Mathematical models for performance of concrete by replacing natural sand with stone dust

Er. S. K. Singh Gaur[1], Dr. Sunil Kumar[2]

[1]Senior Lecturer, Civil Engineering,
A.I.T.H. Awadhpuri, Kanpur,
sushil@aith.ac.in

[2]Professor, Civil Engineering
H.B.T.U., Kanpur,
suniljadon@live.in

Abstract*: *This study is carried out to evaluate the performance of concrete by replacing natural sand with granite stone dust. Compressive strength of concrete was observed by replacing natural sand with granite stone dust in ratio of 20%, 40% and 100% for a constant W/C of 0.45 and a slump of 100 ±20 mm to have pump able properties in concrete. A total of four concrete mixes MS-1, MS-2, MS-3 (with 20%, 40% and 100% replacement of natural sand) including a reference mix M-1(having 100% natural fine aggregate) with a design mix ratio of 1:1.76:2.28 as per IS 10262, were casted. Mechanical properties of NA and stone dust were studied and different concrete mixes were tested for compressive strength after 7, 28, 90 and 120 days of water curing. Samples of all four mixes were also subjected to different temperature ranges of 200°C, 400°C, 600°C and 800°C for duration of one hour after a curing period of 120 days. A mathematical model was developed to observe the compressive strength for different replacement ratios of sand with stone dust at different age and at different temperature exposures and it was observed that age of concrete has a positive correlation with strength whereas % replacement of sand and temperature has a negative effect on strength.

***Keywords*:** Natural coarse aggregate NCA, natural aggregate NA, Green concrete, Construction and demolition waste (C & D waste), Stone dust, Recycled aggregate concrete RAC ,Polycarboxylate ether.

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I. INTRODUCTION

Construction of new structures due to rapid advancement of cities require a huge amount of natural aggregates , which in turn produce several types of ecological imbalances due to blasting , quarrying ,transportation etc. The construction industry in India is growing very fast at an annual rate of 10% over last 10 years, as against the world average of 5.5% per annum. The built up area is expected to increase almost five times from 21 billion sqft to approximately 104 billion sqft in 2030 as per C.S.E. report [1]. In order to fetch the demand of new construction a lot of natural resources are needed. On the other hand demolition of old structures due to over ageing , changes in architectural and functional requirements along with natural disasters produce a substantial amount of construction waste, which is generally stacked in form of landfills.

According to the Building Material Promotion Council (BMPTC), India generates an estimated 150 million MT of construction and demolition (C&D) waste every year as against the official recycling of 6500 MT per day, which is about 1.5% of total waste generated per day. The rest of the waste lies in form of landfills. With increasing demand of natural aggregates for new construction and huge amount of landfills required for construction wastes , generated by demolition activities creates an ecological imbalance thus creating the concept of green concrete by use of recycled construction waste. The advantages of reusing the recycled concrete, rubble & stone dust as alternative coarse & fine aggregate respectively include lower environmental pollution, reduction in valuable land fill space and savings in natural aggregate resources. The use of old construction material in new projects is not a new concept. The recycling industry has become well established in Europe since the end of World War II. In Europe about 30% of demolished waste is recycled. Some other countries like Netherland and Belgium have achieved recycling rates of 90% [2].In India 53 cities were expected to set up recycling facilities to recover materials from C&D wastes by 2017 , but only 13 cities have done that by 2020 [1]. Keeping the global scenario in mind and to have a proper balance of demand of aggregates in construction works, Indian government has taken strong steps by forming guidelines on environment management of construction and demolition wastes under the guidance of Ministry of Environment, Forest and Climate change. In order to create confidence in different sectors of construction industry, it is essential to look after the viability of use of C & D waste in new construction works. Though stone dust is used as a replacement for sand in India for non structural members, but to use stone dust as a substitute of natural sand, in major works, there is a need for proper assessment of strength properties of hardened concrete in ordinary as well as under exposure to high temperature conditions.

