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Effect of Microfines on the Mechanical Properties of Cement Mortar and Concrete

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ABSTRACT

The increasing demand for cement and its adverse impact on the environment are well known. Replacing cement partially with microfine wastes of construction and other industries is perceived to be a way forward in partially mitigating this situation. While binders like fly ash and ground granulated blast furnace slag are found to be good supplementary cementing materials, microfine stone dust, a waste by-product of the quarrying industry, is an inert material. It may not be a suitable material for such partial replacement if workability, as well as mechanical and durability properties of concrete are to be retained at the original level. However, if such partial replacement is done together with a microfine cement produced by cement manufacturers, it could be a suitable replacement material. In this study, cement is partially replaced with stone dust (7.5%) and microfine cement (5% -20%) and the effect of such replacement is studied on workability and mechanical properties of concrete. The study has indicated that partial replacement of cement with stone dust and microfine cement has great potential. At a replacement level of 7.5% stone dust and 15% microfine cement, the concrete has enhanced workability and mechanical properties, making these materials suitable replacement materials to achieve sustainable construction.

KEYWORDS: Reactive microfines, Inert microfines, Partial cement, Stone dust, Workability, Mechanical properties, Microfine cement.

INTRODUCTION

The adverse impact of the increased production of conventional cement and concrete on the environment and the need to use industrial wastes in the production of cement are gaining recognition worldwide. However, in doing so, it is necessary to ensure that the quality of concrete produced is not compromised and the life of structures constructed is not reduced. Several industrial wastes, like fly-ash, silica fume and ground granulated blast furnace slag (GGBS), have been successfully used in the production of high-performance concretes and the production of Portland Pozzolana cement has gained acceptance worldwide.

Some waste materials, like microfine stone dust, are not used in the production of cement and concrete, as these inert materials increase the percentage of insoluble residue in the cement. This may affect the mechanical properties of cement and concrete, primarily

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compressive strength. However, studies have determined that the maximum percentage of insoluble residue specified by different codes can be enhanced (Kraiwood et al., 2000). Further, Carsten Vogt (2010) has concluded that partial replacement of cement with both reactive and inert microfines has great potential and that the replacement can be made to an extent of 30%. Several cement manufacturers produce different reactive microfines for special applications of cement, like grouting, enhancement of workability,… etc. Such reactive microfines have been researched as possible materials for partial replacement of cement, in isolation and also together with other microfines, like fly ash, silica fume,… etc. These studies have indicated that such partial replacement results in an enhancement of mechanical properties of cement mortar and concrete (Narasimha Prasad et al., 2015; Praveen Naik et al., 2014; Sudalaimani and Shanmughasundaram, 2014; Siddharth Upadhyay and Jamnu, 2014). The microfine cement considered in this research has a particle mean diameter of 4.09 µm as against 15.96 µm and 9.21 µm of ordinary Portland cement and GGBS, respectively (Divsholi et al., 2012).

This study aims at identifying the effect of partial replacement of cement with an inert waste material, like stone dust, in combination with a reactive microfine cement, on the mechanical properties of concrete, as well as at identifying the threshold value of such replacement.

MATERIALS AND METHODS

In this study, cement is partially replaced with stone dust and special purpose microfine cement. The replacement of stone dust is kept constant at 7.5%, while microfine cement percentage is varied between (5%, 10%, 15% and 20%). Other percentages of stone dust were not considered, as literature review has suggested that the introduction of stone dust is beneficial when the percentage is less than 10% (Narasimha Prasad et al., 2016; Chowdary, 2015; Shirule et al., 2012; Tahir Celik and Khaled Marar, 1996). For the purpose of this study, mix design for a target compressive strength of 35 MPa is made as per IS 10262:2009. Specimen types and binder quantities are given in Table 1.

