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Effect of Partial Replacement of Fine Aggregate by Alternative Materials in Paver Blocks

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Abstract: The need of concrete is increasing every year as the population of humans are increasing as per their demands i.e. infrastructure developments and shifting composition etc. Due to rising demands and fight to produce good quality of concrete, construction industries have overused the natural materials used in concrete, leads us to extinction in natural materials and results in rising prices of materials. Thus, the environmental problems related with excessive extraction and mining from natural sources have been reported in many countries. Due to finite availability of natural materials, and involvement of economy, it has now become very important to look as for the alternative source for natural materials used in concrete i.e. gravels and crushed sand. Metal swarf and ceramic tile waste is a propitious material that can be used as an alternative for the crushed sand i.e. (fine aggregates) in concrete. The paper demonstrates the potential of re-use for metal swarf and ceramic tile waste i.e. industrial by-product as a substitute of a fine aggregate in concrete. The fine aggregates i.e. (crushed sand) are replaced with fine metal swarf and ceramic tile waste in four different substitution rates i.e. (5%, 10%, 15%, and 20%). Tests were performed to examine the mechanical properties i.e. (compressive strength) as well as the durability of concrete i.e. (water absorption). The results indicate that the compressive strength after 28 days of concrete paver blocks was increased a little by replacing metal swarf by 5% weight of fine sand, compressive strength after 28 days of concrete paver blocks decreases by 7-8% for 10%, 15% and 20% replacement with metal swarf. Compressive strength after 28 days was decreased by replacing ceramic tile waste by 7-15% for 5%, 10%, 15% and 20% replacement. Water absorption increases by approximately 10% for each 5% replacement of metal swarf and water absorption increases drastically while replacing ceramic tile waste i.e. around 100% for 20% fine aggregate replacement with ceramic tile waste.

Keywords: Fine metal swarf, ceramic tile waste, concrete, crushed sand, compressive strength, water absorption.

I. INTRODUCTION

The foundation of the global construction sector is concrete. The need for concrete is growing daily as human population rises in response to their demands, such as infrastructure expansions, changing demographics, etc. The major components of concrete, such as cement, sand, and coarse aggregates, are becoming increasingly scarce as global demand for concrete rises, creating a number of sustainability problems. Aggregates comprise nearly 70% of the primary component material used to produce concrete. Every year, the world's population grows, increasing the demand for building supplies, which will eventually cause shortages of those supplies, drive up costs, and have a severe impact on the environment. Concrete is made up of 25% fine particles, 45% coarse aggregates, 10% cement, 18.5% water, and 1.5% air, according to a report released by UNEP in February [1]. This demonstrates that aggregates are the most important component of the construction sector, with concrete making over 75% of aggregate utilization. The main components of concrete, namely crushed rocks, sand from the earth, and gravels, are fine aggregates and coarse aggregates. According to estimates, each year 40–50 billion metric tonnes of these materials are taken from the ocean's coasts, the sand surrounding river sites, and quarry pits. [1]. Paver blocks have been popular for various commercial, municipal, and industrial locations including parking lots, pedestrian walkways, traffic crossings, container yards, and roadways due to their strength, durability, and aesthetic surfaces. Over a levelling layer of sand and a compacted stone subbase, interlocking paver blocks are laid. Concrete, which is primarily formed of cement, fine aggregates, coarse aggregates (10 mm and below), water, chemical agents, etc., is used to make concrete paver blocks. [2] The use of paver blocks has been proven to be most beneficial on low-traffic roads, although study is also being done on how well they work on high-traffic roads. The paver blocks are used for taxiways, toll booths, and other surfaces (IRC: SP: 63-2004). The majority of the literature claims that the main benefit of employing paver blocks over conventional pavement practices is the ease with which subsurface utilities may be accessed once the pavement has been built. Despite having greater initial construction costs, paver block pavements are proven to be less expensive to maintain than traditional pavement designs, making them more cost-effective for low-volume traffic. [3]

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A. *Alternative for Crushed sand (Fine Aggregates)*

The cost of crushed sand ultimately rises as a result of the crushed sand supply from natural sources approaching its limit. An alternate source that should be widely accessible and meet all necessary technical standards for fine aggregate is needed to meet the demand for sand in the modern building industry. Over the past few decades, extensive study has been done to identify a different source for a fine aggregate (crushed sand). As a result of constant research and development in the building industry, scientists have discovered that a number of waste materials have qualities that are nearly identical to those of fine aggregates.

