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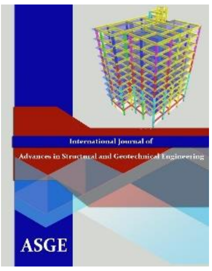

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Uses of Waste Tires in Geotechnical Application – A Review

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ABSTRACT

This paper presents some of the most common applications of waste tire shred in geotechnical engineering. Waste tire shred considered as a substitute alternative backfill in many geotechnical applications. Waste tire was used by geotechnical engineering to improve the mechanical properties of earthen structures. It also contains various shapes and types of waste tire shred and their advantages.

Keywords: *Waste Tires, Backfill, Reinforcement, Permeability, Sandy Soil.*

1. Introduction

All countries around the entire world are facing a serious environmental problem on what to do with disposal of discarded tires. The accumulation of used waste tires at landfill sites also causes dangerous fires occurrence, the high cost of hygiene disposal, and health hazards, this issue has become one of the biggest environmental problems. Increase in the amount of waste tires yearly makes them harder and more costly to dispose of safely without threatening human health and environment. The process of recycling waste tire system is complicated and expensive.

For that reason, providing some solutions to this problem seems to be needed. Some of the solutions are reusing them as filler materials in construction projects, such as road construction, retaining walls, and drainage systems and also about its use as a reinforcement of retaining earth walls.

As a practical point of view, the use of waste tires may be offered in geotechnical applications due to four advantages; (1) the reuse of waste materials such as waste tires and tubes, reduction in environmental health hazard and saving huge spaces and costs to maintenance of wastes, (2) the reduction in consumption of competent natural soil and its cost saving benefit, (3) soil reinforcement, which can demonstrate a substantial increase in shear strength of mixture compared to soil alone, and (4) the exhibition of a higher capacity to absorb and to dissipate energy than soil alone and tend to decrease the stress and shocks transferred into the ground when subjected by dynamic loads. Reinforced earth technique has been gaining.

Ground modification techniques can be classified into four groups of ground improvement techniques. They can be classified as follows; (1) mechanical modification method; (2) hydraulic modification method; (3) physical and chemical modification method (4) modification by inclusion and confinement method. The use of waste tire is considered as modification by inclusion method.

The use of waste tire in geotechnical engineering applications is suitable, because it has a low unit weight, high durability, high thermal insulation and low cost effective when compared to other fill materials.

According to the American Society of Testing and Materials (ASTM, 1998), a waste tire is defined as a tire which is no longer capable of being used for its original purpose. A scrap tire is a tire, which can no longer be used for its original purpose due to wear or damage and still contain wire. Tire shreds are pieces of scrap tires that have a basic geometrical shape and are generally between 1mm and 300 mm in size.

2. Scope of the present paper

The main objectives of the thesis work are to:

- Identify and present the state of the art knowledge in the uses of shredded tires.
- Describe and evaluate tire shreds as a civil engineering construction material.
- Describe and evaluate technical properties of tire shreds from a civil engineering point of view.
- Describe and evaluate environmental properties of tires shreds and identify environmental concerns regarding use of tire shreds as construction material.
- Identify beneficial use and limitations in applications of the use of tire shreds.

3. Applications of Tires

The use the whole tires without mixing with soil has been reported as lightweight embankments fills over soft or unstable ground. The whole tires used as backfill material possess high hydraulic conductivity and high the thermal insulation. The possible drawback is the high compressibility of tire when compacted with that of soils, which may cause serious problem for the superstructure.

4. Applications of Shredded – Tires

Shredded waste tires are now being used as a sub-grade reinforcement for constructing roads over soft soils, as aggregate in leach beds for septic systems, as an additive to asphalt, as substitute for leachate collection stone in land fills, and as sound barriers as stated by Hall, 1991; Ahmed and Lovell, 1993 and Park et al., 1993 . Shredded waste tires are being used as fuel– supplement in coal – fired boilers, an admixture in bituminous concrete, and in low– grade rubber products, such as truck bed liners, doormats, and cushioning foams as reported by Bader, 1992 and Ahmed and Lovell, 1993.

Currently the main methods that consume large quantities of tires include burning for electric power generation, production of cement in cement and lime kilns, and as an energy source to run pulp and paper mills. Even with these uses, the majority of tires are either stockpiled, land filled, or illegally dumped.

