Investigation of mechanical behavior of fibrous concrete containing pumice and metakaolin and chemical resistance to acid attack

Kianoosh Samimi [1*], Mahyar Pakan [1], Amirhossein Firoozbakht [2]

[1] Faculty of Civil, Water and Environmental Engineering, Shahid Beheshti University, Tehran, Iran
[2] Research and Development Service, Imen Rah Consulting Engineering Co., Tehran, Iran.

ABSTRACT

Using fibers to reduce cracks and increase the joint spacing of concrete slabs has become popular in the concrete pavements of airports and freeways recently. However, their durability behavior against acid rain has been less studied. The purpose of this paper is to investigate the mechanical performance and durability of concrete reinforced with polyolefin and polypropylene fibers containing 15% of pozzolanic materials (pumice or metakaolin) instead of Portland type II cement. In this regard, compressive and flexural strength were measured to investigate the mechanical behavior of the studied mixtures at different ages. On the other hand, chemical resistance against acid rain simulated was investigated through the visual examination and weight loss, and also microstructural analysis was performed by SEM analysis and CT scan testing. Based on these results, the addition of both of these fibers in concrete reduces the compressive strength of concretes compared to the similar content in the control concrete. On the contrary, fibers increased the flexural strength, which became much more significant with the addition of pozzolanic materials. However, ordinary and fibrous concrete containing pozzolanic materials showed a weak performance against acid rain. Based on the results of CT scan and SEM analysis, concretes containing pozzolanic materials have a porous structure. Besides, the ratio of calcium to silicon in them is much lower than the control concrete due to decalcification reactions caused by acid attacks

KEYWORDS

Acid attack, CT scan analysis, Metakaolin, Microstructure, Pumice.

[*] Corresponding Author: Email: k_samimi@sbu.ac.ir

1. Introduction

Fiber-Reinforced Concrete (FRC) is a combination of fibers with other components of concrete that improves mechanical properties, reduces permeability, and increases the resistance to severe mechanical shocks [1–3]. The fibers have been also utilized to limit the crack width, which gives beneficial results about the durability of the concrete [4]. Acid rain attacks are one of the main challenges of durability that always lead to the deterioration of concrete structures. This effect leads to the occurrence of the leaching phenomenon over time, as a result, the concrete will deteriorate, lose weight, create cracks, reduce strength, and eventually fail. Zeyad et al. investigated the effect of pumice addition on fiber reinforced concrete. From their results, the mixture incorporated by 10% pumice instead of cement and 2% polypropylene fiber showed little progress in compressive resistance compared to that of the control mix at long-term maturation. On the other hand, the flexural and tensile strength is increased [3]. In fact, there are many studies on the effect of fibers and additives on the mechanical properties of concrete [3-7]. However, the acid rain attack, as well as microstructure study after degradation for pumice and metakaolin-based FRC, are lacking in the literature. Thus, the study of FRC incorporated by pumice and metakaolin can be useful and requires further research in mechanical, chemical, and durability properties.

In this study, the effect of pumice and metakaolin powders on the mechanical resistance of normal concrete (NC) and FRC mixture at an early age and up to long age is investigated. The impact on the chemical resistance under the influence of acid rain attacks was studied. Consequently, the compressive resistance and flexural strength were measured to assess the mechanical properties of the different studied mixtures. Finally, the chemical resistance against H_2SO_4 and HNO_3 attacks in order to simulate acid rain environments is evaluated by weight loss, visual examination and microstructure study using a scanning electron microscope (SEM), X-ray diffraction (XRD) test, and CT scan tests.

2. Materials

In this research, type II Portland cement in accordance with ASTM C150 standard, metakaolin of Tehran and pumice natural pozzolan powder of Khash were used. The gravel with 6–19 mm nominal size and natural sand with a maximum size of 6 mm were used as coarse aggregate and fine aggregate respectively for all formulation. The polypropylene and polyolefin fibers with a length of 25 and 50 mm were used respectively. All concrete mixes were cast by using potable water. The mix proportion of concretes is presented in Table 1.

Table 1. The mix proportion of mixtures (kg/m^3).

Mix Name	CC	P15	M15	EM	EM+ P15	EM+ M15
Water	133.2	133.2	133.2	133.2	133.2	133.2
Cement	370	314.5	314.5	370	314.5	314.5
Pumice	-	55.5	-	-	55.5	-
Metakaolin	-	-	55.5	-	-	55.5
W/Cm	0.36	0.36	0.36	0.36	0.36	0.36
G (6-19mm)	716	716	716	716	716	716
S (0-6mm)	1030	1030	1030	1030	1030	1030
A	0.37	0.37	0.37	0.37	0.37	0.37
SP	2.02	2.25	2.38	3.41	3.9	4.4
PP	0.8	0.8	0.8	0.8	0.8	0.8
PO	4	4	4	4	4	4

3. Experimental Program

Cubic (100×100 mm) and cylindrical (Φ110 x H50 mm) specimens in accordance with ASTM C 31 (2012) and ASTM C511 (2013) respectively were manufactured. All samples were demolded after 24 hours and kept until the age of the test in water.

In this study, mixing of H_2SO_4 and HNO_3 was used for simulating the acid rain condition. The molar ratio of sulfuric acid to nitric acid is considered 9:1. In order to compare the rate of degradation, the samples were immersed during 36 weeks (252 days) in two different media as a control medium and an aggressive medium

SEM associated with an energy dispersive analysis of X-ray (EDAX) Silicon Drift Detector (SDD), XRD Analysis, CT scan, and Compressive and Flexural strength was performed on all samples.

