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Research Article

Assessment of strength and abrasion resistance of elasto-plastic fiber reinforced concrete using geopolymer based recycled aggregates

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ABSTRACT

Recycled aggregates and geopolymer binders are green materials contributing to the sustainability of the planet. We investigated the performance of geopolymer concrete using recycled aggregates (fly ash (FA) and ground granulated blast furnace slag (GGBS)) related to their mechanical properties. Geopolymer concrete were prepared by mixing 50% low calcium fly ash, 50% GGBS, sodium hydroxide and sodium silicate solution, Coarse aggregate (Natural coarse aggregate, Recycled coarse aggregate), Fine aggregate (Crushed Sand, Riverbed Sand) and elastoplastic fibers. Recycled aggregate used was obtained locally from Istanbul, Turkey. To explore the efficiency of recycled aggregate, during the production of geopolymer concrete, partial replacement of recycled coarse aggregate with natural aggregate was made in 10, 20, 30, and 40%. To compare the results, geopolymer concrete containing 100% natural aggregates was made. Since concrete gains strength with time after casting, On Day-28 and Day-90, the compressive strength, split tensile strength, and flexural strength of those geopolymer based concrete were examined. Results of the test showed that the compressive strength of 28 and 90 days w.r.t. different ratios was 26.8, 25.3, 24.2, 23.1, 23 MPa, and 30.2, 28.1, 27.0, 25.2, 25.0, 23.0 Mpa respectively, while split tensile strength was 1.9, 1.5, 1.5, 1.4, 1.4 MPa and 2.0, 1.9, 1.9, 1.6, 1.5 MPa respectively, and the ultimate flexural strength of tested beams were in the range of 3.53 to 4.54MPa. Although the general performance of the produced samples was showing a decrement with the increasing ratio of recycle aggregates, the obtained results indicated that using recycled aggregate is up to some extent of 30% is beneficial in terms of strength.

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INTRODUCTION

With the increase of environmental concerns related to production and usage of ordinary cement-based reinforced concrete, scientists have been vigorously engaged with investigating prospects of utilizing alternative materials to address these concerns [1,2]. To decrease this problem Geopolymer is regarded as an inventive construction material and it had impressive interest from researchers around the world [3]. Consuming geopolymers fabricated by industrial byproducts to replace cement completely or partially can decrease cement consumption, hence dropping CO_2 emissions [4]. On the contrary, Recycled aggregate extracted from recycled concrete can consume accumulated construction byproducts and save non-renewable materials and land resources. The amalgamation of the two materials can protect the environment and save resources [5]. Trying to decrease the reliance on customary concrete constituent materials, which are fast consuming it is found that the alternative concrete composing materials such as recycled aggregate, fly ash and granulated blast furnace slag can contribute strength and durability to the concrete [6,7,8]. On the other hand, the annual production of cement in the world is estimated 1.6 billion tons which contributes 1.6 billion tons of CO_2 into the environment. In other words, cement industry is counted as the major CO_2 emission source, which generates 5–7% of entire CO_2 in the globe [9,10,11]. This amount of carbon dioxide release is projected to cause the climate change. According to performance and mechanical properties of fly ash and slag based geopolymer concrete with recycled aggregate instead of Portland cement-based concrete could contribute strength development. But further increasing recycled aggregate contents in both recycled aggregate concrete and geopolymer recycled concrete, the strength was decreased steadily. the low water availability between old mortar and aggregate causes the formation of weaker (ITZ) interfacial transition zone. The controlling factor for recycled aggregate geopolymer concrete strength failure is projected to be caused the weaker link of ITZ [12]. Through microstructure analysis it is proved that two factors owing to strength weaken, was increased recycled aggregate and the structure of interfacial transition zone (ITZ) [13].It is proved that making 10% replacement of recycled concrete aggregate of natural aggregate the compressive strength plus split tensile strength increased. Furthermore, curing ambient condition for 10% replaced recycled aggregate of natural aggregate in geopolymer concrete, the flexural strength showed good result over compressive strength [14].In this study, geopolymer fabricated from the combination of GGBFS and FA will be used as a binder and RA was partially replaced in NA. This study explores the mechanical and durability properties of elastoplastic fiber reinforced GPC with RA.