II. REVIEW OF LITERATURE WORK

Keeping in view the significance of the research work and problems associated, efforts have been made to review

the literature available on various aspects of the research. Only a few researchers have worked on concrete made with inert and waste materials like stone dust, recycled demolished concrete/ masonry rubbles, glass etc. Frondistou-Yanns evaluated and compared the mechanical properties of conventional concrete and concrete made from recycled concrete. He found that recycled concrete best matches the mechanical behavior of conventional concrete[3]. Nagraj and Banu 1996 reported that the addition of super plasticizers in concrete made with rock dust and pebbles enhance the workability of the mix without enhancing cement content [4]. Test results by Tavakoli and Soroushian (1996) indicated that the strength of recycled aggregate concrete was affected by the strength of the original concrete, percentage of the coarse aggregate in the original concrete, the ratio of top size of aggregate in the original concrete to that of the recycled aggregate, and the Los Angeles abrasion loss as well as the water absorption of the recycled aggregate[5].Shukla et al (1998) have used stone dust as fine aggregate replacing sand in concrete and concluded that the presence of stone dust reduces the workability of concrete[6].Limbachiya et at (2000) studied use of recycled concrete aggregate in high strength concrete[7]. Ajdukiewlcz and Kliszczewicz (2000) examined the mechanical properties of high performance and high strength concretes made with recycled aggregates. In their work, they considered recycled aggregates produced from concrete with compressive strength 40-70 Mpa[8]. Sunil kumar, Sahu a.k. and Sachan a.k., (2003) investigated the effect of partial replacement of river sand with crushed stone dust at a replacement level of 20%, 40% on compressive strength of concrete. They observed that the there was a significant increase in compressive strength of concrete in both the replacement levels of natural sand with stone dust. They further observed that the there was a significant increase in splitting tensile strength of concrete in both the replacement levels of natural sand with stone dust. [9].Tabesh and Abdelfatah (2009) studied influence of recycled concrete aggregates on strength properties of concrete. The compressive and splitting tensile strength of concrete made with recycled coarse aggregate depend on the mix proportions. In general it was observed that the strength of recycled concrete can be 10-25% lower than that of conventional concrete made with natural coarse aggregate[2]. Yehia et al (2015) discussed the suitability of producing concrete with 100% recycled aggregate to meet durability and strength requirements for different applications. Their results showed that concrete with acceptable strength and durability could be produced if high packing density is achieved[12]. The durability aspect and fire resistance of concrete has been studied by many researchers in the past decades[10,13]. Vijayalakshmi et.al. (2013) investigated the effect of replacement of river sand with granite powder on splitting tensile strength of concrete at a replacement level from 0% to 25% at 28 days of curing. They observed that inclusion of granite powder as a replacement of river sand did not much affect the splitting tensile strength at lower replacement levels of 5%, 10% and 15%. At these replacement levels, the splitting tensile strength was similar or slightly lower than that of control concrete. However, increase in substitution rate beyond 15%, there was a significant decrease in splitting tensile strength of concrete[11].

On the basis of literature review, it was observed that no mathematical relationship was found to assess the compressive strength of concrete with variable % of stone dust along with age and different temperature ranges.

Therefore a regressive experimental analysis was carried out to establish a relationship for compressive strength of green concrete with varying age, different % of stone dust and varying temperature ranges.

III. METHODOLOGY OF RESEARCH WORK

A. *Test method*

The experimental program consisted of testing of all ingredients of concrete and properties of fresh and hardened concrete specimens. Cement, river sand, natural coarse aggregate, recycled concrete, water were tested as per B.I.S. procedures. The mechanical properties of aggregates were found out as per IS 383:2016. The fresh concrete was tested for workability by using slump test. The hardened concrete tests consisted of testing of concrete cubes specimens at the age of 7, 28, 90 and 120 days in accordance with the relevant method of testing recommended by B.I.S.by taking M-1 mix (1:1.76:2.28 designed as per IS 10262 with use of natural aggregates) as bench mark, with the mixes MS-1(20% stone dust), MS-2(40% stone dust), MS-3(100% stone dust), The concrete specimens were also tested for fire resistance in a diesel fired muffle furnace exposed to actual fire as per plotted fire exposure curve, for a period of one hour duration to varying temperatures of 200^0C, 400^0C, 600^0C and 800 ^{0}C respectively and then allowed to cool in air to attain normal room temperature before compressive strength testing.

