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Mechanical Properties of Cement Slurry by Partially Substitution of Industry Waste Natural Pozzolans

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***Abstract*—**There have been many reports of the destructive effects of cement on the environment in recent years. In the present research, it has been attempted to reduce the destructive effects of cement by replacing silica fume as adhesive materials instead of cement. The present study has attempted to improve the mechanical properties of cement slurry by using waste material from a glass production factory, located in Qazvin city of Iran, in which accumulation volume has become an environmental threat. The chemical analysis of the waste material indicates that this material contains about 94% of SiO_2 and AL_2O_3 and has a close structure to silica fume. Also, the particle grain size test was performed on the mentioned waste. Then, the unconfined compressive strength test of the slurry was performed by preparing a mixture of water and adhesives with different percentages of cement and silica fume. The water to an adhesive ratio of this mixture is 1:3, and the curing process last 28 days. It was found that the sample had an unconfined compressive strength of about 300 kg/cm^2 in a mixture with equal proportions of cement and silica fume. Besides, the sample had a brittle fracture in the slurry sample made of pure cement, however, the fracture in cement-silica fume slurry mixture is flexible and the structure of the specimen remains coherent after fracture. Therefore, considering the flexibility that is achieved by replacing this waste, it can be used to stabilize soils with cracking potential.

***Keywords*—**Cement replacement, cement slurry, environmental threat, natural pozzolan, silica fume, waste material.

I. INTRODUCTION

IN recent years the replacement of various adhesives instead of cement has become particularly important; and more researches have shown that some natural pozzolans such as zeolite, bentonite, etc., can be used to replace cement for soil improvement. This action can reduce the harmful effects of cement on the environment. On the other hand, the improvement of natural loose soil at the site of some projects such as trenches, roadbeds, etc. or increasing the strength of concrete products has caused to pay attention to natural pozzolans that have less environmental destructive effects than cement; which are also cheaper.

Kalkan found that the resistance and permeability of fine soils in cold regions are affected by freeze-thaw cycles. Therefore, the aim was to reduce these effects on resistance and permeability. In this study, natural fine-grained soil and silica fume were used to consolidate this mixture with optimum moisture. The results showed that the natural fine-grained soil with silica fume has higher resistance compared to sole soil, and silica fume reduced the effects of freeze-thaw cycles on unconfined compressive strength of the samples. Therefore, it has been shown that silica fume can be used to reduce the negative effects of cycles on soil resistance and permeability [1].

Kalkan has investigated the problem of clay cracking, which is generally used for impermeability in the context of linear projects. Silica fume was used as a stabilizer in this study. It was found that by combining silica fume and clay and consolidating them at optimum moisture, the rate of cracks decreased and silica fume had a positive effect on preventing cracking [2].

Kalkan investigated the effects of the drying and wetting cycles on clayey swollen soils. Tests were performed on natural clay and also the mixtures of clay and silica fume that consolidated with optimum moisture. The results show that the silica fume reduces the gradual deformation rate [3].

Kalkan used a mixture of silica fume and rubber fiber in clayey soils intending to investigate the geotechnical properties. The samples were subjected to the unconfined compression, the shear box, the odometer and permeability test after compaction at optimum moisture (natural and improved clay samples). The results showed that the mixture of silica fume and rubber fiber improved the resistance parameters and it was found that the hydraulic conductivity coefficient and swelling pressure decreased in the mentioned mixture [4].

Goodarzi et al. added silica fume and silica fume-lime in a wide range of 2% to 30% to the swelling clays and various experiments were carried out such as Atterberg limits, permeability, unconfined compressive strength, and pH measurement. It was found that silica fume alone did not have many effects; but, the combination of silica fume-lime improves the clay resistance parameters and reduces its permeability [5].

Goodarzi et al. used cement and 10% of silica fume to stabilizing clay with high swelling potential and performed some macroscopic and microscopic scale tests in different curing conditions. The results showed satisfactory outcomes at low temperatures (20 °C) with 28-day curing. On the other hand, although the curing time is shorter at high temperatures (40 °C), no change in the optimum amount of the additive was observed. It was also found that the combination of these two substances could accelerate the process of reaching stable conditions and XRD and SEM analysis showed that the

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combination of cement and silica fume has higher density and these conditions are very effective in improving the swelling problem of clay soils. [6]

Mousavi commonly used silica fume to improve the mechanical properties of cement-reinforced soil. Mousavi deliberates two issues in this study: first, the potential of silica fume in cement replacement and its performance to enhance the filling property by monitoring its pozzolanic effects on compacted clay. Second, the investigation of the mechanical properties of clay improved with different percentages of cement and silica fume. In this research, California bearing ratio tests, direct shear test and unconfined compressive strength were investigated. It was found that the optimum percentages for cement and silica fume in the stabilized soil were 6% and 2%, respectively. And, the 2% addition of silica fume reduces the void between the particles (due to Pozzolan activities) [7].