MATERIALS AND METHODS

In this study we investigated 5 series of geopolymer mixes. Mixes were conducted with the inclusion of 0.4% ratio of elasto-plastic fiber (EP) and the properties of EP is given in table 2. Also, through the whole mixes recycled aggregate was replaced of natural aggregate in different percentages of 10%, 20%, 30% and 40% by weigh. The first mix containing same proportion of compositions to other four mixes but 100% natural aggregate, was casted as a control sample. Also, for the fabrication of each mixture total binders used contains Fly ash, GGBFS, Sodium silicate and Sodium hydroxide Both were acquired from a Chemicals Company called Merck in turkey. The weight ratio of FA and GGBFS was contained an equal weight ratio of 50% FA and 50% GGBFS. Fly ash used in the study was sourced from Cates electrical production Inc., a thermal power plant located in a northern city in Turkey called Çatalağzı/Zonguldak and has a specific gravity of 1.96 g/cm^3 while the GGBS material used in this study was obtained from a cement company in Bolu Turkey that has specific gravity of 2.91g/cm^3. The chemical compositions of FA and GGBS are listed in Table 1.

In the experiment, cube molds of (100×100×100) mm, cylinder molds of (100×200) mm and Beam molds of (100×100×500) mm were used. Molds were oiled with grease to ease the demolding process. Firstly, dry materials namely, No.1 Natural coarse aggregate, No.2 Natural coarse aggregates, No.1 and No.2 Recycled coarse aggregate and fine crashed sand aggregates attained from DÖKMAK Foundry Industry which is in Darıca-Gebze/Kocaeli. with fly ash and GGBFS were mixed for at least 2 min properly, and then, chemicals which were prepared one day prior to use were added along with fibers and mixed for 3 more min. To achieve a better workability MasterGlenium51 supplied by BASF Türk Kimya San. ve Tic. Ltd. Şti. based in Turkey was added. Owing to physical design of the mixer drum each mixture was casted in three batches.

Table 1. Chemical composition of fly ash and slag (%).

Chemical composition	Amount (%)	
	GGBS	Fly ash
SiO_2	40.55	54.08
Al_2O_3	12.83	26.08
Fe_2O_3	1.10	6.681
CaO	35.58	2.002
MgO	5.87	2.676
SO_3^{-2}	0.18	0.735
Na_2O	0.79	0.79
Cl^-	0.0143	0.092
LOI (loss of ignition)	0.03	1.36

Table 2. Elasto-plastic fiber (EP) properties

Type of Fiber	Length (mm)	diameter (mm)	Width (mm)	Slenderness (Lf/de)	Tensile strength (MPa)	Elastic modulus (GPa)	Shear modulus (pa)
EP	40	0.78	1.1	51.3	450	3.6	1.28

RESULTS AND DISCUSSION

Three parameters of compressive, splitting tensile strength and flexural strength were investigated in 28 and 90 days. The test results are shown in Figures 1 and 2. After examining both 28- and 90-days it is noted that as the recycled aggregate proportions increased, strength results were found to be decreased. The reduction degree was found to be significant in the case of 30% and 40% replacement of the recycled aggregate. However, 10% and 20% caused insignificant reduction in strength. the combination of binders was 50% GGBS and 50% fly ash having 0.45 W/B ratio. This combination exhibited an excellent performance in mechanical properties but decreased the workability for the replacement beyond 20%. As expected, geopolymer with natural aggregates showed higher strength than the geopolymer concrete with recycled aggregate, existed cracks in recycled aggregate are the main defects causing the lower strength in compliance with Wangetal. [15]. Also, the void volume is high and existed calcium hydroxide in old and new interfacial zones in recycled geopolymer is an agent of effect in strength [16]. The highest compressive strength was achieved in 28 days specimens result was 26.8 MPa which is mix one and mix 5 found to be the lowest strength having only 23.0 MPa. While for the 90 days results mix one performed the highest strength which is 30.2 MPa also the lowest was mix 5 which is 25.0 MPa. Highest splitting tensile strength in 28 days was mix 1 which is 1.92 MPa and lowest -was mix 5 which is 1.39 MPa and for 90 days test results mix 1 showed highest result which is 1.96 MPa while lowest was mix 5 which is 1.5 MPa. Highest flexural strength result of 28 days test result was exhibit by mix 2 which is 3.48 MPa and lowest was M5 which is 2.11 MPa, for 90 days highest result performed by mix 5 which is 4.54 MPa and lowest was mix 1 which is 3.53 MPa. Also, for durability one of the parameters explored was abrasion. Abrasion resistance of measured specimens was assessed in terms of weight loss. The test of abrasion resistance measurement was conducted in compliant with BS EN 13892-3:2014 [17], which determines horizontal abrasion resistance of concrete surfaces. Results showed that natural aggregates resulted in less weight loss compared to recycled aggregate this may be caused by the increase of void content

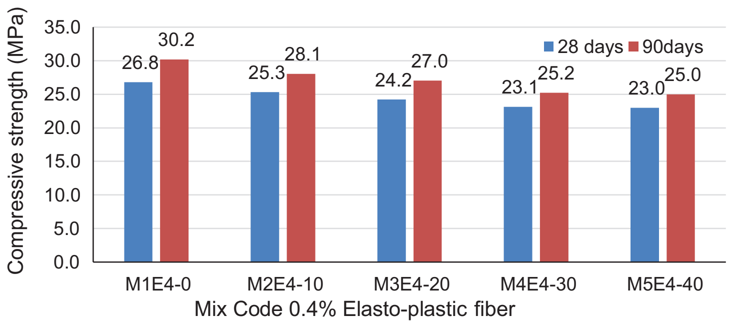

Figure 1. Compressive strength results.

