

# Assessment of Drainage Properties of Tires Derived Aggregates to Be Used As Drainage Layer Material in Leachate Collection System of MSW Landfill

Disha Thakur<sup>1</sup>, M. K. Kaushik<sup>2</sup>M.Tech Student, Department of Civil Engineering, DAVIET, Jalandhar, Punjab, India<sup>1</sup>Assistant Professor, Department of Civil Engineering, DAVIET, Jalandhar, Punjab, India<sup>2</sup>

**ABSTRACT:** The performance of the leachate collection system (LCS) is considered critical for any modern landfill. The reuse of waste tires in civil engineering applications may be as whole tires, tires ground down to shreds, cut in pieces to some intermediate size in form of shreds or chips. High permeability of tire shreds makes them suitable for several landfill applications like leachate collections layer at the base, operations layer and drainage layer in the landfill cap. In the present study, tire derived aggregates (chips/shreds) were used as a replacement of the conventionally used gravel in the drainage layer of leachate collection system. The study included the determination of properties of tire chips/shred using different aspect ratios of 1 and 2, of same and varying sizes under the different conditions. The permeability and compressibility of the TDA were determined. The main objective of the study is to determine the suitability of TDA to be used as the drainage material.

**KEYWORDS:** Tire Derived aggregates, Leachate Collection System, Permeability, Compressibility, Drainage Layer

## I. INTRODUCTION

Landfills are well engineered facilities that are designed, located, operated and monitored to ensure the compliance with federal regulations. Solid waste landfill must be designed to protect the environment from contaminants which may present in waste. Over 290 million used automobiles and especially tires were discarded each year nationwide (USEPA, 2010). It was estimated that 1.2 to 1.5 billion tires were discarded each year worldwide. According to Environmental Protection Agency (EPA), it was estimated that 1 lakh used tires each day were removed amounting 40,000 tonnes waste of rubber each year. However all of these recycling reuse and recovery practise combined can only consume about 22 % of scrap tire that are generated each year in US. According to ICRA, in 1990-91 estimated discarded tyre were 22,846 thousand annually in India. From 1994- 95, discarded tire rate was 31,213 thousand annually. Discarded volumes of scrap tires were greater than 75 million cubic metres in 1993. ICRA expect the tire industry to grow by 5% in 2011 to 2012, -2% in 2012-2013 and again increased to 2-4% in 2013-2014, 6-7% in 2014 - 2015. To utilize the discarded tire and to reduce its harmful effect on the environment, it can be used as an alternative material. The tire derived aggregates (tire chips/shreds) was proposed as an alternative drainage layer material for the drainage layer construction of leachate collection systems (Kaushik et al. 2012). High permeability of tire derived aggregates make them suitable for several landfill applications such as leachate collection medium at the base in the operations layer, foundation layer and as drainage layer in the landfill cap but the most likely application is to use as drainage material for construction of drainage layer of leachate collection and removal system. These tire derived aggregates were used as a substitute for conventionally used granular material (sand, gravel) in landfill construction (Duffy 1995). The performance of the TDA drainage layer depends upon the drainage characteristics of the tire derived aggregates. Shredded scrap tires have been used in leachate collection system for landfill drainage material solely based on their high hydraulic conductivity (Ahmed and Lovell, 1991; Duffy, 1996; Hall, 1991; Edil et al., 1992). The system

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

may be required to collect and remove leachate for extended periods of time, it is important that they must be designed to optimize their long term performance (Rowe and Yu 2012; Rowe et al. 2010; Kaushik et al. 2014 (b) and Kaushik et al. 2015, 2016).

Hence the objectives of the study are:-

1. To study the possibility of reutilization of waste tire chips/shreds (TDA) for different large scale geotechnical applications (such as drainage layer of LCS).
2. To study the drainage properties (compressibility, permeability) of Tire Derived Aggregates (tire shreds/chips).
3. To investigate the effects on permeability of materials by use of different sizes shapes (aspect ratio) tire shreds/ chips in drainage layer.

## II. REVIEW OF LITERATURE

With the increased use of vehicles, many waste tires enter in the environment, potentially causing serious problems. The use of waste tires may be as whole tires, tires ground down to shreds, cut in pieces to some intermediate size in form of shreds or chips. Tire shreds/chips have properties that civil engineers generally need. The properties of TDA having determined based on the several studies. Humphery et al. (1993) presented the engineering properties of scrap tires that are needed to put tire chips into use. The properties include gradation, specific gravity, absorption, compacted density, shear strength, compressibility and coefficient of lateral earth pressure at rest. The 76mm (3-in.) maximum size and high compressibility of the tire chips necessitated design and fabrication of custom made testing equipment. The tests showed that the tire chips are composed of uniformly graded gravel sized particles that absorb only a small amount of water.

