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## Sustainable use of recycled concrete aggregates and waste rubber shreds in drainage layer of landfills

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### ABSTRACT

This paper presents the experimental results on the performance and use of recycled concrete aggregates derived from old concrete/construction and demolition waste and waste rubber shreds in the drainage layer of engineered landfills. About ten test columns having diameter 160 mm and height 1200 mm were set up in the laboratory. Waste rubber shreds of size range 25 mm to 75 mm and recycled concrete aggregates of size 10 mm to 20 mm were compacted either singly or in combination in the test columns, with a total bed thickness of 500 mm. The performance of the drainage layers (single or in combination) were evaluated by determining the effluent characteristics. Physico chemical parameters of effluent leachate such as pH, conductance, total dissolved solids, turbidity, hardness etc., were determined. From the study it is found that leachate sample passed through the combined drainage layer resulted in improvement of various leachate parameters compared to the test columns containing recycled concrete aggregates or waste rubber shreds media alone.

**Keywords:** recycled concrete aggregates, rubber shreds, leachate, engineered landfills.

### 1 INTRODUCTION

Reuse of recycled coarse aggregates from construction and demolition wastes has gained considerable importance in recent times from sustainability point of view. Construction activity leads to generation of solid wastes, which include sand, gravel, broken concrete debris etc. Reuse or management of construction and demolition waste (C&D) is a major concern for policy makers/planners due to increase in C&D waste generation. There is also a growing apprehension of pollution and environmental deterioration due to disposal of C&D waste. Considerable research has been carried out in the countries like the U.S.A, Japan, U.K, France, Germany, India, Denmark etc., on the reuse potential of C&D waste. Germany was the first country to start recycling of demolition waste after the Second World War (Rao et al., 2007). In Denmark the total quantity of old concrete produced and reused in the year 1997 is about 1.06 million metric tons and 0.9 million metric tons respectively. Worldwide generation of old concrete amounts to a huge quantity and therefore, it's appropriate use in any possible manner is a subject of high priority in construction works. C&D wastes may be also produced from environmental disasters, such as earthquakes, hurricanes, tornadoes, and floodwater (Huang et al. 2007; Xiao et al. 2015).

The Central Pollution Control Board (CPCB) of India has estimated that the amount of solid waste generation

in India is about 48 million tons per annum, of which waste from the construction industry accounts for 25%. The total quantity of waste from the construction industry is estimated to be 12 to 14.7 million tons per annum.

Rubber is another material, which is extensively used in manufacture of various products. Rubber used in the manufacture of vehicle tires amounts to about 65% in automobile industry. Rubber is also used as a raw material in the manufacture of an assorted range of items. This has resulted in the generation of a large quantity of rubber wastes annually especially in the automobile industry where vehicle tires are discarded after long use. The discarded tires are being used in slope protection and other stabilization works yet the usages are minimal. Therefore, disposal of rubber waste remains as a major issue around the world due to the environmental concerns (Adhikari et al. 2000). The total volume of scrap tires consumed in end use markets in the U.S. reached approximately 4105.8 thousand tons of tires (Rubber Manufacturers Association, 2009). India is the fourth largest producer of natural rubber (NR) by accounting for 8.1% of the global supply (Indian Rubber Statistics, 2013). The auto-tire sector accounted for 65.3% of the total quantity of NR consumed in the country during the year 2012. With large quantities of rubber being consumed for the manufacture of various products and throughout the world efficient management of rubber waste is a technological challenge (Bhalla et al., 2000). Discarded

rubber tires or tire shreds have been used in many civil engineering applications. Shredded tire obtained from scrap tires have been used as an alternative fill material for road, embankment and backfill construction etc. (Reddy et al., 2010). Whole waste tires have found demand, suitability and economic advantages in fields such as erosion control, highway crash barriers, breakwaters, dams, artificial reefs, playground equipment, etc. Tire shreds have also been used in the leachate collection medium as an alternative material to the conventional gravel (McIsaac and Rowe, 2005; Plameira and Silva, 2007; McIsaac and Rowe, 2007). According to the Mississippi Department of Environmental Quality (2002), the recommended nominal size of the tire shred to be used in leachate collection medium is 50 mm with an acceptable range of 25-100 mm.

