Experimental Study of Recycled Aggregate Concrete Produced from Recycled Fine Aggregate

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Abstract. Currently, in developing countries, the construction industry which uses a huge amount of concrete is booming at a faster growth rate due to an ever-increasing population and urbanization. To satisfy the high concrete demand natural resources like natural sand are depleting and river beds are eroded due to mining of natural sand. On the other hand, construction and demolition wastes disturb the environment due to different construction and demolition activities. Thus, in this study RCFA from concrete cubes at a laboratory was used to check the suitability of RCFA for concrete production as a partial replacement of natural sand. A mix of C - 25 concrete was prepared with 0%, 10%, 20%, 30%, 40%, 50%, and 100% replacement of natural sand by RCFA with and without admixture to check the compressive strength and workability of concrete. The workability of mixes without admixture increases as the replacement ratio of RCFA increases and vice versa for mixes with an admixture. The compressive strength of concrete decreases as the replacement ratio of RCFA increases. Even if there is a decrease in compressive strength as replacement ratio of RCFA increases, it is possible to replace NS up to 20% without an admixture and up to 50% with an admixture for the production of C-25 concrete without a significant compressive strength loss from the control mix.

Keywords: Recycled concrete fine aggregate (RCFA) · Recycled aggregate concrete (RAC) · Workability of concrete · Compressive strength of concrete

1 Introduction

The construction of infrastructures like buildings, bridges, roadways, and railways is increasing from time to time in the construction sector due to the ever-increasing population and urbanization. This demand has led to the construction of high-rise structures and demolishing existing old low-rise ones (Kisku et al. 2017). Newly constructed infrastructures mainly use concrete as the main input. Accordingly, the demand for concrete making ingredients like aggregates is increasing from time to time, since a huge amount of concrete is required in the construction industry for

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different infrastructures. Concrete's versatility, durability, sustainability, and economy have made it the world's most widely used construction material (Kosmatka et al. 2002). As Dixit et al. (2010), the construction industry is responsible for one of the largest impacts of all human activities 40% of raw stone, gravel and sand consumption, 25% of virgin wood, 40% of total energy and 16% of annual water consumption. The current annual consumption of concrete in the world is around 20 billion tons per year (Tosic et al. 2017).

Aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's fresh and hardened properties, mixture proportions, and economy (Kosmatka et al. 2002). From aggregates used in concrete production about 33–40% is a fine aggregate (Sonawane and Pimplikar, 2013). The consumption of natural sand in the world for concrete production is around 1000 million tons per year and making it scarce and limited (Ingalkar and Harle 2017). Accordingly, using this huge amount of fine aggregate in the construction industry depletes the natural environment; especially river beds that are the main sources of natural sand in the construction industry of Ethiopia.

On the other hand, nowadays, the volume of demolished concrete is increasing due to different reasons such as demolishing of structure for construction of new ones, destruction of structures due to natural disasters, crushing of cubes and blocks from different laboratories, destruction of buildings due to a new master plan, destruction of buildings due to the construction of new road, etc. Even if there is no exact recorded data on generation of C & D waste, more than 3 billion tonnes of construction and demolition waste are generated annually in the world (Akhtar and Sarmah 2018). The share of C&D in the total waste generation differs considerably between countries worldwide. According to Ulubeyli et al. (2017), the share is estimated as, Japan (16%), Germany (19%), USA (29%), EU (30%), China (30–40%), Hong Kong (38%), Australia (42%), the UK (50%), and Spain (70%). Per capita C&D waste generation in ton also shows large variations with low values in Norway (0.2), Poland (0.5), Spain (1), intermediate values in Germany and the UK (2), Hong Kong (3), France and Ireland (4), and high values in Luxembourg (15)". As Luangcharoenrat et al. (2019) pointed out, the proportion of construction debris (by weight) that is landfilled in each country shows between 13% and 60% compared with the total amount of waste.

Demolished concrete is available at various construction sites in huge quantity which are now posing a serious problem of disposal. Until now these materials are mostly used for landfilling works. But demolition and construction wastes have the potential to produce concrete by partially replacing natural aggregates. Thus, there are two problems in the construction industry i.e. depletion of natural resources and waste disposal problems. "To solve these two problems, People have started searching for suitable alternative materials that could be used either as an additive or as a partial replacement to the conventional ingredients of concrete so that the existing natural resources could be saved to the possible extent, and could be made available for the future generation" (Sirisala Chandrusha et al. 2017).

Since construction and demolition is booming, using recycled concrete for new concrete production very essential. Even if there is no sound literature on the amount of construction and demolition waste in the Ethiopian construction industry, annually around 204 tons of concrete waste produced from four Bahir Dar city material laboratory institutions (Yehualaw and Woldesenbet 2016). Using recycled concrete aggregate produced by crushing concrete waste reduces the consumption of natural aggregate (NS & NCA) as well as the amount of concrete waste that ends up in landfills which affect the environment negatively. Different researchers done a research and proposes the use of recycled aggregate for concrete production.

