EFFECT OF DIFFERENT TYPES OF FIBER UTILIZATION ON MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE CONTAINING SILICA FUME

Muhammet Gökhan Altun[1] and Meral Oltulu[1*]

ABSTRACT

The use of recycled aggregate (RA) instead of natural aggregate (NA) in concrete is necessary for environmental protection and the effective utilization of resources. The addition of recycled aggregates in concrete increases shrinkage, porosity and decreases the mechanical properties compared to that of normal concrete. This study was aimed at investigating how the addition of various proportions of polypropylene and steel fiber affect the mechanical properties of recycled aggregate concrete (RAC). The natural coarse aggregates (NCAs) used in the production of normal concrete (NC) were replaced in 30% and 50% proportions by recycled coarse aggregates (RCAs) obtained from the demolished buildings. In this case, a polypropylene fiber (PF) content of 0.1% and steel fiber (SF) 1% and 2% volume fractions were used, along with hybrid fibers-a combination of the two. While the material performance of RAC compared to NC is analyzed by reviewing existing published literature, it is not evident what the use of RCAs and hybrid fibers have on the mechanical properties of concrete. The results showed that the compressive strength, flexural strength and impcat resistance of RAC were reduced as the percentage of RCAs increased. It was observed that the compressive strength was increased with the addition of 1% steel fiber in the RAC. The flexural and impact performance of steel fiber-reinforced concrete (Specimens NC and RAC) was increased as the volume fractions of steel fiber increased. The hybrid fiber reinforced concretes showed the best results in their mechanical performance of all the concrete groups.

KEYWORDS

recycled aggregate, polypropylene fiber, steel fiber, compressive strength, flexural strength, impact resistance

1. INTRODUCTION

A rapidly growing population and increasing industrial development has caused an increase in the variety and volume of waste content worldwide. The process of recycling waste materials is very important as waste has a huge negative impact on the natural environment. The operations and advances in the recycling industry will continue to grow and change with the needs of communities.

1. Department of Civil Engineering, Ataturk University, Erzurum, Turkey; *(corresponding author: mroltulu@atauni.edu.tr)

A limit on the consumption of natural resources is an important issue that merits consideration. Natural aggregate resources considered to be one of the most highly consumed natural resources decrease with the increase in concrete production. The use of RAs obtained from demolished concrete structures, delivers both environmental and economic benefits on a global scale [1, 2].

Approximately 11.5 million m^3 of these debris wastes were used in the production of concrete in the production of approximately 170.000 houses as RAs by a facility established in Germany [3]. In Turkey, progress on recovery is supported by policies and incentives carried out by the Ministry of Environment and Urbanization. The Ministry of Environment and Urbanization has fostered studies for inventory and planning activities, development of standards, strengthening of technological infrastructure and local administration, training and guidance activities, and licensing. Furthermore, the Ministry of Environment and Urbanization acts under the motto of "Zero Waste." For this purpose, some incentives are planned such as land allocation, VAT (value-added tax) exemption, tax deduction, SSI (social security institution) premium support etc. to facilities that will be installed in order to recycle wastes without damaging the environment [4, 5].

RAs are generally used as a material filler in road construction and ground works and can also be used in lean concrete. The number of experimental studies about the use of RAs in bearing concretes have increased in recent years [2, 3]. According to recent studies, the replacement proportions of natural aggregate by RAs are very important. If the replacement RA ratio is higher than optimum, the mechanical properties of the concrete can be adversely affected. Butler et al. [6], Etxeberria et al. [7], Fonseca et al. [8], Hoffmann et al. [9], Lima et al. [10], Padmini et al. [11], Tahar et al. [12], Topcu and Guncan [13], Xiao et al. [14] studied the use of RCAs at between 30% to 100% and the results showed that using RCAs decreased the compressive strength. Fonteboa and Abella [15] used RCAs at a 50% level. Medina et al. [16] studied the mechanical properties of RAC. For this purpose, RCAs were used at ratios of 25% and 50%, and the results showed that using RCAs negatively affected the mechanical properties.

Mardani-Aghabaglou et al. [17] investigated the effects of recycled glass and recycled concrete fine aggregates on the durability performance of mortar mixtures. For this purpose, 9 different mortar mixtures were prepared by replacing 25, 50, 75 and 100 wt.% of crushed-limestone fine aggregate with recycled glass and recycled concrete aggregates. As a result, the recycled concrete mixtures containing more than 50% recycled aggregate showed lower performance than the control mixture.

The methods used to improve the mechanical properties of NCs can be applied for RACs. Adding various admixtures to the concrete (such as mineral admixtures and fibers) are some of these methods [18–20]. It has been determined that the mechanical properties of RACs, particularly the tensile and flexural strengths, increase in relation to the use of fibers. In addition, the performance and service life (durability) of concrete mixtures are also positively affected. Thus, the cement dosage can also be reduced [21–27].

In studies by Erdem et al. [25], steel and polypropylene fibers were used at a ratio of 1.0%, and according to the results, using fibers increased the mechanical properties of RACs. Moreover, steel fiber-reinforced RACs showed the best performance under mechanical impacts. Akca et al. [22] experimented with the use of polypropylene fibers. NAs were replaced with RAs by 1.0% and 1.5% of polypropylene fibers that were introduced for each series. The results determined that the optimum fiber content was 1.0% by volume.

He et al. [26] investigated the effect of using rubber powder to compressive and flexural strengths of steel fiber reinforced concretes. The rubber powder was replaced by sand at 4%, 8%, 12% and 16% volume fractions. In addition, 1% steel fiber was added to all mixtures. It was determined that the use of steel fiber improves the mechanical properties of concretes.

As previously mentioned, few studies have been done on the optimum replacement ratio of RCAs and on the fiber ratio in concrete. There are also few studies on the use of hybrid fibers. In this study, RCAs were used at an optimum rate in concrete to investigate the influence of RAs on the mechanical properties of the resulting concretes by using polypropylene and steel fibers separately and in combination.

Within this context, the maximum size of aggregate, water/cement ratio and silica fume ratio were determined to be 16 mm, 0.50 and 5%, respectively. The NCAs used in the production of NC were replaced by 0%, 30% and 50% of RCAs. Hooked-end steel fibers at a volume fraction of 1% and 2%, and a polypropylene fiber volume fraction of 0.1% were used separately and in combination. The mechanical properties (compressive strength, flexural strength and impact resistance) of all concrete specimens were compared to those of the control groups.

2. EXPERIMENTAL PROGRAM

2.1 Materials

In this study, Type 1 42.5 R Portland cement and silica fume (SF) were used as the cementitious materials, and their physical properties and chemical compositions are summarized in Table 1. The specific gravity of Portland cement and silica fume (SF) are 3.14 and 2.24, respectively.

