Experimental Studies On Mechanical And Durability Properties Of High Performance Concrete Made With Metakaolin, Bottom Ash And Steel Slag Aggregate

Karam Venkanna Dora[1], Sri. P.Deepika Rani[2]
[1, 2] Dept of Civil Engineering
[1, 2] KITS-DIVILI

Abstract- *High-performance concrete with industrial byproducts as partial replacements become more popular in recent times. The main purpose of these Industrial by-products are, that they can increase strength by pozzolana reaction and hydration reaction and also they will act as micro fillers in high performance concrete. The scope of the present study is to find the effect of industrial byproducts of metakaolin, bottom-ash and steelslag aggregate replaced by cement, fine aggregate and coarse aggregate respectively towards the functioning performance of HPC. An effort has been made to focus on the influence of industrial by-products on strength properties, durability properties. High Performance Concrete of M30 grade was attempted here with three types of industrial by-products viz. metakaolin, bottom ash and steel slag aggregate. The replacement materials are metakaolin in the replacement percentage of 5%, 10%, 15% and 20% as cement, bottom ash in the replacement percentage of 10%, 20%, 30%, 40% and 50% as fine aggregate and steel slag aggregate in the replacement percentage of 10%, 20%, 30%, 40% and 50% as coarse aggregate. The optimum mixes were found out for the MC,BC and SSC mixes . The binary and ternary mixes are prepared and the durability studies were carried out in finding the optimum mix. The durability studies such as acid resistance, salt resistance, sulphate resistance, and water absorption test were concentrated.*

Keywords*-* Metakaolin, Bottom ash,Steel slag aggregate, durability studies

I. INTRODUCTION

When the general performance of concrete is substantially higher than that of conventional concrete, such concrete is referred to as high performance concrete (HPC). However, from strength point of view, usually high strength, high durability which is regarded as the most favorable factors of being a construction material, are the key attributes to produce the HPC. So, the need for the requirement of high mechanical properties and durability properties has made the researchers find out the appropriate technology through research, and the HPC was the outcome. The incorporation Metakaolin is in widespread use all over the world in the concrete industry. The advantages of Metakaolin not only have many concrete performance benefits, both in mechanical and durability properties, but also the environmental benefits. While the production of Portland cement is associated with high carbon dioxide emissions. Metakaolin is a dehydroxylated form of the clay mineral kaolinite

Bottom ash is the companion to fly ash in process of coal-burning with an approximate amount of 20% by volume of the total ash, depending on the type of boiler, dust collection system, burning temperature and the type of coal. Its particle is porous, irregular and coarser than that of fly ash but its chemical composition is not much different..

Steel slag aggregate is an industrial product that is manufactured under extensive quality management, and contains no organic impurities, clay, shells, or similar materials. This aggregate contains no reactive silica, which is one cause of chemical reaction with alkali aggregates. It reduces environmental impacts, preserves precious natural resources needed to maintain ecosystems, and can reduce the energy that is consumed in mining, stone crushing, and other activities.

II. MATERIALS USED IN CONCRETE

2.1 Cement

Ordinary Portland cement of 43 grade conforming to IS: 8112-2013 was used for the present experimental investigation.

2.2 Cement Replacement Material **- Metakaolin**

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Metakaolin can be produced by primary and secondary sources containing kaolinite are high purity kaolin deposits, kaolinite deposits or tropical soils of lower purity, paper sludge waste which contains kaolinite, oil sand tailings contains kaolinite

2.3 Fine Aggregate Replacement Material – Bottom Ash

Bottom ash obtained from Thermal power plant, Neyveli Lignite Corporation Ltd, at Neyveli, Tamil Nadu in India, was used in the investigation.

2.4 Coarse Aggregate Replacement Material - Steel slag aggregate

The slag resulting from the steel making process are separated into blast furnace and metallurgical slag and then recycled. The steel slag aggregate material was obtained from industries.

2.5 **Water**

Potable water available in the laboratory with pH value between 6 and 8 confirming to the requirements of IS: 456-2000 was used for mixing of concrete and curing the specimens as well.

III. TRIAL MIXES FOR CONVENTIONAL CONCRETE

S.N	**C (kg/m^3)**	**FA (kg/m^3)**	**CA (kg/m^3)**	**water**	**W/C**
1	480	615	1127	191	0.40
2	425	630	1155	191	0.45
3	430	641	1175	172	0.40
4	**383**	**655**	**1200**	**172**	**0.45**
5	384	674	1235	153	0.40
6	340	681	1248.6	153	0.45

The finalized mix proportion was 1:1.71:3.13 with w/c ratio 0.45. Conventional concrete having 28 days of compressive strength of 30 MPa was developed.