As Zega and Di Maio (2011) pointed out, it is possible to replace natural sand up to 30% by recycled concrete fine aggregate for concrete production having a similar mechanical and durable performance with 100% NS concrete using plasticizer admixture. The authors state that replacing natural sand up to 30% by RCFA is possible for structural concrete. On the other hand, Yaprak et al. (2011), state that the concrete produced by using the RCFA show lower strength by 4.3% for 10 RCFA, 5.9% for 20 RCFA, 9.8% for 30 RCFA, 12,7% for 40 RCFA, 18.6% for 50 RCFA and 35.4% for 100 RCFA. The authors state that RCFA can be used up to 10% ratio for producing C30 concrete, between 20% to 50% ratios for producing C 25 concrete.

Pereira et al. (2012), mention that using recycled fine aggregate as natural sand decreases the slump of concrete from 123 mm to 112 mm for mix without admixture, fixed constant 125 mm for regular super plasticizer and decreases from 130 mm (0% replacement) to 120 mm (100% replacement) for high range super plasticizer. The slump of concrete at 50% replacement and using regular super plasticizer increases from 125 mm to 130 mm. Similarly, Cartuxo et al. (2016), state that for the same slump value, the (w/c) increased up to 16.3% for mixes without admixture, the (w/c) decreased up to 15.7% for mixes using regular super plasticizer and, the (w/c) decreased up to 25.5% using high performance super plasticizer. The other researcher Khatib (2005), states that there is a systematic increase in slump of concrete as the content of recycled concrete fine aggregate in the mix increases, whereas there is a decrease in slump with the increase in recycled brick content. Similarly, Kou and Poon (2009), state that the slump of concrete increases as the replacement ratio of natural sand by recycled sand increases with a maximum increment of 5% at full replacement ratio.

Wang et al. (2019), uses both recycled fine and coarse aggregate for concrete production and the author concludes that there is a slight increase in the compressive strength of concrete mixes when NS was replaced with RCFA regardless of the coarse aggregate replacement level. The author observed that the mechanical properties of RCA decreased significantly when using 100% RCA with respective ranges of 8.7–14%, 18.9–23.6%, and 12.6–26.9% for compressive strength, modulus of elasticity and splitting testing strength test respectively. Similarly Kenai et al. (2002), investigated that the mechanical properties of concrete with recycled coarse and fine aggregates and found a reduction in compressive strength after 28 days in the order of 10% to 20% for concrete with recycled coarse aggregates, 10% to 30% for concrete with fine recycled aggregates and up to 35% for concrete with both coarse and fine aggregates. The other researchers Kou and Poon (2009), state that the compressive and tensile splitting strengths of the RA-SCC mixtures prepared without the addition of fly ash decreased with increasing fine recycled aggregate content.

Cartuxo et al. (2016), state that for concrete produced using fine recycled aggregate as natural sand, the compressive strength decreased up to 35% at 7 days, 29% at 28 days and 30% at 56 days for mixes without an admixture, increased up to 47% at

7 days, 35% at 28 days and 43% at 56 days for mixes with regular super plasticizer and, increased up to 82% at 7 days, 63% at 28 days and 59% at 56 days for mixes with high performance super plasticizer. On similar manner Pereira et al. (2012), pointed out that replacing natural sand by recycled concrete fine aggregate showed a decrease in compressive strength with figures of 4.8%, 15.4% and 3.3% for the without admixture, SP_1 and SP_2 families, respectively from the respective control mix at the age of 28 days.

Even if there are lots of researches studied by partially replacing natural sand by recycled concrete fine aggregate none of the researches are conducted by considering the whole water absorption capacity recycled concrete fine aggregate. Accordingly, this research undertaken to investigate the effect of replacement of natural fine aggregate with recycled concrete fine aggregate on properties of concrete by considering the whole absorption capacity of recycled concrete aggregate. The study was evaluated in terms of workability and compressive strength of concrete.

2 Materials and Experimental Design

2.1 Material Preparation and Properties

The recycled concrete fine aggregate used in this work were obtained from Bahir Dar university material laboratory crushed cubes. Then the cubes were crushed by jaw crusher at Zenzelima and the fine part were used as natural sand replacement. The crusher is primary crusher which is used for crushing stone for the production of aggregate. Dry mix were used on RCFA to reduce the amount of mortar on the surface of recycled concrete fine aggregate. When RCFA was dry mixed by mixer the attached mortar is separated (removed) from the fine aggregate. Additionally, RCFA becomes more smother. As compared from recycled concrete fine aggregate before dry mix to that of recycled concrete fine aggregate after dry mix, the mortar was separated from the aggregate after dry mix.

Locally available Lalibela natural sand and Meshenti coarse aggregate that satisfies ASTM requirement were used to conduct tests. Ordinary Portland cement 42.5 N made by Derba cement factory were used as a binding material. Tap water from Bahir Dar university and mega flow SP2 super plasticizer obtained from Addis Ababa with a dosage of 2% of cement were used for the production of concrete.