B. *Aggregate gradation*

The gradation of natural aggregates and stone dust was assured by standard sieve analysis as per IS 383:2016. As per sieve analysis sand and stone dust both belongs to Zone II and were having fineness modulus as 3.03 and 2.28 respectively.

C. *Material used in research work*

1) Cement : PPC conforming to IS 1489

2) Sand : Obtained from Betwa river (Conforming to zone II)

3) Coarse aggregate :Obtained from Kabrai crusher

4) Admixture :polycarboxylatether(conforming to IS-9103)

D. *Properties of ingredients*

Properties of different ingredients were calculated as per B.I.S.and given in table-1.

TABLE 1. PROPERTIES OF SAND, NCA, STONE DUST USED IN PRESENT RESEARCH WORK

Ingredients	Properties										Remark
	Normal consistency (%)	Setting time (min)		Compressive strength (Mpa)		Specific gravity	Bulk density (kg/m^3)	Fineness modulus	Water absorption (%)	Sieving zone	
		Initial	Final	7 days	28 days						
Cement	31.5	185	315	32.7	41.4	-	-	-	-	-	Conforming to IS 1489
Fine aggregate (natural sand)	-	-	-	-	-	2.68	1690	3.03	1.0	II	As per IS 383
Stone dust	-	-	-	-	-	2.70	1595	2.28	8.03	II	As per IS 383
Natural coarse aggregate	-	-	-	-	-	2.75	1490	7.35	0.5	-	-

E. Mix proportions

In order to compare results objectively, a control mix M-1 (prepared with NA) having a characteristic strength f_{ck}=30MPa, and a mean target strength f'_{ck} = 38.25 MPa was needed as benchmark to compare the results with mixes MS-1(80%sand, 20%stonedust), MS-2(60%sand, 40%stonedust), and MS-3(0%sand, 100% stonedust).All concrete mixes were proportioned for 100 ±20 mm slump suitable for pumping with a constant W/C of 0.45 for all four mixes as per table-2. Admixture conforming to IS 9103 (Polycarboxylate ether) was used in different concrete mixes to maintain the desired slump.

TABLE 2. CONCRETE MIX RATIOS ADOPTED IN PRESENT RESEARCH WORK

Mix ID	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)		Water (kg/m^3)	W/C Ratio	Admix % weight of cement
			Sand	Stone dust			
M-1(100% NCA)	437	1000	772	-	197	0.45	0.17
MS-1(80%sand 20% stone dust)	437	1000	618	156	197	0.45	0.21
MS-2(60%sand 40% stone dust)	437	1000	464	312	197	0.45	0.33
MS-3(100% stone dust)	437	1000	-	780	197	0.45	0.63

F. Testing of specimens

Total 96 numbers of cubes with size 100mmX100mmX100mm were casted for finding out a mathematical model for compressive strength with variable % of stone dust and curing age along with exposure of hardened concrete to varying range of fire temperature as per exposure curve shown in figure 1. Twelve beams (including 3 number of beams of reference mix M-1) of size 100mmx100mmx500mm each casted and cured for 28 days for finding out flexural strength of green concrete.