IV. MECHANICAL PROPERTIES OF SINGLE COMBINATION

4.1.Compressive strength

4 mixtures of metakaolin concrete (MC) mixes, 5 mixtures of bottom ash concrete (BC) mixes and 5 mixtures of steel slag aggregate concrete (SSC) mixes were made by replacing cement, fine aggregate and coarse aggregate with the replacement level of 5%, 10%, 15% and 20% for Metakaolin and for Bottom ash and Steel slag aggregate 10%, 20%, 30%, 40% and 50% by volume. These concrete mixes were named as MC1, MC2, MC3, and MC4, BC1, BC2, BC3, BC4 and BC5, SSC1,SSC2, SSC3, SSC4 and SSC5 respectively

The compressive strength of CC, SC, BC and SSC was determined at 28 days. The average compressive strength of cubes was achieved by CC, SC1, SC2, SC3, and SC4 which was about 34.78MPa, 36.41 MPa, 34.14 MPa, 32.47MPa and 31.96 MPa respectively. When metakaolin was replaced with cement, the strength was significantly greater at 5 % replacement of MC than that of the conventional concrete. The compressive strength of bottom ash concrete was achieved in the range of 35.32 MPa, 33.67 MPa, 32.16MPa, 31.05 MPa and 29.42MPa respectively. When Bottom Ash was replaced with fine aggregate, the strength significantly more increased at 10 % replacement than the conventional concrete. For SSC, the compressive strength was observed in the range of 39.56 MPa, 36.56 MPa, 35.87 MPa, 32.96 MPa and 31.40 MPa. When compared with CC, the enhancement of compressive strength was at the level of 10% replacement. The highest percentage of compressive strength obtained from overall results was 5 % MC, 10 % BC and 10 % SSC.

4.2.Split tensile strength

The tensile strength of MC, BC and SSC was determined at 28 days curing. The cylinders were tested for tensile strength and the average results were obtained.

The tensile strength of cylinders was achieved by MC1, MC2, MC3, and MC4 which was about 3.64 MPa, 3.35 MPa, 3.01 MPa and 2.89 MPa respectively and compared with conventional concrete as 2.77Mpa

All the MC mixes obtained higher tensile strength compared with CC, but the higher value increased in 5 % replacement. The tensile strength of bottom ash concrete was achieved in the range of 3.80 MPa, 3.53 MPa, 3.37 MPa, 2.39 MPa and 2.38 MPa respectively and compared with conventional concrete as 2.77 MPa. When BA was replaced with fine aggregate, the tensile strength significantly more increased at 10 %, 20 % and 30 % than the conventional concrete. For SSAC, the tensile strength was observed in the range of 3.88 MPa, 3.61 MPa, 3.28 MPa, 2.33 MPa and 2.21 MPa and compared with conventional concrete as 2.77 MPa. When compared with CC, the enhancement of tensile strength of SSC was at the level of 10% and 20 % replacement. The highest percentage of tensile strength obtained from overall results was 5 % MC, 10 % BC and 10 % SSC.

4.3. Flexural strength

The highest percentage of flexural strength obtained from overall results was 5 % MC, 10 % BC and 10 % SSC. The results for compressive strength, split tensile strength and flexural strength of MC, BC and SSC are presented in Table .

Sl. No	Code Mix	Compressive strength in MPa	Split tensile strength in MPa	Flexuralstrength in MPa
1	**CC**	**34.78**	**2.77**	**7.11**
2	**MC1**	**36.41**	**3.64**	**9.05**
3	MC2	34.14	3.35	8.62
4	MC3	32.47	3.01	7.11
5	MC4	31.96	2.89	6.68
6	**BC1**	**35.32**	**3.80**	**8.94**
7	BC2	33.67	3.53	8.05
8	BC3	32.16	3.37	6.46
9	BC4	31.05	2.39	6.03
10	BC5	29.42	2.38	5.82
11	**SSC1**	**39.56**	**3.88**	**8.67**
12	SSC2	36.56	3.61	8.48
13	SSC3	35.87	3.28	7.11
14	SSC4	32.96	2.33	6.90
15	SSC5	31.40	2.21	6.25

V. MECHANICAL PROPERTIES OF BINARY AND TERNARY MIXES

With the help of optimum replacement percentage level of MC, BC and SSC, the combination mixes were arrived for finding compressive strength at the age of 28, 56, 90 and 180 days, split tensile strength, modulus of elasticity and flexural strength at the age of 28 days curing. The combination mixes could be classified as binary and ternary mixes.