Both natural crushed limestone aggregates and RCAs with a maximum particle size of 16 mm were used as a coarse aggregate. Figure 1 illustrates the appearance of the RCAs. Local river sand was used as a fine aggregate (NFA). The specific gravity and water absorption capacity of the aggregates were determined according to the EN 1097-6 Standard. The experiments conducted on the aggregate showed that the RCAs are about 16% weaker than the NCAs because of their high porosity, and also that the water absorption of the RCAs is almost 3 times higher than that of the NCAs. Similar results were seen in published literature [28–32]. The physical properties of all aggregates are given in Table 2 and the gradation curve of aggregates are shown in Figure 2. Water at the rate of surface moisture of the aggregates was added into the mixing water.

Polypropylene fibers of 9 mm in length and steel fibers of 35 mm in length with a 65 aspect ratio were used both separately and in combination. The pictures of the fibers are shown in Figure 3, and the mechanical properties of polypropylene and steel fibers are presented in Table 3.

2.2 Mixing proportion

A cement content of 350 kg/m^3 and the same water-cement ratio (W/C+SF) of 0.50 were used in all batches. To improve the mechanical properties, silica fume was used at 5% of cement weight in all concrete specimens. Super plasticizer (SP)-based polycarboxylic ether was used at 2% of cement weight in all batches for better workability.

Hooked-end steel fibers at 1% and 2% volume fractions, and polypropylene fibers at a 0.1% volume fraction were used. The NCAs used in the production of NC were replaced with RCAs 30% and 50%. The mixing proportions are listed in Table 4.

TABLE 1. Physical and mechanical properties and chemical components of cement and silica fume.

	Cement (%)	Silica Fume (%)
SiO_2	18.73	91.92
Al_2O_3	4.56	0.42
Fe_2O_3	3.07	0.20
CaO	63.91	2.06
MgO	2.08	3.69
SO_3	2.90	—
K_2O	0.62	—
Na_2O	0.29	—
Cl	0.02	—
Cr_2O_3	—	0.37
C	—	0.21
S	—	0.07
Loss of ignition	3.36	2.30
Specific gravity	3.14	2.24
Blaine specific surface (cm^2/g)	3807	35200
Residual on 0.045 mm sieve	8.98	3.53
28-day compressive strength (MPa)	57.2	—

FIGURE 1. Appearance of the recycled coarse aggregates.

TABLE 2. Physical properties of natural aggregates and recycled coarse aggregates.

	Specific gravity	Water absorption (%)	Surface moisture (%)	Bulk density (g/cm³)
0-2 NFA	2.45	2.09	0.20	2.40
2-4 NFA	2.45	2.39	0.30	2.39
4-8 NCA	2.54	1.51	0.25	2.50
4-8 RCA	2.12	6.64	4.21	1.96
8-16 NCA	2.64	1.95	0.45	2.59
8-16 RCA	2.24	8.19	5.47	2.10

FIGURE 2. Gradation curve of aggregate and standard limits.

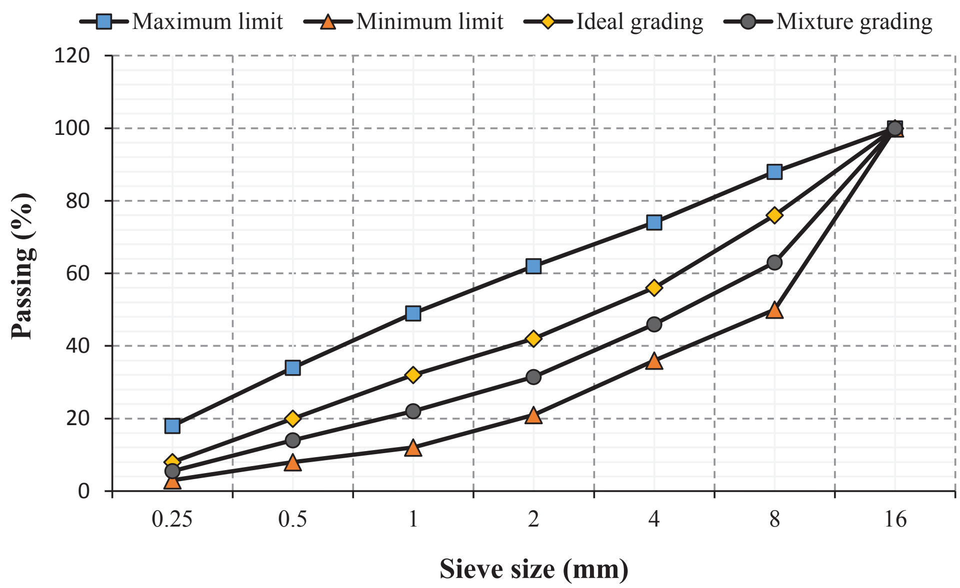


FIGURE 3. Polypropylene fibers (a) and steel fibers (b) used for reinforced concrete.

(a)

(b)

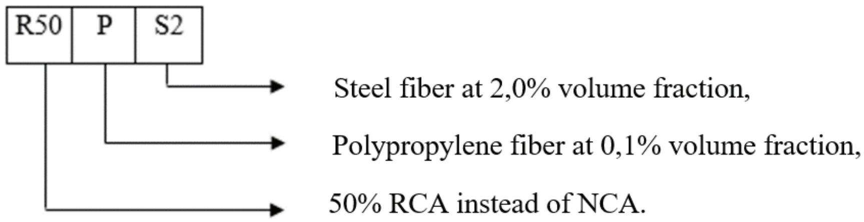
TABLE 3. The physical and mechanical properties of polypropylene fibers and steel fibers.

	Length (mm)	Diameter (mm)	Density (gr/cm^3)	Tensile strength (N/mm^2)	Modulus of elasticity (kN/mm^2)
Polypropylene Fiber	9	0.022	0.90	600–750	3.8
Steel Fiber	35	0.55	7.80	1338–1352	210

TABLE 4. Concrete mix proportions for 1 m^3.

	W/ (C+SF)	Water (kg/m^3)	Cement (kg/m^3)	Silica fume (kg/m^3)	8–16 mm (kg/m^3)		4–8 mm (kg/m^3)		2–4 mm NFA (kg/m^3)	0–2 mm NFA (kg/m^3)	PF V_f (%)	SF V_f (%)
					NCA	RCA	NCA	RCA				
N	0.50	175	333	17	687	—	283	—	244	531	—	—
NP	0.50	175	333	17	687	—	283	—	244	531	0.1	—
NS1	0.50	175	333	17	687	—	283	—	244	531	—	1
NS2	0.50	175	333	17	687	—	283	—	244	531	—	2
NPS1	0.50	175	333	17	687	—	283	—	244	531	0.1	1
NPS2	0.50	175	333	17	687	—	283	—	244	531	0.1	2
R30	0.50	175	333	17	481	175	198	71	244	531	—	—
R30P	0.50	175	333	17	481	175	198	71	244	531	0.1	—
R30S1	0.50	175	333	17	481	175	198	71	244	531	—	1
R30S2	0.50	175	333	17	481	175	198	71	244	531	—	2
R30PS1	0.50	175	333	17	481	175	198	71	244	531	0.1	1
R30PS2	0.50	175	333	17	481	175	198	71	244	531	0.1	2
R50	0.50	175	333	17	343	291	142	118	244	531	—	—
R50P	0.50	175	333	17	343	291	142	118	244	531	0.1	—
R50S1	0.50	175	333	17	343	291	142	118	244	531	—	1
R50S2	0.50	175	333	17	343	291	142	118	244	531	—	2
R50PS1	0.50	175	333	17	343	291	142	118	244	531	0.1	1
R50PS2	0.50	175	333	17	343	291	142	118	244	531	0.1	2

FIGURE 4. The expansion of R50PS2.

