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Recycling of Polypropylene Fiber Reinforced Concrete

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Abstract **-** Many studies are conducted on recycled aggregates. Besides, the use of fiber in concrete is getting more and more widespread. Recycling of fiber-reinforced concrete is important for the environment. This study deals with the recycling of polypropylene fiber-reinforced concrete. The objective of the study is to use recycled aggregates obtained from polypropylene fiber-reinforced concrete in new concrete applications. Since a large portion of the volume of concrete is composed of aggregates, first the aggregate characteristics were investigated. Eight types of fibers were used in the study. Each type of fiber was added into concrete mixtures at three different ratios. The fiber ratios were 600 g/m^3, 1200 g/m^3 and 1800 g/m^3. So, 25 concrete mixtures were produced along with the mixture without fiber. All mixtures had the same water-cement ratio. Specimens had a diameter of 150 mm and a height of 300 mm. Their compressive strength ranged from 33.70 MPa to 45.17 MPa. Polypropylene fiber generally reduced the compressive strength of concrete. Specimens were crushed using a jaw crusher at the end of 120 days. From the crushing process, fiber-containing recycled aggregates were obtained with sizes of 0-4 mm, 7-15 mm and 16-22.4 mm. The sizes of pieces obtained from the crushing process declined as the amount of fiber increased. Fibers served as a bonding material, preventing the cement slurry from being scattered. Particularly, ribbed and hooked fibers were observed to have provided a better adherence with the cement slurry. Water absorption, freezing/thawing and impact strength properties of the aggregates were examined. The properties of aggregates used in the concrete mixture and of fiber-containing recycled aggregates were compared. Water absorption rate of fine aggregates ranged from 4.19% to 6.01%. As the size of fiber-containing recycled aggregates increased, their water absorption capacity increased as well. Weight losses after freezing and thawing varied between 7.1% and 8.2%. Weight losses after freezing and thawing increased. Impact strength of fiber-containing aggregates was approximately twice that of normal aggregates.

Keywords**:** Polypropylene fiber, recycled aggregate, water absorption, freezing-thawing, impact strength.

1. Introduction

Construction sector is consumer of natural resources. Concrete is the most used construction material of the construction sector. Cement and aggregate are the most important two component of concrete. Approximately 75% of the volume of concrete is composed of aggregate. The raw material of cement is natural aggregate. Constant taking of natural aggregate from the nature causes ecological imbalances [1-4]. Construction sector is also producer of waste [5]. Construction waste has been increasing day by day in the world. It is stated that 55% of the world's total cement consumption is done by China. China is both consumer of resources and producer of waste [6]. Construction waste and recycled aggregates generally used as packing material and road bases [7, 8]. Half of construction waste composes of concrete wastes. It is important for environment and economy to use these wastes in structural concretes [9, 11]. After the 1999 Earthquake in Turkey, only in Adapazarı approximately 2 million tonnes of waste concrete came out. It is stated that value of waste concrete was 5.5 million dollar [12]. In 2012, "Urban Transformation law" entered into force in Turkey. In this context, there will be more waste concrete as a result of demolishing risky buildings. There are more studies on using concrete waste, which increases day by day, on fresh concrete as aggregate [13]. It is stated that recycled aggregate may substitute normal aggregate in structural concrete. In a research it is stated that coarse aggregate and fine aggregate obtained from the source concrete having 30 MPa compression strength have more water absorption capacity respectively 11.5 and 3.5 times than normal coarse and fine aggregates. It is indicated that density of recycled aggregates is 20% less than density of normal aggregates [1]. By using up to 50% of recycled aggregates in concretes, it is possible to provide necessary strength and durability in house construction [14].

