INVESTIGATING THE PERFORMANCE OF RECYCLED COARSE AGGREGATE USING SUPERPLASTICIZER ON THE MECHANICAL PROPRTIES OF CONCRETE

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ABSTRACT

Aggregates are the elements that serve as the skeletons in concrete. A large amount of construction and demolition waste is produced when buildings are demolished. Concrete recycling is becoming more popular since it conserves natural resources and reduces the need for disposal. The purpose of this study was to determine how superplasticizer in recycled aggregate concrete (RAC) affected the characteristics of new concrete. Firstly, the recycled coarse aggregate (RCA) (0%,25%,50%, and 100%) had been used as a partial replacement of natural coarse aggregate (NCA) with no admixture and with admixture named poly carboxylic ether (by reducing the water content 15% and using 0.7% admixture of total weight of cement). The physical properties (like fineness modulus, moisture content, and specific gravity) were determined for RCA, NCA and for fine aggregate also. A total of 72 cylinders (4 in Diameter ×8 in Height) were made with mix ratio of (1:1.5:3), w/c=0.5 and cured for 7,14 and 28 days, respectively. It was found that workability value had increased after using superplasticizer in each percentage replacement of RCA. Compressive strength values were decreasing with the increasing percentages of RCA. But while using superplasticizer (SP), compressive strength value had increased in each percentage replacement of RCA. Compressive strength had increased at maximum amount of 42.86% higher for 25% of RCA comparing to no admixture of same percentages of RCA. A cost estimation was also conducted. It was found that at 25% of RCA with SP, though compressive strength value had increased but cost were lower than control specimen of normal aggregate concrete.

Keywords: *Normal Aggregate concrete, RCA, Superplasticizer, Cost and Compressive strength.*

1. INTRODUCTION

Twenty billion tonnes of concrete are thought to be consumed globally. It requires 14 billion tonnes of natural aggregate to make this much concrete. A significant number of mountains must be cut down or aggregate quarries must be dug in order to supply aggregate. It should be mentioned that, after water, concrete is the substance that is used the most. The natural water cycle, bestowed by God, recycles water. Concrete recycling is also essential to maintaining our ecosystem. Several nations, including Germany, the United States of America, Japan, and others, created public projects using recovered aggregate to raise awareness of the recycling of demolished construction materials. Bangladesh could also adopt the same policy. The United Nations (UN) has set several Sustainable Development Goals (SDGs), including SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Recycling of demolished concrete waste will help achieve these goals. Every piece of construction trash is supposed to be recycled correctly using our engineer's creative solutions, considering the sustainability of both our environment and building materials. This is done while keeping in mind that demolished concrete is a resource, not waste. in recycling plants, where the steel reinforcement is separated from concrete. The concrete rubble is crushed in an impact or a jaw crusher to reduce the grain size to produce recycled concrete aggregates (RCA). The RCA can be screened to obtain two fractions: coarse recycled concrete aggregates (CRCA) and fine recycled concrete aggregates (FRCA) (Cartuxo F.,et al., 2016).

When using crushed concrete as aggregate for new concrete, it is important to make sure the aggregates' qualities still meet the criteria. Because recycled aggregates contain residual contaminants and mortar, it is commonly believed that they are inferior to natural aggregates. It results in a reduction in mechanical strength. If the parent concrete is of excellent quality and has high mechanical properties, concrete made with recycled materials may have mechanical qualities comparable to concrete made with natural aggregates.

According to the different test results, recycled coarse aggregate is more porous, less dense, and capable of absorbing more water than natural coarse aggregate. In terms of mechanical and physical characteristics, recycled coarse aggregate is found to be marginally weaker than natural coarse aggregate, but the compressive strength of concrete produced using recycled coarse aggregate is nearly equal to that of concrete made natural coarse aggregate (Bashir A. et al., 2018).

