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Research Article

Chemical resistance of hardened mortar containing andesite and marble industry waste powder

İsmail İsa Atabey [a,*], Serhat Çelikten [a], Mehmet Canbaz [b]

[a] Department of Civil Engineering, Nevşehir Hacı Bektaş Veli University, 50300 Nevşehir, Türkiye
[b] Department of Civil Engineering, Eskişehir Osmangazi University, 26480 Eskişehir, Türkiye

ABSTRACT

The sludge generated during forming processes of marble and andesite rocks is kept in dust form after drying. Due to the high consumption of andesite and marble, the storage and health problems of these dusts arise. Therefore, reducing the environmental impacts of waste and recovering them for the economy is an important issue. For this purpose, in this work, mortar specimens were manufactured using 0%, 5%, 10%, 15% and 20% of waste marble and andesite powders separately by Portland cement. Strength properties of the samples were investigated before and after immersion to the hydrochloric acid (HCl), sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) solutions. The results indicated that partial substitution of Portland cement by andesite and marble powder up to 10% have positive influence on the mechanical properties of the mortars at ambient conditions. In addition, the andesite incorporated mortars have the better performance under the acid and sulfate environments than the other mortars. On the other hand, substitution of Portland cement by marble powder more than 5% has negative influence on the chemical resistance of the mortars.

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1. Introduction

Greenhouse gases along with the natural resources issue are important role on the sustainable development of construction industry. Construction industry is researching for the utilization of substitute alternatives for cement manufacture. In the last decades, there are studies focused on substitution of cement with several wastes such as fly ash, blast furnace slag, rice husk ash, and etc. (Rana et al. 2015; Naik 2008). The CO_2 emission originated from the cement manufacture may also be limited by restricting it with such wastes (Yang et al. 2015; Rana et al. 2015).

Approximately, 7 million tons of natural rock is processed in Turkey for each year, 75% of which is formed at five thousand quarries. Andesite is a type and subtype volcanic and magmatic rock, respectively. Andesite is employed for several architectural and civil engineering applications in Turkey as well as in other countries (Sariisik et al. 2011; Davraz et al. 2018). Powder and sand are disposed as by products during polishing and cutting processes of rocks for several aims. A large-scale andesite manufacture generates vast amount of waste powder; nearly one quarter of the andesite and marble is discharged during polishing, cutting, mining and other applications. Discharge of andesite and marble processing waste powder into the environment can lead to significant health and environmental problems (Soğancıoğlu et al. 2013; Davraz et al. 2018; Ashish 2019; Sarkar et al. 2006). Recovery of waste natural stones in exchange for cement raw materials may cause to significant energy savings processes required for the manufacturing of the final product (Ismail and Ramli 2013; Rana et al. 2015).

The utilization of pozzolans and several admixtures in cementitious composites is a common option for many years (Kara and Arslan 2020). They are employed in concretes, mortars, cements, in the production of structural elements, and combined with other materials such as Portland cement, sand, and lime. Additionally, some al-

* *Corresponding author*. Tel.: +90-384-228-1000 ; Fax: +90-384-228-1123 ; E-mail address: ismailatabey@nevsehir.edu.tr (İ. İ. Atabey)
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ternative sources may have pozzolanic reactivity. Effects of these materials as pozzolanic materials and for improvement of mechanical performance are depending on their pozzolanic activity. The activity can be identified as the reaction performance of SiO_2 available in the potential material reacting with $Ca(OH)_2$, resulting in secondary C-S-H gels. Andesite powder is a SiO_2-rich waste, and so it may have pozzolanic activity. Despite all the work about the application fields and natural abundance of andesite, its use as natural pozzolan and its pozzolanic activity in mortar or concrete are not well established. (Hamidi et al. 2013; Davraz et al. 2018)

Sulfate attack is one of the most detrimental effects on the endurance of building materials. After the sulfate exposure, expansion, cracking, and spalling are observed on the cement-based materials (Chindaprasirt et al. 2007; Collepardi 2003; Sancak and Özkan 2015) Sulfate attack occurs in cement-based materials when the materials are in touch with a source of sulfate ions, which can be rainwater, soil or groundwater. Sulfate attack manifests itself by spalling and cracking of concrete caused by dilatation and decrease in mechanical performance. The durability of cement-based materials to sulfate effect is influenced by various factors, such as water absorption and permeability. (Shanahan and Zayed 2007; Sancak and Özkan 2015).

