ASPS Conference Proceedings 1: 223-228 (2022)

Proceedings of

12th Structural Engineering Convention - An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

Use of recycled aggregate and fly ash in the development of concrete composite

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Paper ID - 020438

Abstract

Continuous economic growth poses severe problems of waste disposal for civil engineering construction and demolition works. In this research work, recycled aggregate (RCA) and fly ash in concrete composites for pavements are presented. The approach adopted here is to replace a large amount of normal aggregates (NA) with recycled aggregate, obtained from various crushed concrete and partial substitution of Portland cement by fly ash to develop rigid pavement concrete. A preliminary test is conducted on the materials which are used in the development of concrete pavement. Results have satisfactory results as per Indian standard guidelines. The compressive strength is determined at a proportion of fly ash varying from 0 to 40%, which gives a wide range of adding fly ash and recycled aggregate to achieve the aggregate's better mechanical property. It also determines the concrete's long-term flexural strength by partially replacing the RCA and fly ash, an important parameter in rigid pavement design. At 28 days and 56 days, the compressive strength is determined for different fly ash and recycled aggregate proportions, and concrete having more fly ash shows better results at 56 days' compressive strength.

Keywords: recycled aggregate; waste material; fly ash; concrete; composite material; cement

1. Introduction

Restoration of the ecosystem and protection of the increasingly dwindling natural resources should be at the core of sustainable growth. Whereas, on the one hand, natural aggregates for the construction of fresh concrete are desperately insufficient. In the other side, a serious ecological and environmental crisis is caused by the large quantities of demolished concrete emitted from damaged and outdated buildings. The use of this 'waste' concrete as aggregates is one of the methods to address this issue. These 'recycled' aggregate can be a reliable alternative to use of NAs in concrete construction [1]. Also, there are examples of imposition of levy for dumping of such waste in landfills. Due to the high demand for building construction, NA resources are declining.

Construction and Demolition (C &D) waste constitutes a significant portion of total solid waste produced globally, and most of it is used in landfills [2]. In the current era, environmentally friendly or sustainability is a big issue. The use of waste materials can minimize the impact on the environment and reduce CO_2 emissions. Demolition waste was first recycled in Germany during the Second World War. Since then, research undertaken in many countries has shown ample potential to establish building waste as a constituent of new concrete. C&D waste could be broken concrete pieces, waste bricks from the houses, and broken pavement. RA could come from the demolition works in buildings, bridge dismantling, airport runways, and concrete pavements. Concrete made using such aggregates is referred to as recycled aggregate concrete (RAC) [3-4].According to a survey, more than 165 million NA is used every year if different civil and other construction works, and approximately 109 million tonnes of construction residue is generated. Using this residue, we can prevent/minimise NA use in concrete and use the demolished aggregate to produce concrete.

M-40 cement concrete mix with a minimum flexural strength is recommended by the Indian road congress (IRC) for the use in the concrete pavements of highways with heavy to heavy traffic loads. The cement concrete (CC) pavement slab is expected to withstand the flexural stresses caused by the heavy traffic loads and the warping effects in the cement concrete (CC) slabs due to the temperature differentials between the top and bottom of the slab caused by the daily variation in temperature during the 24 hours' cycles.

The component layers of a typical rigid pavement or CC pavement structure are shown in Fig. 1. The CC pavement is supported by a prepared soil subgrade, subbase, and a base course. The CC pavement slab has to withstand flexural stresses caused by moving traffic loads and warping action due to daily temperatures variations.

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Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India | 19-22 December, 2022

Published online: December 19, 2022

doi:10.38208/acp.v1.501

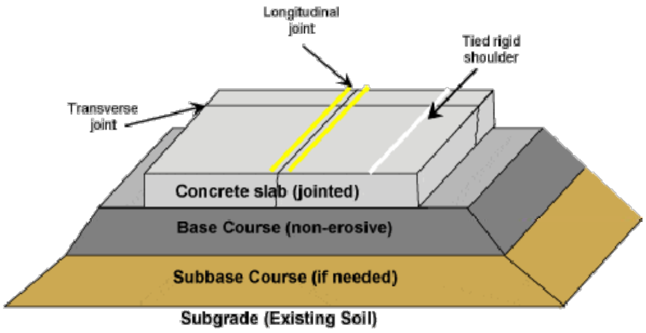

Fig. 1. Different layers of rigid pavement

The high-quality concrete is developed by using the cement and the NA, which is not a sustainable approach because the concrete industry, especially Portland cement manufacture, is a massive contributor to environmental damage and CO_2 emissions. Incorporating the less amount of industrial by-products such as fly ash, slag silica fume,RA in concrete production can lower the environment's impact and enhance the basic properties of hardening concrete and fresh concrete. By using this product has economic, environmental, and technical benefits. Many supplements can be used in RA and cement, which give better strength and durability. For example, fly ash improves workability and long-term strength, minimizes the risk of alkali-silica reaction, reduces permeability, lowering the hydration of mass concrete, and enhancing durability performance [5].