An important reason is the grain size distribution of recycled aggregate within the concrete [15]. It is stated that the most negative effect of using recycled aggregate on structural concrete is the fat mortar on the aggregate [16]. Water absorption value is higher on recycled aggregates than normal aggregates [1, 4, 6, 16-19]. As recycled aggregates contain cracks their water consumption is high [6]. It is stated that before using recycled aggregates at structural concrete, one should know well their components and physical features [17, 18]. Water absorption capacity of recycled aggregates increases with increasing strength of primary concrete that aggregate is produced from and decreases with raising maximum aggregate size. High water absorption capacity of recycled aggregate necessitates arrangements on amount of water of the mixture for the desired workability [19]. State of moisture of recycled aggregates changed the collapse aspects of the fresh concrete [20]. Extraction process gains high importance on productive use of recycled aggregate on structural concrete [21, 22]. Apart from this, using fibre in concrete increases day by day. Generally, steel and polypropylene fibres are used at concretes. There are not many researches on what to do with fibred concretes when its physical life ends. Recycling of fibred concretes is significant for the environment. A research analysed aspects of aggregates recycled from steel and polypropylene fibred concretes as an experiment. With the increase of fibre, pieces passing the sieve also increased. It is stated that in piece with sieve size of 20 mm, type and amount of fibre did not have an effect on water absorption value. It is deduced that in pieces with sieve size of 10 mm, water absorption is decreased with higher ratio of fibre [4].

This research analyses the recycling of polypropylene fibred concretes. Aim of research is to re-use of recycled aggregate of polypropylene fibred concretes in concretes. Hence firstly source concretes with and without polypropylene fibre were produced. Recycled aggregates with and without fibre obtained from breaking of source concretes were analysed.

2. Test Programs

2.1. Materials and Specimens

For producing source concrete, 0-4 mm, 7-15 mm and 16-22.4 mm sized broken aggregate was used. Type of cement is CEM I 42,5 R. Eight types of polypropylene fibres were used in fibred source concretes (Figure 1). Technical aspects of polypropylene fibres were given at Table 1. Three different ratios from each fibre adjusted to source concrete mixture. Ratios of fibre are 600 g/m^3, 1200 g/m^3 and 1800 g/m^3. 25 series of concrete were produced by mixtures without fibre. For producing source concrete, aggregates with broken aggregate showed by N, aggregates obtained from source concretes without fibre showed by K, aggregates obtained from source concretes with polypropylene fibre showed by A, B, C, D, E, F, G, H. For instance A6 means A fibre with 600 g/m^3 admixed; B12 means B fibre with 1200 g/m^3 admixed; C18 means C fibre with 1800 g/m^3 admixed. Water-cement ratio was constant at mixtures. Wetter admixture was used to increase fluidity of fresh concrete. As the ratio of fibre increase in mixture, ratio of wetter admixture is increased as well. Ratios of source concrete mixtures were given at Table 2. Dimensions of source concrete specimens were 150 mm diameter and 300 mm height.

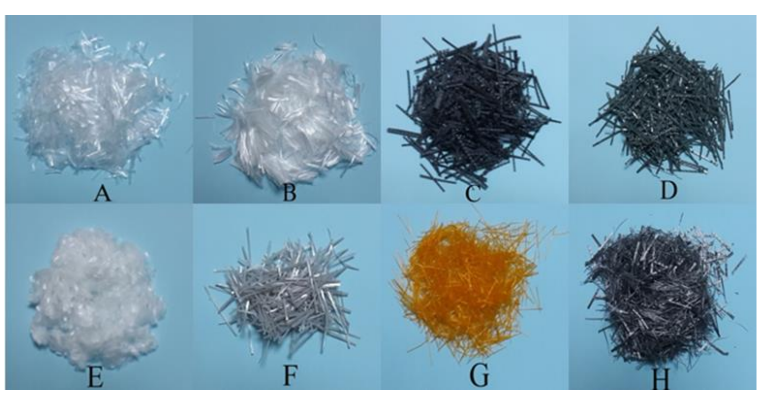

Fig. 1: Polypropylene fibers.

Table 1: Technical properties of polypropylene fibers.