The drainage layer (leachate collection media) of engineered landfills is normally constructed using virgin aggregates. The leachate collection drainage layer is 300-500 mm thick and has permeability greater than 0.01 cm/sec (CPHEEO 2000). Use of virgin aggregates may have an impact on the environment due to various activities involving quarrying, processing of stones, dust pollution, noise pollution etc. Complete substitution of virgin gravel layer with recycled aggregates at the bottom of landfill sites allows to saving of natural stones/granular materials that are more and more difficult to find.

The main objective of the present study is to investigate the potential use of recycled concrete aggregates and waste rubber shreds in the drainage layer of landfills by studying the performance of test columns consisting of recycled aggregates and rubber shreds bed as leachate collection medium. Best combinations of waste rubber shreds and recycled aggregate gravel bed have been identified based on the size of the rubber shreds and percentage reduction in various physico-chemical parameters after the leachate is passed through test columns'.

## 2 MSW LANDFILL LEACHATE

Mangalore City, situated on the west coast (12 ° -52'N latitude and 74 °49'E longitude) with a population of about 650,000 produces an average municipal solid waste (MSW) of 350 tons per day (TPD). The MSW generated from the city is being disposed of at a landfill site, situated at Vamanjoor since 2010. For the present study leachate is synthetically prepared in the laboratory. The selection of leachate was based primarily on the observed similarities of tropical leachates reported in the literature (Sunil et al., 2008; Sunil et al., 2009). Table 1 shows the concentration of each constituent of the leachate selected for this study. Chemicals were used in the preparation of leachate, and demineralized water was used in its dissolution and dilution. The mass of each chemical product was

obtained on a balance with a sensitivity of  $\pm 0.001$  g. The quality of the demineralized water was periodically controlled during each preparation of the synthetic leachate (about 8-10 litres).

Table 1. Chemical composition of synthetic leachate.

SI No.	Parameter	Result
1	pH	7.3
2	Conductance (mS)	7.9
3	TDS (mg/L)	4898.0
4	Turbidity (NTU)	190.0
5	Total hardness (mg/L)	11934
6	BOD (5 day at 27 °C) mg/L	3250
7	COD (mg/L)	16960
8	Chloride (as Cl <sup>-</sup> ) mg/L	1792
9	Ammonia nitrogen (as N) mg/L	852
10	Iron (as Fe) mg/L	32.2
11	Calcium (as Ca) mg/L	465.1
12	Magnesium (as Mg) mg/L	2585.1
13	Chromium Hexavalent (mg/L)	471.8

## 3 EXPERIMENTAL SETUP

The performance of the leachate collection layer with different combinations of recycled aggregate gravel and waste rubber shreds layers have been studied using columns of poly vinyl chloride (PVC) pipes (referred here after as test cols.). Ten laboratory test cols. were constructed using PVC pipes each of height 1200 mm and diameter 160 mm. Details of the test cols. are presented in Table 2. Fig.1 show a close up of waste/old concrete source for recovery of aggregates and Fig.2, show recycled aggregates obtained from old concrete. Fig. 3 illustrate making of rubber shreds in the laboratory. Fig. 4 depicts column study setup for conducting experiments. In test cols. 1 to 7 waste rubber shreds (size range 25 mm to 75 mm) and recycled aggregate gravel layer (size range 10 mm to 20 mm) were compacted either singly or in combination with a total bed thickness of 500 mm (MOE, 1998; CPHEEO, 2000). Upon observing the performance of seven test cols. three more test cols. i.e., 8, 9 and 10 were constructed with a recycled aggregate and waste rubber shreds layer ratio same as that of the test col. that gave best results out of the seven columns (i.e. test col.-3 having waste rubber shreds layer = 200 mm and gravel layer = 300 mm). To study the size effect of rubber shreds, 10 mm, 15 mm and 20 mm width shreds were used in the test cols. 8, 9 and 10 respectively.