RAis obtained from the demolished concrete structure. It has less strength than NA but can be used partially to achieve hardening and fresh concrete properties. The use of RA and supplementary cementing materials, especially FA, could result in a sustainable contribution. Various manufacturing by-products and recycled materials provide several environmental benefits by providing potential diversion of usable materials from waste streams. Under standard operating conditions, thermal power plants tend to be capable of producing fly ash which is typically poor in carbon (<5%) and high in glass (>75%),with a fine particle size distribution (>40% under 10μ and <20% above 45μm).

The study has shown that recycled coarse aggregate (RCA) is suitable for producing a wide range of designated mixes made with binary types of cement with a satisfactory engineering and durability performance. The mixes are designed for equivalent 28 days' cube strength. The use of RAs in concrete provided a promising solution to construction and demolished waste management. RAC is utilised in where lower-end concrete is needed [6]. RAC's workability for the same water content in the concrete is lower, as many researchers have reported, for cases when the replacement levels reach 50% [7]. The air content of RAC's is marginally higher (approximately 4% to 5.5%) than that of NA-made concrete at 100% replacement [8]. This increased air content may be due to the higher RA porosity. The bulk density of fresh concrete obtained from NAs is approximately 2400 kg/m3.

In contrast, the concrete made with RAs is significantly lighter, ~2150 kg/m3, regardless of the cement type. The lower density results from the aggregates' specific gravity, which is due to the type of concrete used for aggregate production. Besides, high air content in the recycled concrete leads to an additional decrease in the density of fresh concrete. While researchers have reported a reduced strength in RAC, it should be noted that the extent of the decline is related to the type of concrete, replacement ratio, water/cement ratio, and the moisture condition of the RA [1]. It is found that at a high w/c ratio (between 0.6 and 0.75), RAC's strength is comparable to that of reference concrete, even at a replacement level of 75% [8].

Owing to the heavy absorption of these aggregates, the use of RA in concrete causes substantial shrinkage. Some researches suggest that in RAC at the age of 90, the shrinkage could be about 0.55–0.8 mm/m, although the equivalent value for NAC is just around 0.30 mm/m [8]. With the inclusion of fly ash AND concentrated silica fume RA can be used for producing standard structural concrete.RAC strength and reference concrete are considered to be equal even at 100% substitution, given the water-cement ratio is greater than 0.55.However, as the water-cement ratio is reduced to 0.40, RAC's strength was only about 75% of the reference mix [9]. The flexural and splitting strengths ratio to the compressive strength is in the range of 16–23% and 9–13%, respectively [8]. Compared to the ACI guidelines, these values are about 10–15 percent lower. The analysis by Rao indicates a decrease in strength of 15-20 percent relative to comparison concrete at 100 percent replacement [9]. In another study, where the direct tensile strength of concrete was determined, the difference in RAC's tensile strength and referenced concrete at 28 days was less than 10%.Studies have also shown that additional cementitious admixtures, such as silica fume, etc. can lead to improvement in RAC properties. The modulus of elasticity of RAC is in the range of 50–70% of normal concrete. It depends on the water-cement ratio and the replacement level of RA [10-12].

A study to determine the various mechanical properties (flexural and compressive) of concrete developed using different RCA proportions and fly ash is carried out. It concludes that with the increase in RA percentage, the concrete's mechanical properties decrease, but the slump value increases due to RA's porous nature. Decreased resistance to carbonation and chloride ions penetration and sulphate attack was observed with a high RCA ratio of more than 30% [13-15].This research's main objectives are to determine the long-term flexural strength and compressive strength at the different fly ash and RCA ratios at 28 days and 56 days and understand the effect of fly ash and RA workability of concrete. The RA used in for experimental investigation is shown in Fig. 2.

