

## **EXPERIMENTAL EVALUATION OF PERVIOUS CONCRETE PAVEMENT INCORPORATING ALTERNATIVE MATERIAL REPLACEMENTS**

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**ABSTRACT-**The rapid urbanization process has risen a major demand of sustainable pavement solutions that could be able to alleviate the storm water run offs as well as environmental impacts. The high permeability and capacity to facilitate recharge of ground water have made pervious concrete pavement to be a very good alternative to impervious pavements that are used traditionally. The proposed study is an experimental analysis of pervious concrete pavement using single alternative and industrial by-products, i.e. metakaolin instead of cement and copper slag instead of coarse aggregate, as partial substitutes. The overall goal is to determine the effect of these materials on the mechanical, hydraulic, and the durability of pervious concrete. The compressive strength, split

tensile strength, flexural strength, density, porosity, and permeability characteristics were assessed using the standard laboratory tests. The findings show that adding metakaolin reduces the bonding property and the strength formation of pervious concrete whereas copper slag aggregate helps to increase the aggregate interlocking and load bearing capacity of the pervious concrete without unduly affecting permeability. A combination of metakaolin and copper slag was optimal as it showed a balanced enhancement of both the strength and infiltration capacity. The results indicated the use of metakaolin and copper slag in the pervious concrete pavement is a feasible and sustainable solution to the development of the eco-friendly infrastructure. The research paper will help

to advance the use of waste, and lessen the use of cement alongside the functional use of pervious concrete pavements in cities.

**Keywords:** Pervious concrete pavement, Rigid pavement materials, eco-friendly construction materials, Green pavement technology and Sustainable pavement etc.

## I. INTRODUCTION

Porous permeable, or no-fines concrete, or pervious concrete is a special type of concrete that is reinforced with a high interconnected void structure, such that water will flow directly through the pavement surface. Pervious concrete unlike the traditional concrete, has little to no fine aggregate, a factor that makes it porous and therefore, the storm water permeates rapidly through the porous matrix. This peculiar feature predisposes pervious concrete to be the environmental-friendly pavement material that is highly applicable in low-traffic environments including car parks, footways, pedestrian walks, residential roads, and parking bays.

The first environmental benefit of the pervious concrete is that the concrete can reduce surface runoff, alleviate urban flooding, and encourage ground water recharge. Pervaporation concrete also aids in pollutant filtration by passing rainwater

through a pavement layer which reduces the drainage system load on the storm water drainage system, and enhances water quality in general. Such advantages are in line with the current Sustainable Urban Drainage Systems (SUDS) and Low-Impact Development (LID) approaches.

The pervious concrete is usually composed of cement, coarse aggregates, and water and in some cases, other cementitious materials or chemic admixtures, in a material perspective. High porosity that is achieved due to the lack of fine aggregates is usually between 15 and 30 percent and this has a direct impact on permeability and strength. Although an increase in porosity leads to an increase in infiltration capacity, it leads to a decrease in mechanical strength where optimization of mix design becomes very essential. Such parameters like the aggregate size, water-cement ratio, the paste content, and the compaction method are relevant to the determination of the pervious concrete performance. Although good in environment, pervious concrete has problems associated with reduced compressive and flexural strength, abrasion resistance and blockage of pores with time. To overcome these shortcomings, recent studies have considered using additional cementitious material, fibers and recycled or

industrial by-product aggregates to enhance strength and durability but not usually decrease permeability.

## II. OBJECTIVES

- To design and build pervious concrete pavement mixes through the partial replacement of cement with metakaolin and natural coarse aggregate with copper slag aggregate.
- To experimentally test the mechanical properties of the pervious concrete using metakaolin and copper slag, such as compressive strength and flexural strength which is pertinent in pavement.
- To examine the permeability properties and porosity structure of pervious concrete mixtures with other materials, to ensure that they adhere to the specifications of pervious pavement.
- To find the most appropriate replacement percentages of metakaolin and copper slag that can give a balance between strength, permeability and durability.
- The objective of the experiment is to determine the durability performance of modified pervious concrete based on the abrasion resistance and other sensitivity durability parameters in the service conditions of pavement.

- To assess the possibilities of the sustainability of the application of industrial by-products including metakaolin and copper slag in pervious concrete pavements by decreasing the amount of cement and the amount of natural aggregates used.

## III. Literature Review

**Sathe and Dandin (2025)** [1] performed an experimental research on permeable concrete using fly ash (FA) and ground granulated blast furnace slag (GGBS) as a partial replacement of cement. The experiment compared workability, compressive strength, split tensile strength, density, porosity and permeability, and replacement levels. It was found that mixes with FA and GGBS made at compressive strength values of the order of 18-25 MPa at 28 days old, then later-age strength being greater than the control mix as a result of pozzolanic and latent hydraulic reactions, although early-age strength was slightly decreased. Split tensile had a similar trend and it improved gradually as the age of curing increased. Permeability coefficients were found in the acceptable range of 2-5 mm/s, and the porosity was in the range of 15-25% which proves that the interconnected pore structure is maintained, which is crucial in drainage. A replacement

level of FA and GGBS was determined which gave an optimum result in performance both in strength and permeability. This research found partial substitution of cement by FA and GGBS to be technically feasible and environmentally friendly, with a lower consumption of cement and carbon emissions, a high structural capacity and hydraulic performance, and that the proposed permeable concrete can be used as sustainable pavement and urban storm water management.

**Lu, Yang, and Jiang (2025) [2]** researched the optimum mix design of pervious concrete with the focus on the knowledge of the relations between mix parameters and the key performance properties. The experimentally determined the influence of water cement ratio, aggregate cement ratio and target porosity on mechanical and hydraulic performance such as compressive strength, flexural strength, permeability coefficient and void ratio. The findings showed that compressive strength between 15 and 32 Mpa were attainable through optimum mix design and the higher the compressive strength, the lower was the target porosity and the target content of the paste. Coefficients of permeability were

reported to be between 1.5 and 6.0 mm/s with a clear inverse correlation with strength. Examination of the correlation showed a negative correlation between, porosity and compressive strength with positive correlation between porosity and permeability. The authors have concluded that rational mix proportioning, which relies on correlation analysis, can greatly enhance the predictability of performance of pervious concrete, which provides a real guideline in designing sustainable and durable pervious concrete pavement that is also hydraulically efficient to sustain urban infrastructure.