Recycled aggregate has greater bulk density, crushing and impact values, and water absorption than natural aggregate. The compressive strength of recycled aggregate concrete can be increased by up to 15% when compared to natural aggregate concrete by substituting up to 30% of NCA with RCA. The variation is also influenced by the original concrete from which the aggregates were taken out. When RCA was added to native coarse aggregate in percentages ranging from 10 to 30 percent, the concrete mixes exhibited favourable performances (Siddiquie N.A. et al., 2023). RCA concrete outperforms NCA concrete in terms of compressive strength at a specific threshold w/c ratio. The investigation's findings indicate that, in order for the RCA concrete to contribute to strength based on the parent attached mortar, a minimum amount of water must be used (Singh K.K. et al. 2023).

In order to examine the mechanical properties of RAC, four replacement ratios of coarse recycled aggregate CRA (0%, 25%, 50%, and 100%) in RAC mixtures were used. According to their findings, when the replacement ratio of CRA was 100%, the compressive strength of RAC was 20–25% lower than that of the normal aggregate concrete (NAC) (Etxeberria M. et al., 2007).

Macroeconomically speaking, the abundance of edges and angles on recycled aggregate particles and the first cracks in the rough surface of the hardened cement mortar attached to the surface cause the physical and mechanical properties of recycled aggregate to deteriorate. These include a decrease in surface density, an increase in water absorption, a rise in the crushing index, and an increase in water content (Zhong C. et al., 2022).

The porous surface of the recycled concrete aggregates allows for high water absorption. Furthermore, a consistent downward trend in the compressive strength was found as the percentage of the RCA rises. Nevertheless, the addition of calcined clay as a cement substitute (pozzolanic admixture) significantly increased the compressive strength and enhanced the concrete's strength development (Olofinnade O M. et al., 2019).

The efficacy of the SP was compromised by the addition of FRCA. It was found that adding high-performance SP and FRCA at the same time is a feasible and sustainable way to produce structural concrete from a durability perspective (Cartuxo F. et al., 2016).

There was not availability of research which has studied the effect of SP whereas RCA was used as a partial and fully replacement with NCA. Besides, since the high amount of water content in RCA badly affects the mechanical properties of concrete, it is required to use the chemical, which will reduce the need for water in concrete mixing in the case of using RCA as a coarse aggregate. So, this study incorporates the use of SP to increase the mechanical properties along with deducing the water content in concrete. Besides, the study also emphasizes the cost of concrete specimens so that it can provide a feasible solution of increasing compressive strength along with a cost deduction.

2. METHODOLOGY

To determine the strength and other properties, specimens were made using partially and fully from RCA in place of coarse aggregates with no admixture and using SP as an admixture and an experimental investigation was carried out. The strength of various mixes and conventional concrete was measured after 7, 14 and 28 days of moist curing. Concrete cylinders were cast in order to examine the effects of the inclusion of RCA and the effect of SP in those replacements of RCA as coarse aggregate.

2.1 Materials Collection

2.1.1 Fine Aggregate

Numerous factors, such as the fineness modulus, moisture content, specific gravity, and silt content, affect the proportions of the concrete mix. Fine aggregates are the particles that stay on a 0.075mm sieve after passing through a 4.75mm screen. Sand, surkhi, stone screens, cinders, burnt clays, fly ash, and other materials can be used as fine aggregates in concrete.

Table 1: Properties of Fine Aggregate

Properties	Sand
Fineness Modulus	2.56
Moisture Content	2.97%
Specific Gravity	1.97

2.1.2 Coarse Aggregate

Coarse aggregate makes up the bulk of the mix's volume. As a result, it significantly affects how the concrete mix is designed. The properties of a coarse aggregate, such as crushing strength, maximum size, shape, and water absorption affect the amounts of water, cement, and fine aggregate. More than the size of 4.75mm of particles are referred as "coarse aggregates". Coarse aggregate, which includes things like pebbles, gravel and stone chips, is used in concrete. In this investigation, two distinct types of coarse aggregates were used. They are NCA and RCA. RCA was collected from a demolished building site. The RCA was crushed manually in the labaratory and graded by ASTM C33-03. The mortar adhered to RCA was cleaned by washing.