The hydraulic conductivity of tire shreds is reduced to 0.01 cm/sec under a normal stress of 21,000 psf (Reddy and Saichek 1998). The tire shreds were compressed by 65% under this high normal stress, but even under this extreme stress condition, the shredded scrap tires met the minimum hydraulic conductivity requirement for drainage materials in landfill covers, which is 0.001 cm/s. Tire shreds have high Permeability and retain it even under high vertical loads. Shredded scrap tires can also be proposed as an alternative drainage material, because of their high hydraulic conductivity (Hall 1991, Edil et al., 1992, Ahmed and Lovell 1993, Duffy 1995). Hydraulic conductivity was measured for the maximum, minimum, and average tire shred size by many researchers and the obtained results showed no definite relationship between hydraulic conductivity and tire shred size.

Criteria for the tire shreds made leachate drainage layers when used as drainage material in place of conventionally used drainage materials was specified by Geosyntec Consultants (1998). Similarly, criteria had also been proposed for the landfill covers when prepared by using tire shreds as drainage material. Tire shreds should not be placed directly on a geomembrane liner because of the possibility that steel belts protruding from the cut edges of the tire shreds could puncture the liner when subjected to the weight of the overlying waste. Granular soil/ gravel must be place of minimum thickness 304.8mm over the liner, must be placed as a protective layer. Warith et al., 2004 conducted many experiments on using lower quality and high quality tire shreds, concluded that under applied vertical loads resulting in average vertical stresses of up to 440 kPa, the maximum normal strain recorded for each type of tire chip was observed to plateau at a strain level near or slightly greater than 0.5.

Thus the various studies on the properties of the tire derived aggregates showed that the TDA has the properties so that it can be used as an alternative drainage layer material.

## III. MATERIAL AND METHOD

Material should be such that to satisfy requirements like it should be permeable enough to collect and transport liquid. The material should be compatible with the waste. The material should not damage the liner. Sometimes geotextile should be used between geomembrane and the drainage layer. Materials that can be used are granular soil (sand and gravel, geosynthetics (geonets and geocomposites) and alternative material (recycled material like shredded tires.) The tire chips/shreds used should be light weight, less compressible, less thermal conductivity.

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

### Material Tested For Different Drainage Properties

However gravel was used as a drainage material in landfill drainage layer as the hydraulic conductivity was observed in the range of  $10^{-2}$  to  $10^1$  m/sec. Gravel were observed with excellent drainage properties and therefore used all over the world as the landfill drainage material. Now, due to changed mining policies, environmental regulations gravel had become a scarce natural resource. The availability of this drainage material is reducing day by day. Many projects in the studied area had been delayed by years because of the non-availability of gravel (river aggregate) for the civil/geotechnical engineering projects. The Government of India under the guidance by Hon'ble Supreme Court of India had banned the illegal mining of natural aggregates from most of the rivers of the state. So, to continue with the development processes, it is up most important to find any alternative material for the replacement of conventional material which may be used as an efficient drainage material.

### Tire Derived Aggregates:-

**Tire shreds:-**The shreds of tire having size 17x9cm are used for the purpose. The permeability can be determined in the same manner by varying the head from 5cm to 15cm (as 5, 10, 15 cm). Tire derived aggregate (TDA) were prepared by cutting scrap tires into 25 to 300 mm pieces. TDA has the excellent drainage properties as hydraulic conductivity and porosity. Tire derived aggregates can also maintains its structural integrity for longer duration. Being the comparatively lighter material, the tire derived aggregates are easier to handle and may results into reduction in transportation costs. Tire derived aggregates of thickness 900 mm needed to achieve equal thickness of 300 mm of gravel, due to high compressibility of the tire derived aggregates. Additionally, hydraulic conductivity of the tire rubber under various overburden pressure levels also becomes important parameter required to be considered if these scrap tires are being utilized as drainage application.