Fiber	Length (mm)	Width (mm)	Thickness (mm)	Shape
A	12	0.48	0.30	Circular
B	19	0.48	0.30	Circular
C	30	1.20	0.30	Ribbed
D	30	1.20	0.45	Double Hook
E	30	0.48	0.30	Circular
F	40	0.433	0.433	Flat
G	18	0.3	0.50	Circular
H	20	0.6/1.3	0.18/0.22	Flat

Table 2: Ratios and amounts of materials used within the source concretes.

Ingredients		K	Fiber mixtures		
			600 gr/m³	**1200 gr/m³**	**1800 gr/m³**
Sand (0-4 mm)	(kg/m^3)	1127	1127	1127	1127
Crushed Stone (7-15 mm)	(kg/m^3)	451	451	451	451
Crushed Stone (16-22.4 mm)	(kg/m^3)	301	301	301	301
Water	(kg/m^3)	156	156	156	156
Cement	(kg/m^3)	300	300	300	300
Polypropylene Fiber	g/m³	-	600	1200	1800
Additive	%	0,6	0,8	0,9	1,1
Water-cement ratio	W/C	0.52	0,52	0,52	0,52
Unit weight	(kg/m^3)	2335	2335	2335	2335

2.1. Compressive Strength of Source Concrete

Compression strength of source concretes changes between 33.70-45.17 MPa. Polypropylene fibre admixture generally decreased with concrete's compression strength. The highest compression strength of fibred mixtures is A18 (Table 3).

Table 3: Compressive strength (28 days).

Mixtures	f_c (Mpa)	Mixtures	f_c (Mpa)
K	**41.58**	**K**	**41.58**
A6	34.13	E6	37.89
A12	37.92	E12	42.74
A18	**45.17**	E18	42.76
B6	37.12	F6	33.70
B12	35.63	F12	37.54
B18	35.68	F18	38.74
C6	38.19	G6	34.12
C12	40.86	G12	36.84
C18	43.83	G18	36.79
D6	40.59	H6	33.71
D12	42.77	H12	35.75
D18	44.99	H18	39.01

2.1. Breaking of Source Concrete

Source concretes were broken 120 days later by jaw crusher. Specimens were broken in three different sizes. According to the size of aggregate, source concretes were broken. 45 specimens obtained from each serial and 15 of them were broken by 0-4 mm, 15 of them were broken by 7-15 mm and 15 of them were broken by 16-22.4 mm sizes (Figure 2). Here the aim is to re-use obtained aggregates in concretes. Figure 2 shows aggregates with 1800 g/m^3 fibre admixed source concrete. As amount of fibre increases, sizes of pieces at the end of the breaking decreased. Sizes of pieces obtained from D, E, F, G, H fibred concretes were smaller than sizes of pieces obtained from A, B and C fibred concretes. During the breaking fibres served as a bridge to dispersal of cement mortar. Especially C and D fibres had better adherence with cement mortar because they are ribbed and hooked. During breaking, some polypropylene fibres were broken. It is observed that C, D and G fibres have more resistant to breaking. As pieces get smaller, bond between fibres and cement mortar were broken off. It is observed that fibres with low thickness stayed in cement mortar even their pieces were getting smaller. Especially H fibre is an example to this.

Fig. 2: Recycling aggregates.

3. Aggregate Experiments and Findings

3.1. Water Absorption

Water absorption test was done according to EN 1097-6 standards. Water absorption test was done for all aggregates. Water absorption values of fine aggregate decreased in comparison with normal aggregate at the control mixture and A, B, C fibres and increased at D, E, F, G and H fibres (Figure 3). Ratio of fibre at aggregates did not change much the water absorption values of fine aggregates. Water absorption values of coarse aggregate with 7-15 mm decreased in A, B, C fibred mixtures and increased in control and D, E, F, G and H fibred mixtures (Figure 4). Water absorption values of coarse aggregate with 16-22.4 mm increased in all mixtures in comparison with normal aggregate.