Physical Properties of Aggregates (Fine and Coarse Aggregate)

Gradation of Aggregate: The grading of aggregate is very essential for the production of good and suitable concrete. Well-graded aggregate decreases the porousness of concrete produced and also the cement consumption. The gradation of coarse aggregate, recycled concrete fine aggregate and natural fine aggregate satisfies ASTM standards as illustrated on the graph below. As shown on Figs. 1 and 2 the gradation of both fine and coarse aggregate is within the recommended limit of ASTM standard.

The rest physical properties of aggregates are tabulated in Table 1.

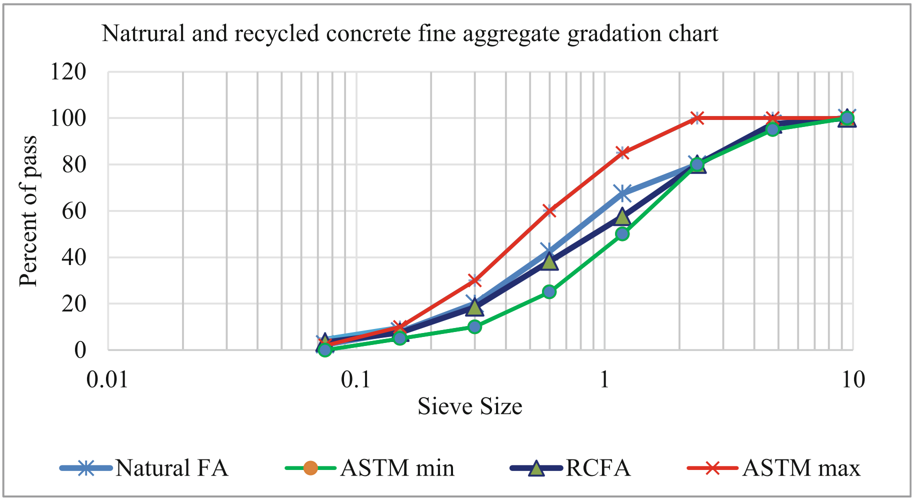

Fig. 1. Recycled and natural sand gradation chart

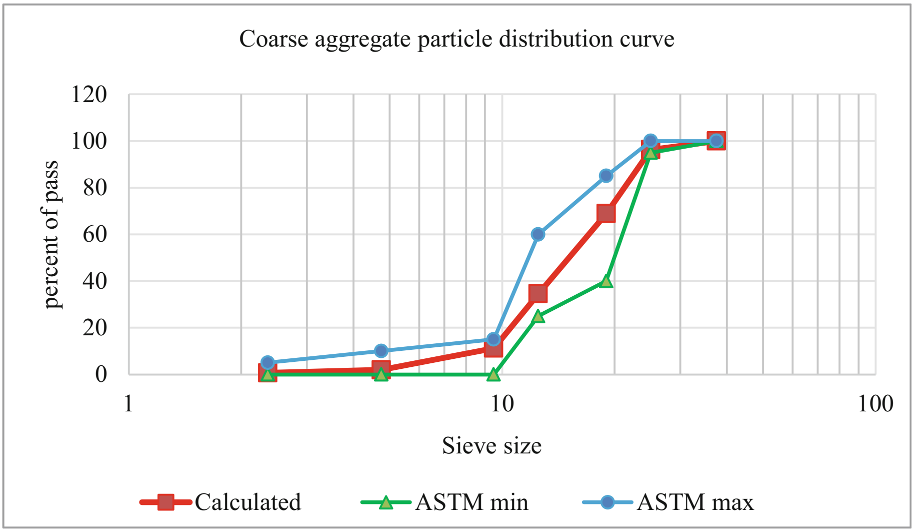

Fig. 2. Coarse aggregate gradation chart

Table 1. Physical test results of aggregates

Type of test	Coarse aggregate	Natural fine aggregate	Recycled concrete fine aggregate	
			Before dry mix	After dry mix
Unit weight	1707 kg/m^3	1619 kg/m^3	1386.33 kg/m^3	1523.70 kg/m^3
Specific gravity	2.83	2.68	2.34	2.42
Absorption capacity	1.43%	2.46	13.76%	10.4%
Moisture content	0.343	1.82	–	2.62%
Silt content	–	1.897	–	2.05%
Finesse modulus	–	2.86	–	3.04

2.2 Mix Design

After conducting the physical properties recycled concrete fine aggregate and natural fine and coarse aggregate mix design was performed by using ACI 211. The quantities of each concrete making ingredients are tabulated in Tables 2 and 3.