Table 1. Specimen types and binder quantities

Sl. No.	Specimen Type	Binders
1	**C**	Cement only
2	**C1**	72.5% cement+20% microfine cement+7.5% stone dust
3	**C2**	77.5% cement+15% microfine cement +7.5% stone dust
4	**C3**	82.5% cement+10% microfine cement +7.5% stone dust
5	**C4**	87.5% cement+5% microfine cement +7.5% stone dust

43 Grade Ordinary Portland cement conforming to IS 8112:1989 is used in the study. Microfine cement and microfine stone dust (passing through 75 micron sieve) are used for partial replacement of cement. The physical and chemical properties of cement and the replacement binder materials are indicated in Tables 2 and 3, respectively. It can be observed that Magnesium Oxide content, Total Sulphur content measured as Sulphuric Anhydride (SO_3), Lime Saturation Factor (LSF), Silica Ratio, Alumina Ratio, Chloride content and Loss on Ignition (LOI) are within the limits of max. 6.0, max. 3.5, between 0.66 and 1.02, between 2 and 3, min. 0.66, max. 0.10, max. 5.0 as set by IS 8112:2013, respectively. The percentage of Insoluble Residue in samples C1-C4 is greater than the maximum limit of 4.00% specified by IS 8112:2013. However, Kiattikomol et al. (2000) have revealed that insoluble residue up to 7% results in a reduction of compressive strength by about 11% during the initial few days of curing and thereafter the reduction of compressive strength is much less. In the present study, since a performance enhancer like microfine cement is used in combination with stone dust, the effect

of increase in percentage of insoluble residue can possibly be overcome.

Table 2. Physical properties of cement and binder materials

Sl. No.	Property	Microfine Cement	Stone Dust	Cement
1	Fineness (m^2/kg)	1200	140	327
2	Bulk Density (kg/m^3)	878	1610	1169
3	Specific Gravity	2.90	2.77	3.13

Table 3. Chemical properties of cement and binder materials

Sl. No.	Property	Microfine Cement	Stone Dust	Cement	C1	C2	C3	C4
1	Silica (SiO_2, % by mass)	35.6	62.22	21.6	23.95	23.22	22.48	21.74
2	Alumina (Al_2O_3, % by mass)	21.7	15.01	4.8	8.72	8.26	7.8	7.36
3	Ferric Oxide (Fe_2O_3, % by mass)	1.4	8.37	3.9	3.38	3.48	3.59	3.72
4	Calcium Oxide (CaO, % by mass)	33.5	3.52	62.7	56.32	57.46	58.61	59.72
5	Magnesium Oxide (MgO, % by mass)	6.3	4.00	0.9	2.27	2.04	1.82	1.59
6	Total Sulphur Content Calculated as Sulphuric Anhydride (SO_3)	0.11	0.05	2.5	2.17	2.28	2.39	2.48
7	Lime Saturation Factor*			0.89	0.69	0.72	0.76	0.8
8	Silica Ratio**			2.48	1.98	1.98	1.97	1.96
9	Alumina Ratio***			1.23	2.58	2.37	2.17	1.98
10	Chloride Content (% by mass)			0.02	0.01	0.011	0.011	0.011
11	Loss of Ignition (% by mass)	0.67	1.71	1.8	1.94	2.05	2.17	2.34
12	Insoluble Residue (% by mass)	0.49	81.40	0.75	6.69	6.59	6.49	6.39

* Lime Saturation Factor = $CaO/(2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3)$

**Silica Ratio = $SiO_2/(Al_2O_3+Fe_2O_3)$

***Alumina Ratio = Al_2O_3/Fe_2O_3

Scanning Electron Microscopy (SEM) images of these materials are also shown in Figs. 1, 2 and 3, respectively. SEM analysis of cement, microfine cement and stone dust indicates that the particles are angular and not spherical in shape. Microfine cement particles are the finest, followed by cement and then by stone dust. This suggests better packing density for concretes containing these replacements.

