A Suitability Study of Using Crushed Fluorescent Lamp Waste as Fine Aggregates

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doi: https://doi.org/10.21467/proceedings.112.42

ABSTRACT

Fluorescent lamp wastes are one of the discarded electrical devices. These lamp wastes pose serious health concerns, and require extreme care in its disposal to avoid any adverse impacts. Also, with the widespread use of energy efficient LED lamps for lighting purposes, environmental concerns related to disposal of used mercury containing fluorescent lamps have become progressively important. This paper explores the possibility of replacement of fine aggregates in mortar with different proportions of fluorescent lamp wastes in order to find the optimum percentage of replacement to get better properties. Fluorescent lamp wastes were collected and crushed to the grading of fine aggregates. Compressive strength and bulk density of mortar cubes with 0%, 25%, 50%, 75% and 100% replacement of fine aggregates with fluorescent lamp wastes were evaluated after 7 days of initial curing. The compressive strength and bulk density of mortar was found to be decreasing with increasing percentage of lamp waste added. The replacement of fine aggregate by 25% lamp waste has greater strength compared to other proportions. Bulk density was found to be lesser at higher replacement levels and can be tried in producing light weight mortar. The utilization of lamp waste in mortar/concrete is a noble attempt in reducing the negative impact of lamp wastes on the environment.

Keywords: Mortar, Fine Aggregate, Fluorescent lamp, Compressive strength, Bulk density.

1 Introduction

Mortar is a bonding agent between building materials, which is mainly a mixture of water, fine aggregate (sand, surki) and binding material like cement, lime etc. The applications of mortar in various construction phases have made it a very important civil engineering material. In earlier period, river sand is commonly used as fine aggregate, which had created over exploitation of natural resources and many other problems like erosions. Currently, M-sand is used as fine aggregates which are produced by crushing of hard granite stones. It is also a limited resource and the quarry in which the manufacturing of M-sand taking place is available only in few states such as Tamil Nadu and Karnataka. Thus, the transportation of this M-sand to other states is very difficult and the transportation cost also increases.

The improved performance of light emitting diode lamps (LED) lamps has outplayed fluorescent lamps. Advantages of LED lamps over fluorescent lamp includes LED light is directional, last longer than fluorescent lamps, more rugged than fluorescent lamps, more energy efficient and does not produce UV lights while fluorescent lamp produce. Fluorescent lamps are non-recyclable and these are now dumped in large quantities in electricity board premises, hostels and several households. If the trend is like this, within few months LED will completely replace all the fluorescent lamps. This study is an attempt to investigate the effect of replacement of fine aggregate with crushed fluorescent lamp waste.

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

Akshay et al. (2019) conducted experimental investigation on partially replacement of fine aggregate with fluorescent lamp powder and coarse aggregate with rubber. For the effect of crumb rubber content, the test results shown that there was a systematic reduction in the compressive and dry density with the increase in rubber content from 0 % to 30 %. Concrete paving block containing rubber particles seem to provide better skid resistance. It is possible to fabricate block containing rubber and tube light powder up to 30 % and 14% by coarse aggregate volume using chemical and mineral admixtures. Pandey et al. (2018) conducted a review on the effect of replacement of cement by crushed fluorescent lamp. Compressive strength was about 22% higher while split tensile strength was about 0.3% higher and flexural strength was 3.70% higher for the fluorescent light tube waste aggregate mixes when compared with the control concrete. Weight loss due to acid attack on 10% aggregate was 1.3% while 20% aggregate was 1.8% and that of 30% aggregate was 2.2% which are very low. Weight loss due to alkaline attack on 10%, 20%, 30% lamp aggregates were 0.3%, 1.8%, 2.2% respectively which are also low. So optimum level of replacement suggested was 10%.