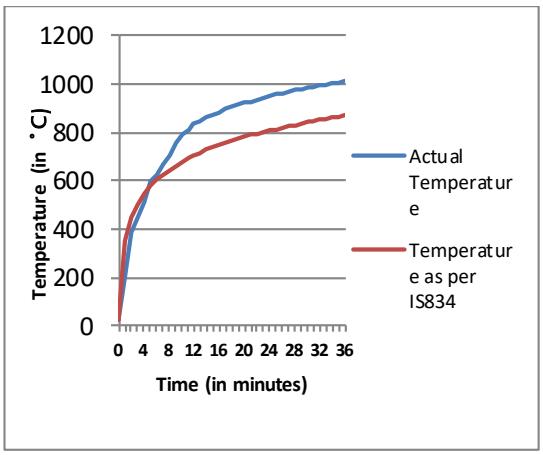

Fig. 1. Actual and standard fire curves for different mix analysis

IV. RESULTS AND DISCUSSION

Effect of admixture was seen to obtain desired slump of 100±20 mm for different mixes M-1 , MS-1, MS-2, MS-3 and compressive strength of all samples was found out in a compression testing machine of 100 tonne capacity after a curing period of 7,28,90 and 120 days in water to see the performance of processed concrete. The concrete specimens were also tested for fire resistance in a diesel fired muffle furnace exposed to actual fire for a period of one hour duration to varying temperatures of 200^0C,400^0C, 600^0C and 800 ^{0}C respectively and then cooling down to room temperature before compressive strength testing.

A. Dose of admixture for different mixes

It was observed that dose of admixture increases as % of replacement of stone dust increases to achieve same workability (pump able concrete with 100 ±20 mm slump) with 0.45 as W/C ratio for all mixes.

B. Compressive Strength

The results of compressive strength for different mixes after a curing period of 7, 28, 90 and 120 days are shown in table 3.It is observed from the table that compressive strength for all mixes increases as curing period is increased.

TABLE 3. COMPRESSIVE STRENGTH TEST RESULTS FOR DIFFERENT MIXES IN WATER CURING

Mix Designation	7 days		28 days		90 days		120days	
	Density	Comp. Str.	Density	Comp. Str.	Density	Comp. Str.	Density	Comp. Str.
M-1	2515	28.0	2565	41.0	2455	44.5	2505	46.0
	2520	32.0	2575	40.0	2405	42.0	2520	43.0
	2565	31.0	2605	44.0	2505	44.0	2565	45.5
MS-1	2451	30.0	2455	42.0	2435	48.0	2460	50.0
	2453	32.0	2451	44.0	2445	43.5	2453	47.0
	2455	28.0	2456	41.5	2450	45.0	2450	48.0
MS-2	2460	38.0	2465	46.0	2465	49.0	2455	54.0
	2458	36.0	2460	42.0	2455	48.0	2460	52.0
	2456	32.5	2452	43.0	2460	47.0	2465	49.0
MS-3	2459	23.0	2465	36.5	2463	43.5	2470	44.0

	2463	21.5	2463	40.0	2465	41.0	2456	42.0
	2467	20.0	2455	39.0	2467	40.0	2460	41.0

A total of 48 test samples were tested for compressive strength with varying % of stone dust along with varying curing period in days. A multiple variable regression analysis was performed by taking % of stone dust, curing period in days and density of different samples in Kg/m^3 as independent variables. After regression analysis it was found that density of samples does not have a good correlation with compressive strength. Therefore it was left in further analysis and only two independent variables were considered and we found following mathematical model for compressive strength of green concrete: -

f_{cc} = 34.78+0.127 A -0.0495 S, where A is age in days & S is % of stone dust as substitute for natural sand.

R= 0.787, R^2= 0.619 (valid for 0% to 100% replacement level of stone dust and up to 120 days age)

A total of 60 compressive strength tests were performed for obtaining a correlation between compressive strength as dependent variable and replacement percentage of sand and temperature as independent variables for a curing age of 120 days and 0% to 100% replacement level of sand with stone dust and for a temperature range of room temperature to 800^0c.

f_{cc} = 50.47 -0.0254 T-0. 0646S

(valid for 0% to 100% replacement of sand & for room temp. to 800^0C)

R =0.922 , R^2 =0.851 where T is temp. in ^{0}c and S is % of Stone dust *as substitute for natural sand*.

