Optimization of Replacements of the Supplementary Waste Materials for Production of Cost Effective Concrete

Mandela Lalitha[1], Magapu Durga[2], Dr. Kusuma Sundara Kumar[3*]

[1]M.Tech Student, Dept. of Civil Engineering, Bonam Venkata Chalamayya Engineering College-Odalarevu Konaseema, Andhra Pradesh, India.
lalithamandela9@gmail.com

[2] Asst.Professor, Dept. of Civil Engineering, Bonam Venkata Chalamayya Engineering College-Odalarevu Konaseema, Andhra Pradesh, India
mdurga.bvce@bvcgroup.in

[3]Professor, Dept. of R &D, Bonam Venkata Chalamayya Engineering College-Odalarevu Konaseema, Andhra Pradesh, India.

*skkusuma123@gmail.com

Abstract. The research effort focuses on replacing and adding inexpensive materials to both pervious and conventional rigid concrete pavement. The operative use of unwanted and recycled materials in different proportions—such as rubber chips, steel slag, fly ash, and silica fume—in rigid concrete pavements is the subject of research. To test the flexural, split tensile, and compressive strengths of the concrete, cubes, cylinders, and slabs are cast. The ideal replacement content for each material was determined from earlier research investigations, and it was applied in this study to raise the standard of both conventional and pervious concrete pavements. Fly ash and silica fumes were utilised in place of 8% to 25% of the cement. The coarse aggregates were substituted with rubber chips and steel slag, ranging from 2% to 30%, respectively. In order to determine the effective percentage replacement of cementitious particles and coarse aggregates in concrete, the best replacement values were identified. Additionally, the combination of the aforementioned materials was carried out, and 1 metre by 1 metre slabs were cast. This allowed for the maximum utilisation of recycled materials in the concrete without compromising the pavement's strength. The creation of high-quality, cost-effective concrete for the building of both conventional stiff concrete pavements and pervious concrete pavements is the main objective of this research. This will be achieved through a set of tests intended to confirm the robustness and longevity of the stiff concrete pavement.

Keywords: Concrete, Supplementary materials, waste, optimal utilization

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1 Introduction

Longevity, firmness, and ability to withstand heavy-duty vehicle movements are its main characteristics of Cement concrete (CC) pavement. When it comes to building, the main disadvantage of CC pavement is its initial cost. Pavement costs may be lowered by mixing recyclable and unwanted materials into the pavement. It is imperative to acknowledge that any noteworthy alterations to the pavement's strength and durability criteria need to be avoided. Moreover, the durability and strength requirements must be within allowable bounds. The different additional components that were used include rubber chips, steel slag, fly ash, and silica fume, in that order.[1-2]

PERVIOUS RIGID CONCRETE PAVEMENT

Pervious concrete is a structural concrete pavement that has a considerable proportion of interconnected voids, often between 15 and 35 percent. Similar to ordinary concrete, it is made of cement, coarse aggregates, and water; however, it has very little to no sand, which gives it an easily permeable, open-cell structure that permits water to pass through. The construction of pervious concrete pavement requires greater control and attention to detail than that of standard cement concrete pavement. It is believed that the thickness and porosity of the pervious concrete pavement are more significant than its strength and smoothness. However, one common outcome of this outdated infrastructure—especially in cities—is storm water runoff.[3-4]

Permeable pavement technologies have the potential to greatly reduce stormwater runoff, especially in urban areas. Benefits of this system, according to water-sensitive urban design, include lowering the risk of floods, replenishing groundwater, and enhancing water quality. Pervious concrete is defined as "a zero-slump, open-graded material consisting of Portland cement, coarse aggregate, little to no fine aggregate, with or without admixtures and water," by ACI Committee 522. These ingredients will mix to form a solid substance with linked pores that allow water to pass through.[5-8]

Pervious concrete slabs help to reduce urban heat in the evening when the sun sets since they cool down rapidly. The main aspect affecting the performance difference between pervious and plain concrete is consolidation. Both types of concrete require densification in order to achieve maximum strength. However, the well-graded aggregates and paste between the particles in conventional concrete allow the concrete to flow when vibratory energy is applied as mechanical vibration. The flowing property of concrete allows it to consolidate to a consistent, repeatable density. Because there are no fine aggregates and only a thin layer of paste between the coarse aggregate particles in pervious concrete, this flow does not occur when the concrete is vibrated. The only way to attain consistent and predictable density is to apply a substantial amount of compactive energy.[9-12]

NEED FOR SUPPLEMENTARY MATERIALS:

