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UTILISING READY-MIX CONCRETE WASTE FOR PRODUCTION OF SUSTAINABLE CONCRETE AND CREATING CIRCULAR ECONOMY

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Abstract

Circular economy in ready mixed concrete and construction industry is becoming popular all over the world and India is no exception to this. In this article the authors explore the use of ready-mix concrete industry waste when put back into concrete how the properties of concrete change and its effectiveness and suitability to ready-mix concrete industry. The authors also try to explore possibility of making a simple model for circular economy in ready-mix concrete industry especially with respect to use of ready-mix concrete waste. Ready-mix waste recycled aggregate (RWRA) obtained from the crushing of the ready-mix concrete waste can be used in the construction industry. Ready mix concrete waste is generated due to a result of poor workmanship, improper

mix design, waste due to cleaning of equipment and various other reasons, which is dumped in the RMC plant or used as a landfill. Hence an attempt has been made to study the possibility of the reusing of the Ready-mix waste recycled aggregate (RWRA) in the place of the normal crushed aggregates. The Ready-mix waste recycled aggregate (RWRA) is divided into two different types i.e. Ready-mix waste recycled fine aggregate (RWRFA) and Ready-mix waste recycled coarse aggregate (RWPCA). The basic properties of the aggregates such as water absorption, specific gravity, sieve analysis, abrasion & impact resistance were considered. The replacement of the normal crushed aggregates by the Ready-mix waste recycled aggregate (RWRA) was carried out in five stages of 20%, 40%, 60%, 80% & 100% replacement. To enhance the properties of the concrete GGBS and PC based superplasticizer was used. The workability of the fresh concrete and the compressive strength of the hardened concrete were studied. The preceding properties were tested for three different periods of curing of 7, 14, and 28 days. All these mixes were designed for M25 grade of concrete. A comparison made between the results of a laboratory investigation on various physical properties of the concrete with Ready-mix waste recycled aggregate (RWRA) and the concrete with normal crushed aggregates found that the results are encouraging to use the Ready-mix waste recycled aggregate (RWRA) in the preparation of concrete. The study also discusses cost of normal crushed aggregate and Ready-mix concrete waste recycled aggregates collected from Ready-mix concrete plant in Bengaluru region.

Novelty & Uniqueness: *As of the twenty-first century, ready mix concrete (RMC) in India refers to pre-mixed concrete that is made in controlled conditions at a batching plant and delivered to construction sites in a ready for use state. It is primarily utilized in commercial buildings, residential developments, and projects related to infrastructure and offers benefits like consistent quality, shorter construction times, less material waste, and improved site cleanliness. The Indian RMC market is currently estimated to be around 240 million cubic meters, and it is projected to grow at a compound annual growth rate of 7-8% until 2030 due to the country's expanding urbanization and infrastructure development. Out of total production, Bengaluru, a leading city in construction, is expected to contribute significantly to India's ready mix concrete production volume. As a major city, it typically accounts for 10-15% of the total market due to its high construction activities. Assuming Bengaluru accounts for approximately 12% of India's total ready mix concrete production, the estimated*

production for Bengaluru in 2024 is approximately 29.85 million cubic meters, based on calculations and industry trends. Every year, 4-6 million tons of waste are produced by India's Ready-Mix Concrete (RMC) facilities, which make up 3% of the total amount of concrete produced under an RMC plan. Similarly, 0.6 to 0.9 million tons of ready-mix waste are produced annually in the Bengaluru region.

“Based on the available data of ready-mix concrete production and waste generation particularly in Ready-Mix Concrete (RMC) Plant annually, authors have made a unique attempt for encouraging the use of Ready-Mix Waste Recycled Aggregate (RWRA) in the concrete production. And cost comparison is performed between normal crushed aggregate and ready-mix concrete waste recycled aggregate collected from ready-mix concrete plant in Bengaluru region”. This study helps to lower energy needs for the extraction of raw materials, fuel consumption, power consumption, and transportation expenses in addition to lowering the use of natural aggregate. It makes a substantial contribution to lowering carbon footprints and achieving environmental objectives.

Keywords: Circular Economy; Ready-mix Concrete (RMC); Ready-mix Waste Recycled aggregate (RWRA); Ready-mix Waste Recycled Coarse Aggregate (RWRCA); Ready-mix Waste Recycled Fine Aggregate (RWRFA); GGBS- Ground-granulated blast furnace slag & PC based superplasticizer; Compressive strength.