Table 2: Properties of coarse aggregate

Properties	Natural Aggregate	Recycled Aggregate
Fineness Modulus	7.01	7.13
Specific Gravity	2.64	2.58
Moisture Content	0.81%	0.84%

2.1.3 Cement

It is a fine powder that is created by heating a mixture of clay, limestone, and other minerals in a kiln and then grinding it until it is very fine. Cement reacts chemically with water to create a strong binding substance that may be used to join different materials, such as gravel and sand, to make concrete. The specific gravity of cement falls in the range between 3.12 and 3.16. The cement used in this study had a specific gravity of 3.16.

2.1.4 Water

Water is necessary throughout the concrete-making process in order to moisten the aggregate, precipitate chemicals with the cement, and lubricate the mixture for ease of workability. Concrete was mixed in this investigation using potable water.

2.1.5 Admixture

Chemical admixtures known as "superplasticizers" plasticize wet concrete more successfully than plasticizers. Workability is significantly increased by superplasticizers at a particular water-to-cement ratio. Superplasticizers can be used to reduce the water content of materials by up to 30% while maintaining their workability over time. In the range of 0.5 percent to 3 percent by weight of cement, superplasticizers can be used at higher doses than conventional plasticizers. In this experiment, polycarboxylic ether was used as a SP and it's P^H was greater than 6.

2.2 Mix Design

Concrete mix design is the process of determining the proper proportions of cement, water, fine, and coarse aggregates to allow concrete to attain the desired goal strength in structures. Numerous constituent material properties are required for concrete mix design; these properties have already been evaluated. In the experiment, cement: fine aggregate: coarse aggregate was 1:1.5:3 and water to cement ratio was 0.5 to build concrete mix. Before mixing, the aggregates were immersed in water to verify that they were SSD compliant. For superplasticizer, water content reduced by 15% and superplasticizer was 0.7% of the weight of cement. Four different percentages of (0, 25, 50, and 100) % replacemnt of RCA as coarse agregate were used. A total of eight sets were prepared, where half of the specimens were prepared with no SP, and the rest half was prepared by using SP as admixture. The proportion of cement to water in each concrete mix had been kept constant. Half of the concrete samples where superplasticizer were used, the total amount of water was reduced by 15% and an amount of superplasticizer equal to 0.7 % of the cement weight in the concrete mixture was added.

2.3 Casting and Curing

Following the slump test, the resulting mix was placed into 4" × 8" steel molds with prior oiling in the mold, carefully tempered to remove any voids, and then allowed to air cure. These molds were taken out after a day and the test specimens were then submerged in water to cure. The concrete cylinders were cured for 7, 14, and 28 days respectively. A total of 72 concrete specimens were cast of which nine specimens were prepared for each mix, taking into account different curing periods. After a specific curing period, as stated, the specimens were subjected to compressive strength tests.

2.4 Test of Concrete

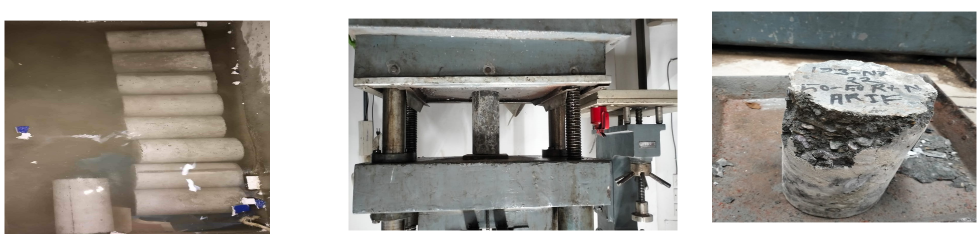
2.4.1 Slump Test

The slump test was the test performed on newly mixed concrete to determine the workability. Before new concrete settles, the slump test measures how fluid it is. This is done in order to determine how smoothly freshly poured concrete flows and whether it is workable. The slump test is the most used method of measuring the consistency of concrete, which can be employed either in the laboratory or at the site of work. The slump value was found to be between 73 mm to 134 mm, after a slump test by utilizing the slump cone.