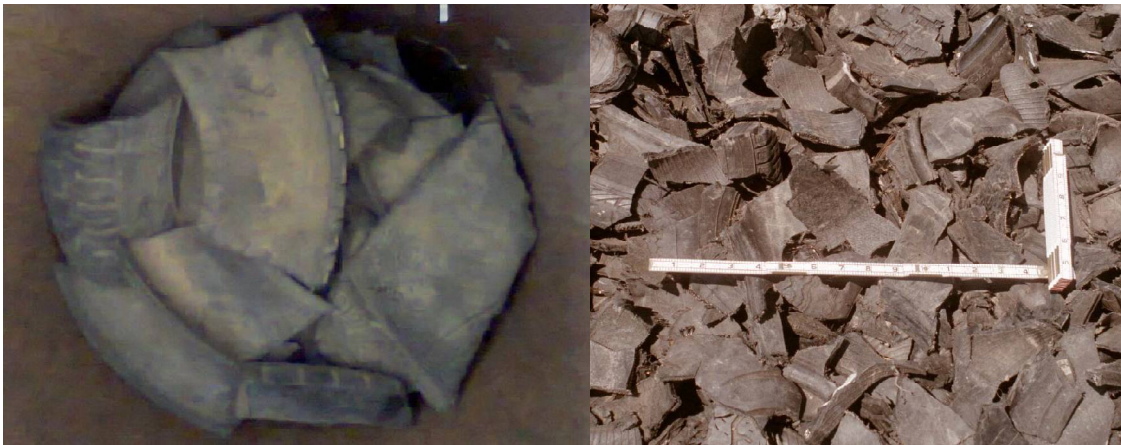


Fig. 1 Tire Derived Aggregate used as a Drainage Layer Material

### Tire chips with varying size and same aspect ratio:-

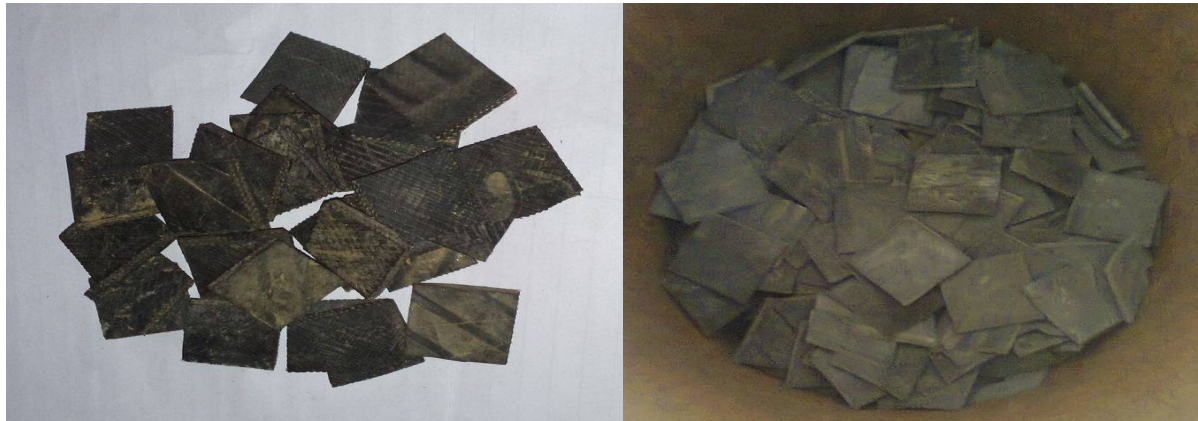
Firstly the tire chips of different sizes as 2.5x2.5cm, 5x5cm, 10x10cm are used to determine the permeability. The aspect ratio of the tire chips is 1 and 2 respectively. Thus the variations in the hydraulic conductivity/permeability of these samples are determined. As the test is performed on the samples, the difference in the values occurs with the sizes. The permeability of tire chips can be evaluated with change in the water head.



## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016



(a) 2.5×2.5 cm Tire Chips

(b) 5×5 cm Tire Chips



(c) 10×10 cm Tire Chips

Figure 2 (a, b, c) Tire Chips of Aspect Ratio 1

### Tire strips with varying size and same aspect ratio:-

The strips of sizes 2.5×5 cm, 3.5×7 cm and 5 × 10 cm has been used, having the aspect ratio 2. The variation in the permeability can be determined with change in water head and sizes.



(a) 2.5×5 cm Tire Chips

(b) 3.5×7 cm Tire Chips

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016



(a) 5×10 cm Tire Chips

Figure 3 (a, b, c) Tire Chips of Aspect Ratio 2

## Experimental Setup And Test Procedure Adopted For Hydraulic Conductivity And Compressibility Testing Of Tire Derived Aggregates:

Hydraulic conductivity and compressibility test apparatus (shown in Fig. 4 and 5) were developed for the experimental study to assess the drainage characteristics of TDA. Fig. 4 showed the schematic representation of the test setup used for the hydraulic conductivity determination. The internal diameter and the effective height of permeameter were 30.48 cm and 92 cm respectively. The permeameter was connected with the upper reservoir containing leachate and leachate was allowed to flow from upper reservoir in the permeameter through the drainage material (tire derived aggregate) so that all air bubbles present between the void space may be removed. The valve was closed after removing all air entrapped and the permeameter was filled entirely (up to top level with leachate) with the leachate. The tire derived aggregates samples of average size and aspect particular size and aspect ratio were filled in the permeameter. Upper drainage plate was placed over the tire derived aggregates. TDA were compressed up to desired density level using hydraulic jack and reaction frame. Leachate was allowed to flow through the tires, a steady flow condition were established. The head of leachate was kept 5 cm above the upper drainage plate. After establish steady state flow conditions leachate was collected in the lower reservoir and hence, the hydraulic conductivity of tire derived aggregates was determined. In the similar manner, hydraulic conductivity of gravel was also measured.

