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Experimental Investigation on Mechanical Properties of WGP-Metakaolin Cement Mortars

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ABSTRACT

Disposal of waste materials poses a major problem worldwide. This paper presents the results of laboratory research that examines the incorporation of waste glass particles (WGP) as a partial replacement for the sand in cement mortars. Some mechanical properties of these WGP mixtures are studied while, for the first time, the combination of these mixtures with metakaolin (MK) is investigated as ordinary-weight mortar. In this research, the performance of cement mortar mixtures incorporating 5%, 10% and 15% of WGP as fine aggregate and 10% of MK as cement replacements was investigated. In this study, mainly two sets of mortar specimens were made by using two types of WGP. In the first set, WGP included "passed sieve #4 - remained sieve #8" but in the second set, WGP included "passed sieve #8 – remained sieve #16". Hence to examine characteristics of WGP-MK mortar, 9 groups of mortar, totally 135 specimens containing 15 control samples were made. Compressive strength and water absorption test were performed and the results were analyzed. Results showed an increase in compressive strength in each set with 5% replacement but a decrease in compressive strength with 15% replacement whereas with 10% replacement, no major changes on compressive strength of mortar would occur. In the case of 15% WGP-containing mortar, the decrease of compressive strength is compensated with MK. However, the water absorption results for the second set are desirable. By using combined 15% WGP with 10% MK, a kind of mortar is obtained that is environment friendly (because of using WGP) without major changes compared with control mortar.

Key Words: Waste Glass Particles, Metakaolin, Mechanical Properties, Recycling

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1. INTRODUCTION

Waste materials have continued to increase due to the continued demands of resource use. The use of glass has been growing all over the world in packing, automotive, construction and industrial applications. This results in a great generation of urban and industrial waste that can be stored or eliminated. With increasing restrictions on landfills, industries have to find effective ways for recycling their wastes and by-products. From the viewpoint of the sustainable society, recycle of wastes is one of the most important purposes as the global environmental problem. Waste materials as partial replacement of natural aggregates or cement in concrete, including construction and demolition waste [1], agricultural waste [2], inorganic wastes [3], mining waste [4], municipal solid waste [5], wood waste ash [6], footwear industry waste [7], steel chips waste [8], waste polymer modifier [9], tire rubber [10-12], glass [13-16] etc have been studied. These replacements reduce the demand on the natural resources for construction materials and provides multiple alternatives to the traditional ingredients of concrete mixes [17-19]. Glass aggregates are grainy particles with a smooth surface structure and a very low ability to absorb water. These properties contribute to the reduced strength of the concrete as well as reduced drying shrinkage [20-23]. Researchers have studied the use of waste glass powder because of its high silica content [24-26]. Glass, which is an amorphous material, has been shown to exhibit pozzolanic properties when ground finer than 75 lm, [24,26].

Besides, pozzolanic materials as partial replacement of cement in concrete or cement mortars, including silica fume, zeolite, fly ash, blast furnace slag, metakaolin [27-30] etc also have been studied. A review of the literature has revealed that MK as partial cement replacement cause to improve some mechanical properties and durability of concrete. The results show on average an increase in compressive strength and a decrease in water absorption when MK is added as cement replacement. H. Paiva et al investigated the effect of MK dispersion on the fresh and hardened state properties of concrete. Their work allowed concluding on the relevance of using high range water reducer admixture to control workability in concrete formulations including MK, or other fine particle systems, in order to achieve a good dispersion and a better efficiency [29]. Hasanzadeh et al studied the mechanical properties of concrete containing MK and indicated that there was an increase in the compressive strength and decrease in the proportion of water absorbed by concrete containing MK [30]. Hasanzadeh et al replaced sand with crumb rubber from worn vehicle tires in various proportions and proportions of cement with MK, compensating with MK the decrease in compressive strength caused by using rubber in concrete [31].

This study investigates the use of WGP as alternative to aggregates and MK as alternative to cement in the production of cement mortar specimens. The performance of the specimens was investigated through compressive strength and water absorption.