2.4.2 Compressive Strength Test

Concrete's compressive strength test is an essential laboratory test that assesses the material's resistance to axial stresses. It is usually performed by crushing concrete cylinder specimens. This test is crucial for determining the performance and quality of concrete mixtures as well as for making sure that it will be able to fullfill the necessary structural and design requirements. A universal testing apparatus was employed for loading. The testing apparatus has a 1000 kN capacity and a 250 kN loading rate per minute. The test protocol complies with ASTM standard specification C39 for cylinders

(a) (b) (c) (d)



(e) (f) (g)

Figure 1: (a)Recycled Coarse Aggregate (b) Super Plasticizer (c) Concrete Mixing (d) Slump value test (e)Water Curing (f) Compressive strength Test (g) Cylinder specimen after testing.

3. RESULTS AND DISCUSSIONS

3.1 Slump value variation

Both the water absorption percentages and slump value test has been conducted for all the percentages of recycled coarse aggregate in concrete. Since water absorption percentages were increasing with increasing percentages of RCA, a reduction of slump value was noticed for increasing the RCA percentages. While using the SP significantly increasing of slump value was observed for each percentage with compare to no admixture of same percentages.

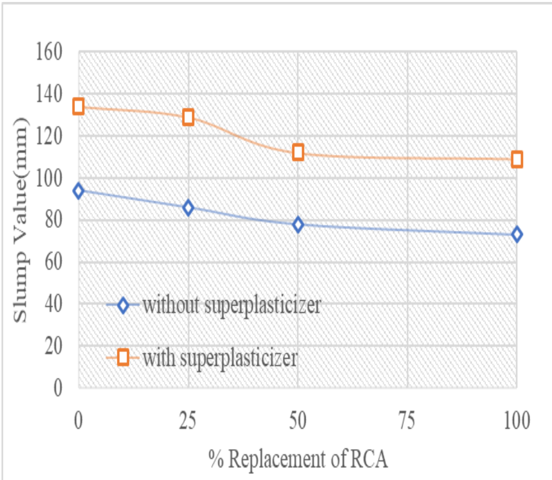


Figure 2: Slump value for different percentages replacement of RCA

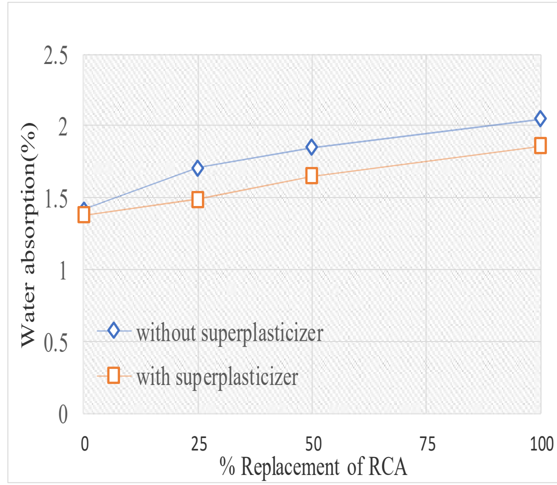


Figure 3: Water absorption (%) for different percentages of replacement of RCA

3.2 Compressive Strength

ASTMC39 specifications were used to conduct the compressive strength test. Total 8 percentages combinations with 9 cylinders for each percentage's replacement of RCA with coarse aggregate for 3 different curing periods (7 days,14 days and 28 days) and total 72 cylinders were used for determining the compressive strength of concrete.

Table 3: Compressive Strength value for different percentages replacement of RCA for all curing periods.

Coarse Aggregate (%)	Compressive strength (7 days) MPa	Compressive strength (14 days) MPa	Compressive strength (28 days) MPa
0% RCA +100 % NCA	10.98	15.91	20.13
25% RCA+75% NCA	9.93	12.9	16.03
50% RCA +50% NCA	8.26	11.47	15.41
100% RCA +0 % NCA	6.17	11.1	13.44
0% RCA +100 % NCA+ SP	13.11	19.49	23.11
25%RCA +75% NCA + SP	12.25	16.26	22.90
50% RCA +50 %NCA+ SP	10.52	14.63	18.21
100%RCA +0 %NCA+ SP	8.86	12.58	14.60