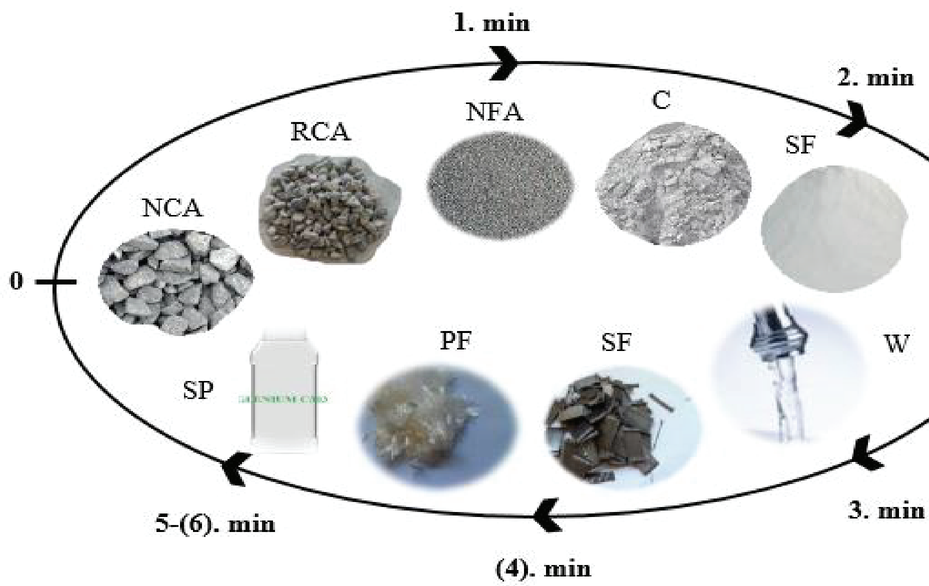


Different codes have been used to identify the individual concrete groups to make the results easier to understand and interpret. The abbreviations are normal concrete (N), recycled aggregate concrete (R), polypropylene fiber (P), 1% steel fiber (S1) and 2% steel fiber (S2). For example, the code for R50PS2 is shown in detail in Figure 4.

2.3 Mixing procedure

All materials were mixed in a pan mixer. Firstly, the dry coarse and fine aggregates were mixed together for one minute in the mixer. Then cement and silica fume were added and mixed for another minute. Later, water equivalent to 70% of the water required for the mix was added. Then, a hyper plasticizer was mixed with the rest of the required water, and they were added to mix with the cementitious composite for another 2 minutes. In fibrous samples, the fibers were added last and mixed together with the mixture for another two minutes. The total mixing time in non-fiber samples was five minutes, while in fibrous samples it was six minutes. The concrete mixing procedure used in this study is shown schematically in Figure 5.

FIGURE 5. Concrete mixing procedure.



2.4 Test methods

All specimens were stored in molds for about 24 hours and were then cured in lime-saturated water at a temperature of 23 ± 2°C, until the day of testing. Each value was determined by calculating the average of 3 different specimens. Compressive strength tests were performed at 7 and 28 days on 150x150x150 mm cubic specimens in accordance with EN 12390-3.

The flexural strength test was performed at 28 days on 70x70x280 mm beam specimens, with 10 kgf/cm^2.min loading speed, in accordance with EN 12390-5. The flexural strength can be calculated with equation (1) as follows:

$$F = \frac{3PL}{2bd^2} \tag{1}$$

where, E is the flexural strength (MPa), P is the load (N), L is the distance between supports (mm), b and d are the cross section lengths of specimen (mm).

The impact tests were conducted with the drop weight test machine as described by ACI Commitee 544 at 28 days on 64x150 mm disk specimens. The aparatus of the equipment are hammer, steel bowl and the test specimen. In this method briefly, a 4.45 kg hammer is dropped sequentially from heights of up to 457 mm on the steel bowl with a 64 mm diameter which is placed on a concrete disc specimen of 150 mm diameter by 64 mm thickness. Then, the number of blows were determined at first visible crack and ultimate crack. The impact energy can be calculated with equations (1–5) as follows:

$$H = \frac{gt^2}{2} \tag{2}$$

$$V = gt \tag{3}$$

$$m = \frac{W}{g} \tag{4}$$

$$U = \frac{mV^2}{2} \tag{5}$$

$$\text{Impact energy} = n \times U \tag{6}$$

where, U is the energy that occured with a blow (kNmm), W is the weight of the hammer (kg), m is the mass of the hammer (N), H is the drop height of the hammer (mm), t is the drop time of the hammer (s), g is the acceleration of gravity (mm/s^2), V is the velocity of the hammer at the moment of blow (mm/s), and n is the number of blows.

3. RESULTS AND DISCUSSION

3.1 Fresh State Properties

The workabiliy of fresh concrete is an important factor that can affect its flowability and the mechanical properties of the hardened concrete. Therefore, the slump and unit weight tests were conducted to control the workability of the fresh concrete. The detailed workability test results are given in Table 5.

These results indicated that the workability of concrete containing RCA was decreased when compared to the use of NCA. The reduction in the workability compared to the control specimen was 13% and 39% in the R30 and R50 groups, respectively. The adverse effect of RCA on the workability is due to its high water absorption capacity. Similar results were reported in other studies [28, 33–35]. The concrete with RCA had a lower density, causing a lower unit weight in the concrete samples. The unit weights of concretes decreased by 8 to 9% with the increase in the RCA content as in previous studies [36–38].

The use of polypropylene fiber slightly increased the flow values of the NP and R30P specimens while no effect was seen on the R50P specimen. These results showed that using polypropylene fiber produced no significant change in the workability, similar to previous studies [39, 40]. Also, adding polypropylene fiber had no effect on the density of either NCs or RACs because of their lower density and lower volume fractions. In this respect, polypropylene fibers display good advantages in terms of workability.

TABLE 5. The results of fresh concrete tests.

	Weight (kg/m^3)	(%) Increase/decrease compared to NC	Slump (mm)	(%) Increase/decrease compared to NC
N	2405	—	115	—
NP	2408	0	120	4
NS1	2456	2	50	–57
NS2	2478	3	20	–83
NPS1	2457	2	60	–48
NPS2	2482	3	20	–83
R30	2219	–8	100	–13
R30P	2216	–8	110	–4
R30S1	2261	–6	45	–61
R30S2	2270	–6	0	–100
R30PS1	2264	–6	50	–57
R30PS2	2274	–5	0	–100
R50	2182	–9	70	–39
R50P	2174	–10	70	–39
R50S1	2238	–7	30	–74
R50S2	2248	–7	0	–100
R50PS1	2235	–7	30	–74
R50PS2	2249	–6	0	–100

In NCs, using steel fiber at 1.0% and 2.0% volume fractions decreased the workability by 57% and 83%, respectively, so the workability in the fresh concrete samples decreased with an increase in the steel fiber volume fractions. Furthermore, the unit weights of fibrous concrete samples were higher than those of the NCs because of their higher density [41–43].

