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Use of crushed rock powder as replacement of fine aggregate in mortar and concrete

Nagabhushana[1] and H. Sharada bai[2]
[1]*Department of Civil Engineering, JSS Academy of Technical Education, Bangalore-560060, India*
[2]*Department of Civil Engineering, UVCE, Bangalore University, Bangalore-560056, India*
nagabhushanajss@gmail.com; sharadaj29@yahoo.com

Abstract

Concrete is a major building material which is used in construction throughout the world. It is extremely versatile and is used for all types of structures. Due to rapid growth in construction activity, the consumption of concrete is increasing every year. This results in excessive extraction of natural aggregates. The use of these materials is being constrained by urbanization, zoning regulations, increased cost and environmental concern. Thus, it is becoming inevitable to use alternative materials for aggregates in concrete which include recycled aggregates, fly ash, manufactured sand, crushed rock powder etc. The use of such materials not only results in conservation of natural resources but also helps in maintaining good environmental conditions. The present investigation aims in the study of properties of mortar and concrete in which Crushed Rock Powder (CRP) is used as a partial and full replacement for natural sand. For mortar, CRP is replaced at 20% 40%, 60%, 80% and 100%. The basic strength properties of concrete were investigated by replacing natural sand by CRP at replacement levels of 20%, 30% and 40%.

Keywords: Crushed Rock Powder (CRP), alternate building materials.

Introduction

Concrete is a widely used construction material consisting of cementing material, fine aggregate, coarse aggregate and required quantity of water, where in the fine aggregate is usually natural sand. The use of sand in construction results in excessive sand mining which is objectionable. Due to rapid growth in construction activity, the available sources of natural sand are getting exhausted. (Palaniraj, 2003) Also, good quality sand may have to be transported from long distance, which adds to the cost of construction. In some cases, natural sand may not be of good quality. Therefore, it is necessary to replace natural sand in concrete by an alternate material either partially or completely without compromising the quality of concrete. (Dhir & Carthy, 2000) CRP is one such material which can be used to replace sand as fine aggregate. The present study is aimed at utilizing Crushed Rock Powder as fine aggregate in cement mortar and cement concrete, replacing natural sand. The study on mortar includes determination of compressive strength of different mortar mixes. (Nadgir & Bhavikatti, 2006) The study on concrete includes determination of compressive strength, split tensile strength and flexural strength of different grades of concrete.

Experimental program

In the first stage of this investigation, the compressive strengths of different grades of cement mortar are observed by replacing natural sand by CRP at different levels of replacement namely 20%, 40%, 60% 80% and 100%. In the second stage, the finer particles in CRP, finer than 150 micron are removed by screening and this modified CRP is named as Conditioned Crushed Rock Powder (CCRP) and is used as replacement of sand in mortar. Four mortar mixes 1:4, 1:5, 1:6 and 1:8 were selected for the study of both CRP and CCRP mortars. Moulds of size 70.7mm x 70.7mm x 70.7mm were used which gives cross sectional area of 5000mm^2. The compressive strength of both types of mortars are obtained at age of 3days, 7days and 28days.In the third stage of this investigation, fine aggregate in concrete is replaced by CRP at 0%, 20%, 30% and 40% replacement. Three grades of concrete M20, M30 and M40 were selected for the study. The study includes determination of compressive strength, split tensile strength and flexural strength at the ages of 7 days and 28 days. (Jaafer *et al*., 2002) The strength properties of concrete with CRP replacement are compared with that of Normal Concrete (NC) which does not contain CRP.

Experimental procedure

Materials used

In this study, 53 grade ordinary Portland cement conforming to IS 12269 1987 is used. Natural river sand belonging to zone III as per IS 383-1970 is used in this investigation. Crushed stone of 20mm maximum size has been used as coarse aggregate. Only for M40 grade of concrete, a super plasticizer conforming to IS 9103-1979 (Conplast SP-430) has been used. (Ilangovan & Shanthakumar, 2005)

Test procedures

*Compressive strength of CRP mortars***:** The materials required for the number of specimens were dry mixed and then mixed with calculated amount of water. The quantity of water is obtained as per IS4032-1988. It is given by Percentage of water equal to (P/4 +3) percent of combined weight of cement and fine aggregate, where P is the percentage of water required to produce a cement paste of standard Consistency.