Thavasumony et al. (2015) conducted study of concrete by partial replacement of fine aggregate with the fluorescent lamp powder. 10% of the cement used in concrete production can be effectively added with Fluorescent lamp Powder. Usage of fluorescent lamp Powder in concrete will not only be economical but also satisfies all the requirements of a good concrete, providing good solution for the disposal of a solid waste as it is recycled without affecting the environment. Ling and Poon (2017) conducted study on spent fluorescent lamp glass (FG) as a substitute for fine aggregate in cement mortar. The flexural and compressive strengths decreased with increasing lamp glass content in the mortar mixes. However, the reduction rate of the FG-A mix (with heating) was relatively lower as compared to the corresponding FG-B mix (without heating). This might be due to the fact that the FG-A was free from the organic lacquer and the smooth coating. All the tested samples were below the regulatory limit of 0.5 mg/L for Hg, except for the mortar containing 40% FG. It is therefore suggested that the percentage of FG used in the mortar should be controlled at a maximum limit of 30%. Thus, it can be seen that researchers have tried using fluorescent lamp waste as fine aggregates. With the widespread use of energy efficient LED lamps for lighting purposes, environmental concerns related to disposal of used mercury containing fluorescent lamps have become progressively important. This paper explores the possibility of replacement of fine aggregates in mortar with different proportions of crushed fluorescent lamp wastes in order to find the optimum percentage of replacement to get better properties.

2 Experimental Programme

2.1 Materials Used

Ordinary Portland Cement (OPC) of 43-grade conforming to IS 8112:1989 is used through-out the investigation. Manufactured sand conforming to Zone II as per IS 383:2016 is used as fine aggregate. A fluorescent lamp, or fluorescent tube, is a low-pressure mercury-vapour gas-discharge lamp that uses fluorescence to produce visible light. Because they contain mercury, many fluorescent lamps are classified as hazardous waste. The United States Environmental Protection Agency recommends that fluorescent lamps be segregated from general waste for recycling or safe disposal, and some jurisdictions require recycling of them. So with the aim of recycling of florescent lamps, 10 disposed fluorescent lamps were collected from the nearby surroundings. With the help of abrasion testing machine, the fluorescent lamps are ground and processed to a size similar to that of M-sand. The collected and the processed lamps are shown in Figure 1. Potable well water is used for the preparation of mortar cubes. In this mix design, the water to cement ratio is taken as 0.50.

Proceedings DOI: 10.21467/proceedings.112

Series: AIJR Proceedings
ISBN: 978-81-947843-3-3
ISSN: 2582-3922

(a) fluorescent lamp (b) crushed lamp waste

Figure 1. Preparation of crushed lamp waste for the partial replacement of fine aggregate

2.2 Methodology

The fine aggregates (M-sand and crushed fluorescent lamp aggregate) were tested for their properties such as particle size, bulk density, void ratio, porosity and specific gravity. Particle size distribution was obtained by sieve analysis. After ascertaining the properties of aggregates, mortar specimens were cast by replacing M-sand with lamp waste aggregate at increments of 25% from 0 to 100% (i.e. specimens are cast by 0%, 25%, 50%, 75% and 100% replacement). Table 1 gives the details of quantities of ingredients taken in the preparation of mortar.

The size of the mortar specimen used was cubical of size 50 mm. The ratio of fine aggregate to cement (by weight) used for all the mortar mixes was kept constant at 1.50 (to simulate the mortar fraction of medium strength concrete). Mortar was mixed thoroughly in a Hobart mortar mixer. After mixing, the fresh mortar is placed in the specially fabricated timber moulds (shown in Figure 2) and compacted using square tamping rods. The specimen is kept undisturbed for 24 hours by covering with polyethylene sheet. The specimen is then demoulded and transferred to the curing tank for wet curing. Figure 2 shows the mould used and the specimens made for this experimental study.

After 7 days of water curing, further tests were conducted to evaluate the effect of crushed lamp waste aggregates on the mortar strength and bulk density. The specimens from the curing tank were taken and surface was cleaned and wiped with a cotton cloth. The specimen was placed in the compression testing machine centrally on the base plate. Then the load was applied gradually without shock and continuously till the specimen failed. The maximum load at which the specimen failed was recorded and compressive strength was noted as the average of three specimens. Bulk density also called as apparent or volumetric density is calculated by dividing the mass of the mortar by the volume of the specimen.