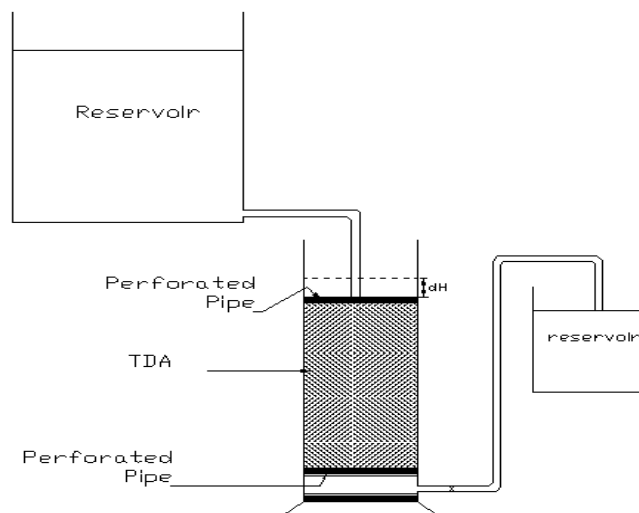


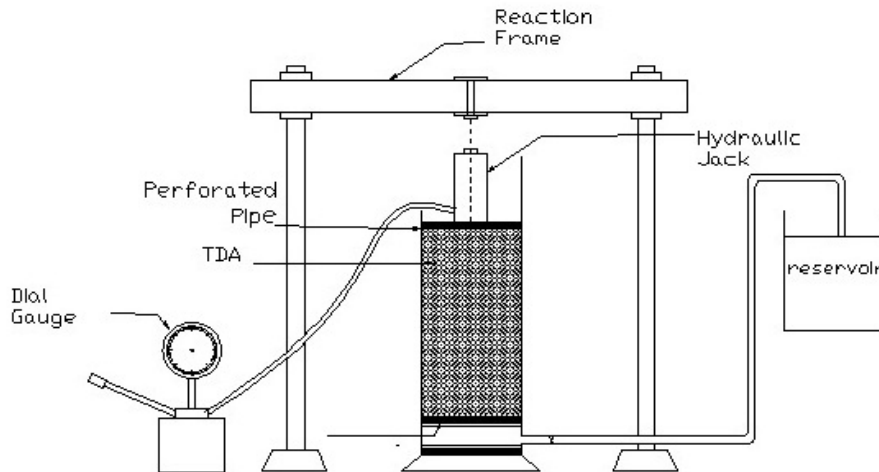
Fig. 4: Schematic of Constant Head Permeameter used in study

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

Fig. 5 showed the schematic representation of the compressibility test apparatus used in the study. The compressibility test was done for the tire shreds and chips of size 5×5 cm. The tire derived aggregates were placed in the rigid wall cylindrical permeameter. Increasing vertical stress levels were applied and the vertical strain levels (deformation) were measured. The vertical compression caused by increasing stress level was measured. The compressibility behavior was measured as per the change in the height of the tire derived aggregates filled portion on application of stress levels of varying magnitudes. The vertical stress levels were applied on the tire derived aggregates samples by means of a hydraulic jack and reaction frame. The stress applied was measured using dial gauge attached to the hydraulic jack. The stress levels were increased to next incremental levels and was maintained for 2 to 5 minutes and then again released to zero level. The samples were loaded and then unloaded repeatedly. The average strain response observed for the TDA sample was calculated by measuring the initial and the final height of the sample after the stress was applied.



**Fig. 5: Schematic of Compressibility apparatus used in study**

The observed hydraulic conductivity and compressibility responses were used to select the optimum tire chips size and aspect ratio for the possible use as drainage layer material in the construction of leachate collection and removal system of the MSW landfills.

### IV. RESULTS AND DISCUSSION

The use of tire derived aggregates/shreds had been identified for civil engineering applications, such as highway embankments, pavements, retaining structures, and lightweight fill material. The permeability/hydraulic conductivity were measured on the different size tire shreds/chips under different test conditions. Depending upon the varying test conditions the properties of shreds/chips were determined. On tire chips/shreds with aspect ratio 1 (sizes 2.5×2.5, 5×5, 10×10 cm) and aspect ratio 2 (sizes 2.5×5, 3.5×7, 5×10 cm) and tire shreds with average size 17×9 cm, tests were performed and following results were obtained.

Permeability characteristics of the tire derived aggregates:

**1. Aspect Ratio:1**

**a) Tire Chips (2.5×2.5 cm)**

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.135	0.16	5
0.08	0.33	10
0.067	0.5	15

The test is performed on the tire chips of sizes 2.5×2.5 cm. Results showed that with increase in the hydraulic gradient the values of permeability goes on decreasing. The values of permeability ranged from 0.135 to 0.067 cm/sec.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

**b) Tire Chips (5×5 cm)**

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.09	0.16	5
0.08	0.33	10
0.07	0.5	15

As the water head is increased from 5,10,15 cm, the hydraulic gradient values goes on increasing having the values from 0.16,0.33, 0.5 and reduction in the permeability values. The change in permeability values ranges from 0.09 to 0.07 cm/sec.

**c) Tire Chips (10×10 cm)**

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.174	0.16	5
0.101	0.33	10
0.076	0.5	15

Similarly the variation in permeability values of tire chips of size 10×10 cm is determined. The graph showed decrease in permeability. The permeability decreases from value 0.174 to 0.076 cm/sec. The permeability of the tire chips increase from the previous sizes.