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1. Introduction

The product, services are managed by an economical system as long as possible this is referred to as circular economy. Using materials judiciously and redesigning the product once after its use, putting that to use into a new way of using in another product, not wasting any material constitutes the basis for circular economy. Another definition of circular economy is a model of consuming and producing materials (products) which involves sharing, reusing, leasing, repairing, refurbishing, recycling of existing products/materials as long as possible. Ready-mix concrete has been a boon to the construction industry in providing concrete for both

speedy and quality construction. When ready mixed concrete completely can absorb principles of circular economy we can have a better positive impact on the environment especially in urban areas where huge concrete production is taking place.

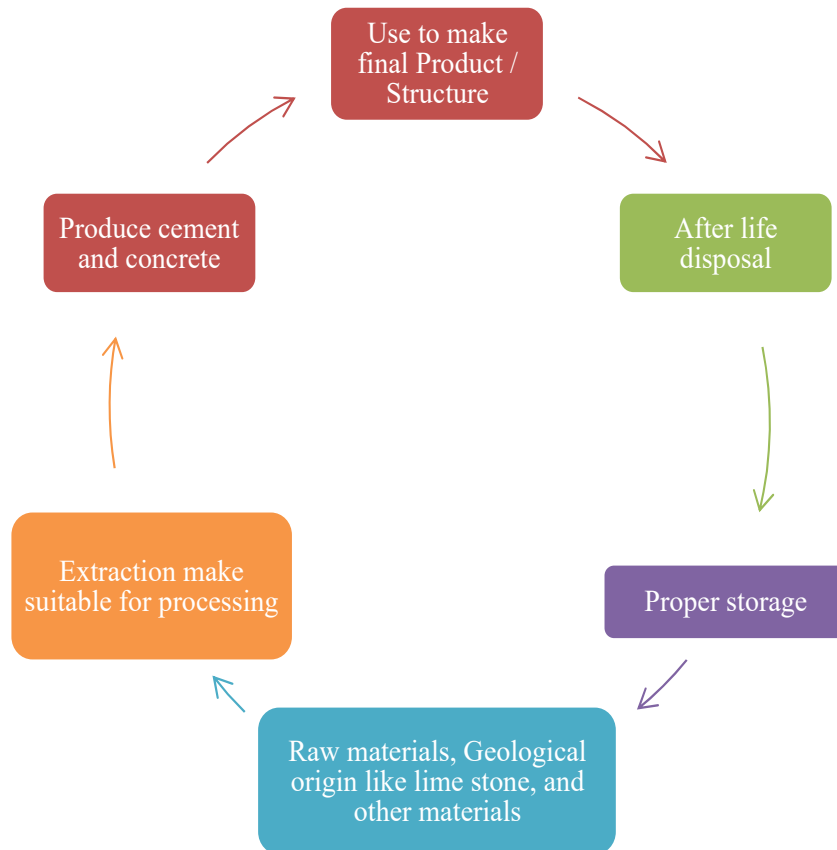


Figure 1: An integrated model of resource flows for a Circular Economy in ready-mix concrete based on the work of (Velenturf et al 2019b).

Circular Economy is used here to refer to an inclusive model of embedding the production-consumption system within the biosphere, not separate to it Fig_1. Whilst many different interpretations or definitions are used in theory and practice (Julian_Kirchherr_et_al_2017) this model is considered the most appropriate to apply to cement and concrete (ATM_Marsh_et_al_2021). The industrial by-products commonly used to produce concrete (e.g. metallurgical slags), as well as concrete itself, interact with the biosphere in different ways – for example, through carbonation and weathering processes. In addition, the sheer mass of concrete stocks in buildings and infrastructure – estimated to be ~0.4 Tt (Emily_Elhacham_et_al_2020) – means that concrete now exists on a comparable scale to biomass stocks. Therefore, it is logical to consider concrete (and related input and output