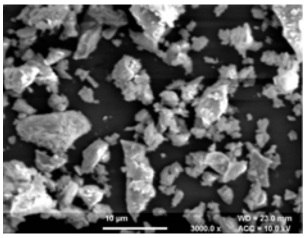

Figure (1): SEM image of cement

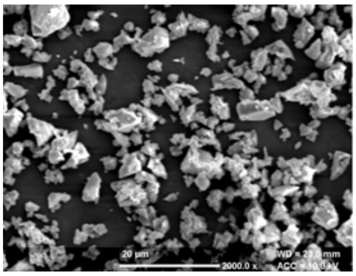

Figure (2): SEM image of microfine cement

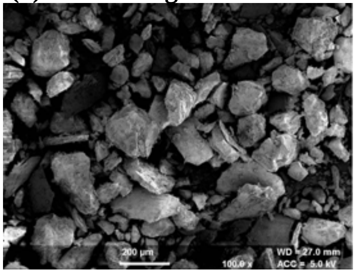

Figure (3): SEM image of stone dust

Two types of river sand of Zones I and IV were used in this study and the sand had a specific gravity of 2.70 and 2.63, respectively. Granite coarse aggregates of 19mm and down size were used with a specific gravity of 2.9. A sulphonated napthalene-based polymer, which gets instantly dispersed in water and is formulated to give water reduction without loss of workability, was the plasticizer used in the study.

The workability of fresh concrete was measured using slump test and flow table test. The concrete specimens were subjected to compressive, split tensile, flexure strength tests, as well as to modulus of elasticity test as per IS 516:1959. Compressive strength test was conducted on 150mm cubes, while cylindrical specimens of 150mm diameter and 300mm height were used for split tensile strength test and (100mm x 100mm x 500mm) prisms were used for flexural strength test.

Pull test to determine the bond strength between concrete and steel was conducted on 150mm cubes using 16mm diameter tor steel bars inserted at the centre. The test was conducted on a Universal Testing Machine (UTM) and only failure load, corresponding slip and pattern of failure were determined. Impact energy for 28 days aged specimens was obtained, using a modified impact testing machine, on 150mm diameter and 60mm thickness specimens. The number of blows required to the first failure and the final failure was used to calculate the impact energy.

All the specimens were cast using a laboratory pan mixer, compacted on vibrating table and cured in shaded curing tanks.

RESULTS AND DISCUSSION

A slump value greater than 100mm, not resulting in collapse of the concrete in the slump test, was achieved to have concrete suitable sections with congested reinforcement (Nevile and Brooks, 1987). The results of the slump test are given in Table 4.

Table 4. Plasticizer requirement

Sl. No.	Specimen Type	Plasticizer (%)	Slump Value (mm)	Average Spread (mm)
1	**C**	0.6	106	425
2	**C1**	0.5	108	495
3	**C2**	0.6	108	480
4	**C3**	0.8	100	475
5	**C4**	1.0	103	435

From this, it can be made out that a slump value of (100-110) mm could be achieved with a small quantity of plasticizer addition. Further, it can be observed that for this slump value, the percentage of plasticizer addition is 0.6% for both the reference mix and mix C2, where cement is partially replaced with 15% microfine cement and 7.5% stone dust. For this slump value, the plasticizer requirement is 0.5% for mix C1, where cement is partially replaced with 20% microfine cement and 7.5% stone dust. Again, the plasticizer requirement is 0.8% and 1%, respectively, when cement is replaced with 10% microfine cement and 7.5% stone dust (C3) and 5% alccofine and 7.5% stone dust (C4). These values indicate that ultrafine particles of microfine cement have resulted in better workability at higher levels of microfine cement addition, whereas at lower levels of microfine cement addition, their effect is negated by the presence of stone dust. It was noted during trials that at higher percentages of plasticizer addition in excess of 1.4%, the setting time of concrete was abnormally affected for all specimen types.

The results of the average spread on a flow table are also given in Table 4. The values greater than 400mm but less than 500 mm indicate a medium to high workability, which is similar to the results from the slump test.

The results of compressive strength on the different specimen types at 3, 7, 28, 56 and 90 days are shown in Figures 4 and 5.

