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# EXPERIMENTAL STUDY ON PERVIOUS PAVEMENT USING PERVIOUS CONCRETE WITH FLY ASH AND METAKAOLIN

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***Abstract:*** *Civilization is the part of human life, and technology which is advancing rapidly from centuries. Many efforts are made so far in developing of new construction materials. In the construction industry, concrete technology is plays a vital role. The usage of supplementary cementitious materials, such as Silica fume, Fly ash, Metakaolin, Hypo sludge, Rice husk ash etc. in concrete is a new innovative usage in the technology. The increasing amount of waste is a concerning reality that has across the sustainability issues of the environment. "The production of cement also reasons for the global warming by releasing $CO_2$ in the environment. Therefore, formulation of concrete with different type of industrial waste can help in minimizing the environmental problems. The utilization of pozzolanic materials like fly ash (FA) and metakaolin (MK) in concrete is growing in construction industry all around the world to reduce the $CO_2$. release into the environment and reduce energy consumption. By using this industrial waste it can be possible to reduce the cost of the materials and we can get low cost pervious concrete (LCPC) with high strength compare to traditional pervious concrete. In this study low cost pervious pavement using pervious concrete cast with supplementary cementitious materials (SCM) fly ash (FA) and metakaolin (MK). The cement has been partially replaced by fly ash and metakaolin accordingly in range of 0%, 5%, 10%, 15% and 20% by weight of cement for 0.35 water/cement ratio. Also cement has been partially replaced by combination of metakaolin and fly ash (MK: FA) in various three proportions accordingly in range of 5:15, 10:10, and 15:5 by weight of cement. For all mix water/cement ratio is 0.35. The Infiltration rate test, density and compression test were carried out. After experiment concluded that combination of metakaolin and fly ash give good compressive strength with cost effectiveness.*

***Key words*** - Low cost pervious concrete (LCPC), High strength pervious concrete (HSPC), Supplementary cementations materials (SCM), Metakaolin (MK), Fly ash (FA), Cement (OPC 53 Grade), Fine Aggregate and coarse Aggregate.

## I. INTRODUCTION

Pervious concrete is the special type of high porosity concrete which is used for flatwork applications which allows water from precipitation and other sources to passing through, so it reducing the runoff from a site and recharging ground water levels. As cement industry is one of the most polluted industry, so for reducing the pollution and cost of concrete cement may be fully or partially replaced by waste materials like fly ash, metakaolin, rice husk ash, ceramic powder, furnace slag, silica fume etc. The key ingredient in the pervious concrete mix is cement, which helps in binding and achieving strength. Cement production is major responsible for the greenhouse gases emitted in the environment. So an alternative for reducing cement usage in concrete makes concrete eco-friendly. Thus there comes an idea of partially replacing cement with supplementary cementations materials, (SCM). Material which used as partial replacement of cement must possess cementitious properties, and the effect of it on the environment should be minimal. In this research, cement is partially replaced with metakaolin (MK) and fly ash (FA) to improve the mechanical properties of pervious concrete. Metakaolin mainly used for improving strength of pervious concrete. So, main aim of this research is to use supplementary cementations materials (SCM) to develop a high strength pervious concrete (HSPC) with less cost so called as a low cost pervious concrete (LCPC).

## II. EXPERIMENTAL MATERIALS

The materials used during the present research are Cement, Fine aggregate, Coarse aggregate, Metakaolin, Fly ash and Water.

### (i). Metakaolin

Metakaolin is the anhydrous calcined form of the clay mineral kaolinite. It was mainly used for

replacement of cement as supplementary cementations materials, (SCM) for providing high strength. It has pozzolanic properties. It is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800ºC. The quality and reactivity of metakaolin is strongly dependent of the characteristics of the raw material used. Metakaolin can be produced from a variety of primary and secondary sources containing kaolinite like high purity kaolin deposits, kaolinite deposits or tropical soils of lower purity, paper sludge waste and oil sand tailings. Physical properties of metakaolin are given below and chemical properties of metakaolin as per Table 2. Figure 1 shows the metakaolin.