materials) alongside stocks and flows of natural materials within the system boundaries of the biophysical environment. Concrete has been proved to be one of the leading construction materials for more than a century. However due to poor-workmanship, excess concrete due to margin in order, wrong mix proportion, cleaning of the RMC equipment & trucks will result in the generation of a lot of RMC waste which is just dumped off in the RMC or used as a landfill. From overall global perspective, it is estimated that over 125million tons of concrete or 0.5% of total concrete production is generated as waste every year, confirming that it is a relevant part of burden for RMC plants. Hence cost effective, sustainable, energy saving process considering the environmental factors must be designed to handle the huge amount of RMC waste generated. The major constituents of the concrete are the coarse aggregates, fine aggregates, cement and water. In our research project the normal crushed coarse and fine aggregates are replaced by the RWRCA and RWRFA respectively. To enhance the property of the concrete PC based super-plasticizer is used and a mineral admixture GGBS is used. The ready mixed concrete waste is:

- a. Dumped in concrete plant then sent outside for land filling.
- b. The ready mixed waste idling in a ready mixed concrete plant when completely dry creates dry waste which increases air pollution in the area owing this particles flying all around. By crushing and using this to make new concrete we are trying to solve.
- c. Management of waste generated.
- d. Reduction on environmental issues caused by dumping or idling the waste in unauthorised sites, pits etc.
- e. Also logistics issues related in the transportation of left over Ready-mix concrete waste.

2. LITERATURE REVIEW

Lot of literature available on construction and demolition waste and how that can be reutilised to create circular economy (Ginga, Jason Maximino C. Ongpeng, & Ma. Klarissa M. Daly, 3 July 2020) discuss on construction and demolition waste (CDW) which accounts for about 30% of total solid waste produced around the world, Circular economy (CE) is a possible solution to reduce or eliminate the CDW being dumped. The paper discusses various facts of how CDW can be used to create circular economy and provides guidance to future work in to CE, CDW. Luis Alberto Lopez Ruiz et al makes an attempt to review on CE in the construction

and demolition waste sector. This study proposes a theoretical frame work approach to the adoption of the CE concept in the CDW sector. The authors conclude that CE is relevant, innovative concept that is gaining worldwide attention in scientific landscape. Alastair T M Marsh et al argue that circular economy principles can be in synergy with decarbonisation effects in the cement and concrete industries. Thousands of papers have been published by scientists like Abhishek_Verma_et_al_2017 on recycled aggregate. There is study also conducted on use of recycled concrete aggregate by Makul_N_et_al_2021, where they discuss in detail about use of RCA to produce green concrete.

Sajan_K_et_al_2022, describes the existing mechanical characteristics of recycled concrete under various aggregate replacement ratios.

Chanda_S_P_et_al_2022 has made studies on use of recycled aggregate concrete with M sand but the current research focus on the use of ready mixed concrete industry waste to be used in production of ready-mixed concrete.

Research Gap: Not much literature available on the use of Ready-mixed concrete waste generated after supplying concrete to customers and the left over concretes deposited in trucks, rejected concrete, excess batched not used along with normal day to day slurry waste generated. There is dearth of such literature on Indian Ready-mixed concrete industry especially in Bangalore which is a very huge market for Ready-mixed concrete.

3. MATERIAL USED

3.1 Cement: Cement is one of the most important building materials. The cement acts as a binding material that sets and hardens to adhere to building units. In our research project Dalmia ordinary Portland cement 53 grades confirm to IS 269 2015 testing was used for making concrete (Table 1).

3.2 Aggregates: Normal crushed coarse aggregates confirming to IS 383 1970 and to testing requirements as per testing IS 2386 is used (Table 4). Normal crushed fine aggregates confirming to IS 383 1970 (Zone II) is used (Table 5).

3.3 Water: Clean potable water is used in making the concrete.

3.4 Ready-mix waste recycled aggregates (RWRA): The RMC waste is collected and then is crushed to the required sizes namely 12mm, 20mm and fine aggregates (Table 4 & Table 5). Aggregates are collected and are used as the replacement to the normal crushed aggregates. The recycled aggregates can be divided into the RWRFA and RWRCA. However, the strength

of the recycled aggregates is comparatively lesser than that of the normal crushed aggregates. The density of the recycled aggregates is found to be lesser and exhibits greater water absorption.

3.5 Admixture: GGBS confirming to IS 12089 1987 is used (Table 2). PC Based superplasticizer confirming to IS 9103 1999 is used as a chemical admixture (Table 3).

