Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 25 No. 3-2020
ISSN:1813-1786 (Print) 2313-7770 (Online)

Effect of Partial CRM with Marble Powder, Silica Fume and Ground Granulated Blast Furnace Slag on Concrete

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Abstract- Marble powder (MP), Silica fume (SF) and Ground Granulated Blast-furnace Slag (GGBS) are environmental hazards. In this study MP, GGBS and SF are used as cement replacement material (CRM) in concrete and their compressive strength are compared. An attempt is made to study the role of these waste materials, with minimum value addition. Consistency of cement as well as cement plus waste materials was calculated to determine their water demand. Cement concrete cylinders and cubes with 5%, 7.5% and 10% waste materials (the three types of waste materials were replaced individually) as CRM and also concrete cubes and cylinders with 10%, 20%, 30% and 40% waste materials (the three types of waste materials were used as a combination) as CRM were cast and then their compressive strengths, split cylinder tensile strength and permeability were determined. Le-Chatlier's apparatus was used to determine the soundness of cement as well as the mixture of cement and waste material. Test results revealed that while partially replacing the waste materials, both compressive strength and the split cylinder tensile strength reduce as compared to control mix. GGBS was the best among the three as it showed comparatively better compressive and tensile strength whereas marble powder gave minimum strength. By replacing 10% GGBS in cement concrete the compressive strength reduced up to 36% and with 10% marble powder it dropped by 50.6%. X-Ray diffraction analysis was done to assess their reactivity. Chemical composition of the three waste materials and of cement was determined by Energy Dispersive X-ray Spectroscopy (EDS). Hence, application of these waste materials with minimum value addition only in lean concrete can be considered. By using these waste materials as CRM will make the environment friendly.

Keywords- **:** Cement Replacement, Marble Powder, GGBS, Silica Fumes, compressive strength, concrete.

I. INTRODUCTION

Cement is a costly material (requires energy resources like coal and oil for the manufacturing) and caused pollution during its manufacturing (1). Therefore, researchers are trying to not only make the cement concrete economical but also to protect the environment, by using the industrial wastes. As, with the advancement in the construction industry different materials are investigated as cement replacement material (CRM) (1). The most popular industrial wastes GGBS, SF and MP are cheaply and easily available industrial wastes. Beside these materials are also pollutants for environment and causing different man-made hazards (2-4).Therefore, by using them as CRMs will not only reduce the concrete construction cost but also will reduce the pollution.

MP is waste generated from marble industry in powder form. A large amountof waste is produced during the cutting process, about 20-25% of total marble quarried has reached as high as millions of tons. The chemical conformation of marble will greatly vary depending on the location and the minerals or impurities present in the limestone during recrystallization. (5-6)studied the effect of marble powder blended cement concrete on strength. The sand was replaced with MP from 5% to 50% with 5% increment. Initially the compressive strength and tensile strength decrease up to 20% replacement and then started increasing up to 50%. The initial decrease in strength was due to increased water demand, but later on the strength increased due to decrease in the porosity as marble powder is a better filling material. (7) studied the effect on compressive strength of mortar cubes when MP was used as CRM in one case and in another it was replaced for fine aggregate. The cement and fine aggregate (sand) were replaced with marble powder from 5% to 20% with 5% increment. The compressive strength decreases in both the cases, while the decrease was more when marble powder was used as CRM. The increase in marble powder content also increased the slump and hence workability of the mix. This shows that the marble powder is not a good pozzolanic material; however, it is a better filling material (1)also studied the effect of marble stone waste on compressive strength of concrete cubes when cement was partially replaced with marble waste as CRM from 10% to 50% with 10% increment. The compressive strength (fc) decreases with the increase in the marble stone waste. The decrease in strength was 29% at 10% replacement and 76% at 50% replacement. The results indicate that the marble powder is not a good CRM; however, it is better filler. Further research of the use of MP has been done to make sustainale concrete (8). Partially replacing cement by dried waste marble powder slurry have also been investiated in an effort to increase durability properties of concrete (9).