Due to the extensive building being done to upgrade and develop infrastructural amenities, road aggregates have grown more expensive in many places of India. Pavement construction must therefore focus on using alternative materials in order to improve quality and justify the cost of developing a road. Supplementary materials are materials that are obtained as waste from the manufacturing of steel, cement, electricity from thermal power plants, etc. Research and technological developments are currently concentrated on the recycling of these additional components to either increase the quality or decrease the price of concrete.[13-15]

The present focus is on environmentally sustainable development, and one of the most important ways to minimize environmental impact is by employing waste materials in concrete. The primary focus of this work is the utilisation of four additional materials: rubber chips, fly ash, steel slag, and silica fume. Even if fly ash is already used as a pozzolanic element in the making of cement, recycling fly ash into a different form is essential for efficient management. [16]

When fly ash is substituted for cementitious material, its inert properties increase the concrete's resistance to chloride ion penetration and reduce drying shrinkage.Due to its high silicon dioxide content and potential for environmental harm if left unmanaged, silica fume—a byproduct of the manufacturing of silicon metal or ferrosilicon alloys—must be disposed of properly. The significant rise in the transportation sector has resulted in an increase in rubber waste from tyre wear and tearing.[17]

The primary aim of the research is:To assess the mechanical and long-term qualities of medium-strength conventional and pervious concrete by substituting additional waste materials and industrial byproducts for the concrete's original constituents. When the strength of the concrete pavement is within allowable bounds, figuring out the optimal percentage replacement of industrial by products and supplementary materials helps to improve social and environmental standards while also lowering overall construction costs.[18]

2 Materials and Methods

This section discusses the various attributes of the materials used in the research endeavor. The materials are assessed for appropriateness for concrete pavements based on their properties. To ascertain the exact grade of the materials to be utilized in the concrete pavement, a number of tests are also conducted. This chapter also includes a thorough discussion of the methods and techniques for figuring out whether the materials to be used are viable. Moreover, a thorough explanation of the process employed to ascertain the strength and durability is given. Cement 53 Grade OPC ensures better workability and concrete properties. It also shows, to some extent, greater resistance to other normal reasons of concrete deterioration, including sulphate attack and alkali reactions.

Better Concoctions The fine aggregates used in the research project were supplied by the nearby karur sand wholesaler and dealer. The findings of the fine aggregate test, which was conducted in compliance with IS: 2386-1986 and IS: 383-1970, were included. 3.2.3 Compact Groupings Coarse aggregates up to 20 mm in size are used in the research project. The characteristics of the aggregates are assessed in compliance with IS: 2386-1963 and found to be suitable for Indian Standards.

Portland cement concrete is enhanced by the addition of silica fume, which increases the material's resistance to abrasion, bond strength, and compressive strength. Rubber chips In recent decades, rubber's unwillingness to break down and the result-ing difficulty in disposing of it have posed a serious environmental concern. These problems can be solved with the use of concrete generated from this waste product. The tires of the MRF brand are bought from surrounding service stations. Steel Slag Steel slag replacement is a component of both the fine and coarse aggregate replacement processes. Slag is a byproduct of smelting metal, and during the refining process, hundreds of tons of it are produced globally.

3 Experimental Work

Both conventional concrete and pervious concrete are subjected to the mechanical property testing. The mechanical testing include of flexural, split tensile, and compressive tests. Only pervious concrete is subjected to a permeability test in addition to mechanical testing. This test measures the rate at which water exits the specimen and determines whether or not it is suitable for use as a pavement drainage layer. Test of Compression After the specimens' surfaces were completely dry and free of moisture, all of the cubes and cylinders were evaluated in a drying environment. Three cubes and three cylinders were examined after seven and twenty-eight days for each mix percentage.

The specimen was correctly positioned and centred within the testing machine, and tests were conducted in accordance with IS: 516-1959 code using a 2000kN compressive testing machine at a constant load of 140 kg/cm^2 per minute. The tensile strength of the concrete in test cylinder specimens is determined using this indirect test procedure.

Two points of loading are used to evaluate the flexural strength of beams measuring 100 mm by 100 mm by 500 mm in length. Concrete pavement slab test setup. One-third of the slab's overall length is where the line loads are applied. The deflectometers measure the deflections of the different nodes. Deflections are measured at intervals of 0.5 kN of the evenly applied force. The slab's deflections are measured in millimetres and recorded until the pavement's first fracture appears. Test for Permeability The 75mm diameter and 75mm length specimens were employed in the permeability test. Flexible sealing glue was placed to the specimen's upper border in order to prevent leaks down its sides. Different water heights were used for the experiment.