Table 1: Chemical & Physical Properties of Cement

SL NO	PARTICULARS	TEST RESULTS	SPECIFICATIONS AS PER IS:269 2015
A	Chemical Requirements		
1	Lime Saturation Factor	0.87	0.8-1.02
2	Alumina Modulus	0.90	Min. 0.66
3	Insoluble residue, percent by mass	4.29	Max. 5.0
4	Magnesia, percent by mass	1.55	Max 6.0
5	Total Sulphur Content Calculated as sulphuric anhydride (SO ₃), percent by mass	2.85	Max 3.5
6	Loss on Ignition , percent by mass	3.8	Max 4.0
7	Tricalcium Aluminate (C ₃ A), percent by mass	5.32	-
8	Chloride Content, percent by mass	0.064	Max 0.1 Max 0.05 for prestressed Structures
B	Physical Requirements		
9	Fineness m ² /kg	308	Min. 225
10	Normal Consistency (%)	25.3	-
11	Soundness by Le-Chatelier's Method	1.0 mm	Max. 10
	Soundness by Autoclave expansion method, percent	0.04	Max. 0.8
12	Initial Setting Time (Minutes)	150	Min. 30
	Final Setting Time(Minutes)	230	Max. 600
13	Compressive Strength (MPa)		
	a)72+/-1h (average of three results)	33.5	Min. 27
	b)168+/-2h (average of three results)	46.0	Min. 37
	c) 672+/-4h (average of three results)	58.5	Min. 53

Table 2: Chemical & Physical Properties of GGBS

SL NO	CHARACTERISTICS	TEST RESULTS	SPECIFICATIONS AS PER IS: 16714:2018
A	Chemical Requirements:		
1	Manganese Oxide (MnO) %	0.1	5.5 Max
2	Magnesium Oxide (MgO) %	7.27	17.0 Max
3	Sulphide Sulphur (S) %	0.46	2.0 Max
4	Sulphate (as SO ₃) %	0.4	3.0 Max
5	Insoluble residue (I R) %	0.31	3.0 Max
6	Chloride Content (CI) %	0.005	0.1 Max
7	Glass Content %	92	85 Min
8	Loss on Ignition %	0.22	3.0 Max
9	$\frac{\text{CaO}+\text{MgO}+1/3 \text{ Al}_2\text{O}_3}{\text{SiO}_2+2/3 \text{ Al}_2\text{O}_3}$	1.09	1.0 % (Min)
10	$\frac{\text{CaO}+\text{MgO}+ \text{Al}_2\text{O}_3}{\text{SiO}_2}$	1.98	1.0 % (Min)
B	Physical Requirements		
1	Specific Gravity	2.91	Not Specified
2	Specific Surface Area (M ² /Kg)	367	320 (Min)
3	Slag Activity Index		
	a) 7 Days	70.82	60 % (Min)*
	b) 28 Days	82.13	75 % (Min)**

Note:

Slag Activity Index ((SAI) shall be determined using blend of 50% GGBS and 50% control OPC 43 confirming to IS 269.

* Not less than 60% of control OPC 43 grade cement mortar cubes.

**Not less than 75% of control OPC 43 grade cement mortar cubes.

Table 3: Properties of PC based Superplasticizer.

SL NO	TEST CONDUCTED	TEST VALUE	MANUFACTURE S STATED VALUE	REQUIREMENTS AS PER IS 9103-1999
1	PH	7.96	7+/- 1	Minimum 6. As per amendment No. 2 dated Aug-2007
2	Relative Density@ 27°+/- 2° C	1.083	1.100+/-0.02	Within 0.02 of the value stated by the manufacturer
3	Solid Content (%)	22.97	22+/-5	0.95T-1.05T T= Manufacturer stated value
4	Water Soluble Chlorides (%)	0.014	0.010+/-10	Within 10% of the value or within 0.2% whichever is greater as stated by the manufacturer

Table 4: Properties of Coarse Aggregates

PROPERTIES	NORMAL CRUSHED COARSE AGGREGATES	READYMIX WASTE RECYCLED COARSE AGGREGATES (RWRCA)
Specific gravity	2.64	2.42
Water absorption	0.5%	3.5%
Impact value	18.73%	25.08%
Abrasion value	4.44%	15.36%