Physical properties of Metakaolin

| | |
|---|---|
| Physical form- | Powder |
| Color- | white/grey |
| Specific gravity- | 2.50 |

Figure 1. Metakaolin

**(ii). Fly ash**

Fly ash conforming to IS: 3812-2003 is been used. Fly ash used in this research is Class-C fly ash. Fly ash is a fine powder which is the byproduct of burning pulverized coal in electric generation power plants. Fly ash is a pozzolanic, a substance containing siliceous and aluminous materials which forms cement in the presence of water. When it mixed with lime and water, fly ash forms a compound similar to Portland cement. This makes fly ash suitable as a prime material in blended cement, mosaic tiles, and hollow blocks, among other building materials. When used in concrete mixes, fly ash improves the strength and segregation of the concrete and makes it easier to pump. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Nowadays Fly ash usage in cement, concrete and other cement based applications was high in India. Physical properties of fly ash are given below and chemical properties of fly ash as per Table 2. Figure 2 shows the fly ash which was collected from NTPC Tanda, Uttar Pradesh.

Physical properties of Fly ash

| | |
|---|---|
| Specific Gravity | 2.20 |
| Bulk density | 1540 Kg/m$^3$ |
| Porosity | 20.80% |
| Water absorption | 7.60% |

Figure 2. Fly ash

**(iii). Cement**

The OPC 53 Grade cement conforming to IS:12269-1987 was used for all pervious concrete mixes. Cement is a fine, greenish grey powder. Cement is mixed with water, sand, aggregate to make pervious concrete. In this research cement is replace by industrial waste up to 20% by weight. Physical and chemical properties of cement as per Table 1 and Table 2. Figure 3 shows the cement which was collected from local market, Lucknow, Uttar Pradesh.

Figure 3. Cement

Table 1 Physical properties of Cement

| Property | Value for Cement | IS:12269:1987 |
|---|---|---|
| Specific Gravity | 3.15 | 3.10 to 3.15 |
| Initial setting time | 35 minute | 30 minimum minutes |
| Final setting time | 178 minute | 600 maximum minutes |

Table 2. Chemical properties of Cement, Metakaolin and Fly ash

| Sr. No. | Particulars | Cement | Metakaolin | Fly ash |
|---|---|---|---|---|
| 1 | Silicon dioxide ($SiO_2$) | 22.9% | 47.55% | 2.54% |
| 2 | Aluminum oxide ($Al_2O_3$) | 4.29% | 35.58% | 1.76% |
| 3 | Iron oxide ($Fe_2O_3$) | 2.80% | 0.11% | 0.40% |
| 4 | Titanium dioxide ($TiO_2$) | - | 0.35% | - |
| 5 | Calcium Oxide (CaO) | 63.20% | 0.52% | 50.10% |
| 6 | Magnesium Oxide (MgO) | 1.92% | 0.40% | 1.25% |
| 7 | Sodium Oxide ($Na_2O$) | 0.7% | 0.28% | 0.11% |
| 8 | Potassium Oxide ($K_2O$) | 0.5% | 0.10% | 2.32% |
| 9 | Sulfur trioxide ($SO_3$) | 0.35% | - | 0.65 mg/ 100 gm |
| 10 | Loss on Ignition | 1.70% | 15.01% | 41.42% |

**(iv). Fine aggregate**

Generally, the sand was used as a fine aggregate in concrete. Sand is the naturally available materials which are composed of finely divided rocks and minerals particles. The aggregate which is passing through 4.75 mm IS sieves are known as fine aggregates. The natural river sand of well graded and passing through 4.75 mm sieve as per IS 383:1970 are used for pervious concrete. Physical properties of Fine aggregate as per Table 5 and Figure 4 shows the fine aggregate which was collected from locally available, Lucknow, Uttar Pradesh.

