Micronised Silica Effects on Concrete of Substations

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Abstract
Concrete is by far the most important building material in the world. Worldwide, more than 10 billion tons are produced each year. Electrical infrastructures also possess a considerable proportion. Some researchers suggest a limit of aggregate replacement by weight in order to maintain the standard requirements of 5% of absorption capacity for aggregates in structural concrete. Micronised silica is a potentially available resource that was used as an aggregate replacement in this research. As a result, because of its filler characteristic it can decrease the porosity of concretes.
Tests were carried out in order to evaluate the mechanical properties and the durability of this concrete. The main effects of Micronised silica fillers are because of their physical nature. Tests include compressive strength, electrical resistivity, and modulus of elasticity. Moreover, in order to reach constant workability, polycarboxylate base super plasticizers were used. It causes a better packing of cement granular skeleton and a larger dispersion of cement grains.
Results show that the replacement of aggregate with Micronised silica in concrete not only may increase the mechanical properties of concrete but also decrease the amount of consumed aggregate in construction projects as well.

1. Introduction

Concrete, with the annual per capital consumption of around one ton, is the most commonly utilized material in human societies after water. Therefore, performing studies on concrete properties is of promising significance for engineers and researchers. Some of the applications of concrete include the necessary material for building structures such as dams, pavements, and civil projects. Concrete is often produced by blending Portland cement, sand, aggregate, and water. Only in 1992, 500 million tons of concrete was produced in the United States [1]. Lamp posts and other structures are applied which bear the loads of electrical facilities distributed throughout roads and cities are no exception for the vast applications of concrete materials. Although a considerable proportion of lamp posts are constructed from metal structures, the role of concrete materials in their construction cannot be ignored. The need for electrical energy in human societies has paved the way for the utilization of various electrical equipments which in turn, calls for the development of special infrastructures, a significant example is load transmission equipments needed for any facility complex. Water is the most commonly used material by humans, the most abundant matter in the earth's crust and the basic cause of creation and destruction of natural materials [1]. The small size and high reactivity of water molecules account for its easy penetration in porous materials. Along with being a major physical factor in the reduction of quality, water is where the exchange and transmission of many ions takes place. This causes concrete quality to decline. The corrosion phenomenon and concrete destruction takes place in the presence of water and in a situation where the interaction between water and concrete is not disturbed; this is because this subject is quite costly and in some cases impractical. Today, the costs imposed by corrosion and destruction of structures are comparable to the costs of wars, and that implies the increasing significance of structure protection against corrosion and destruction, and sustained development and economy are some of the main motivators for the human being toward this target. The end point for the exploitation life of a structure is marked by the fact that its use is either unsafe or uneconomical, thus most structures undergo destruction and subsequently sudden life termination, under some specific load transmission conditions named “ultimate strength limit”. The durability factor is a factor which influences the lifetime of concrete structures, and is defined by long-term exploitation in a specific environment; gradual destructions due to undesired conditions have been studied by researchers. As mentioned above, environmental destructions of concrete are mainly brought about by the presence of water, and are divided into physical and chemical mechanisms. Physical destructions such as freezing and melting cycles along with the erosion of surfaces have been long studied. What has been the main focus of the researchers of concrete durability, due to the vast damage brought about, chemical destructions have two main origins: one is the excessive expansion of one concrete component, owing to chemical reactions, which leads to the destruction of the nearby network, and the other origin is the reactions that demolish the useful hydratation products. In the first type, the solution of active ions in water and provision of reactivity in this environment which easily penetrates through the concrete causes numerous problems such as armature oxidation, expansive reaction of reactive aggregates, and expansive reaction of insoluble products left by the exchange of aggressive ions with hydratation products. The second type includes all ion exchanges which lead to demolition of C-S-H gels and useful ettringites and formation of soluble products. Against such threats, two major methods have been introduced to control the permeability of the concrete and eliminate some potentials and mechanisms in it. The studies reveal the higher significance of the permeability control [2]. An issue which has been recently studied, to improve the physical properties and durability of concrete, is the use of filler materials. Addition of fine powders, taking advantage of super lubricants, considerably improves the concrete behavior, which can be applied as fillers to treat the pores and reduce porosity owing to the small size of these particles [3]. Different fillers can be employed in different applications. For instance, among nonpozzolan fillers, limestone and dolomite powders are mostly applied to self compacting concrete [4]. Furthermore, replacement of plaster present in pozzolan concrete with fine calcic particles as filler modifies hydratation rate and the consequent heat [3,5]. Moreover as condensation process continues, tiny filler particles improve the condensation of transition zone along with more and more condensation of the adhesive [6-8]. Due to the smaller size, the filler grains possess a stronger transition zone compared to the aggregate. In addition, the seepage of the exploited silica (diorite) is equivalent to completely hydrated cement with a water to cement ratio of about 0.42 and is considered as a very low diffusive aggregate [1]. In 1958, researchers presented a diagram demonstrating the relations between permeability, strength, and porosity [9]. In this study, Micronised silica has been exploited as the filler in the concrete materials used in lamp posts and electricity transmission and distribution infrastructures, and its effect has been studied through the mentioned diagram and a series of experiments. Silica, with the chemical formula of SiO_2, is the most abundant chemical compound in the earth's crust. Quartz is one of the poly-amorphs of silica which is stable in normal conditions of pressure and temperature; therefore, the silica is freely found in nature in the form of quartz. The material for the experiments have been provided through the Tahmasbabad silica mine, located in the rural area around Soltanieh, Abhar in the Zanjan Province, Iran; whose applications had previously been confined to abrasives, casting sand and glasswork. In order to produce Micronised silica, the silica ore extracted is modified, in the stages of crushing, milling and jet milling, into materials passing through a sieve with the grade of #200. Figure 1 presents Micronised silica and Figure 2 depicts Micronised silica particles shot by SEM microscope.