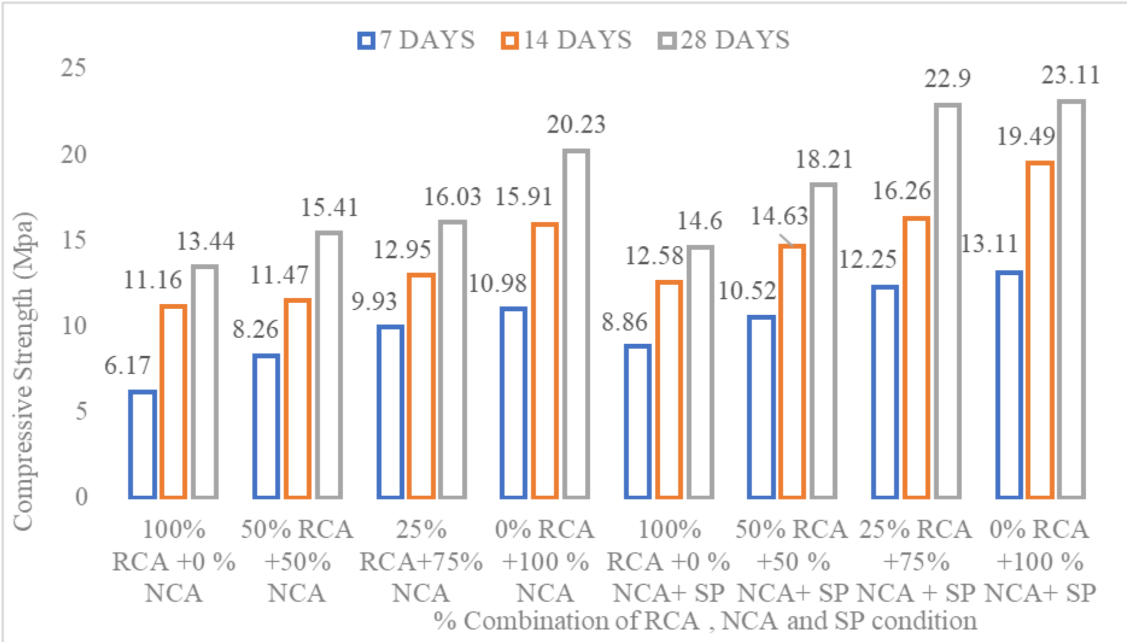


Figure 4: Compressive Strength Bar chart for different curing periods

100% RCA+0% NCA =100% recycled coarse aggregate and 0% natural coarse aggregate in place of coarse aggregate.
100% RCA+0% NCA+SP=100% recycled coarse aggregate and 0% natural coarse aggregate in place of coarse aggregate with using superplasticizer as an admixture.
Similarly, 0% RCA, 25% RCA, 50%RCA means 0%, 25%,50%, of recycled coarse aggregate respectively and 50 % NCA, 75% NCA, 100% NCA means 50%,75% ,100% of natural coarse aggregate respectively.
Normal aggregate concrete (NAC)= 0% RCA + 100% NCA

3.2.1 Effect of RCA

Compressive strength value was decreased with the increasing percentages of RCA. Highest value of compressive strength was found at normal aggregate concrete and which was 20.13 MPa for 28 days curing ages. After that compressive strength value was found least at 100 % RCA and it was13.44 MPa at the same curing periods. In case of using SP, similar pattern of decreasing compressive strength with the increasing percentages of RCA was noticed.