(a) fabricated timber moulds

(b) Demoulded mortar specimen

Figure 2. Mortar specimen during and after casting

Table 1. Mix proportion of mortar

Percentage of replacement	Cement (gm)	M-Sand (gm)	Fluorescent lamp (gm)	Water (gm)
0	150	225	0	75
25	150	168.75	56.25	75
50	150	112.50	112.50	75
75	150	56.25	168.75	75
100	150	0	225	75

3 Results and Discussion

3.1 Properties of Aggregates

The sieve analysis results of fluorescent lamp aggregate and M-sand are shown in Table 2. The % finer of crushed lamp aggregate appears to be similar to M-sand. Their particle size distribution curve is shown in Figure 3. It can be noted that the crushed lamp aggregates are marginally finer in size and flaky compared to the gradation of M-sand tested. The gradation properties are extracted from the gradation curve and tabulated in Table 3. The lower fineness modulus (2.46) of crushed lamp waste indicates that the particles are finer compared to M -sand (having fineness modulus of 2.98). However, the effective size of crushed lamp waste (0.43 mm) was higher than M-sand (effective size of 0.19 mm). The uniformity coefficient of M-sand is 7.89, and is much higher than the crushed lamp waste (4.18). This indicates that the M-sand is better graded and crushed lamp waste aggregates are more uniformly graded.

ISBN: 978-81-947843-3-3

ISSN: 2582-3922

Table 2. Sieve analysis results of aggregates used in the study

Sieve opening (mm)	% finer	
	fluorescent lamp aggregate	M-sand (normal aggregate)
4.75	99.5	99.4
2.36	95.7	82.2
1.18	30.8	53.6
0.6	13.7	35.1
0.3	6.3	22.3
0.15	0.1	5.8
0.075	0	1.7

Table 3. Gradation properties of aggregates

Property	fluorescent lamp aggregate	M-sand (normal aggregate)
Fineness modulus	2.46	2.98
Effective size (mm)	0.43	0.19
Uniformity coefficient	4.18	7.89
Coefficient of curvature	1.80	0.80