Figure 1- Micronised silica

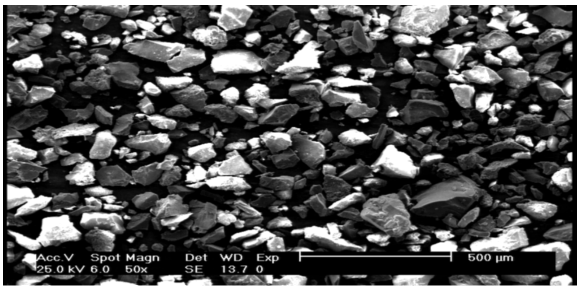

Figure 2- Microstructure of Micronised silica

Aggregation diagram of Micronised silica and the cement used are illustrated in Figure 3. Besides, the chemical properties obtained from the XRF experiment of the Micronised silica are presented in Table 1. In addition, the results of the XRD experiment depicted in Figure 4, is also indicative of the crystal structure of the materials in use which prohibits the pozzolanic characteristics from emerging, and also results in a lack of reactivity with cement.

In the geographical regions close to the mine where extraction was carried out in Turkey and from the Keciborlu Mine in Isparta, a Micronised silica has been produced which has been claimed by Davraz and Gunduz to have an amorphous structure, while the result of their experiment conveys a decrease in the strength of the mortar [10]. Also regarding Table 1, the percentage of Na_2O is below the maximum stated amount in the ASTM C1240-03 standard (the amount equals 1.5%) and thus, there is no such threat of the aggregate alkaline reaction phenomenon (concrete cancer).