Table 5: Properties of Fine Aggregates

PROPERTIES	NORMAL CRUSHED FINE AGGREGATES	READYMIX WASTE RECYCLED FINE AGGREGATES (RWRFA)
Specific gravity	2.57	2.06
Water absorption	3%	5%

4. OBJECTIVE OF STUDY

The major aim of the research project is to collect the RMC waste generated in the RMC plants and utilize the crushed recycled aggregates in the making of concrete in Bangalore. This approach will help in dealing of the RMC waste that is generated on day-to-day basis in the most effective way. An attempt to compare the characteristics of the normal crushed aggregates and the recycled aggregates have been made to use the recycled aggregates in the

most effective way in the making of the concrete. The comparison between the strength of the concrete with normal crushed aggregates and the concrete with recycled aggregates will help us comment on the suitability of the recycled aggregates Fig2.

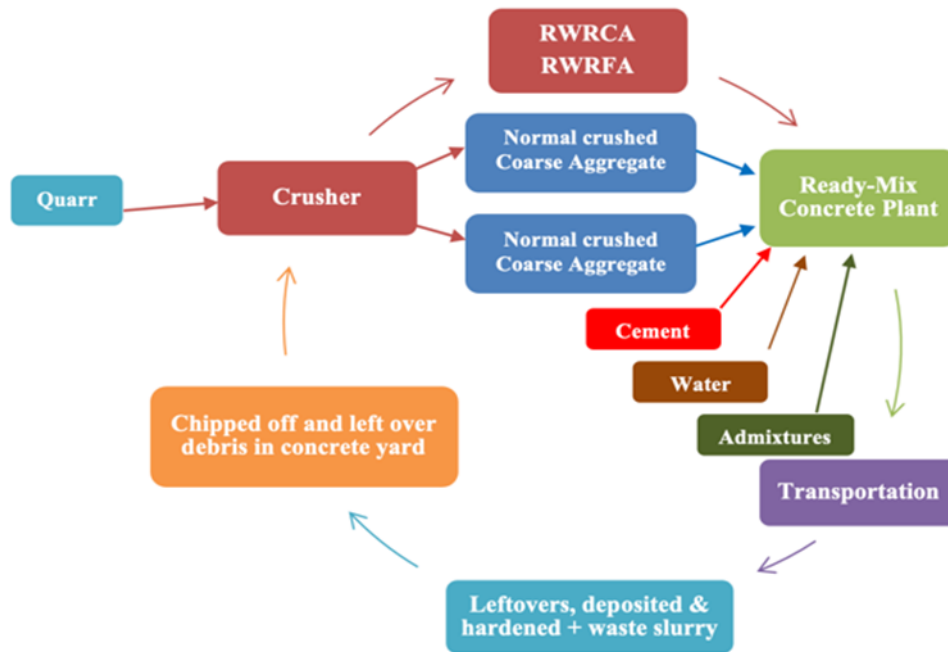


Figure 2: Model for Circular Economy Resource Flow in Ready-mix Concrete

5. MIX PROPORTION & EXPERIMENTAL PROGRAM

The concrete was designed for a mix of M25 grade concrete. The normal crushed aggregates were replaced by the Ready-mix waste recycled aggregates (RWRA). Two control setups were used to compare the results of the concrete with normal crushed aggregates and concrete with Ready-mix waste recycled aggregates (RWRA).

Control Mix 1: Standard 320kg mix of OPC with PC based superplasticizer.

Control Mix 2: Standard OPC (160Kg) + GGBS (160kg) with PC based superplasticizer.

Percentage replacement of the normal crushed aggregates by the Ready-mix waste recycled aggregates (RWRA) in the various trials. The first set of the trials dealt with the replacement of the only normal crushed coarse aggregates using the Ready-mix waste recycled coarse aggregates (RWRCA). The various percentages of the normal crushed coarse aggregates and Ready-mix waste recycled coarse aggregates (RWRCA) in each trial are given in Table 6.

Similarly, the next set of trials was done by replacing only the normal crushed fine aggregates. The various percentages of normal crushed fine aggregates and recycled fine aggregates in each trial are given in Table_7. Next set of trials were carried out by replacing both normal crushed fine aggregates and normal crushed coarse aggregates are given in Table 8.

Table 6:Percentage replacement of normal crushed coarse aggregates alone by Ready-mix waste recycled coarse aggregate (RWRCA).