## 4 METHODOLOGY

In this study, recycled aggregates were obtained from the old broken concrete wastes and other C&D wastes. The old concrete aggregates were crushed and cleaned thoroughly before using them in the drainage layer. To study the removal efficiency, MSW leachate was applied on the drainage layer of test cols. and allowed to stand for about 48 hours.

Table 2. Details of test columns.

Test Col.	Rubber shreds (mm)		Recycled aggregate drainage layer thickness (mm)	
	Length mm	Width mm	Rubber shred ( $t_s$ )	Gravel ( $t_g$ )
1	25-75	10-25	--	500
2		10-25	100	400
3		10-25	200	300
4		10-25	250	250
5		10-25	300	200
6		10-25	400	100
7		10-25	500	--
8		10	200	300
9		15	200	300
10		20	200	300

Height of col = 1200 mm & dia=160 mm; gravel size=10-20 mm

After 48 hours, the effluent leachate was collected through the outlet valve of test cols. and analyzed to determine various parameters such as those presented in Table 1 as per the Standard Methods (APHA,1980; APHA,1998).



Fig. 1 Concrete waste source for recovery of aggregates



Fig. 2 Recycled aggregates from waste concrete source

## 5 RESULTS AND DISCUSSION

The physico-chemical parameters of leachate before passing through the test cols. are shown in Table-1. As seen from Table 1, the permissible limits of the parameters of synthetic leachate are observed to exceed

the USEPA permissible limits. During experiments the leachate was passed through all test cols. separately. After 48 hours, the effluent from all test cols. were analyzed for various physico-chemical parameters. Percentage removal or reduction in various leachate parameters after passing through the test cols.



Fig. 3 Cutting rubber strips to required dimensions in lab.



Fig. 4. Laboratory column studies setup.

were calculated using Eq.1, where  $l_p$  and  $l_t$  are physico-chemical parameters of raw leachate and treated leachate respectively.

$$\%reduction = \left( \frac{l_p - l_t}{l_p} \right) \times 100 \quad (1)$$

The experimental results of treated leachate are plotted as percentage reduction vs  $t_s/t_g$  ratio ( $t_s$ =thickness of waste rubber shreds layer;  $t_g$ =thickness of recycled aggregate gravel layer) as shown in Figs. 5 & 6. From Figs. 5 & 6 it is seen that improvement in various physico-chemical parameters of the effluent leachate is significant in the range of  $t_s/t_g = 0.25$ -1.5. For  $t_s/t_g$  ratio beyond 1.5 the removal efficiency or improvement is not prominent. The results presented in Figs. 5 & 6 are for initial seven test cols. where  $t_s/t_g$  ratio are kept as: test col.-1 ( $t_s = 0$  mm and  $t_g$  500 mm,  $t_s/t_g = 0$ ); test col.-2 ( $t_s = 100$  mm and  $t_g$  400 mm,  $t_s/t_g = 0.25$  mm); test col.-3 ( $t_s = 200$  mm and  $t_g$  300 mm,  $t_s/t_g = 0.67$ );



test col.-4 ( $t_s = 250$  mm and  $t_g = 250$  mm,  $t_s/t_g = 1$ ); test col.-5 ( $t_s = 300$  mm and  $t_g = 200$  mm,  $t_s/t_g = 1.5$ ); test col.-6 ( $t_s = 400$  mm and  $t_g = 100$  mm,  $t_s/t_g = 4$ ); test col.-7 ( $t_s = 500$  mm and  $t_g = 0$  mm,  $t_s/t_g = \infty$ ); From Table 3, it is observed that the percentage improvement in terms of reduction in various physico-chemical parameters of leachate samples was maximum for test col.-3 having  $t_s/t_g = 0.667$ . As recycled aggregate (gravel) is an inert material and this performance is mainly attributed to the presence of waste rubber layer in the leachate collection media. Laboratory studies conducted by Bhalla et al. (2010) to show the effectiveness of scrap tires in leachate collection media concluded that improvement in various physico-chemical parameters was maximum at  $t_s/t_g$  of 0.667. According to Bhalla et al., (2010), scrap-tire-shreds have high porosity, high rubber content and the compressibility is several orders of magnitude greater than conventional gravel layer. Due to the high rate of compressibility, scrap-tire-shreds bed work as better filter media.