Fig. 2. Recycled aggregate

2. Characterization of materials

2.1 Gradation of aggregate

Proper gradation of coarse aggregate is one of the most important factors in producing workable concrete. Proper gradation ensures that a sample of aggregates contains all standards fractions of aggregate in a required proportion such that the sample includes minimum voids. It leads to economic, higher strength and lower shrinkage, and greater durability. Gradation of 20 mm of natural coarse aggregate (NCA) and RCA using sieve analysis conforming IS 383-1970 is shown in Fig. 3. Gradation of 10 mm of natural fine aggregate (NFA) and recycled fine aggregate (RFA) is done using sieve analysis conforming IS 383-1970 is shown in Fig. 4.

2.2 Specific gravity

NCA and RCA's specific gravity size larger than 10 mm is done using the basket method and pycnometer method, respectively, conforming IS 2386 (part III)-1963. The obtained values are 2.85 and 2.49. A nominal mix is prepared with a cement of specific gravity 3.15. Any change in this value of specific gravity will affect the mix design. Hence, it is necessary to test the specific gravity of the cement procured before the mixing process. The specific gravity of cement is determined using Le Chatelier flask with the reference of IS 2720 (Part III).

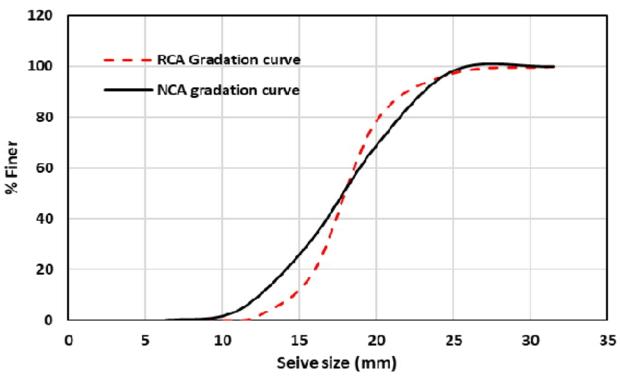

Fig. 3. Comparison gradation curve of NCAand RCA

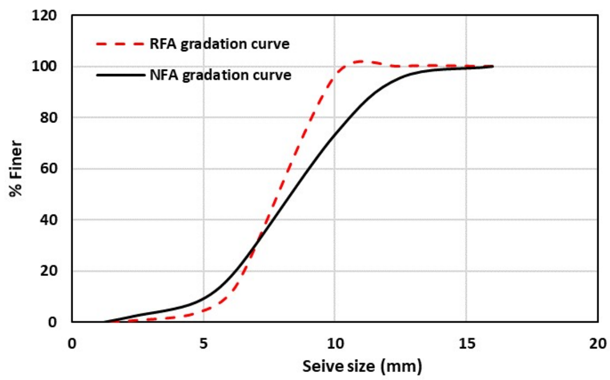

Fig. 4. Comparison gradation curve of NFA and RFA

2.3 Impact value

During the construction process of pavement layers, particularly compaction by heavy rollers and heavy wheel loads of traffic, the road aggregate is subjected to impact or pounding action. There is a possibility of some stones breaking under small pieces. The aggregate impact test is carried out to evaluate the resistance to aggregate to fracture under repeated impacts. The impact value of natural aggregate is determining with the reference of IS 2386 (Part IV). The impact value of a NA and RA is 20.2% and 26.3%, respectively.

2.4 Crushing value

The stone aggregate used for the construction of road pavement should possess good resistance to cursing under the roller during construction and under the application of heavy wheel loads on the pavement during service life. The aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. The crushing value of a NA and RA is 23.17% and 25.78%, respectively, determined with respect to IS 2386 (Part IV).

2.5 Abrasion value

The aggregate's abrasion values are determined from the Los Angeles abrasion test to find percentage wear due to the relative rubbing action between the aggregate and the steel balls used as an abrasive charge. The abrasion value of a NA and RAis 27.18% and 28.5%, respectively, determined as per IS 2386 (Part IV). An aggregate's impact, crushing, and abrasion valuesare less than 30 %, a good aggregate for pavement concrete construction.

2.6 Water absorption of aggregates

A water absorption test is done to determine the water holding capacity of water under a specified condition. The aggregates are kept in water for 24 hrs and then put in the oven for dry at 105^{o}C; measure the weight of dry and wet aggregate as shown in Fig. 5. Water absorption of coarse aggregates as per IS 2386 (Part III) – 1963 is tabulated in Table 1.