TRIAL NO	% OF NORMAL CRUSHED COARSE AGGREGATES	READYMIX WASTE RECYCLED COARSE AGGREGATES (RWRCA)
RWRCA-20	80	20
RWRCA-40	60	40
RWRCA-60	40	60
RWRCA-80	20	80
RWRCA-100	0	100

Table 7:Percentage replacement of normal crushed fine aggregates alone by the Ready-mix waste recycled fine aggregate (RWRFA).

TRIAL NO	% OF NORMAL CRUSHED FINE AGGREGATES	READYMIX WASTE RECYCLED FINE AGGREGATES (RWRFA)
RWRFA-20	80	20
RWRFA-40	60	40
RWRFA-60	40	60
RWRFA-80	20	80
RWRFA-100	0	100

Table 8: Percentage replacement of both Ready-mix wastes recycled coarse and fine aggregates (RWRCA+FA).

TRIAL NO	READYMIX WASTE RECYCLED COARSE AGGREGATES (RWRCA)	READYMIX WASTE RECYCLED FINE AGGREGATES (RWRFA)
RWRCA+FA-20	20	20
RWRCA+FA-40	40	40
RWRCA+FA-100	100	100

6. TEST CONDUCTED AND COMPARISION

6.1 Test on the Fresh Concrete: Slump Cone Test

6.2 Test on the Hardened Concrete: Compression Test

Variation of slump at 30 min and compressive strength at 28 days, replacement of normal crushed coarse aggregates with ready-mix waste recycled coarse aggregates given in Table 9 & Fig 3.

Variation of slump at 30 min and compressive strength at 28 days, replacement of the normal crushed fine aggregates with ready-mix waste recycled fine aggregates given in Table 10 & Fig 4.

Variation of the slump at 30 min and compressive strength at 28 days, replacement of both normal crushed fine and coarse aggregates with ready-mix waste recycled coarse and fine aggregates are given in Table 11&Fig 5.

Table 9:Variation of slump at 30 min and compressive strength at 28 days, replacement of normal crushed coarse aggregates with ready-mix waste recycled coarse aggregates

TRIAL NO	SLUMP AT 30 MIN IN MM	COMPRESSIVE STRENGTH AT 28DAYSMPA
Control mix-1	150	44.34
Controlmix-2	130	39.25
RWRCA-20	120	34.60
RWRCA-40	120	34.37
RWRCA-60	120	32.67
RWRCA-80	125	29.91
RWRCA-100	130	27.67