Silica fume (SF), before the mid-1970s, nearly all silica fumes were discharged into the atmosphere. SF consists of very fine vitreous particles 100 times smaller than those of OPC, and with a surface area of 20,000 m^2/kg. Because of its extreme fineness and high silica content, it is a highly effective pozzolanic material.(4)studied the effect of SF on compressive strength of cement concrete when cement was partially replaced with SF as CRM from 5% to 50%. The results show that the compressive strength is maximum (32.56% increase) at 15% replacement. The silica content in the SF makes it a pozzolanic material. However, when the silica fumes were replaced more than 15%, the water demand increases and the strength decreases. (9)studied the effect of SF as CRM in the production of High Performance Concrete (HPC). The cement was partially replaced with silica fumes from 2.5% to 12.5% with 2.5% increment and the compressive strength (fc), split tensile strength (fct) and flexural strength (ff)were checked. The results show that the optimum level of replacement was 7.5% as all the 03 types of strengths were maximum. The compressive strength mainly depends on the percentage of silica content in the SF because of its high pozzolanic nature to form more densely packed C-S-H gel. HPC with SF can be effectively used in high rise buildings since high early strength is required, and the construction period can be reduced. (10)studied the effect of SFand size of aggregate on long-term drying shrinkage of mortar. SF was used as a partial replacement by weight of cement from 0% to 30%. The maximum size of fine aggregate was 1.18 and 2.36 mm, respectively, in series I and II mortar mixes. A detailed review of SF and waste glass in concrete has also been detailed (11). SF has been investigated to check mechanical properties of concrete alongwith dynamic behaviour under impact loading (12).

Ground granulated blast-furnace slag (GGBS) is the granular material (13)studied the effect of GGBS on compressive strength and flexural strength of cement concrete when cement was partially replaced with GGBS as CRM from 10% to 40%. The results show that the compressive strength (fc) and flexural strength (ff) both decrease as the GGBS content increases. The reason is the increase in the water demand with the increase in the GGBS content.(2)studied the effect of GGBS on compressive strength and flexural strength of cement concrete when cement was partially replaced with GGBS as CRM from 10% to 70%. The results show that the compressive strength and flexural strength both decrease as the GGBS content increases. The reason is the increase in the water demand with the increase in the GGBS content. Research efforts have been made in the deveoplement of geopolymer concrete with the use of FA, GGBS alongwith the addition of high magnesium nickel slag and better results have been obtained with this combination (14). Optimum use of micro silica and GGBS have been found to give better results (15). The primary purpose of this research is to compare the performance of these three industrial wastes (MP, SF and GGBS) by their partial replacement with the cement and then performing tests on the fresh properties and compressive strength of cement concrete. In previous researches MP, SF and GGBS were replaced individually with cement in concrete. In this research combination of these materials is replaced. Another thing missing in previous researches is that no work is done to know chemical reason for change in concrete behavior by replacement of cement. In this research chemical analysis of the reactants i.e. MP, SF,GGBS and OPC were carried out. X-Ray Diffraction (XRD) test of products i.e. concrete specimens were performed. This was done to know the chemical reason for change in concrete behaviour.

II. Experimental Methodology and Material Properties

Type I cement conformed to ASTM C150 was used. The physical and chemical parameters of cement are given in Table 1.Lawrancepur sand used was as per ASTM C778 for concrete. The Vicat apparatus was used to determine the consistency of the cement as well as that of the mixture as per ASTM C187. Le-Chatelier's apparatus was used to determine the soundness of cement as well as that of the mixture (mixture of cement and waste materials) as per BS: EN-196-3.

