

EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN AND FINE AGGREGATE WITH M-SAND AND WASTE FOUNDRY SAND

Vaibhav K Vidyapati¹, Sharath Babu Khedagi²

¹Post Graduate Student ,Dept. of Civil Engineering, East Point College of Engineering and Technology, Bengaluru,Karnataka,India

²Assistant Professor, Dept. of Civil Engineering, East Point College of Engineering and Technology, Bengaluru, Karnataka, India

Abstract - Nowadays, due to rapid urbanization, the construction industry is booming, Concrete is one of the main materials used in the construction field, due to the more demand for cement and natural sand, but these material have a more cause to environmental problems .higher carbon dioxide emissions by cement production and natural sand also scarcity in river beds cause natural degradation in environment. so using alternative for these materials are necessary, in this current study ,the use of metakaolin ,manufacture sand and waste foundry sand replacement is essential in this present situation . Metakaolin is a more reactive type of pozzolanic material produced from kaolin clay, which contributes positively to the strength and durability of concrete. M-sand is a good alternative to natural river sand and is considered an eco-friendly material. The waste foundry sand can be used as a partial replacement of fine aggregate in this current investigation, finding an optimum replacement level by partial replacement of cement with metakaolin at different percentages (0%,5%,10%,15%, and 20%) with 80% M-sand and 20% foundry sand for replacement levels. From the optimum level, fixed metakaolin changed the M-sand and foundry sand ratio (85%/15% and 75%/25 %). In this study, the utilization of combined materials is necessary to reduce environmental problems and encourage sustainable development. To observe the strength performance by testing the compressive strength of M30 grade of concrete at 7 days and 28 days and workability tests are conducted.

Key Words: Metakaolin, M- sand, Waste foundry sand, Concrete, Partial replacement, Workability, Compressive strength.

1. INTRODUCTION

In the construction sector, basic material is concrete and plays the best role in civil infrastructure at present, due to the rapid growth of population and urbanization, so much infrastructure is increasing. The necessity of concrete and natural sand in construction is increasing, but the production of cement contributes about 8 percent of CO₂ emissions worldwide. This dangerous greenhouse gas has led to environmental problems. Further using more of this material

will seriously face problems in the upcoming days and cause harm to the ecosystem.

Similarly , continuous usage of river sand so much scarcity nowadays as natural sand has become very rare, and the price has also increased. Removal of sand from riverbeds leads to environmental degradation, groundwater issues, and creates environmental problems, so the utilization of alternative materials must be necessary at present to slow down these problems. So, utilization of industrial waste by-products and materials in concrete can lower the impact on the environment and performance.

Significance of this current study involves utilization of these combined materials like Metakaolin as a partial replacement for cement, M-sand, and foundry sand used as fine aggregate rather than the use of river sand, which promotes eco-friendly construction. So in this current study the main objectives are to :

1. To determine best optimal replacement levels using metakaolin and M-Sand with waste foundry sand .
2. To evaluate and compare strength results to usual conventional concrete and other replacement percentage mixes.
3. To examine waste from industry like waste foundry sand and M- sand along with metakaolin enhance concrete strength and promote sustain ability .
4. To evaluate slump and compression test at 7 and 28 days.

2. LITERATURE REVIEW

Deshmukh & Choudhary [1] in this study presents investigate finding the best percentage metakaolin and m-sand so result compressive test & flexural strength at 70 % m-sand and 15% metakaolin replacement . studied the strength performance by using sustainable M- sand replacement of river sand, Quality parameter .

Agilandeswari, Ravichandran & Saravanan [2] In this present paper study strength investigate find the optimum replacement level in (0%,5%,10%,15%) Investigated mechanical parameters (compressive, split tensile, flexural) of

concrete with metakaolin and M-sand, non-destructive test on cubes and acid resistance are performed and 10% metakaolin as optimum was found and study concludes improve strength.

Rao Yella Manda, Mahesh2, Ayinala, Kesava Rao, Naga Venkat [3] Author Investigated the performance using metakaolin and m-sand. Study explores optimum replacement level metakaolin at 0,5,10,15,20 % with cement and m-sand is 50%, M30 grade and test was carried out like compressive strength, tensile and non-destructive tests and find 15% metakaolin and 50 % m-sand optimum.