MIX PROPORTION FOR THE PRESENT STUDY

In this study, the trial batch mix is used to determine the mix percentage, i.e., the appropriate weight-to-cement ratio is chosen. The chosen w/c ratio is used to cast a small sample mix in order to verify the appropriate wet consistency. Making many trial batches typically proved helpful in obtaining the best cost-effective combination with the required qualities. With w/c = 0.52, the mix percentage is 1:0:4.05.

PARTIAL REPLACEMENT OF SUPPLEMENTARY MATERIALS: Additional waste materials are added to the constant mix proportions in this investigation. The following additional waste items were employed in this experimental study: rubber chips, steel slag, fly ash, and silica fumes. The following table 1 provided the finalised blend proportions:

Table 1. Mix ID for Pervious Concrete Replacement Mixes

Sl No	Combination	Mix ID
1.	Nominal	N
2.	Fly ash 10%	AC1
3.	Fly ash 15%	AC2
4.	Fly ash 20%	AC3
5.	Fly ash 25%	AC4
6.	Silica fume 8%	AC5
7.	Silica fume 10%	AC6
8.	Silica fume 12%	AC7
9.	Steel Slag 2%	AC8
10.	Steel Slag 4%	AC9
11.	Steel Slag 6%	AC10
12.	Steel Slag 8%	AC11
13.	Rubber 2%	AC15
14.	Rubber 4%	AC16
15.	Rubber 6%	AC17
16.	12% Silica fume + 4% Steel Slag	D1
17.	12% Silica fume + 6% Steel Slag	D2
18.	15% Fly ash + 4% Steel Slag	D3
19.	20% Fly ash + 6% Steel Slag	D4
20.	15% Fly ash + 10% SF + 4% Slag	T1
21.	15% Fly ash + 10% SF + 6% Slag	T2
22.	15% Fly ash + 12% SF + 4% Slag	T3
23.	15% Fly ash + 12% SF + 6% Slag	T4

4 Results and Discussion

Behaviour of the Pervious Concrete Pavement on Triple Component Replacement : The three material combinations were chosen based on the best results from several testing, and slabs were cast with their flexural behaviour examined. Of the three replacement mixtures, the steel slag addition of 4% results in the highest strength. The stiffness of the mix T1 is around 40% of the maximum strength. When comparing the

strength of T1 mix to T3, it can be seen that adding 2% silica fume lowers the deflection value and adding 2% silica fume raises the ultimate strength.
The load and deflection curve for the three component replacement mixes reveals that mixes T1 and T2 have their stiffness values deflect after 3 kN of load, while mixes T3 and T4 have their stiffness changes in its direction after 2 kN of load. This is because the addition of steel slag to the mix slightly reduces its strength.

Table 2. Flexural Strength of Triple Component Replacement in Pervious Concrete Pavement

Sl no	Mix ID	ULTIMATE LOAD (kN)
1	N	11.48
2	T1	9.45
3	T2	9.09
4	T3	10.82
5	T4	10.03

ANALYTICAL EXAMINATION OF THE FLEXTURAL ACTIVITIES OF THE OLD CONCRETE PAVEMENT:

ANSYS, a finite element analysis program, was used to develop a finite element model for the analytical investigation that was similar to the typical concrete pavement. Pervious concrete pavement behavior has been simulated using the ANSYS software. In particular, the modeling procedure calls for the addition of Solid 65, a three-dimensional element with crushing and fracturing capabilities. For situations when reinforcing bars are not present, pervious concrete is simulated using an eight-node solid element called Solid 65. The solid element consists of eight nodes, each of which has three degrees of freedom that allow translations in the x, y, and z dimensions. The element is prone to plastic deformation, crushing, and fracture in three orthogonal directions.

This model will determine the deflection patterns at each load increment, and it may determine the deflections at any area of the pervious concrete slab just by providing the pervious concrete mix's cross-sectional size, density, and Young's modulus. It was expected in the analytical investigation that the plane section would stay plane following bending. For the research, a load versus deflection curve is created up to 5 kN. After that, the load is applied till the pervious concrete slab fails. Since there is no reinforcement in the pavement, the failure occurs suddenly, hence the deflectometers are removed after a 5 kN load. As a result, the proposed model will produce improved outcomes up until the initial fracture.

It was found that, for the nominal mix, the experimental deflection was 4.5 mm, whereas the analytical model's deflection was 4.43 mm, after comparing the findings of the experimental and analytical investigations. Furthermore, compared to the analytic models, the experimental values for S1 through S6 in the single replacement trials displayed a larger deflection. It is also found that the triple component replacement in the experimental investigation has larger values than in the analytical models. Load vs Deflection curve for Triple replacement, in pervious concrete are given in the figure 1 and Deflection pattern of mix in pervious concrete are given in figure 2.