Waste tires can be used in the field and applications of earthwork. A new design procedure for using shredded scrap tires as a lightweight fill material in high way construction was developed by Bosscher et al., (1997). They performed laboratory model test, filed tests and numerical analyses to study embankments constructed using discarded shredded tires. The results of numerical analysis were showed that FEM typical over predicted the amount of displacement measured at the surface of the model test . Generally the results of this study supported the use of tire shreds as an environmentally acceptable lightweight fill in highway applications of properly confined (Marei, 2004)

Addition, tire chips can be used to replace aggregate, improve drainage , and provide thermal insulation (Hamphery et al., 1993 , Eaton et al., 1994; Edil and Bosscher, 1994 and Benson et al., 1996. One potential problem when using tire chips in earthwork applications is spontaneous combusted for example, two tire chip embankments spontaneous combusted in the state of Washington (Nightingale and Green, 1997). However, many other embankments have been built and are in operation without any evidence of this phenomenon. (Tatlisoz, et al., 1998).

In this context, the use of shredded tires in highway applications was considered a potentially significant avenue for putting scrap tires into beneficial reuse. There are number of ways in which shredded tires can be used in highway construction, regular fills , retaining – wall backfills , and edge drains .

The lightweight fill application is particularly interesting because it would not only provide a means of disposing scrap tires but also help solve difficult economical and technical problems associated with economical and technical problems associated with settlement and instability of highway construction over soft ground (Bosscher et al., 1997).

The use of scrap tires in highway applications has allowed recycling of this troublesome material and provided both cost and engineering benefits. These applications include retaining wall backfill; fill for road embankments and subsurface drainage system. Most of these projects used tire chips or shreds ranging from 13 to 152 mm in size. Larger tire shreds have distinct advantage over the smaller shred materials when used as subsurface drainage structure (Graham et al, 1999) .

Using tire shred as retaining wall backfill has several potential benefits in areas where the underlying soil is compressible or weak (Tweedie et al., 1998) .

The use of inclusions (or reinforcements) to improve the mechanical properties of earthen structure dates to ancient times. it is only within the last three decades , however , that analytical and experimental studies have led to current soil reinforcemental techniques (zornberg et al., 1998; Elias et al., 2001; Bathurst et al., 2001). Traditional soil reinforcing techniques involve the use of continuous geosyntheic inclusions (e.g; geogrids and geogtextiles) oriented in a preferred direction to enhance the stability of the soil mass (Zornberg et al., 2004) .

This application does not introduce the use of pure tire shred, but introduces the use of tire shred – soil composite as backfill material for highway embankments. To the best knowledge of the author no exothermic reactions have been reported. Backfills of tire shred – soil composites would potentially address technical problems associated with low shear strength of backfill material in highway project. Indeed, tire shreds within the soil mass may induce reinforcement mechanism that make them particularly suitable material for geotechnical infrastructure (Zornberg et al., 2004).

5. Soil Reinforcement:

5.1. Concept of Soil Reinforcement:

The concept of reinforced earth is not new; the basic principles are demonstrated abundantly in nature by animals and birds. The earliest remaining examples of soil reinforcement are large religious towers called Ziggarrat of ancient city of Dur-kurigatzu at Baghdad, which was built by the Babylonians and was constructed of clay bricks, reinforced with woven mats of reed laid horizontally on a layer of sand and gravel (Bagir, 1944). Ancient Egyptians and Indians used straw as reinforcement to strength on adobe bricks building mud walls and grain storage bins (Lee et al., 1973) Also, the Great Wall of China. Parts of which were completed circa 200 B.C., contains examples of reinforced soil , in which the tamarisk branches were used to reinforce clay and gravel mixtures (Dept. of Transport, 1977). The Romans also used soil reinforcing techniques. They constructed the reed - reinforced earth levees along the Tiber (Jones, 1985).

Pasley (1822), introduced a form of reinforced earth for military construction in the British Army. He showed that a significant reduction could be made in the pressures acting on retaining walls if the backfill was reinforced by horizontal layers of brushwood or wooden planks.

Soil reinforcement is composed of two main parts, the tensile members and soil. Soil is the most abundant and least expansive construction material which has proper strength to carry compressive stresses but has virtually no tensile strength. Furthermore, in addition to its weakness under tensile stresses, soil has an importance physical property such as volume contraction and dilation. Soil dilatancy involves the volumetric increase which is usually associated with dense soil during shear processes. In contrast, loose soil undergoes contraction under shearing.

By adding linear or planar reinforcement, that are strong in tension to the soil, a composite material can be produced. This material is similar to reinforced concrete and has higher strength characteristics than unreinforced soil. However, slopes can be constructed at angles much steeper than the internal angle of friction of the soil.

The French architect and inventor Henri Vidal (1969) pioneered the development of modern earth reinforcement techniques. His concept was for a composite material formed from flat reinforcing strips laid horizontally in a friction soil. The system he developed, known as "reinforced earth" in the different parts of the world, was patented in 1966 as Terre Armee in France. Also, this concept was proposed by Casagrande who idealized the problem in the form of a weak soil reinforced by high- strength membranes laid horizontally in layers (Westergad, 1978). The first highway use of a Vidal reinforced earth retaining wall was for a highway near Nice, France.