2. Experimental procedure

2.1. Materials used

Materials used to produce mortars in this study are fine aggregates, Portland cement type II (complying with Iranian specification 389), water, MK, WGP and superplasticizer. Crushed mixed natural sand with a specific gravity of 2.61, bulk density of 1770 kg/m3 and saturated surface-dry absorption of 4.1% was used. Grain size distribution for fine aggregate used is shown in Fig 1. A proportion of 443 kg of cement per cubic meter was obtained for the mortar mix design. The fixed water-to-cement ratio of 0.47 and the consumer water used was drinking water. In the mix design, MK replaced 10% volume of the cement. Replacement of cement with 10% MK was made based on previous studies and economic considerations [30]. The physical properties of the MK used and the chemical compositions of cement and MK used are presented in Tables 1 and 2 respectively. Glass particles (Fig. 2) were prepared from recycled construction waste glass with specific gravity equal to 2.5. In the mix design, WGP replaced 5%, 10% and 15% volume of the sand. Also in the mixes, superplasticizer (known by brand name Gelenium) with a polycarboxylic base in a proportion of 1.5% weight cement materials were used, with the specifications presented in Table 3.

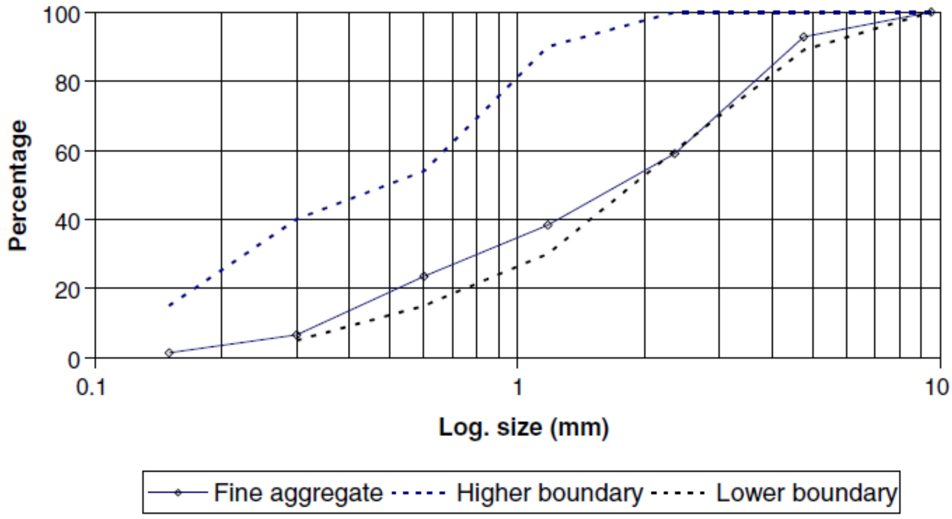

Fig. 1: Fine aggregate grading, with the Iranian Standard boundaries.

Table 1: Physical properties of MK used in the study

Color	PH	Specific Gravity	Bulk Density (Kg/Lit)	Blain Specific Surface (cm^2/gr)	Interaction with Lime, mg/gr (Chapelle Test)
White	4-5	2.6	0.4-0.5	22000-25000	740-1000

Table 2: Chemical composition of consumed cement & MK

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	L.O.I.
cement	63.2	22.5	4.9	3.6	1.8	1.5	0.6	0.2	1.05
MK	0.09	53	45	0.9	0.03	-	0.03	0.1	1

Table 3: Specification of the superplasticizer used

Physical State	Color	Base	Ion Chlorine	Unit Weight gr/cm^3
Liquid	Bluish Yellow	Polycarboxylic Ether	Chlorine Ion-Free	1.1

Fig. 2: Waste glass particles.