Durability to acid attack is an important environmental effect for building materials employed in structural components. Acid attack is generally originated from several industrial processes and other related applications (Selim et al. 2020). It has been stated that hydrated and unhydrated cement phases are decomposed after subjecting to acid attack. Besides, the damage of attack depends primarily on concentration of acid as well as duration of the attack. Acid effect mechanism includes generally pore expanding bringing about porosity and hence a decline in strength of the exposed building material (Selim et al. 2020; Chi and Stegeman 2000; Beddoe and Dorner 2005; Çelikten 2021).

There are many studies performed regarding substituting marble dusts for cement in cement-based composites. (Yamanel et al. 2019; Ashish 2019; Rana et al. 2015; Selim et al. 2020; Singh et al. 2017; Rashwan et al. 2020; Ghorbani et al. 2020; Khodabakhshian et al. 2018; Zhang et al. 2020, Khyaliya et al. 2017; Ergün 2011). There is a variation in the durability and mechanical performance towards the marble dust incorporation. Literature review has identified a few previous studies on the use of andesite powder in mortar/concrete manufacture (Hamidi et al. 2013; Davraz et al. 2018; Sariisik et al. 2011). Pozzolanic effect of mortar containing andesite powder is reported but the literature on this issue is generally quite limited. Besides, the evaluation of the durability properties of the andesite powder incorporated cementitious composites and comparison of their performance with the plain composites is important.

Acid and sulfate attack on marble powder-based mortars or other cement-based composites has previously been evaluated using mixes modified with waste marble powder. In order to encourage the recovery of waste andesite, this research aimed to determine and compare the resistance of globally studied marble powder-modified mixes with waste andesite-modified mixes under the effect of chemical attacks of acid (HCl) and sulfate ($MgSO_4$ and Na_2SO_4) solutions. Use of waste natural stones powder in place of cement are carried out in literature. But the usage of andesite powder as substitution material in cementitious composites did not take enough attention; therefore, more study on the issue may attract recycling andesite powder in the cementitious composites which could also help for protection of natural resources. In this study, the blended cements manufactured by using the waste andesite and marble powder were subjected to acid and sulphate solution and the mortars chemical resistance were investigated. Compressive strength, flexural strength, hydrochloric acid resistance, sodium sulfate and magnesium sulfate resistance of cement mortar containing andesite and marble powder were investigated.

2. Materials

2.1. Cement

Ordinary Portland cement produced by Eskişehir Cement Factory of grade CEM I 42.5 R in compliance with TS EN 197-1 (2012) was used in the mortars. The density of the cement was 3.13 g/cm^3. X-ray fluorescence results of cement is given in Table 1.

2.2. Andesite and marble powder

Waste andesite powder (AP) and waste marble powder (MP) were employed in the mortar mixtures. The powders were taken from a quarry in Afyon city of Turkey. The density of AP and MP were 2.68 and 2.34 g/cm3, respectively. Before using AP and MP in mortar mixtures, they were sieved from 125 µm sieve and dried at 105°C. The chemical oxide compositions of AP and MP are given in Table 1. Sieve analysis of AP and MP are presented in Table 2.

2.3. Sand

Standard sand (Rilem Cembureau) defined in TS EN 196-1 (TS EN 196-1 2009) was employed for mortar mortar manufacture. The water absorption rate and dry specific gravity of the sand were 0.57% and 2.63, respectively. Sieve analysis of standard sand is given in Table 3.

Table 1. Chemical oxide compositions of cement, andesite and marble powder.

Oxide Content, %	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	K_2O	Na_2O	MgO	LOI
Cement (PC)	62.87	19.91	5.31	3.23	3.27	0.64	0.29	1.88	2.6
Andesite Powder (AP)	6.32	57.82	19.24	5.87	0.22	2.88	3.14	1.87	1.8
Marble Powder (MP)	58.41	4.57	0.59	0.24	0.17	1.1	0.27	4.56	30.0

Table 2. Sieve analysis of andesite and marble powder.

Sieve size, mm	0.125-0.090	0.090-0.062	0.062-0.012	0.012-0
AP, %	12	29	54	5
MP, %	8	24	61	7

Table 3. Sieve analysis of sand.