Since the introduction of the Vidal concept, the use of earth reinforcement has rapidly increased. Several types of reinforcement systems have been developed for applications in walls, embankments and strengthening of in - situ ground. There exists a wide variety of both reinforcement and facing material. The facing material ranges from mortar to precast panels and geogrids. The reinforcement also varies as several different materials used such as; galvanized strip , welded wire mesh , geotextiles and geogrids.

There are several advantages of reinforced earth techniques. For example, the stress transfer between soil and reinforcement creates a composite material with improved structural properties compared to non-reinforced soil. The deformation response characteristics of reinforced earth structures often provide technically attractive solutions on sites with poor foundation soils. In comparison with conventional retaining walls, reinforced soil structures are extremely tolerant of large deformations. The use of in-situ soil reinforcement to retain excavations offers construction advantages over classical excavation bracing schemes, in that it avoids both obstructions with the excavation such as cross - lot braces, and the excessive-noise associated with driving of sheet piles.

Reinforced earth can often provide the most economical retaining wall for embankments constructed under the constraints of limited access or right -of- way (Mitchell and Villet, 1987). The materials used are less expensive than those required for a conventional wall. The ease and speed of construction generally accompanied with the soil reinforcement techniques is significant part of cost savings relative to conventional walls. In addition, there is great flexibility in choosing the facing elements to address aesthetic requirements. Available facing arrangements vary from concrete panels of different geometric shapes, textures, and colors.

6. Different Systems for Soil Reinforcement

The soil reinforcement systems have three main constituents; backfill, facing element and reinforcement. The reinforcement material range from metallic to nonmetallic materials, while the reinforcement geometries are strips , sheets, rods, grids, shredded tires and fibers. Rod, strip and sheet reinforcements transfer stress to the soil mainly by friction, but grid reinforcements transfer stress to the ground predominantly through passive resistance and friction. Thus the available systems of reinforced earth are categorized according to the reinforcement geometry.

6.1. Sheet Reinforcement

Continuous sheets of synthetic fabrics laid down alternately with layer of soil to form a composite reinforced soil material are shown in Figure 1. The stress transfer mechanism between soil and Fabric sheets is mainly due to friction.

The backfill materials for sheet reinforcement often consist of granular soil varying from silty sand to gravel. Furthermore, facing elements consist of either wrapping geotextile around the exposed soil or precast concrete panels. Care should be taken to protect the wrapping geotextiles from ultraviolet light by covering it with shotcrcete, gunite or asphalt emulsion.

6.2. Strip Reinforcement

Strip reinforcement methods involve a coherent reinforced soil mass by the interaction of longitudinal linear reinforcing strips and the backfill material. The strips either metallic or nonmetallic, Figure (2.1b), are normally placed perpendicular to the wall face in horizontal layers between successive lifts of backfill material.

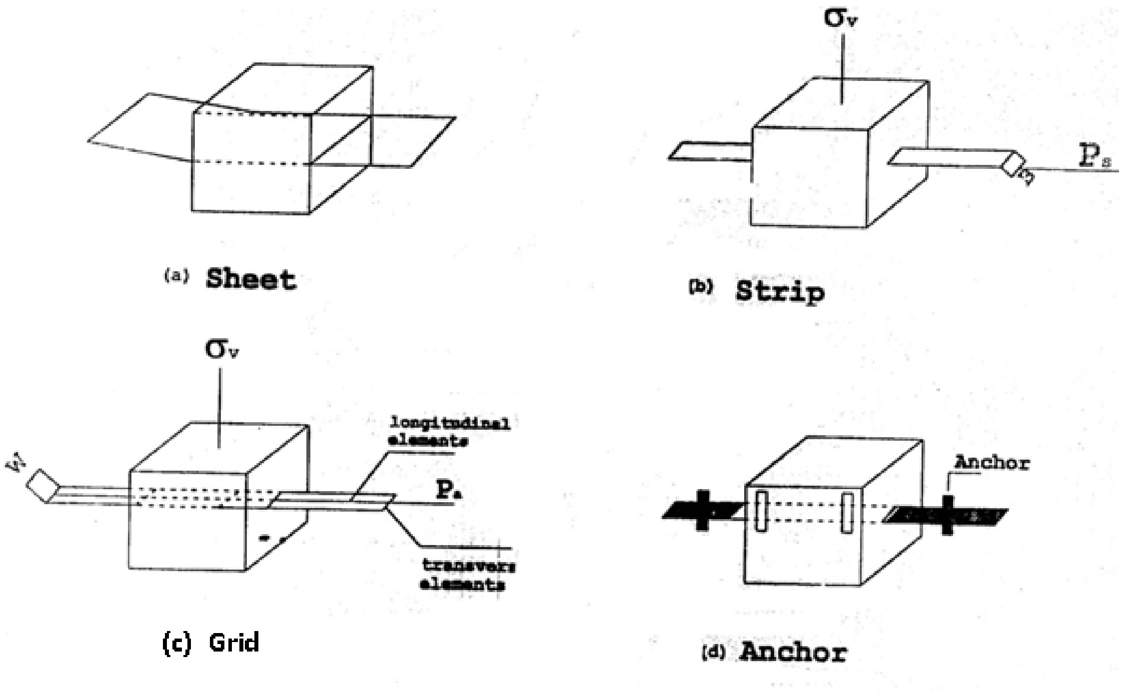
Facing elements connected to the reinforcement are prefabricated metal elements or precast concrete panels. Prefabricated galvanized steel strips, either smooth or ribbed, can be used as strip reinforcement. Avoiding the problem of metal corrosion especially in adverse environments can be made by using plastic strips