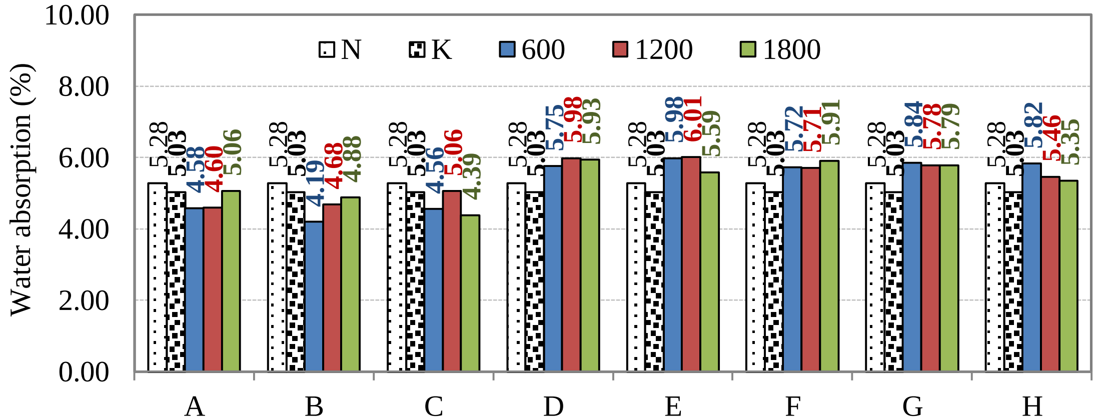

Fig. 3: Water absorption (0-4 mm).

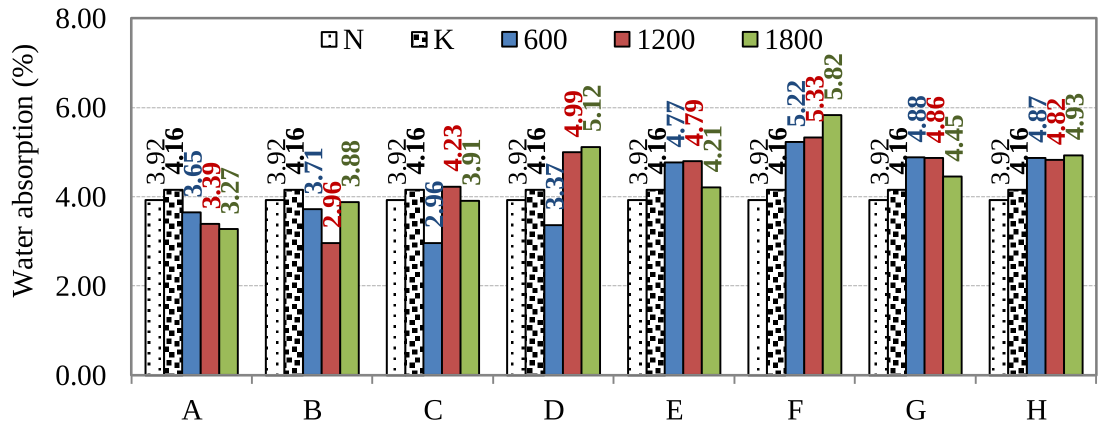

Fig. 4: Water absorption (7-15 mm).

Especially water absorption values of D, E, F, G and H fibred aggregates increased much (Figure 5). As size of pieces of recycled aggregates get larger, their water absorption values increased as well. This shows that as size of pieces gets larger, amount of fat mortar increases on aggregate. Water absorption value of fine aggregate is larger than water absorption value of coarse aggregate. As size of aggregate gets larger their water absorption value decreased.