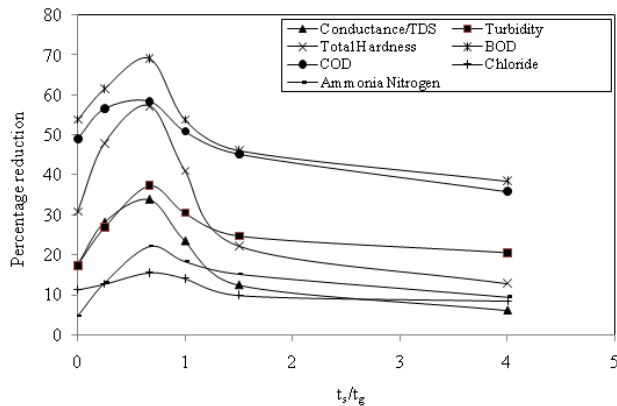


Fig. 5. Percentage reduction with ( $t_s/t_g$ ) ratio after 48 hours.

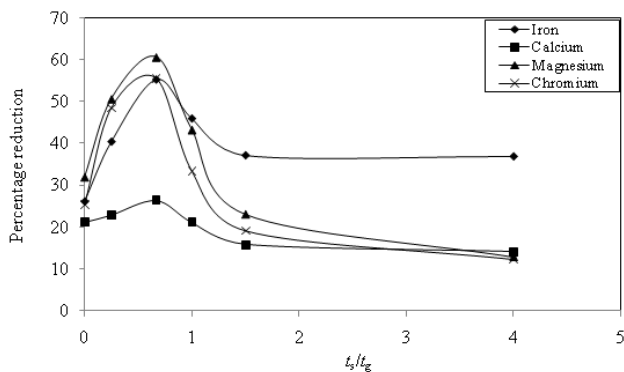


Fig. 6. Leachate parameters with ( $t_s/t_g$ ) ratio after 48 hours.

Thus, the improvement in the effluent characteristics after passing the leachate into the leachate collection layer containing the mixture of rubber shreds and recycled aggregate gravel is attributed largely due to the sorption of chemicals and filterability.

Table 3. Percentage improvement in physico-chemical parameters (after 48 hours)

Parameter	T-1	T-2	T-3	T-4	T-5	T-6	T-7
$t_g$ (cm)	50	40	30	25	20	10	0
$t_s$ (cm)	0	10	20	25	30	40	50
$t_s/ t_g$	0	0.25	0.67	1	1.5	4	--
TDS (mg/L)	17.59	28.23	33.92	23.54	12.53	6.20	2.28
Turbidity(NTU)	17.37	26.84	37.37	30.53	24.74	20.53	14.21
Hardness (mg/L)	30.77	47.86	57.26	41.03	22.22	12.82	7.69
BOD (mg/L)	53085	61.54	69.23	53.85	46.15	38.46	30.77
COD (mg/L)	49.06	56.60	58.49	50.94	45.28	35.85	28.30
Chloride (mg/L)	11.27	12.68	15.49	14.08	9.86	8.45	7.04
A-Nitrogen (mg/L)	4.69	13.03	22.18	18.43	15.26	9.51	3.99
Iron (mg/L)	25.95	40.35	55.31	45.93	37.06	36.81	36.06
Calcium (mg/L)	21.05	22.81	26.32	21.05	15.79	14.04	5.26
Magnesium (mg/L)	31.82	50.57	60.61	43.18	22.92	12.69	7.95
Cr <sup>6+</sup> (mg/L)	25.24	48.37	55.45	33.34	19.12	12.29	2.80

\*A-ammonium; Cr<sup>6+</sup>-Chromium hexavalent; T-1- test col 1

For the present study, the best combination of drainage layer corresponds to test col.-3.