**Ahmed et al. (2025) [3]** examined the possibility of using recycled crushed clay brick (CCB) waste as an aggregate in pervious concrete, particularly in terms of mechanical performance, hydraulic behavior, clogging behavior, and maintenance performance. The experiment assessed compressive strength, flexural strength, porosity, permeability, and long-term clogging resistance conditions at simulated load with the sediment. The findings also showed that the pervious concrete mix using crushed clay brick showed compressive strength between 12 and 22 Mpa that was lower than normal mixes but these were sufficient to support

low-to medium-traffic pavement. The permeability coefficient was reported as 2.0-6.5 mm/s; this was due to the porous structure and rough surface of the aggregates of bricks. Values of porosity were kept at an average of 18-28 percent, which is effective in the infiltration of storm water. Clogging tests showed that mixes with crushed clay brick were more susceptible to clogging because of higher fines retention but the permeability of up to 70-85 percent could be obtained after regular maintenance procedures (vacuum sweeping and pressure washing). The paper has found that pervious concrete waste of crushed clay brick can be effectively used as a sustainable substitute aggregate using proper mix design and care plans, thus facilitating conservation of resources, and enhanced environmental performance of permeable pavements.

**Banerji et al. (2025) [4]** examined the application of basic oxygen furnace (BOF) slag instead of natural aggregates in porous concrete pavements to achieve sustainability. The paper has also investigated how the addition of BOF slag impacts the pivotal performance parameters through compressive strength, density, porosity, and permeability and the durability-associated parameters applicable

to the pavement applications. It was found that the porous concrete mixes with BOF slag attained compressive strength values of between 20 and 30 MPa and these were similar or even greater than the conventional porous concrete as a result of angular shape and greater stiffness of slag aggregates. Values of 1.8 to 5.0 mm/s were noticed in permeability coefficients, whereas the level of porosity was not exceeded in 15-25 percent, which means that sufficient drainage capacity was ensured. There was also the use of BOF slag, which helped in enhancing the structural stability and abrasion resistance of the pavement. The authors came to the conclusion that BOF slag can be used as a sustainable and viable alternative aggregate in the construction of porous concrete pavement with positive environmental impact as a result of industrial waste use and adequate mechanical and hydraulic performance to meet the sustainability of the transportation infrastructure.

**Liu et al. (2025) [5]** performed a combined experimental and numerical research to assess how the permeability and the strength of pervious concrete depends on target porosity and water to cement (w/c) ratio. The experiment used numerical modeling to

interpret the transport and mechanical behavior by analyzing the compressive strength, permeability coefficient, porosity and pore structure using laboratory testing. The findings showed that compressive strength declined considerably with target porosity with reported compressive strength of 14 to 32 Mpa and permeability coefficients of 1.2 to 6.8mm/s as porosity went up. A w/c ratio above an optimum level resulted in decreased strength through weaker bonding of paste, and very low w/c ratios had an adverse impact on permeability through clogging channels in pores. Computer simulations were consistent with experiments, showing that strength and permeability have a strong inverse relationship. The optimum target porosity found out was 18-22% and w/c ratio of approximately 0.30-0.35 giving a compromise between mechanical strength and hydraulic efficiency. The authors came to a conclusion that the key to designing the pervious concrete pavements with predictable performance and long life is in careful management of porosity and w/c ratio.

**Nguyen, Le, and Huynh (2025) [6]** the authors tested the performance of high-volume coal combustion residual (CCR)

concrete in pavement applications and focused on engineering, durability, microstructural, economic, and environmental issues. The experiment examined compressive strength, flexural strength, abrasion resistance, permeability, and durability attributes of concrete mixes that had large percentages of CCR as a cementitious substitute. The findings revealed that CCR-based concrete had a compressive strength of 25-40 Mpa and flexural strength with a range of 4.0-5.5 Mpa and this proved to be suitable to use in pavement. Durability tests revealed more resistance to sulfate attack and less shrinkage during drying than those of conventional concrete, which was attributed to the improved microstructure that had been formed by the reactions of pozzolans. The findings of permeability and pore refinement indicated increased long-term solubility and ingress of harmful factors. Economic and environmental audit showed that there was a significant cut on cost of material and the embodied carbon emissions as a result of reduction in consumption of cement. The authors have concluded that high-volume CCR-based concrete is a viable and sustainable construction material that has sufficient mechanical characteristics, increased durability, and considerable

environmental benefits, and therefore should be utilized in the construction of sustainable transportation infrastructure.

**Sain, Gaur, and Sarkar (2025) [7]** evaluated the infiltration rate in modified block pavement systems with pervious concrete layers to increase the efficiency of storm water management. Experimentally the infiltration rate, reduction of surface runoff, clogging behavior and structural adequacy were experimentally tested under repeated conditions of loading. The findings showed that the modified block pavements obtained infiltration rates within 150-450 mm/h, which is far better than the traditional impervious block pavements. By including pervious concrete layers, the subsurface water recharge was enhanced and also sufficient load bearing capacity was ensured to sustain light to moderate traffic conditions. With time there was progressive loss of capacity of infiltration proportional to the clogging of the surfaces, but periodical maintenance allowed to recover until 70-80 percent of the initial infiltration rate. The research established that incorporation of pervious concrete into block pavement systems is a powerful approach to enhance urban drainage and reduce surface run off as long as appropriate

design and maintenance procedures are adopted which then offers the introduction of modified block pavements to sustainable urban infrastructural systems.

**Pushpakumara and Bandara (2025) [8]** examined the use of copper slag waste as a partial substitute to natural fine aggregate in concrete, and the aim of the study was to enhance the performance of the material as well as ensure the efficient use of waste products. In the study, fresh properties, compressive strength, split tensile strength, flexural strength, density and the properties associated with durability were considered under various replacement levels of the fine aggregate containing copper slag. The findings revealed that the concrete mixes with slag of copper yielded higher compressive strength values of about 30-45 MPa and more so at the replacement levels of 40-60, which was due to dense and angular characteristics of the slag particles. It was found that workability increased as a result of the smooth surface texture of copper slag, whereas water absorption was less, which suggested a denser microstructure. Tests on durability indicated a higher level of resistance to chloride intrusion and lesser permeability as compared to the traditional concrete.