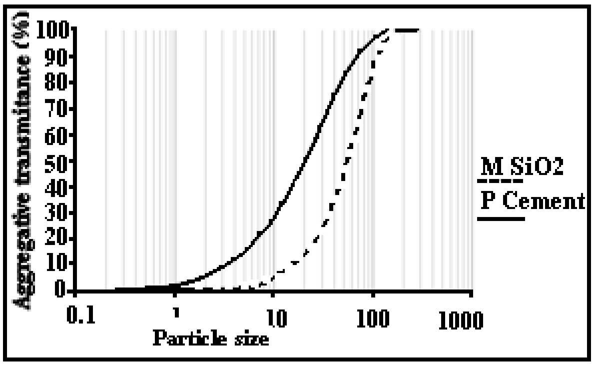

Figure 3- Particle sizing of Micronised silica and consumed cement

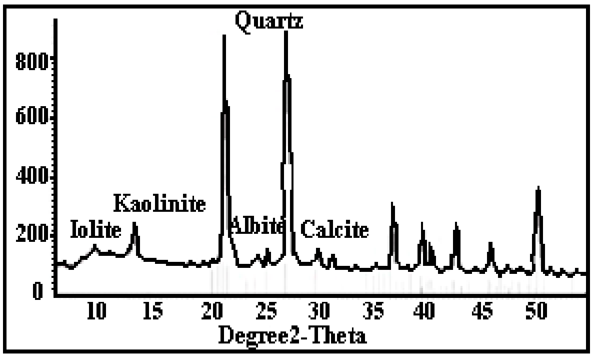

Figure 4- XRD test of Micronised silica

Table 1- XRF analysis

SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	K_2O	P_2O_5	TiO_2	LOI
88.8	4.5	0.43	2.24	0.088	0.19	0.051	0.82	0.04	0.31	2.36

2. Materials and experiment methods

In order to test changes in some of the mechanical features and endurance of the concrete, samples of concrete were made by replacing the aggregate with Micronised silica (filler properties investigation).

In the process of replacing the aggregate, samples were categorized in two general strength ranges (caused by different aggregation). In the strength range of below 40MPa (at the age of 28 days), four mixtures were made and the difference lied in the percentage of the aggregate replacement with Micronised silica. In the strength range of around 50MPa (at the age of 28 days), five mixtures were made and again the difference lied in the percentage of the aggregate replacement with Micronised silica. This fact is shown in Table 2 by pattern A, and also the batch number is written next to the English letter. The replacement percentage is indicated in front of each letter. For instance, 2A-10 denotes a ten percent replacement of the aggregate by the Micronised silica in the second batch. The dimensions of the samples built for experiment are as follows:

Compressive strength test: cubic sample 10×10×10

Nondestructive ultrasonic test: cubic sample 10×10×10

Nondestructive electrical resistance test: prismatic sample

30×7.5×7.5

Some of the samples were shown in figure 5.

Figure 5- Built samples

The concreted samples remained in the mold for 12 to 24 hours while their surface was constantly kept moist. After removing from the mold, the samples were saturated in processing conditions and inside a lime environment and were exposed to an average temperature of around 22 to 26 degrees Celsius. The mixtures made based on the absolute volume method according to Table 2. As it can be seen from Table 2, the ratio of water to cement has been considered lower in the stronger plan in order that the strength changes in the two strength ranges are comparable.

3. Tests and results

3-1. Compressive strength tests

The compressive strength experiment is one of the frequently used, most similar and most precise experiments in investigating the characteristics of the concrete. This experiment was performed on the samples in which Micronised silica had replaced aggregate. The results can be viewed in Figure 6 for the first batch including samples having the control sample with stated aggregation in Figure 7 (strength average of below 40 MPa), and at the ages of 7 and 28.