Binary mixes involved combinations of metakaolin and bottom ash (MKBAC), metakaolin and steel slag aggregate(MKSSAC), bottom ash and steel slag aggregate (BASSAC), and Ternary mixes represents combination of three materials such as metakaolin, bottom ash and steel slag aggregate (MKBASSAC) as HPC. The detail about summary of test plan for binary and ternary mixes for mechanical properties is given in Table.

Sl. No.	Age in day	Compressive strength (MPa)				
		CC	MKBAC	MKSSAC	BASSAC	MKBASSAC
1	28	30.16	31.99	37.59	36.68	28.48
2	56	35.59	38.17	42.16	40.04	34.28
3	90	39.72	43.22	44.60	40.95	38.94
4	180	47.40	62.30	62.79	56.52	51.00

5.1 DURABILITY STUDIES OF HIGH PERFORMANCECONCRETE

The production of high performance concrete involves appropriate selection and proportioning of the constituents of materials. It tends to produce a composite mainly characterised by its low porosity and fine pore structure.

** Acid resistance test was performed to evaluate the resistance of the concrete cubes subjected to acid attack. The acid resistance tests were carried out on 150 mm size cube specimens after the age of 28 days curing. The cube specimens were weighed and then immersed in water diluted sulphuric acid with one percent by weight for 30 days continuously.

Sl. No.	Mix Name	Weightof the cube (kg)		Compressive strength (MPa)		Loss in percentage (%)
		Before	**After**	**Before**	**After**	**Strength loss**
1	CC	8.86	8.12	30.16	28.78	4.57
2	MKBAC	8.52	8.23	31.99	31.13	2.68
3	MKSSAC	8.62	8.61	37.59	36.02	4.17
4	BASSAC	8.59	8.26	36.68	35.53	3.13
5	MKBASSAC	8.84	8.32	28.48	27.81	2.35

All the mass loss values were lower with respect to CC and very low value of mass loss presented in the mix BASSAC which was 2.22 %. The strength loss obtained lower value in the mix MKBASSAC which was 2.35 % due to the presence of all three industrial by-products. Thus, from the test results, it is observed that the MKBAC mix had low percentage of strength loss. The addition of metakaolin, bottom ash and steel slag aggregate significantly improved the acid resistance of the concrete according to the results of mass loss and strength loss when compared to conventional concrete.

5.2 Test Results on Salt Resistance

Sl. No.	Mix Name	Weightof the cube (kg)		Compressive strength (MPa)		Loss in percentage (%)
		Before	After	Before	After	Strength loss
1	CC	8.84	8.12	30.16	28.43	8.88
2	MKBAC	8.80	8.62	31.99	30.08	5.97
3	MKSSAC	8.72	8.43	37.59	35.89	4.52
4	BASSAC	8.62	8.49	36.68	34.93	4.77
5	MKBASSAC	8.92	8.32	28.48	27.12	4.77

from the test results, it was observed that the combination of all mixes was prone to salt attack particularly in the mix BASSAC 1.53%. Which had low mass loss in percentage. Hence, the HPC mixes containing BASSAC exhibited more resistance against salt attack. This was due to the decreased grain size and interconnection of the particles with well compacted. All the mass loss values were lower with respect to CC and very low value of mass loss presented in the mix BASSAC which was 1 %. Hence, the HPC mixes MKSSAC exhibited more resistance 3.38 % obtained against salt attack in mass loss in terms of percentage. The compressive strength of CC, MKBAC, MKSSAC, BASSAC and MKBASSAC was measured before and after immersion.
Thus, from the test results, it was observed that the combination of MKBAC mix had higher value of 5.97 % of strength loss and the results of mass loss and strength loss when compared with conventional concrete.
The results indicated that the mix of MKSSAC, BASSAC and MKBASSAC had moderate percentage of compressive strength for the mixes and reduced rate of deterioration subjected to salt attack.

5.3Test Results on Sulphate Resistance

MKBAC, MKSSAC, and BASSAC and MKBASSAC varied from 2.16 % to 3.70 % with respect to CC. Thus, from the test results, it was observed that the combination of all mixes was prone to sulphate attack particularly MKSSAC mix had lower percentage of 2.16 % in mass loss in percentage. Hence, the HPC mixes containing MKSSAC mix exhibited more resistance against sulphate attack

Sl. No.	Mix Name	Weightof the cube (kg)		Compressive strength (MPa)		Loss in percentage (%)
		Before	After	Before	After	Strength loss
1	CC	8.31	8.267	30.16	28.38	5.90
2	MKBAC	8.58	8.265	31.99	30.78	3.78
3	MKSSAC	8.51	8.329	37.59	36.09	3.99
4	BASSAC	8.84	8.629	36.68	35.19	4.06
5	MKBASSAC	8.41	8.128	28.48	27.14	4.70

The results indicated that the mix of MKBASSAC and BASSAC had moderate percentage compressive strength and reduced rate of deterioration of the concrete subjected to sulphate attack. Sulphate combine with soluble calcium hydroxide generated from the hydration of Portland cement to form calcium sulphate or gypsum. The volume of the resulting gypsum is greater than the sum of its components, causing internal pressures which fracture the concrete. The strength loss obtained lower value in the mix MKBAC which was 3.78 %. Thus, from the test results, it was observed that the combination of MKBAC mix had low percentage of strength loss and the results of mass loss and strength loss when compared with conventional concrete.