Nonetheless, segregation and bleeding caused marginal strength loss as a result of excessive replacement levels. Conclusion of the research was to the effect that copper slag waste is feasible as a fine aggregate substitute in concrete to an optimum extent, as it provides a better mechanical performance, sustained durability, and high level of environmental consideration by saving natural sand as well as reducing disposal of industrial waste.

#### **IV. METHODOLOGY**

The current experiment results through a systematic approach to experimental methods to determine the performance of pervious concrete pavement in which metakaolin is used as a partial substitute of cement and copper slag as a partial substitute of coarse aggregate. The methodology will be organized in such a way that the effect of each substitute material on mechanical and hydraulic performance of pervious concrete will be determined separately.

In the first stage all constituent materials, such as Ordinary Portland Cement, metakaolin, natural coarse aggregate, copper slag aggregate, and water are purchased and analyzed in terms of physical and mechanical characteristics in accordance

with the Standard IS/ASTM procedures. Special gravity, particle size distribution, water absorption and bulk density are some of the properties that are established to guarantee suitability and consistency of the material.

Some standard control mix of pervious concrete is initially prepared with no material substitute and taken as reference mix. In order to investigate the influence of metakaolin, mixes with cement are created by replacing cement with metakaolin in different proportions such as 6, 12, 18, and 24 percent, which are referred to as C-M-6, C-M-12, C-M-18 and C-M-24 respectively. In these mixes, sand and coarse aggregate materials are held constant at 100 percent and the only material changed is cement with metakaolin.

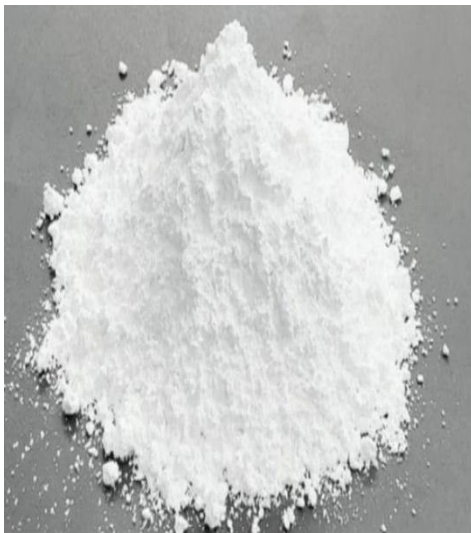
In the same way, in order to assess the effect of copper slag aggregate, another bunch of mixes are made by substituting natural coarse aggregate with copper slag to a parts of 5, 10, 15 and 20 as M12-CS-5, M12-CS-10, M12-CS-15, and M12-CS-20, respectively. Cement and sand contents in these mixes are maintained at 100-percent and the variations in performance can only be attributed to an aggregate replacement.

In all mixes, water- cement and aggregate-binder ratios are held constant to ensure

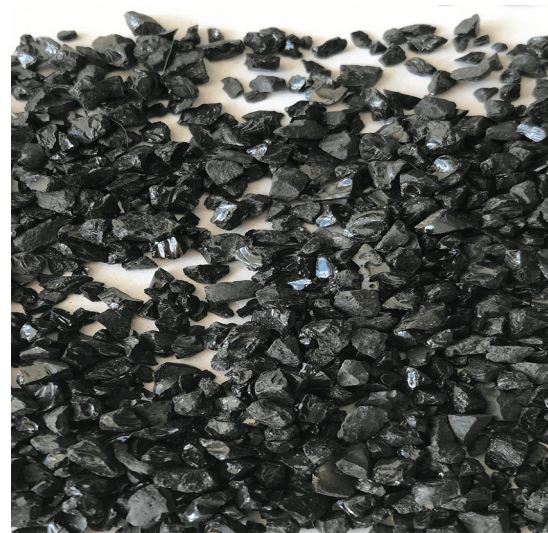
comparability. Fresh concrete is homogenized and poured into standard test specimens in a controlled compaction in order to retain the interconnected pore structure of pervious concrete. The specimens are cured with standard conditions and with definite time periods.

The hardened concrete tests are performed to test compressive strength, split tensile strength, flexural strength, porosity and

permeability. The findings of the metakaolin-modified mixes, copper slag-modified mixes, and the standard mix are used to determine the trends, performance enhancement, and the best level of replacement. The experimental results give the information about the appropriateness of metakaolin and copper slag in creating sustainable and high-performing pervious concrete pavements.



**Fig. 1 Metakaolin for Concrete Mix**



**Fig. 2 Copper Slag Aggregate**

**Table 3.1 Cement Partial replacement by Metakaolin in Concrete Mix**

Mix	Cement	Sand	Coarse Aggregate	Metakaolin
<b>Standard Mix</b>	100%	0%	100%	0%
<b>C-M-6</b>	94%	0%	100%	6%
<b>C-M-12</b>	88%	0%	100%	12%
<b>C-M-18</b>	82%	0%	100%	18%
<b>C-M-24</b>	76%	0%	100%	24%

**Table 3.2 Coarse Aggregate Partial replacement by Copper Slag Aggregate in Concrete Mix**

Mix	Cement	Sand	Coarse Aggregate	Copper Slag Aggregate
<b>Standard Mix</b>	100%	0%	100%	0%
<b>M12-CS-5</b>	100%	0%	95%	5%
<b>M12- CS-10</b>	100%	0%	90%	10%
<b>M12- CS-15</b>	100%	0%	85%	15%
<b>M12- CS-20</b>	100%	0%	80%	20%

**Table 3.4 Combined Partial replacement of Copper Slag Aggregate and Metakaolin in Concrete Mix**

Mix	Cement	Sand	Coarse Aggregate	Metakaolin	CSA
<b>Standard Mix</b>	100%	0%	100%	0%	0%
<b>Optimum Mix</b>	88%	0%	85%	12%	15%

*Note: 12% Metakaolin + 15% Copper Slag Aggregate (CAS) is the optimum balanced and recommended replacement level.*

## **V. EXPERIMENT WORK**

The cement experimental study was performed to test its basic physical characteristics, which are the key determinants of rigid pavement concrete performance. Standard consistency test had been performed to establish the maximum amount of water needed to form cement paste of standard plasticity. Initial setting time test was carried out to determine the time that will be available in mixing, placing and compaction of the concrete once water has been added. Final setting time test was done to ascertain the duration required by the cement paste to reach adequate rigidity and hardness. The entire tests were performed according to IS 4031 (Parts 4 and 5) in order to assure that the Indian Standard specifications of a pavement grade concrete were followed.