Table 1: Chemical and Physical properties of OPC

Chemical Properties	
Loss on ignition %	1.76
Insoluble residue %	0.46
Sulphate as SO3 %	2.8
MgO %	1.7
Physical Properties	
Fineness by Blaine cm^2/g	3000-3200

Initial setting time (min)	110
Final setting time (min)	180
Lechatlier's Expansion (mm)	1
Autoclave Expansion (%)	0.03

2.1. Energy Dispersive x-ray Spectroscopy (EDS)

EDS and chemical composition of the waste material and type I cement was done. The chemical composition of the waste materials tells us about the compounds present in these materials. Usually SiO2, Al2O3 and CaO are responsible of reactivity in the waste materials.

2.2. X-Ray Diffraction (XRD) Analysis

The XRD analysis of the concrete samples was done to determine their reactivity and particle size. The extensive peaks in the XRD form at 22º 2θ specify the occurrence of amorphous silica, while sharp peaks indicate crystalline nature.

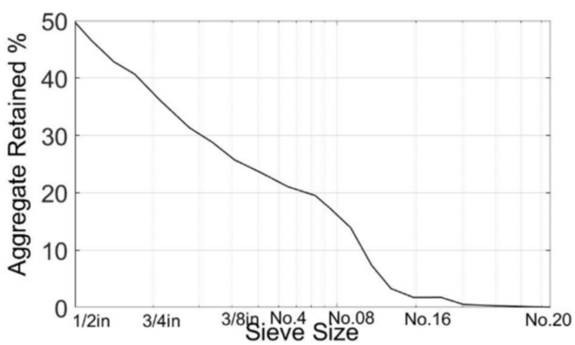


Figure 1. Gradation Curve of Coarse Aggregates

2.3. Mix Design Details

Concrete samples containing different 5ages of MP, SF and GGBS as CR were according to ASTM C192. The detail is given in Tables2, 3 and 4. The mix ratio was 1:1.5:3 and the Water to Binder ratio (W/B) was 0.45. Combine samples (C) containing 10%, 20%, 30% and 40% combined waste materials as CR were cast according to ASTM C192. The detail is given in Table 5. Cubes and cylinders were cast for each mix. The size of the cube was 150 x 150 x 150 mm and that of cylinder was 150 mm diameter (D) and 300 mm height (H). The concrete samples after casting were left in the moulds for 24 h. The samples were then demolded and transferred in the curing tank containing potable water. The samples were cured in the water tank for 7 and 28 days according to ASTM C39. The coarse aggregates from Margalla hills were used. The sieve analysis of coarse aggregates was done according to ASTM C33 and its gradation curve is shown in Figure 1. Table 6 tells the nomenclature for the different type of mixes.

Table 2: Mix design details (MP Replacement)

CR of MP	Cement Weight	MP Weight	Sand Weight	Aggregates Weight	Water Weight
(%)	(kg)	(kg)	(kg)	(kg)	(kg)
5	21.42	1.13	33.82	67.64	10.15
7.5	20.85	1.69	33.82	67.64	10.15
10	20.30	2.25	33.82	67.64	10.15
Total Wt.	62.57	5.07	101.46	202.92	30.45

Table 3:Mix design details (SF Replacement)

CRof SF	Cement Weight	SF Weight	Sand Weight	Aggregates Wight	Water Weight
(%)	(kg)	(kg)	(kg)	(kg)	(kg)
5	21.42	1.13	33.82	67.64	10.15
7.5	20.85	1.69	33.82	67.64	10.15
10	20.30	2.25	33.82	67.64	10.15
Total Wt.	62.57	5.07	101.46	202.92	30.45

Table 4:Mix design details (GGBS Replacement)

Cof GGBS	Cement Weight	GGBS Weight	Sand Weight	Aggregates Weight	Water Weight
(%)	(kg)	(kg)	(kg)	(kg)	(kg)
10	20.30	2.25	33.82	67.64	10.15
20	18.04	4.50	33.82	67.64	10.15
30	15.78	6.76	33.82	67.64	10.15
Total Wt.	60.87	17.67	101.46	202.92	30.45

Table 5: Mix design details (C Replacement)