Table 2. Mix proportion by weight for mixes without admixture

Mix designation	Percent of RCFA	W/C ratio	Adjusted W/C	Weight of materials in Kg/m^3					Total weight of materials (Kg/m^3)
				Cement	RCFA	Sand	CA	Water	
0RCFA100NS	0%	0.49	0.54	365	–	786.0	1141.0	196.00	2488
10RCFA90NS	10%	0.49	0.55	365	74	707.4	1138.3	201.27	2486
20RCFA80NS	20%	0.49	0.57	365	148	628.8	1135.6	206.54	2484
30RCFA70NS	30%	0.49	0.58	365	222	550.2	1132.9	211.81	2482
40RCFA60NS	40%	0.49	0.59	365	296	471.6	1130.2	217.08	2480
50RCFA50NS	50%	0.49	0.61	365	370	393.0	1127.5	222.35	2478
100RCFA0NS	100%	0.49	0.68	365	740	–	1114.0	248.70	2468

Table 3. Mix proportion by weight for mixes with admixture

Mix Designation	Percent of RCFA	Percent of admixture	W/C ratio	Adjusted W/C	Weight of materials in Kg/m^3						Total weight of materials (Kg/m^3)
					Cement	RCFA	Sand	CA	Water	Admixture	
10RCFA90NS	10%	2% Cement	0.49	0.44	365	72.6	693	1138	161.20	7.3	2437
20RCFA80NS	20%	2% Cement	0.49	0.45	365	145.2	616	1136	165.30	7.3	2434
30RCFA70NS	30%	2% Cement	0.49	0.46	365	217.8	539	1133	169.40	7.3	2431
40RCFA60NS	40%	2% Cement	0.49	0.48	365	290.4	462	1130	173.47	7.3	2428
50RCFA50NS	50%	2% Cement	0.49	0.49	365	363.0	385	1128	177.60	7.3	2425
100RCFA0NS	100%	2% Cement	0.49	0.54	365	726.0	–	1114	198.08	7.3	2410

2.3 Test Methods for Materials

To check the suitability of concrete making ingredients different standards were adopted. The following are the test methods adopted for concrete making ingredients (Tables 4 and 5).

Table 4. Test methods for concrete making materials

Aggregate type and properties		Test methods
Gradation test	CA & FA	ASTM C 136 and ASTM C 33
Bulk density test	CA & FA	ASTM C 29
Water absorption test	CA	ASTM C127
	FA	ASTM C128
Specific gravity test	CA	ASTM C 127
	FA	ASTM C128
Silt content	FA	IS 2386
Organic impurity	FA	ASTM C 40
Moisture content	CA & FA	ASTM C 566

Table 5. Test methods for concrete

Concrete properties	Test method
Workability	ASTM C 143 M-08
Compressive strength	BS 1881-116

2.4 Experimental Design

This research focuses on replacing natural sand by recycled concrete fine aggregate for normal concrete production. Natural sand was replaced with recycled concrete fine aggregate partially and fully to analyze the effect of replacing natural sand by RCFA on concrete properties. To do the experimental work 0%, 10%, 20%, 30%, 40%, 50%, and 100% of natural sand is replaced by RCFA with and without admixture, and tests were conducted on hardened and fresh properties of concrete. 0% replacement is used as a control mix (reference mix). A total of 13 series of mixes and 117 cubes were prepared and tested for workability and compressive strength. Since recycled aggregate has high water absorption capacity three enhancement methods were used to compromise high water absorption capacity of recycled concrete fine aggregate. The methods were dry mix, using high range water reducing admixture and stage mix.

2.5 Mixing and Testing Methods for Concrete

Mix without Admixture: After all ingredients were prepared coarse aggregate, RCFA, and NS were added to the mixer and dry mix was conducted. Then cement was added to the mixer and dry mixed. Finally, water is added to the mix gradually and the concrete mixed uniformly. Once the concrete mixed uniformly, the workability of concrete was checked by a slump test. After the slump test, the concrete was cast in 15 cm * 15 cm * 15 cm cube molds. After one day cast cubes were demolded and cured into curing tanks at Bahir Dar Institute of Technology construction material laboratory. A total of 63 cubes were cast in this mix.

Mix with an Admixture: In this mixing procedure, after all ingredients were prepared RCFA, NS, and 67% mixing water were added to the mixer and mixed for 4 min. Then coarse aggregate was added to the mixer and mixed for 2 min. Finally, the remaining 33% mixing water, cement, and admixture were added to the mix and mixed for 4 min until the concrete was mixed uniformly. Once the concrete was mixed uniformly workability of concrete was checked by slump test. After testing the slump, the concrete was cast in 15 cm * 15 cm * 15 cm cube molds. After one-day cast cubes were demolded and cured into curing tanks at Bahir Dar Institute of Technology construction material laboratory. In this mixing method, the water reducing capacity of admixture was assumed to be 20% and the water content is reduced by 20%. This 20% was selected since high range water reducers can reduce the amount of mixing water by 12% to 30%. According to Cartuxo et al. (2016), high range water reducers can reduce the free mixing water up to 25.5% with the same slump to the control mix. In this mixing method, a total of 54 cubes were cast.