The experimental studies on aggregates were carried out to determine their suitability in the use of rigid pavement concrete. Course aggregate tests such as abrasion, impact, and crushing tests were carried out to determine their resistance to wear, impact loads, and compressive forces in traffic conditions. These are essential properties which are used in making pavement concrete durable and strong. To

ascertain their physical properties in regard to mix design, workability as well as water demand, tests on fine aggregates, including specific gravity and water absorption, were conducted. All aggregate tests were done according to IS 2386 (Parts 3 and 4) in a bid to meet the requirements of Indian Standard on pavement construction.

The experiment on concrete was conducted to determine the fresh and hardened properties of rigid pavement concrete. The test in question was the slump test which was conducted to determine how easy fresh concrete is to place and how workable it is. The load-carrying capacity and the development of the strength of concrete were done by compressive strength tests on the 7<sup>th</sup> and 28<sup>th</sup> days. Split tensile strength test was conducted to test tensile resistance of concrete which is essential in controlling crack in rigid pavements. Also the abrasion resistance test was conducted to determine the durability of the surface to wear under traffic and the Rapid Chloride Penetration Test (RCPT) was done to test the permeability and stability of concrete. All tests were done to comply with the relevant codes of IS and generally accepted good practices to give reliable and reproducible results.



**Fig. 3 Concrete Samples**

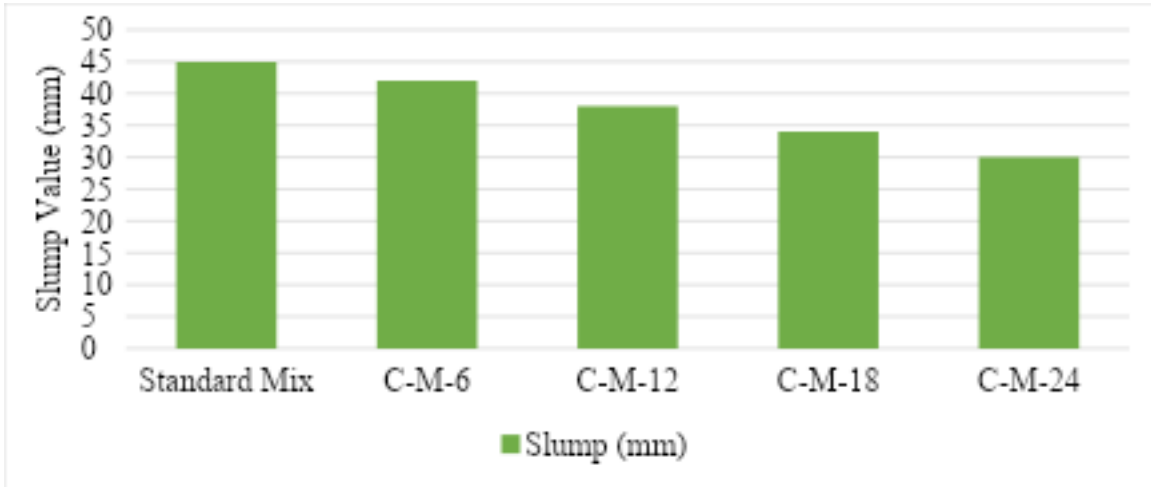
## **VI. RESULT AND DISCUSSION**

The findings reveal that the normal consistency of the blended paste is proportional to metakaolin content increase because it is finer and has a high surface area which results into increased demand of water. Initial and final setting times also rise gradually with the degree of metakaolin replacement, which suggests that the setting is delayed due to the dilution of the clinker material, and the pozzolanic character of the metakaolin. Nonetheless, any mixes meet the limit requirements as indicated in the IS 4031, which proves that cement replacement with metakaolin to 24 percent presents a good setting behavior. The delay in setting that is evident is beneficial to rigid pavement concrete since it gives the

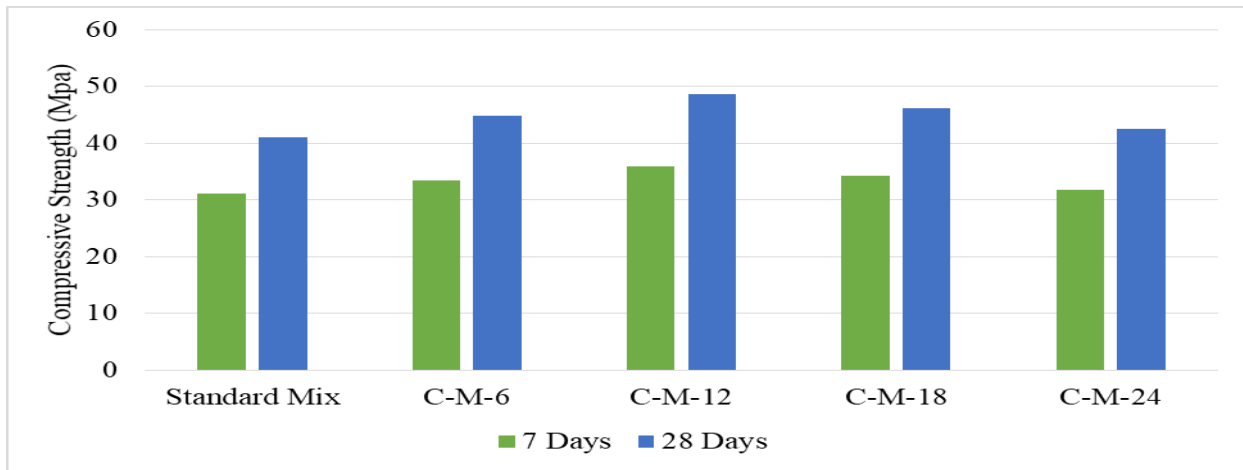
concrete ample time to mix, place and finish.