CR Total	CRof MP	CRof SF	CR of GGBS
(%)	(%)	(%)	(%)
0	0	0	0
10	2.5	2.5	5
20	5	5	10
30	7.5	7.5	15
40	10	10	20
Total			

Table 6:Nomenclature of mix designs (Combined case)

Sample	Name
Ordinary Portland Concrete	OPC
5% CR byMP	M1
7.5% CR byMP	M2
10% CR by MP	M3
5% CR by SF	S1
7.5% CR bySF	S2
10% CR bySF	S3
10 % CR by GGBS	G1
20 % CR by GGBS	G2
30 % CR by GGBS	G3
10% CR of Combined Mix	C1
20% CRof Combined Mix	C2
30% CR of Combined Mix	C3
40% CR of Combined Mix	C4

III. Results and Discussion

Chemical analysis of OPC, MP, SF and GGBS was carried out to determine the compounds present in them. The results are tabulated in Tables7, 8 and 9. The abbreviated symbols used are explained as C ($CaCO_3$), O (SiO_2), Mg (MgO), Al (Al_2O_3), Si (SiO_2), K (Feldspar) and CA (Wollastonite). It is noted that the silica content in OPC is 32.5%, SF is 35.63%, MP is 1.30% and in GGBS is 12.22%. The calcium content in OPC is 36.93%, in SF 0.55%, in MP 32.20%, and in GGBS is 24.32%. The silica and calcium contents are mainly responsible for forming calcium silicate hydrates responsible for strength. It is noted that both silica and calcium contents collectively in OPC are greater than those in the waste materials. Obviously, the OPC will exhibit the greater strength than the concrete specimens partially replaced by waste materials. It is noted that the SF content of the waste materials used in this study is far lesser. It may be expected from the results that strength of the samples partially replaced by these wastes materials would be lesser than OPC.

Table 7: Chemical composition of OPC against MP

	OPC		MP	
Element	**Weight(%)**	**Atomic(%)**	**Weight(%)**	**Atomic(%)**
CK	4.00	7.36	14.02	22.25
OK	40.17	62.37	50.68	60.36
MgK	0.78	0.71	0.99	0.78
AlK	1.98	1.62	0.29	0.21
SiK	32.5	5.30	1.30	0.88
SK	1.32	0.91	**0**	**0**
KK	0.93	0.53	0.25	0.12
CaK	36.93	20.36	32.20	15.31
FeK	2.16	0.86	0.25	0.09
TiK	0	0	0	0
Total	100		100	

Table 8:Chemical composition of OPC against SF

	OPC		SF	
Element	**Weight(%)**	**Atomic(%)**	**Weight(%)**	**Atomic(%)**
CK	4.00	7.36	5.88	9.34
OK	40.17	62.37	52.86	62.99
MgK	0.78	0.71	0.97	0.81
AlK	1.98	1.62	**0**	**0**
SiK	32.5	5.30	1.69	1.33
SK	1.32	0.91	35.63	24.19
KK	0.93	0.53	1.82	0.89
CaK	36.93	20.36	0.55	0.26
FeK	2.16	0.86	0.59	0.20
TiK	0	0	0	0
Total	100		100	

Table 9:Chemical composition of OPC against GGBS

	OPC		GGBS	
Element	**Weight(%)**	**Atomic(%)**	**Weight(%)**	**Atomic(%)**
CK	4.00	7.36	**0**	**0**
OK	40.17	62.37	50.42	67.74
MgK	0.78	0.71	3.51	3.10
AlK	1.98	1.62	6.81	5.43
SiK	32.5	5.30	12.22	9.35
SK	1.32	0.91	0.65	0.44
KK	0.93	0.53	0.42	0.23
CaK	36.93	20.36	24.32	13004
FeK	2.16	0.86	1.17	0.45
TiK			**0.48**	**0.21**
Total	100		100.0	