Thus the results from the tire chips of different sizes with same aspect ratio, showed that as the size of tire chips increases, the permeability increases. This is due to presence of larger voids in the sample. The void ratio is more in the bigger size of tires. So the larger tire chips sizes are having the high permeability values than smaller tire chips sizes. On an average, permeability value increases from 0.094 to 0.117 cm/sec.

**2. ASPECT RATIO: 2**

The table showed the values of permeability of tire strips with aspect ratio 2 (size 5×2.5,7×3.5, 5×10 cm) at the different hydraulic gradient. The value of permeability decreases with increase in hydraulic gradient.

**a) Tire chips (5×2.5)cm**

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.18	0.16	5
0.10	0.33	10
0.07	0.5	15

The change in permeability values ranges from 0.18 to 0.07 cm/sec. From the Figure 6, it is clear that the tire chips of 2.5x5 cm gives gradual decrease in permeability values. This size of tire chips does not give the free drainage of water through material.

**b) Tire chips (3.5x7)cm**

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.16	0.16	5
0.09	0.33	10
0.08	0.5	15

Similarly the variation in permeability values of tire chips of size 3.5×7 cm is determined. The permeability decreases from value 0.16 to 0.08 cm/sec. The permeability of the tire chips increase from the previous sizes. The graph showed the gradual decrease in the permeability of sample.

**c) Tire chips (10x5)cm**

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.16	0.16	5
0.09	0.33	10
0.07	0.5	15

As the water head is increased from 5,10,15 cm, the hydraulic gradient values goes on increasing having the values from 0.16,0.33, 0.5 and the change in permeability values ranges from 0.16 to 0.07 cm/sec. From the graph, it is clear

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

that the tire chips of 10×5 cm gives gradual decrease in permeability values. This size of tire chips does not give the free drainage of water through material.

### TIRE SHRED (17×9) CM

Permeability, k (cm/sec)	Hydraulic gradient, i	Head, h (cm)
0.21	0.16	5
0.114	0.33	10
0.086	0.5	15

The table showed the permeability of tire shreds with hydraulic gradient values. The permeability also decreases with increase in hydraulic gradient. So the quantity of water flowing out is higher. The value ranges from 0.21 to 0.086 cm/sec.

In comparison to the other sizes, shapes of tires, the tires shreds are larger and irregular in size and having more voids. The result also indicates that due to higher void ratio and larger size of tire shreds, the permeability increases as compared to the tire chips. The combined variation in the permeability of the tire chips and shreds is given in figure 6.

### COMPARISION OF PERMEABILITY (k) OF DIFFERENT SIZES TIRE CHIPS (A.R. – 1 & 2) AND TIRE SHREDS WITH HYDRAULIC GRADIENT (i)

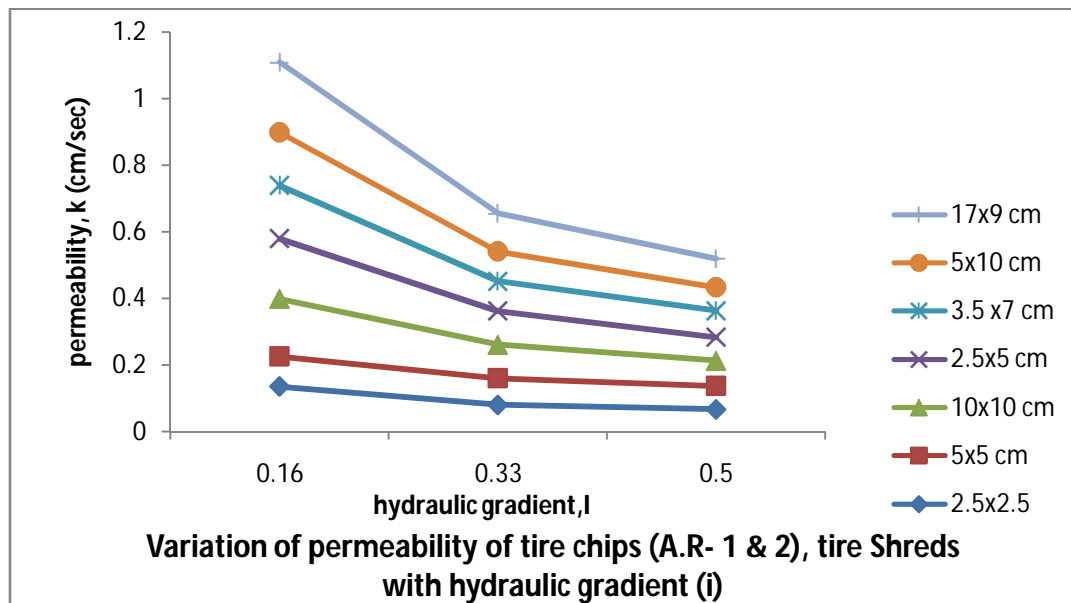


Figure 6. Variation of permeability of tire chips (A.R.- 1&2) and Tire shreds with hydraulic gradient



## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

**Table 1. Comparison of permeability of tire chips/shreds (aspect ratio- 1&2, thickness of layer of tire chips/shreds = 60 cm).**

Sr. No.	Size		Aspect Ratio	Hydraulic gradient (i)	Time (in sec)	Permeability (k) cm/sec
	Tire Chips (cm)	Tire Shreds (cm)				
1	2.5×2.5	-	1	0.16	10	0.135
2	5×5	-				0.09
3	10×10	-				0.174
4	2.5×2.5	-	1	0.33	10	0.08
5	5×5	-				0.08
6	10×10	-				0.101
7	2.5×2.5	-	1	0.5	10	0.067
8	5×5	-				0.07
9	10×10	-				0.076
10	5×2.5	-	2	0.16	10	0.18
11	3.5×7	-				0.16
12	10×5	-				0.16
13	5×2.5	-	2	0.33	10	0.10
14	3.5×7	-				0.09
15	10×5	-				0.09
16	5×2.5	-	2	0.5	10	0.07
17	3.5×7	-				0.08
18	10×5	-				0.07
19	-	17×9	≈ 2	0.16	10	0.21
				0.33		0.114
				0.5		0.086

### Compressibility characteristics of the tire derived aggregates:

The compressibility behavior of the tire chips (5 × 5 cm) was done because it had the free draining and tire shred have the high permeability as compared to the other sizes.

### Tire chips (5×5 cm):-

The compressibility of tyre chips was measured by applied load levels of different magnitude on tyre chips sample. For the compressibility testing, tyre chips of size 5 cm × 5 cm and aspect ratio (A.R. = 1) were taken. The initial thickness of the material (tyre chips) was taken approximately equal to 60 cm.

The load settlement values were determined and had been shown in table 4.5.8.

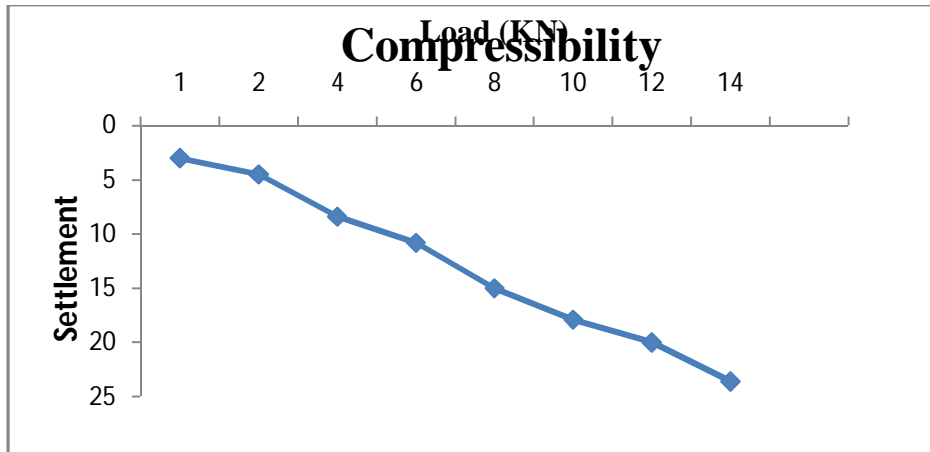
**Table 2 Variation of Load V/s Settlement**

S. No.	Load (KN)	Stress (Kpa)	Initial thickness of sample (cm)	Final thickness of sample (cm)	Settlement (cm)
1.	1	13.7	60	57	3.0
2.	2	27.42	60	55.5	4.5
3.	4	54.84	60	51.6	8.4
4.	6	82.27	60	49.2	10.8
5.	8	109.69	60	45	15.0
6.	10	137.12	60	42.1	17.9
7.	12	164.5	60	40.0	20.0
8.	14	191.9	60	36.4	23.6

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016



**Figure 7** Change in settlement with respect to load applied on tyre chips of size 5×5 cm (aspect ratio = 1)

It is clearly evident from the figure 4.21 that as the load on the material (tyre chips of size 5 cm× 5 cm and A.R. was 1) increased, the settlement values increased respectively. Hence, tyre chips are compressible in nature.

**Tire shred ( 17×9 cm):-**

The tire derived aggregates were highly compressible than that of the gravel. The compressibility of TDA was observed in the range of 44-48% (Table 3). As the result showed tires are highly compressible.