6.3. Grid Reinforcement

This system is composed of metallic or polymeric tensile resistant arranged in rectangular grids. The grids are laid in horizontal planes in the backfill material to resist outward movement, of the reinforced soil mass. Grid systems stabilize the surrounding soil mass by a transfer of stress through passive resistance on transverse members of the grid and by friction that develops along the longitudinal members.

6.4. Anchor Reinforcement

The anchored reinforcement system was developed and patented by the Transport and Road Research Laboratory (TRRL) of Crowthorne, England (Chrisiopher et al., 1989). This technique is used for strengthening soil in-situ rather than an earth fill as in the case of reinforced soil. The stress transfer between soil and reinforcement is assumed to be primarily through passive resistance, it is likely to be more efficient in cohesive soils than the other systems which rely mainly on friction.



(a) **Sheet** (b) **Strip**

(c) **Grid** (d) **Anchor**

Figure 1: Common forms of reinforcement (Jones,1985)

7. Bearing Capacity of Sand Reinforced with Randomly Distributed Tire Shreds

Plant roots stabilize soils through reinforcement of soil in nature, against erosion and failure of deep slopes. Presently, reinforcement is an effective and reliable technique for increasing strength and stability of soils. The technique used today varies in the applications ranging from retaining structure and embankments to surged stabilization and surface drainage systems.

The first type of reinforcement used in modern soil reinforcement has been developed by Vidal, (1969) using long steel strips.

Fortunately, variety of materials with different shapes and techniques are nowadays used in civil engineering applications. In general soil reinforcements can be classified into two major categories based on their stiffness. First one is ideally inextensible; second one is ideally extensible inclusions.

The former includes high modulus metal. Strips and bars, while the latter includes relatively low modulus natural and synthetic fibers, plants roots and polymer fabrics. Soil reinforced with randomly – a distributed inclusion is another type of reinforced soil, which has attracted considerable attraction over past years, such as concrete technology and more recently in soils. In this type of soil reinforcement, soil is mixed randomly with discrete small inclusions such as tire shreds, fibers, filaments and small meshes until it become like a homogeneous material.

Reuse and recycling of scraped tires is essential to avoid growing stockpiles of discarded tires around the world's uses for scrap tires in civil engineering applications are growing recently. Scrap tires are used in the production of paving material which is called rubber modified asphalt and in retaining walls as embankments material. More recently tires were shredded into smaller pieces.

Producing a bulk material, which was used as subgrade fill alone or mixed with granular soil to improve the engineering properties of the soil.

Several studies were made to investigate the feasibility of using shredded waste tires as reinforcement to increase the bearing capacity of soil. Many tests were made to determine the effects of shred content and shred aspect ratio on bearing capacity of reinforced soil shred content can be defined as:

$$X = \frac{W_{ts}}{W_{ts} + W_s}$$

Where W_{ts} is the weight of tire shreds
and
W_s is the dry weight of the soil.

and aspect ratio can be defined as

$$\eta = \frac{l_{ts}}{w_{ts}}$$

Where L_{ts} is the length of the individual tire shred.

and

W_{ts} is the width of the individual of tire shred.

8. Tire Shreds Performance Evaluation

8.1. Protection of Public Health.

Generally, tire shred when used as reinforced material, will provide protection of public health. Uncontaminated whole shreds tire are considered non–hazardous insert material (Crwqcb, 1998). Thus, the material should have no health effect or impacts on humans.

Standard practice for use of shred tires in civil engineering applications, developed by the (ASTM, 1998), includes a material safety data sheet for whole shred tires. No known health effects occur due to acute (short term) exposure. The material contains untreated naphthenic or aromatic extender oil. This oil could be released from the surface through skin contact.