1) *Fine Metal Swarf:* The cost of crushed sand ultimately rises as a result of the crushed sand supply from natural sources approaching its limit. The demand for sand as an alternative source that should be widely accessible and meet the necessary technical criteria for fine aggregate in modern times requires sustainable expansion in the construction industry. Over the past few decades, extensive study has been done to identify a different supply of fine aggregate (crushed sand). As a result of constant research and development in the building industry, scientists have discovered that a number of waste materials have qualities that are nearly identical to those of fine aggregates.
2) *Ceramic Tile Waste:* Almost all buildings employ ceramic tiles as major construction materials. These tiles are typically made starting with the raw materials, which are then ground and mixed, granulated by spray drying, pressed, fired and/or polished, and then glazed. About 2 wt% of the finished products are waste mud, which is the silt of washed-down particles from various production operations. This mud is far too impure to be reused in the creation of tiles; instead, it is typically disposed of as garbage in landfills. It contains both coarse particles (feldspar, quartz, and ground-fired tiles) and fine particles (clay minerals like kaolinite and mica). Due to the enormous volume of garbage produced annually and the rising expense of disposal, removal of this waste mud has grown increasingly difficult. Utilizing this trash for other purposes is one option to find a solution to this issue. The processing of ceramics results in the production of ceramic waste. These wastes pollute the groundwater, the air, and the soil. Mud and tile, which are the pollutants of the ceramics industry, are produced by the refinery systems of the ceramic factory and are kept there as waste. There is sufficient tile waste on the planet to be used as fine aggregate in concrete. Natural materials sintered at high temperatures are used to make tile.

Fig. 1 Fine Metal swarf

Fig. 2 Ceramic Tile waste

II. EARLIER RESEARCH

Salman Ahmad et al. (2023) used low-density polyethene (LDPE) waste plastic as a binding material in the production of LDPE-bonded sand paver blocks. In order to create paver blocks, the LDPE waste plastic was melted outdoors while being combined with sand. Sand particle size, coconut fibre content, and the LDPE-to-sand ratio all varied. We measured the density, compressive strength, and water absorption of paver blocks. According to their findings, adding coconut fibre at a rate of 3% increased compressive strength by 18.4% and decreased water absorption by 54.1%. The highest compressive strength is produced by the finest sand, and the best experimental results were seen at an LDPE to sand ratio of 30:70. The water-logged areas can use the sustainable paver blocks created by this research. [4]

Rani Fahmi Zakaria et al. (2023) tested Low-density polyethylene (LDPE) and polyethylene terephthalate (PET) plastic as a replacement for fine particles to see how they affected the compressive strength of paving blocks. A minimum compressive strength of 12.5 MPa was specified for the paving stones in their study, which were off-plan C quality and typically employed as a pedestrian facility. With volume variations of 0%, 5%, 10%, and 15%, plastic wastes (LDPE and PET) were used as a partial replacement for fine aggregates. Additionally, by substituting fly ash for cement in LDPE mixes (LDPEF) with a 15% fly ash content, fly ash was added. Cylinder specimens of 150 mm in diameter and 300 mm in length were used for the compressive strength test. They discovered that the compressive strength was reduced by 35.26%, 37.69%, and 40.68% for LDPE, 34.15%, 52.22%, and 56.53% for PET, and 23.14%, 18.01%, and 24.65% for LDPEF, respectively, when LDPE and PET plastic wastes were used as a partial replacement of fine aggregate. However, the tested paving blocks' compressive strength result largely exceeds the 12.5 MPa minimum requirement for compressive strength for paving blocks of quality C. [5]

M. Vijayakumar et al. (2022) casted concrete with various mix ratios by substituting fine aggregate with C&D waste at a rate of 0%, 20%, 40%, and 80%. The compressive strength of paving blocks was evaluated. The findings showed that fine aggregate replacement using construction and demolition waste fine aggregate in the range of 40% to 60% may achieve maximum strength while reducing concrete costs by 3.28 percent. The results show that P-Sand can successfully replace fine aggregate with only a slight strength increase. [6]