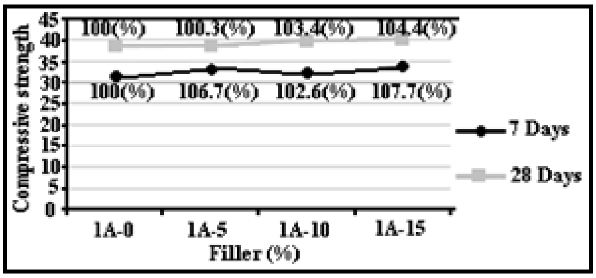

Figure 6- Results of compressive strength of first batch

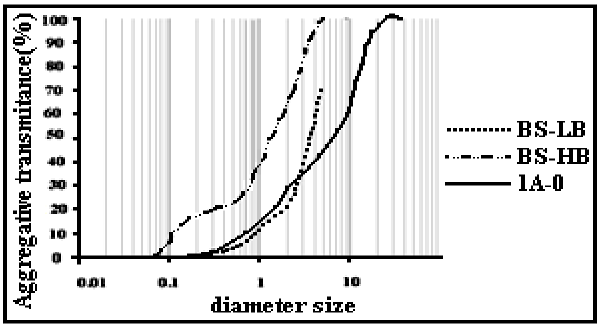

Figure 7- Grading curve of control sample of the first batch

Table 2- Mix designs

Mix name	Micronised silica (Kg/m^3)	W/C	Aggregate			Cement (Kg/m^3)	Superplasticizer (Kg/m^3)
			Corse gravel (Kg/m^3)	Fine gravel (Kg/m^3)	Sand (Kg/m^3)		
1A-15	600	0.4	517	345	854	400	2
1A-10	400	0.4	523	349	864	400	3
1A-5	200	0.4	528	352	873	400	6
1A-0	0	0.4	534	356	883	400	0
2A-20	710	0.45	343	515	859	375	10
2A-15	563	0.45	346	520	866	375	9
2A-10	375	0.45	350	526	876	375	8
2A-5	187	0.45	354	531	885	375	5
2A-0	0	0.45	357	543	894	375	0

With regard to inspecting the effects of filler, only those parts of aggregation diagram which vary widely with replacement percentage of filler are adapted to the BS standard range. Besides, the diagram of aggregation changes caused by aggregate replacement by Micronised silica can be observed in Figure 8.

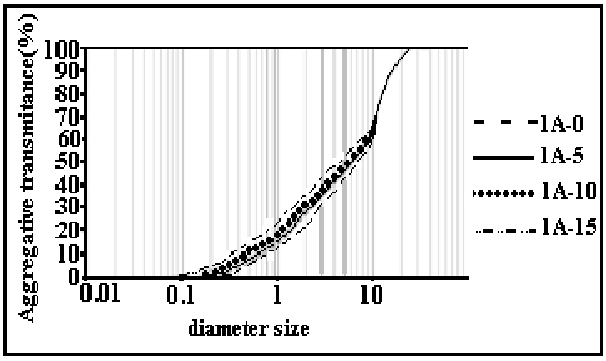

Figure 8- variation of aggregate grading of first batch

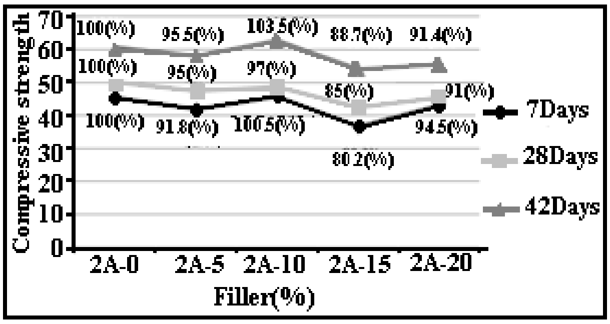

Figure 9- Results of compressive strength of second batch

The results in the first batch (average strength of below 40MPa) indicate an increase of strength as the replacement percentage increases.

As it can be seen, at the ages of 7 and 28 days, a sample with 15% replacement of aggregate by Micronised silica has the highest strength, where at the age of 7 days, the amount of growth of the strength compared to the control sample is 107.5% and at the age of 28 days the above-mentioned amount is 104.5%. Also in Figure **9**, results of compressive strength experiment can be seen, at the ages of 7 and 28 and 42 days for the second batch including samples having control sample with stated aggregation in Figure 10 (strength average of around 50 MPa).

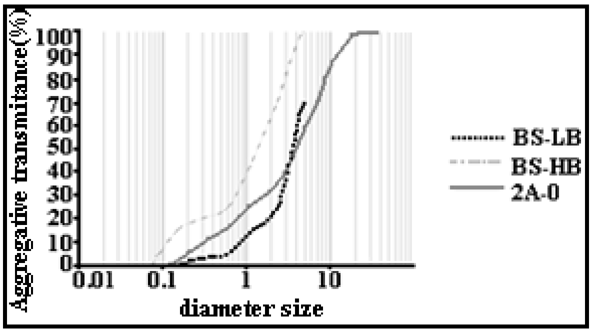

Figure 10- Grading curve of control sample of the second batch

The results in the second batch (strength average of around 50MPa) indicates a decrease in strength where control samples have the highest strength and as the replacement percentage of aggregate by Micronised silica increases, the strength decreases gradually. The diagram of aggregation changes, caused by replacement by the Micronised silica can be viewed in Figure 11.