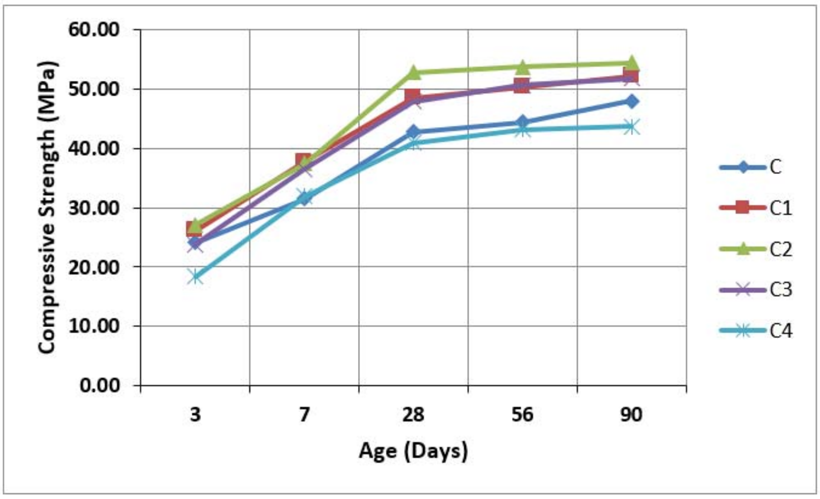

Figure (4): Variation of compressive strength of concrete with curing age

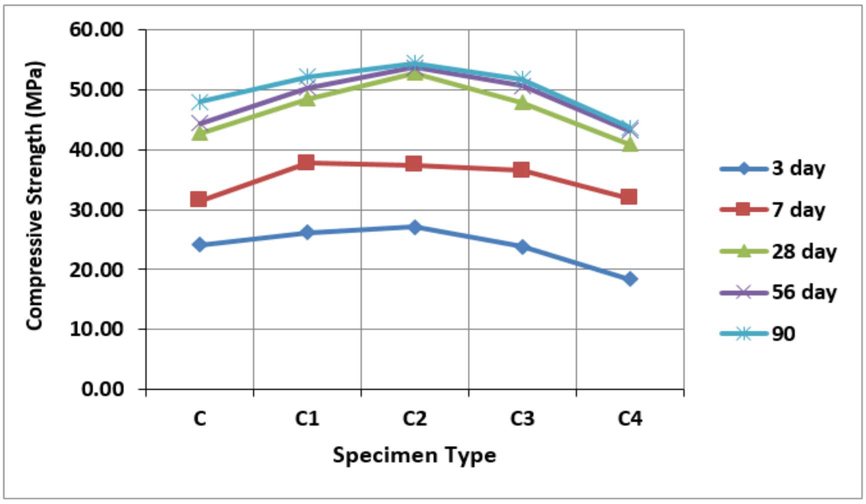

Figure (5): Variation of compressive strength for different specimen types

From Figure 4, it can be seen that 28- day compressive strength of specimens C1, C2 and C3 is higher than the compressive strength of the reference mix C by 13.41%, 23.36% and 18.39%, respectively. However, the 28- day compressive strength of specimen C4 is less than the compressive strength of reference mix C marginally by 4.37%. Similarly, it can be seen that both 90-day compressive strength of specimens C1, C2 and C3 is more than the compressive strength of the reference mix C by 8.73%, 4.35% and 7.90%, respectively. However, 90-day compressive strength of specimen C4 is less than the compressive strength of the reference mix C by 8.86%. The gain in the initial strength of specimens C1 and C2 is higher than in the reference mix by 8.40% and 12.04%, respectively, whereas the gain in the initial strength of specimens C3 and C4 is less than in the reference mix by 1.61% and 23.84%, respectively. It can also be seen from Figure 5 that the compressive strength of specimen C2 is highest for all days of testing; *viz*., 3, 7, 28, 56 and 90 days.