While preparing the specimens for each proportion, a reference mix using cement and natural sand is prepared. This is done in order to compare CRP mortar with the normal mortar. For each CRP replacement, the total fine aggregate quantity is obtained as the combination of natural sand and CRP. For example, the first set of specimens consists of 20% CRP and 80% of natural sand

Fig 1 variation of 28 day compressive strength of CRP mortar with % CRP replacement

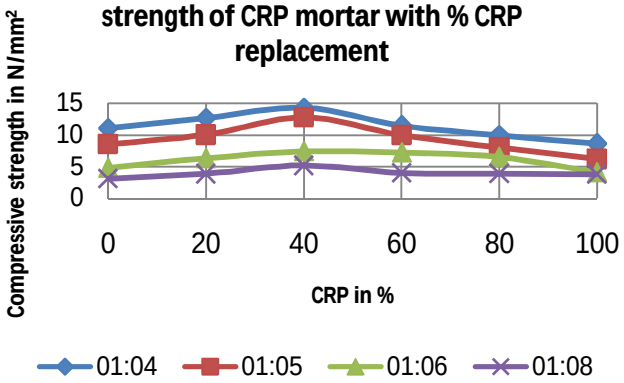


Fig 2 variation of 28 day compressive strength of CCRP mortar with % CCRP replacement

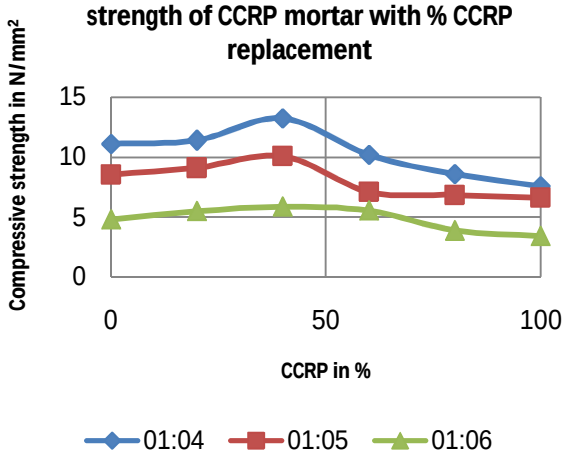
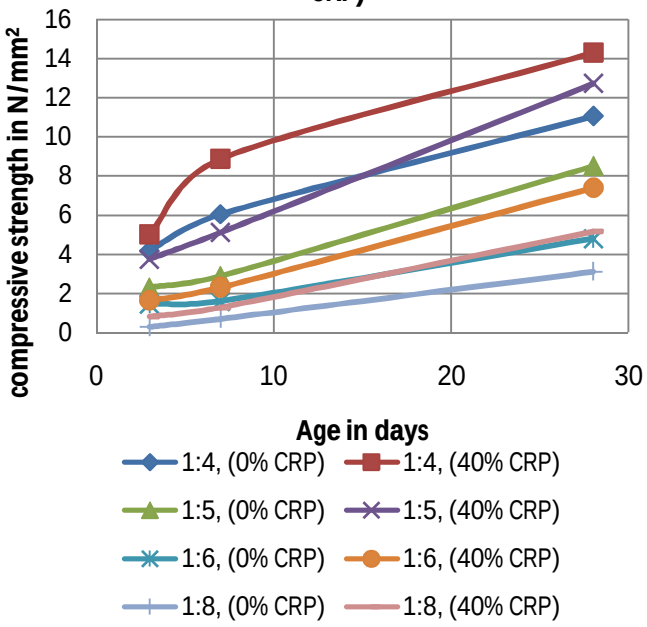


Fig 3 variation in compressive strength of CRP mortars at different age (0% CRP, 40% CRP)



as fine aggregate. For each mortar mix and for each replacement level of CRP, 18 specimens were casted. The results were obtained by testing 6 specimens each at 3 days, 7 days and 28 days. The testing of specimens was carried out as per IS 4031-1988. Specimens were tested with a gradually increasing compressive load until they fail by crushing.