Sieve size, mm	2.00	1.60	1.00	0.50	0.16	0.08
Remaining on Sieve, %	0.0	3.2	32.6	68.8	87.2	99.6

3. Methodology

The andesite powder (AP) and marble powder (MP) were utilized in the mortar mixtures as substitution material by the Portland Cement (PC). In preparation of binder paste, AP and MP were employed as a substitution material of cement in 0%, 5%, 10%, 15% and 20% proportion by mass. The proportion of water (W) to total binder content (W/AP+PC) or (W/MP+PC) ratio was 0.5 and sand to total cementitious material proportion of content was 3. The amounts of materials used for the production of mortar mixtures for three-cell mortar mold (4x4x16 cm) are illustrated in Table 4. As seen on the table, the mortar mixes were coded as the substitution of cement respectively. Moreover, the mixing process of the mortars included the following steps. Water and powder binder were poured to the case of Hobart mixer and run at low running rate of 140 rpm for 30 sec. After that, the sand was poured in the bowl in 30 sec. Then, the mixture was mixed at high running rate 30 sec. After high running rate, the mixture was kept waiting at stopped condition for 90 sec. Then, the mixture was mixed at high running rate of 280 rpm for 60 sec. Finally, the mixture was casted into 4×4×16 cm molds after waiting 15 sec. according the TS EN 196-1. After that, the mixes were kept at standard curing conditions until the day of testing. After curing process, mortar specimens with the dimensions of 4×4×16 cm were extracted from the molds to employ the several tests. Three specimens were used for each test and the final results calculated from averaging of results of three specimens.

Firstly, the unit weight values of the mortars were determined in saturated dry surface conditions. Flexural strength (FS) test was conducted on complying with TS EN 1015-11 (TS EN 1015-11:2000) standard, using three-point loading assembly on prismatic specimens with 100 mm span distance between supports. After the FS test, two samples of broken prisms were used to measure the compressive strength (CS) (4×4 cm), complying with TS EN 1015-11. Average of three prismatic samples results were taken as FS value, and average of six samples was taken as CS value. In addition, 6 specimens for each mix were exposed to 5% $MgSO_4$, 5% Na_2SO_4 and HCl (pH=2) solutions for 90 and 180 days, separately. The FS and CS tests were done on these specimens before and after exposure to the solutions. 56 days aged specimens were used for the FS and CS tests before the immersion to determine the pozzolanic effects of the AP and MP.

Table 4. Amounts of materials used in the mortars (g).

Mix	PC	MP	AP	Water	Sand
PC	450.0	-	-	225	1350
MP5	427.5	22.5	-	225	1350
MP10	405.0	45.0	-	225	1350
MP15	382.5	67.5	-	225	1350
MP20	360.0	90.0	-	225	1350
AP5	427.5	-	22.5	225	1350
AP10	405.0	-	45.0	225	1350
AP15	382.5	-	67.5	225	1350
AP20	360.0	-	90.0	225	1350

4. Results and Discussion

4.1. Unit weight

Unit weights of mortars are illustrated in Table 5. The average unit weight value of PC mortars was 2.09. The unit weights of AP and MP incorporated mortars were ranged between 2.13 g/cm^3 and 2.21 g/cm^3 and between 2.11 g/cm^3 and 2.18 g/cm^3 before immersion to acid or sulfate solutions, respectively. The results show that the hardened average unit weights of AP and MP incorporated mortars were up to 3% and 4% higher than the unit weights of PC mortars before immersion to solutions, respectively. The average unit weight of the MP incorporated mortars increased to about 2% and 3% after immersion of the HCl solution for 90 and 180 days, respectively. Due to the difference in the concentration of the HCl, Na_2SO_4 and $MgSO_4$ solutions and the water in the mortar, the unit weights of the mortars were increased up to 4.2%, 6.1% and 7% after immersion of the solutions, respectively. The increase in the unit weights of the mortars with the solution immersion was compatible with the density of the acid or sulfate solutions.

4.2. Flexural strength

The final flexural strength (FS) results in the mortars are plotted in Figs. 1, 2 and 3. From the results, it could be observed that both powder type and substitution level of cement had important impacts on the final FS development of the mortars. The FS values of mortar specimens after acid solution exposure were compared relative to the FS values of unexposed specimens. The FS values of AP and MP incorporated mortars after exposure to 90 and 180 days HCl (pH=2%) solutions are illustrated in Fig 1. After the subjection of HCl solutions for 90 and 180 days, the MP incorporated mortars exhibited the lowest FS values. After the immersion HCl solution for 90 and 180 days the FS values of MP15 mortars were decreased to almost 4.8% and 17.9%, respectively. Minimum FS reductions in all the mortars were determined for AP15 coded mortars. After the immersion for 90 and 180 days, the FS values of AP15 mortars were decreased to almost 0.3% and 6.1%, respectively. It's concluded that the AP containing mortars performed better against HCl acid attack than the other mortars.

Table 5. Unit weight values of the mortars (g/cm^3).