Steel fibers negatively effect the workability in NCs and RACs. A 1.0% steel fiber content decreased the slumps on R30S1 and R50S1 specimens at 61% and 74% ratios respectively. The slump values displayed a reduction as expected, with the addition of fibres when compared with the results of plain concrete. This result is caused by using RCAs and steel fibers that have more specific area together in concrete. The use of hybrid fibers leads to low values in the slump. This situation is caused by steel fibers, because polypropylene fibers have no effect on the workability and density.

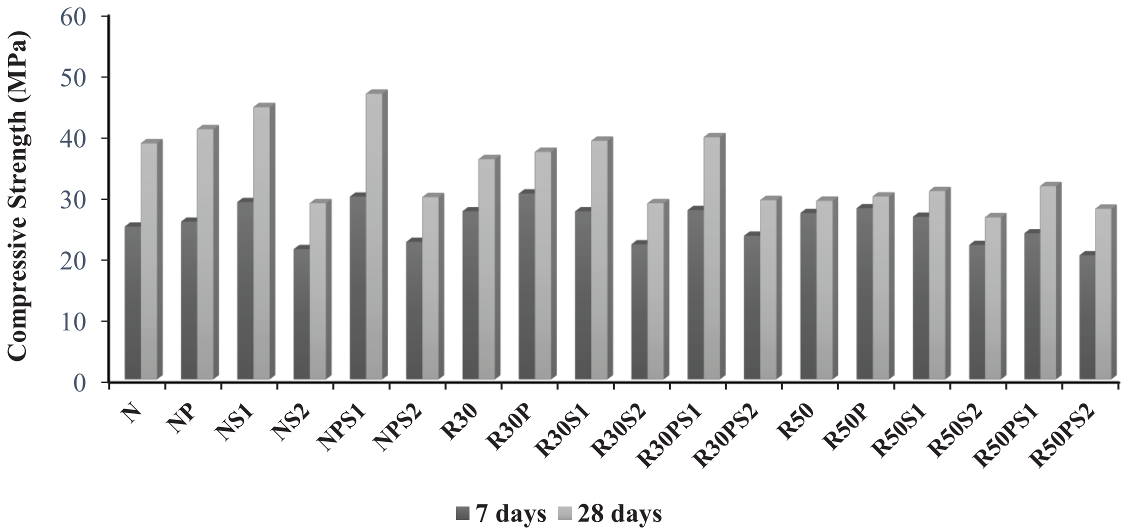
3.2 Compressive strengths

The compressive strength tests were performed on NCs, RACs, fiber reinforced concretes and fiber reinforced RACs. The results of compressive tests are shown in Table 6 and in Figure 6. It was found that the compressive strength (at 7 days) of R30 and R50 concrete groups were

TABLE 6. The results of compressive tests.

	Compressive strength (MPa) 7 days	(%) Increase/decrease compared to NC	Compressive strength (MPa) 28 days	(%) Increase/ decrease compared to NC
N	25.0	—	38.6	—
NP	25.8	3	40.9	6
NS1	29.0	16	44.5	15
NS2	21.3	–15	28.8	–25
NPS1	29.9	19	46.7	21
NPS2	22.5	–10	29.8	–23
R30	27.5	10	36.0	–7
R30P	30.4	22	37.2	–4
R30S1	27.5	10	39.0	1
R30S2	22.1	–11	28.8	–25
R30PS1	27.7	11	39.6	3
R30PS2	23.5	–6	29.3	–24
R50	27.2	9	29.2	–24
R50P	28.0	12	29.9	–23
R50S1	26.6	7	30.8	–20
R50S2	22.0	–12	26.5	–31
R50PS1	23.9	–4	31.6	–18
R50PS2	20.3	–19	27.9	–28

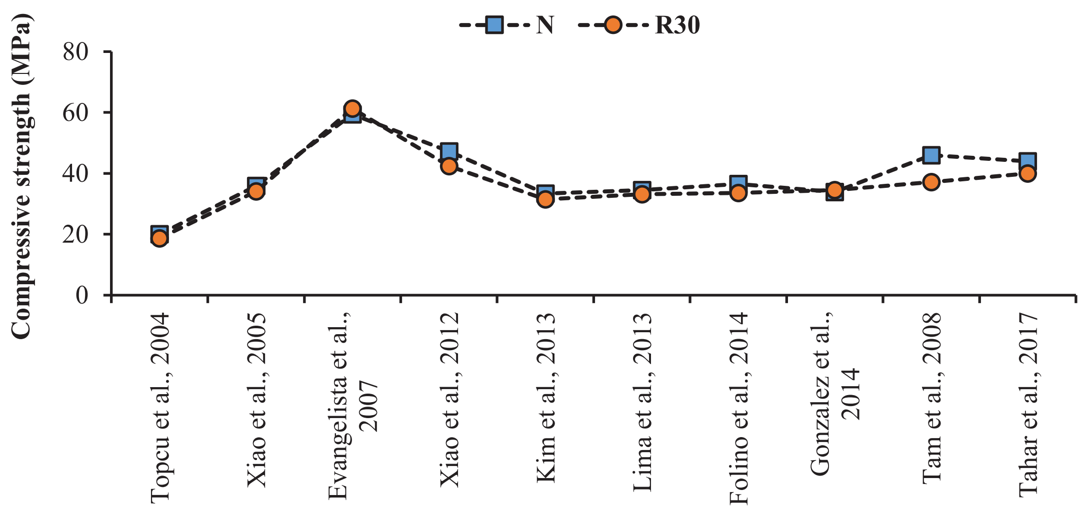
FIGURE 6. The results of the compressive test.



higher than the control group by 10% and 9% ratios, respectively. This happens according to the better adherence between RA and cement paste [44].

In contrast, the obtained compressive strengths at age 7 days decreases as RCA ratio increases. As an example, in the R30 and R50 concrete groups, the 28-days compressive strengths were lower than that of the control group at 7% and 24% ratios, respectively. The reason for this is that there is a second interface of RA-cement paste in addition to the interface of aggregate-cement paste [6, 9, 10, 45]. As a result, the RAs can use a 30% ratio instead of normal aggregates in concretes and should not exceed that ratio. The addition of RCA up to 30% has little difference in compressive strengths between RACs and NCs. Similar results of previous studies [10, 12–14, 30, 31, 45–49] are shown in Figure 7.

FIGURE 7. Relationship between compressive strength of N and R30 concretes according to the literature.