Compressive strength of CCRP mortars: In the second stage of this investigation, the CRP obtained from the source is subjected to screening. The finer particles of size less than 150 micron were removed and Conditioned Crushed Rock Powder - CCRP was obtained. This was done to observe if any change in the compressive strength would occur due to the removal of very fine particles in CRP. (Sahu *et al*., 2003) The specimens were prepared by replacing sand by CCRP at same levels of replacement as in CRP mortar. The specimens were tested at the end of desired curing period to get the compressive strength.

*Tests on CRP concrete***:** The mix designs of M20, M30 and M40 grade concretes were obtained as per IS10262-1982. The mix proportion for M20 concrete was 1:1.43:3.1 with a water-cement ratio of 0.5. The mix proportion for M30 concrete was 1:1.20:2.59 with a water-cement ratio of 0.39. The mix proportion for M40 concrete was 1:0.87: 3.12 with a water-cement ratio of 0.31.

The workability of concrete was measured using slump test. For M20 and M30 grades of concrete, the slump values for different CRP Concretes were maintained around 100mm and 70mm respectively. (Shahul Hameed & Sekar, 2009) For M40 grade of concrete, because of the decrease in the workability of concrete below acceptable limits, a super plasticizer with proper dosage was made use of to arrive at slump of about 70mm.

The compressive strength, split tensile strength and flexural strength are obtained as per IS-516-1959. For the compressive strength, cube specimens of size 150mm were casted. Required quantity of water was added to get an homogeneous mixture. The fresh concrete was poured into the moulds in three layers and compacted using vibrator. After 24 hours, the specimens were demoulded and were kept for curing. The specimens were subjected to gradually increasing compressive load till the failure in a Compression Testing Machine of 100T capacity.

For the split tensile strength, cylindrical specimens of diameter 150mm and height 300mm were prepared by pouring concrete in three layers. For flexural strength, the prism specimens of size 100mm x 100mm x 500mm were prepared. The specimens were tested in a 100KN capacity flexure testing machine by applying two points loading to get the flexural strength.

Results and discussions

The results of this investigation are shown in Table 1 to 10 and Fig. 1 to 8. The results are discussed with respect to different parameters.

Indian Journal of Science and Technology Vol. 4 No. 8 (Aug 2011) ISSN: 0974- 6846

Fig 4 variation in compressive strength of CCRP mortars at different age (0% CCRP, 40% CCRP)

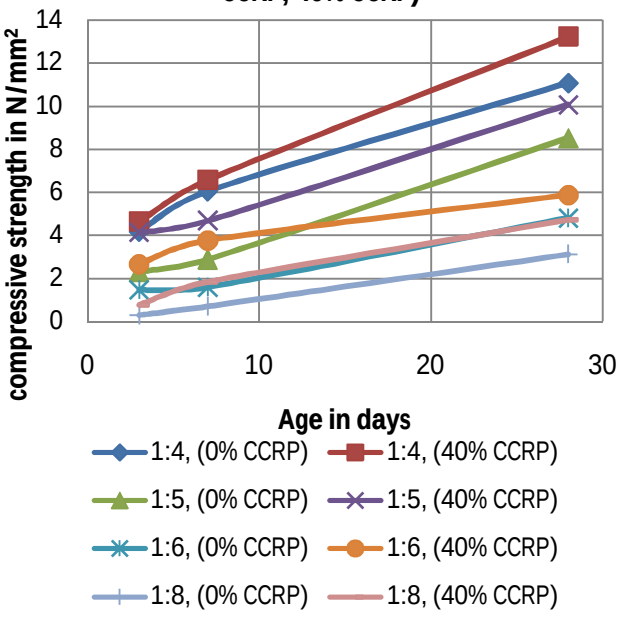
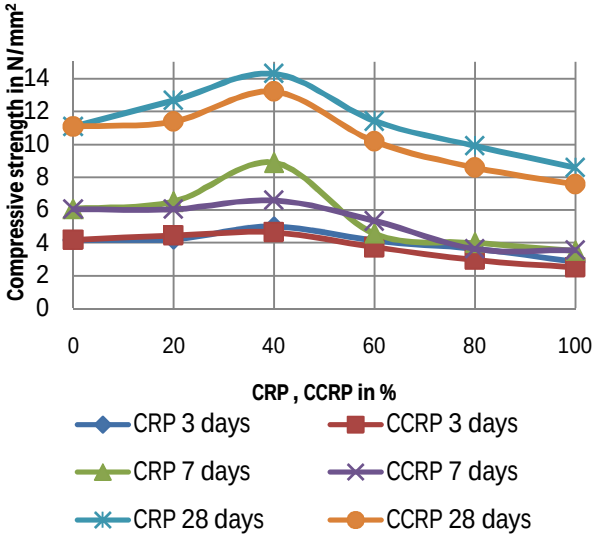