Table- 1. Water absorption of aggregate

Type of aggregate	*Surface saturated Weight (gm)*	*Oven dry Weight (gm)*	*Water absorption %*
N.C.A	493	490	0.61%
N.F.A	523	518	0.96%
R.C.A	220	213	3.28%
R.F.A	375	355	5.63%

Fig. 5.Water absorption test for aggregate

3. Design mix of concrete

A concrete mix design involves a process of preparation in which a mix of ingredients creates the required strength and durability for the concrete structure. The maximum nominal size of aggregates to be used in concrete may be as large as possible within limits prescribed by IS 456:2000. A significant replacement of natural coarse aggregate with recycled concrete aggregate derived from crushed concrete rubble and fly ash in varying proportions is used in the solution adopted here. First, fix the water-cement ratio (0.40), and depending upon the required workability and maximum size of the aggregate, water content is determined ($170kg/m^3$). The water-cement ratio and water content weight of cement selected for $1m^3$ of concrete ($425kg/m^3$). Considering the total volume of the concrete $1m^3$, the volume of the water (0.170), volume of cement (0.137), assume air volume (0.02). And the total volume of fine and coarse aggregate is determined (0.672).The fine-grain and coarse grain aggregate content are determined by using the DIN curve. In the DIN curve, all the constituent's gradation in a single graph is plotted to determine the percentage of fine aggregate and coarse aggregate, which gives the concrete's maximum density. From the DIN curve % of soil (40%)- A, NCA (30%)- B, NFA (30%)- C, and the total weight of the fine aggregate, coarse aggregate, and sand (Combined grading) is determined for $1m^3$ of concrete as shown in Fig. 6. The quantity required for different concrete mixes, the fly ash, is varied from 0%, 20%, 40%, and the RA is 0%, 30%, 50%, 100%.As per the methodology discussed, the different constituent quantity is determined for a diverse concrete mix, as illustrated in Table 2.

4. Experimental investigations

The casting was performed using the obtain mix design; around 15 kg of the mix was prepared for different mix proportions. A total of 108 samples were cast for 12 mixes.

i. 72 cubes of size 100mm x100mm x100mm.
ii. 36 beam of size 100mm x100mm x500mm.

For the sample preparation, the concrete mix is placed in the mould and compacted with the vibration table's help, as shown in Fig. 7 (a). Then the mould kept intact for 24 hours. Lastly the specimens are kept for curing for 28 days and 56 days, as shown in Fig. 7 (b).

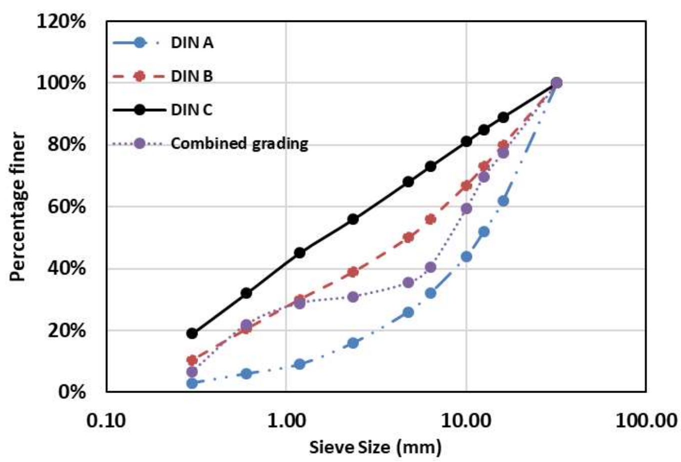

Fig. 6. DIN fit curve

Table- 2.Design mix of concrete

Mix Code	F.A %	Cement wt. (kg)	F.A wt. (kg)	NCA (kg)	NFA (kg)	RCA (kg)	RFA (kg)
RCA0	0	425	0	546	546	0	0
	20	340	85	538	538	0	0
	30	298	128	534	534	0	0
	40	255	170	530	530	0	0
RCA30	0	425	0	383	383	110	171
	20	340	85	377	377	108	169
	30	298	128	374	374	108	168
	40	255	170	371	371	107	166
RCA50	0	425	0	273	273	173	280
	20	340	85	269	269	170	276
	30	298	128	267	267	169	274
	40	255	170	265	265	168	272
RCA100	0	425	0	0	0	362	576
	20	340	85	0	0	356	568
	30	298	128	0	0	354	564
	40	255	170	0	0	351	559

4.1 Effect of fly ash and RA on workability

The concrete's workability is determined with the help of the compaction factor as per IS: 1199-1959. The compaction factor test is used for concrete, with low workability for which the slump test is not suitable. The compaction factor is the ratio of weights of partially compacted to fully compacted concrete. The compaction factor results are shown in Fig. 8 for both recycled aggregate and fly ash variation. The compaction factor of the concrete is quite less and decreases as the proportion of RCA increases.