Physical properties of Fine aggregate

| Property | Values |
|---|---|
| Source | Lucknow Uttar Pradesh |
| Specific Gravity | 2.66 |
| Fineness modulus | 3.16 |

Figure 4. Fine aggregate

**(v). Coarse aggregate**

Coarse aggregate size10-20mm as per IS 383:1970 are used for pervious concrete. Aggregate reserve most of volume of the concrete show they are important constituents of pervious concrete. Aggregate give body to concrete, reduce shrinkage and effect economy. Physical properties of coarse aggregate as per given below and Figure 5 shows the coarse aggregate which was collected from locally available, Lucknow, Uttar Pradesh.

Physical properties of coarse aggregate

| **Property** | **Values** |
|---|---|
| Specific Gravity | 2.81 |
| Fineness modulus | 6.94 |

Figure 5. Coarse aggregate

**(f). Water**

Ordinary drinking water available locally was used for casting and curing of all specimen of this research. Water is an important ingredient of pervious concrete which is actually participates in the chemical reaction with cement

## III. DESIGN MIX

The mix proportion of pervious concrete is not same as conventional concrete. There is no codal provision for preparation for mix design. The mix proportion is based on the literature review and guideline given by National ready-mix concrete association (NRMCA). **[11]**

Water/Cement ratio is 0.35 for all mix proportion. Metakaolin added in proportion of 20% of total weight of cement content. And also fly was added in proportion of 20% of total weight of cement content. Finally combination of Metakaolin: Fly ash (MK: FA) were added in proportion of 20% of total weight of cement content. The mix proportion of normal pervious concrete as per National ready-mix concrete association (NRMCA) shows in Table 3. The mix proportion of pervious concrete with 1) metakaolin, 2) fly ash, and 3) MK: FA accordingly shows in Table 4, Table 5 and Table 6.

Table 3 Mix proportion of pervious concrete as per (NRMCA)

| **Pervious Concrete Mixes** | **Cement ($Kg/m^3$)** | **Fine Aggregate ($Kg/m^3$)** | **Coarse Aggregate (10-20 mm) ($Kg/m^3$)** | **W/C ratio** |
|---|---|---|---|---|
| Normal (NC) | 369.6 | 297.73 | 1617 | 0.35 |

Table 4 Mix proportion with Metakaolin (MK)

| Pervious Concrete Mixes | Cement ($Kg/m^3$) | Cement replaced by Metakaolin (%) | Metakaolin ($Kg/m^3$) | Fine Aggregate ($Kg/m^3$) | Coarse Aggregate (10-20 mm) ($Kg/m^3$) | W/C ratio |
|---|---|---|---|---|---|---|
| PM1 | 351.15 | 5 | 18.45 | 297.73 | 1617 | 0.35 |
| PM2 | 332.64 | 10 | 36.96 | | | |
| PM3 | 314.16 | 15 | 55.44 | | | |
| PM4 | 295.68 | 20 | 73.92 | | | |

Table 5 Mix proportion with Fly ash (FA)

| Pervious Concrete Mixes | Cement ($Kg/m^3$) | Cement replaced by Fly Ash (%) | Fly Ash ($Kg/m^3$) | Fine Aggregate ($Kg/m^3$) | Coarse Aggregate (10-20 mm) ($Kg/m^3$) | W/C ratio |
|---|---|---|---|---|---|---|
| PF1 | 351.15 | 5 | 18.45 | 297.73 | 1617 | 0.35 |
| PF2 | 332.64 | 10 | 36.96 | | | |
| PF3 | 314.16 | 15 | 55.44 | | | |
| PF4 | 295.68 | 20 | 73.92 | | | |

Table 6 Mix proportion with MK:FA

| Pervious Concrete Mixes | Cement ($Kg/m^3$) | Cement replaced by MK:FA (%) | Metakaolin ($Kg/m^3$) | Fly Ash ($Kg/m^3$) | Fine Aggregate ($Kg/m^3$) | Coarse Aggregate (10-20 mm) ($Kg/m^3$) | W/C ratio |
|---|---|---|---|---|---|---|---|
| PMF1 | 295.68 | 5:15 | 18.45 | 55.44 | 297.73 | 1617 | 0.3 |
| PMF2 | | 10:10 | 36.96 | 36.96 | | | 5 |
| PMF3 | | 15:5 | 5544 | 18.45 | | | |

