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Properties of polypropylene fiber reinforced concrete using recycled aggregates

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HIGHLIGHTS

- Recycled aggregates were incorporated into mixtures by ratio of 25–30–55%.
- Compressive strength between 32 and 43 MPa was attained with recycled aggregates.
- Optimum fiber content was determined as 1% by volume.
- The greatest negative impact of RCA was experienced at water penetration depths.
- Use of RCA is more suitable at constructions that have low structural risk factor.

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ABSTRACT

In this study, recycling of rubble obtained during urban transformation and manufacturing new concrete using this material was experimentally studied. Different combinations were generated using the recycled concrete aggregates and polypropylene fiber. Natural aggregates were replaced by recycled concrete aggregates (RCAs) and volume of 0%, 1% and 1.5% fiber were introduced for each series. Although concretes' physical and mechanical properties were affected negatively by RCA due to RCA's higher porosity and water absorption capacity, high strength concrete was eventually manufactured. Additionally, although fiber content increases flexural properties, there is no significant difference observed between 1% and 1.5%. Percentage contribution ratios of parameters which influence the results of experiments were also calculated by means of analysis of variance (ANOVA) method. As the result of ANOVA which is carried out on specimens containing fiber and recycled concrete aggregate, main factor on changes of compressive strength were determined as aggregate type, while fiber content were also influential on flexural and splitting tensile strength besides aggregate type.

1. Introduction

Recycling has become prominent in construction industry in the last decades with the term of sustainable structural materials. In the case of not providing sustainable material flow, it is possible to deplete natural resources, since they are not unlimited.

Urban Transformation Project has been put into practice in 2012 and will take approximately 20 years in Turkey [1]. As a result of the project, more than 5 million tons of construction and demolition waste (C&D waste) will be produced annually. Due to the fact that it takes 50% of raw materials from nature, consumes 40% of total energy and creates 50% of total waste [2], construction has become a critical industry in respect to term of sustainable materials. Amount of recycled or landfilled C&D wastes differs from country to country. In Hong Kong, approximately 20 million tons of C&D waste was produced in 2004. While 12% of the waste was disposed of at landfills, 88% was used as filling materials [3]. 180 million tons of C&D waste is generated in European Countries per year. Only 28% is recycled and reused; rest of it is sent to landfills. Netherlands, Denmark and Belgium are the most accomplished EU countries on waste management via recycling generated wastes 90%, 81% and 87%, respectively [4]. It is necessary to stated that studies for the reuse of waste that is generated during construction or demolition process should be carried out especially in fast developing countries in construction industry (such as Turkey). However, due to the fact that people are not able to abandon customary methods, aggregate being a cheap structural material and lack of recycling consciousness; RCA does not have a wide-spread use in Turkey as well as many countries. RCA is

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Table 1
Chemical composition of the cement (%).

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl^-
CEM I 42.5R	19.8	4.7	3.18	64.35	1.27	0.64	0.35	2.49	0.008

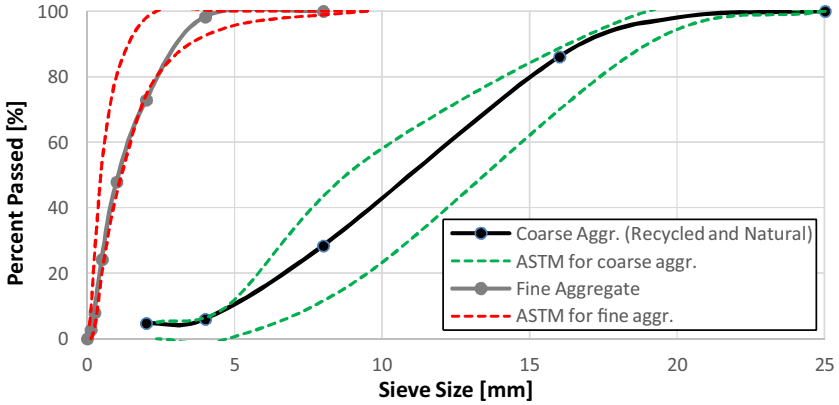

Fig. 1. Aggregates grading.