The findings have shown that there was a gradual decrease in the values of abrasion, impact, and crushing, as the content of copper slag aggregates increased. The abrasion value of Los Angeles dropped as the control mix consisted of 26.5% to 22.6% when the percentage of copper slag was substituted at 20% and this implied increased resistance to wear. On the same note, there was a steady decrease in the aggregate impact and crushing values, indicating enhanced toughness and compressive strength by the mixture of the aggregate. This is due to the hardness, angularity, as well as thick structure of copper slag which is high. All mixes meet the limits of the IS code, and it is made sure

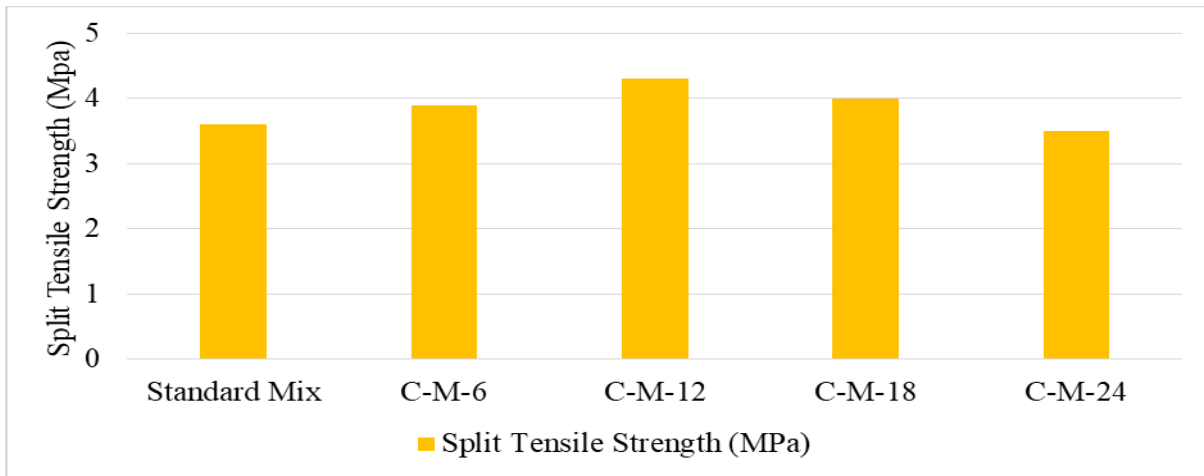
that replacing up to 20 percent of copper concrete.  
 slag with it can be used in rigid pavement



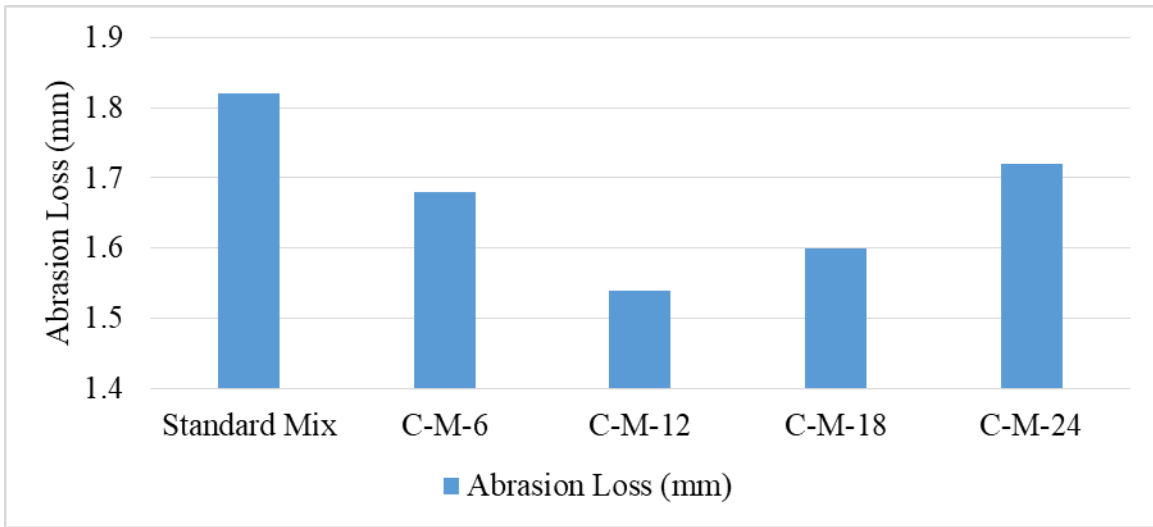
**Fig. 4 Slump Result – Metakaolin Blended Concrete**



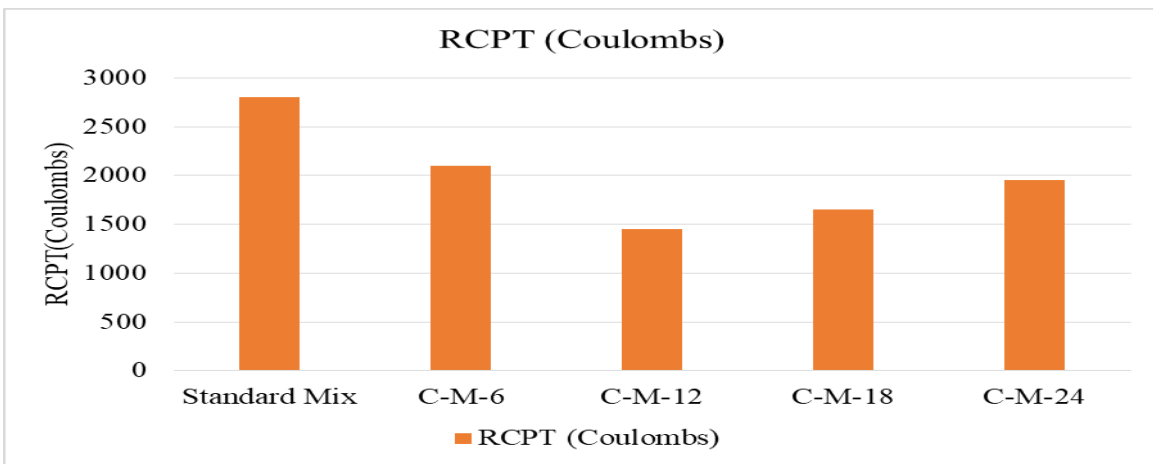
**Fig. 5 Compressive Strength – Metakaolin Blended Concrete**