2.2. Mixture proportions

Mainly in addition to the control sample, two sets of mortar specimens were made by using two types of WGP. In the first set, WGP included “passed sieve #4 - remained sieve #8” but in the second set, WGP included “passed sieve #8 – remained sieve #16”. In the both sets, 5%, 10%, and 15% by volume of fine aggregates were replaced by WGP. The mixtures were designated as Sx-Ry, which stands for ‘Set Number ‘x’, Replaced Aggregate by ‘y’ percent’, The mixtures containing MK are designated as Sx-Ry-M10. The control mixture in this research is designated as ‘C’. Mixture proportioning for control sample is sand:1803, cement:443, water:201, superplasticizer:6.6 kg/m3.

2.3. Mixing, casting and testing

The interior of the mixing drum was initially wetted with water to minimize absorption of water added as a part of the mortar mixture. At first MK was mixed with part of the water as the same weight containing half of the required amount of superplasticizer, followed by the fine aggregates, WGP, cement, remained water, half of the superplasticizer was always retained to be added during the last 3 min of the mixing period. After casting, all mortar specimens were covered with wet burlap in the laboratory at 21 ± 1 _C and 65% relative humidity for 24 h. Twenty-four hours after placing mortar in moulds, samples were demoulded and were kept in a completely humid environment (95 ± 5% RH and temperature of 21 _C) for 28 days.

The compressive strength of specimens was determined according to the British Standard BS 1881:part 116:1993. To conduct compressive test, cubic samples of 70*70*70 mm were used. The compressive strength test was conducted at day 28 and loading speed of 0.25 Mpa/sec. For each case, five samples were tested and averaged. To determine water absorption, samples were tested according to BS 1881-122:1983, i.e., the water absorption of concrete specimens was determined from the mass difference of the sample between dry and wet states divided by its mass in dry condition.

Hence to examine characteristics of WGP-MK mortar, 9 groups of mortar, totally 135 specimens containing 15 control samples were made. Compressive strength and water absorption test were performed and the results were analyzed.

3. Results and discussion

The results of the compressive strength test on the 28-day old samples are presented in Figure 3. As seen, the presence of 5% WGP in the cement mortar results in an about 10% and 14% increase in the compressive strength in set 1 and 2 respectively. The presence of 10% WGP in the cement mortar results in an about 3% decrease in set 1 but 5% increase in set 2. The presence of 15% WGP in the cement mortar results in an about 17% and 9% decrease in the compressive strength in set 1 and 2 respectively. The presence of 10% MK in the cement mortar leads to about 8% increase in the compressive strength of the mortar compared to the control mortar. The presence of combined 15% WGP and 10% MK in the cement mortar results no major changes in the compressive strength compared to the control mortar.