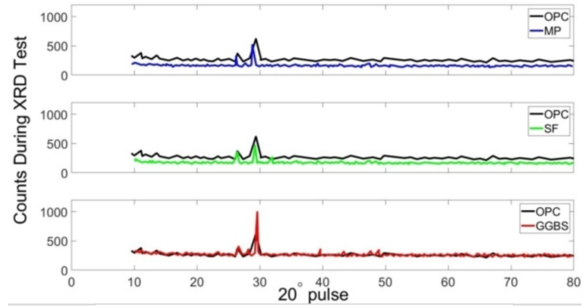


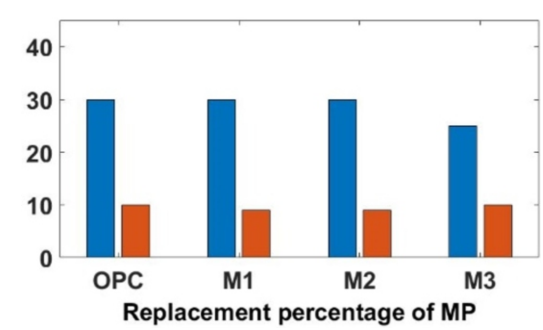
Figure 2. XRD pattern for Concrete containing 0% replacement against MP,SFand GGBS

3.1. XRD Analysis and Results

The XRD analysis of the three waste materials displays up and down peaks. Figure 2 expression humps at 22º (2θ) which indicate the presence of amorphous silica. Fig 2 shows more broad humps in OPC (with 0% replacement) which is an indication of reactivity. Contrary to that, sharp peaks have been observed in case of MP, SF and GGBS which is an indication of unreactive crystalline silica leading to less reactivity of these materials. Furthermore, it has also been obsrved that out of the three cement replacement materils, GGBS has a higher peak than SF and MP which advocates its better reactivity. The results correlate well with the earlier results obtained in the chemical analysis where MP, SF and GGBS have shown lesser silica and calcium contents than OPC which are mainly responsible for forming calcium silicate hydrates, Therefore a reduced strength has been obtained for MP, SF and GGBS.

3.2. Initial Setting Time and Soundness of Cement

Figure 3 shows the results of initial setting time and soundness of CRM. The results show that by adding the waste materials in cement, there is a minimal impact on the intial setting times in case of MP and CF as their replacement levels were low (less tan 10 %). While in case of GGBS and combine case, the initial setting times have increased. This may be attributed to increase in the %age of cement replacement materials (greator than 10%) with respect to cement, which further leads to slow pozzolanic reaction of these materials. Furthermore, a similar trend has been noted in case of soundness test.