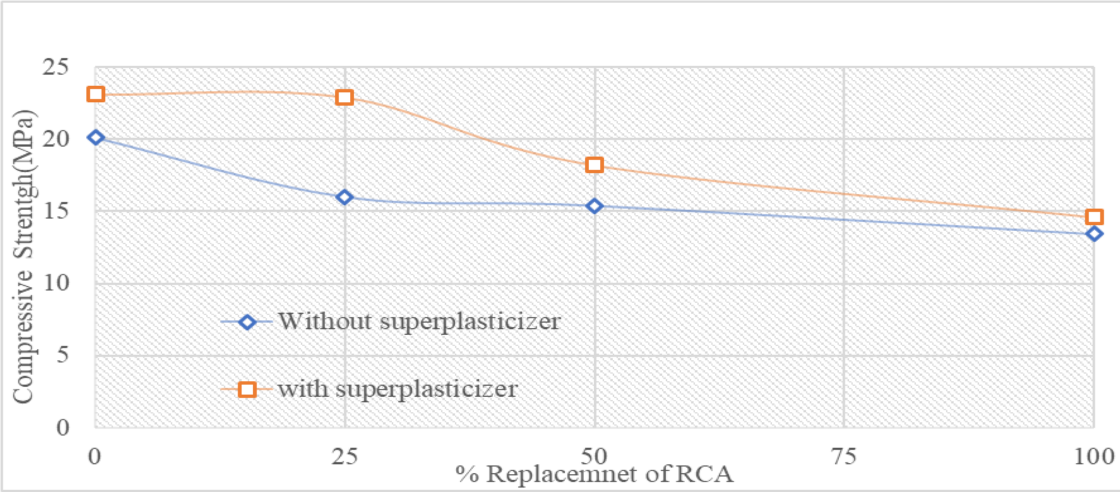


Figure 5: Effect of RCA on compressive strength at 28 days for various % replacement of RCA

3.2.2 Effect of superplasticizer

In the below figure the 28 days compressive strength gain increasing rate with compare between with SP and without SP was shown, whereas compressive strength gains at no SP used was marked as baseline and which value was 100 % for each percentage replacement of RCA. After using SP, how much compressive strength had increased at each percentage replacement of RCA was analyzed. It was observed that compressive strength value had increased at each percentage replacement, maximum percentage strength increasing rate was 42.86 % at 25% replacement of RCA.

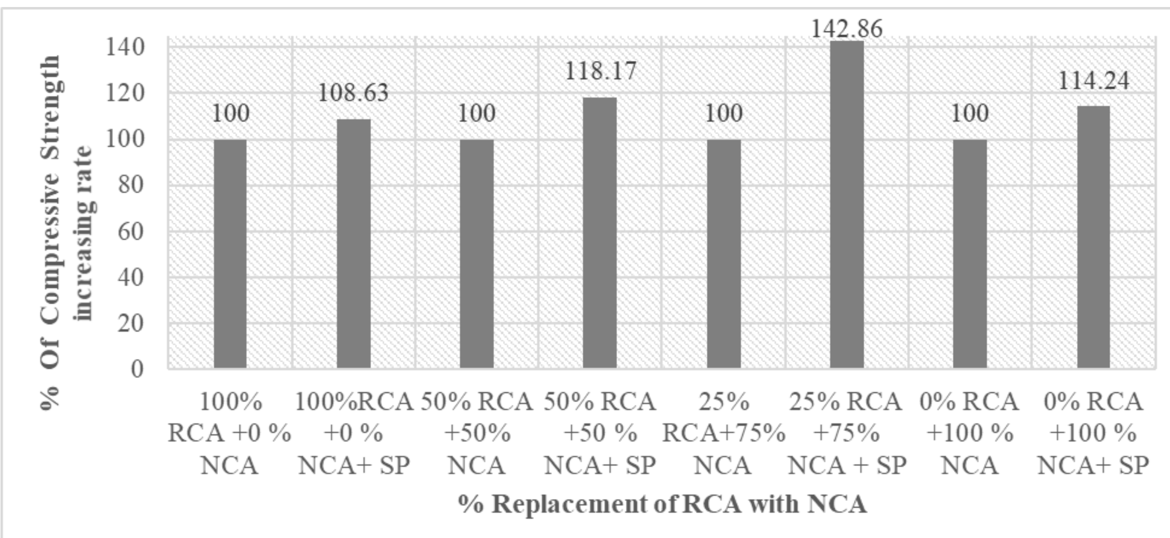


Figure 6: % of compressive strength increasing rate at 28 days curing period comparing between without SP (100% as baseline) and with SP.

3.3 Cost Estimation

A cost estimation was conducted for each percentages replacement of RCA for both using SP and no SP case. Cost was declined with the increase of percentages replacement of RCA. Here, though the cost of RCA collection was lower compared to NCA but labour cost was higher than NCA. RCA cost includes the processing cost according to ASTM C33-03.