(a) casting

(b) curing

Fig. 7. Concrete specimens

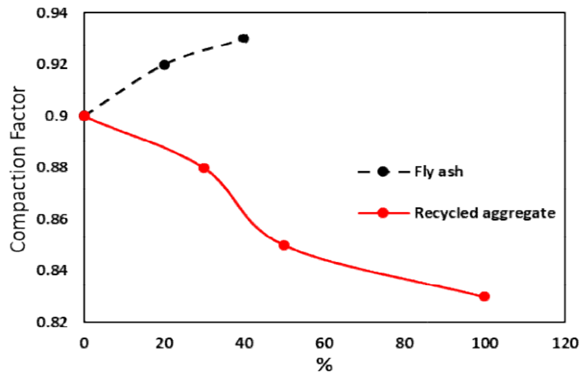

Fig. 8. Compaction factor vs. % of Fly ash and RA

The reason behind this is the fineness of fly ash, which is more as compared to cement. The higher specific area of fly ash, which is about 450 m^2/kg, provides more surface area to be wetted by solution, increasing workability. RA is more porous than NA, and they absorbed more water to NA, resulting in lower workability.

4.2 Effect of fly ash and RA on compressive strength

Compressive testing of cubic specimens of size 100mm for different mix proportions was done as per IS 516-1959 using a UTM machine, as shown in Fig. 9. The loading rate of the UTM is 0.230MPa/s. Failure stress of the cubes gives the compressive strength of the cube. Fig. 10. shows the compressive strength at 28 days and 56 days, and it can be concluded that by varying the % of the RA in the mix, the concrete's compressive strength decreases; this is due to the ITZ presence. Also, it shows that by keeping the RA % fix and vary the % of the fly ash, the strength is decreasing due to poor cementing property of the fly ash. It shows that the concrete's compressive strength at 56 days is more than 28 days for a particular mix. The reason behind that is the fly ash is gain strength at the latter stages, which give the additional strength to the concrete.

4.3 Effect of fly ash and RA on flexural strength

Flexural strength is an indirect test to determine the tensile strength of concrete. Flexural strength of concrete was performed after 56 days of curing as per IS: 512-2002 on a beam specimen of size 100x100x500mm using a UTM machine.The four-point test is conducted on the beam, as shown in Fig. 11.

Fig. 9. Compression test in UTM

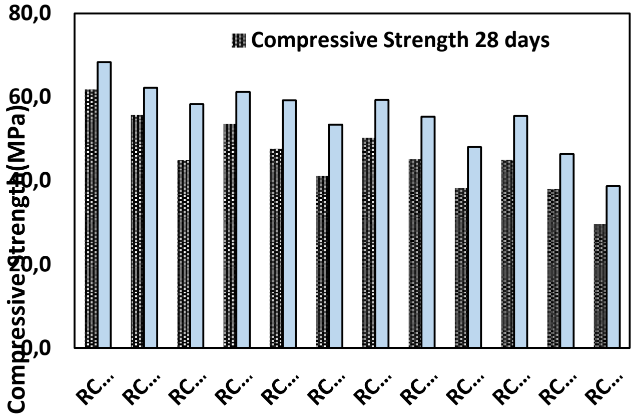

Fig. 10. Compression of compressive strength of concrete

Fig. 11. Flexural strength test

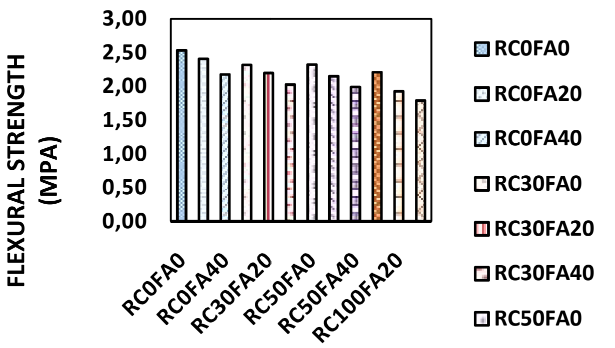

Fig. 12.Flexural strength vs.the different proportion of concrete

Fig. 12. shows the flexural strength at 28 days and 56 days, and it can be concluded that the strength decreases by increasing the RCA content. In the RCA, there is weak and thicker ITZ, which reduces the concrete's flexural strength.As the % of the RA in the concrete increases, ITZ increases, decreasing the concrete's indirect tensile strength. By keeping the RA fix and varying the fly ash proportion, the flexural strength is also reducing as the fly ash has less cementitious property. It reduces the concrete's strength.