Prolonged contact with these oils has been shown to cause skin cancer in laboratory studies with animals. Untreated naphthenic or aromatic oils are classified as carcinogenic by International Agency for research on cancer prolonged or repeated contact may cause skin irritation or sensitization (allergic skin reaction).

Employees, who have prolonged contact with whole tire shreds, should practice good personal hygiene by frequent washing of hands and arms with soap and water. Contaminated clothing should be removed and laundered before reuse. A shower should be taken at the end of each day. Hands hauled be washed before eating, smoking, or using the restroom.

Use of suitable personal protective equipment (PPE) including eye protection and protective gloves and shoes is recommended.

Rubber tires contain potentially carcinogenic materials (including nitrosamines), carbon monoxide and dioxide, acrid fumes, and flammable hydrocarbons may be liberated as result from thermal decomposition or combustion should be avoided.

8.2. Protection of Environment

Generally, tire shreds, when used as reinforced material, will provide suitable protection of the environment. Two of the most pressing environmental hazards related to the tire stockpiles are the catastrophic fires and insect breeding.

Scrap tires are serious fire hazards, which pollute the air with large quantities of smoke, hydrocarbons, and residue. Discarded tires have 75% void space hence, the tire fires are virtually impossible to extinguish once started.

The tire pile fires are dangerous and highly polluting and the clean up after wards is very expensive.

In addition to the fire hazard, pools of water retained by whole or shredded waste tires created an ideal breeding ground for most quitoes, which were shown to spread various dangerous diseases (Engstrom and lamb, 1994).

8.3. Durability

Since tire shreds are a coarse grained material, they are not susceptible to puncture or tearing. The material is considered non biodegradable and resistant to cracking and freeze – thaw cycle. Thus, from perspective of durability, tire shreds are suitable material for reinforcement.

8.4. Operational Impact

Production of tire shreds requires specialized shredding equipment and additional personnel to operate and maintain the equipment. Handling, traffic ability, and storage requirements are comparable to those for soil.

The loose or exposed at the cut edges of tire shreds metal wires can be a hazard to personal walking on the shreds. Tire shreds metal wires can also cause flats in site vehicle tires. Thus, track mounted or steel – wheeled equipment should be used when practical to mitigate this problem .Tire shreds are relatively easy to place and grade on slopes 3 horizontal to 1 vertical (3H: IV) or flatter. However, tire shreds with excessive amount of long, exposed steel belt can be difficult to spread.

Experience shows that only a modest compactive effort is needed to compact tire shreds. Tire shreds have a compressibility that is several orders of magnitude greater than materials typically used for reinforcement.

8.5. Cost Impact

Using tire shreds as reinforced material can be cost effective, despite additional labor and equipment requirements to shred the tires, as compared to costs usually associated with reinforced soil.

9. Material Characteristics

9.1. General

The material characteristics of shredded scrap tire have been divided into two categories:

(i) General tire and tire shred characteristics.

(ii) Engineering prosperities of tire shreds.

The general characteristics include the material composition of the scrap tires, which are most commonly uncounted. Engineering properties include the results of laboratory testing on tire shreds and mixture of tire shreds and soil.

9.2. General Tire and Tire Shred Characteristics

Modern tires are composed of a combination of natural rubber and synthetic rubber elastomers derived from oil and gas. Multiple carbon blacks, extender oils, waxes, antioxidants and other materials are added to enhance performance characteristics and manufacturing efficiency.

Different polymers and additives are generally, utilized in each section of a tire to optimize performance characteristics. Due to the composition and curing process, tires retain their basic chemical properties and physical shape even when shredded into smaller pieces (Gray, 1997) .

Unless the tires are very old, steel and/or fabric reinforcement will have been added to improve strength, especially in the bead area bordering the rim. Steel belts and beads in the tire shreds (up to several inches or more in length) can be exposed. These can be dangerous to both equipment and personnel.

Dissolution of exposed steel (iron) and zinc oxide can occur in aqueous environments depending upon PH conditions (Gray, 1997) . The source of zinc leached from tire shreds could be zinc oxide in the rubber or zinc coating on the steel belt and bead wire. Some initial studies indicate that tire shreds that are continuously submerged below the water table leach trace quantities of organics; however, the levels are too low to be of concern, except under very stringent circumstance (Humphrey, 1996b; Humphrey et al., 1997). In contrast, for tire shreds placed both above and below the water table, tire shreds may be considered virtually non – biodegradable. (Gray, 1997 and Humphrey et al., 1997).

Although tire composition varies by manufacturer and type, the predominant inorganic constituents include :

(i) Steel from reinforcing wire representing 5% - 15 % of total weight ;

(ii) Titanium dioxide used in white side walls and raised letters ;

(iii) Zink oxide and sulfur distributed uniformly within the polymer matrix to achieve vulcanization.