The results of the split tensile strength test in Figure 6 indicate that the split tensile strength at 28 days and 90 days is considerably higher than that of the reference mix, with the increase varying from 15.96% to 30.12% at 28 days and from 13.83% to 30.59% at 90 days. The gain in initial strength is also higher for specimens C2, C3 and C4 by 11.69%, 9.68% and 10.48%, respectively. However, for specimen C1, the gain in initial strength is less than in the reference mix by 5.24%. Further, similar to the compressive strength test results, the split tensile strength of specimen C2 is highest for all days of testing; *viz*., 3, 7, 28, 56 and 90 days, as can be seen from Figure 7.

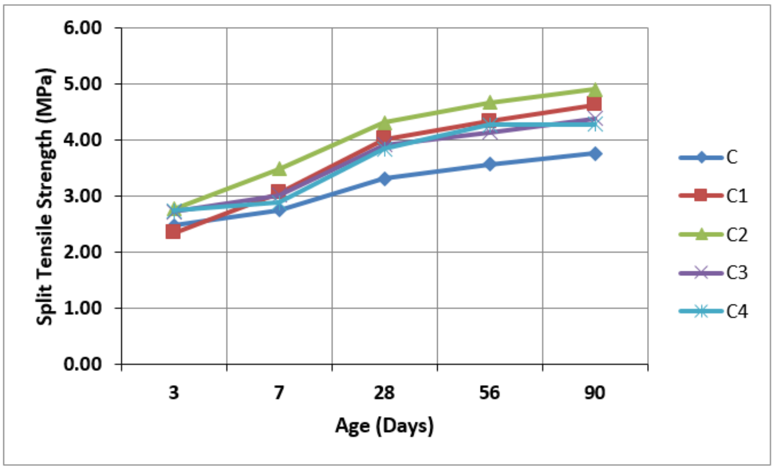

Figure (6): Variation of split tensile strength with curing age

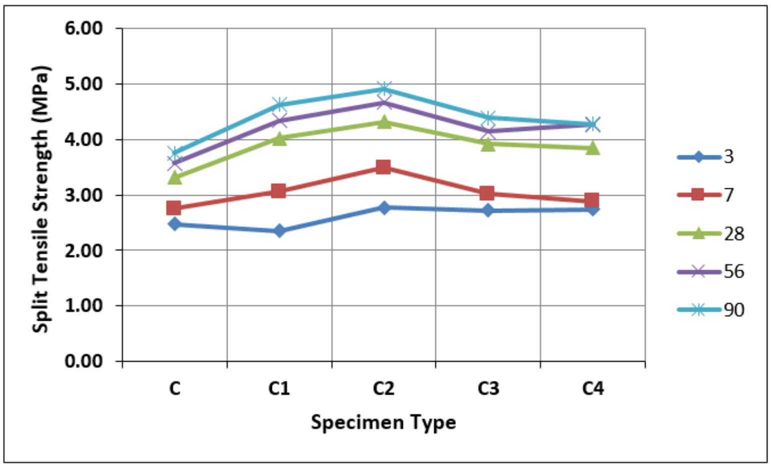

Figure (7): Variation in split tensile strength for different specimen types

The results of the flexural strength test are shown in Figures 8 and 9. From these figures, it can be observed that specimens C2 and C3 show a marginal increase in flexural strength over the reference mix for 3, 28 and 90 days at 10.95%, 5.58% and 6.69%; and 6.92%, 1.45% and 2.76%, respectively. In respect of specimen C1, there is a marginal decrease in flexural strength for the 3, 28 and 90 days at 1.15%, 1.43% and 0.59%, respectively, whereas for specimen C4, the decrease is substantial at 9.80%, 14.05% and 14.17%, respectively. The flexural strength of specimen C2 is highest for all days of testing; *viz.*, 3, 7, 28, 56 and 90 days, as can be seen from Figure 9.