Fig 5 variation in compressive strength of 1:4 CRP mortar and CCRP mortar



CRP Mortars and CCRP mortars

Effect of replacement of CRP and CCRP on compressive strength of mortar: The results of compression test on CRP mortars and compressive strength ratios with respect to normal mortars (without CRP) are shown in Table 1 and 2 respectively. The results of CRP mortars are also represented in Fig 1 and 3. From Table 1 and 2 and Fig 1, it is observed that the compressive strength of CRP mortars increase with CRP content up to 40% replacement. Thereafter, the strength decreases with CRP content. From Table 2, it is observed that the compressive strength of 1:4, 1:5, 1:6 and 1:8 mix proportions at 40% CRP are higher than normal mortar by

Fig 6 Variation of 28 day compressive strength of concrete

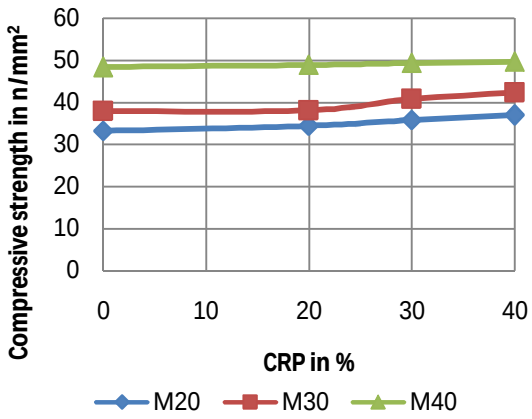


Fig 7 Variation of 28 day split tensile strength of concrete

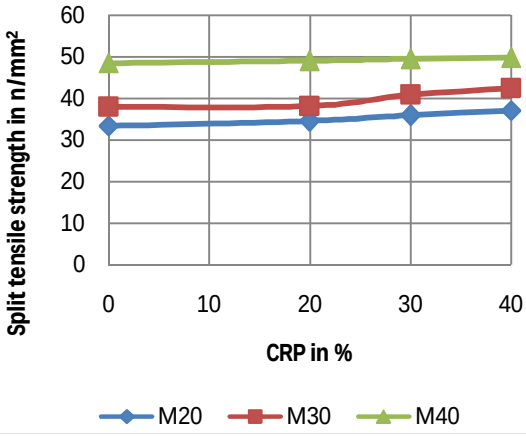
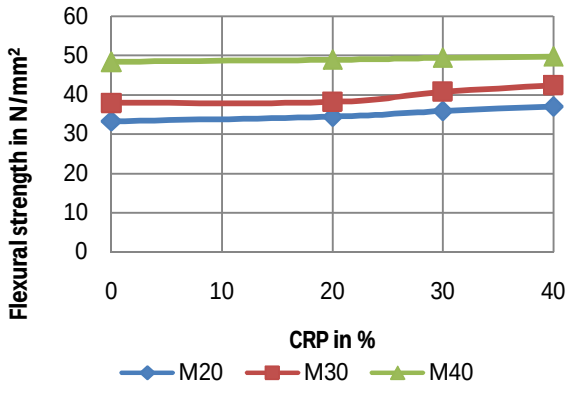