VI. CONCLUSIONS:

The use of industrial by-products is becoming more popular for producing high performance concrete. Metakaolin, bottom ash and steel slag aggregate are introduced to enhance the overall performance of concrete. This research study represents a method of using industrial by-products for producing concrete. The physical properties of specific gravity and chemical properties of all combinations are studied. The results of experimental and analytical investigations to examine the effective performance of these concretes strength are reported and discussed. It includes compressive strength, split tensile strength of cubes and cylinders, and flexural strength of prisms for all the specimens.

1. Concrete with 5 % metakaolin replacement of cement had higher compressive strength on an average of 36.42 MPa at 28 curing days which was almost 4.46% higher Wrt CC.
2. Similarly, concrete with 10 % steel slag aggregate replacement of coarse aggregate obtained higher compressive strength value on an average of 39.55MPa at 28 curing days which was almost 12.02 % with respect to CC.
3. For MC, it was observed that the there was maximum increase in the tensile strength and flexural strength of nearly 23.9 % and 21.43 % respectively. It was also understood that the split tensile strength increases in 5% Metakaolin content and beyond that the strength decreases. For BC, there was a maximum increase in tensile strength and flexural strength of nearly 27.10 % and 20.46 % with respect to CC. For SSC, it was observed that the maximum increase was in tensile strength and flexural strength of nearly 28.6 % and 17.99% with respect to CC.
4. The compressive strength of CC, MKBA, MKSSA, BASSA and MKBASSA was measured before and after immersion. The HPC mixes are found to have an excellent acid resistance in 1 % sulphuric acid solution. For acid resistance test for all mixes, it was observed that the superior performance towards mass loss in MKSSAC mix was 2.75 % and strength loss was also very less in MKBASSAC mix which was 5.53 % with respect to CC. For salt resistance test for all mixes, it was observed that the superior performance towards mass loss in BASSAC mix was 4.30 % and strength loss was also very less in mix which was 8.60 % with respect to CC.
5. The concrete BASSAC was found to have an excellent sulphate resistance in 5% sodium sulphate solution and it was the best of other types of concrete because the mass loss was 1.63 % and the strength loss in MKBAC mix was 5.58 % with respect to CC.
6. Compared with all the specimens, the MKSSA yielded better results in all aspects in the concrete.
7. For binary and ternary mixes, the optimum replacement percentage level was found from single combination results..

REFERENCES

[1] Abul, K. Azad, and Ibrahim, Y. Hakeem., (2013), Flexural behaviour of hybrid concrete beams reinforced with ultra-high performance concrete bars, *Construction and Building Materials*, Vol.49, pp.128-133

[2] Adriana Trocoli Abdon Danta, Monica Batista Leite, and Koji de Jesus Nagahama., (2013), Prediction of compressive strength of concrete containing construction and demolition waste using artificial neural network, *Construction and Building Materials*, Vol. 38, pp.717

[3] Aggarwal, P., Aggarwal, Y., and Gupta, S.M., (2007), Effect of Bottom ash as replacement of Fine aggregates in concrete, *Asian Journal of Civil Engineering (Building and Housing)*, Vol.08, No. 01, pp.49-62

[4] Agarwal, V., and Sharma, A., (2010), Prediction of slump in concrete using Artificial Neural Networks, World Academy Science, *Engineering and Technology*, Vol.04, No. 09, pp.279-286

[5] Bharatkumar, B.H., Narayanan, R., Raghuprasad, B.K., and Ramachandramurthy, D.S., (2001), Mix proportioning of high performance concrete, *Cement and Concrete Composites*, Vol.23, pp.71-80

[6] Chore, H.S., and Joshi, M.P., (2015), Multiple regression models for prediction of compressive strength of concrete comprising industrial waste products, *The Indian Concrete Journal*, Vol.89, Issue 09, pp.33-46

[7] Indian Standard – *Specification for 43 grade Ordinary Portland cement to* IS 8112- 2013, Bureau of Indian Standards, New Delhi, 2013-722X. Y. Jing, F. Wu, Z. Li, R. Hu and D. Zhang,