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Research paper

Experimental Study on Mechanical Properties on Ternary Blend of Concrete

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Abstract

A major problem in cement manufacturing is the increased emission of CO_2. About 5% of worldwide man-made emission of CO_2 is generated. Cement being the predominant material of concrete, the usage needs to be reduced by using admixtures or SCMs to replace partially, the percentage of OPC in concrete. Admixtures like Metakaolin (MK) and Waste Glass Powder (GP) were used to replace OPC, producing a ternary blended concrete. The cement replacement with GP is from 5% to 45% and MK is from 45% to 5% both in steps of 5% and hence a total of ten combinations including control mixture (100% cement) were studied for M30 grade. Mechanical properties are evaluated by conducting compressive, split tensile strength tests. The initial compressive strength of mix containing 20% GP and 30% MK with 50% OPC, after 7 days curing is found to be higher by 5%, compared with control mix.

Key words: *Ordinary Portland Cement, Ternary Blend, Metakaolin, Waste Glass Powder, Supplementary Cementitious Materials*

1. Introduction

The Supplementary Cementitious Materials (SCM) contribute to the properties of hardened concrete through the pozzolanic activity. Some of the examples of SCM's are fly-ash, GGBFS, Metakaolin, waste glass etc. They are industrial by-products and they are partially replaced with Portland cement which reduces the amount of cement needed for concrete and CO_2 impacts. Since the cementitious content of concrete is only about 7 to 15%, these SCM's typically account only for 2 to 8% of overall concrete materials in buildings. SCM's are used in 65% of ready mixed concrete.

Ternary blended cements are produced by blending cement with two complementary cementitious materials such as fly ash, slag, silica fume etc. In order to use materials effectively and reduce the cost of construction, the ternary blended cements including Portland clinkers along with two other SCM's is a better option as it presents several advantages over binary blend. With the development of individual grinding and mixing techniques in cement industry, it has become more easier to produce such market-oriented cements. The binary cement (Portland cement blends with slag or fly ash or limestone or any other admixture), has gained great popularity in many countries. However, each kind of binary cement has its own shortfalls.

In this study a ternary blended concrete was created using Waste Glass Powder(GP) and Metakaolin (MK) [4]. G.M.Sadiqul Islam et al. in their investigation found that when glass is grinded to small particles, it undergoes reactions with hydrates of cement forming Calcium Silicate Hydrates (C–S–H) [1]. K.Ramakrishnan et al . in their investigation proved that Glass Powder with good fineness would induce pozzolanic reaction instead of Alikali Silica Reaction (ASR) expansion and it totally eliminated it. [2]. Jitendra.B et al. in their investigation found that waste glass when grinded to fine powder shows good cementitious properties as it contains SiO_2 and hence can be used for cement replacement of concrete and contribute in strength development. [5]. O.R.Kavitha et al. found that metakaolin inclusion enhanced the macro level properties. They also found that micro level studies showed micro crack width which fell due to addition of metakaolin in the control mixture. Also the cementitious action of metakaolin minimizes $CaOH_2$ and reduces the Ca-Si ratio in C–S–H. [6]. E.Moulin et al. in their investigation told that metakaolin replacement benefits involves higher levels of long term strength, reduced diffusion coefficients and increase in sulphate resistance which are linked to refined pore structure [9]. V.R.Sivakumara et al. in their investigation found that the inclusion of metakaolin inhances the mechanical properties of concrete and reduces the workability.

2. Experimental Investigations

Cement

Cement used in this work was OPC 43 grade pertaining to IS 8112. The characteristics of this cement was assessed by carrying out tests and the values are presented in Table 1. The cement color is grey. The chemical composition of cement is shown in Table 2.

Waste Glass Powder (GP)

Well grinded glass powder (GP) from Ashwin Ceramics, Chennai was used. The various physical and chemical properties of the GP are shown in Table 2 and Table 3. The GP here is the SCM which reacts with hydroxides in cement inducing reaction giving cementitious products which supports the enhancement of strength. In this work, the GP fineness used was 70 microns and also accelerated mortar bar test was not performed in this experimental work.

Metakaolin (MK)

Metakaolin is one of the mostly used pozzolanic material in recent years. Metakaolin helps in the reduction of $CaOH_2$ which is formed due to the cement hydration which pertains to paltry durability. It makes Concrete more resistive to sulphate attack and reduces the effect of alkali-silica reaction. Metakaolin is obtained from ASTRAA chemicals, Chennai.
The experience of the manufacturer ASTRAA Chemicals, Chennai has shown that optimum percentage of replacement is achieved at 10% to 15% of the cement with metakaolin. It has an upper hand of able to replace some of the OPC with MK, instead of simply adding it to the mix combinations, so that existing color or formulae or mixes never change or will marginally change due to the dosage of pigment. The superplasticizers are based on the cement composition in the concrete.
It is very important to know that the apparent cementitious content will get increased and it is found that this will affect not only the pigment and admixture quantities but also the w/c ratio which is a very important factor in mix design.