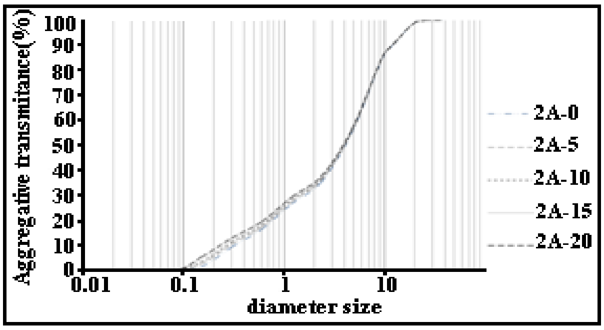

Figure 11- variation of aggregate grading of second batch

3-2. Ultrasonic tests

One of the approaches for non-destructively measuring the compressive strength and predicting the elasticity module of the concrete sample is the ultrasonic device. This device works by sending ultrasonic mechanical waves from one probe and receiving them through another probe and then calculating the velocity of the waves from the medium between the two probes. Based on this and regarding the recommended standard by the research center of the Ministry of Residence and Urban Planning of Iran, we can predict the values of the elasticity module and the compressive strength. To this end, four sides of the 10×10×10 samples each of which is perpendicular to another, were lubricated and tested by means of the probes of the ultrasonic device. Based on the values obtained from the average velocities caused by this experiment, prediction of results for the elasticity module in the second batch of the samples in which Micronised silica has been replaced by their aggregate, is shown in Figure 12.

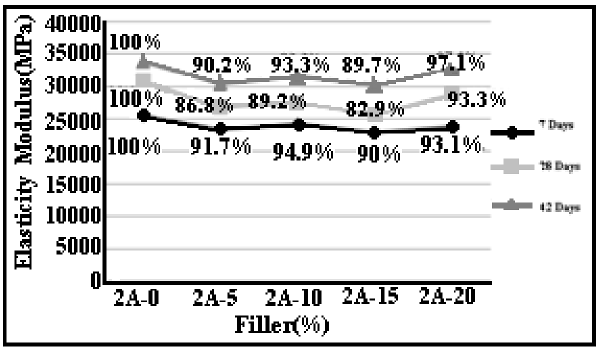

Figure 12- Elasticity module forecasted by the ultrasonic device for the second batch

As it can be observed, these results confirm the results of the compressive strength experiment to a good extent.

3-3. Electrical resistance tests

The ions which have penetrated into the concrete move through the pores inside the concrete structure and therefore, concrete has electrical conductivity. The electrical resistance of the concrete depends directly on its permeability and environmental conditions (the amount of penetrating ions and the concrete moisture). Certainly, the more the permeability of the concrete, the more easily and the more rapidly the ions can move into the concrete environment. The more penetrating ions, the less the electrical resistance of the concrete will be. Hence, the concrete with high electrical resistance has better performance in terms of chloride penetration and the start of their armatures corrosion which leads to its decay, compaered with concrete with low electrical resistance. The more chloride enters concrete, the less the electrical resistance. When measuring electrical resistance, the electrical resistance of the concrete on the armature is usually considered. The devices used for determining the potential or the corrosion intensity can also be used to measure the electrical resistance and by doing so, we can determine the possibility of corrosion in the structure. The main reason for the presence of the armatures in lamp posts is their long length. Since the tensile strength and therefore, the bending strength of concrete is very low, the compressive load caused by the weight of the posts and electrical equipment is not much; the main concern for the sudden failure of concrete structures is due to the lateral loads which cause a great bending, because of the long lengths of the posts. In order to prevent the failure of the mentioned structures because of the stated loads, armatures are installed in the lamp posts lengthwise. To this purpose, a resistance measurement is performed on each 30×7.5×7.5 sample from four sides using the probes of the electrical resistance device and the average of the results is presented as electrical resistance. In case the electrical resistance is more than 12 kilo ohms per centimeter, there is no possibility of corrosion, and in cases where it is less than 5 kilo ohms per centimeter, corrosion definitely exists and any value in between these two implies a possibility of corrosion. Figure **13** indicates the results of the concrete samples electrical resistance. As observed in Figure **13**, as the replacement percentage of aggregate by Micronised silica increases the electrical resistance decreases.

