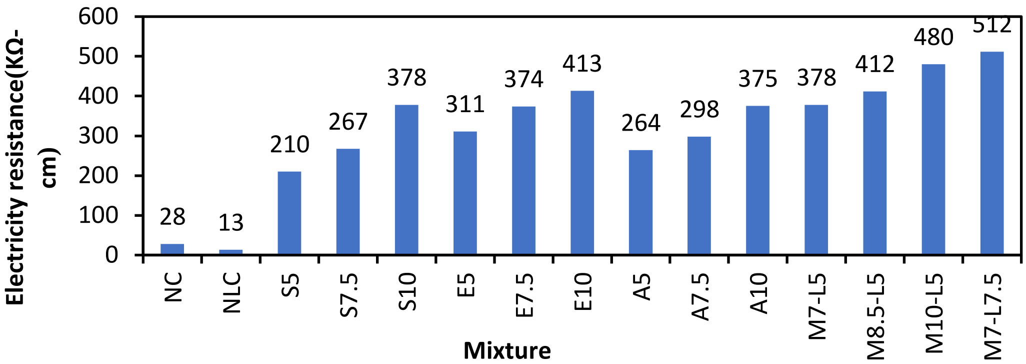

Figure 20. The effect of polymer materials and Microsilica on the electrical resistance of lightweight concrete.

Table 7. Correlation between Charge Passing and Chloride Permeability

Charge passing coulombs	$4000 <$	$2001 - 4000$	$1001 - 2000$	$100 - 1000$	< 100
Chloride permeability rating	High	Moderate	Low	Very Low	Negligible

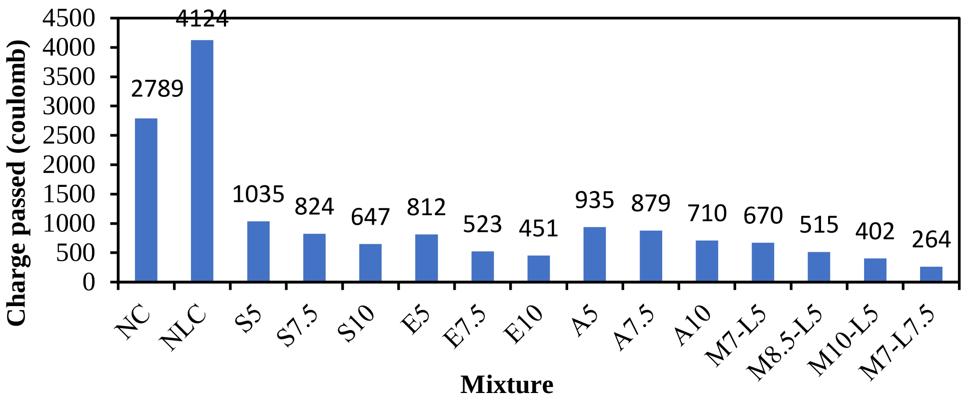

Figure 21. The effect of polymer and Microsilica materials on the penetration of chlorine ions in lightweight concrete.

4. Conclusion

In this research, the effect of three different polymer latexes including styrene butadiene rubber, ethylene vinyl acetate and acrylic latex on the mechanical and durability properties of structural lightweight concrete was investigated. The results of this research are summarized as follows:

1) Polymeric materials did not have a great impact on the compressive strength, so that the increase in strength for lightweight concrete containing latex compared to lightweight concrete without latex was less than 5 MPa.

2) The samples of normal concrete and lightweight concrete without additives have shown bending strength equal to 2.4 and 1.8 MPa, respectively. While the use of latex has improved at least 30% compared to normal concrete and 70% compared to lightweight concrete.

3) Ordinary concrete and lightweight concrete without latex have water absorption of 3.54 and 12.4%, respectively, while samples containing latex or a combination of latex and micro silica, except for a few designs, all show water absorption of less than 2%.

4) The use of latexes has improved the durable properties of the coating, porosity and short-term water absorption, which has reduced the porosity to one-third and the short-term water absorption to half of the case where polymer materials are not used. It has also reduced the rate of capillary water absorption, which is one of the most important criteria in the durability of concrete, up to eight times.

5) The electrical resistance of samples containing 7.5% latex had the highest resistance compared to mixtures without latex, so that the sample containing 7.5% ethylene vinyl acetate 413 had the highest value, which was 10% more than acrylic latex and styrene butadiene.

6) The main thing that should be noted in the use of polymer latexes is the increase in their cost. According to the results obtained from this research, it showed that despite the two-fold increase in the production of lightweight concrete modified with polymer, this increase will reduce costs such of, maintenance and reconstruction costs, which in the long run It brings significant added value.

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