Ghavami investigated the effect of silica fume as industrial waste and Nano silica on kaolinite clay structure with low resistance properties. To investigate the strength, silica fume was added to the clay at the rates of 5% - 10% - 15%, then standard Procter, Atterberg limits, unconfined compressive strength, and California Bearing Ratio (CBR) tests were performed. SEM images were also prepared from soil stabilization changes at the microscopic scale. It was found that the silica fume and nano silica increased the optimum moisture content and reduced the maximum dry density of the stabilized soil. The combination of 15% silica fume and 3% Nano silica with kaolinite clay increased the compressive strength by 70% and 55%, respectively. It also showed a two-fold increase in CBR results. Finally, SEM images show that the silica fume and Nano silica fill the voids between the clay particles and form a denser mass [8].

Ahmad and Chen investigated the effects of silica fume and basalt fiber on the mechanical properties and microscopic structure of magnesium phosphate cement slurry. Several slurry samples were prepared with different percentages of silica fume and basalt fiber. It was observed that with the addition of silica fume, the compressive strength and flexibility of the slurry increased by 0% to 10% [9].

Saygili and Dayan investigated the effect of silica fume and polypropylene fiber on the strength and behavior of lime-reinforced clays under freeze-thaw cycles. They have performed an unconfined compressive strength test to investigate the resistance behavior of the specimens. The specimens were compacted with optimum moisture content and were subjected to 2-5 and 8 freeze-thaw cycles with 28 days of curing. Then, the strength reduction of the specimens was recorded to observe the durability of the specimens. Polypropylene fiber with 0.25% to 1% and silica fume with 2.5% to 10% by weight of dry kaolinite were added. The compressive strength increased by adding fiber and silica fume, and the presence of fiber has improved the friction resistance and the specimens had better interlock due to the cementation reactions between lime and silica fume and the presence of fiber. Finally, the results showed that the silica fume-fiber mixture obtained from industrial waste in kaolinite clay is an economic and environmental stabilizer [10].

Phanikumar et al. investigated the effect of silica fume as a stabilizer on the swelling soil. In this study, the swelling and shrinkage properties of clays were investigated in projects with sub-structure. Resistance tests revealed that with increasing silica fume content, plastic index and liquid limit of samples decreased. Besides, the consolidation and strength of soils that contain silica fume improved and the CBR content of the improved samples increased significantly [11].

Finally, according to researches on silica fume and its combination with various materials such as cement, lime, and plastic waste, it has specified that the silica fume has positive effects on soil improvement (including fine soils such as clay). On the other hand, since this material can also be obtained from industrial waste, therefore, while using this material in engineering, environmental damages by such methods can be prevented.

In the present study, the waste from the glass production factory in Qazvin, has been investigated. As this waste is excreted from the factory in clot form and has a fine-grained nature (particles smaller than 0.075 mm), it can cause respiratory problems in the province and its areas over time due to the waste deposited in open space. Therefore, this study has attempted to convert this volume of residual waste from a threat to an opportunity for optimal use.

II. EXPERIMENTAL METHODS

In the present study, the desired waste was first chemically analyzed; then, particle grain size tests were carried out with wet methods to evaluate the granulation and classification of the waste by considering its fineness. At the same time, the Atterberg limit test was performed to obtain PL - LL - PI values. These parameters have been presented in Table I.

Based on the chemical experiments which results have been presented in Table II, it was found that the waste includes about 88.5% SiO_2 and about 6.5% Al_2O_3. On the other hand, it is found that the CaO content is negligible; so, in theory, we will have the problem of adhesion.

The waste material leaves the factory with the aggregate appearance (Fig. 1); therefore, due to the uncertainty in the complete crushing of the aggregates, the results obtained by sieving are not reliable. Therefore, hydrometric grading techniques were used to ensure complete soil aggregation.

TABLE I
ENGINEERING PROPERTIES OF THE WASTE MATERIAL

Properties	Standard	Value
Liquid limit (LL), %	ASTM-D4318 [12]	35.5
Plastic limit (PL), %	ASTM-D4318 [12]	27.74
Plasticity index (PI), %	ASTM-D4318 [12]	7.76
Unified soil classification system (USCS)	ASTM-D2487 [13]	ML
Specific gravity	ASTM-D854 [14]	2.719

The hydrometric grading curve has been shown in Fig. 2, and the major volume of this soil is silt according to the defined range for silt particle size (0.002 - 0.075 mm) based on the Unified System. Also, about 97% of the waste passed the sieve score No. 200 wet grading. Finally, by comparing the chemical results obtained with similar models, this waste is named silica fume.