Mrunali Indurkar et al. (2022) employed lathe metal debris as a fibre and added up to 30% by weight at a gap of 10% (i.e., 0%, 10%, 20%, and 30%) in M20 and M30 concrete grades. They compared fiber-reinforced concrete with lathe metal scrap (metal steel scrap) added in varying weight amounts to plain cement concrete. The compressive strengths of normal cement concrete and lathe metal scrap reinforced concrete (LMSRC) M20 and M30 are being compared analytically. Comparing LMSRC's 28-day compressive strength to normal cement concrete's 28-day compressive strength, it was discovered that LMSRC's strength was higher. [7]

Lailesh Late et al. (2021) presented an experimental investigation employing fine and coarse waste glass to produce paver blocks. Some of the mechanical and physical characteristics of paving blocks with varying amounts of fine and coarse aggregate substitution in place of fine glass (FG) and coarse glass (CG). The test results revealed that because FG is pozolanic, replacing it with FA at a level of 20% by weight has a significant impact on the paving blocks' compressive strength, flexural strength, splitting tensile strength, and abrasion resistance when compared to the control sample. At a FG replacement level of 20%, the paving block samples exhibit compressive strength, flexural strength, splitting tensile strength, and abrasion resistance that are, respectively, 69%, 90%, 47%, and 15% higher than the control sample. According to their test results, FG at a concentration of 20% has the potential to be used in the manufacture of paving blocks. The beneficial effect on these properties of CG replacement with FA is small as compared with FG. [8]

Shubhangi Kadam et al. (2021) dealt with the partial replacement of cement by waste plastic and sand by using ceramic waste. The samples of pavers were cast using plastic waste to replace 5%, 10%, 15%, and 20% of the cement, and ceramic waste to replace 10% of the sand, and they were examined after curing for 7, 14, and 28 days to examine changes in characteristics. They came to the conclusion that paver blocks made of plastic and ceramic quickly attained a very high compressive strength of 60.60 MPa. It was discovered that the compressive strength of plastic and ceramic paver blocks increased with replacement up to 15%; 10% replacement of plastic and ceramic results in slightly higher compressive strengths. The compressive strength is reduced somewhat by complete replacement with 20% plastic and 10% ceramic, resulting in 43.635 MPa. The strongest paver block was determined to have a maximum strength of 60.60 MPa at 15% plastic and 10% ceramic replacement, which is extremely high and suitable for light-weight traffic. [9]

J. Venkateswara Rao et al. (2020) compared the results of an experimental investigation on the compressive and flexural strength of traditional M-40 uni-paver concrete blocks with paver blocks made by combining partial replacements of the cement and fine aggregate with fly ash and pond ash, respectively.

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While maintaining the performance of the paver block in terms of its strength aspect, the incorporation of these industrial items led to the saving of cement and, as a consequence, an overall saving of roughly 10% in the economy per paver block manufacturing. The paver block used in this experimental study was a specimen with a zigzag shape and dimensions of 201 mm, 100 mm, and 80 mm. Initially, pond ash and fly ash were substituted for fine aggregate and cement, respectively, in percentages of 5, 10, 15, and 20. Following the replacement of the fine aggregate and cement, the mechanical properties of the paver blocks were used to assess how well they performed. They came to the conclusion that by substituting pond ash for 10% of the aggregate fines in conventional paver blocks, the compressive strength could be increased by 11%. The experimental study on the efficient use of industrial wastes, such as fly ash and pond ash, as an alternative source material for fine aggregate and cement. The amount of aggregate fines that pond ash could replace, up to 5%, yielded the greatest increase in flexural strength. Additionally, the efficient utilization of industrial wastes, including pond ash and fly ash, can reduce costs while simultaneously increasing the mechanical qualities of concrete paver blocks. [10]

III.METHODOLOGY

This section describe the details of various materials used in experiment and methodology that has been followed in this program for evaluation of different properties like mechanical property i.e. (compressive strength), durability properties i.e. (water absorption) by replacing the fine aggregates with ceramic tile waste and steel swarf at several percentage levels in the casting of concretes pavers. This section also describes about the procedure that have been adopted for physical testing of various materials such as cement, sand, coarse aggregates and this chapter includes the details of specimens used in testing, procedure of preparation of specimens and casting for different test, details of mix design, age of specimens for testing and various testing procedures used in tests.