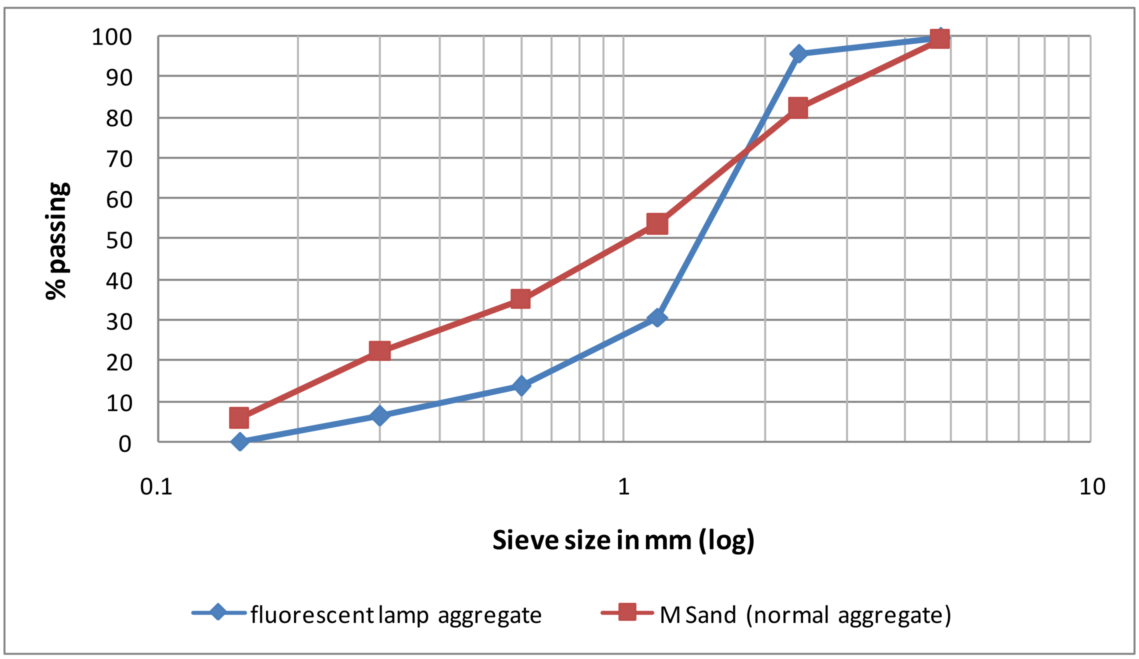

Figure 3. Particle size distribution curve of aggregates

The engineering properties of aggregates are shown in Table 4. It is observed that the specific gravity and bulk density of crushed fluorescent lamp aggregates are lower compared to M-sand which indicates that the former is lighter compared to normal aggregates, and could find as a useful inclusion in light weight applications. The void ratio and open porosity values of both the aggregates were however comparable.

Table 4. Engineering properties of aggregates

Property	fluorescent lamp aggregate	M-sand (normal aggregate)
Specific gravity	2.20	2.62
Bulk density (g/cm^3)	1.43	1.52
Void ratio	0.65	0.66
Porosity (%)	39.5	39.8

3.2 Properties of Mortar

The hardened properties of mortar such as compressive strength and bulk density were tested after 7 days of water curing. The variation of compressive strength with the percentage replacement level of fine aggregate with crushed fluorescent lamp waste is shown in Figure 4. From the results obtained, it could be inferred that there is an inverse relation between compressive strength with percentage of fluorescent lamp waste used. As the fine aggregate is replaced by crushed lamp waste, the compressive strength was found to reduce. The reduction in strength may be due to the flakiness of crushed lamp aggregates and lower bond between the aggregate and the cement paste. The interfacial transition zone between the lamp waste aggregate and the paste might be weaker which led to the reduction in strength. At 25% replacement, the decrease in strength was only 2 MPa. When the aggregates are completely replaced by crushed fluorescent lamp waste aggregates, the reduction in the compressive strength was observed to be 31.1%. Figure 5 shows the variation of bulk density of mortar with the replacement level of fine aggregate with crushed fluorescent lamp waste. Similar to the observations in strength, a declining trend was observed with increase in the replacement level. As the conventional aggregates were replaced by crushed lamp aggregates whose specific gravity is less, it causes reduction in the mass of mortar for the same volume, and hence a reduction in the mortar bulk density. When the aggregates are completely replaced by crushed fluorescent lamp waste aggregates, the reduction in the bulk density was observed to be 10.7%. However, 25% replacement causes only a reduction of bulk density of 2.4% with a strength reduction of 6.7%. Thus, from the results obtained, the replacement level suggested is 25% for non-important construction applications or non-load bearing components.

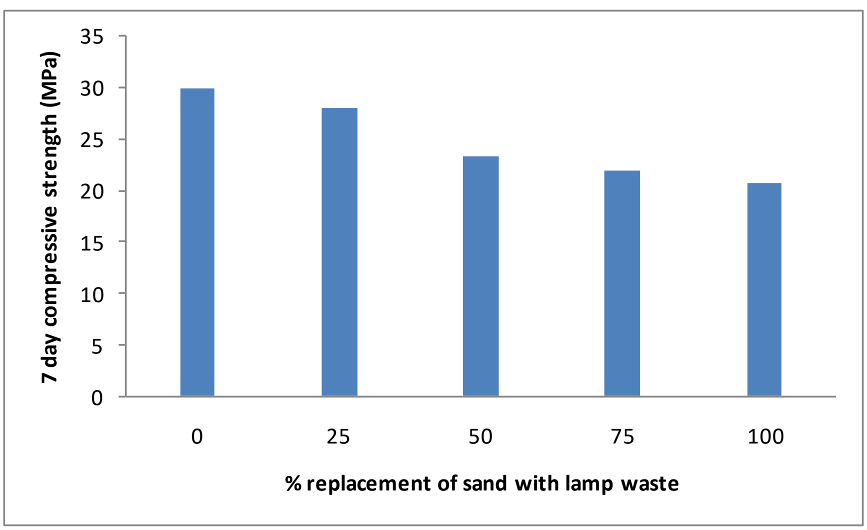

Figure 4. Effect of sand replacement on the compressive strength of mortar

Proceedings DOI: 10.21467/proceedings.112
Series: AIJR Proceedings
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ISSN: 2582-3922