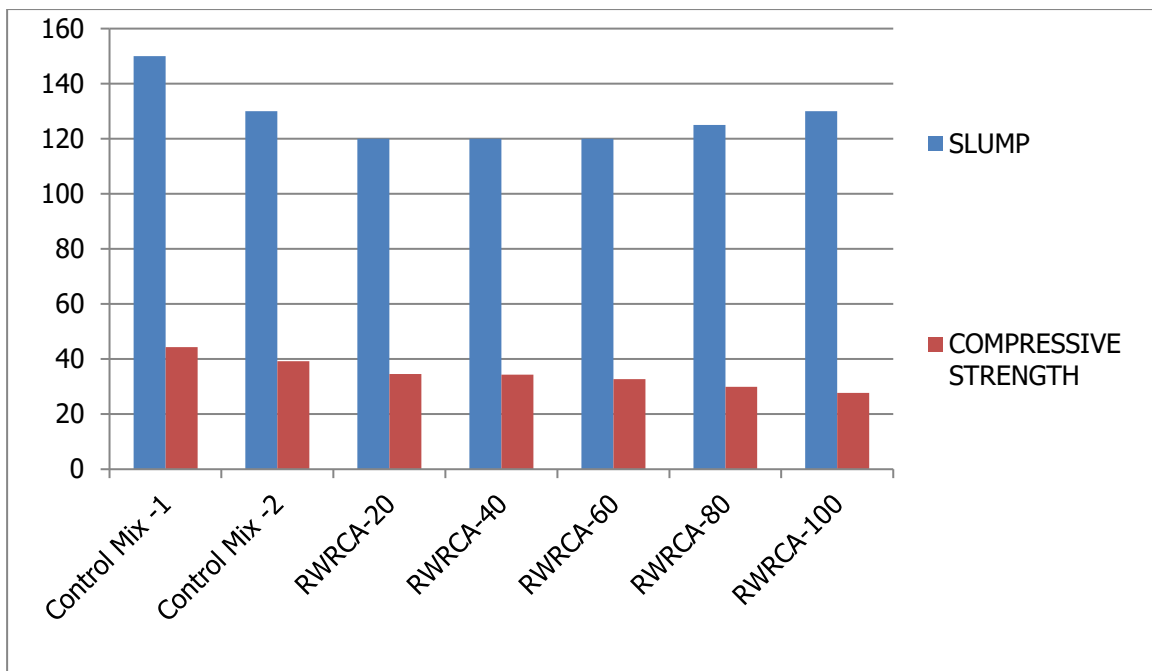


Figure 3: Variation of slump at 30 min and compressive strength at 28 days, replacement of normal crushed coarse aggregates with ready-mix waste recycled coarse aggregates

Table 10: Variation of slump at 30 min and compressive strength at 28 days, replacement of the normal crushed fine aggregates with ready-mix waste recycled fine aggregates

TRIAL NO	SLUMP AT 30 MIN IN (MM)	COMPRESSIVE STRENGTH AT 28DAYS (MPA)
Control mix-1	150	44.34
Control mix-2	130	39.25
RWRFA-20	130	33.57
RWRFA-40	120	32.91
RWRFA-60	120	31.6
RWRFA-80	120	30.73
RWRFA-100	130	28.48

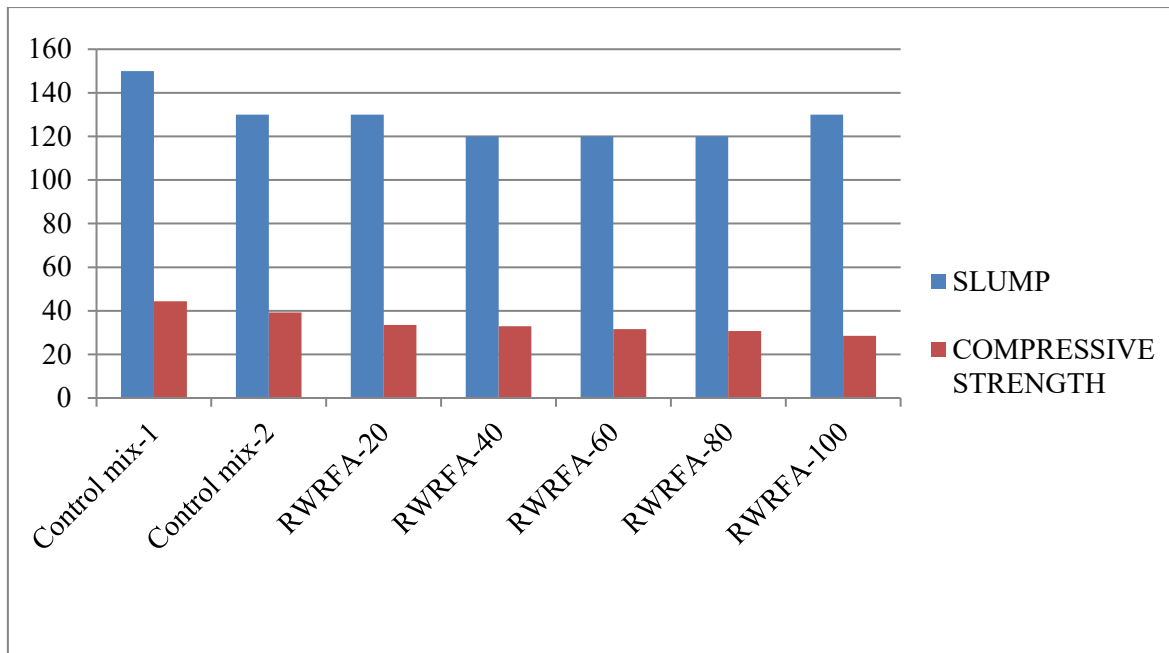


Figure 4: Variation of slump at 30 min and compressive strength at 28 days, replacement of the normal crushed fine aggregates with ready-mix waste recycled fine aggregates.