4. Discussion and Results

4.1 Mechanical resistant

The compressive strength of M15 and P15 mixtures from 28 to 365 days is higher compared to control concrete. However, this increase in the P15 mixture is much more significant than in the M15 mixture. So that the compressive strength of P15 mixture was 17.1%, 11.43% and 29.49% higher than the corresponding compressive strength in the control sample at the ages of 28, 90 and 365 days, respectively. The highest flexural strength is related to EM + P15 mixture at 365 days and the lowest flexural strength is related to control sample (CC) at 7 days old. The flexural strength of EM + P15 mixture was 37.36%, 41.67%, 38.46%, 29.73% higher than the flexural strength of the control sample at the ages of 7, 28, 90 and 365 days, respectively. Replacement of cement with 15% metakaolin or pumice in ordinary concrete increased flexural strength at all maintenance ages.

4.2 Weight loss

CC showed less weight loss than other mixing designs from the tenth week of immersion against acid rain. At the end of the test period, weight loss 2.24% for CC mixture versus 2.51%, 2.32%, 2.67%, 3.55% and 3.3% for P15, EM, EM + P15, M15 and EM + M15 were observed, respectively.

4.3 Microstructure analysis

The SEM image of the CC sample shows that the amorphous CSH and CH crystalline phases are well dispersed throughout the aggregates. Another morphology was also observed in the CC sample, which represents amorphous silica (albite or quartz). Microstructure analysis shows that CH phases are also rarely observed in the structure of P15 and M15 mixtures, which can be due to the presence of pozzolanic materials in the cement matrix and subsequent consumption of the CH phase in pozzolanic reactions to produce CSH gel during 36 weeks of water Curing. This observation is consistent with the results of the CT scan analysis. The CT scan results shows that samples containing metakaolin have more cavities than the control sample, which indicates their poor performance. On the other hand, based on these results, the performance of P15 and EM + P15 mixtures is much better than M15 and EM + M15. Therefore, the amount of porosity in concrete (CC <EM <P15 <EM + P15 <M15 <EM + M15) is completely consistent with the results of weight reduction of the mixture.

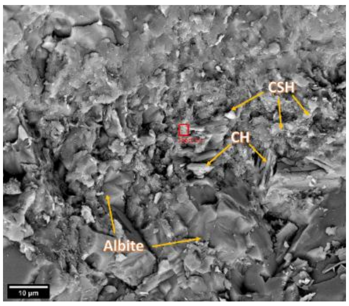

Fig 1. The SEM image of CC.

5. Conclusions

This study focuses on the effect of using two different pozzolans including pumice and metakaolin in normal concrete and reinforced concrete with polyolefin and polypropylene fibers. The mechanical properties and durability against acid rain have been investigated for six mixed designs, the main results of which are as follows:

.

1-The replacement of Portland cement by 15% of pozzolan materials was useful in NC and FRC for increasing mechanical resistance because of the high specific surface area and a dense structure product due to the pozzolanic reaction.

2-Pozzolan mixes mix shows a negative performance against acid attack. This negative behavior can be due to the abundance of portlandite in pozzolan mixes. Since it was more reactive with respect to the H_2SO_4 attack. As a result, portlandite leaching can be high in the cement matrix. In addition, the high amount of C-S-H gel from the pozzolanic reaction of pumice causes the intensification of C-S-H gel decalcification reactions.

3-The EM + M15 mixture design showed a more porous structure than other mixing designs. In addition, the CSH phase due to the pozzolanic reaction was widely observed in both M15 and EM + M15 designs.In acidic environment, the Ca / Si ratio decreased significantly in the two designs due to the increased desalination, which leads to increased degradation in the concrete structure. The EDX spectrum of the EM + M15 mixed design shows that the Ca / Si ratio is very low (< 0.1) and therefore it will be difficult to observe the CSH phase by SEM images in the mix.

6. References

[1]C.X. Qian, P. Stroeven, Development of hybrid polypropylene-steel fibre-reinforced concrete, Cement and Concrete Research, 30(1) (2000) 63-69.
[2] J. Wang, Q. Dai, R. Si, S. Guo, Mechanical, durability, and microstructural properties of macro synthetic polypropylene (PP) fiber-reinforced rubber concrete, Journal of Cleaner Production, 234 (2019) 1351-1364.
[3] A.M. Zeyad, A.H. Khan, B.A. Tayeh, Durability and strength characteristics of high-strength concrete incorporated with volcanic pumice powder and polypropylene fibers, Journal of Materials Research and Technology, 9(1) (2020) 806-818.
[4] S.E. Vakili, P. Homami, M.R. Esfahani, Effect of fibers and hybrid fibers on the shear strength of lightweight concrete beams reinforced with GFRP bars, in, Elsevier, pp. 290-297.
[5] S. Ullah Khan, T. Ayub, Flexure and shear behaviour of self-compacting reinforced concrete beams with polyethylene terephthalate fibres and strips, in, Elsevier, pp. 200-211.
[6] S.M.S. Kazmi, M.J. Munir, Y.-F. Wu, I. Patnaikuni, Y. Zhou, F. Xing, Axial stress-strain behavior of macro-synthetic fiber reinforced recycled aggregate concrete, Cement and Concrete Composites, 97 (2019) 341-356.
[7] X. Hu, Y. Guo, J. Lv, J. Mao, The Mechanical Properties and Chloride Resistance of Concrete Reinforced with Hybrid Polypropylene and Basalt Fibres, Materials, 12(15) (2019) 2371-2371