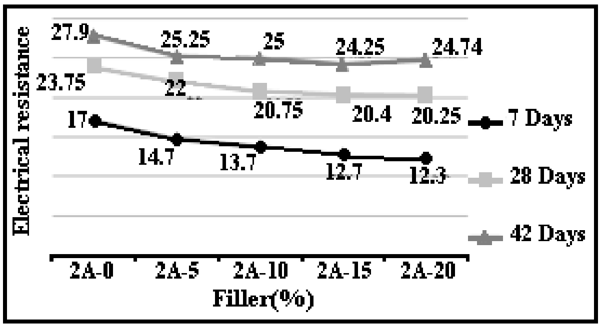

Figure 13-Electrical resistance of second batch (KΩ.cm)

With regard to Diagram 10 in each age, the control samples have the highest value of electrical resistance. This fact implies that the performance of these materials with their separate filler, effect resistance, permeability, and durability, which is disturbing to the proper hydration of the concrete.

4. Conclusion and suggestions

- In light of the general high strength of concrete compared to the weight of lamp posts and small lateral loads like wind in low altitudes and the lack of need for very high strengths, The demand of g Micronised silica in this kind of concrete is deemed useful, considering a reduction in the utilization of aggregate in non-corrosive environments.
- Use of Micronised silica in medium strengths and the grading curves, are in the lower right region of the BS standard curve, play a more effective role in improving concrete strength.
- With an increase in the percentage of Micronised silica in concrete with high strength whose low region of aggregation diagrams lies completely on the BS standard area, the elasticity module at first decreases and then increases therefore a uniform trend does not exist in this case compared to aggregate replaced by Micronised silica.
- Regarding the sudden decrease of electrical resistance after replacing low percentages of Micronised silica, even though electrical resistance is over 12 kilo ohms per centimeter in samples of the second batch, the application of these materials in environments which require durability in the presence of the chlorine ion is not recommended while implying the possibility of disturbance in cement hydration.

5. Acknowledgement

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6. Bibliography

[1] P. K. Mehta, “Concrete, Structure, Properties, and Materials”, MC-Graw Hill, 3rd edition, 2003, pp. 3-19 & 121-128.

[2] Verbeck, G. J., inPerformance of Concrete,Swenson,E.G.,ed., University of Toronto Press, Toronto, 1968.

[3] M. Heikal, , M.S. Morsy, Limestone-filled pozzolanic cement, Cem. Concr. Res. 30 (11) (2000) 1827–1834.

[4] P. Billberg, Fine mortar rheology in mix design of SCC, in: A. Skarendahl, O. Petersson (Eds.), Proceedings of the First International RILEM Symposium on Self-Compacting Concrete, RILEM, Cachan Cedex, 1999, pp. 47–58.

[5] S. El-Alfi, H. Darweesh, H. El-Didamony, Substitution of gypsum by limestone in the low heat Portland cement, Ceram-Silik, 44 (2000) 107-111.

[6] V. Bonavetti, H. Donza, V. Rahhal, E. Irassar, Influence of initial curing on the properties of concrete containing limestone blended cement, Cem. Concr. Res. 30 (5) (2000) 703– 708.

[7] V.L. Bonavetti, V.F. Rahhal, E.F. Irassar, Studies on the carboaluminate formation in limestone filler-blended cements, Cem. Concr. Res. 31 (6) (2001) 853– 859.

[8] M. Nehdi, Why some carbonate fillers cause rapid increases of viscosity in dispersed cement-based materials, Cem. Concr. Res. 30 (10) (2000) 1663–1669.

[9] Powers, T.C., J. Am. Ceram. Soc., Vol. 61, No. 1, 1958, pp. 1–5.

[10] M. Davraz, L. Gunduz, Reduction of alkali silica reaction risk in concrete by natural (micronised) amorphous silica, Construction and Building Materials, 22 (2008) 1093–1099

[11] National building and housing research center of Iran. Tests standard for assessment of concrete strength in structure (Non-destructive and Semi-destructive tests).