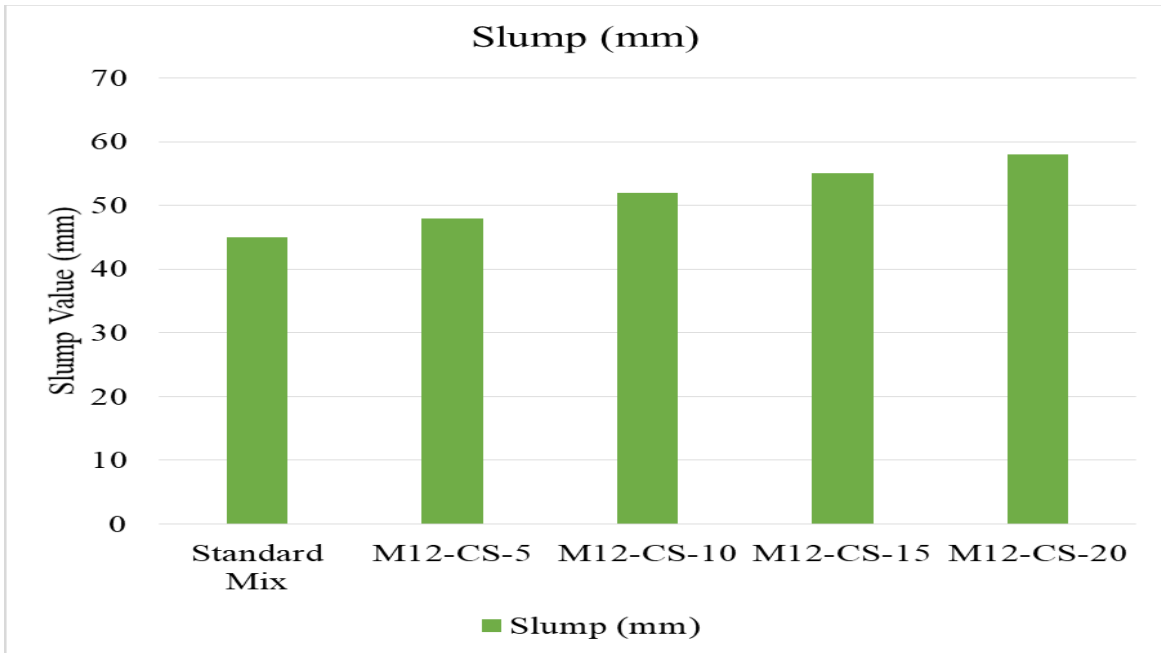
**Fig. 6 Split Tensile Strength – Metakaolin Blended Concrete**



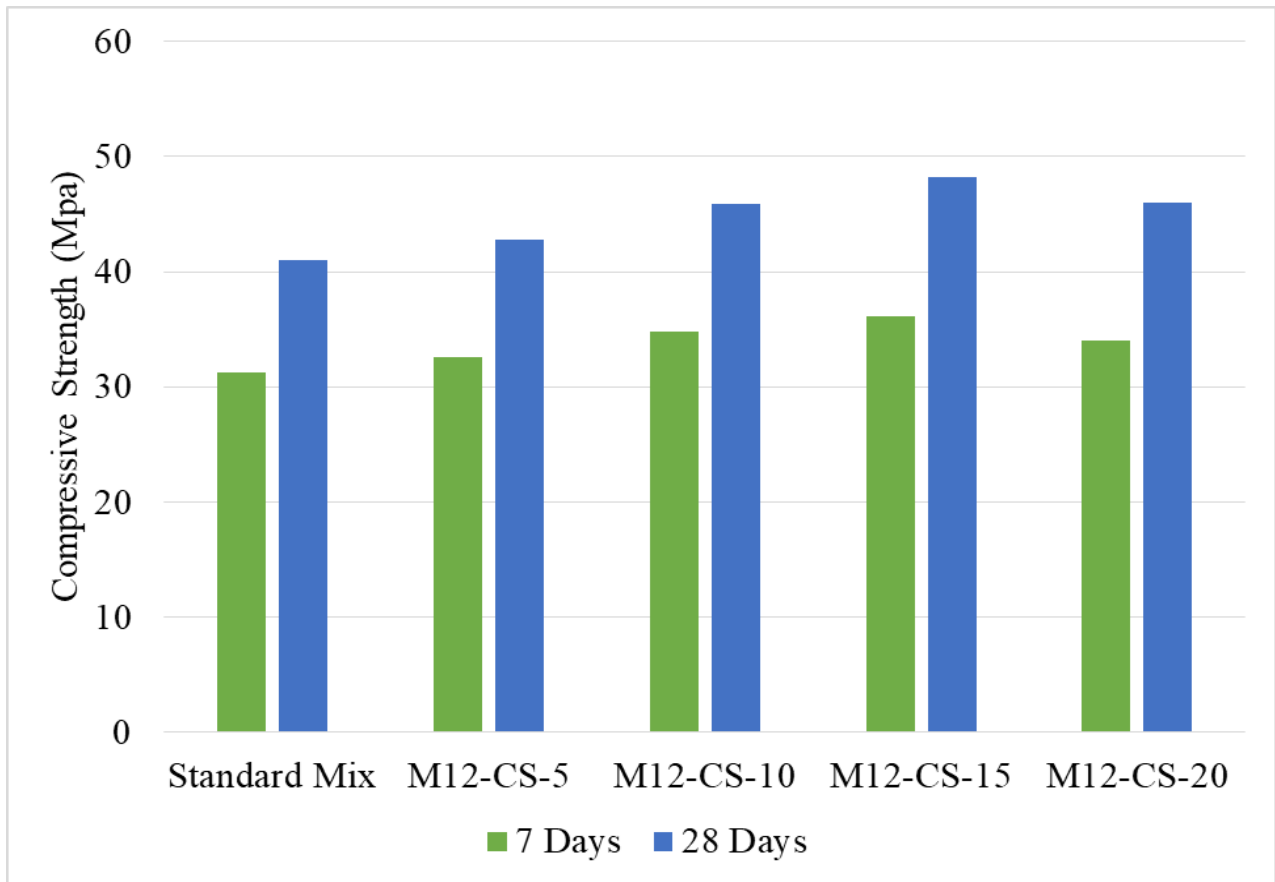
**Fig. 7 Abrasion Loss – Metakaolin Blended Concrete**



