International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-2, December, 2019

Strength Parameters of Paver Blocks By Incorporating Used Foundry Sand

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ABSTRACT---All over the world the handling and disposal of waste products from the manufacturing industry are of big concern these days. In this context, the volume of used foundry sand is such that the disposal creates a big environmental problem for all the countries where the foundry industries are in abundance. New methodologies should be employed to utilize the used foundry sand in making value-added products in a commercial manner to keep the environment free from the potential adverse effects of the accumulation of this waste product. This research is an attempt to put forward the idea of utilizing the used foundry sand in commercial production of value-added products like paver blocks from a techno-economical point of view. This will be beneficial to the ecological and environmental systems for sustainable development progressing towards a greener world.

Keywords: Compressive strength, flexural strength, paver blocks, used foundry sand, water absorption.

I. INTRODUCTION

Used foundry sand is an industrial waste product obtained after dismantling the mould from the casting industries. Every year foundries generate between 9 and 13 million tons of sand that is unfit for continued use in the mould-making process. The foundries in India produce around two million tons of used foundry sand yearly. There are a number of ways for reusing a substantial amount of the non-hazardous sand including roadbeds, construction fill, etc. It is unfortunate to note that much of this sand is currently disposed of in landfills. The discarded sand obtained from the foundries is known as "Used Foundry Sand", "Waste Foundry Sand". The foundry waste sand can be disposed of effectively by utilizing it in various construction-oriented uses in an economical manner. Earlier studies denoted the usage of foundry used sand instead of fine aggregates in different proportions for normal concrete in laboratory conditions. However, studies in which used foundry sand is a constituent for the commercial manufacture of building products where higher load capacity and durability are of importance are still in a nascent stage. In the proposed study the application of 'used foundry sand' for manufacturing commercial commodities like interlock paver blocks is examined.

Revised Manuscript Received on December 30, 2019.
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II.USED FOUNDRY SAND

By crushing the waste moulds from the metal foundries we can get the 'used foundry sand'. There are two varieties of waste foundry sand namely 'green sand' and 'chemically bonded sand'. Either varieties of sand discarded from foundries are appropriate for value-added usage even though they are showing varied chemical as well as physical features. Released moulds from foundry are shown in Fig.1.

Fig. 1.Released Moulds from Foundry

Details of 'chemically bonded' and 'green sand' are described below.

A. Green Sand

The 'green sand' in its original form is made by the blending of different materials of natural origin. The main constituent of 'green sand' is pure silica sand. The other ingredients include water, additives with carbon content and bentonite. The colour of 'green sand' is black which is attributed to the presence of carbon in the mixture. The bentonite has a particle size of less than two hundred microns and its function is to hold all the ingredients with the combined action of water.

B. Chemically Bonded Sand

For making the mould for the casting of metals with very high melting temperatures, 'chemically bonded used foundry sand' is used. Apart from green sand where clay is used as the binder, in chemically bonded used foundry sand, the binder used is of organic origin. However, it should be noted that binders with inorganic origin can also be employed in the making of chemically bonded sand which is the base material for building the mould for specific applications.

The salient physical properties of green sand stated by the Recycled Materials Resource Center are shown in Table I [1].

Table-I: Green Sand - Physical Properties

Sl.No.	Property	Value
1	Specific Gravity	2.39-2.70
2	Water Absorption	0.76% -6.20%
3	Bulk Density	160 lb/ft^3
4	Moisture Content	0.1% -15%
5	Hydraulic Conductivity	10^{-3}cm/sec-10^{-9}cm/sec

Du L et al (2002) reported the percentage of chemical oxides present in used foundry sand [2].In that percentage of thirteen oxides were stated with silicon dioxide as the major contributor.