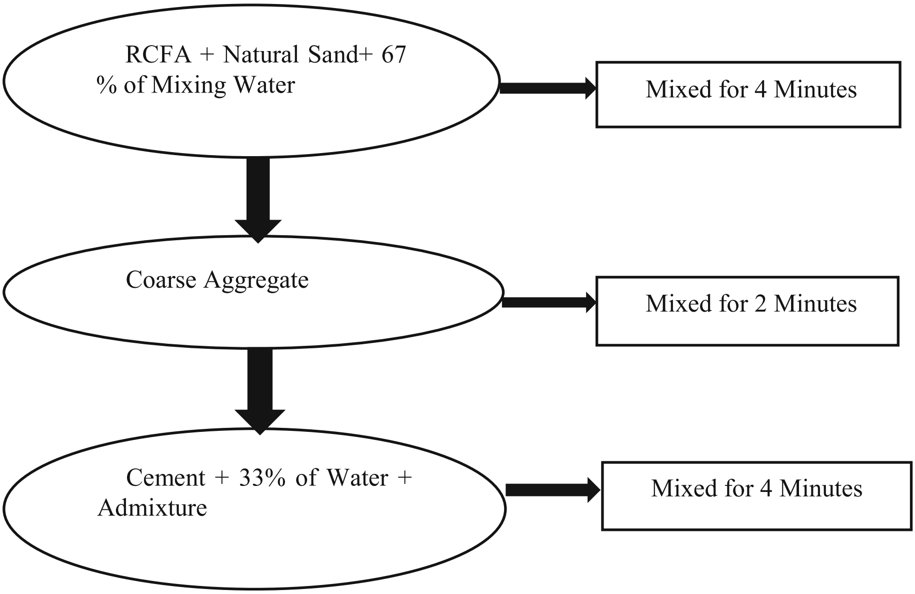

Fig. 3. Mixing procedure for mixes with an admixture adopted from Cartuxo et al. (2016)

Slump Test: The slump test of concrete was conducted after thoroughly mixing concrete by using ASTM C-143 M-08 standard.

Compressive Strength Test: Compressive strength test was carried out according to BS 1881-116 standard by using a hydraulic compression machine of capacity 2000 KN. The loading rate of the machine was 0.35 MPa/s. After casting concrete by 15 cm * 15 cm * 15 cm cubes and curing in curing tank, compressive strength test was conducted at 3rd, 7th and 28th day by using a compressive strength machine at Bahir Dar Institute of Technology.

3 Results and Discussions

In this section the results from slump test, compressive strength test and unit cost of concrete are discussed.

3.1 Workability of Concrete Produced from Recycled Concrete Aggregate

The slump test was performed to study the effects recycled fine aggregate concrete on workability according to ASTM C-143 M-08. The water to cement ratio varies due to the different water absorption capacity of each trial mix.

Workability of Concrete Mixes Without Admixture

Table 6. Workability of mixes without admixture

Mix designation	Percent of RCFA	W/C ratio	Adjusted W/C	Slump (mm)
0RCFA100NS	0%	0.49	0.54	40
10RCFA90NS	10%	0.49	0.55	42
20RCFA80NS	20%	0.49	0.57	45
30RCFA70NS	30%	0.49	0.58	47
40RCFA60NS	40%	0.49	0.59	50
50RCFA50NS	50%	0.49	0.61	55
100RCFA0NS	100%	0.49	0.68	71

W/C ratio = water to cement ratio for the production of C 25 concrete. Adjusted W/C ratio = water to cement ratio by considering absorption.

Concrete mixes without an admixture were done by considering all the absorption capacity of recycled concrete fine aggregate to the mix. As shown in Table 6 above the slump of concrete was increased as the replacement ratio of natural sand by RCFA was increased. This because the RCFA does not absorb all the water added to the mix by considering its water absorption capacity. "As Cartuxo et al. (2016) states, about 10 min are required for RCFA to absorb about 70% of its absorption capacity." Thus, if an adjustment is done on the mix design of concrete, the slump of concrete increases as the replacement of NS by RCFA increases. This result is also argued by (Kou and Poon

2009) and (Khatib 2005). The authors state that the workability of concrete increases as the replacement ratio increases at an early age and reduces substantially as time goes because of RCFA water absorption. The slump of concrete in mixes without an admixture was increased by 5%, 12.5%, 17.5%, 25%, 37.5%, and 77.5% from the control mix at 10%, 20%, 30%, 40%, 50%, and 100% replacement ratios respectively. Even if the slump of concrete increases as replacement ratio increases, the concrete was bleeding and segregated at higher replacement ratios.

Workability of Concrete Mixes with Admixture

Table 7. Workability of concrete for mixes with admixture

Mix designation	Percent of RCFA	Percent of admixture	W/C ratio	Adjusted W/C	Slump (mm)
10RCFA90NS	10%	2% Cement	0.49	0.44	45
20RCFA80NS	20%	2% Cement	0.49	0.45	40
30RCFA70NS	30%	2% Cement	0.49	0.46	37
40RCFA60NS	40%	2% Cement	0.49	0.48	35
50RCFA50NS	50%	2% Cement	0.49	0.49	32
100RCFA0NS	100%	2% Cement	0.49	0.54	27

Unlike concrete mixes mixed without an admixture, the slump of fresh concrete for mixes with an admixture and stage mixing was decreased as the percent of replacement of RCFA increases. This is because the stage mix gives time for RCFA to partially saturate and absorb more water. Besides, the effectiveness of high range water reducing admixtures decreases as the replacement ratio of RCFA increases (Pereira et al. 2012). Thus, the slump of the concrete mix was decreased as the replacement ratio of RCFA increases. This result is argued by test results found by (Solyman 2005), (Cartuxo et al. 2016) and (Pereira et al. 2012). Even if the slump of concrete decreases as the replacement ratio of RCFA increases, all concrete mixes mixed with an admixture have a suitable slump for concrete work (25 mm to 50 mm). As compared to the control mix, a maximum of 32.5% slump loss was observed at 100% replacement of natural sand by RCFA. To easily understand the difference, the slump results are shown in the graph below (Table 7).