## IV. EXPERIMENTAL METHODOLOGY

The experimental investigation carried out on low cost pervious concrete (LCPC) by replacement of cement with metakaolin and fly ash up to 20% by weight of cement. For all mix proportion W/C ration is constant 0.35. Pervious concrete contains cement, sand, aggregate, water; metakaolin and/or fly ash specimen were casted in lab. Three cube samples were casted on mould size 150mm x 150 mm x 150mm for each concrete mix with partial replacement of cement by metakaolin and partial replacement of cement by fly ash for compression test. For infiltration test 300mm x 300mm x 120mm panel casted for each mixes and tested. After 24 hours the specimens were de-molded and curing was done. For compression test specimen tested after 7 and 28 days

### i. Compressive Strength Test (IS: 516-1959)

For compression test, specimen of size 150mm x 150mm x 150mm were casted and tested in compression testing machine with reference of the test procedure given in IS: 516-1959.

Equation for finding out compression test is given below

Compressive strength= P/A ($N/mm^2$)

Where,

P= Failure of specimen (N)

A= Cross Sectional area of specimen ($mm^2$)

Figure 6. Compressive strength tests

### ii. Infiltration test (ASTM C1701)

Infiltration test was carried out with reference of the test procedure given in ASTM C1701. Infiltration test was used for finding the water passing ability of pervious concrete panel which was casted and placed in field. Infiltration test has been carried out manually. The test consists of four main components: Installing the infiltration ring, rewetting the concrete, testing the concrete and calculating the results. For infiltration rate test of pervious concrete panel of 300mm x 300mm x 120mm were casted. The ring is then placed on the cleaned surface and secured in place with plumber's putty. Then water is poured onto the surface and measuring the time for the free water to disperse. With the help of measured volume of water, time required for draining out all the water and cross sectional area of cube Infiltration rate of Pervious Concrete is found out. In this experiment study infiltration rate carried out on panel with mud operation and without it.

Equation for infiltration test is here.

$$P = KM/D2*T$$

Where, P= infiltration, M=Water mass, D=Ring diameter, T=time, K=Constant

Figure 7. Infiltration test

## EXPERIMENTAL RESULT AND DISCUSSION

Table 7. Compressive strength of various pervious concrete mixes

| Pervious Concrete Mixes | MK:FA | Compressive strength (N/mm$^2$) | |
|---|---|---|---|
| | | 7 days | 28 days |
| NC | 0:0 | 7.73 | 13.60 |
| PF1 | 0:5 | 7.66 | 13.45 |
| PF2 | 0:10 | 7.19 | 12.61 |
| PF3 | 0:15 | 6.54 | 11.56 |
| PF4 | 0:20 | 6.19 | 10.83 |
| PM1 | 5:0 | 9.82 | 17.21 |
| PM2 | 10:0 | 10.01 | 17.59 |
| PM3 | 15:0 | 10.53 | 18.47 |
| PM4 | 20:0 | 11.54 | 20.21 |
| PMF1 | 5:15 | 8.59 | 15.08 |
| PMF2 | 10:10 | 8.80 | 15.39 |
| PMF3 | 15:5 | 10.20 | 17.84 |