Table 1: Cement - Physical properties.

S.No	Cement Properties	Results
1.	Specific Gravity	3.15
2.	Soundness by Le Chatelier (mm)	7
3.	Initial Setting Time in minutes	35
4.	Final Setting Time in minutes	450

Table 2: Cement, GP and MK - Chemical composition

Formulae	Composition (%)		
	Cement	GP	MK
CaO	69.00	8.83	0.28
SiO_2	24.91	75.31	52.86
Al_2O_3	5.85	1.11	44.10
Fe_2O_3	0.20	-	0.45
MgO	0.04	2.80	0.20
Na_2O	-	10.77	0.25
K_2O	-	0.41	0.20
Loss on Ignition	-	0.32	0.85

Table 3: GP and MK - Physical properties

S.No	Properties	SCMs	
		GP	MK
1.	Specific Gravity	2.5	2.6
2.	Particle size	<70 microns	<70 microns
3.	pH	6	-
4.	Appearance	Off White	Bright White

Coarse and Fine Aggregates (CA & FA)

Grinded waste materials which are commercially available was used as CA with sieve size ranging from 20 mm to 12.5 mm sieve. The specific gravity of CA and that of the sand which was used as FA is 2.70 each and the fineness of FA was 3.35. The FA is devoid of clay, silt, organic impurities etc, and it was also noted to be less than 4.75 mm size as per IS: 383-1970 (Zone: II)

Chemical Admixtures

Super plasticizers were added to improve workability of concrete. CERAPLAST 300- RS(G)- Modified high performance admixture for ready mixed concrete. It pumpable concrete with excellent workability retention even in extreme temperatures. It improves durability, reduces heat of hydration even with very high strength cements.

3. Methodology

Details of Specimens

M30 Grade concrete with sample of size 100mm X 100mm X 100mm cubes were cast for both the control mix (CM) as well as SCMs replaced mixes. The SCMs were used by replacing partially cement with GP and MK. The cement composition was kept at 50% of weight for all the mixes and the FA and CA compositions were also kept constant at 100% with nil replacement as per the requirements. The rest of the 50% of the binder contains GP from 45–5% variation by weight in step of 5% and the other portion with MK with 5–45% variation in step of 5% respectively for estimation of compressive properties. The mix designations, proportions used and their compositions viz. cement, GP and MK are tabulated in Table 4. The same mixes were followed for other tests. For split tensile test diameter of 100 mm and 200 mm height cylindrical samples were cast for same mix.

Mix Design and Mix Proportions

Concrete grade used in the work is M30 with OPC 43 cement. Since MK was used with GP as SCM whose hydro intake is very high and hence a uniform w/bn ratio of 0.4 along with a super-plasticizer was taken for all the mixes used in this experimental work. The concrete is of medium workability where the Slump lies between 50 to 90 mm. The mix proportions of all 10 mixes per cu-m of concrete is presented in Table 5. The mix ratio was 1:2.03:3.33.

Table 4: Composition of OPC, GP, MK, FA and CA.

Mixes	OPC (%)	GP (%)	MK (%)	FA (%)	CA (%)	Super Plasticizer-SP (%)
CM	100	0	0	100	100	100
GM1	50	5	45	100	100	100
GM2	50	10	40	100	100	100

GM3	50	15	35	100	100	100
GM4	50	20	30	100	100	100
GM5	50	25	25	100	100	100
GM6	50	30	20	100	100	100
GM7	50	35	15	100	100	100
GM8	50	40	10	100	100	100
GM9	50	45	5	100	100	100

Table 5: Mix proportions for 1 m^3 of concrete

Mixes	OPC (kg)	GP (kg)	MK (kg)	FA (kg)	CA (kg)	Water (kg)	SP (kg)
CM	370	0	0	750.40	1230.80	161.75	7.40
GM1	185	14.68	137.43	750.40	1230.80	161.75	7.40
GM2	185	29.36	122.15	750.40	1230.80	161.75	7.40
GM3	185	44.04	106.88	750.40	1230.80	161.75	7.40
GM4	185	58.73	91.62	750.40	1230.80	161.75	7.40
GM5	185	73.41	76.35	750.40	1230.80	161.75	7.40
GM6	185	88.10	61.08	750.40	1230.80	161.75	7.40
GM7	185	102.77	45.80	750.40	1230.80	161.75	7.40
GM8	185	117.46	30.54	750.40	1230.80	161.75	7.40
GM9	185	132.14	15.27	750.40	1230.80	161.75	7.40

4. Specimen Testing

Compression Strength Test

The important mechanical test is the compression strength test since most of the concrete characteristics, their properties and the structural design pertains towards compression strength. The testing is done in a Uniform CTM of 3000kN capacity at various curing ages such as 7, 14 and 28 days as per the specifications of IS 516: 1959. The test set up is shown in Figure 1.