The addition of polypropylene fiber by 0.1% volume fraction increases compressive strengths (7 and 28 days) of both NCs and RACs. The reason for extra increase of 7-day compressive strength is due to the positive effect of using RA and the improving workability of polypropylene fibers [39, 40]. Consequently, with the use of polypropylene fibers, the compressive strength of RACs were improved in a small amount.

Compared to the control group, the addition of 1% steel fiber increased the 7 and 28-days compressive strength in 16% and 15% ratios, while 2% steel fiber decreased in 15% and 25% ratios, respectively. The reason for this decrease is that the increasing interface adversely effects the workability within the use of steel fibers [43, 50].

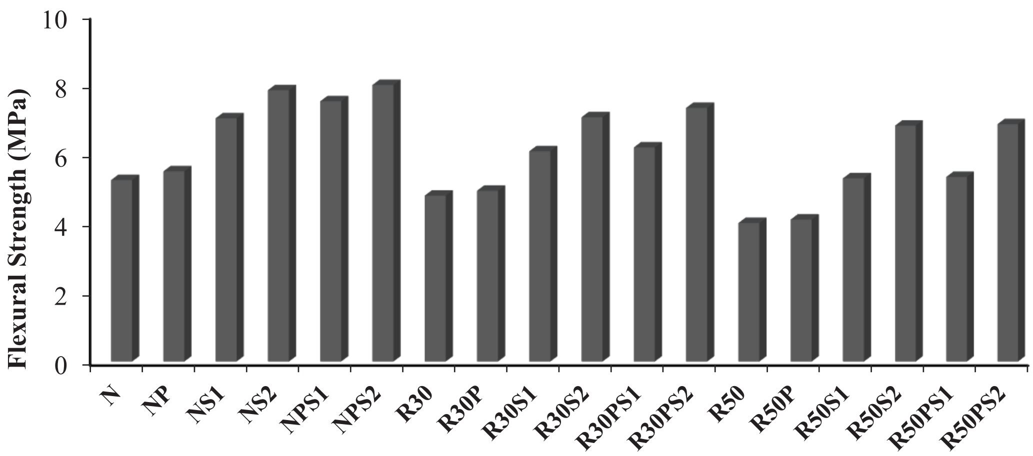
The effect of steel fiber on RACs was similar to that of NCs. A 1% steel fiber increased the 28 days compressive strength of R30S1 and R50S1 concrete groups, while 2% steel fibers effected it negatively. It was found that the 7 and 28 days compressive strengths of R30S1 concrete groups were higher than that of the control group at 10% and 1% ratios, respectively. In R30S1 groups, the negative effect of RA was fixed with steel fibers. These values support using 30% RCA as the optimal rate.

Polypropylene and steel fiber mixture by 1% ratio positively affected the 28-days compressive strength in both NCs and RACs. NPS1 concrete group showed a maximum performance with a 21% increased rate compared to control group (N), while R30PS1 with 3% compared to control group (N).

3.3 Flexural strengths

The flexural tests were performed on NCs, RACs, fiber reinforced concretes and fiber reinforced RACs. The results of flexural tests are shown in Figure 8. The use of RCA effected flexural strengths of concretes negatively. The flexural strengths of 30% and 50% RACs were lower than that of the NCs in 9% and 24% ratios, respectively. This outcome is caused by the adherence of cement paste on the RAs and second interface transition zone between cement and RA, similar to the obtained results of previous studies [33, 35, 51]. Addition of 0.1% polypropylene fibers increased the flexural strengths of NCs [40, 53–55]. Similar results were obtained from RACs samples.

FIGURE 8. The results of the flexural test [52].



The flexural strengths increased with the increase of steel fiber content. The amount of increase in this study was 34% and 49% ratios in 1% and 2% steel fiber reinforced concretes, respectively. Fibers incorporated into concrete can hamper the growth of the cracks inside the concrete and improve the tensile strength and ductility of the concrete [42, 50, 56–58]. Also, the addition of fiber gives more positive results in RACs.

Using hybrid fiber in both NCs and RACs caused better performance for the flexural strength of specimens. The flexural strength of NPS1 and NPS2 specimens are higher than the N concrete specimen by 43% and 52% ratios. The increase in flexural strength is mainly due to the bridging effect of fibres which restrains crack formation.

The workability of concrete containing RCA was decreased when compared to the use of NCA. The adverse effect of RCA on the workability is due to its high water absorption capacity. Similarly, the use of RCA effected flexural strengths of concretes negatively. On the other hand, the workability in the fresh concrete samples decreased when using steel fiber. However, the flexural strengths increased with the increase of steel fiber content. It is understood from Figure 9 that there is an inverse ratio between workability and flexural strength.

According to the experimental results, flexural strength of the hybrid fiber reinforced concrete groups showed the best performance. The mechanical properties of RAC improved with the hybrid fiber content. This result implies that hybrid fibers should be used especially in the RAC depending on the fiber type and amount.

3.4 Impact resistance

The results of impact tests, performed on recycled aggregate concretes, steel fiber concretes, polypropylene fiber concretes and hybrid fiber concretes, are shown in Figure 10. Figure 10 shows that the use of RCAs adversely affected the impact resistance of the concretes. The impact energy of concretes decreased with the increased proportion of RCA, likewise with the results for the compressive and flexural strength tests. The reason for this is that the adherence between the cement paste and the RAs is weaker than the adherence between the cement paste and the natural aggregate [16, 25].

FIGURE 9. Relationship between workability and flexural strength of concretes.