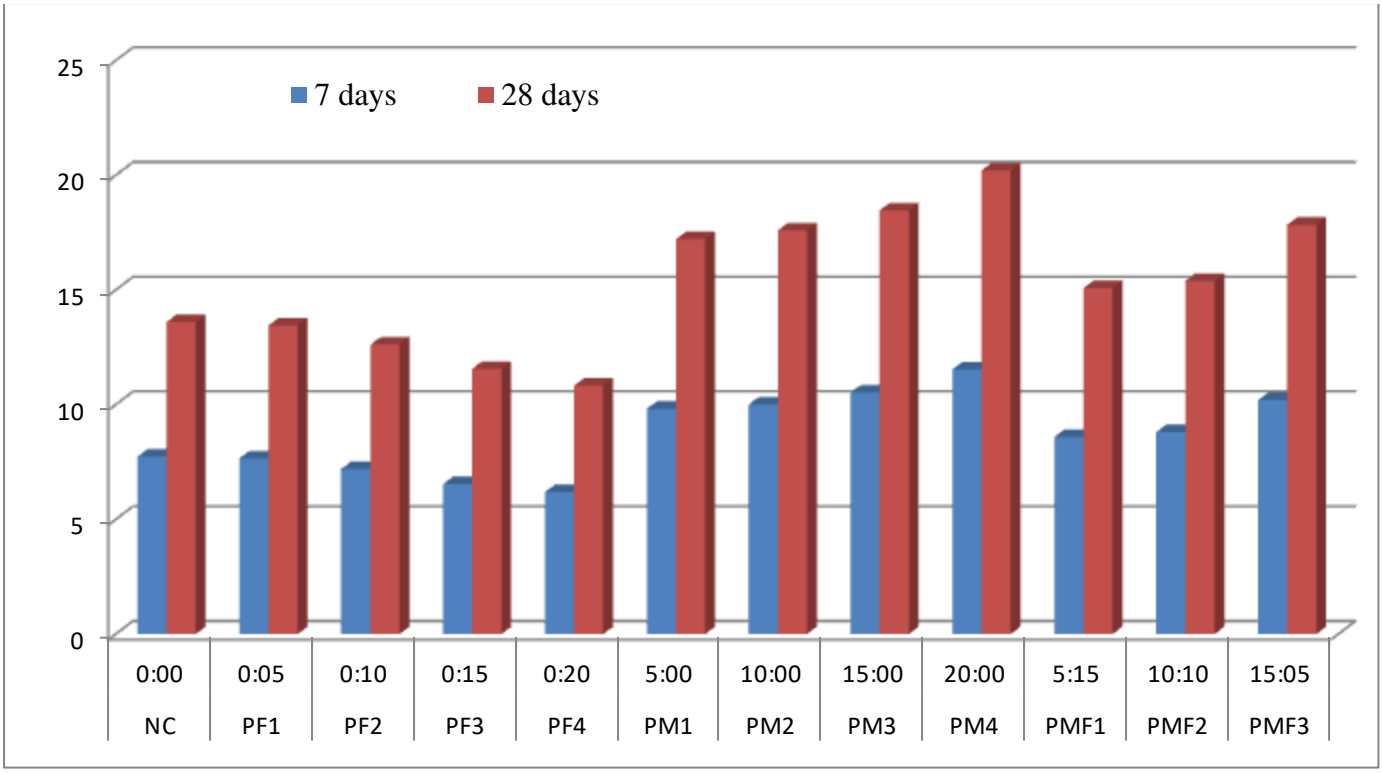


Figure 8. Compressive strength of various Pervious concrete Mixes

Table 8 Permeability of various pervious concrete mixes

| Pervious Concrete Mixes | Permeability (lit/min/m$^2$) | |
|---|---|---|
| | Without mud operation | With mud operation |
| NC | 453 | 349 |
| PMF1 | 417 | 379 |
| PMF2 | 382 | 302 |
| PMF3 | 299 | 223 |