R. Rajkumar, Lakshman Prasath, Sharon [4] Investigation was conducted using metakaolin, demolition waste and foundry sand this study involves compression, split, and flexural done for seven and twenty-eight days. ratios of 5,10,15,20,25 percentage replacement and grade of M20 and found 15 % of metakaolin and 30% demolition waste and 30% waste foundry sand as optimum.

Mahendra, Abhiram & raj Kumar, harish [5] find the optimum replacement level in (0,5,10, and 15%) Investigated mechanical parameters (compressive, split tensile, flexural) of concrete with metakaolin and M-sand 15% replacement of metakaolin is optimum, non-destructive tests on cubes are conducted. M40 and M30 grade.

Sangeetha & Rishisha [6] both author investigate using metakaolin and m-sand find out a best replacement level, so replaced with 5–30% Metakaolin & fully replaced by M-Sand and at the final got the maximum compressive strength and flexural and tensile 15 per metakaolin optimum at twenty-eight and fifty-six days for M30 grade.

Hemanth Rama Raju, Sravani Ramya [7] In this paper both are study to find best optimum with replacement of metakaolin percentage level 0,5,10,15, and 20% and 20,30,40,50,75 and 100 percentage of replacement of robo sand done by grade of concrete is M35 and compressive, flexural and split, found 15 percent metakaolin and 50 percent robo sand as optimum.

Akhil, Praveen, Bhagavathi [8] During this study only the metakaolin performance in concrete is carried out with different replacement % of metakaolin (0,7.5,10,12.5,15,17.5 %) in this investigation 10 % metakaolin was founded as optimum at seven & twenty-eight days of compressive and other mechanical properties test.

Jyothi & Chaitanya [9] During this current study author replacement of metakaolin at 0,10,15,20,25,30 percentage and for M70 grade check for how much durable cubes by different chemicals of HCL and H₂SO₄ 0.5 and 1 percent and mechanical tests strength cubes, prisms and cylinders. study concludes with 15 percent is best percentage replacement. Satyendra, Rajiv & Yadav [10] Author studied the optimum percentage to verified by different percent by (0,5,10,15,20 %

) of M25 grade only strength check test by compression at twenty-eight days and concludes that 10 % is optimum.

3. MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Ordinary Portland Cement (OPC)

The Dalmia OPC 53 grade cement was used in this study, conforming to IS 269. It was selected because of its high strength and application in construction works. The cement chosen was fresh, lump-free, and well protected from moisture by storing it in a dry place. After testing the specific gravity is observed as 3.15.

3.1.2 Metakaolin

The metakaolin was sourced from Herenba Instruments & Engineers, Chennai. The material is (research grade 1) metakaolin, having pure milk white colour. Created by calcining kaolin clay, it helps improve more strength and decreases permeability, and specific gravity found to be 2.6.

3.1.3 M- Sand (Manufacture Sand)

The M-sand crushed form of hard rocks in small particles. These are regarded as environmentally friendly compared to river sand, and they serve as an alternative to river sand for use in concrete works. In this current study zone II m-sand is utilized as fine aggregate replacement no use of natural sand.

3.1.4 Waste Foundry Sand

Waste Foundry sand is brought from the Geetha metal casting industry. It has fine particles, make moulds for casting metal, use quality silica sand and later its disposal waste. It is used in construction industry as substitute, and promotes environmentally friendly construction.

3.1.5 Coarse Aggregate

In this current study the aggregate of crushed coarse sizes of 20 mm and 12.5 mm are used in concrete mixes. It was tough, durable and with no impurity, clean and well graded for better strength to concrete.

3.1.6 Superplasticizer

In this current study Robusto chemicals (HRWRA) superplasticizer was PEC (Polycarboxylate Ether) based employed to enhance workability and decrease usage of H₂O in concrete and make easy mixing of concrete.

3.1.7 Water

Water was clean, free from harsh contamination, and it was used to prepare and cure the concrete samples. Water is an essential component of the cement hydration process and achieve to strength gain.