Mortar mixtures	Before immersion	HCl 90d	HCl 180d	Na_2SO_4 90d	Na_2SO_4 180d	$MgSO_4$ 90d	$MgSO_4$ 180d
PC	2.09	2.16	2.13	2.18	2.21	2.17	2.19
MP5	2.11	2.21	2.19	2.14	2.16	2.21	2.22
MP10	2.15	2.21	2.18	2.18	2.19	2.18	2.17
MP15	2.17	2.24	2.22	2.24	2.25	2.20	2.21
MP20	2.18	2.19	2.20	2.25	2.27	2.24	2.25
AP5	2.13	2.23	2.22	2.24	2.26	2.27	2.28
AP10	2.19	2.26	2.21	2.28	2.30	2.28	2.29
AP15	2.17	2.24	2.20	2.25	2.26	2.28	2.31
AP20	2.21	2.23	2.23	2.33	2.32	2.31	2.31

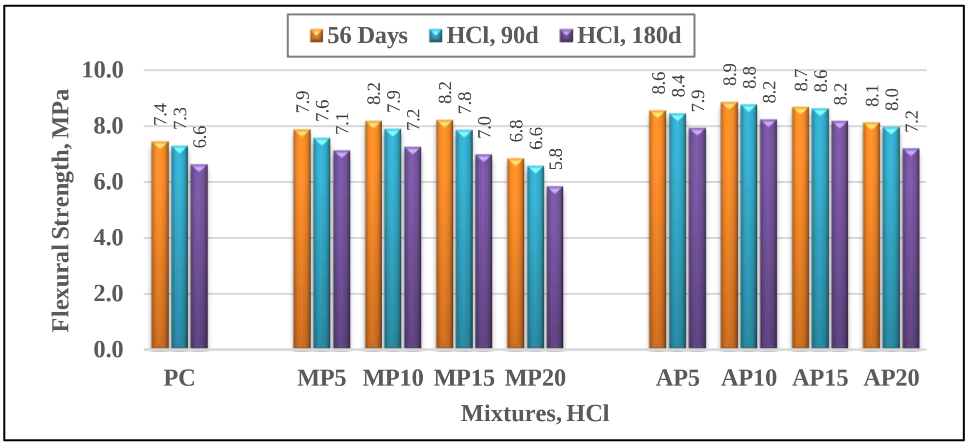

Fig. 1. Flexural strength of mortars exposed to HCl.

The final FS values of AP and MP incorporated mortars mixtures after subjection to 5% Na_2SO_4 solution for 90 days were in the ranges of 6.9-8.2 MPa and 8.1-9.1 MPa, respectively (Fig. 2). The final FS values of AP and MP incorporated mortars after immersion for 180 days were in the ranges of 6.6-8.0 MPa and 8.1-9.0 MPa, respectively. The results indicated that relative to PC mortar mixture, FS increased across all the periods up to 10% AP and MP ratios. FSs of mortars were enhanced with the employment of MP/AP partially in place of cement with respect to PC mortar. When exposure to Na_2SO_4 time increases from 90 days to 180 days, FSs of all the mortars decreased due to degradation of cement paste formation. Maximum FS loss was about 5.8% in MP15 mortars subjected to Na_2SO_4 solution for 180d.

The FS results of the mortars subjected to 5% $MgSO_4$ solution are represented in Fig. 3. The sulfate resistance of the mortars was considered with respect to difference in FS of specimens after immersion to 5% $MgSO_4$ solution for 90 and 180 days, separately. After the immersion for 90 and 180 days, the FS values of PC mortars were decreased to almost 0.5% and 3.0 %, respectively. FS values of MP mortars decreased between 2% and 3.5% after subjecting 5% $MgSO_4$ solution for 90 days. At 180 days' immersion, the strength losses increased and the strength loss of MP-containing mortars was between 4% and 13%. As for the mortars containing andesite, lower strength values compared to PC mortars under the influence of $MgSO_4$ for 90 days were only seen in mortars with code AP20. After immersion of 180 days, FS loss was observed between 1.8% and 5.9% in other mortars except AP15. FS loss was not observed in AP15 coded mortars under the influence of $MgSO_4$ for 90 or 180 days. In general, FS values of AP modified mortars better than MP modified mortars under the 5% $MgSO_4$ attack for 90 and 180 days. The better performance of the AP-incorporated mortars in the acid and sulfate solutions can be attributed to the pozzolanic activity of the AP. The pozzolanic activity of the AP was also reported in a previous work (Hamidi et al. 2013; Davraz et al. 2018).