A. Mix Proportion

Concrete was designed according to Standard Specifications IS15658:2006 to have 30 MPa compressive strength of 28 days of curing ages. Additional concrete mixtures were made by replacing fine aggregates by fine metal swarf and ceramic tile waste at several percentages (5%, 10%, 15%, and 20%) by weight. The water cement ratio is kept constant for all designed concrete mixtures. The mix proportion for all concrete mixtures are given in table 1.

Table 1 Mix proportion of concrete as per M30 grade

	0%	5%	10%	15%	20%
Cement (kg/m^3)	404.35	404.35	404.35	404.35	404.35
Metal swarf/ ceramic tile waste (%)	0	5	10	15	20
Metal swarf/ ceramic tile waste (kg/m^3)	0	26.917	53.834	80.751	107.668
Sand (kg/m^3)	538.34	511.423	484.506	457.589	430.672
W/C	0.46	0.46	0.46	0.46	0.46
Water (kg/m^3)	190.01	190.01	190.01	190.01	190.01
Coarse aggregates (kg/m^3)	1255.07	1255.07	1255.07	1255.07	1255.07

B. Specimens Preparation and Casting

A very careful procedure was adopted in the mixing, batching and casting operations. The cement, fine aggregates, coarse aggregates, water were weighed. Fine aggregates were partially replaced in fixed amount and dry mixed separately to uniform color. The cement, fine aggregates, coarse aggregates, were dry mixed separately. Superplasticizer was added in water separately in different container as per requirement with required quantity. These were hand mixed or mixed in machine to a uniform color on a watertight platform.

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Fig. 3 Dry mix of concrete mix

Fig. 4 Mixing of concrete mix with mixer

The samples were allowed to kept first at ambient condition of temperature 24 hours in the paver mold. After 24 hours, these samples with care were demolded so that edges of sample could not break, and testing can be done in good manner. Then samples were placed in curing tank at ambient temperature of 27± 2 °C and cured till testing or as per requirement of the test. All specific details of various tests are given in table 2.

Table 2 Detail of specimens

Test	Specimen	All testing ages
Compressive strength	60 mm thick Milano/Cosmic Shape Pavers	Compressive strength
Water absorption	60 mm thick Milano/Cosmic Shape Pavers	

C. Testing Procedure

After curing ages of required time period, the samples were taken out from curing tank and then the surface of each samples are wiped off. All samples tests for compressive strength and water absorption were performed as per Indian Standard Specifications. The compressive of samples was done after 7, 14 and 28 days of curing age.

The following test procedure of all properties is given below:

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Fig. 5 casting of samples

1) *Compressive Strength:* Compressive strength is the important mechanical property that used to give characteristic compressive strength of concrete. Compressive strength for all concrete paver samples were done as per Indian Standard Specifications. Furthermore, the paver block test was evaluated at the curing age of 7 days, 28 days and 56 days. Concrete samples were kept demolded for 24 hours and after casting, the concrete samples were placed in curing tanks for required curing age. Then after each curing age the samples were taken out and then the testing was done in CTM by applying specified load rate i.e. 140 kg/cm2/min. Then the load of the machine was increased until the concrete specimens do not break, and the maximum amount of load was taken and noted down of concrete specimens.

Fig. 6 Compression Testing Machine

Fig. 7 Testing of sample in CTM

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The formula used to calculate compressive strength is:

σ = P/A

where,

A = Area of cross section of cube (mm2)

P = Maximum load sustained by the cube (N)

σ = Compressive strength (N/mm2)

The various results of compressive strength testing were done for 5 specimens at 7 days, 14 days and 28 days of curing age for each concrete sample in N/mm^2.