Smaller concentrations of calcium and aluminum are present, along with traces of magnesium, phosphorus, potassium, silica, sodium and chloride (Gray, 1997).

Whole and shredded tires have a flash point in excess of 580° F (322°C), meaning that tires are combustible if exposed to continuous source of ignition capable of generating such temperatures. Although a lighter or cigarette can ignite a localized tire surface, continued combustion generally requires, another fuel source to provide sustained high temperature exposure (Gray, 1997). Past experience has shown that self – ignited fires of tire shreds most commonly occur in thick fills (at least 20 ft (6m) deep (Humphrey, 1996 a).

The nominal size and shape of tire shreds can very depending on the type of shredding machinery used and the setting of its cutting mechanism. Tire shreds have a wide range of sizes, from 76 mm (3in) up to 305 mm (12in), which is ordinarily the largest size recommended. shred sizes normally range from 12 mm(1/2 in) up to 76 mm(3 in). Usually , tire shreds are irregular in shape with the smaller dimension being the size specified by manufacturer and the larger dimension possibly being two or more times as much .The shreds , on other hand , are cubical in shape. some shreds or chips may have pieces of steel belt exposed along the edges . To minimize potential compaction problems (i.e. to reduce void space) it may be desirable to use smaller size of tire shreds.

Small– sized shreds are produced by processing the material through more than one shredder– each adjusted to produce finer cuts than its predecessor. Classifiers can also be used to separate the finer sizes from coarser ones.

Usually the shreds are irregularly shaped with the smaller dimension being the size specified by the manufacture.

9.3. Engineering Properties of Shredded Tires

The tire composition varies by manufacture and type. Automobile tires are made of natural rubber, synthetic rubber elastomers, polymers, and other additives. Steel reinforcing is also provided to improve strength. Tires are designed to withstand the rigors of the environment so that they are durable and safe when used on vehicle. Even the discarded tires maintain their chemical composition requiring hundreds of years to fully decompose (Hoffman, 1974)

Some of the properties of tire shreds that are of particular interest when they are planned for use in reinforced sand include:

1- General properties.
2- Specific gravity.
3- Compacted unit weight (density).
4- Particles size and shape (gradation).
5- Water absorption.
6- Compressibility.
7- Hydraulic conductivity.
8- Shear strength.
9- Interfaces shear strength.
10- Environmental consideration.
11- Physical compatibility consideration.
12- Permeability.

9.3.1. General properties

Laboratory testing on tire shreds has been performed for various purposes. Only those properties applicable to the use of tire shreds as reinforced sandy soil .

Physical characteristics of tire shreds are dependant upon the shred size (gradation) and uniformity (Geosyntec, 1998)

9.3.2. Specific Gravity

The specific gravity of tire shreds is the ratio of unit weight (density) of solids of the shreds divided by unit weight of water. (A material, whose unit weight of solids equals the unit weight of water, has a specific gravity of 1.0). The specific gravity is evaluated in accordance with ASTM- C 127 (ASTM, 1997 b) .

The specific gravity of tire shreds is usually less than one half the values obtained for the common earthen materials usually tested by this method, so it is permissible to use a minimum weight of test sample that is half the value specified in standard test (Humphrey, 1996b).

The apparent specific gravities of tire shreds depend on the amount of glass belting or steel wire in the tire and range from 1.02 to 1.27. This mean that the tire shreds are denser than water and will sink in water (The high end of the range generally have a greater proportion of steel belted shreds). For comparison, the specific gravity of soil typically ranges between 2.6 and 2.8 which is more than twice as tire shreds (Humphrey, 1996 b).

9.3.3. Compacted Unit Weight (Density)

The unit weight is the ratio of the weight of a substance to the volume of a substance. Evaluation of the compaction characteristics of tire shreds is useful in determining the compactive effort required to achieve a workable material density. Previous studies have shown that compactive energy has only small effect on the resulting dry density (unit weight). This indicates that the maximum dry density can be achieved with only a moderate amount of compactive energy.

Moreover, water content has been shown to have only a small effect on compacted density (Manion and Humphrey, 1992)

The density (unit weight) of tire shreds increases due to compression under the weight of overlying material. loosely dumped tire shreds typically exhibit dry densities between 3.3 and 4.8 kN/m^3 (Humphrey, 1997).

For comparison, the compacted dry density of soil typically ranges between 100 and 125 Ib/ ft^3. (15.6 and 19.5 kN /m^3) (Terzaghi and peck, 1967) . Thus the compacted tire shreds exhibit dry densities, which are approximately 60% less than those of compacted soils.