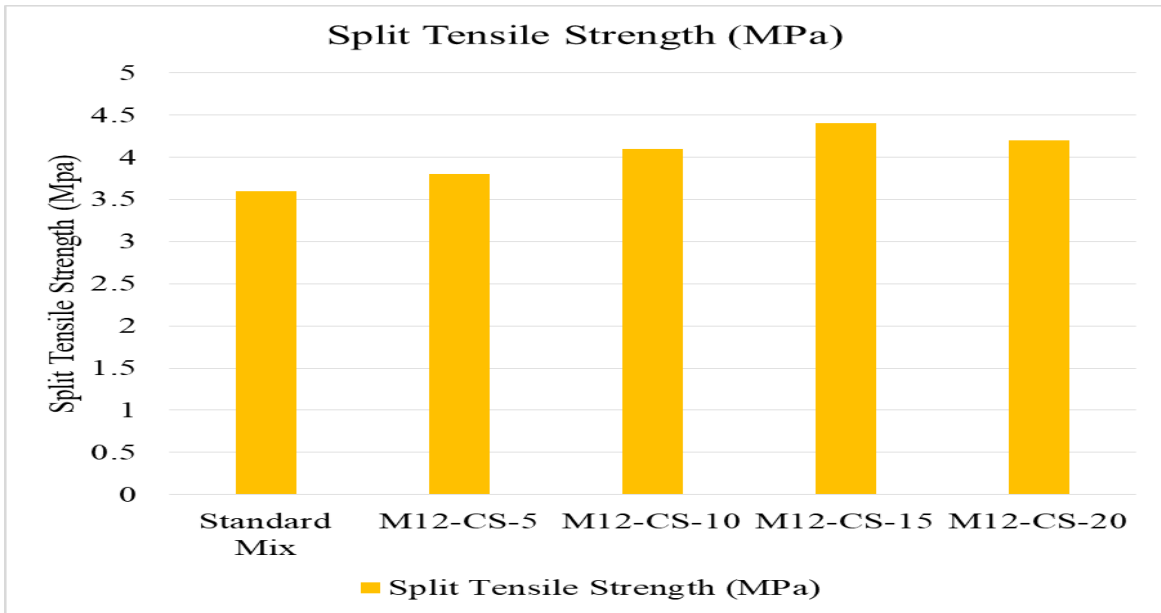
**Fig. 8 RCPT – Metakaolin Blended Concrete**



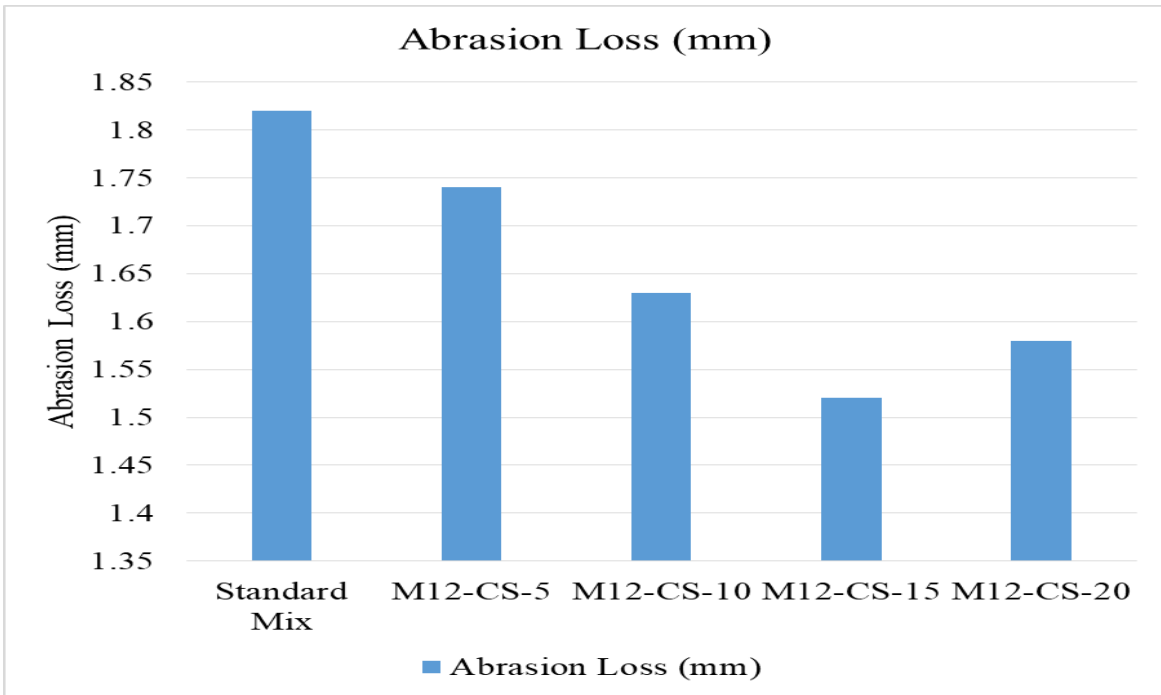
**Fig. 9 Slump Result – Copper Slag Aggregate Concrete**