**Table 4.3** Compressibility of the Tire Derived Aggregates under loading

S. No.	Load (kN)	Stress (kPa)	Initial thickness of sample (cm)	Final thickness of sample (cm)	Settlement (cm)
1.	1	13.7	60	56	4.0
2.	2	27.42	60	54.5	5.5
3.	3	41.13	60	51.2	8.8
4.	5	68.56	60	49	11
5.	6	82.27	60	46.5	13.5
6.	8	109.69	60	42.3	17.7
7.	10	137.12	60	40.2	19.8
8.	11	150.83	60	36.8	23.2
9.	15	205.68	60	31.2	28.8

**Conversion factor: 1kN= 13.7 kPa**

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

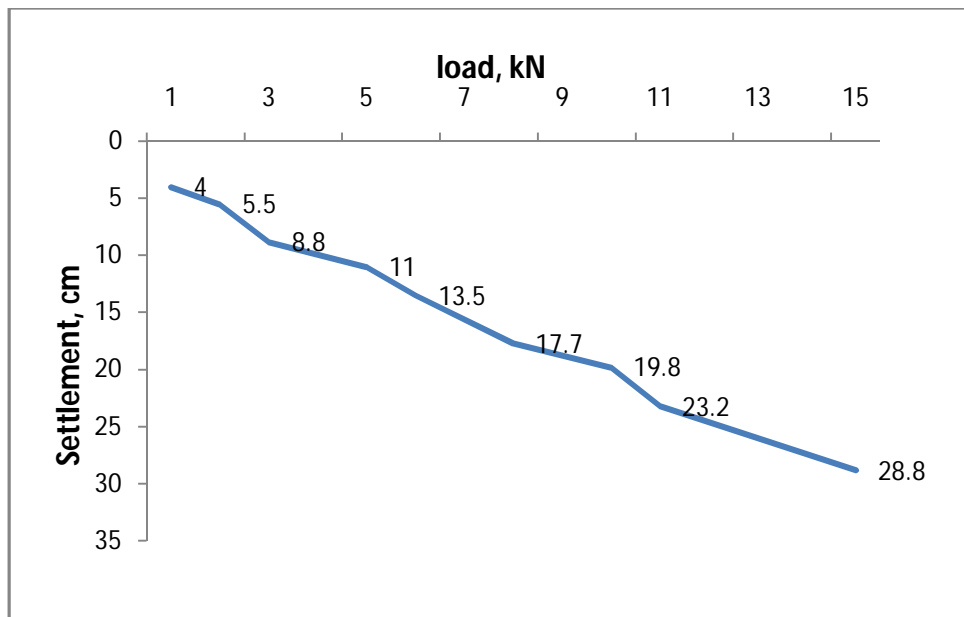


Fig. 4.3 Load- settlement behaviour of the TDA

## V. CONCLUSION

In this research work, different sizes tire chips/shreds of varying aspect ratio were used as drainage layer material in landfill cover system replacing natural aggregates completely/partially as a resource conservation measure.

The study revealed that tire chips of aspect ratio 1 of the average size 5 cm x 5 cm were observed most appropriate for draining /percolating rainfall water through them. Few experiments were also conducted to investigate the effect of high hydraulic gradient on drainage capability of different size tire shreds/chips. The experiments revealed that same tire chips of aspect ratio 1 were capable of providing relatively faster release of water through them even on relatively high hydraulic gradient value.

The experimental investigation showed that tire shreds/chips of aspect ratio 1 (5 x 5) cm and aspect ratio 2 (5 x 10) cm were good for obtaining relatively free draining. Although, the tire shreds (17x 9 cm) are having better drainage properties because of the high void ratio. So they can be used as an alternative drainage material.

The compressibility behaviour of the tire shreds and tire chips were nearly similar. However the shreds were slightly more compressible than tire chips.

From the test results it can be concluded that the tire derived aggregates have the good drainage properties in comparison to the conventionally used gravel, and thus can be used as an alternative drainage layer material in the leachate collection system.

## REFERENCES

1. ASTM (1993) "Test method for permeability of Granular soil (constant head)- ASTM D 2434-685 (revised Sept. 1993 and reapproved 2000)" American Society for Testing and Materials, W. Conshohocken, PA.
2. ASTM (1998), "Standard Practice for Use of Scrap Tires in Civil Engineering Applications- ASTM D 6270-98", American Society for Testing and Materials, W. Conshohocken, PA, 19p.
3. ASTM (2003). "Standard practice for classification of soils for engg. purposes, unified soil classification system" American Society for Testing and Materials ASTM D2487.
4. ASCE (2005), "Drainage layer in engineered MSW landfill." Proc, Geofrontier 2005, ASCE, Reston, Va.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