Fig. 1: Compressive strength test

Fig. 2: Split Tensile

Splitting Tensile Test

This is another important mechanical test involving an indirect testing to determine the tensile strength of concrete samples. The test was carried out at 28 days curing age of the cylinder samples of size 100mm dia and 200mm length, in a Uniform CTM of 3000kN capacity as per IS:516-1959. The load is applied slowly untill the samples splits and values are tabulated. The test set up is shown in Figure 2.

5. Results and Discussion

The cement percentage was kept at 50% of the weight of the mix. The other 50% composition consisted of glass powder varying from 45–5% by weight in step of 5% and with MK varying from 5–45% by weight in step of 5% respectively for the estimation of compression strength. The same proportions were used for remaining test such as splitting tensile test.

Compression Strength

The Compression strengths of the samples for mixes at various curing ages are shown in Table 6. Figure 3 represents the change in compression strengths for all mixes. For all mixes 2 cubes each for all curing periods ie., 7days,14days and 28days were casted and mean strength was taken. The early curing value (7days) strength of mix GM4 (50 + 20 + 30) and GM5 (50 + 25 + 25) and GM6 (50 + 30 + 20) was higher than that of control concrete by 11.33%, 6.73% and 1.23% respectively. The increase in strengths of the mixes GM4, GM5 and GM6 was 16.35%, 13.77 and 7.26% respectively after 14days. Similarly, the increase in strength of GM4, GM5 and GM6 was 14.42%, 12.25 and 5.90% respectively after 28 days curing. From this data it was found that the greatest strength on comparison with the control concrete was obtained in the mix GM4 with GM5 in close race with it followed by GM6. Though the strengths of the mixes GM5 and GM6 was higher than that of control concrete, the value had a reduced trend on comparison with GM4. The strengths of GM1, GM2 and GM3 were lesser than control concrete at all 7 days, 14 days and 28 days. The strength fall was due to more amount of MK with relatively lower amount of GP. Similarly, the compressive strength of GM7, GM8 and GM9 was low than the control concrete at all ages. It is found in the Fig.3 that the increase in development of strengths for SCM viz. GP and MK was higher when both the SCM's were replaced beyond 20% and strength dropped anytime when either of them were replaced below 20%.

Table 6: Variation in Compressive Strength

Mixes	OPC:GP:MK	Compressive Strength (MPa)		
		7-days	14-days	28-days
CM	100+0+0	23.46	29.47	35.92
GM1	50+05+45	15.74	24.26	28.56
GM2	50+10+40	16.88	24.06	30.23
GM3	50+15+35	19.80	28.20	35.21
GM4	50+20+30	26.12	34.29	41.10
GM5	50+25+25	25.04	33.53	40.32
GM6	50+30+20	23.75	31.61	38.04
GM7	50+35+15	20.08	29.25	35.32
GM8	50+40+10	17.62	26.32	31.13
GM9	50+45+05	14.22	23.33	29.40