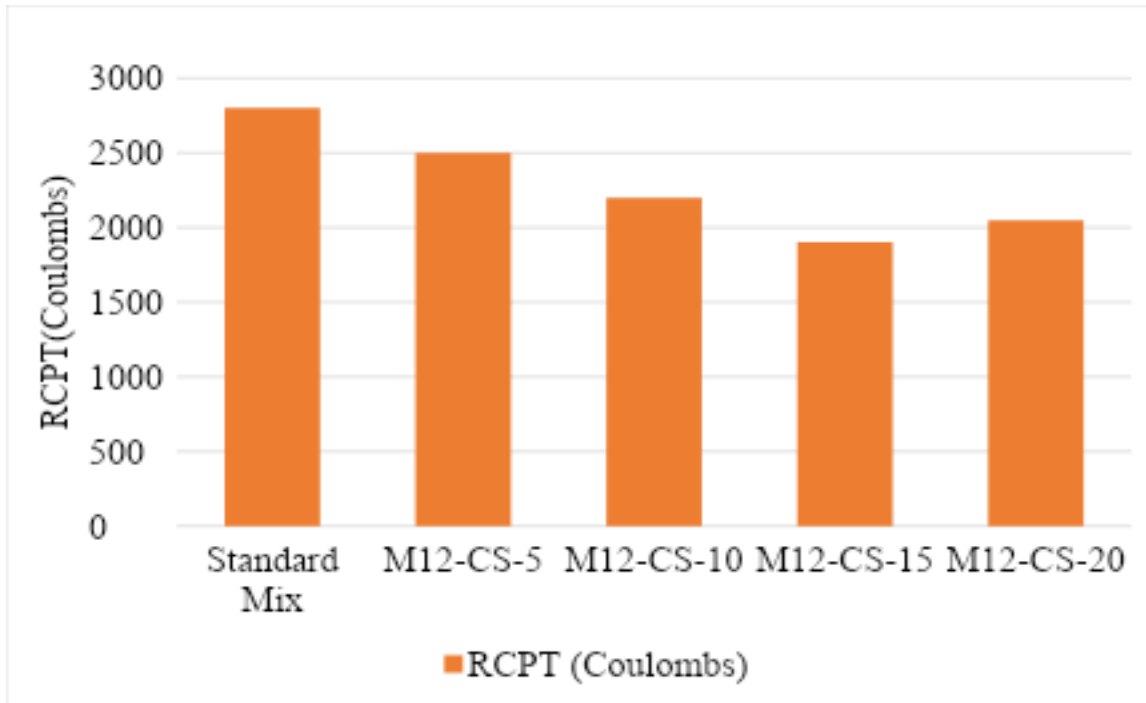
**Fig. 10 Compressive Strength – Copper Slag Aggregate Concrete**



**Fig. 11 Split Tensile Strength – Copper Slag Aggregate Concrete**



**Fig. 12 Abrasion Loss – Copper Slag Aggregate Concrete**



**Fig. 13 RCPT – Copper Slag Aggregate Concrete**

## VII. CONCLUSION

The outcome has shown that normal consistency of the blended paste is proportional to the growth in the metakaolin content since it is finer and has a high surface area that translates to higher demand of water. The initial setting time and the final setting time also increases gradually with the extent of replacement of the clinker material, which indicates that the setting is retarded because the clinker material has been diluted and the latitude-like characteristic of the pozzolanic metakaolin. However, any replacement is within the

limit requirements as provided in the IS 4031 that shows that cement replacement to metakaolin at 24% forms a good setting behavior. The fact that it has taken longer to set that is positive to the rigid pavement concrete in that the concrete will have plenty of time to mix, place and finish. The results have revealed that the values of abrasion, impact and crushing reduced gradually with increase in the content of copper slag aggregates. When the percentage of copper slag was replaced at 20% and this meant that the abrasion value of Los Angeles decreased as the percentage of control mix was between 26.5% and 22.6% giving a

connotation of a high resistance to wear. Similarly, a gradual reduction was observed in the aggregate effect as well as the crushing values, which meant that the mixture of the aggregate resulted in improved toughness and compressive strength. This is attributed to the hardness, angularity and thick structure of copper slag that is high. All mixes are within the confines of the IS code, and it is ensured that the maximum replacement of up to 20% of the copper slag with it in rigid pavement concrete is possible.

The experimental study assessed the performance of rigid pavement concrete using metakaolin as a partial replacement of cement as well as copper slag as a partial replacement of coarse aggregate. The findings have a clear indication that the two materials have a great impact on the fresh, mechanical, and durability of concrete when utilized under optimal conditions. In the case of metakaolin-blended concrete, the outcomes show that the workability of the concrete gradually decreases with an increase in metakaolin content as it is very fine and requires more water. Mechanical performance however increased significantly to a replacement optimum level of 12%. The compressive strength that was measured after 28 days at this level rose to

41.0 MPa of the control mix to 48.6 Mpa and the split tensile strength also improved significantly. Reduction in the loss of abrasion and the minimum RCPT of 1450 coulombs in 12% replacement is a confirmation of the development of a more compact microstructure and a better strength. At the point beyond this optimum, strength and durability began to decrease which was mainly because of the weakening of cementitious substances.

The behavior of copper slag aggregate concrete was the reverse with respect to workability where the slump values were found to rise steadily with the proportional copper slag content. This has been enhanced by the fact that the copper slag aggregates have a smooth surface texture and reduced absorption of water. The characteristics of the strength maximized at 15% replacement whereby the 28-day compressive strength stood at 48.2 Mpa, and split tensile strength rose considerably relative to the control mix. Resistance to abrasion also increased, as well as, surface wear resistance, which is essential in rigid pavements. RCPT values increased to the optimum level of replacement, which is an indication of increased resistance to chloride penetration and durability. The study makes it clear that metakaolin and copper slag could be used

successfully in rigid pavement concrete in enhancing its strength and durability properties at the optimum replacement rates. The most optimal contents were found to be 12% metakaolin to be used in place of cement and 15% copper slag to be used in place of coarse aggregate. The altered concrete blends met the performance standards of M40 Pavement Quality Concrete according to the guidelines of the IRC, and helped with enhancing sustainability through the decreased use of cement and the use of industrial by-products. The findings justify that the use of metakaolin and copper slag in the construction of rigid pavements should be put into practice to deliver improved performance and environmental advantages.

#### **VIII. FUTURE SCOPE OF WORK**

- This paper can be furthered to analyze the synergistic effect of using metakaolin and copper slag together in pervious concrete in order to determine strength, permeability, and durability of the product.
- The tests which can be conducted to determine the performance of pervious concrete in aggressive environment include long-term durability tests including freeze thaw resistance, sulfate

attack, carbonation and alkali silica reaction test.

- Field trials and full-scale pavement sections can also be built to confirm laboratory findings by loading up those in practice and at different climatic conditions.
- The effect of the fiber reinforcement (polypropylene, steel, or natural fibers) on mechanical strength and crack resistance of the pervious concrete made with other materials can be explored.
- The possibilities of optimization of void content and permeability properties through various aggregate gradations and replacement levels can be pursued in order to promote storm water infiltration performance.

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- [17] IS 4031 (Parts I to XV) – Methods of Physical and Chemical Tests for Hydraulic Cement.