6. Benda, C.C., (1995), "Engineering Properties of Scrap Tires Used in Geotechnical Applications" Report 95- 1, Materials and Res. Div., Vermont Agency of Transportation, Vt.
7. Beaven R. P., Powrie W., Hudson A. P. and Parkes D. (2006) "Compressibility of tyres for use in landfill drainage systems". Proceedings of the Institution of Civil Engineers, Waste and Resource Management, 159, No. 4, 173–180.
8. Bernal A., Salgado, R. and Lovell C.W. 1999, "Shredded tires and rubber-sand as lightweight backfill." *Journal of geotechnical and geoenvironmental engineering, ASCE 125(2), 132-141.*
9. Edil, T.B., Fox, P.J., and Ahl, S.W., (1992), "Hydraulic Conductivity and Compressibility of Waste Tire Chips", Fifteenth Annual Madison Waste Conference, University of Wisconsin,
10. Edil T.B., and Bosscher P.J. (1994). "Engineering properties of tire chips and soil mixtures." *Geotechnical Testing Journal*, ASTM, 14(4), 453-464. Edil, T. B., Park, J. K., and Kim, J. Y. (2004). "Effectiveness of scrap tire chips as sportive drainage material." *J. Environ. Eng.*, 130(7), 824–831.
11. Hudson et al., 2003, "Bulk Compressibility and Hydraulic Conductivity of used tyres for landfill drainage applications." Proceeding Sardina 2003: Ninth international waste Management and Landfill Symposium, 6-10 October, Sardina, Italy, 9p.
12. Hudson, A.P., Beaven, R.P., Powrie, W. and Parkes, D. (2007) "Hydraulic Conductivity of Tyres in landfill drainage systems." *J. Waste and Resource Management* 160(WR2), 63-70.
13. Humphrey, D. N., (2011), "*Civil Engineering applications using Tire derived aggregate (TDA)*", Publication #DRRR-2011-038, California Integrated Waste Management Board, California.
14. Kaushik M. K., Agnihotri A., Bansal A. (2012) "Beneficial use of Shredded Tires of different sizes with gravel as Drainage layer of Landfill Leachate Collection System" Proc. of Indian Geotechnical Conference 2012, Indian Institute of Technology (IIT), Delhi, India
15. Kaushik M. K., Kumar A., Bansal A. (2014a), "Performance assessment of tyre chips - gravel mixes as leachate drainage layer materials", *International Journal of Geotechnical Engineering*, 9(5): 453-470
16. Kaushik et al., (2015), "Performance Assessment of Gravel-Tire Chips Mixes as Drainage Layer Materials Using Real Active MSW Landfill Leachate" *Geotech. Geological Engg.* 33(4):1081–1098.
17. Kaushik M. K., Kumar A., Bansal A. (2016), "Drainage performance of different sizes tire chips used alone and mixed with natural aggregates as leachate drainage layer material", *Journal of Geotechnical and Geological Engineering* (doi: 10.1007/s10706-015-9937-x).
18. Madison Edil, T. B., and Bosscher, P.J. (1994), "Engineering Properties of Tire Chips and Soil Mixtures," *Geotechnical Testing Journal*, Vol. 17, No. 4, pp. 453-464.
19. Reddy, K.R., and Saichek, R.E., (1998), "Assessment of Damage to Geomembrane Liners by Shredded Scrap Tires", *Geotechnical Testing Journal*, Vol.21, No.4, pp. 307-316.
20. Reddy, K.R. and Saichek, R.E., (1998), "Characterization and Performance Assessment of Shredded Scrap Tires as Leachate Drainage Material in Landfills", Proceedings of the Fourteenth International Conference on Solid Waste Technology and Management, Philadelphia, PA.
21. Reddy, K. R., Stark, T. D., and Marella, A. \_2008\_. "Clogging potential of tire shred- drainage layer in landfill cover systems." *Int. J. Geotech. Eng.*, 2\_4\_, 407–416.
22. Reddy, K. R., and Saichek, R. E. \_1998b\_. "Characterization and performance assessment of shredded scrap tires as leachate drainage material in landfills." *Proc., 14th Int. Conf. on Solid Waste Technology and Management*, Widener Univ., Chester, Pa.
23. Reddy, K., and Marella, A. (2001). "Properties of different size scrap tire shreds: implications on using as drainage material in landfill cover systems." *Proc., 7th International Conference on Solid Waste Technology and Management*, PA, 1-19.
24. Reddy, K.R., Stark T.D., and Marella, A. (2010), "Beneficial Use of Shredded Tires as Drainage Material in Cover Systems for Abandoned Landfill" proceeding of Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management ,Vol. 14, No. 1, January1, 2010. @ ASCE.
25. Stark, T. D., and Poeppel, A. R. \_1994\_. "Landfill liner interface strengths from torsional-ring-shear tests." *J. Geotech. Eng.*, 120\_3\_, 597–615.
26. U.S. Environmental Protection Agency (1994). "Design and construction of RCRA/CERCLA final covers." *Rep. No. EPA 822-R-94-001*, Office of Research and Development, Washington D.C.60.
27. Warith M.A., Evgin E., Benson P.A.S. (2004), "Suitability of shredded tires for use in landfill leachate collection systems", *Journal of Waste Management*, 24 (10):967-979.

## ABBREVIATIONS

TDA	Tire Derived Aggregates (any combination of tire shreds and tire chips)
LCS	Leachate collection system
MoEF	Ministry of Environment Forest, Government of India (GoI)
RCRA	Resource Conservation and Recovery Act
ENVIS	Environmental Information System
USEPA	United State Environmental Protection Act
EPA	Environmental Protection Agency
ICRA	Indian Independent and Professional Investment Information and Credit Rating Agency