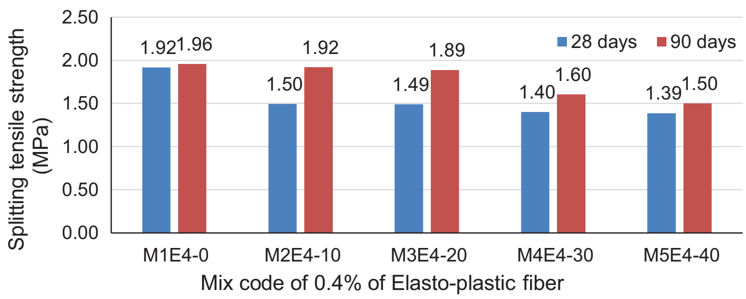

Figure2. Splitting tensile Strength results.

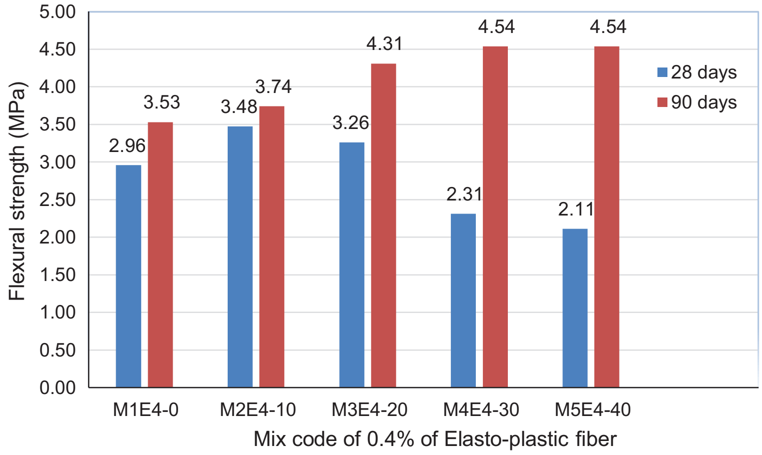

Figure 3. Flexural strength results.

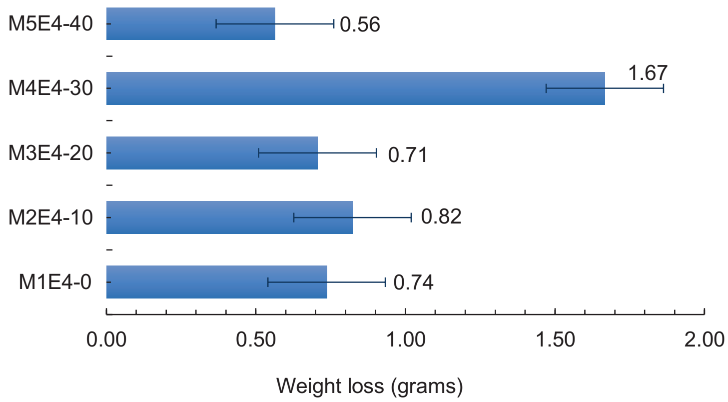

Figure 4. Average weight loss due to abrasion for 0.4% fiber inclusion.

and porosity that exists inside the recycled aggregates that weakened its wear-resisting strength [18, 19].

CONCLUSIONS

This experiment was conducted with fly ash and GGBS based geopolymer concrete with different proportions of recycled aggregate reinforcing with elasto-plastic fibers, after performing compressive, splitting and flexural tests following conclusions can be accounted:

- Using recycled aggregates in the geopolymeric matrix up to a certain limit is feasible in terms of utilizing wastes and by-product materials, thus, creating a sustainable binding material is achievable.
- Using non-cementitious binders such as GGBS and fly ash instead of ordinary Portland cement (OPC) in the matrix could result in improved strength of the recycled aggregates geopolymer concrete.
- based on the research results to achieve excellent mechanical properties and workability the incorporation of Fly ash and GGBS binder having 1:1 ratio with 0.45 water-binder ratio can give promising geopolymer concrete.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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