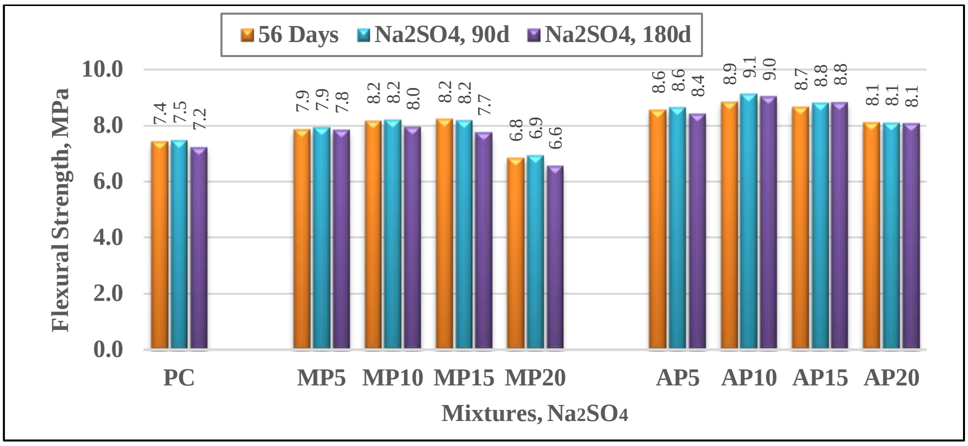

Fig. 2. Flexural strength of mortars exposed to Na_2SO_4.

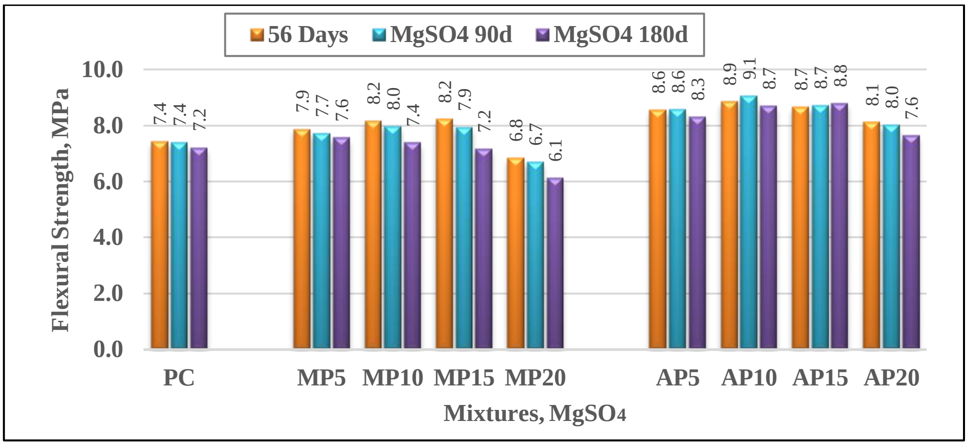

Fig. 3. Flexural strength of mortars exposed to $MgSO_4$.

4.3. Compressive strength

The compressive strength (CS) values of mortars after exposure to HCl, Na_2SO_4 and $MgSO_4$ solutions are presented in Figs. 4, 5 and 6, respectively. The highest CS values was obtained from the AP10-coded mortars before exposure to the solutions. Besides, except for the MP20, the CSs of all the AP or MP incorporated mortars had higher CS than the PC mortar. The positive effect of AP (Hamidi et al. 2013; Davraz et al. 2018) and MP (Yamanel et al. 2019; Ashish 2019) on the CS of the Portland cement-based mortars was also reported in previous works. The acid durability of the mortars was determined with respect to change in CS of mortar samples after immersion to HCl solution for 90 and 180 days, separately. Fig. 4 illustrates the initial and final CS results of the mortars after exposure to the HCl solution. The CS results of PC mortars after 90- and 180-days immersion in 5% HCl acid solution were 46.4 and 40.3 MPa, respectively. Initial CS value of PC mortar was 49.3 before immersion to solution. The highest CS values were observed on the MP incorporated mortars for MP5 as 48.6-45.0 MPa and on the AP modified mortars for AP10 as 58.9-52.2 MPa after subjection for 90 and 180 days', respectively. Minimum CS loss was about 10.6% in AP5 mortars after exposure to HCl-180d. Selim et al. (2020) studied the sulfuric and acetic acid resistances of marble dust incorporated Portland cement pastes. Their results showed that 5% replacement of MP by cement improved the acid resistance of pastes. However, replacement of marble dust by Portland cement at high levels of 15% and 20% decreased the acid resistance of pastes, significantly. These findings are compatible with this present work. The worse acid resistance of MP15 and MP20 mortars with respect to the PC and MP5 mortars can be attributed to the filler effect of MP and its low pozzolanic activity.