3.2 Mix Design

The M30 grade of concrete mix design was made following IS 10262:2019 and IS 456:2000. For control mix proportion is 1:1.92:3.35 (cement :fine aggregate :coarse aggregate) and water /cement ratio 0.45 was constant for all mixes .in this investigation of partial replacement of cement with metakaolin at (5,10,15 and 20 %) and fine aggregate with M-sand 80 % and 20 % waste foundry sand all replacement mixes was prepared and increasing admixture dosage (0.55 ,0.6,0.65,0.75,0.8 %) weight by cement to maintain workability for (0,5,10,15,20%) mixes with fixed w/c ratio. After finding optimum metakaolin percentage mix ,fixed percentage of metakaolin with varying sand ratio of (85% and 15%) and (75% and 25%) of M-sand and waste foundry sand mix proportion was made.

Table - 1 : All mixes mix proportion

Materials	M0	M1 5%	M2 10%	M3 15%	M4 20%
Cement (kg/m ³)	360	342	324	306	288
Metakaolin (kg/m ³)	-----	18	36	54	72
M- sand (kg/m ³)	691.5	552	551.2	550.2	549.4
Waste foundry sand (kg/m ³)	-----	128.6	128.4	128.1	127.9
20 mm (kg/m ³)	725.11	723.8	722.5	721.4	720.1
12.5 mm (K g / m ³)	479.82	479	478.1	477.4	476.5
Water (L/ m ³)	162	162	162	162	162
Admixture (kg/m ³)	1.98	2.16	2.34	2.7	2.88

Table -2 : 15% Metakaolin optimum with varying sand ratio % mixes

Materials	M3-A 85 % M-Sand /15 % foundry sand	M3-B 75% M-Sand /25% foundry sand
M- sand (kg/m ³)	580.55	512.25
waste foundry sand (kg/m ³)	102.45	170.75
Admixture dosage (kg/m ³)	2.7	2.7

3.3 Methodology

3.3.1 Material Collection

Firstly , in this current study material like Dalmia cement OPC (53 grade) was collected and similarly other materials such as M- sand ,coarse aggregate of 20mm size and 12.5 mm size are taken and casting sand was brought from the Geetha metal casting industry. that is sieved by 4.75 mm remove unwanted things and metakaolin is purchased from Herenba Instruments & Engineers, Chennai. Very superior quality pure white and research grade 1 and admixture Robusto chemicals, finally water. Fine aggerate and coarse aggerate are clean, tough and free from impurities and best quality were collected.

3.3.2 Testing of Materials

After collecting materials, the testing of all materials finding properties , specific gravity ,sieve analysis and silt content, moisture content as per IS standard procedure was done.

3.3.3 Mix Design Preparation

From the values found from testing of material are added in mix design as per IS 10262:2019 code are calculated mix proportion .

3.3.4 Batching and Mixing of Materials

As per mix proportion each materials were batched correctly using weighing balance and all materials are put near the pan mixer first pan mixer is properly cleaned no left concrete stick to inside blades and put water inside first and rotate the mixer all old concrete are removed after that complete dry of mixer then first cement, metakaolin and fine aggregate like

m- sand and foundry sand ,20 mm and 12.5 mm coarse aggregate is placed inside the pan mixer and start the machine.

First proper mixing of dry materials until coarse aggregate and fine aggregate cement ,metakaolin and uniformly mixed later slowly add water inside mixer and again start mixing the blade that help to mix the material uniformly ,slowly added the robusto chemicals superplasticizer as per different mixes as mix plan is 0% control mix ,5,10,15 and20 percent metakaolin replacement with cement and fine aggregate M-sand 80 percent and 20 percent waste foundry sand for replacement mixes and water is kept constant 0.45 only admixture dosage is increased to 0.55,0.6,0.65,0.75,0.8 and from after finding optimum level from that again two new mixes sand ratio changed to 15 percent foundry and 85 percent M-sand and another 25 percent foundry sand and with 75 percent M- sand mixes, slump test carried out done accurately in this current study.

3.3.5 Casting

After the uniform proper mix the cubes size of 150 mm x150 mmx150 mm was used The internal surface of the cube mould was cleaned first and greased to ensure that the concrete did not attach to the mould and easy remove of cubes then mix concrete is placed into the mould in three layer, one layer by using tamping rod 35 times compacted for each layer properly and fill up to tip of the cube air pockets were removed. Later after few minutes the top of surface is properly leveled and finish nicely.

3.3.6 Curing

After casting cubes next day by using spanner lose the bolt and nut of mould carefully and then slowly remove cube from the mould and put the cube in separate water tank at 7 days and 28 days.