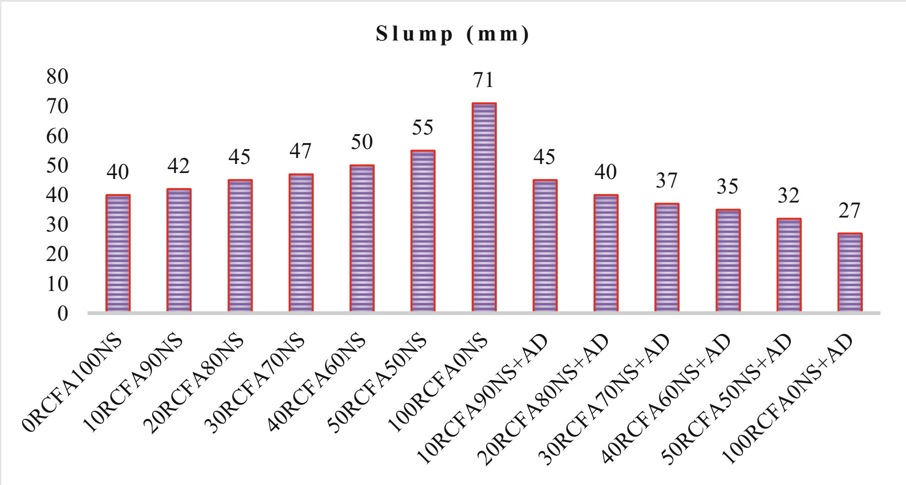

Fig. 4. Slump of concrete using RCFA at different replacement ratio

3.2 Compressive Strength Test

Compressive Strength Without Admixture

Table 8. Compressive strength without admixture

Mix designation	Percent of RCFA	W/C ratio	Adjusted W/C ratio	Average compressive strength		
				3 day	7 day	28 day
0RCFA100NS	Control (0)	0.49	0.54	21.41	29.87	36.54
10RCFA90NS	10	0.49	0.55	21.03	29.74	36.45
20RCFA80NS	20	0.49	0.57	19.84	28.13	34.75
30RCFA70NS	30	0.49	0.58	18.47	26.37	33.24
40RCFA60NS	40	0.49	0.59	17.77	25.14	31.58
50RCFA50NS	50	0.49	0.61	16.84	24.05	30.16
100RCFA0NS	100	0.49	0.68	12.40	19.68	25.42

Partially replacing NS by RCFA reduces the compressive strength of concrete as the replacement ratio of RCFA increases this is because the high absorption capacity of RCFA increases the water to cement ratio in the mixture. The 3rd day compressive strength of concrete reduced by 2%, 7%, 14%, 17%, 21%, and 42% from the control mix with 10%, 20%, 30%, 40%, 50%, and 100% replacement ratios respectively. Similarly, the compressive strength of concrete reduced from 0% to 34% at the 7th day, and from 0% to 30% at 28th day with replacement ratios ranging from 10% to 100%. This result is similar to the test result found by Cartuxo et al. (2016). The author found that full replacement of natural sand with RCFA reduces the compressive strength of concrete by 35%, and 29% at 7th, and 28th day respectively. Generally, the compressive strength of concrete reduces as the replacement ratio of natural sand by RCFA increases. When the age of concrete is increased the reduction in compressive strength of concrete from the control mix is decreased in all the concrete mixtures. This is due to the fact that the hydration of unhydrated cement paste on the surface of RCFA. At 20% replacement ratio, even if the compressive strength of concrete is lower than the control mix by 4.9% at the age of 28 days, it is slightly higher than the target mean strength of C 25 grade concrete. Thus, according to test results, C 25 can be produced by partially replacing natural sand with 20% RCFA and using locally available construction materials in Bahir Dar (Table 8).

Compressive Strength with Admixture

Table 9. Compressive strength with admixture

Mix designation	Percent of RCFA	W/C ratio	Adjusted W/C ratio	Average compressive strength		
				3 day	7 day	28 day
0RCFA100NS	0			21.41	29.87	36.54
10RCFA90NS+Ad	10	0.49	0.44	29.35	37.19	42.36
20RCFA80NS+Ad	20	0.49	0.45	28.91	36.34	40.26
30RCFA70NS+Ad	30	0.49	0.46	26.79	34.60	37.29
40RCFA60NS+Ad	40	0.49	0.48	25.13	32.89	35.41
50RCFA50NS+Ad	50	0.49	0.49	24.29	31.33	34.69
100RCFA0NS+Ad	100	0.49	0.54	19.86	26.03	29.72