Fig 8 Variation of 28 day flexural strength of concrete



Indian Journal of Science and Technology Vol. 4 No. 8 (Aug 2011) ISSN: 0974- 6846

Table.1 Compressive strengths of various grades of CRP mortars

Mortar mix	% CRP	3 days strength N/mm^2	7 days strength N/mm^2	28 days strength N/mm^2
1:4	0	4.18	6.05	11.08
	20	4.22	6.50	12.69
	40	5.01	8.88	14.31
	60	4.12	4.57	11.41
	80	3.64	4.00	9.92
	100	2.83	3.52	8.60
1:5	0	2.31	2.88	8.52
	20	3.70	4.58	10.01
	40	3.76	5.12	12.75
	60	2.80	3.78	9.92
	80	1.79	2.72	8.02
	100	1.75	2.17	6.18
1:6	0	1.47	1.60	4.80
	20	1.55	2.29	6.34
	40	1.64	2.31	7.41
	60	1.51	2.13	7.22
	80	1.24	1.95	6.57
	100	0.89	1.49	4.08
1:8	0	0.28	0.69	3.12
	20	0.53	1.16	3.86
	40	0.81	1.28	5.16
	60	0.79	1.23	4.00
	80	0.79	1.13	3.91
	100	0.52	1.04	3.82

Table 2. Compressive strength ratios of various grades of CRP mortars with respect to normal mortars

Mortar mix	% CRP	3 days strength	7 days strength	28 days strength
1:4	0	1.00	1.00	1.00
	20	1.01	1.07	1.15
	40	1.20	1.47	1.29
	60	0.99	0.76	1.03
	80	0.87	0.66	0.90
	100	0.68	0.58	0.78
1:5	0	1.00	1.00	1.00
	20	1.60	1.59	1.18
	40	1.63	1.78	1.50
	60	1.21	1.31	1.16
	80	0.78	0.94	0.94
	100	0.76	0.75	0.73
1:6	0	1.00	1.00	1.00
	20	1.05	1.43	1.32
	40	1.12	1.44	1.54
	60	1.03	1.33	1.50
	80	0.84	1.22	1.37
	100	0.61	0.93	0.85
1:8	0	1.00	1.00	1.00
	20	1.89	1.68	1.24
	40	2.89	1.86	1.65
	60	2.82	1.78	1.28
	80	2.82	1.64	1.25
	100	1.86	1.51	1.22

Table 3. Compressive strengths of various grades of CCRP mortars

Mortar mix	% CCRP	3 days strength N/mm^2	7 days strength N/mm^2	28 days strength N/mm^2
1:4	0	4.18	6.05	11.08
	20	4.45	6.06	11.39
	40	4.65	6.59	13.23
	60	3.73	5.33	10.18
	80	2.96	3.63	8.60
	100	2.51	3.56	7.56
1:5	0	2.31	2.88	8.52
	20	3.58	4.65	9.10
	40	4.14	4.69	10.07
	60	2.77	3.37	7.08
	80	2.73	3.25	6.84
	100	2.45	2.86	6.64
1:6	0	1.47	1.60	4.80
	20	2.49	2.96	5.48
	40	2.67	3.77	5.88
	60	2.62	3.15	5.56
	80	2.61	3.13	3.88
	100	2.38	2.85	3.44
1:8	0	0.28	0.69	3.12
	20	0.70	1.70	4.60
	40	0.78	1.85	4.72
	60	0.73	1.56	4.28
	80	0.59	1.54	3.60
	100	0.57	1.48	3.18

Table 4. Compressive strength ratios of various grades of CCRP mortars with respect to normal mortars