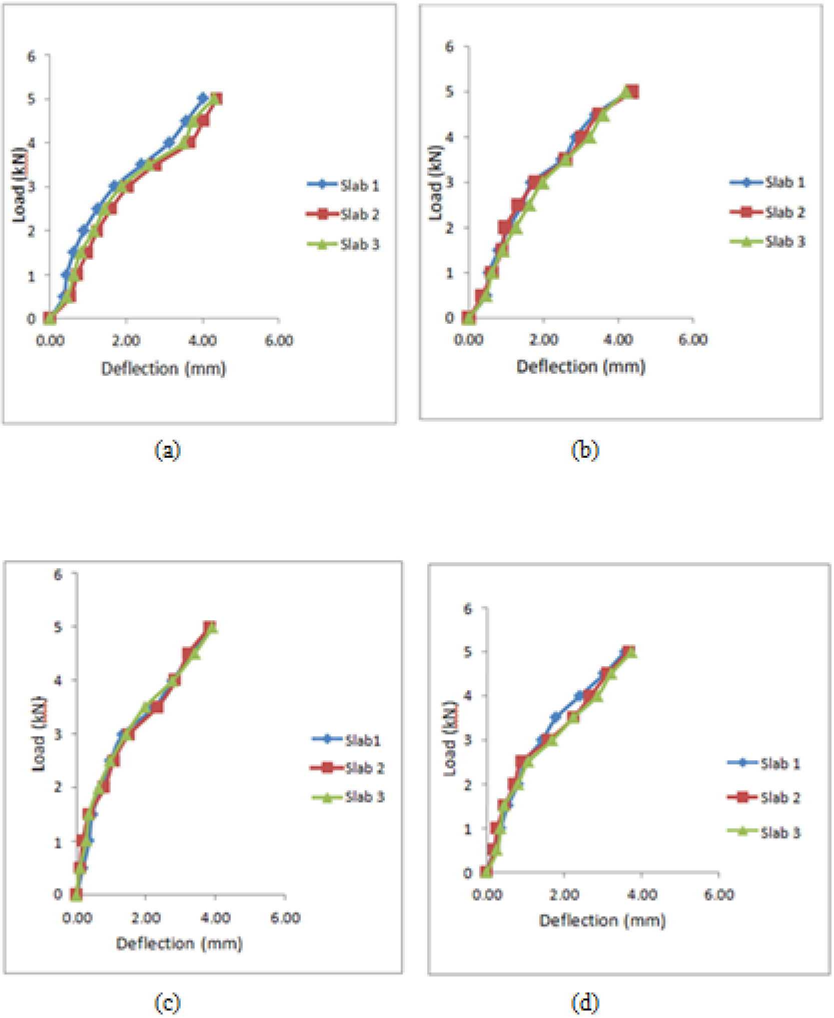

Fig.1 Load vs Deflection curve for Triple replacement, in pervious concrete (a) T1 mix (b) T2 mix (c) T3 mix (d) T4 mix