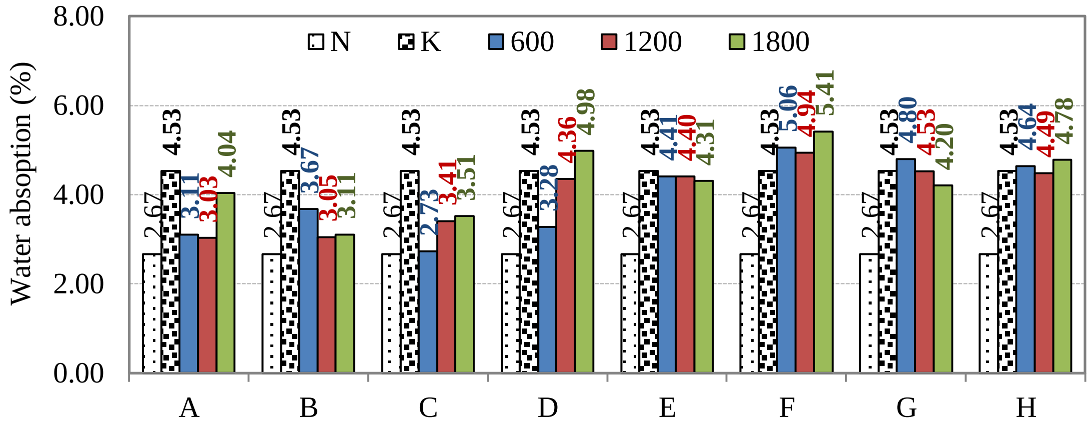

Fig. 5: Water absorption (16-22.4 mm).

3.2 Impact Strength

Impact strength test was done according to EN 1097-2 standards. Impact strength test was done only with coarse aggregates with sizes of 16-22.4 mm. Weight loss of impact strength increased two times than normal aggregate. Weight loss of impact strength is 10.11% for normal aggregate. The biggest weight loss is D6 mixture with 22.89%. In fibred aggregates, it is observed that ratio of fibre did not have much effect over the weight loss after impact strength. It is determined that weight losses of A, B, C, E, G specimens were lower than weight loss of aggregate obtained from concrete without fibre (K). Weight losses of D, F, H specimens increased a bit in comparison with weight loss of K specimen (Figure 6). Increase of weight loss after the impact strength is the reason of fat mortar on the aggregate. Fat mortar could be pressed easily under impact strength. Therefore pressed mortar is observed as a failure.

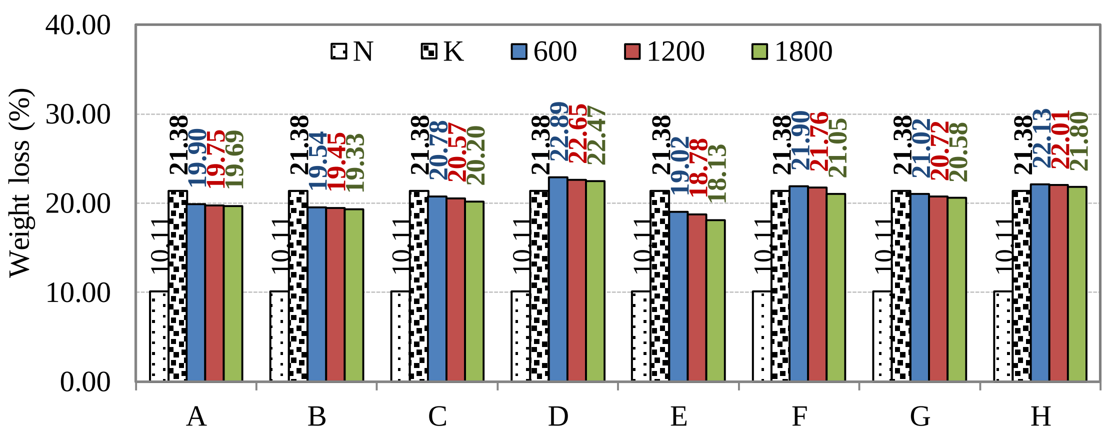

Fig. 6: Weight loss after impact strength (16-22.4 mm).

3.2 Freeze-Thaw test

Freeze-thaw test was done according to EN 1367-2 standards. In freeze-thaw test magnesium sulphate was used. Freeze-thaw test was only done on coarse aggregates with size of 16-22.4 mm. Freeze-thaw test was done twice for each specimen and average of test results were taken (Figure 7).