Mortar mix	% CCRP	3 days strength	7 days strength	28 days strength
1:4	0	1.00	1.00	1.00
	20	1.07	1.01	1.03
	40	1.11	1.09	1.19
	60	0.89	0.88	0.92
	80	0.71	0.60	0.78
	100	0.60	0.59	0.68
1:5	0	1.00	1.00	1.00
	20	1.55	1.62	1.07
	40	1.79	1.63	1.18
	60	1.20	1.17	0.83
	80	1.18	1.13	0.80
	100	1.06	0.99	0.78
1:6	0	1.00	1.00	1.00
	20	1.69	1.85	1.14
	40	1.82	2.36	1.23
	60	1.78	1.97	1.16
	80	1.78	1.96	0.81
	100	1.62	1.78	0.72
1:8	0	1.00	1.00	1.00
	20	2.50	2.46	1.47
	40	2.79	2.68	1.51
	60	2.61	2.26	1.37
	80	2.11	2.23	1.15
	100	2.04	2.14	1.02

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29%, 50%, 54% and 65%. It is also seen that for mortar mixes 1:4 and 1:5, the compressive strength ratios of CRP mortars beyond 60% of CRP, are less than 1 showing that the strengths are less than normal mortar. For leaner mix of 1:6, the strength decreases only at 100% of CRP and for a further leaner mix of 1:8; there is no reduction in strength in comparison to normal mortar, for all replacement levels of CRP including 100%.

Similar observations can be made for CCRP mortars using Table 3. Based on 28 days compressive strength of CCRP mortars of 1:4, 1:5, 1:6 and 1:8 mix proportions, it can be observed that at 40% CCRP, the compressive strength increase by 10%, 18%, 23% and 51% when compared to normal mortar containing only natural sand. From Table 4, it can be observed that for mortar mixes 1:4 and 1:5, the compressive strength ratios of CCRP mortars beyond 40% of CCRP, are less than 1, showing that the strengths are less than normal mortar. For CCRP mortars of 1:6 and 1:8, the pattern of reduction in strength with increase in CRP replacement beyond 40% is similar to that of CRP mortars in comparison to normal mortar.

Effect of age on compressive strength of CRP and CCRP mortars: From the results, it is observed that for 1:4, 1:5, 1:6 and 1:8 CRP mortars, the average 3 day strength is about 35%, 29%, 23% and 16% when compared to 28 day strength. The corresponding average seven day strengths are 48%, 38%, 33% and 27% when compared to 28day strength. It is also observed that for CCRP mortars, the 3 day strengths of 1:4, 1:5, 1:6, and 1:8 mixes are 36%, 37%, 51% and 15% when compared to 28 day strength. The corresponding seven day strengths of CCRP mortars are 50%, 45%, 62% and 37% when compared to 28 day strength.

Compressive strength of CRP concrete

From Table 5, it is observed that the compressive strength of concrete increases with the percentage of CRP. From Table 6 it is seen that for M20 concrete, the increase in 28 day compressive strength is 4%, 8%, and 11% at CRP replacement of 20%, 30% and 40% respectively, when compared to normal concrete. For M30 concrete, the increase in 28 day compressive strength is 6%, 8% and 12% at CRP replacement of 20%, 30% and 40% respectively, when compared to normal concrete. The corresponding increase in 28 day compressive strength of M40 concrete is 1%, 2% and 3% at 20%, 30% and 40% of CRP. From the results, it can be observed that 7 day strength is about 60% of 28 day strength, for both CRP concrete and normal concrete. Similar observations were also made earlier (Nagaraj & Zahida Banu, 1996) The strength of CRP concrete in comparison to normal concrete reduces as the grade of concrete becoming higher.

Table 5. compressive strength of concrete

Grade of Concrete	% CRP	7 days strength N/mm^2	28 days strength N/mm^2
M20	0	19.26	33.33
	20	20.21	34.54
	30	21.46	35.92
	40	22.22	37.04
M30	0	21.22	37.98
	20	22.52	38.22
	30	24.62	40.89
	40	26.67	42.44
M40	0	25.49	48.44
	20	26.96	49.02
	30	28.74	49.48
	40	32.14	49.78

Table 6. Compressive strength ratios of CRP concrete with respect to normal concrete

Grade of Concrete	% CRP	7 days strength	28 days strength
M20	0	1.00	1.00
	20	1.05	1.04
	30	1.11	1.08
	40	1.15	1.11
M30	0	1.00	1.00
	20	1.06	1.06
	30	1.16	1.08
	40	1.26	1.12
M40	0	1.00	1.00
	20	1.06	1.01
	30	1.13	1.02
	40	1.26	1.03