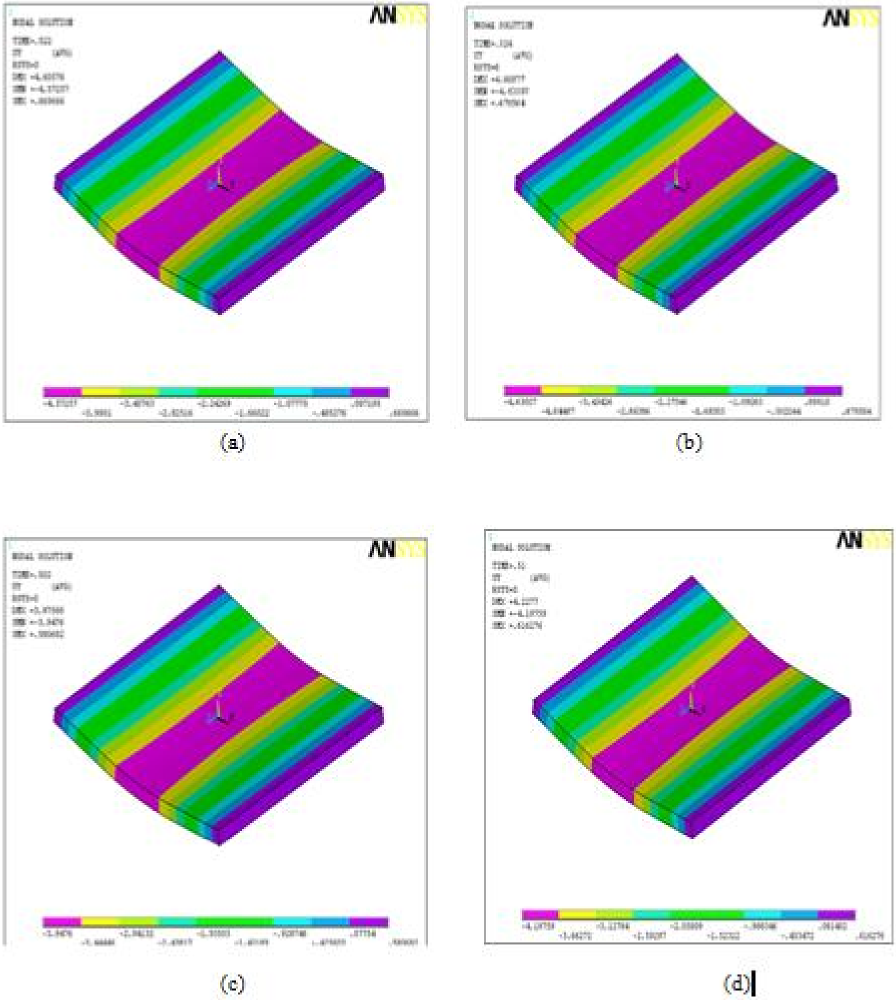

Fig.2 Deflection pattern of mix in pervious concrete (a) T1 mix (b) T2 mix (c) T3 mix (d) T4 mix

5 Conclusions

COMPRESSIVE STRENGTH OF TRIPLE COMPONENT REPLACEMENT After the compressive test was carried out for the various combinations of supplemental material replacements, it was concluded that the compressive strength of the various combination mixes was appropriate above the required strength. It is found that concrete with 4% instead of 6% replacement of coarse particles with steel slag has a better strength. The concrete's strength is also impacted by the addition of silica fumes.

The compressive test of pervious concrete has been performed for a range of substitution combinations of additional components. The T3 mix is found to have a higher compressive strength. Adding extra silica fume mix to the pervious concrete mix increases its compressive strength and lowers its permeability rating. By adding more steel slag, the mix's compressive strength is decreased. Moreover, the addition of fly ash has less of an effect on the compressive strength of the mix because it can only account for 15% of the replacement.

T3, T2, and T4 are the next three mixes in the three mix replacement category with the second-highest strength relative to the nominal mix. The 6% replacement steel slag has the lowest compressive strength among the three replacement mixes since the percentages of fly ash and silica fume are stabilized to fixed percentage replacements.

FLEXURAL STRENGTH OF TRIPLE COMPONENT REPLACEMENT As discussed in chapter 3, casting beam specimens allows for the determination of the concrete's flexural strength. Steel slag has an impact on flexural strength; adding 6% of steel slag in place of coarse aggregates results in a little decrease in flexural strength. The highest values are obtained when steel slag (4 percent) and silica fume (10 percent) are used in place of cementitious material. The flexural strength value somewhat decreases as the fraction of silica fumes increases.

The results demonstrate that mix T1, which has the maximum split tensile strength attainable, contains 10% of silica fume and 4% of slag. When the steel slag is increased to 6%, the value begins to decline. Furthermore, the split tensile value drops to 12 percent silica fume when 6% steel slag is added to the pervious concrete in place of coarse particles. The silica fume's strength is demonstrated to increase with content, however the main drawback is the loss of workability.

SPLIT TENSILE STRENGTH OF TRIPLE COMPONENT REPLACEMENT The results clearly shows that mix C1, which has the highest split tensile strength, contains 10% of silica fume and 4% of slag. When the steel slag is increased to 6%, the value begins to decline. Furthermore, applying 12 percent silica fume instead of coarse aggregates with 6 percent steel slag results in a drop in the value. The silica fume's strength is found to increase as content increases, but the main drawback is the loss of workability. The flexural strength of pervious concrete is ascertained by casting beam specimens that mimic regular concrete.

When steel slag is present, flexural strength is decreased; when steel slag is substituted for coarse aggregates at a proportion of 6, flexural strength is slightly reduced. The blend T3 shows the highest values of flexural strength. 10% silica fume is used in place of cementitious material in this mix, and 4% steel slag is substituted. The flexural strength value somewhat decreases as the fraction of silica fumes increases. Of the three component replacement mixes, the T2 mix—which consists of 15% of fly ash, 10% of silica fume, and 6% slag—has the maximum value for stiffness. Additionally, the load and deflection data from the PCP make it clear that the deflection values are within acceptable boundaries.

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