3.3.7 Testing and Result

Testing of cubes at 7 and 28 days by using digital compressive strength test machine to check strength performance of cubes was carried out placing the cube and noted down results.

4. RESULTS AND DISCUSSION

4.1 Workability Test Results

After mixing process the fresh concrete was slowly placed inside slump cone done for all mixes. First quality ,cleaned slump cone is put on the flat surface before casting process after mixing finished by using equipment concrete is poured in cone three equal section each section 25 time compacted by tamping the concrete mix with tamping rod and finally top surface leveled and slowly removed vertically slump cone ,slump test is done see the each value for different mixes

,Metakaolin ,M- sand ,and foundry sand and how it was performed come to know at different replacement of metakaolin slight reduction in workability as metakaolin percentage increases but by using admixture dosage target slump was 100 to 110 mm is maintained.

Table -3: Slump cone test observations

Sl. No	Replacement (%) metakaolin ,M-sand and waste foundry sand	Admixture dosage (%)	Slump value (mm)	Slump type
1	M0 +100 %	0.55	110	True
2	M1 (5%) +80/20	0.6	108	True
3	M2 (10%)+80/20	0.65	105	True
4	M3 (15%)+80/20	0.75	103	True
5	M4 (20%) +80/20	0.8	101	True

Table -4 : 15 % metakaolin optimum with varying sand % slump cone test observations

Sl. No	Replacement (%) metakaolin ,M-Sand and waste foundry sand	Admixture dosage (%)	Slump values (mm)	Slump type
1	M3-A (15 %) +85/15	0.75	106	True
2	M3 -B (15%) +75/25	0.75	98	True



Fig -1: Slump sample

4.2 Compression Strength Test Results

The compression test was conducted to find out strength performance and how much strength was gained for all different mixes, 150 mm x 150 mm cube size with different replacement levels at seven and twenty-eight days. All cubes are put in controlled water tank and before testing take out from tank and air dried before testing and placed under digital compression test machine. From strength values finding out best optimum percentage mix and comparing strength to control mix.



Fig -2 : Cube testing

Table -5 : Compression test values for 7 days

Sl.No	Mix ID	Metakaolin (%)	M-sand (%)	Foundry sand (%)	7 days strength (N/mm ²)
1	M0	0	100	0	21.62
2	M1	5	80	20	22.84
3	M2	10	80	20	24.55
4	M3	15	80	20	25.92
5	M4	20	80	20	25.11

Chart-1: 7 days compressive strength for varying metakaolin %

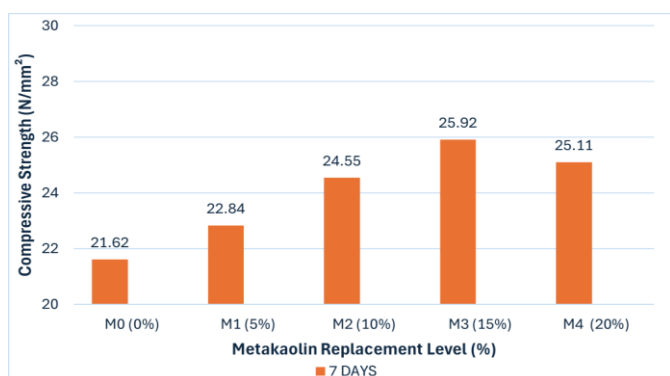


Table -6 : Compression test values for 28 days

Sl.No	Mix ID	Metakaolin (%)	M-sand (%)	Foundry sand (%)	28 days strength (N/mm ²)
1	M0	0	100	0	33.22
2	M1	5	80	20	35.04
3	M2	10	80	20	38.08
4	M3	15	80	20	40.47
5	M4	20	80	20	38.94