III. CONCRETE PAVER BLOCKS

In the middle of the twentieth century, only paver blocks made of concrete came in to picture of building products. Many drastic changes have occurred in the manufacture of paver blocks right from the beginning. Two types of concrete block pavements are in existence. The first one uses non-interlocking blocks and is termed as 'Concrete Block Pavements (CBP)' or noninterlocking block pavements. The second type uses interlocking blocks and termed as 'Interlocking Concrete Paver Blocks (ICBP)'. Specifications of concrete paver blocks are set forth in Indian standard IS 15658-2006[3]. Indian road congress has specifications for interlocking concrete pavement [4]. European Standardization Committee also published requirements and test methods for concrete blocks [5].

IV. RESEARCH SIGNIFICANCE

Used foundry sand is normally used for filling low lying areas. In India, a large quantity of used foundry sand is available as waste material. Natural river sand is almost unavailable in most parts of India. The production of rock sand is also facing problems due to various environmental issues. In this context foundry used sand in place of river sand or manufactured sand partially or fully for the manufacture of commercial products like paving blocks is beneficial both economically and environmentally.

V. LITERATURE REVIEW

Marchioni et al (2012) conducted experiments on the practicability of the application of spent foundry sand for the manufacture of paver units in Brazil[6]. They found that 18% spent foundry sand is ideal for the production of paving blocks. Kewal et al (2015) studied the properties of paving units made of geopolymer concrete with used foundry sand [7]. It is reported that the addition of used foundry decreases the compressive strength of paver blocks. Santos et al (2018) investigated the properties of paver units with the interlocking property made using used foundry sand and found that the strength in compression was less in comparison to the specification laid by the Brazilian standards[8]. KauswalaTausif et al (2018) conducted an experimental study on foundry sand usage in paver blocks and reported that the maximum strength in compression was achieved at foundry sand usage of 10% of the fine aggregate mass [9]. SupriyaKulkarni and VikhyatKatti (2017) studied properties of paver blocks made with foundry sand and found that the strength in compression decreases with the waste foundry sand percentage increase and the percentage water absorption increases with the percentage of waste foundry sand[10].

VI. EXPERIMENTAL INVESTIGATION

The experimental investigation includes the selection of sources of all materials and the testing of materials for finding out the properties. Adequate quantity of materials procured and conducted tests in order to get the relevant properties for the mix design of concrete. The used foundry sand was collected from a local foundry. The cement used was conforming to IS 12269-2013[11]. The coarse aggregates used were 10 mm graded aggregate conforming to IS 383-2016[12]. Quarry sand with zone II grading was used as fine aggregate. The plasticizer used was superplasticizer based on sulfonated naphthalene formaldehyde conforming to IS: 9103- 1999[13]. The test results of the materials are shown in Table II.

Table-II: Material Properties

Property	Cement	Fine Aggregate	Coarse Aggregate	Used Foundry Sand	Plasticizer
Specific Gravity	3.15	2.77	2.78	2.62	1.265
Water Absorption	-	1.05%	0.85%	1.80	-
Bulk Density	1440	1800	1560	1450	-
Grading Zone	-	II	-	III	-

Potable water was used in the concrete mix and the dissolved solids are within limits of Table 1 of Indian Standard: 456-2000[14].

VII. EXPERIMENTAL METHODOLOGY

The Indian standard code for the concrete paver blocks specifies certain minimum thickness and strength of concrete according to the traffic conditions. As per Table 1 of IS-15658-2006, for heavy traffic, minimum compressive strength is 50N/mm2 and the minimum thickness of the paver block is 100 mm. Hence a concrete of M-50 and mould size of 200mm x 100mm x 100mm is selected for the preparation of the sample paver blocks.M-50 grade concrete was designed to attain target mean strength of 58.25MPa as per IS:10262-2016[15]. The fine aggregate was replaced with 0-40% of used foundry sand with 10% increments for the paver block samples. The mix proportions for the paver blocks are shown in Table III.