The residual CS of the mortars after immersion to 5% Na_2SO_4 solution are shown in the Fig. 5. The final CS values of MP and AP mortars were in the ranges of 46.4-57 MPa and 56.1-69.4 after subjection to Na_2SO_4 solution for 90 days. After exposure for 180 days, average values of the MP and AP incorporated mortars were decreased between 9.1 MPa and 5.8 MPa in comparison with the values calculated after 90 days' immersion. The maximum final CS values of 57.0 and 69.4 MPa were observed on the mortar mixtures manufactured as the MP10 and AP10 in all the series for 90 days, respectively. The enhanced durability may be attributed to the decline of $Ca(OH)_2$ (Portlandite) formed as a result of the hydration of cement because of the decrement in cement content by substitution. Therefore, the amount of gypsum occurred from the reaction between sulfates and the Portlandite declined, and consequently the ettringite formation, the reason for volume deterioration and expansion, is controlled (Rashwan et al. 2020). The highest CS value of 61.2 MPa was achieved on the AP10 mortars after subjection to Na_2SO_4 solution for 180 days. Besides, increase in the waste powder ratio had negative influence on the final CS of the mortar mixtures as reported for the results in sulfate environment after %10 ratio. The lowest residual final CS of 39.5 MPa was calculated for the MP20 after subjection to Na_2SO_4 solution for 180 days.

The initial and final CS values of the mortars after subjection in 5% $MgSO_4$ solution for 90 and 180 days are illustrated in the Fig. 6. While the lowest final CS of 36.4 MPa was seen on the MP20 mortars after immersion to the solution for 180 days, the highest CS of 62.9 MPa was obtained on the AP10 mortars at same condition. AP mortars had superior performance under the $MgSO_4$ attack than the PC and MP mortars. Previous studies reported that reducing the content of $Ca(OH)_2$ in Portland-cement-based composites by incorporating various pozzolans can improve the $MgSO_4$ durability of these composites and reduce softening of C-S-H gel and the degree of attack (Zhang et al. 2020). The better durability performance of the AP incorporated mortars indicated that AP had considerable pozzolanic activity in addition to its filler effect.

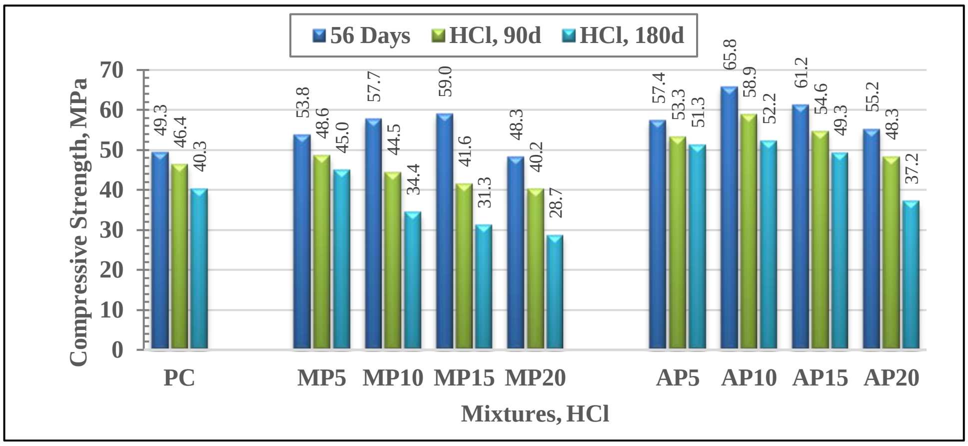

Fig. 4. Compressive strength of mortars exposed to HCl.

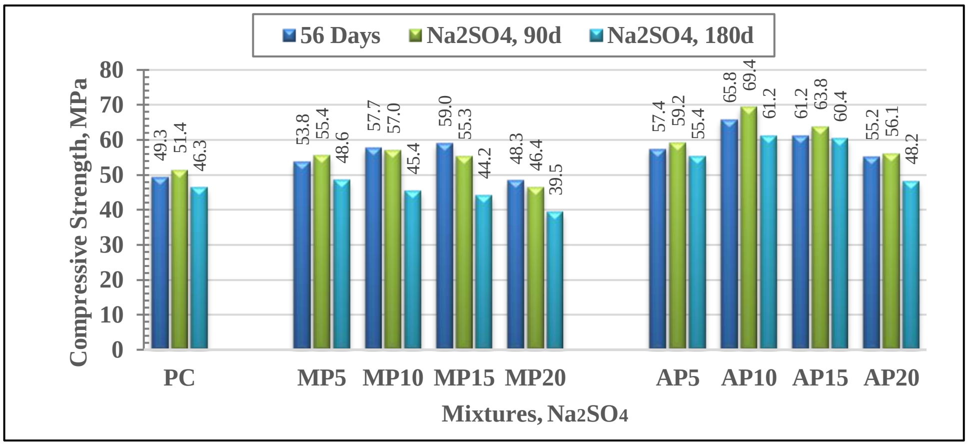

Fig. 5. Compressive strength of mortars exposed to Na_2SO_4.