Chart-2 : 28 days of compressive strength for varying metakaolin %

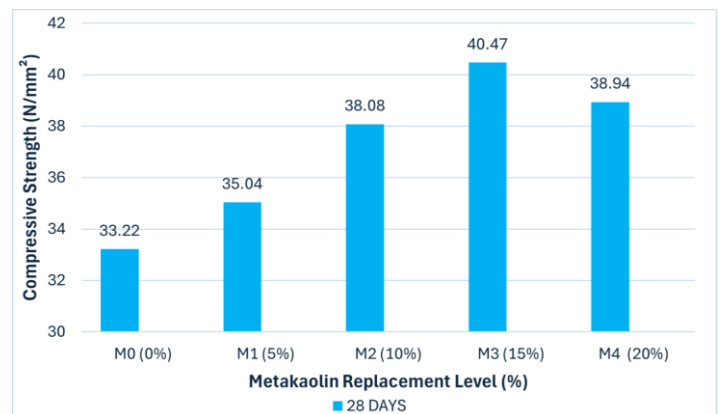


Table -7: Compressive strength observation for 7 and 28 days

Sl. No.	Mix ID	Metakaolin (%)	M-sand (%)	Foundry sand (%)	Compressive strength (N/mm ²)	
					7 days	28 days
1	M0	0	100	0	21.62	33.22
2	M1	5	80	20	22.84	35.04
3	M2	10	80	20	24.55	38.08
4	M3	15	80	20	25.92	40.47
5	M4	20	80	20	25.11	38.94

Chart-3 : 7 and 28-days of compressive strength for varying metakaolin %

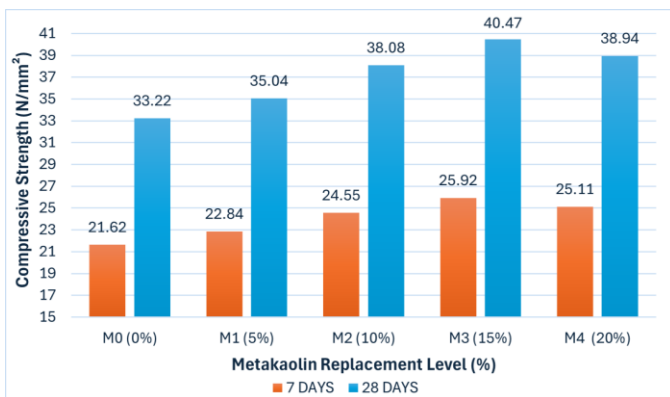
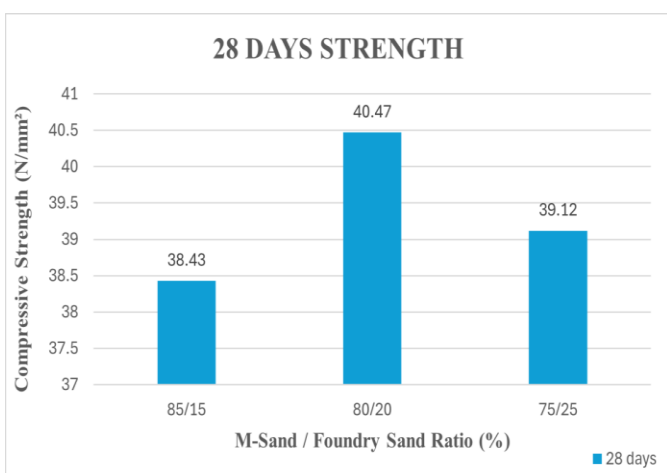


Table -8 : 15 % metakaolin optimum with varying sand % at 28 days strength values

SI. No.	Mix ID	Metakaolin (%)	M-sand (%)	Foundry sand (%)	28 days strength N/mm ²
1	M3 -A	15	85	15	38.43
2	M3	15	80	20	40.47
3	M3-B	15	75	25	39.12

Chart-4: 28 days strength of varying m-sand /foundry sand %



4.3 DISCUSSION

The conventional concrete mix recorded compressive strengths of 21.62 N/mm² and 33.22 N/mm² after 7 and 28

days, so improvement of strength due to increasing metakaolin. replacement mix with a combination of 15% metakaolin and 80/20 M-sand with foundry waste sand found out maximum compressive strength of 25.92 N/mm² at 7 days and 40.47 N/mm² at twenty- eight days. After finding 15% optimum from fixed metakaolin varying fine aggregate sand ratio replacement 85%/15% and 75%/25% of M- sand and waste foundry sand for 28 days strength ,in this varying sand ratio % also 15% metakaolin and 80/20 % M-sand and foundry sand mix is optimum. Beyond 15% strength goes slightly decreases as metakaolin percentage increased further move led to less strength and beat the normal mix.