Table-III: Mix Proportions

Paver Block Desig-nation	Materials(Kg.)					
	Cement	Water	Fine Aggregate	Coarse Aggregate	Used Foundry Sand	Plasticizer
P0	450.0	153.0	879.0	1070.0	0.0	2.25
P1	450.0	153.0	791.1	1070.0	87.9	2.25
P2	450.0	153.0	703.2	1070.0	175.8	2.25
P3	450.0	153.0	615.3	1070.0	263.7	2.25
P4	450.0	153.0	527.4	1070.0	351.6	2.25

The samples were cast at the laboratory with heavy mechanical vibration for the compaction and cured in water for the testing of water absorption, tensile splitting strength, compressive strength at 28 days, breaking load and flexural strength.

The details of the number of samples taken for the proposed tests as per clause 8.5 of IS: 15658-2006 is given in Table IV.

Table-IV: Number of Samples for Different Tests

PaverBlock Design-nation	Number of Samples				Total
	Water Absorption	Compressive Strength	Tensile Split Strength	Flexure Strength	
P0	3	4	4	4	15
P1	3	4	4	4	15
P2	3	4	4	4	15
P3	3	4	4	4	15
P4	3	4	4	4	15
Total	15	20	20	20	75

VIII. PROCEDURES OF TESTS CONDUCTED ON SAMPLES

A. Water Absorption

Tests for water absorption were conducted on paver samples as per Annex C of IS: 15658-2006. The specimens stored in water for 24 hours at atmospheric temperatures were used for water absorption tests. Specimens for absorption tests were taken out of the water and kept aside to dry for one minute. Excess water seen on the specimen was wiped off using clean cotton. The specimen then weighed in the digital electronic balance and the weight noted in Newton was recorded as the wet weight.

After noting down the wet weights, specimens were put in an electric oven with temperature control at 100°C for 24 hours and noted the weights. The specimens were put back in the oven for 2 hours and noted the weight again. These processes were repeated such that two consecutive masses of the same specimen showed a variation within 0.2%. The final mass of every sample was taken in Newton and recorded as the dry weight of the sample.

B. Compressive Strength

The compressive strength tests on paver blocks were conducted as per guidelines specified in Annex D of the Indian standard IS 15658-2006. The specimen kept at 25ºC water for 24 hours was used for the testing. The specimen was put in a compression testing machine with 4mm thick plywood on the bottom and top side of the specimen. The size of plywood was 210 mm x 110 mm providing 5mm clearance all along the sides.

The compression testing machine was conforming to IS 14858-2000[16]. For finding the compressive strengths, the loads were applied until de-lamination occurred. The maximum loads applied to the specimens were recorded in Newton for the calculation of compressive strengths.

C. Tensile Splitting Strength

The tensile splitting strength tests on paver units were conducted according to Annex F of IS: 15658-2006. The specimen kept for 24 hours in water at 25ºC was used for the testing. The wiped samples were positioned with packing pieces on the testing machine as per standard practice. The tests were carried out along the centres of the breadths of the blocks parallel to the longer edges.

D. Breaking Load and Flexural Strength

The breaking load and flexural strength tests were conducted as per Annex G of IS: 15658-2006. The specimens stored in the water of 25ºC for 48 hours were tested immediately after removing from the water. The tests were conducted using UTM (Universal Testing Machine) where bottom roller supports were set at 150 mm apart. The application of loads was such that the increment of loading was continuous and shock-free up to the occurrence of the collapse. The load at which the collapse occurred was recorded in Newtons as the breaking load.

IX. RESULTS

The tests were carried out on the specimens with detailed modus operandi set forth in IS: 15658-2006. The test results are furnished below.

A. Water Absorption Test Results

The percentage values of water absorption of paver blocks incorporating used foundry sand are given in Table V.

Table-V: Water Absorption Values

Paver Block Designation	% Used Foundry Sand	Water Absorption (%)
P0	0%	3.31
P1	10%	3.78
P2	20%	4.14
P3	30%	3.85
P4	40%	3.68

A graphical representation of the values of water absorption with respect to the percentage of used foundry sand is given in Fig.2.