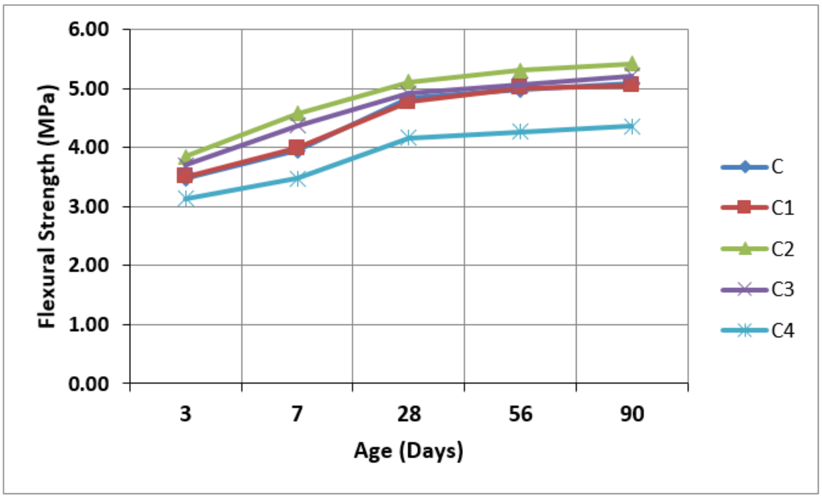

Figure (8): Variation of flexural strength with curing age

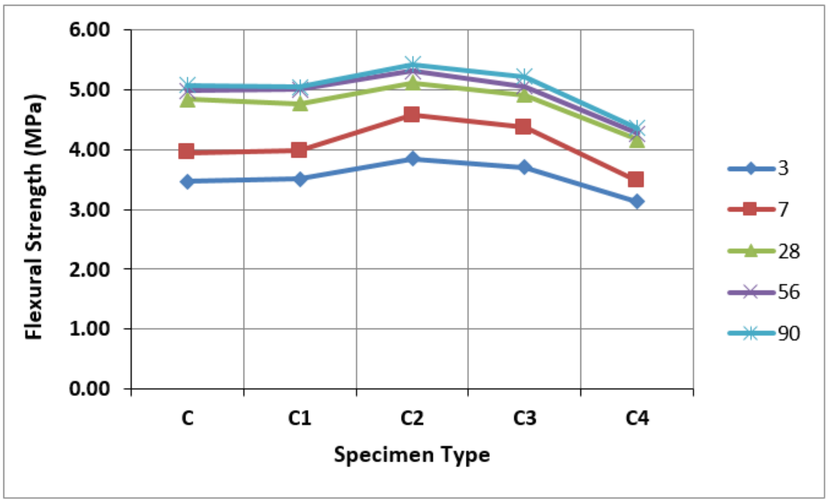

Figure (9): Variation in flexural strength for different specimen types

The impact energy absorbed by the specimens at the age of 28 days, corresponding to first and final failure, is given in Figure 10. The images of the Modified Drop Impact Testing Machine and the specimens after final failure are shown in Figures 11 and 12, respectively. Except for specimen C1, whose impact energy is in excess of the impact energy of the reference mix by about 15%, the other specimens C2, C3 and C4 have absorbed impact energy to an extent of about 100% in excess of the impact energy of the reference mix both at first crack and at final failure, indicating excellent resistance to impact. Even here, specimen C2 has recorded the highest resistance to impact, which is 107.38% and 99.38% over the impact energy sustained by the reference mix.