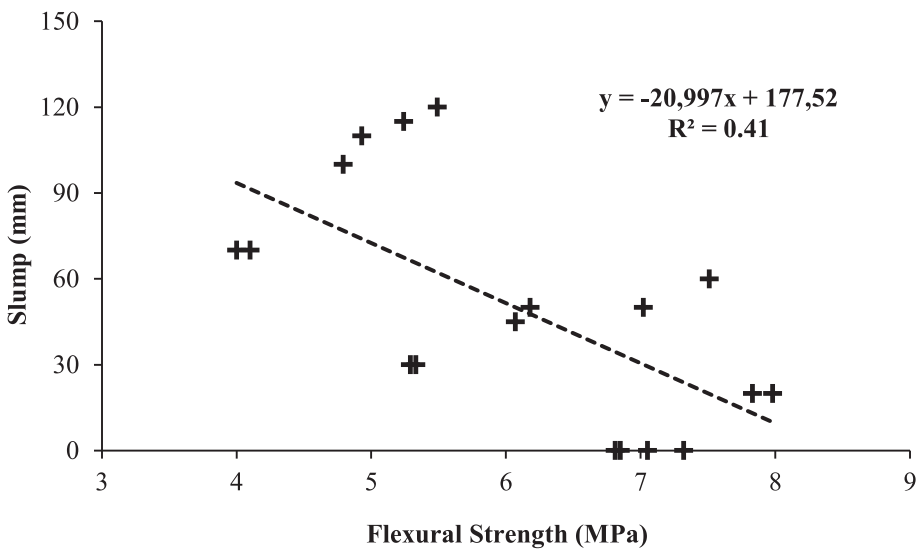
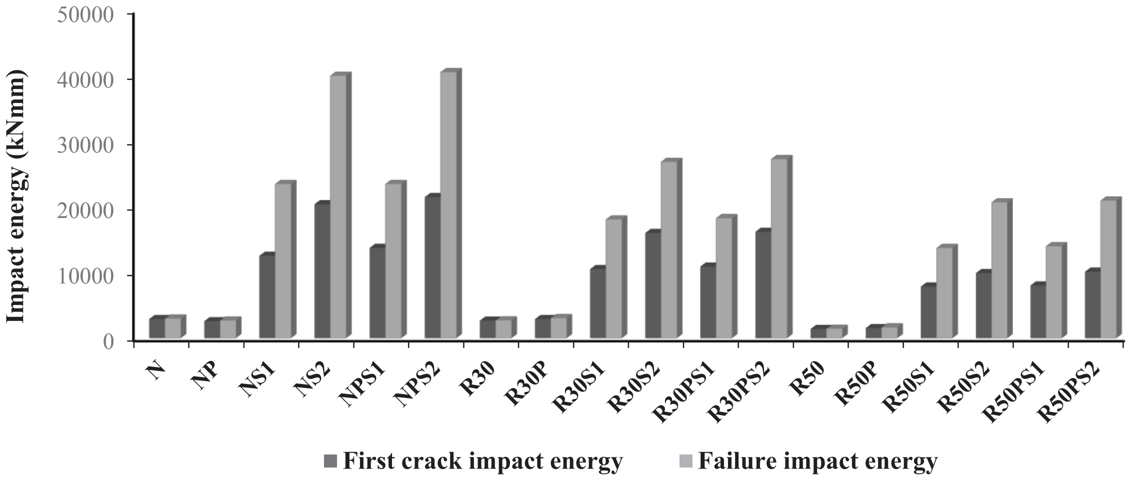


FIGURE 10. Test results of impact resistance [52].



Using 0.1% polypropylene fiber slightly increased the impact resistance in both NCs and RACs similar to findings of Badr et al. [39], Nili and Afroughsabet [41], Mindess et al. [59], Mindess and Vondran [60], Mindess and Yan [61], Wang et al. [62], Toutanji et al. [63] about the results of normal concretes.

Steel fibers increased the impact resistance of concretes too much due to their high energy absorption capacity, and the impact resistance increased with an increase in the steel fiber volume fraction [64–67].

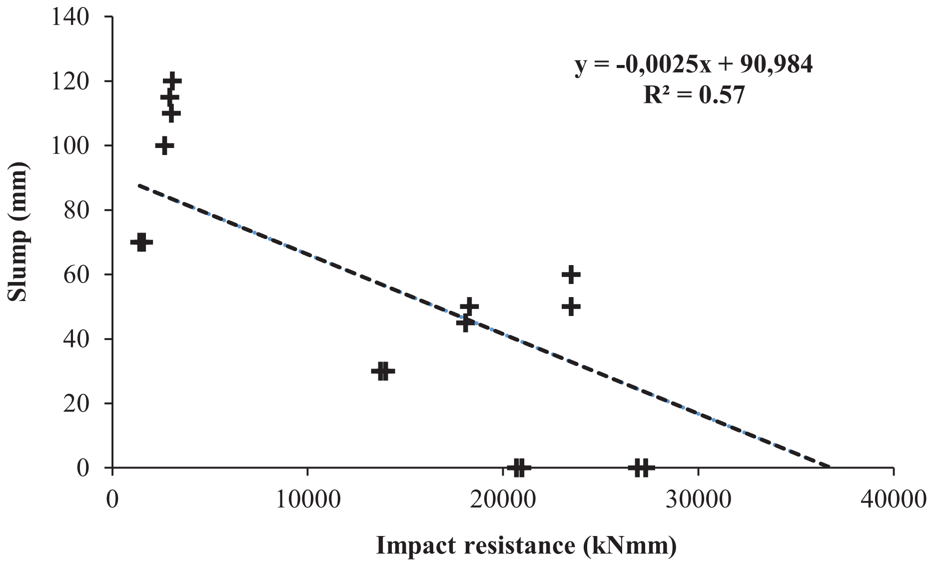
The workability of concrete containing RCA and steel fiber was decreased. The impact energy of concretes decreased with the increased proportion of RCA but using steel fibers increased the impact resistance of RACs as it did for NCs. The use of 1% steel fiber in RACs with 30% RCA content increased the first crack energy and failure energy 3.5 times and 6.0 times, respectively. RACs with 50% RCA content and 1% steel fiber increased the first crack energy and failure energy about 3 times and 4.5 times respectively. RACs with 30% RCA content and 2% steel fiber increased the first crack energy and failure energy 5.5 times and 9 times, respectively, and 2% steel fiber in RACs with 50% RCA content increased the first crack energy and failure energy 3 times and 7 times respectively. As shown in Figure 11, there is an inverse ratio between workability and impact resistance, likewise with the relationship between workability and flexural strength.

4. CONCLUSIONS

By taking into account environmental preservation and effective utilization of resources, the use of RCAs is an important topic for research for the concrete industry. A series of experimental tests were conducted to evaluate the mechanical properties of RACs with fibers. From that research, the following conclusions are drawn.

The workability was reduced with an increase of RCA content. Steel fibers provided a negative effect on the workability of both RACs and NCs. In addition, using polypropylene fiber has no significant contribution on the workability in all concretes. The density of RACs

FIGURE 11. Relationship between workability and impact resistance of concretes.



decreased with the increase in percentage of RCAs. The density of RCAs are lower than that of NCAs because old mortar has higher porosity and water absorption than that of NCAs. The density of RACs decreased with the increase in percentage of RCAs.

The addition of RCA up to 30% has little difference in compressive strengths between RACs and NCs. The results of the compressive tests, use of RCA increased the compressive strength at 7-days but decreased the compressive strength at 28-days with the increase of RCA content. Beyond 30% RCA content, the decrease was substantial.

In both NCs and RACs, using polypropylene fiber increased the compressive strengths at 7 and 28-days by a small amount. Using steel fiber and hybrid fiber at 1.0% volume fraction increased the compressive strength, while using 2.0% of steel fibers reduced the compressive strength due to the poor workability.

The results of the flexural and impact tests showed that the use of RCA decreased the flexural strength and impact resistance at 28 days with the increase of RCA content. Using polypropylene and steel fiber increased the flexural strength and impact resistance in all concretes. The flexural strength and impact resistance increased with the increase of steel fiber volume fraction in chosen ratios. The flexural strength and impact resistance in specimens containing fibers depends only on the amount of fiber content; hybrid fiber concretes showed the best performance against flexural and impact loads.

Although many scientific studies were carried out about RACs, there is not enough research about hybrid fiber reinforced recycled aggregate concretes. For future work, the various mechanical and durability properties of RACs should be investigated by using hybrid fibers at different ratios and parameters. In addition, the workability of fresh concrete and the compatibility of recycled aggregate-cement-plasticizer should be investigated with the help of SEM, MIP analyses, and XRD patterns.