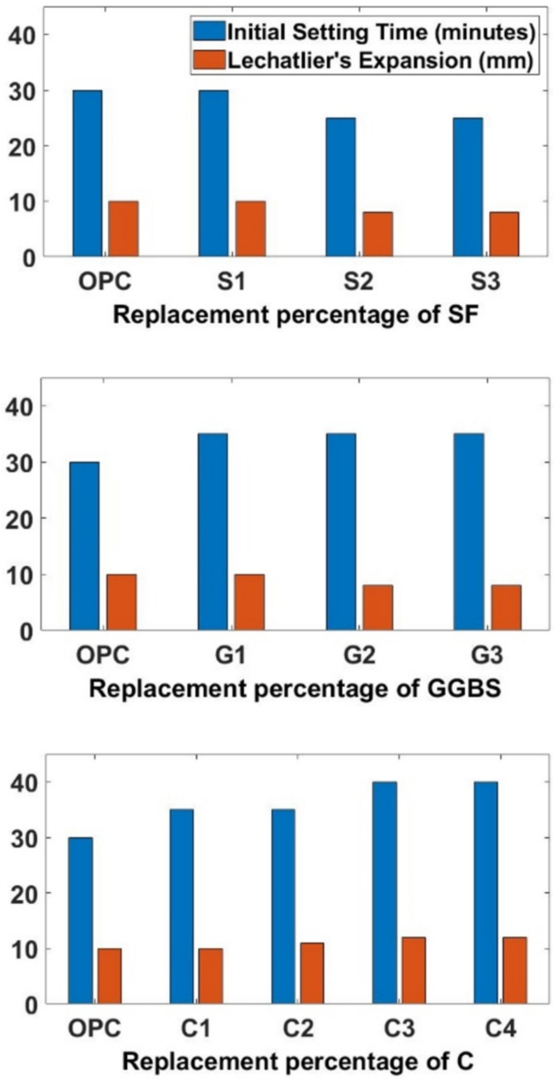


Figure 3. Initial Setting Time and Soundness of MP, SF, GGBS and Combine

3.3. Spilt Strength of concrete specimens (ASTMC39): The spilt strength of concrete specimens is determined in the compression testing machine after 7 and 28 days.Figure 4 shows that OPC has maximum split tensile strength. Split tensile strength of M1 decreased by 29.4% at 7 days and 37.9% at 28 days. Comparing M1 and M2, M2 has relatively more strengths than M1. From M1 to M2 percent split tensile strength increases by 15.1% at 7 days and 17.7% at 28 days. After M2 percent replacement, strengths incline to decrease. From M2 to M3 split tensile strength decreases by 4.6% at 7 days and 6.7% at 28 days. M2 shows better results due to denser mix.

By replacing cement with silica fumes, split tensile strengths decreases w.r.t OPC. Split tensile strength of S1 decreased by 53.9% at 7 days and 34.5% at 28 days w.r.t OPC. While in case of S2 and S3, relatively denser mixes are obtained which give better result than S1.

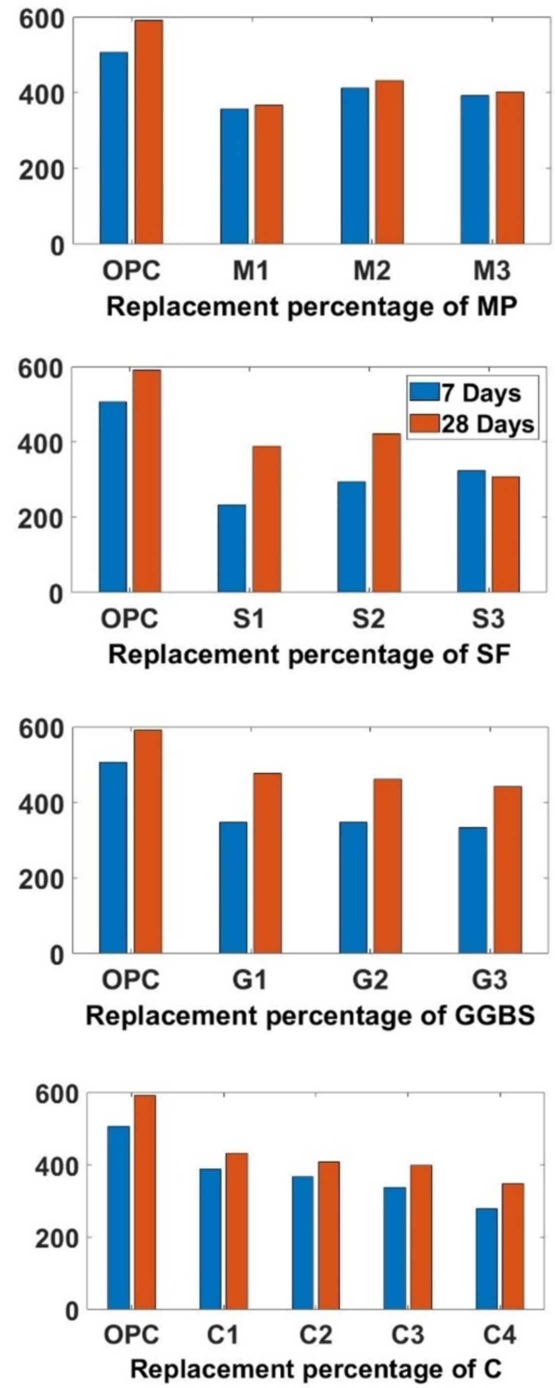


Figure 4. Split Tensile Strength of MP, SF, GGBS and Combine

By replacing cement with GGBS split tensile strengths decreases w.r.t OPC. Split tensile strength of G1 decreased by 31.4% at 7 days and 19.2% at 28 days w.r.t OPC. These results show that in case of G1, the workability is relatively higher and mix is denser than G2 and G3, hence better results are obtained in case of G1.