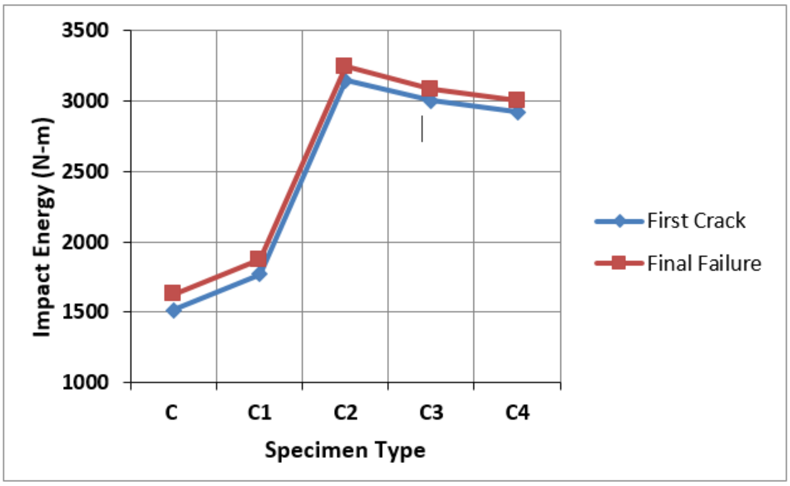

Figure (10): Variation in impact energy for different specimen types

Figure (11): Modified drop impact testing machine

Figure (12): Failure pattern on final impact failure

The pullout test results are tabulated in Table 5. From this table, it can be noted that specimen C2 has recorded the highest failure load at 78.33 kN which exceeds the failure load of the reference mix by 21.22%, whereas specimens C1 and C4 have recorded an increase of 8.97% and 17.00%, respectively. Specimen C3 has a failure load less than the reference mix by a marginal value of 0.53%. Further, the failure pattern was similar in all the cases with a vertical crack which developed along the line of insertion of the bar.

The values of modulus of elasticity for different specimen types are given in Table 6. From this table, it can be noted that modulus of elasticity for all specimen types is higher than that for the reference mix and modulus of elasticity for specimen C2 is highest at 32.03 GPa.

Table 5. Variation of pull-out load for different specimen types

Sl. No.	Specimen Type	Failure Load (kN)	% Change in Failure Load w.r.t. Reference Mix
1	**C**	64.67	-
2	**C1**	70.67	+8.97
3	**C2**	78.33	+21.22
4	**C3**	64.33	-0.53
5	**C4**	75.67	+17.00

Table 6. Variation of modulus of elasticity for different specimen types

Sl. No.	Specimen Type	Modulus of Elasticity (GPa)	% Increase w.r.t. Reference Mix
1	**C**	27.42	-
2	**C1**	30.00	9.41
3	**C2**	32.03	16.81
4	**C3**	29.01	5.80
5	**C4**	27.87	1.64

Ho et al. (2002) have indicated that the introduction of stone dust to mixes must be limited. The critical value of such introduction of stone dust to concrete mixes is found to be about 10% (Narasimha Prasad et al., 2016). In this study, the introduction of stone dust was limited to 7.5% and a performance enhancing reactive microfine cement was introduced in varying percentages (5%-20%). The results indicate that at partial replacement of cement with 7.5% stone dust and 15% microfine cement, the concrete shows highest values of compressive, flexural, split tensile and impact strengths, as well as a high value of modulus of elasticity. These findings are in agreement with Albukersh and Fairfiled (2011), who have concluded that concrete mixes containing granite dust exhibit good fresh properties and better than expected mechanical properties. Felixkala and Partheeban (2010) and Illangovan et al. (2008) have also demonstrated that the introduction of granite dust into concrete mixes has beneficial effects on the mechanical properties of concrete. The better packing density achieved by using stone dust and microfine cement as partial replacement for cement, together with the properties of microfine cement in reducing the water requirement of the resulting concrete, appear to have ensured better hydration of concrete and thus improved mechanical properties.

CONCLUSIONS

In this study, the effect of stone dust, microfine cement and ordinary Portland cement, in a ternary blend on the mechanical properties of the concrete was analyzed. It is seen that stone dust can be used to partially replace cement and in a ternary blend with a reactive microfine, the mechanical properties of the concrete are enhanced. The microfine cement appears to participate both in hydraulic and pozzolanic reactions in the concrete, while stone dust refines the pore structure and provides more nucleation sites for better hydration.

SCOPE FOR FURTHER STUDY

Since aggregates play a significant role in the durability properties of concrete, a detailed study on the effect of replacement of stone dust (an aggregate by-product) and microfine cement on the durability properties of concrete is necessary to conclude on the appropriateness of such replacement.

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