C. Mathematical model for flexural strength of concrete obtained by substituting sand with stone dust

Flexural strength of green concrete was calculated experimentally with help of 12 beams (including 3 number of beams of reference mix M-1) of size 100mmx100mmx500mm each casted and cured for 28 days by substituting natural fine aggregate (sand) with C&D waste granite stone dust in ratio of 20% (MS-1),40%(MS-2) and 100%(MS-3).

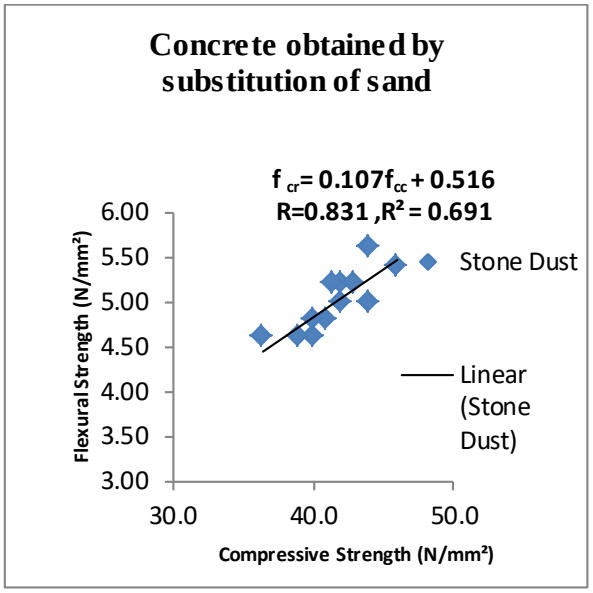

Fig. 2. Flexural. Strength VS Comp. strength for MS-1, MS-2 &MS-3 mix concrete

A better flexural strength in comparison to NAC is observed experimentally in case of substitution of sand with stone dust and justified with empirical formula. A larger % difference was observed between experimental values and values obtained by formula recommended by IS code, in case of concrete obtained by substituting sand with stone dust.

V. CONCLUSIONS

From the experimental results and by further multivariable mathematical regression analyses following conclusions have been drawn:

- For a particular W/C ratio, workability of green concrete reduces with increase in % of stone dust and desired workability is achievable by addition of admixture. The dose of admixture increases with increase in % of stone dust.
- Effect of age of green concrete has got a positive correlation with compressive strength and it is found that one day increase in age of green concrete increases compressive strength by 0.127 MPa. Whereas by 1% increase in stone dust quantity, compressive strength of green concrete decreases by 0.0495 MPa, which shows that 100% sand can be successfully replaced with stone dust with only 4.95% strength reduction in compressive strength.
- Better flexural strength was observed in case of green concrete, therefore it is concluded from present research work that sand can be economically substituted with stone dust up to 40 % replacement values and yielding

better strength properties as can be calculated from empirical formulae obtained in research work.

- Temperature as well as % of stone dust has a negative correlation with compressive strength. It is found that by 1^0C increase in temperature , compressive strength of green concrete reduces by 0.0254 MPa and a unit % increase in stone dust quantity, reduces the compressive strength of green concrete by 0. 0646 MPa at higher temperature which shows that when 100% sand was replaced with stone dust then only 6.46 % reduction in compressive strength was observed at different temperature ranges .Therefore strength properties of green concrete can be very well estimated with above derived mathematical formulae.

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Author Profile

Er. S. K. Singh Gaur
B.E. (CIVIL) I.I.T. ROORKEE, M.E. (Civil)
Sr. lecturer, Civil Engineering, A.I.T.H. Awadhpuri, Kanpur
Area of interest: Structural engineering and Recycled construction material, Concrete technology
Email: sushil@aith.ac.in, Contact: 9839026833

Dr. Sunil Kumar
Professor, Civil Engineering Department, H.B.T.U., Kanpur
B.Sc. (Civil engg.), M.Tech. Phd.
Area of interest: Structural Analysis, Advanced RCC Design, Waste Utilization
Email: suniljadon@live.in, Contact: 98398168200