As shown in Table 9 above, at 3rd day 37%, 35%, 25%, 17%, and 13% compressive strength increment were obtained from the control mix when 10%, 20%, 30%, 40%, and 50% of NS was replaced by RCFA respectively. But at the full replacement of NS by RCFA there is a loss of 7% compressive strength from the control mix. Similarly, at 7th day there is 24%, 22%, 16%, 10%, 5% compressive strength increment at 10%, 20%, 30%, 40%, and 50% replacement ratio of NS by RCFA respectively. But, at the full replacement of NS by RCFA there is a loss 13% compressive strength from the control mix. At the age of 28th day 16%, 10%, 2% compressive strength increment was obtained at 10%, 20%, and 30% replacement of NS by RCFA respectively. But at 40%, 50%, and 100% replacement of NS by RCFA there is a loss of 3%, 5%, and 19% compressive strength from the control mix respectively.

The compressive strength increment at an early age is higher for all mixes as compared to the control mix. This is due to the fact that the admixture used in the mix accelerates the strength gain of concrete. Since the admixture used was high range water reducing and accelerating admixture. From the test results obtained, RCFA can replace NS up to 50% by using water-reducing admixture for the production of C 25 concrete with a slight increment in compressive strength (3.5%) from the target mean strength. This finding is supported by (Ahmed 2014), the concrete containing RCFA contents up to 50% exhibited similar or slightly better at all ages from the control mix. From the test results, C 25 concrete can be produced by partially replacing NS with RCFA up to 50% by using different enhancement methods. Even if the compressive strength of concrete produced at 50% replacement is slightly lower than the control mix, it attains the target mean strength. To easily understand the difference in results, the results are shown in Fig. 5 below.

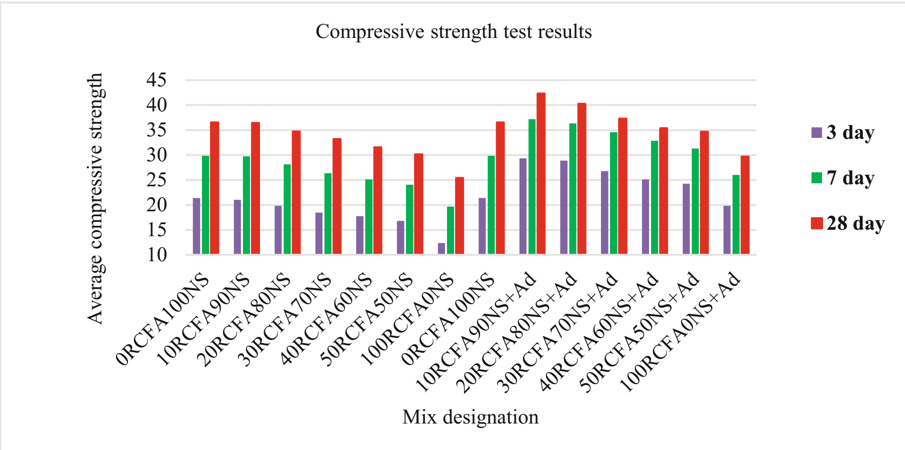

Fig. 5. Compressive strength test results

3.3 Cost Comparison

In this work, only material costs were considered to estimate the cost of concrete. The costs of the materials were collected from local material suppliers in Bahir Dar.