Table 4: Cost details of each material used in the concrete mix design.

Material Name	**Unit**	**Weight**	**Price +Labour=Total (Tk)**	**Price Per Kg (Tk)**
Cement	1 bag	50 kg	550+50	12
Fine Aggregate	1 cft	45 kg	55+30 = 65	1.44
NCA	1 cft	47 kg	220+40 = 260	5.53
RCA	1 cft	49 kg	90+60 = 150	3.06
SP	1 litre	1.01kg	120+40 = 160	158.41

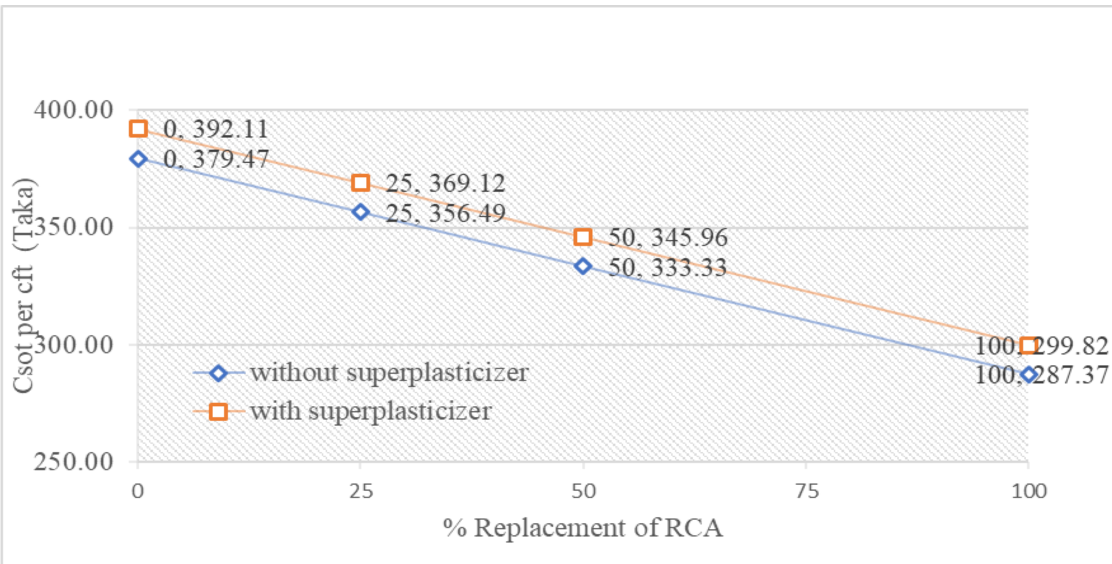


Figure 7: Comparison of Cost per cubic feet cylinder

For normal aggregate concrete cost was 379.74 taka per cft and it became 287.37 taka after using 100% replacement of coarse aggregate with RCA. While using SP cost increase 12.63 taka per cft with compare to concrete with no SP.

4. CONCLUSIONS

This experiment uses the RCA as partial and fully replacement with coarse aggregate for both using SP and without SP in concrete. The slump value of 100% NCA with no SP and 100% NCA with SP were 94 mm and 130 mm respectively, which has increased to the value of 48 mm like as other percentage which is visible to use in practical cases. Compressive strength of concrete was decrease with the increasing percentages of RCA used. The addition of SP to recycled aggregate concrete significantly increased compressive strength. For various ranges of NCA replacements and specimen ages, concrete compressive strength has increased by (8–42) % at 28 days curing periods for using SP.

Maximum amount of increasing strength was found in RCA 25% and which was 42.86%. For 100% NCA it was found that the compressive strength value was 20.13 MPa and cost was 379.47 taka per cft concrete. But in case RCA 25% with SP compressive strength value was 22.90MPa and cost was 369.12 taka for per cft concrete which is 10.35 taka less than normal aggregate concrete. In this case, though strength had increased but cost was lower than normal aggregate concrete. So from the experiment, it is recommended to use 25 % replacement of coarse aggregate with RCA with SP, as it is increased the compressive strength and also cost was declined. In the same time, it will resolve the problem of waste dumping, which will helpful towards building sustainable environment.

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