Table 2
Content of the recycled concrete aggregate.

Content	Concrete particles	Brick&Tile particles	Gypsum particles	Shell particles	Stucco particles	River aggregate	Glazed tile
%	97.53	1.74	0.20	0.17	0.13	0.13	0.10

mostly used as a filling material for building construction, road foundations and hydraulics work spaces [5].

Investigations of RCA usability in structural concrete manufacture are gaining popularity day by day. Rakshvir and Barai [5] and Kartam et al. [6] state that RCA is able to be used in structural concrete rather than its use as filling material. In Spain, use of RCA in structural concretes has been regulated and encouraged with a regulation (EHE-08) that has been put into effect [7]. Committee of American Concrete Institute (ACI) put emphasis on reuse of concrete waste by publishing a document called "Removal and Reuse of Hardened Concrete" in 2001. Also in Turkey, there is a regulation which indicates that debris is able to be used in the manufacturing of concrete with or without raw materials [8].

In literature, unless natural aggregate is replaced by more than 20–30% by RCA, it is seen that there is no significant negative influence of RCA on physical and mechanical properties of concrete [9–13]. Despite the fact that loss of approximately 20% of compressive strength is observed in the case of 100% RCA replacement, it is possible to come up with discrepancies on achieved results. These discrepancies may be arisen by heterogeneous structure of RCA.

Sheen et al. [14] investigated the effect of brick and tiles presence in RCA. As a result of the experimental study, decreasing is observed on compressive strength of concrete due to high water absorption capacity of fine grained RCA. Furthermore, decreasing compressive strength also depends on content of brick and tile. Additionally, a 10–23% loss (arising from brick and tile content) in the flexural tensile strength is observed on concrete prepared with recycled aggregate when compared with control specimen. While Ajdukiewicz and Kliszczewicz [15] stated that concretes manufactured with RCA has 10% lower flexural strength, Topçu and Şengel [16] observed a reduction of 13% on flexural strength when replacement ratio reaches 100%. In another research, it is stated that failure was generally observed on brick and tile particles that was called the mechanically weakest point [17].

Although some authors such as Matias et al. [4] reporting that replacement ratio (natural aggregate by recycled aggregate) does not have a considerable influence on splitting tensile strength as much as seen on compressive strength, Vazquez et al. [18] observed a reduction within the range of 6–20% when replacement ratio is increased to 100%. However, loss of strength was negligible when RCA incorporation ratio was lower than 50%. Evangelista and De Brito [19] confirmed Vazquez et al. that loss of 5% was observed with replacement of 30%, and 23% with 100%.

In the study [13] on recycled aggregate concretes' (RAC) water penetration depth under pressure, water penetration depths are observed to be around 30 mm independent from the replacement ratio when water/cement (w/c) ratio is lower than 0.45. In another study, it is stated that penetration depths are respectively 15, 16 and 17 mm for replacement ratios of 0%, 20% and 30% [20]. Besides, concretes having 5%, 11% and 19% RCA have a lower modulus of elasticity for incorporation ratios of 20%, 50% and 100%, respectively [13]. Having low resistance to deformation is due to porous structure of RCA which has a significant influence on modulus of elasticity.

This study is aimed to investigate usability of polypropylene fiber in recycled aggregate concrete in order to be used primarily in field concrete, since the use of PP fiber in field concrete is gaining popularity nowadays. How fiber usage influences physical, mechanical and durability properties of RAC is not common in the existing studies of literature. For this purpose, different polypropylene fiber contents have been introduced into concretes that have different amount of RCA. Parameters of unit weight, ultrasonic pulse velocity, compressive strength, splitting tensile strength, flexural tensile strength, pull-out behavior of PP fibers, static and dynamic modulus of elasticity and water penetration depth under pressure were investigated.

2. Experimental programme

In this study, RCAs (4/16 and 8/32 mm) were incorporated into the mixture by replacing natural coarse aggregates which have the same granulometry. Afterwards, volume of 0%, 1% and 1.5% polypropylene fibers were used in mixtures for each series. In this manner, 12 different mixtures were prepared and notation of mixtures was generated. Letters and numbers are used in the coding, "N" for natural