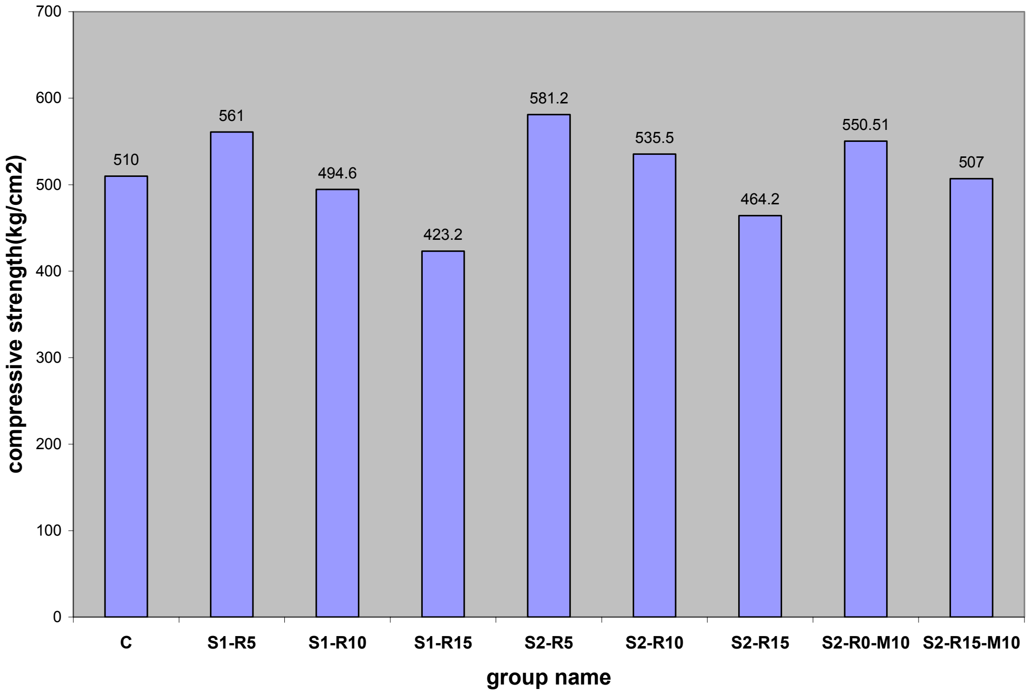

Figure 3: Results of compressive strength test on 28-day old samples

The results of the water absorption test on the 28-day old samples are presented in Figure 4. As seen, the presence of 5% WGP in the cement mortar results in an about 11% increase of water absorption in set 1 but 15% decrease in set 2. The presence of 10% WGP in the cement mortar results in an about 13% increase in set 1 but 17% decrease in set 2. The presence of 15% WGP in the cement mortar results in an about 19% and 5% increase in the water absorption in set 1 and 2 respectively. The presence of 10% MK in the cement mortar leads to about 10% decrease in the water absorption of the mortar compared to the control mortar. The presence of combined 15% WGP and 10% MK in the cement mortar results no major changes in the water absorption compared to the control mortar.