2) *Water Absorption Test:* Absorption testing is a popular method of determining the water-tightness of concrete. A water absorption test, such as BS 1881-122: 2011 Testing Concrete: Method for Determination of Water Absorption, measures the amount of water that penetrates into concrete samples when submersed. The lower the absorption, the better the result. The absorption tests will improve over time – as the concrete is saturated and crystals continue to grow. Therefore, when testing durability of concrete that has a crystalline admixture within the mix-design – testing the absorption at later stages will give more realistic results. In the end, you are looking for the most definitive results in this process. The importance of concrete durability cannot be underestimated, especially when hoping to build a sustainable concrete structure that will last well into the future.

IV.RESULTS

We have used Paver Blocks by 5% replacement of fine aggregate by metal swarf = 15+3 = 18 pavers (15 pavers for compression tests after 7, 14, and 28 days, 3 pavers for water absorption).

The same type of pavers are used for 10%, 15%, and 20% replacement.

Therefore, the total number of metal swarf-based paver blocks is 18+18+18+18 = 72 paver blocks.

The same number of pavers are used for ceramic tile waste-based concrete paver blocks. So the total tested paver blocks are 160 including conventional paver blocks. The compressive strength of paver blocks is estimated at 7, 14, and 28 days, and comparisons have been shown in figures 8 to 13.

Variation in water absorption due to replacement of fine sand with metal swarf has been shown in figure 14, and with ceramic tile waste has been shown in figure 15.

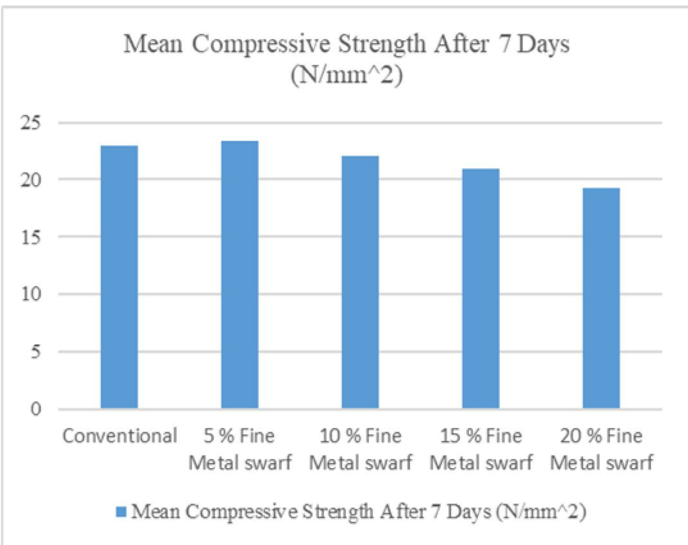

Fig. 8 Mean Compressive strength of metal swarf based concrete paver blocks after 7 days

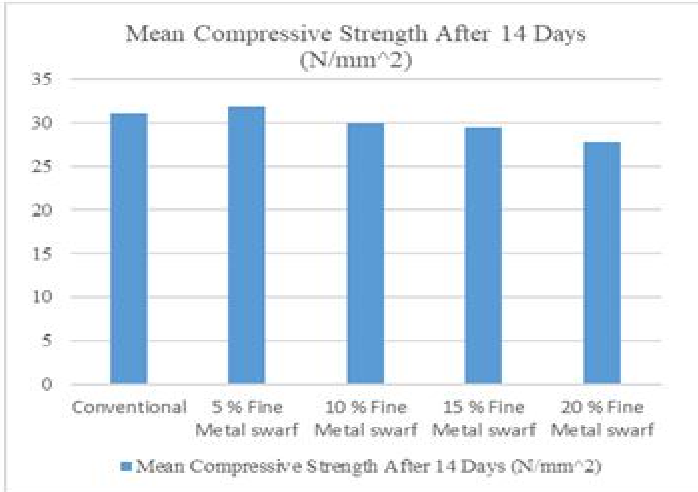

Fig. 9 Mean Compressive strength of metal swarf based concrete paver blocks after 14 days