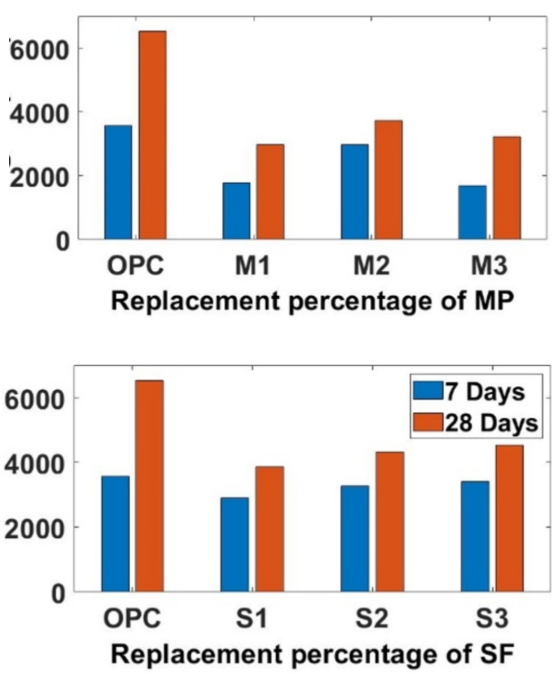
Split tensile strength of C1 decreased by 23.5% at 7 days and 26.9% at 28 days w.r.t OPC. From C1 to C2 split tensile strength decreases by 5.7% and from C2 to C3 the strength increases by 2.4% at 28 days. From C3 to C4 split tensile strength increases by 17.5% at 7 days and 12.5% at 28 days.

These results show that the workability of the mix decreases with increasing replacement and the density of the mix is also decreasing and hence the splitting strength.

3.4. Compressive strength of CRM Specimens

The compressive strength of concrete specimens is determined in the compression testing machine after 7 and 28 days. Figure 5 shows that OPC has maximum compressive strength. By replacing cement with marble powder, strengths dereases. Compressive strength of OPC is greater than that of M2 by 25.5% at 7 days and 42.0 % at 28 days. However, comparing M1, M2 and M3, strength of M2 is greater than M1 which may be due to decreased porosity. From M1 to M2 percent compressive strength increases by 56.1% at 7 days and 15.1% at 28 days. After M2 percent replacement strengths tends to decrease. From M2 to M3 compressive strength decreases by 15.7% at 7 days and 13.8% at 28 days. Better strength is obtained in case of M2 which may be attributed to denser mix.

By replacing cement with silica fumes compressive strengths decreases w.r.t OPC. Compressive strength of S1 decreased by 18.8% at 7 days and 40.8% at 28 days w.r.t OPC. Comparison of S1, S2 and S3 reveals that maximum compressive strength is obtained at S2.