Weight loss of normal aggregate used at source concrete after freeze-thaw is 2.1%. Weight loss of aggregate obtained from concrete without fibre after freeze-thaw is calculated as 5.5%. Weight loss of fibred aggregate after freeze-thaw is calculated between 7.1% and 8.2%. Reasons of the increase of the loss is thawing of fat mortar on aggregate. After the freeze-thaw, fibres in the mortar broke off and lost its function to serve as a bridge.

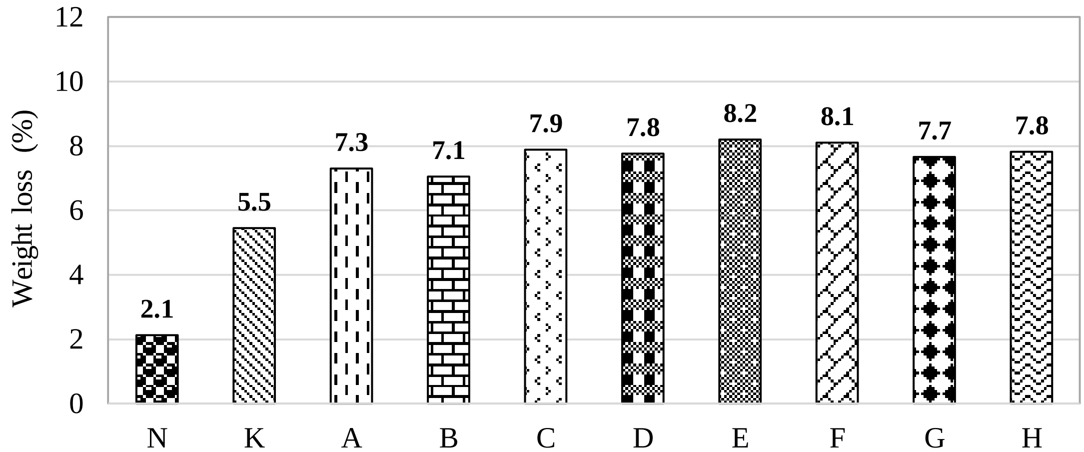

Fig. 7: Weight loss after freeze-thaw (16-22.4 mm).

4. Conclusion

Water absorption value of normal fine aggregate is 5.28%. The highest water absorption value of fibred aggregates is 6.01%. The lowest water absorption value of fibred aggregate is 4.19%. Water absorption value of fine aggregate is larger than water absorption value of coarse aggregate. As sizes of pieces get larger, aggregates, water absorption value decreased. Most ingredients of the fine aggregate is pieces of mortar. As sizes of pieces get smaller, fat mortar on aggregate was pressed and achieved the size of fine aggregate. Therefore water absorption values of fine aggregates increased. Especially at coarse aggregates with sizes of 16-22.4 mm, fibres increased water absorption value in a significant measure. As water absorption value of fine aggregates is high, this would increase water absorption value of concrete with recycled aggregate.

Weight loss of impact strength is 10.11% for normal aggregate. The biggest weight loss was calculated as 22.89%. At the end of the impact strength, weight loss increased by two times. This is also reason of the fat mortar on the aggregate. In fibred aggregates, it is observed that ratio of fibre did not have much effect over the weight loss after impact strength. Fat mortar could be pressed easily under impact strength. Therefore pressed mortar is observed as a failure.

Weight loss of normal aggregate used at source concrete is 2.1% after freeze-thaw. Weight loss of recycled aggregate without fibre increased 2.6 times after freeze-thaw in comparison with normal aggregate. Weight loss of fibred aggregates increased between 33. And 3.9 times after freeze-thaw in comparison with normal aggregate. Reason of these losses is the thawing of fat mortar on aggregates. After the freeze-thaw, fibres in the mortar broke off and lost its function to serve as a bridge. By considering these features of aggregates, our researches on recycling of fibred aggregates in concrete continues.

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