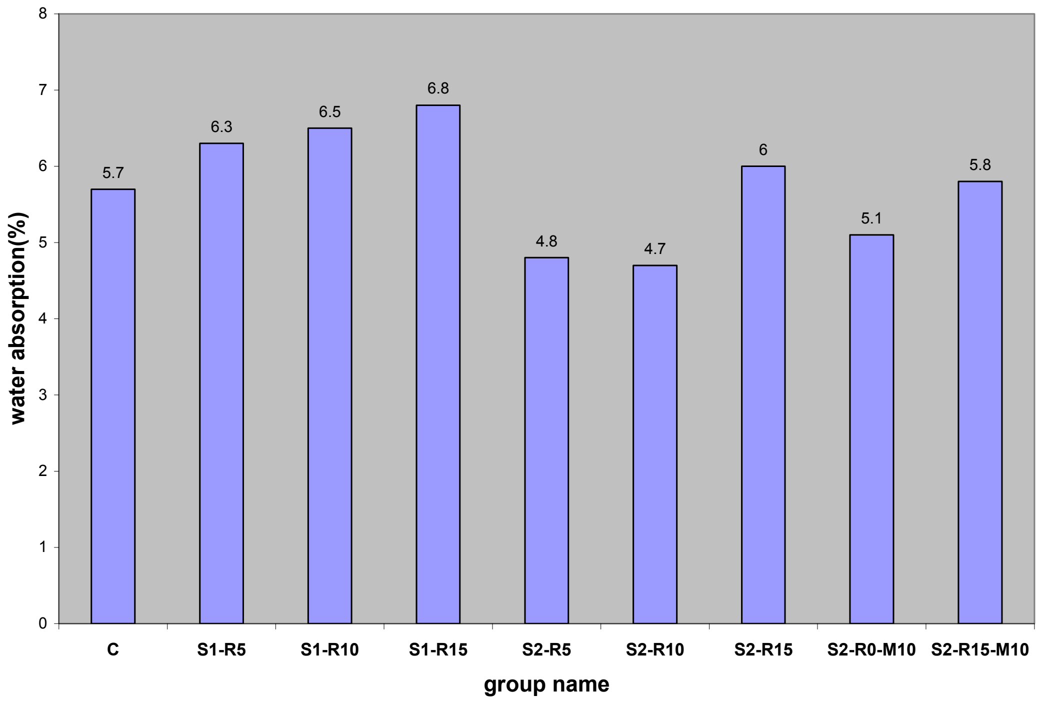

Figure 4: Results of water absorption test on 28-day old samples

Since the interaction of MK and calcium hydroxide (Figure 5) result in silicates and hydrated calcium aluminosilicates, stable and insoluble cement products, although calcium hydroxide is a soluble product, when such stable products are formed, the mortar strength increases. Also, the increase in the strength and decrease in the water absorption can be attributed to a decrease in porosity, denser cement paste, transition zone and formation of hydrated silicate. The increase in the strength by using 5% WGP can be attributed to improvement in fine aggregate grading and this is more noticed with finer WGP.

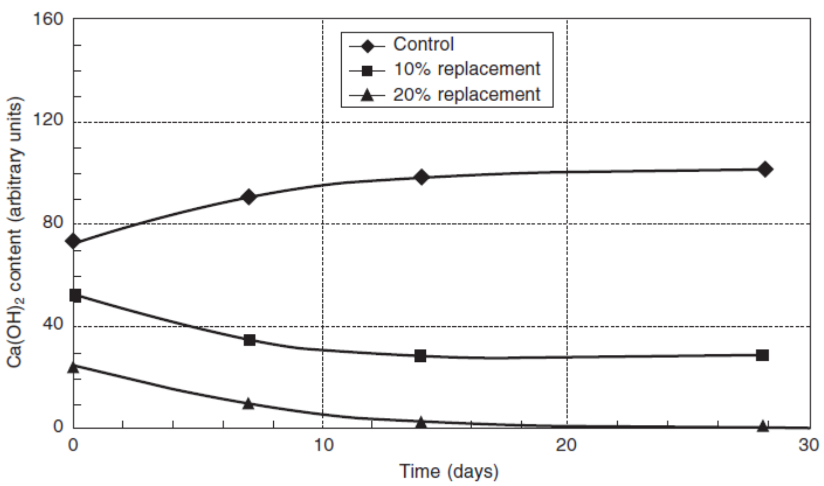

Figure 5: The effect of MK on the Calcium Hydroxide content of concrete (Larbi & Bijen, 1991) [32]

The compressive strength and water absorption of mortars containing 15% WGP combined with 10% MK have no major changes compared with control mortar. This indicates the positive effect of using two substances combined (i.e. WGP and MK) in the cement mortar. It can be implied that using over 15% WGP in cement mortar triggers a major decrease in the compressive strength and increase in the water absorption. Hence, replacement up to 15% WGP (specially combined with MK) is referred to as optimal proportion for compressive strength and water absorption. Consequently, a kind of mortar is obtained that is environment friendly (because of using WGP) without major changes compared with control mortar.

4. Conclusion

In this study, the compressive strength and water absorption after 28 days and WGP-MK mortars were studied whereupon the summary more important findings are as follows:

- Incorporating 5% of WGP as fine aggregate in the cement mortar results in an about 10-14% increase in the compressive strength. By using 10% WGP as sand replacement, no major changes on compressive strength of mortar would occur. The presence of 10% MK in the cement mortar leads to about 8% increase in the compressive strength of the mortar compared to the control mortar.
- The use of WGP (passed sieve #4 - remained sieve #8) in cement mortar cause to increase water absorption but the use of WGP (passed sieve #8 – remained sieve #16) up to 10% cause to decrease water absorption of mortar. The presence of 10% MK in the cement mortar leads to about 10% decrease in the water absorption of the mortar compared to the control mortar.
- It can be implied that using over 15% WGP in cement mortar triggers a major decrease in the compressive strength and increase in the water absorption. Hence, replacement up to 15% WGP (specially combined with 10% MK) is referred to as optimal proportion for compressive strength and water absorption.
- By using combined 15% WGP with 10% MK, a kind of mortar is obtained that is environment friendly without major changes compared with control mortar.

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