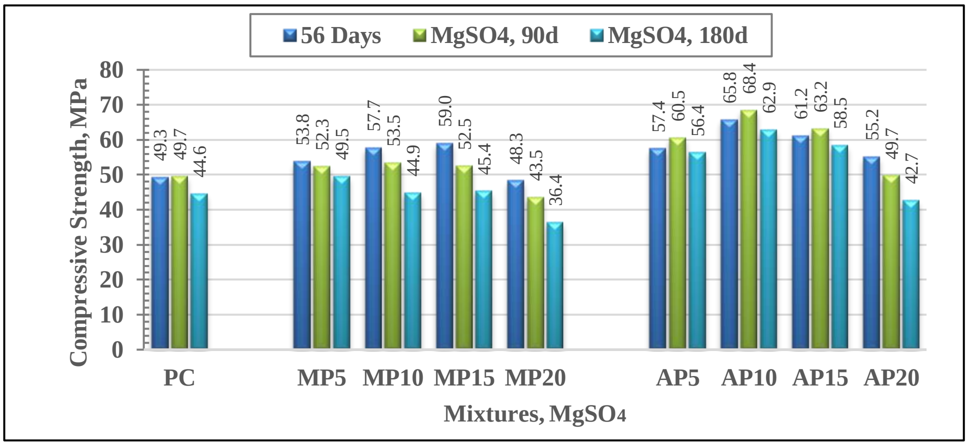

Fig. 6. Compressive strength of mortars exposed to $MgSO_4$.

5. Conclusions

- Utilization of AP and MP as substitution material for cement may contribute to reduce CO_2 emission by reducing cement consumption. Thus, it can help to conserve the environment.
- The most suitable replacement ratios for concretes containing MP and AP exposed to environmental conditions were determined as 5% and 10%, respectively.
- The strength development of mortar was affected by the level of cement replacement with AP. AP content greater than or equal to 10% is beneficial to the compressive strength of mortar, whereas the flexural strength significantly increases up to an AP content of 15% and begins to decrease at an AP content of 20%.
- The substitution of AP with PC up to 10% enhanced the acid and sulfate durability of the mortars, significantly.
- Substitution of MP by PC up to 15% increased the mechanical properties of mortars at ambient conditions. However, incorporation of MP in PC mortars had negative effect on the durability properties of the mortars. These states indicated that MP had only filler effect on the mortars with very low pozzolanic effect.
- HCI solution had more detrimental influence on the mortars than the sulfate solutions. The CS loss of mortars was in the range of 18% and 47% after immersion of 180d in HCI solution. The CS losses of mortars was in the ranges of 3-25% and 2-25% after immersion of 180d in Na_2SO_4 and $MgSO_4$ solutions, respectively.

The utilization of AP up to 20% substitution for cement is recommended for mortar production in respect of waste elimination. Besides, use of AP by cement is recommended in mortars subjected to hazardous environmental impacts.

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Conflict of Interest

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References

Ashish DK (2019). Concrete made with waste marble powder and supplementary cementitious material for sustainable development. *Journal of Cleaner Production,* 211, 716-729.

Beddoe RE, Dorner HW (2005). Modelling acid attack on concrete: part I. The essential mechanisms. *Cement and Concrete Research,* 35, 2333–2339.

Çelikten S, (2022). The influence of blast furnace slag content on the mechanical and durability properties of raw perlite-based geopolymer mortars. *Journal of Engineering Research,* 10(2B), 112-123.

Chindaprasirt P, Kanchanda P, Sathonsaowaphak A and Cao HT (2007). Sulfate resistance of blended cements containing fly ash and rice husk ash. *Construction and Building Materials,* 21(6), 1356–1361.

Collepardi M (2003). A state-of-the-art review on delayed ettringite attack on concrete. *Cement and Concrete Composites,* 25(4-5), 401–407.

Davraz M, Ceylan H, Topçu İB, Uygunoğlu T (2018). Pozzolanic effect of andesite waste powder on mechanical properties of high strength concrete. *Construction and Building Materials*, 165, 494-503.

Ergün A (2011). Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. *Construction and Building Materials*, 25(2) , 806-812.