TABLE II
CHEMICAL ANALYSIS RESULT

Element	Unit	DL	Scheme	K-1
SiO_2	%	0.05	WR-01	88.43
Al_2O_3	%	0.05	WR-01	6.44
BaO	%	0.05	WR-01	0.05
CaO	%	0.05	WR-01	0.29
Fe_2O_3	%	0.05	WR-01	0.89
K_2O	%	0.05	WR-01	1.60
MgO	%	0.05	WR-01	0.22
P_2O_5	%	0.05	WR-01	0.06
TiO_2	%	0.05	WR-01	0.28
LOI	%	0.05	WR-01	1.73

Fig. 1 The primary shape of waste material

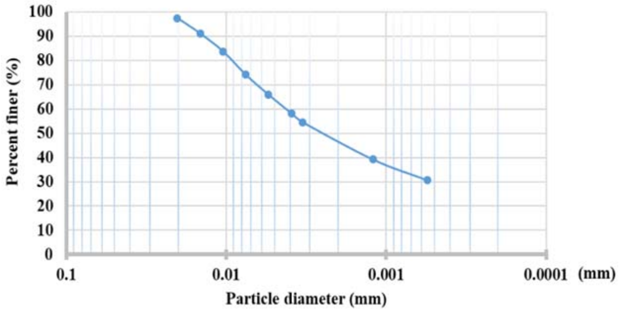

Fig. 2 Grain size distribution of the soil

III. SPECIMEN PREPARATION

In this study, 12 specimens with different percentages of cement and waste mixture were prepared. The construction method was that the pure cement with water to cement ratio of 0.33 were first prepared. Then, by holding the content value of water and adhesives constant, the cement was replaced with waste by weight percent ranging from 0% to 37.5% and poured into 5 x 5 cm molds. Portland Type II cement was used to compare the slurry resistance changes made by cement and waste.

The specimens made after initial curing were kept in the mold for 24 hours using a plastic coating to retain the moisture. After 24 hours and before separating the specimens from the mold, it was observed that the specimen with SF/C = 0% had more shrinkage than the specimen with SF/C = 100%. It was also found that during the fabrication of the specimen, because of keeping the water to cement ratio constant, A1 and A2 samples (Table III) were more fluid than other specimens. Also, water absorption was increased by rising the amount of waste and decreasing the amount of cement. Then, the specimens were released from the mold and kept in a tub for 28 days at constant ambient temperature.

TABLE III
SAMPLES SPECIFICATION

Sample Code	Cement Weight - C (gr)	Waste Weight - SF (gr)	Water Weight (gr)	SF/C (%)
A1 – A2	300	0	100	0
B1 – B2	270	30	100	11.1
C1 – C2	240	60	100	25
D1 – D2	210	90	100	42.8
E1 – E2	180	120	100	66.6
F1 – F2	150	150	100	100

IV. RESULTS

The slurry samples were subjected to unconfined compressive strength test after 28 days of curing in the bathtub. Data on the final force applied before sample failure, including final compressive stress, and displacement rate of each specimen were recorded. Given that two specimens were made for each mixing percentage to increase the accuracy of the tests, Table IV provides information on the average of both specimens.

TABLE IV
THE AVERAGE RESULTS OF EACH SAMPLE SERIES

Sample Series	F_{ave} (ton)	$(q_u)_{ave}$ $(\frac{kg}{cm^2})$	D.L (mm)	ε_y
A	24.7	988	1.665	0.333
B	16.7	668	1.41	0.282
C	15.55	622	1.185	0.237
D	12.05	482	1.12	0.224
E	10.8	432	1.185	0.237
F	7.7	308	1.44	0.288

In series of specimen A, which was pure cement slurry, it was observed that the compressive strength is 988 kg/cm^2. A decreasing trend is also observed in subsequent series of specimens (B - C - D - E - F) (Fig. 3). Finally, the compressive strength in the specimen with equal ratios of cement and waste reached the value of 308 kg/cm^2. On the other hand, in the results obtained from the final strain calculation of the specimens using the displacement and initial length of the specimen (Fig. 4), it can be seen that:

(1) By increasing the amount of waste and replacing it with cement, the final strain of the specimens to specimen D has a decreasing trend and by examining the fracture images of the specimens, it can be concluded that by adding waste instead of 30% of the cement consumed, while achieving the minimum fracture strain (Fig. 4 - Sample D), specimens have a more coherent structure than pure cement specimens after fracture (Fig. 5).
(2) By examining the decreasing-increasing trend of Fig. 4 as well as Fig. 5, it can be seen that while increasing the

final strain from specimen D to specimen F, again the fracture of the specimen has a softer and coherent state than that of the pure cement slurry. Fig. 5 shows the coherence state of the specimens after failure. Therefore, since two specimens were made for each mixing ratio according to Table III, they were put together after the experiment for observation and comparison of specimens.