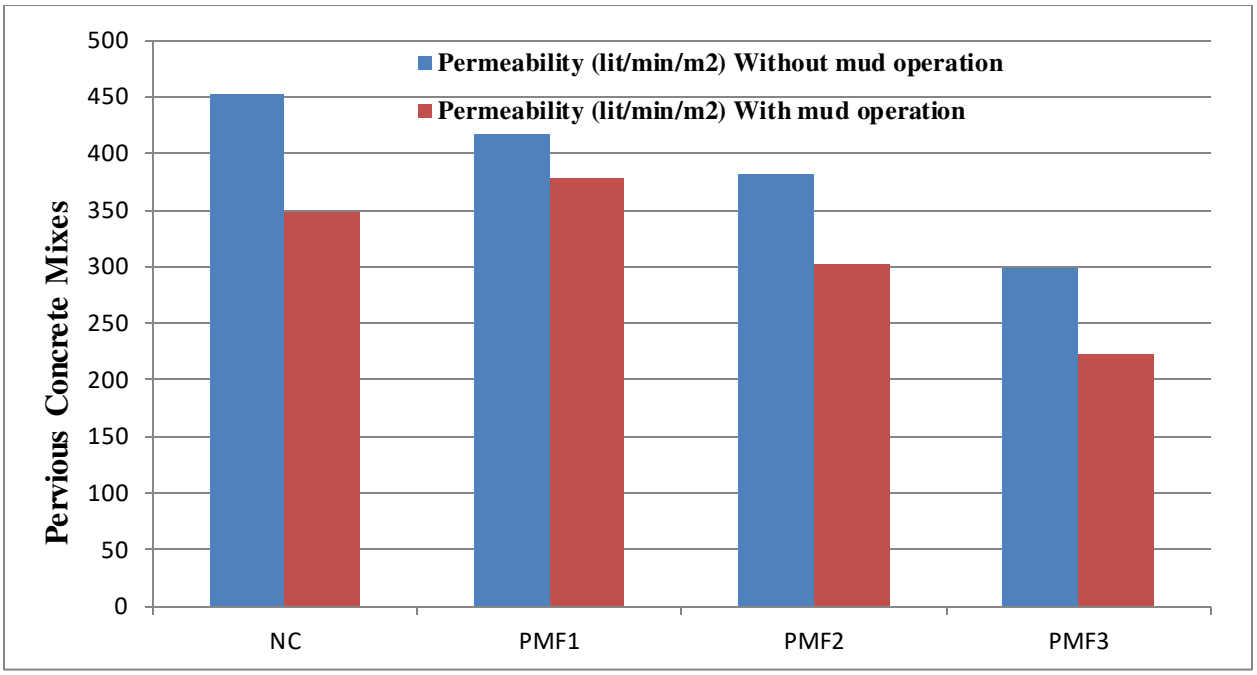


Figure 9. Permeability of various pervious concrete mixes

Figure 9 gives the permeability of various pervious concrete mixes. For NC pervious concrete mix maximum permeability 453 (lit/min/$m^2$) compare to normal concrete was achieved. It was clear seen that permeability decrease with increasing percentage of metakaolin increase.

**Cost Comparison**

Material cost of various materials which used in experimental investigation as per Table 9 and cost of various pervious concrete mixes show in Table 10.

Table 9 Material cost per kg (based on Local Market Lucknow, Uttar Pradesh)

| Materials | Rupees per kg |
|---|---|
| Cement | 7.6 ₹ |
| Fine aggregate | 0.75 ₹ |
| Coarse aggregate | 0.9 ₹ |
| Fly ash | 0.5 ₹ |
| Metakaolin | 15 ₹ |

Table 10 Cost per $m^3$ for pervious concrete mixes

| Pervious Concrete Mixes | Cement cost | Fly Ash cost | Metakaolin cost | Fine Aggregate cost | Coarse Aggregate cost | Total cost Rs. per $m^3$ |
|---|---|---|---|---|---|---|
| **NC** | 2808.96 | | | 223.975 | 1455.3 | 4488.235 |
| **PF1** | 2668.74 | 9.225 | | 223.975 | 1455.3 | 4357.204 |
| **PF2** | 2528.06 | 18.48 | | 223.975 | 1455.3 | 4225.815 |
| **PF3** | 2387.16 | 27.72 | | 223.975 | 1455.3 | 4094.155 |
| **PF4** | 2247.16 | 36.96 | | 223.975 | 1455.3 | 3963.395 |
| **PM1** | 2668.74 | | 276.75 | 223.975 | 1455.3 | 4624.765 |
| **PM2** | 2528.06 | | 554.4 | 223.975 | 1455.3 | 4761.735 |
| **PM3** | 2387.61 | | 831.6 | 223.975 | 1455.3 | 4898.485 |
| **PM4** | 2247.16 | | 1108.8 | 223.975 | 1455.3 | 5035.235 |
| **PMF1** | 2247.16 | 27.72 | 276.75 | 223.975 | 1455.3 | 4230.905 |
| **PMF2** | 2247.16 | 18.48 | 554.4 | 223.975 | 1455.3 | 4499.315 |
| **PMF3** | 2247.16 | 9.225 | 831.6 | 223.975 | 1455.3 | 4767.26 |