The laboratory compacted densities of a mixture of tire shreds and soil indicate, as expected, that the more soil in the mixture, the higher the density.

Tire shreds or chips have a maximum density that is approximately one-third to one–fourth that of typical earthen fill material. The coarser the size of the scrap tire particle, the lower the compacted unit weight.

The reported data on dry unit weight of shredded scrap tires is summarized in Table 1. As can be seen from this table, the investigators used different testing conditions to determine the unit weight of scrap tires.

These testing conditions included using shreds with different sizes from 0.08 inches to 5.5 inches. Based on these tests the dry unit weight of tire shreds was found to vary from 15 pcf for loose tire shred mix containing shreds of 0.08 to 1 inches in size to 53 pcf for compacted tire shreds of 1 to 3 inches in size (Reddy et al., 1998)

9.3.4. Particle Size and Shape (Gradation).

Tire shreds generally have relatively uniform grading (i.e., mostly the same size). Sizes of tire shreds are determined based on an anticipated application of this material. The whole tires are cut by shredder knives.

The required size is achieved by adjusting the screen size on a slow rotating shredder screen (i.e., trammel). Typically, multiple passes through the shredder are required for tire shred sizes of less than 12 in (300 mm). The gradation of tire shreds is evaluated in accordance with ASTM- D 422 (ASTM, 1997 a) .

The sample size should be large enough to contain a representative selection of particle sizes.

Since the specific gravity of tire shreds is usually less than half the values obtained from common earthen materials usually tested by this method, it is permissible to use a minimum weight of test sample that is half of the value specified in the testing standard (Humphrey, 1996 b). The most unusual properties of tire shreds are their flat and somewhat irregular particle shape and their relatively low unit weight. The flat shreds especially the larger sizes, tend to lay on top of one another and develop some degree of particle interlock. They also tend to be oriented parallel to the horizontal shear plane.

Particle size distribution can be determined by performing a standard sieve analysis using the procedures of ASTM- D422. No modification of the standard test method is required, expect that tire shreds larger than 76 mm (3 in) cannot be screened through standard sieves. A limited amount of geotechnical analysis has been performed on different sizes of tire chips. Grain size analysis has indicated that the tire chips can be classified as well graded sand with gravel (ASTM- D2487)

9.3.5. Water Absorption

Absorption capacity is the amount of water absorbed on to the surface of the tire shreds and is expressed as the percent (%) water (based on the dry weight of the shreds). Water absorption capacity of tire shreds generally ranges from about 2 % to 4 % (Humphrey, 1997).

9.3.6. Compressibility

Compressibility is the property of a material pertaining to its susceptibility to volume change due to changes in stress.

Tire shreds are relatively compressible material during the initial stages of loading than conventional soils subsequent loading cycles normally result in significantly less compressibility of tire shreds or chips. Higher amounts of exposed steel belts appear to result in higher compressibility, especially during the first loading cycle, probably because of less rebound.

Tire shreds are highly compressible because of their high porosity and high rubber content. Tire shreds compress when a load is applied primarily due to two mechanisms:

a- Bending and orientation of the shreds into a more compact packing arrangement,

b- The compression of individual tire shreds under stress.

The compressibility of tire shreds is generally measured by placing the tire shreds in containers that have diameters ranging from 6 to 29 inches, and then measuring the vertical compression (or strain) caused by an increasing vertical stress. The compressibility values of tire shreds measured in experiments by various investigators are summarized in Table 2.

Table 1: Unit weight of different size tire shreds(After Redddy et al., 2001).