The size effect of waste rubber shreds in test col. 3, was further investigated using test cols.-8, 9 and 10 respectively. The width of the rubber shreds in the above test cols. was varied in the following manner: test col.-3 ( $t_r/t_g = 0.667$  and waste rubber shreds width = 10 to 20 mm). test col.-8 ( $t_r/t_g = 0.667$  and waste rubber shreds width ( $w$ ) = 10 mm,  $w/t_g = 0.033$ ); test col.-9 ( $t_r/t_g = 0.667$  and  $w = 15$  mm,  $w/t_g = 0.05$ ); test col-10 ( $t_r/t_g = 0.667$  and  $w = 20$  mm,  $w/t_g = 0.066$ ). The comparative performance of the test cols. 8, 9 and 10 are presented in Table 4. It is seen that conductance/TDS of leachate after passing through test cols. 8, 9 and 10 almost remained the same (<2% reduction). Similarly, removal of turbidity, total hardness, COD, ammonia nitrogen, iron, calcium, magnesium and chromium are less than 10%. Percentage removal of chloride and BOD are in the range of 9-10 %. To summarize, smaller size rubber shreds do not provide any better sorption characteristics. The absorption of leachate constituents onto the rubber media is a physical phenomena to some extent. Beyond that rubber shreds do not participate or absorption on rubber shreds is minimal even when the shred size is reduced. However, the study implies that recycled aggregates and waste rubber shreds can be a potential alternative material for the construction of leachate collection system of engineered landfills. When the appropriate thickness of waste rubber shred bed is used in the recycled aggregate drainage layer, it will improve the reduction of various leachate parameters of environmental concern.

Table 4. Comparative performance of test cols 3,8,9 and 10 with recycled aggregates layer thickness ( $t_r/t_g=0.67$ ,  $w=10\text{mm}$ ,  $15\text{mm}$  &  $20\text{mm}$ ) after 48 hours..

Parameter	T3	T-8	T-9	T10
$t_g(\text{cm})$	30	30	30	30
$t_s(\text{cm})$	20	20	20	20
$w(\text{cm})$	10-20	10	15	20
$w/t_g$	--	0.03	0.05	0.07
Conductance (mS)	33.92	34.10	33.59	33.33
Turbidity (NTU)	37.37	38.14	37.63	36.60
Hardness (mg/L)	57.26	58.47	57.63	56.78
BOD (mg/L)	69.23	71.43	71.43	64.29
COD (mg/L)	58.46	60.0	58.18	56.36
Chloride (mg/L)	15.49	15.94	15.94	14.49
A-Nitrogen (mg/L)	22.18	22.39	21.29	21.56
Iron (mg/L)	55.31	55.70	55.14	54.70
Calcium (mg/L)	26.32	27.59	25.86	25.86
Magnesium (mg/L)	60.61	61.84	61.09	60.15
$\text{Cr}^{6+}$ (mg/L)	55.45	55.23	55.06	54.55

\*A-ammonium;  $\text{Cr}^{6+}$ -Chromium hexavalent; T-1- test col 1

## 6 CONCLUSIONS

The study found that leachate parameters of environmental concern are reduced after passing the leachate through a combined drainage layer, consisting of waste rubber shreds bed and recycled aggregate gravel bed as compared to using either a conventional gravel or waste rubber shreds bed.

When the combination waste rubber shreds and recycled aggregate gravel bed were used, it is observed that the improvement in various physico-chemical parameters of leachate was significant in the range of  $t_r/t_g = 0.25-1.5$ . For  $t_r/t_g > 1.5$  improvement was almost negligible.

Improvement in terms of various physico-chemical parameters of leachate was not significant when smaller size waste rubber shreds were used in the drainage layer. The percentage improvement was corresponding to test col.-3 ( $t_r/t_g = 0.667$ ,  $w = 10-20\text{ mm}$ ), followed by test col.-8 ( $t_r/t_g = 0.667$ ,  $w = 10\text{ mm}$ ), test col.-9 ( $t_r/t_g = 0.667$ ,  $w = 15\text{ mm}$ ) and test col.-10 ( $t_r/t_g = 0.667$ ,  $w = 20\text{ mm}$ ) for chloride and BOD is about 9-10% only.

The use of rubber shreds and recycled aggregates in the drainage layer of landfill helps to treat the leachate to some extent and at the same time solve the disposal problems of rubber waste and C&D waste by converting it to a beneficial material. Therefore the study emphasizes the use of recycled aggregates and rubber waste in leachate collection media from sustainability considerations.

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