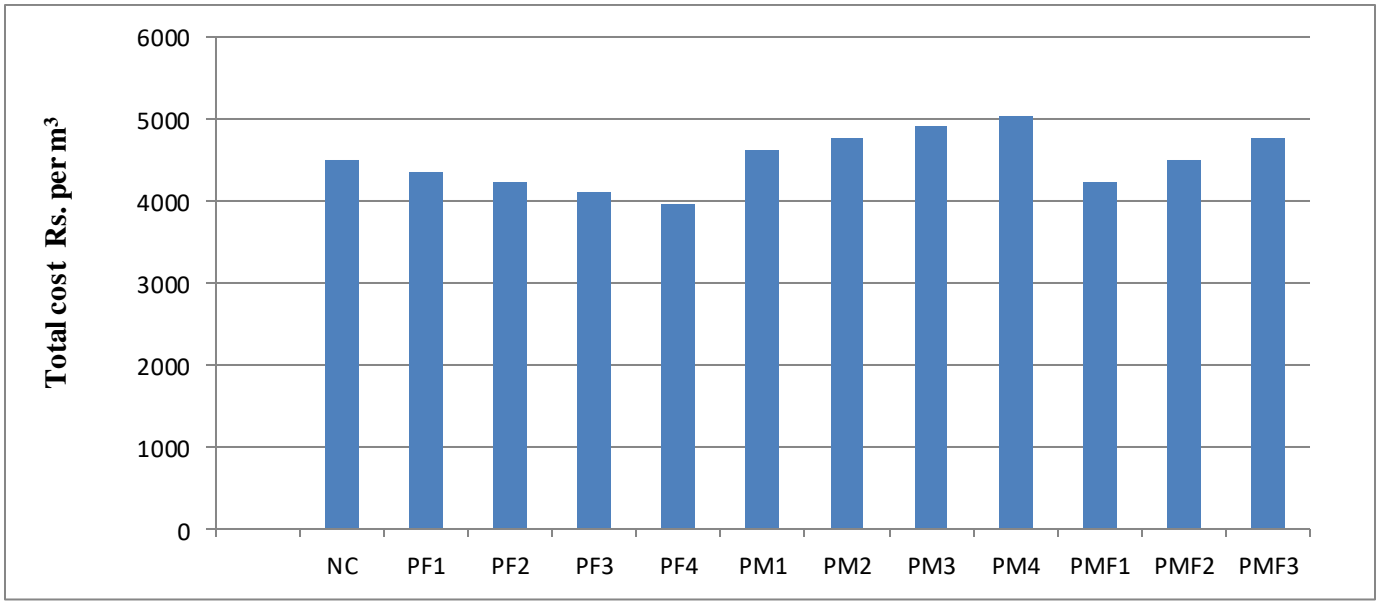


Figure 10. Cost comparison of various mixes

Table 10 show cost per $m^3$ for pervious concrete mixes. It was observed that fly ash based pervious concrete cost is low compare to normal concrete. But for metakaolin based pervious concrete cost is high because of metakaolin price is high compare to fly ash. For PMF1 pervious concrete price is low than normal pervious concrete. So pervious concrete with use of industrial give cost effectiveness.

## V. CONCLUSION

Based on experimental investigation on pervious concrete following conclusion are made:

1. It was observed that compressive strength of fly ash based pervious concrete decrease with fly ash percentage increase.
2. Metakaolin give high compressive strength for metakaolin based pervious concrete but due high cost of metakaolin it was proven costly.
3. For concrete mixes of PMF1, PMF2, PMF3 compressive strength is good but at same time permeability is decrease with amount of metakaolin increase. So higher use of metakaolin decrease permeability.
4. Mixes of two industrial waste 5% metakaolin and 15% fly ash give low cost pervious concrete with high strength.
5. It is possible alternative solution for safe disposal of fly ash and metakaolin

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