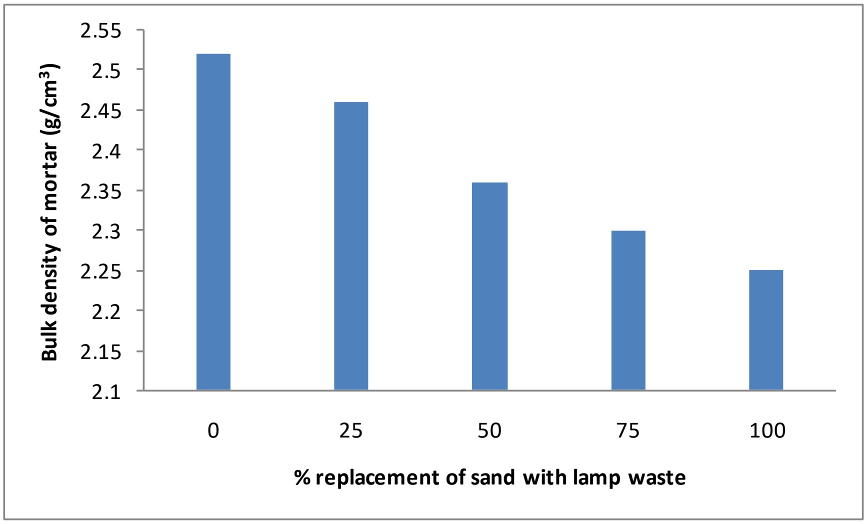

Figure 5. Effect of sand replacement on the bulk density of mortar

4 Conclusion

Fluorescent lamp wastes are one of the discarded electrical devices, and poses serious threats on the environment related to its disposal. This paper attempted to study the preparation of fine aggregates by crushing fluorescent lamp and evaluated its properties in comparison to the manufactured sand (normal aggregate). Furthermore, the compressive strength and bulk density of mortar cubes with 0%, 25%, 50%, 75% and 100% replacement of fine aggregates with fluorescent lamp wastes were evaluated after 7 days of initial wet curing. Based on this study, the following conclusions could be drawn.

- The crushed fluorescent lamp aggregates are marginally finer in size and flaky in nature compared to the gradation and shape of Manufactured Sand (normal aggregate). The fineness modulus of crushed fluorescent lamp waste (2.46) is lower compared to M-sand (having fineness modulus of 2.98).
- The effective size of crushed lamp waste (0.43 mm) was higher than M-sand (effective size of 0.19 mm). The uniformity coefficient of M-sand is 7.89, and is much higher than the crushed lamp waste (4.18). This indicates that the M-sand is better well graded and crushed lamp waste aggregates are more uniformly graded.
- The specific gravity and bulk density of crushed fluorescent lamp aggregates are lower compared to M-sand which indicates that the former is lighter compared to normal aggregates, and could find as a useful inclusion in light weight applications.
- The replacement of normal aggregates with crushed fluorescent lamp waste aggregates caused a reduction in the 7 day compressive strength and bulk density of mortar. The reduction in strength is attributed possibly to the weak interfacial transition zone, lower bond and flakiness of lamp waste aggregates. The reduction in bulk density is due to the low specific gravity and possibly lesser packing.
- The cement mortar made with crushed fluorescent lamp waste aggregates only (complete replacement of manufactured sand) showed 31.1% drop in compressive strength and a reduction of 10.7% in bulk density when compared to the control mortar mix (without sand replacement). However, the replacement level of 25% had only reduction of 6.7% and 2.4% for compressive strength and bulk density respectively when compared to the control mix. The suggested replacement level from the current study is 25%.

Higher replacement levels can be used for light weight and non-structural applications, thereby utilising the crushed lamp waste in cementitious systems causing lesser environmental concerns.

How to Cite this Article:

Joshy, H. C., Mansoor, A K., Rameez, Z., Sarath, S., & Ramaswamy, K. P. (2021). A Suitability Study of Using Crushed Fluorescent Lamp Waste as Fine Aggregates. *AIJR Proceedings*, 349-356.

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