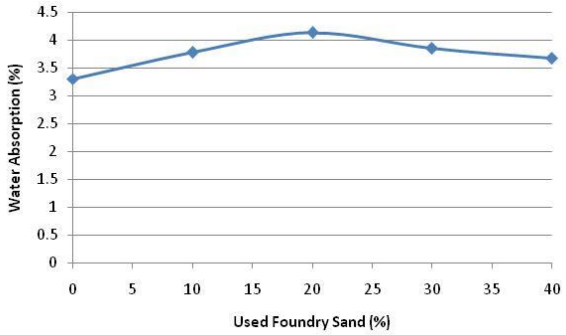

Fig. 2. Water Absorption Vs % Used Foundry Sand

B. Compressive Strength Test Results

Apparent average compressive strengths obtained for paver blocks incorporating used foundry sand are given in Table VI.

Table-VI: Apparent Compressive Strengths

Paver Block Designation	% Used Foundry Sand	Apparent Average 28 Day Compressive Strength (N/mm^2)
P0	0%	59.0
P1	10%	61.4
P2	20%	62.9
P3	30%	65.1
P4	40%	62.6

The clause D-5 and Table 5 of IS: 15658-2006 specifies certain correcting factor to be applied on 'apparent compressive strength' for the arrival of the corrected compressive strength of the paver blocks. For the plain block of 100mm thickness, the 'correction factor' is 1.18. The corrected compressive strengths of paver block samples are shown in Table VII.

Table-VII: Corrected Compressive Strengths

Paver Block Designation	% Used Foundry Sand	Corrected Average 28 Day Compressive Strength (N/mm^2)
P0	0%	69.6
P1	10%	72.5
P2	20%	74.2
P3	30%	76.8
P4	40%	73.9

A graphical representation of the values of corrected compressive strengths of the 'paver blocks' with respect to the used foundry sand percentage is given in Fig.3.

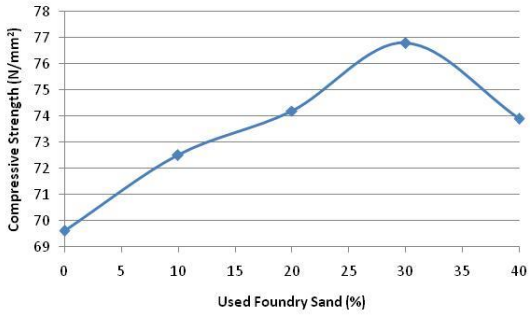

Fig.3. Compressive Strength Vs % Used Foundry Sand

C. Tensile Split Strength Test Results

The formula for calculating the tensile split strength as per IS: 15658-2006 and BS EN 1338-2003 is

$$T = 0.637 \times k \times (P/S) \quad (1)$$

In this

'T '= Tensile Splitting Strength, in Mega Pascal; and

'P '= Failure Load in Newtons.

$S = l \times t$

l= Average failure length in millimeter,

t= Average thickness of specimen in millimeter

Here the value of k is nowhere specified in IS: 15658-2006. It should be noted that as per 'BS EN 1338-2003' the stipulated correction factor for paver blocks of thickness 100 mm is 1.11.

The average tensile splitting strengths at 28 days obtained for paver blocks incorporating used foundry sand considering the value of k as 1.00 are shown in Table VIII.

Table-VIII: Tensile Splitting Strengths

Paver Block Designation	% Used Foundry Sand	Average Tensile Split Strength at 28 Days(MPa)
P0	0%	5.5
P1	10%	5.1
P2	20%	4.8
P3	30%	4.5
P4	40%	4.1

A line graph of the values of tensile splitting strengths of the paver blocks with respect to the percentage of used foundry sand is given in Fig.4.

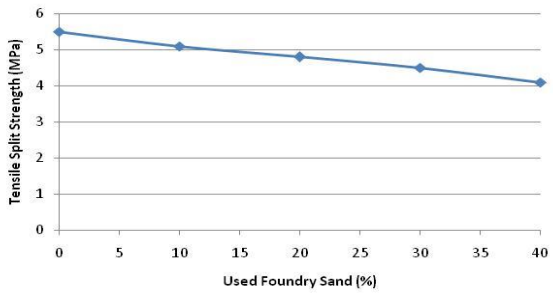

Fig.4. Tensile Split Strength Vs % Used Foundry Sand

D. Breaking Load Results

The average characteristic breaking load obtained for paver blocks with used foundry sand are given in Table IX.