Finally, in this study the effect of different types of fiber utilization on the mechanical properties of recycled aggregate concrete containing silica fume were investigated by using fixed water/binder ratio. For future works, it is recommended that the slump value of the mixtures be kept constant with the use of a suitable water reducing admixture.

REFERENCES

[1] Marinkovic, S., Radonjanin, V., Malesev, M., & Ignjatovic, I. (2010). Comparative environmental assessment of natural and recycled aggregate concrete. Waste Management, 30, 2255–2264.

[2] Oikonomou, N. D. (2005). Recycled concrete aggregates. Cement and Concrete Composites, 27, 315–318.

[3] Khalaf, F. M., & Devenny, A. S. (2004). Recycling of demolished masonary rubble as coarse aggregate in concrete: review. ASCE Journal of Meterials In Civil Engineering, 16, 331–340.

[4] Kılıc, N. (2012). Recycling attact in urban transformation. Izmir Chamer of Commerce, Arge & Bülten.

[5] Kose, H. O, Ayaz, S., & Koroglu B. (2007). Waste management in Turkey, Evaluation of national regulations and implementation results performance audit report, T.C. The Court of Accounts.

[6] Butler, L., West, J. S., & Tighe, S. L. (2013). Effect of recycled concrete coarse aggregate from multiple sources on the hardened properites of concrete with equivalent compressive strength. Construction and Building Materials, 47, 1292–1301.

[7] Etxeberria, M., Vazquez, E., Mari, A., & Barra, M. (2007). Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. Cement and Concrete Research, 37, 735–742.

[8] Fonseca, N., Brito, J. D., & Evangelista, L. (2011). The influence of curing conditions on the mechanical performance of concrete made with recycled concrete waste. Cement and Concrete Composites, 33, 637–643.

[9] Hoffmann, C., Schubert, S., Leemann, A., & Motavalli, M. (2012). Recycled concrete and mixed rubble as aggregates: influence of variations in composition on the concrete properties and their use as structural material. Construction and Building Materials, 35, 701–709.

[10] Lima, C., Caggiano, A., Faella, C., Martinelli, E., Pepe, M., & Realfonzo, R. (2013). Physical properties and mechanical behaviour of concrete made with recycled aggregates and fly ash. Construction and Building Materials, 47, 547–559.

[11] Padmini, A. K., Ramamurthy, K., & Mathews, M. S. (2009). influence of parent on the properties of recycled aggregate concrete. Construction and Building Materials, 23, 829–836.

[12] Tahar, Z. E. A., Ngo, T. T., Kadri, E. H., Bouvet, A., Debieb, F., & Aggoun, S. (2017). Effect of cement and admixture on the utilization of recycled aggregates in concrete. Construction and Building Materials, 149, 91–102.

[13] Topcu, I. B., & Guncan, N. F. (1995). Using waste concrete as aggregate. Cement and Concrete Research, 25, 1385–1390.

[14] Xiao, J., Li, J., & Zhang, C. (2005). Mechanical properties of recycled aggregate concrete under uniaxial loading. Cement and Concrete Research, 35, 1187–1194.

[15] Fonteboa, B. G., & Abella, F. M. (2008). Concretes with aggregates from demolition waste and silica fume. meterials and mechanical properties. Building and Enviroment, 43, 429–437.

[16] Medina, C., Rojas, M. I. S. D., & Frias, M. (2013). Freeze-thaw durability properties of concrete using contaminated ceramic aggregate. Journal of Cleaner Production, 40, 151–160.

[17] Mardani-Aghabaglou, A., Beglarigale, A., Yazıcı, H., & Ramyar, K. (2018). Comparison of recycled glass and recycled concrete aggregates bearing mortar mixtures exposed to high temperature, abrasion and drying. Journal of Green Building, 13(4), 39–59.

[18] Banthia, N., & Sheng, J. (1996). Fracture toughness of micro-fiber reinforced cement composites. Cement and Concrete Composites, 18, 251–269.

[19] Kayali, O., Haque, M., & Zhu, B. (2003). Some characteristics of high strength fiber reinforced lightweight aggregate concrete. Cement and Concrete Composites, 25, 207–213.

[20] Poon, C. S., Shui, Z. H., & Lam, L. (2004). Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures. Cement and Concrete Research, 34, 2215–2222.

[21] Ahmadi, M., Farzin, S., Hassani, A., & Motamedi, M. (2017). Mechanical properties of the concrete containing recycled fibers and aggregates. Construction and Building Materials. 144, 392–398.

[22] Akca, K. R., Cakır, O., & Ipek, M. (2015). Properties of polypropylene fiber reinforced concrete using recycled aggregates. Construction and Building Materials, 98, 620–630.