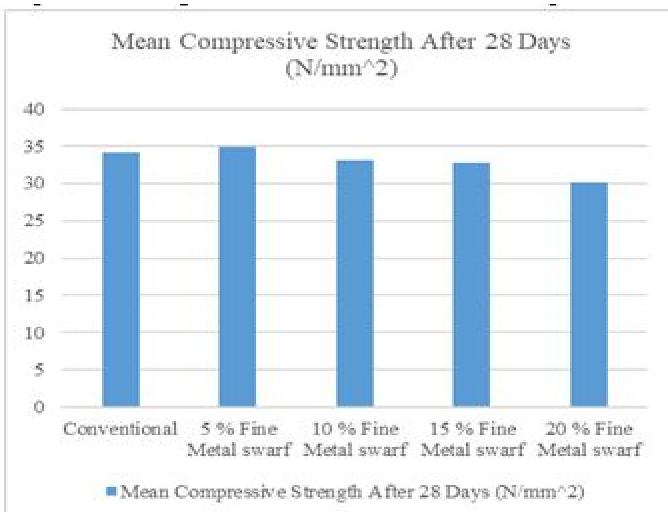

Fig. 10 Mean Compressive strength of metal swarf based concrete paver blocks after 28 days

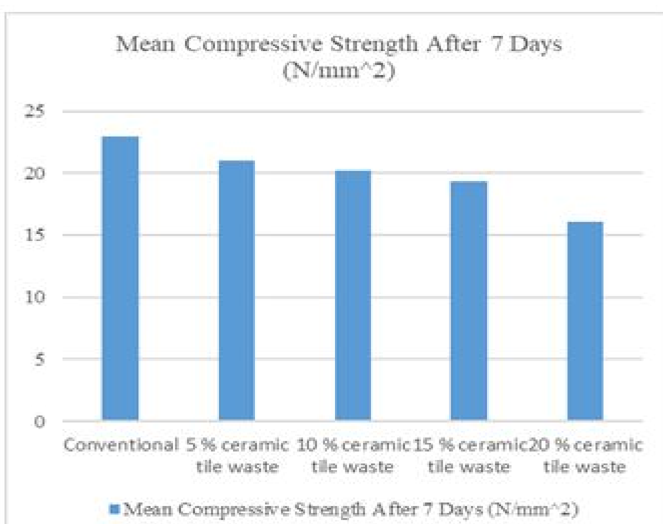

Fig. 11 Mean Compressive strength of ceramic tile waste based concrete paver blocks after 7 days

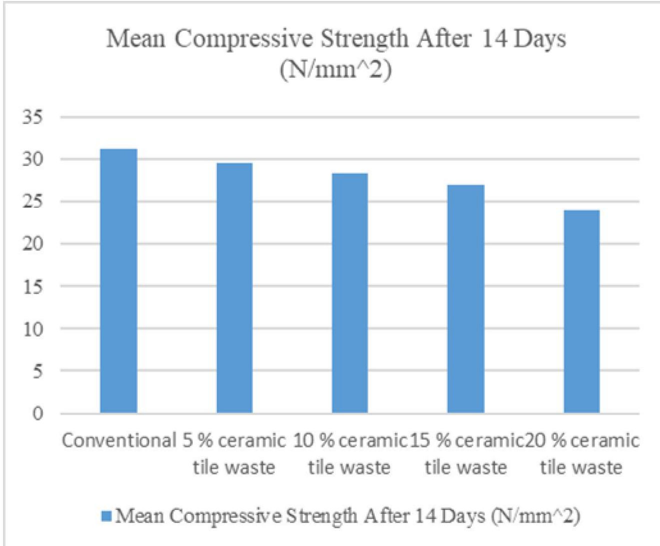

Fig. 12 Mean Compressive strength of ceramic tile waste based concrete paver blocks after 14 days

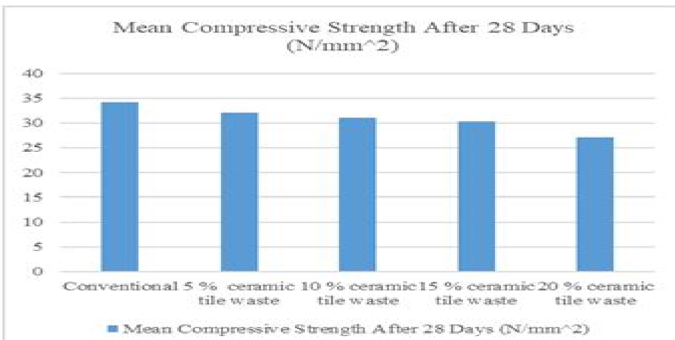

Fig. 13 Mean Compressive strength of ceramic tile waste based concrete paver blocks after 28 days