Ghorbani S, Mohammadi-Khatami M, Ghorbani S, Elmi A, Farzan M, Soleimani V, ... & Tavakkolizadeh M (2020). Effect of magnetized water on the fresh, hardened and durability properties of mortar mixes with marble waste dust as partial replacement of cement. *Construction and Building Materials*, 121049.

Hamidi M, Kacimi L, Cyr M, Clastres P (2013). Evaluation and improvement of pozzolanic activity of andesite for its use in eco-efficient cement. *Construction and Building Materials,* 47, 1268-1277.

Ismail S, Ramli M (2013). Engineering properties of treated recycled concrete aggregate (RCA) for structural applications. *Construction and Building Materials,* 44, 464-476.

Kara İB, Arslan M, (2020). Effects of plasticizer and antifreeze on concrete at elevated temperatures and different cooling regimes. *Revista de la Construcción,* 19(3), 347-357.

Karakuş A (2011). Investigating on possible use of Diyarbakir basalt waste in stone mastic asphalt. *Construction and Building Materials*, 25(8), 3502-3507.

Khodabakhshian A, Ghalehnovi M, De Brito J, Shamsabadi EA (2018). Durability performance of structural concrete containing silica fume and marble industry waste powder. *Journal of Cleaner Production*, 170, 42-60.

Khyaliya RK, Kabeer KSA, Vyas AK (2017). Evaluation of strength and durability of lean mortar mixes containing marble waste. *Construction and Building Materials,* 147, 598-607.

Naik TR (2008). Sustainability of concrete construction. *Practice Periodical on Structural Design and Construction*, 13(2), 98-103.

Rana A, Kalla P, Csetenyi LJ (2015). Sustainable use of marble slurry in concrete. *Journal of Cleaner Production*, 94, 304-311.

Rashwan MA, Al-Basiony TM, Mashaly AO, Khalil MM (2020). Behaviour of fresh and hardened concrete incorporating marble and granite sludge as cement replacement. *Journal of Building Engineering*, 32, 101697.

Sancak E, Özkan Ş (2015). Sodium sulphate effect on cement produced with building stone waste. *Journal of Materials*, 2015.

Sariisik A, Sariisik G, Şentürk A (2011). Applications of glaze and decor on dimensioned andesites used in construction sector. *Construction and Building Materials*, 25(9), 3694-3702.

Sarkar R, Das SK, Mandal PK, Maiti HS (2006). Phase and microstructure evolution during hydrothermal solidification of clay–quartz mixture with marble dust source of reactive lime. *Journal of the European Ceramic Society*, 26(3), 297-304.

Selim FA, Hashem FS, Amin MS (2020). Mechanical, microstructural and acid resistance aspects of improved hardened Portland cement pastes incorporating marble dust and fine kaolinite sand. *Construction and Building Materials*, 251, 118992.

Shanahan N, Zayed A (2007). Cement composition and sulfate attack. Part I, *Cement and Concrete Research*, 37(4), 618–623.

Shi C, Stegemann JA (2000). Acid corrosion resistance of different cementing materials. *Cement and Concrete Research,* 30, 803–808.

Singh M, Srivastava A, Bhunia D (2017). An investigation on effect of partial replacement of cement by waste marble slurry. *Construction and Building Materials,* 134, 471-488.

Sogancioglu M, Yel E, Yilmaz-Keskin US (2013). Utilization of andesite processing wastewater treatment sludge as admixture in concrete mix. *Construction and Building Materials*, 46, 150-155.

TS EN 196-1 (2009). Method of testing cement, Part 1. Determination of strength. Turkish Standard, Ankara, Türkiye.

TS EN 197-1 (2012). Cement – Part 1: Composition, specification and conformity criteria for common cements. Turkish Standard, Ankara, Türkiye.

TS EN 1015-11 (2000). Mortar Testing Method. Part 11: Measurement of Compressive and Flexural Tensile Strength of Mortar, Turkish Standard, Ankara, Türkiye.

Yamanel K, Durak U, İlkentapar S, Atabey İİ, Karahan O, Atiş CD (2019). Influence of waste marble powder as a replacement of cement on the properties of mortar. *Journal of Construction,* 18(2), 290-300.

Yang KH, Jung YB, Cho MS, Tae SH (2015). Effect of supplementary cementitious materials on reduction of CO_2 emissions from concrete. *Journal of Cleaner Production*, 103, 774-783.

Zhang S, Cao K, Wang C, Wang X, Wang J, Sun B (2020). Effect of silica fume and waste marble powder on the mechanical and durability properties of cellular concrete. *Construction and Building Materials,* 241, 117980.