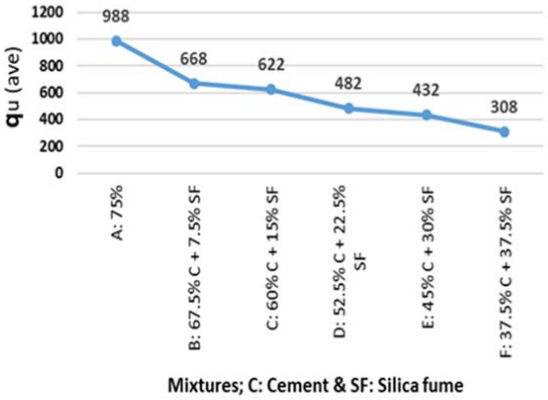

Fig. 3 Unconfined compressive strength values based on different mixtures of cement and silica fume

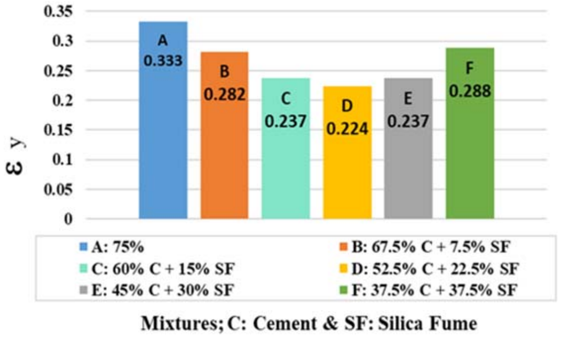

Fig. 4 Values of ε_y based on different mixtures of cement and silica fume

(3) Comparison of Figs. 3 and 4 in specimen D shows that by replacing 30% of the waste instead of cement, the ultimate compressive strength of the specimen is approximately half of the pure cement while obtaining the final minimum strain.

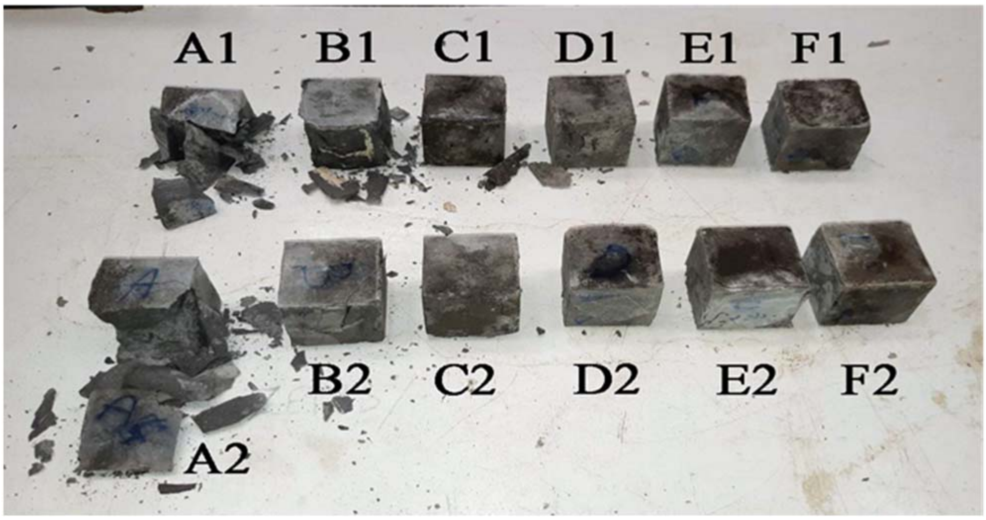

Fig. 5 The coherence state of the specimens after failure

V. CONCLUSION

In present study, the waste material from the glass factory that became an environmental threat was investigated and chemical analysis showed that it has the nature of silica fume and it can be a natural adhesive. Considering the chemical and engineering properties of this waste, it was used to investigate its effect on cement slurry and was replaced with different weight percentages and 28-day curing time. After performing the unconfined compressive strength test, it was found that the minimum fracture strain was obtained by replacing the waste with 30% of the cement consumed (specimen D - Fig. 4). Also by examining the appearance of specimens after fracture, it was found that by increasing the waste content and replacing it with cement, the specimens had a more coherent structure than that of pure cement and, fewer cracks were observed on the surface of the specimens containing the waste (Fig. 5). Therefore, based on the observations, the results obtained and the work of previous researchers, this waste can be used in cases where it is necessary to control the cracking and strain of the specimen.

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