All pavers' initial weights were measured after the specimens were manufactured. Concrete pavers are submerged in water for 24 hours after 7, 14, and 28 days of cure are complete. The concrete pavers ' initial weight serves as a measure of how much water they will eventually absorb. It is computed and compared how much water absorbed by self-cured and air-dried pavers. In Figures 14 and 15, respectively, comparisons of concrete paver blocks made from fine metal swarf and ceramic waste, are illustrated.

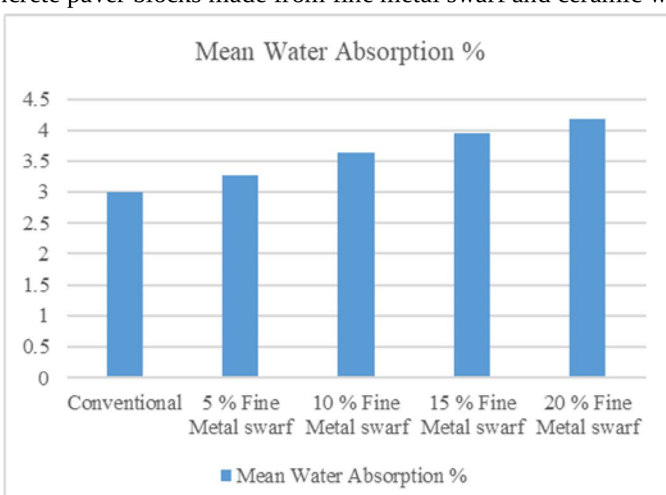

Fig. 14 Mean Water Absorption % of fine metal swarf based concrete paver blocks

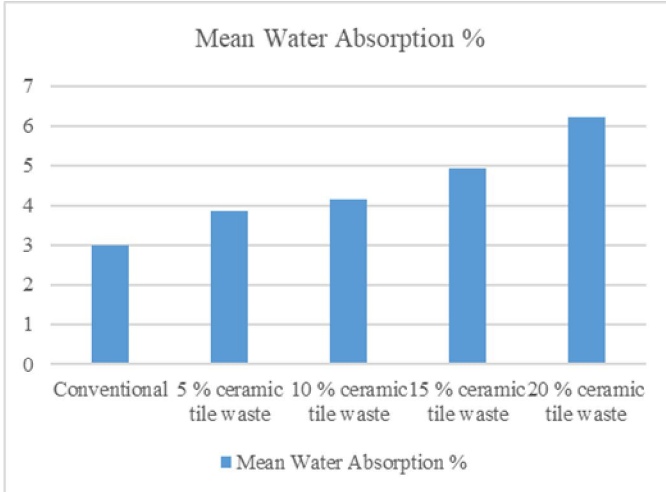

Fig. 15 Mean Water Absorption % of fine metal swarf based concrete paver blocks

V. CONCLUSIONS

For the present, experimental investigation has been on M-30-grade concrete pavers with the replacement of metal swarf and ceramic tile waste as fine aggregates in various percentages. After testing 160 concrete paver blocks with 5%, 10%, 15%, and 20% replacement of fine sand with metal swarf and ceramic tile waste, The results indicate that the compressive strength after 28 days of concrete paver blocks was increased a little by replacing metal swarf with 5% weight of fine sand, but the compressive strength after 28 days of concrete paver blocks decreased by 7-8% for 10%, 15%, and 20% replacement with metal swarf. Compressive strength after 28 days was decreased by replacing ceramic tile waste by 7–15% for 5%, 10%, 15%, and 20% replacement. Water absorption increases by approximately 10% for each 5% replacement of metal swarf, and water absorption increases drastically while replacing ceramic tile waste, i.e., around 100% for a 20% fine aggregate replacement with ceramic tile waste.

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