Table 11: Variation of the slump at 30 min and compressive strength at 28 days, replacement of both normal crushed fine and coarse aggregates with ready-mix waste recycled coarse and fine aggregates

TRIAL NO	SLUMP AT 30 MIN IN MM	COMPRESSIVE STRENGTH AT 28 TH DAY MPA
Control mix-1	150	44.34
Control mix-2	130	39.25
RWRCA+FA-20	140	36.56
RWRCA+FA-40	120	31.26
RWRCA+FA-100	100	27.97

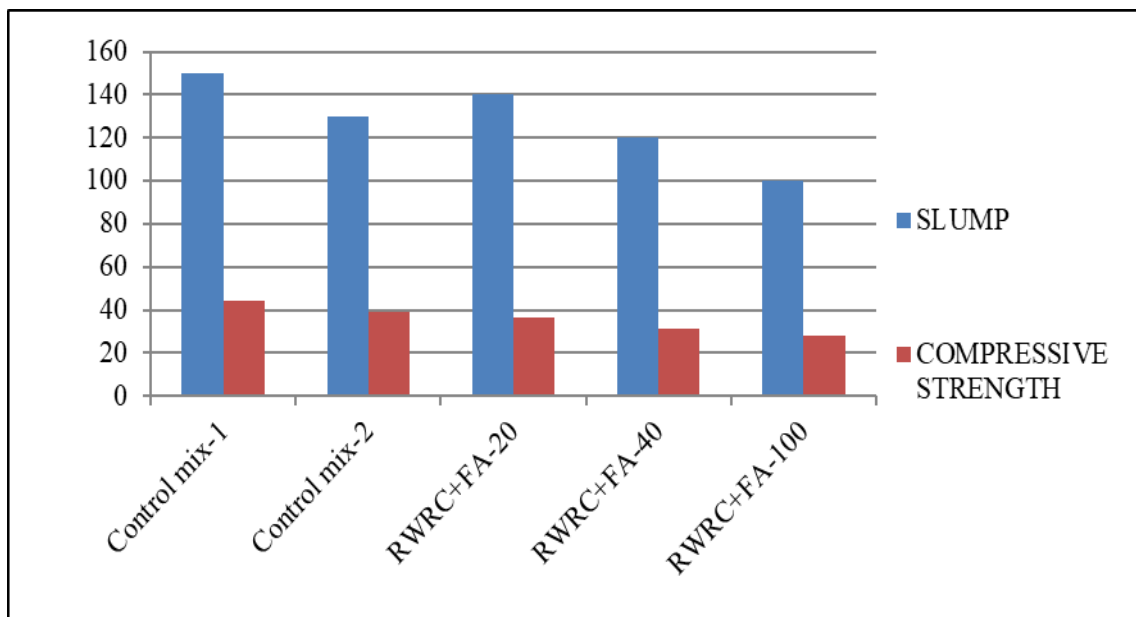


Figure 5: Variation of the slump at 30 min and compressive strength at 28 days, replacement of both normal crushed fine and coarse aggregates with ready-mix waste recycled coarse and fine aggregates.

7. COMMERCIAL BENEFITS

Average cost of normal crushed coarse aggregate and normal crushed fine aggregate in Bangalore is about 800 Rs/Ton. Now if use a micro (small) crusher to crush, screen the ready mixed concrete waste and make RWRCFA and RWRFA the cost will come to about only 100 to 150 Rs/ton which is for crushing, other operational costs. So a saving of almost 600 Rs/ton which is about 15 % of concrete cost itself. On the other hand if a centrally located crusher plant is installed and many ready mixed concrete plants allow the waste to be sent there crushed and get back the cost works out almost equal to existing cost of standard normal crushed aggregates and in this case there is no direct price gain but we are recycling and making a greener, environmental friendly aggregate to be put into use.

8. CONCLUSION

- Due to the use of recycled aggregates in construction it reduces the impact of the waste materials on the environment, hence a sustainable, greener concrete is produced, virgin materials saved.
- Recycled aggregates have higher water absorption than the normal aggregates.

- Compressive strength of the recycled concrete is lower than that of the control setup. Not much data available on overall durability especially on the selected ready-mix waste recycled aggregates.
- The various tests conducted on the recycled aggregates exhibits satisfactory results compared to that of normal crushed aggregates.
- There is direct economic benefit to concrete producers especially if they install micro crushing units just to crush and recycle the waste produced on their RMC plant.

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