Table 7. Split tensile strength of concrete

Grade of Concrete	% CRP	7 days strength N/mm^2	28 days strength N/mm^2
M20	0	1.60	2.64
	20	1.68	2.78
	30	1.71	2.88
	40	1.78	2.93
M30	0	2.17	2.79
	20	2.21	2.83
	30	2.26	2.91
	40	2.36	2.98
M40	0	2.26	3.30
	20	2.28	3.38
	30	2.31	3.49
	40	2.55	3.51

Split tensile strength of CRP concrete

The variation in split tensile strength can be observed in Table 7 with different levels of CRP replacement. Table 8 shows split tensile strength ratios of CRP concrete with respect to normal concrete. Here, it is observed that for M20 concrete, the increase in 28 day split tensile strength is 5%, 9% and 11% at CRP replacement of 20%. 30% and 40% respectively, when compared to normal concrete. For M30 concrete, the corresponding values are 1%, 4% and 7%. For M40 concrete, the increase in 28 day split tensile strength is 2%, 6% and 6% at CRP percentage of 20%, 30% and 40% respectively when compared to normal concrete.

Flexural strength of CRP concrete

The variation in flexural strength of concrete at different ages of curing can be observed using Table 9. Table 10 shows flexural strength ratios of concrete for different grades at different ages. The variation is shown in figure-7. From this it is observed that for M20 concrete the increase in 28 days flexural strength is 1%, 2% and 4% at CRP replacement of 20%, 30% and 40% respectively, when compared to normal concrete. The corresponding values for M30 concrete are 7%, 11% and

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Table 8. Split tensile strength ratios of CRP concrete with respect normal concrete

Grade of Concrete	% CRP	7 days strength	28 days strength
M20	0	1.00	1.00
	20	1.05	1.05
	30	1.07	1.09
	40	1.11	1.11
M30	0	1.00	1.00
	20	1.02	1.01
	30	1.04	1.04
	40	1.09	1.07
M40	0	1.00	1.00
	20	1.01	1.02
	30	1.02	1.06
	40	1.13	1.06

Table 9. Flexural strength of concrete

Grade of Concrete	% CRP	7 days strength N/mm^2	28 days strength N/mm^2
M20	0	4.17	8.75
	20	4.64	8.82
	30	5.39	8.94
	40	6.17	9.09
M30	0	6.67	9.83
	20	7.50	10.50
	30	8.00	10.86
	40	8.67	11.34
M40	0	7.42	10.00
	20	8.42	10.67
	30	8.75	11.25
	40	9.42	11.75

Table 10. Flexural strength ratios of CRP concrete with respect to normal concrete

Grade of Concrete	% CRP	7 days strength	28 days strength
M20	0	1.00	1.00
	20	1.11	1.01
	30	1.29	1.02
	40	1.48	1.04
M30	0	1.00	1.00
	20	1.12	1.07
	30	1.20	1.11
	40	1.30	1.15
M40	0	1.00	1.00
	20	1.13	1.07
	30	1.18	1.13
	40	1.27	1.18

15%. For M40 concrete, the corresponding increase, in 28 day flexural strength is 7%, 13% and 18% at 20%, 30% and 40% of CRP, when compared to normal concrete.

Conclusions

This study reveals that in case of cement mortars, the natural sand can be replaced by Crushed Rock Powder (CRP). The strength of mortar containing 40% CRP is much higher than normal mortar containing only sand as fine aggregate. Though the trend in variation of compressive strength with percentage of CCRP was found to be similar to that of CRP mortar, the strength of CCRP mortar is less than that of CRP mortars. It is better to use CRP without removing the finer particles. For lean mortar mixes, CRP can be replaced up to 100%. For rich mortar mixes, CRP can be replaced up to 40%. It is concluded that the compressive strength, split tensile strength and flexural strengths of concrete are not affected with the replacement of sand by CRP as fine aggregate up to 40%. Hence, CRP can be effectively used to replace natural sand, without reduction in the strength of concrete with CRP replacement level up to 40%.

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