Table-IX: Characteristic Breaking Loads

Paver Block Designation	% Used Foundry Sand	Average Characteristic Breaking Load (kN)
P0	0%	33.00
P1	10%	31.50
P2	20%	28.50
P3	30%	27.00
P4	40%	23.50

A graphical representation of the values of the characteristic breaking loads of the paver blocks with respect to the percentage of used foundry sand is given in Fig.5.

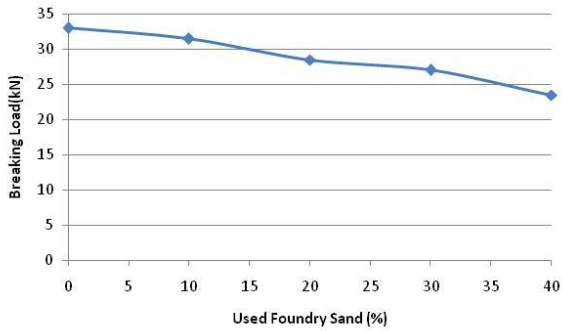

Fig.5. Characteristic Breaking Load Vs % Used Foundry Sand

E. Flexural Strength Results

The average strengths attained by paver blocks incorporating used foundry sand in flexure are given in Table X.

Table-X: Flexural Strengths

Paver Block Designation	% Used Foundry Sand	Average Flexural Strength (N/mm^2)
P0	0%	7.4
P1	10%	7.1
P2	20%	6.4
P3	30%	6.1
P4	40%	5.3

A line graph of the average strength values of paver blocks in flexure with respect to the percentage of used foundry sand is given in Fig.6.

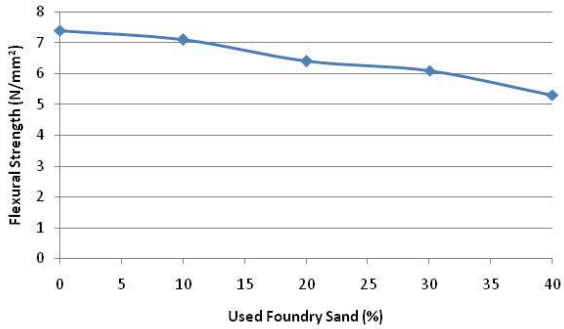

Fig.6. Flexural Strength Vs % Used Foundry Sand

X. DISCUSSION ON RESULTS

A. Water Absorption

The paver blocks incorporating used foundry sand are found to be having more percentage absorption of water than that of the paver blocks made without used foundry sand. Indian standard IS 15658-2006 permits the absorption of water up to 7% for paver units. Here the maximum value obtained is 4.14% only and hence complies with the standards. The water absorption increased with percentage addition of used foundry sand within 20% and decreased thereafter. The percentage increase in absorption of water of paver samples with used foundry sand to the normal paver sample is found to be 14.20%, 25.08%, 16.31% and 11.18% for 10%, 20%, 30%, and 40% of used foundry sand in the total fine aggregates by mass respectively.

B. Compressive Strengths

The 28th-day compressive strength of paver block samples incorporating used foundry sand is found to be more than that of the paver blocks made without used foundry sand. As per clause 6.2.5.2 of IS: 15658-2006 the minimum compressive strength for the M-50 grade paver block is 54.0N/mm^2. Here the minimum compressive strength obtained is 69.6 N/mm^2 and the maximum is 76.8 N/mm^2. Hence the compressive strength criterion has complied. Compressive strength is found to be increasing with an increasing percentage of used foundry sand up to 30% and decreased thereafter. Percentage increment in compressive strength of paver blocks incorporating used foundry sand to the normal paver blocks is found to be 4.17%, 6.61%, 10.34% and 6.18% for 10%, 20%, 30%, and 40% of used foundry sand in the total fine aggregates by mass respectively.