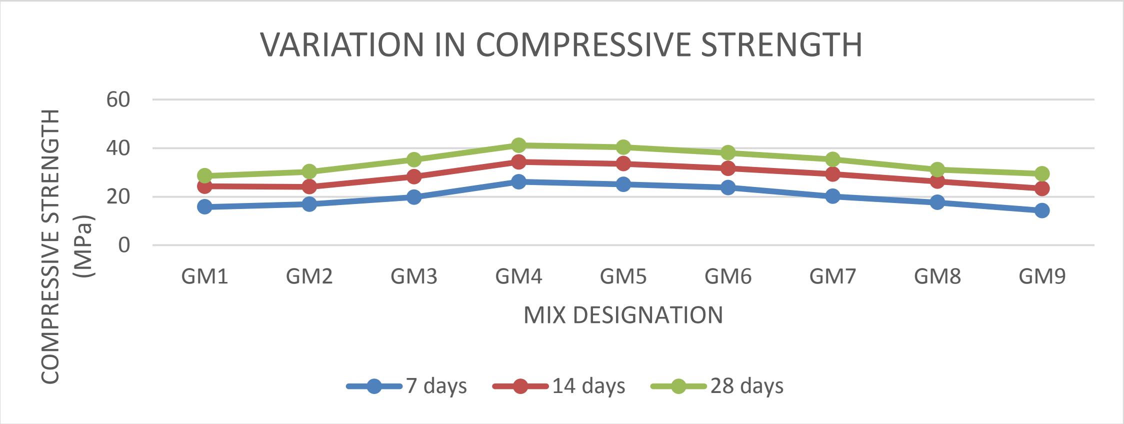

Fig. 3: Variation in Compressive Strength

Splitting Tensile Strength

The outcomes of this mechanical test for all the mixes are shown in the Table 7. We know that concrete materials are highly poor in tension. The strengths of the mixes GM4 (50 + 20 + 30), GM5 (50 + 25 + 25) and GM6(50 + 30 + 20) are the highest of the values of other compositions. The increase in strength of GM4, GM5 and GM6 to that of control concrete were 15.78%, 10.52% and 3.03%respectively for 28 days curing. Hence it was found that the most suitable SCM mix was GM4 with 20% GP and 30% MK. The strength of the mix GM1, GM2 and GM3 were found to be less than that of CM. This fall in strength is owed to higher MK content and lower GP. The additional MK becomes an unreactive material and secondary cementitious colloid is not formed. Also the strengths of the mix GM7, GM8 and GM9 were also found to be less than that of CM and this fall in strength was because of high GP content and lower MK. The variation of strength for the mixes were similar to that of compressive strength.

Table 7: Variation in Split Tensile Strength

Mixes	OPC:GP:MK	Split Tensile Strength (MPa) @28 days
CM	100+0+0	3.04
GM1	50+05+45	2.52
GM2	50+10+40	2.95
GM3	50+15+35	2.96
GM4	50+20+30	3.52
GM5	50+25+25	3.36
GM6	50+30+20	3.13
GM7	50+35+15	2.99
GM8	50+40+10	2.73
GM9	50+45+05	2.63

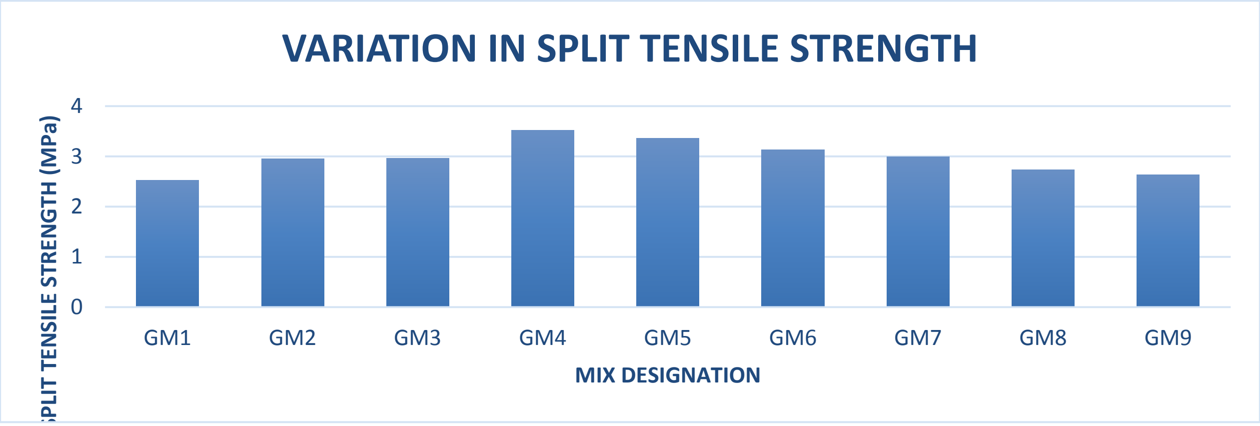

Fig. 4: Variation in Split Tensile Strength.

6. Conclusion

Based on the values obtained from the tests, the following conclusions were derived.

- The partially replaced cement containing mixture of GP and MK viz. GM4 (50:20:30) was found to be the optimum mix in this experimental work yielding the highest values for both the mechanical tests. Hence in this work, 20% replacement of binder with GP and 30% replacement of binder with MK yielded highest strengths. GM5 (50:25:25) followed the mix GM4 with slight variation in compressive strength of about 1.93% with GM4 at 28 days.
- Similarly, in the Splitting tensile strength test the same mixture GM4 (50:20:30) yielded the highest value, closely followed by GM5 with variation between them was 4.76%.
- The high strength combination is GM4 (50% OPC +20% GP + 30% MK) having better mechanical properties over all other mixes can be put for use as an effective SCM in the near future.

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