5. Conclusions

The use of RA and fly ash is a good step towards sustainability. It will reduce the impact on the environment as well as save natural resources. A preliminary test is conducted on the materials which are used in the development of concrete pavement. Results have satisfactory results as per Indian standard guidelines. The main conclusions can be drawn as follows:

- The aggregate's crushing value is 23.17%; as per Indian standard, the value should not be more than 30%; hence, the aggregate can be used for pavement purposes.
- The aggregate's impact value is 20.2%, so it has a satisfactory result as per Indian standard.
- The water absorption value is 0.96%, which is less than 2%; hence it can be used for construction purposes.
- The workability of fresh concrete increases with an increase in the proportion of fly ash. It is due to more fineness of fly ash particles, which enhances workability through a ball-bearing effect. RAis more porous than NA, and they absorbed more water than NA, resulting in lower workability.
- Flexural strength decreases with increased RCA proportion in concrete compared to normal aggregate concrete due to weaker ITZ. The RA surface is more porous and weak, easily cracking under tensile stress and decreasing the concrete's flexural strength.
- The compressive strength of the concrete with more RCA is less than NA concrete due to ITZ, and failure occurs at the interface, which shows that the ITZ is weak in RCA concrete.
- Results show that 56 days' compressive strength is more than 28 days' compressive strength in the concrete with high replacement of fly ash with cement. Firm ash uses calcium hydroxides produced during cement hydration. Fly ash uses this to show a cementitious property, which increases the later age strength.
- All the failure takes place at the interfaces that show failure occurs due to RCA's breakage.
- RCA concrete can be used up to 30% of NA replacement for rigid pavement having low traffic volume.
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Disclosures

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References

1. CrentsilSagoe KK, Brown T, Taylor AH. Performance of concrete made with commercially produced coarse recycled concrete aggregate. Construction and Building Materials 2001; 31:707–12.
2. Corinaldesi V, Giuggiolini M, Moriconi G. Use of rubble from building demolition in mortars. Waste Management 2002; 22:893–9.
3. Oikonomou ND. Recycled concrete aggregates. Construction and Building Materials 2005; 27:315–8.
4. Poon CS, Kou SC, Lam L. Use of recycled aggregates in molded concrete bricks and blocks. Construction and Building Materials 2002; 16:281–9.
5. Berndt ML. Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. Construction and Building Materials 2009; 23:2605–13.
6. Olorunsogo FT, Padayachee N. Performance of recycled aggregate concrete monitored by durability indexes. Construction and Building Materials 2002; 32:179–85.
7. Topcu BI, Sengel S. Properties of concretes produced with waste concrete aggregate. Construction and Building Materials 2004; 34:1307–12.
8. Katz A. Properties of concrete made with recycled aggregate from partially hydrated old concrete. Construction and Building Materials 2003; 33:703–11.
9. Rao A, Jha KN, Misra S. Use of Aggregate from Recycled Construction and demolition waste in concrete. Resources Conservation and Recycling 2007; 50: 71-81.
10. Kou SC, Poon CS, Chan D. Influence of fly ash as a cement replacement on the properties of recycled aggregate concrete. Journal of Materials in Civil Engineering, ASCE, 2007; 19(9):709–17.
11. Kou SC, Poon CS. Long-term mechanical and durability properties of recycled aggregate concrete prepared with the incorporation of fly ash. Construction and Building Materials.2013; 37; 12-9.
12. Limbachiya M, Meddah MS, Ouchagour Y. Use of recycled aggregate in fly ash concrete. Construction and Building Materials 2012; 27:439-449.
13. Majhi RK, Nayak AN, Mukherjee BB, Development of sustainable concrete using RCA and ground granulated blast furnace slag. Construction and Building Materials 2018; 159:417-430.
14. Evangelista L, de Brito J. Durability performance of concrete made with fine recycled concrete aggregates. Construction and Building Materials 2010; 32:9–14.
15. Sagoe-Crentsil KK, Brown T, Taylor AH. Performance of concrete made with commercially produced coarse recycled concrete aggregate. Construction and Building Materials 2011; 31:707–12.