5. CONCLUSION

a) The best compressive strength of optimum mix with 15% metakaolin content using a blend of 80/20 % M-sand and waste foundry sand for 28 days found out as 40.47 N/mm².

b) The 15% metakaolin and 80% M-sand and 20 % waste foundry sand combination give more strength as 40.47 N/mm² compared to conventional concrete 33.22 N/mm² and different sand ratio replacement mixes.

c) From compression test values mixing of metakaolin ,M-sand and waste foundry sand strength performance is enhanced.

d) Beyond 15 percent of metakaolin and 20 % foundry sand led to a fall in compressive strength.

e) As metakaolin percentage increases slightly decreasing in workability but it can be maintained by (PCE) based Superplasticizer.

f) study promote to eco-friendly construction from waste material and reduces cement use in construction field.

REFERENCES

- [1] Deshmukh & Choudhary (2025),“ Comparative analysis of concrete strength and quality using M-sand and metakaolin as sustainable replacements,” International Journal of Progressive Research in Engineering Management and Science (IJPREMS) , Vol.05, Issue 12, pp : 339-343.
- [2] Agilandeswari, Ravichandran & Saravanan (2022) ,“Strength assessment of concrete made with metakaolin and M-Sand,” International Journal of Engineering Research & Technology (IJERT), Vol.10 ,Issue 06.
- [3] Rao Yella Manda, Mahesh, Ayinala, Kesava Rao, Naga Venkat (2021), “Study on mechanical properties of concrete by fractional replacement of cement with Metakaolin and Sand with M-Sand by Using M30 grade” ,

- Turkish Journal of Computer and Mathematics Education (TURCOMAT), Vol.12, No.2.
- [4] R.Rajkumar, Lakshman Prasath, Sharon (2019), "Experimental investigation on the strength characteristics of concrete made with metakaolin, foundry sand and demolition waste," International Journal of Civil Engineering and Technology (IJCIET) Volume 10, Issue 03.
- [5] Mahendra, Abhiram & raj Kumar, harish (2018), "Partial replacement of cement and fine aggregate with metakaolin and manufacture sand," International Journal of Civil Engineering and Technology (IJCIET) Volume 9, Issue 5.
- [6] Sangeetha & Rishisha (2018), "Study of concrete strength parameters using metakaolin as a partial replacement of cement and M- Sand as fine Aggregate," International Journal of Engineering & Technology, (IJET), 7 (2.33).
- [7] Hemanth Rama Raju, Sravani Ramya Singam (2017), "An experimental investigation on partial replacement of cement with metakaolin and fine aggregate with Robo sand," International Research Journal of Engineering and Technology (IRJET), e-ISSN: 2395 - 0056 ,Volume 04, Issue 04.
- [8] Akhil, Praveen, Bhagavathi (2016), "An experimental investigation on the characteristics of metakaolin in concrete," International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Volume 4, Issue 08.
- [9] Jyothi & Chaitanya (2015), "Partial replacement of cement with metakaolin in high strength concrete," International journal of engineering research and science and technology (IJERST), ISSN 2319-5991, Vol. 4, No. 4.
- [10] Satyendra, Rajiv & Yadav (2015), "Experimental study of concrete with metakaolin as partial replacement of OPC," International Journal of Advanced Engineering Research and Science (IJAERS), Vol-2, Issue-6, ISSN: 2349-6495.
- [11] Amritpal Kaur & Rajwinder (2015), "Strength and durability properties of concrete with partial replacement of cement with metakaolin and marble dust," International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 4 Issue 07.
- [12] Nova John (2013), "Strength properties of metakaolin admixed concrete," International Journal of Scientific and Research Publications (IJSRP), ISSN 2250-3153, Volume 3, Issue 6.
- [13] Dinakar & Pradosh, Sahoo, Sriram (2013) - "Effect of metakaolin content on the properties of high strength concrete," International Journal of Concrete Structures and Materials (IJCSM), Vol.7, No.3, pp.215-223, ISSN 1976-0485.
- [14] B.B Patil & P. D. Kumbhar (2012), " Strength and durability properties of high-performance concrete incorporating high reactivity metakaolin," International Journal of Modern Engineering Research (IJMER) ,Vol.2, Issue.3, pp-1099-1104, ISSN: 2249-6645.
- [15] Beulah M , Prahallada (2012) , "Effect of replacement of cement by metakaolin on the properties of high-performance concrete subjected to hydrochloric acid attack," International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 6.