[23] Carneiro, J. A., Lima, P. R. L., Leite, M. B., &Filho, R. D. T. (2014). Compressive stress strain behavior of steel fiber reinforced recycled aggregate concrete. Cement and Concrete Composites, 46, 65–72.
[24] Chen, G. M., He, Y. H., Yang, H., Chen, J. F., & Guo, Y. C. (2014). Compressive behavior of steel fiber reinforced recycled aggregate concrete after exposure to elevated temperatures. Construction and Building Materials, 71, 1–15.
[25] Erdem, S., Dawson, A. R., & Thom, N. H. (2011). Microstructure linked strength properties and impact response of conventional and recycled concrete reinforced with steel and synthetic macro fibers. Construction and Building Materials, 25, 4025–4036.
[26] He, X. J., Chang, G. Y., Sha, L. L., & Hong, X. Z. (2015). Compressive and flexural behaviours of a new steel fibre reinforced recycled aggregate concrete with crumb rubber. Construction and Building Materials, 79, 263–272.
[27] Song, P. S., Hwang, S., & Sheu, B. C. (2005). Strength properties of nylon and polypropylene fiber reinforced concretes. Cement and Concrete Research, 35, 1546–1550.
[28] Matias, D., Brito, J. D., Rosa, A., & Pedro, D. (2013). Mechanical properties of concrete produced with recycled coarse aggregates—influence of the use of superplasticizers. Construction and Building Materials, 44, 101–109.
[29] Rao, A., Jha, K. N., & Misra, S. (2007). Use of aggregates from recycled conctruction and demolition waste in concrete. Resources Conservation and Recycling, 50, 71–81.
[30] Tam, V. W. Y., Wang, K., & Tam, C. M. (2008). Assessing relationships among properties of demolished concrete, recycled aggregate and recycled aggregate concrete using regression analysis. Journal of Hazardous Meterials, 152, 703–714.
[31] Topcu, I. B., & Sengel, S. (2004). Properties of concretes produced with waste concrete aggregate. Cement and Concrete Research, 34, 1307–1312.
[32] Wagih, A. M., El-Karmoty, H. Z., Ebid, M., & Okba, S. H. (2013). Recycled construction and demolition concrete waste as aggregate for structural concrete. Housing and Building National Research Center Journal, 9, 193–200.
[33] Emam-Ali, E., & Al-Tersawy, A. H. (2012). Recycled glass as a partial replacement of fine aggregate in self compacting concrete. Construction and Building Materials, 35, 785–791.
[34] Ismail, S., & Ramli, M. (2013). Engineering properties of treated recycled concrete aggregate (rca) for structural applications. Construction and Building Materials, 44, 464–476.
[35] Jimenez, J. R., Ayuso, J., Lopez, M., Fernandez, J. M., & Brito, J. D. (2013). Use of fine recycled aggregates from ceramic waste in masonry mortar manufacturing. Construction and Building Materials, 40, 679–690.
[36] Debieb, F., Courard, L., Kenai, S., & Degeimbre, R. (2010). Mechanical and durability properties of concrete using contaminated recycled aggregates. Cement and Concrete Composites, 32, 421–426.
[37] Kwan, W. H., Ramli, M., Kam, K. J., & Sulieman, M. Z. (2012). Influence of the amount of recycled coarse aggregate in concrete design and durability properties. Construction and Building Materials, 26, 565–573.
[38] Martinez, I., Etxeberria, M., Pavon, E., & Diaz, N. (2013). Comparative analysis of the properties of recycled and natural aggregate in masonry mortars. Construction and Building Materials, 49, 384–392.
[39] Badr, A., Ashour, A. F., & Platten, A. K. (2005). Statistical variations in impcat resistance of polypropylene fibre reinforced concrete. International Journal of Impact Engineering, 32, 1907–1920.
[40] Nili, M., & Afroughsabet, V. (2010). The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete. Construction and Building Materials, 24, 927–933.
[41] Baran, E., Akis, T., & Yesilmen, S. (2012). Pull-out behaviour of prestressing stands in steel fiber reinforced concrete. Construction and Building Materials, 28, 362–371.
[42] Khaloo, A., Raisi, E. M., Hosseini, P., & Tahsiri, H. (2014). Mechanical performance of self compacting concrete reinforced with steel fibers. Construction and Building Materials, 51, 179–186.
[43] Song, P. S., & Hwang, S. (2004). Mechanical properties of high strength steel fiber reinforced concrete. Construction and Building Materials, 18, 669–673.
[44] Rao, M. C., Bhattacharyya, S. K., & Barai, S. V. (2011). Behaivour of recycled aggregate concrete under drop weight impact load. Construction and Building Materials, 25, 69–80.
[45] Evangelista, L., & Brito, J. D. (2007). Mechanical behaviour of concrete made with fine recycled concrete aggregates. Cement and Concrete Composites, 29, 397–401.

[46] Folino, P. & Xargay, H. (2014). Recycled aggregate concrete—mechanical behavior under aniaxial and triaxial compression. Construction and Building Materials, 56, 21–31.
[47] Gonzalez, V. C. L. & Moriconi, G. (2014). The influence of recycled concrete aggregates on the behavior of beam-column joints under cyclic loading. Engineering Structures, 60, 148–154.
[48] Kim, S. W. & Yun, H. D. (2013). Influence of recycled coarse aggregates on the bond behavior of deformed bars in concrete. Engineering Structures, 48, 133–143.
[49] Xiao, J., Huang, Y., Yang, J., & Zhang, C. (2012). Mechanical properties of confined recycled aggregate concrete under axial compression. Construction and Building Materials, 26, 591–603.
[50] Eren, O., & Celik, T. (1997). Effect of silica fume and steel fibers on some properties of high strength concrete. Construction and Building Materials, 11, 373–382.
[51] Panda, K. C., & Bal, P. K. (2013). Properties of self compacting concrete using recycled coarse aggregate. Procedia Engineering, 51, 159–164.
[52] Altun, M. G., & Oltulu, M. (2019). Improving the impact resistance of recycled aggregate concretes with different types of fibers. Challenge Journal of Structural Mechanics, 5, 19–28.
[53] Alhozaimy, A. M., Soroushian, P., & Mirza, F. (1996). Mechanical properties of polypropylene fiber reinforced concrete and the effects of puzzolanic materials. Cement and Concrete Composites, 18, 85–92.
[54] Manolis, G. D., Gareis, P. J., Tsonos, A. D., & Neal, J. A. (1997). Dynamic properties of polypropylene fiber reinforced concrete slabs. Cement and Concrete Composites, 19, 341–349.
[55] Mazaheripour, H., Ghanbarpour, S., Mirmoradi, S. H., & Hosseinpour, I. (2011). The effect of polypropylene fibers on the properties of fresh and hardened lightweight self-compacting concrete. Construction and Building Materials, 25, 351–358.
[56] Abdul-Ahad, R. B., & Aziz, Q. Q. (1999). Flexural strength of reinforced concrete t-beams with steel fibers. Cement and Concrete Composites, 21, 263–268.
[57] Chenkui, H., & Guafon, Z. (1995). Properties of steel fibre reinforced concrete containing larger coarse aggregate. Cement and Concrete Composites, 17, 199–206.
[58] Pajak, M., & Ponikiewski, T. (2013). Flexural behaviour of self compacting concrete reinforced with different types of steel fibers. Construction and Building Materials, 47, 397–408.
[59] Mindess, S., Banthia, N., & Bentur, A. (1986). The response of reinforced concrete beams with a fibre concrete matrix to impact loading. The International Journal of Cement Composites and Lightweight Concrete, 8, 165–170.
[60] Mindess, S., & Vondran, G. (1988). Properties of concrete reinforced with fibrillated polypropylene fibres under impact loading. Cement and Concrete Research, 18, 109–115.
[61] Mindess, S., & Yan, C. (1993). Perforation of plain and fibre reinforced concretes subjected to low velocity impact loading. Cement and Concrete Research, 23, 83–92.
[62] Wang, N., Mindess, S., & Ko, K. (1996). Fibre reinforced concrete beams under impact loading. Cement and Concrete Research, 26, 363–376.
[63] Toutanji, H., McNeil, S., & Bayasi, Z. (1998). Chloride permeability and impact resistance of polypropylene fiber reinforced silica fume concrete. Cement and Concrete Research, 28, 961–968.
[64] Marar, K., Eren, O., & Celik, T. (2001). Relationship between impact energy and compression toughness energy of high-strenght fiber-reinforced concrete. Materials Letters, 47, 297–304.
[65] Nataraja, M. C., Dhang, N., & Gupta, A. P. (1999). Statistical variations in impact resistance of steel fiber reinforced concrete subjected to drop weight test. Cement and Concrete Research, 29, 989–995.
[66] Nataraja, M. C., Nagaraj, T. S., & Basavaraja, S. B. (2005). Reproportioning of steel fibre reinforced concrete mixes and their impact resistance. Cement and Concrete Research, 35, 2350–2359.
[67] Mohammadi, Y., Azad, R. C., Singh, S. P., Kaushik, S. K. (2009). Impact resistance of steel fibrous concrete containing fibres of mixed aspect ratio. Construction and Building Materials, 23, 183–189.