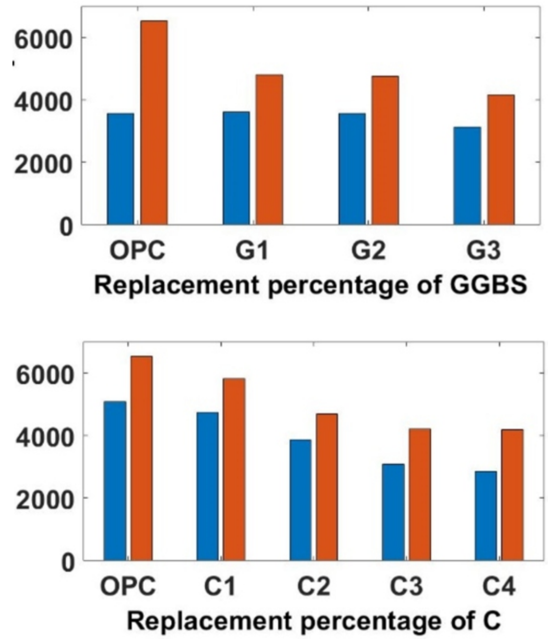


Figure 5. Compressive Strength of MP, SF, GGBS and Combine

Similarly, GGBS replacement also decreased compressive strengths. Compressive strength of G1 decreased by 1.1% at 7 days and 26.2% at 28 days with respect to OPC. From G1 to G2 percent compressive strength decreases by 0.8% at 28 days and from G2 to G3 compressive strength decreases by 12.5% at 28 days.

By replacing cement with combined mix compressive strengths at 28 days also decreases. The maximum compressive strength is obtained for C1. However, compressive strength of OPC is greater than that of C1 by 6.8% at 7 days and 10.9 % at 28 days. Further replacement in case of C2, C3 and C4 also has proven to give poor results as compared to OPC due to the amorphous materials.

3.5. Maximum Particle Size in samples

Particle sizes at maximum intensities are calculated by Scherrer formula and results are given in Figure 6. OPC shows different particle size than the other materials and hence results in its different behavior from other samples. OPC shows greater strength values in experiment results. So it can be concluded that lesser particle size of OPC corresponds to higher strengths and higher particle sizes of other samples (M2, S3, G1 and C1) correspond to low strength.

Based on these results on MP, SF and GGBS as CR in concrete, the following conclusions can be drawn.

a) Chemical analysis of OPC, MP, SF and GGBS reveals that both silica and calcium contents collectively in OPC are greater than those in the waste materials i.e. SF, MP and GGBS. These contents are mainly responsible for forming

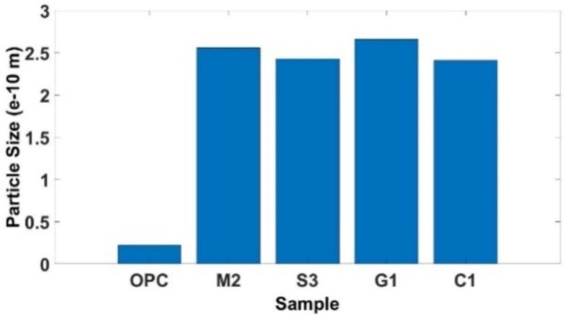


Figure 6. Particle Sizes in MP, SF, GGBS and Combine from Scherrer formula CONCLUSIONS

calcium silicate hydrates and ultimately the strength.

b) The XRD analysis of replacement materials reveals a little amount of amorphous silica in them. The compressive strength results of concrete specimens also show that with CR, there is a drop in the compressive strength of concrete. So, it can be concluded that all the three CR materials are old waste materials and have little pozzolanic activity.

c) The initial setting time results show a minimal impact on the intial setting times in case of MP and CF as their replacement levels were less than10 %. Whereas for GGBS and combine case, an increase in initial setting times have been observed which may be attributed to slow pozzolanic reaction.

d) The compressive strength (fc') and spilt cylinder strength results of the concrete specimens show that due to less pozzolonic activity, all the cement replacement materials have shown lesser strengths. However, GGBS is best of all the three waste materials used in this study. It gives maximum strengths when used as CR in CC. This conclusion is also supported by the XRD test results where GGBS has been found to have a higher peak than SF and MP. The combined case C1 where 2.5% MP, 2.5 % SF and 5 % GGBS have given better results as compared to C2, C3 and C4.

e) Particle sizes by Scherrer formula indicate that OPC has lesser particle size than other cement replacement materials. As a result, OPC has given higher strength as compared to other materials.

Further research on durability aspects of these waste material in the concrete is recommended. Furthermore, use of recycled aggregates along with the addition of the cement replacement materials in concrete may also be looked into.

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