C. Tensile Splitting Strengths

The 28th-day tensile splitting strength of paver block samples made with used foundry sand is found to be less than that of the paver blocks made without used foundry sand. Tensile splitting strength decreased with percentage increment of used foundry sand. The percentage decrement in tensile splitting strength of paver blocks incorporating used foundry sand to the normal paver blocks is found to be 7.27%, 12.73%, 18.18% and 25.45% for 10%, 20%, 30%, and 40% of used foundry sand in the total fine aggregates by mass respectively.

D. Breaking Loads

The characteristic breaking loads of paver blocks made with used foundry sand is found to be less than that of the paver blocks made without used foundry sand. As per clause G-7 of IS: 15658-2006 the minimum characteristic breaking load of paver blocks for heavy-duty industrial roads is 7 kN. Here the minimum and maximum characteristic breaking load obtained is 23.50 kN and 33.00 kN respectively. Hence the characteristic breaking load criterion has complied. The characteristic breaking load decreased with the percentage increment of used foundry sand. The percentage decrease in characteristic breaking load of paver blocks with used foundry sand to the normal paver blocks is found to be 4.55%, 13.64%, 18.18% and 28.79% for 10%, 20%, 30%, and 40% of used foundry sand in the total fine aggregates respectively.

E. Flexural Strengths

The flexural strength of paver blocks made with used foundry sand is found to be less than that of the paver blocks made without used foundry sand. Since the characteristic breaking load criterion has complied, the flexural strength criterion also complies accordingly. The flexural strength of paver blocks decreased with an increase in the percentage of used foundry sand. The percentage decrease in flexural strength of paver blocks with used foundry sand to the normal paver blocks is found to be 4.05%, 13.51%, 17.57% and 28.38% for 10%, 20%, 30%, and 40% of used foundry sand in the total fine aggregates by mass respectively.

A column chart of the percentage variation of water absorption, compressive strength, tensile split strength, breaking load and flexure strength with respect to the percentage used foundry sand in paver blocks is shown in Fg.7.

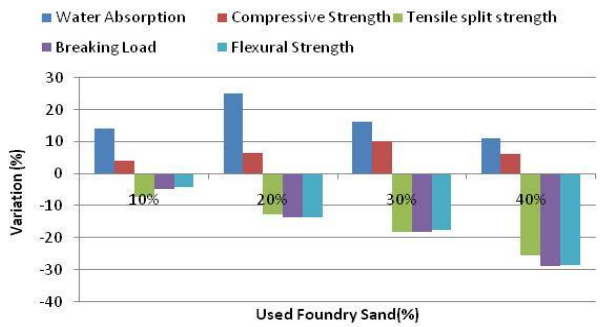

Fig.7. Strength Variation Vs % Used Foundry Sand

XI. CONCLUSIONS

Subsequent to various tests conducted on normal and used foundry sand incorporated paver blocks, it is worthwhile to arrive at the conclusions given below.

1. The water absorption of the paver blocks incorporating used foundry sand increasing up to 20% substitution and decreases afterward. However, the water absorption values are within limits for all replacements up to 40%.
2. The strength in compression of paver block incorporating used foundry sand increases up to 30% replacement and decreases afterward. However, the compressive strength values are within limits for all replacements up to 40%. Splitting tensile strengths of paver blocks incorporating used foundry sand decreases for all replacement levels up to 40%.
3. The characteristic breaking loads of paver block incorporating used foundry sand decreases for all replacement levels up to 40%. However, the characteristic breaking load values are within limits for all replacements up to 40%.
4. The strengths of paver block in flexure incorporating used foundry sand decreases for all replacement level up to 40%.
5. At an optimum 30% used foundry sand can be utilized in the manufacturing of paver blocks in consideration of the strength in compression.
6. It is ascertained that used foundry sand can effectively be utilized in the manufacture of paver blocks for different applications.

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