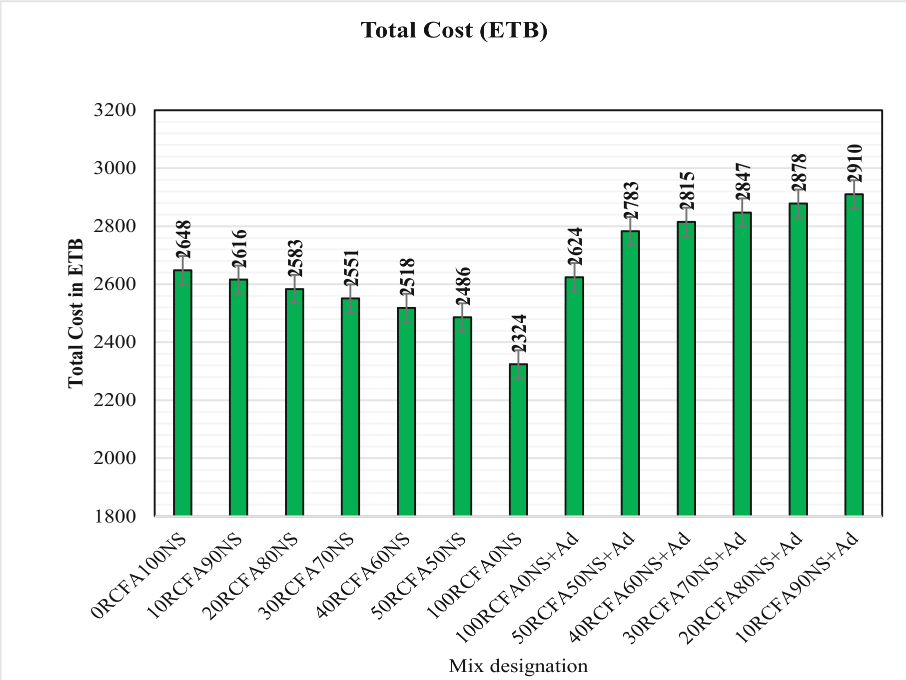

Fig. 6. Unit cost comparison for concrete using RCFA

Partially replacing natural sand by 10%, 20%, 30%, 40%, 50%, and 100% with RCFA without an admixture can save a material cost of 1.23%, 2.45%, 3.68%, 4.9%, 6.13%, and 12.25% respectively from the control mix. Though, the compressive strength of concrete reduces as the replacement ratio of NS by RCFA increases. Unlikely, as shown on Fig. 6 above using admixture in concrete incurs a material cost of 9.89%, 8.69%, 7.49%, 6.29% and 5.09% at 10%, 20%, 30%, 40%, and 50% replacement of natural sand by RCFA respectively. However, the full replacement of natural sand by RCFA with an admixture can save a material cost of 0.92% from the control mixture. Even if using an admixture in concrete incurs a cost, it increases the compressive strength of concrete. At the age of 28 days, the compressive strength of concrete can be increased by 16% at 10% replacement of natural sand with RCFA even if the mix is the costliest. Generally, the material cost of concrete decreases as the replacement ratio of natural sand by RCFA increases regardless of compressive strength loss.

According to the test results, replacing natural sand by RCFA up to 20% without an admixture and up to 50% with an admixture doesn't have a significant effect on the compressive strength of concrete. Thus, one can save a material cost of 2.45% by replacing NS with 20% RCFA. From this, a contractor can save approximately 6500 Birr from 100 m^3 concrete by replacing 20% of natural sand with RCFA. For mixes with an admixture, one can replace natural sand by RCFA up to 50% without a significant compressive strength loss from the control mix. However, the material cost of concrete is increased by 5.09% from conventional concrete. Even if the cost of concrete produced using an admixture is costly, using an admixture with RCFA is very essential to solve waste disposal problems. By using an admixture, the optimum percent replacement of natural sand with RCFA is increased from 20% to 50%, and one can reduce 30% concrete waste by using admixture regardless of cost increment. Thus, when using RCFA as natural sand one can use up to 20% to save material cost and the other can use up to 50% with an admixture to solve waste disposal problems.

The construction industry is economical if it conserves natural resources, reduces energy consumption, solves waste disposal problems, and preserves the environment from degradation. Even if using water-reducing admixtures in concrete increases the material cost of concrete, the above-listed benefits are obtained when using recycled concrete fine aggregate as natural sand. Using recycled concrete fine aggregate saves waste transportation cost, saves landfill space, saves landfill charges, saves soil and groundwater contamination, reduces natural sand extraction, saves river beds from erosion, ensures sustainability, and improves the public image and environmental concern. Therefore, using construction and demolition waste for concrete production is very essential.

4 Conclusions

Finally, the following conclusions are drawn from the test results obtained from concrete produced by using RCFA as a partial replacement of natural sand.

1. Except for high water absorption and lower specific gravity, the physical properties of RCFA comply with the standards for good concrete production. Hence, RCFA can partially replace natural sand by using a dry mix, stage mix, and an admixture as an enhancement of RCFA.
2. The slump of concrete increases as replacement ratio RCFA increases for mixes without an admixture. This is because the concrete doesn't absorb all the water added to the concrete by considering the water absorption capacity of RCFA. When stage mix and an admixture were used, the slump of concrete was reduced as the replacement ratio NS by RCFA increases because the long mixing time gives the concrete to absorb the water added to the concrete by considering RCFA water absorption.
3. The compressive strength of concrete decreased as the replacement of RCFA increases since the amount of water added to the concrete was increased due to the high-water absorption capacity of RCFA. But, the compressive strength of concrete can be enhanced by using high range water reducing admixture and stage mixing. A maximum compressive strength increment of 16% is obtained at 28 days when 10% of sand is replaced by RCFA and using an admixture. Generally, the compressive strength of concrete reduces 5% to 30% for mixes without admixture and 3% to 19% for mixes with an admixture from the control mix at the age of 28 days.
4. From the test results, RCFA can replace NS up 20% by applying dry mix on RCFA and up to 50% by applying dry mix, stage mixing, and high range water reducing admixture without a significant compressive strength loss from the control mix.

5. From the cost comparison between conventional concrete and RCFA concrete, RCFA can save about 2.45% material cost than conventional concrete for a mix without an admixture at a 20% replacement ratio. Unlikely for mixes with an admixture the concrete incurs a material cost of 5.09% than conventional concrete at maximum replacement ratio of 50%.
6. Even if using RCFA incurs a cost, it should be used for concrete production to satisfy the NS demand, to reduce the waste released to the environment (waste disposal problem), to reduce energy consumption, and to reduce erosion of river beds for NS mining.

Generally, using RCFA for aggregate production is very essential for sustainability in the construction industry. Since sustainability is necessary and it isn't an option, using alternative construction materials like RCFA is economical to preserve the environment, to reduce natural resource extraction, to reduce energy consumption, and to solve waste disposal crises in the construction industry.

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