Reference	Tire Shred Size (inch)	Dry Unit Weight (pcf)	Specific Test Conditions
Bressette, 1984	0.2-2.5	25-38	
ASTM 1998			
Humphrey, et al.,1992	0.08-3	21.4	
Humphrey and Manion,1992			
Manion and Humphrey, 1992	0.08-2	25.5-30.3	No compaction
Humphrey and Sandford ,1993			
ASTM, 1998	0.08-1	31.1	
	0.05-2	29.3	No compaction
Ahmed ,1993	0.05-1	30.8	No compaction
Ahmed and Lovell 1993	0.05-1	31.2	ASTM D 4253
ASTM, 1998	0.5	29.7	ASTM D 4253
	0.5-2	38.6	
	0.5-1	40.0	50 % Standard compaction energy
Humphrey et al., 1992	0.08-3	39	
Humphrey and Manion, 1992			
Manion and Humphrey, 1992	0.08-2	39.3-40.4	60% Standard compaction energy
Humphrey and Sandford,			
ASTM 1998	0.08-1	15.3	
Ahmed, 1993	0.4-2	40	
Ahmed and Lovell, 1993	0.5-1.5	40.6	Standard compaction energy
ASTM, 1998	0.5-1 0.5	41 39.8	6 inch-diameter mold compacted
Edil and Bosscher1992	0.75-3	37.0	10lb- rammer falling 12 inches
Edil and Bosscher1994			
ASTM 1998	0.75-3	35.0	12 inch-diameter mold compacted
			60lb- rammer falling 18 inches
Humphrey and Manion, 1992	0.08-2	41.5	Modified - compaction energy
Manion and Humphrey, 1992			
ASTM ,1998			
Ahmed, 1993	0.5-2 0.5-1	41.7 42.7 24-33	Loose
Ahmed and Lovell, 1993			
ASTM, 1998			
Upton and Machan,1993	2	45	Compacted
		52-53	Surcharged with 3 feet soil, paveme highway traffic
Newcomb and Drescher,1994	0.78-1.8	31.2-35.2	
Black and Shakoor,1994	< 0.04-0.27	33	
Duffy,1995	2.	30-50	
Masad et al..,1996	0.18	39.4	
Cecich et al,1996	0.2-0.6	35.1-37.3	ASTM D 1557
Andrews and Guay,1996	1-2 < 0.08	40 33.3	
Wu et al., 1997	< 0.37 < 0.74 < 1.5	31.5-37.5 35.8 37.4	Tested tire shreds without steel in tests
Twecdie, et al., 1998	1.5 3	44.3 43.1	Full scale field tests
Chu, 1998	0.25 – 1.5	43.2 – 43.6	No compaction
Reddy and Saichek, 1998	0.5 – 5.5	26	

Table 2: Compressibility of different size tire shreds (After Redddy et al., 2001).

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Reference	Tire Shred Size (inch)	Compressibility (%)	Specific Test Conditions (Stress in psf)
Hall, 1991	0.75-1.5	30	1440
	0.08-2	33-37	4176(compacted)
Humphrey et al.,1992	0.08-2	52	4176 (loose)
ASTM,1998	0.08-1 0.08-1	33-35 45	4176(compacted) 4176 (loose)
Manion and Humphrey,1992	0.08-3	38-41	4176(compacted)
ASTM,1998	0.08-2	29-37	4176(compacted)
Ahmed and Lovell, 1993	0.5-1.5	27	-
Newcomb and Dreschcr, 1994	1.18	25 40	104 8532
Edil and Bosscher, 1994	2-3	37	14400
Zimmerman,1997	8-16	55	793
Nickels and Humphery, 1997	3	18-28	522
ASTM, 1998	0.5-5.5	31	665
Reddy and Saichek, 1998	0.5-5.5 0.5-5.5	50 65	3400 21000

From experiments conducted by many researches, it is found that initially loosely placed tire shreds are compressed more than that of slightly compacted tire shreds, and it appears that larger tire shreds are compressed more than smaller tire shreds.

Edil and Bosscher (1994) and Humphrey and Sandford (1993) have shown that preloading can control the compressibility of tire chips . Edil and Bosscher (1994) recommend a soil cap at least 1 m thick to be placed over tire chips or tire chip - soil fills to limit settlements under traffic loads or surcharge . Humphrey and Sandford (1993) suggest that a soil cap 0.6 - 1.8 m thick should be placed on top of tire chip embankments to prevent excessive deflection of overlying layers. Bosscher et al., (1997) reported that the compressibility of tire chips can be reduced significantly by adding 30 – 40 % sand by volume (Tatlisoz et al., 1998).

9.3.7. Hydraulic Conductivity

Hydraulic conductivity is defined as the rate of water flow under laminar flow conditions through a unit cross - sectional area of porous medium under unit hydraulic gradient and standard temperature conditions.

As stated earlier, hydraulic conductivity is of primary importance when assessing the feasibility of using tire shreds as a drainages material. Several investigators have measured the hydraulic conductivity of tire shreds using permeameters with diameters ranging from 8 to 12 inches. Some permeameters had provisions to apply a vertical stress to the sample in order to simulate the compression that would occur under the weight of an overlying soil cover. (Reddy et al., 2001).

The wide range in values of hydraulic conductivity may be due to differences in size, initial density, hydraulic gradients, and confining pressures under study conditions (Donovan et al., 1996 and Humphrey 1996b)

The hydraulic conductivity of a mixture of tire shreds and soil greatly depends on the percentage of soil in the mix, shred size, initial density, hydraulic gradients, soil type, and confining pressures. The hydraulic conductivity decreases significantly as the percent of soil in the mix increases. For mixtures of tire shreds and soil, with 30% to 50% soil by weight, hydraulic conductivities approach those of the soil itself (Geosyntec, 1998)

Table 3 summarizes the hydraulic conductivity of tire shreds based on previous investigations. it can be seen from this table that the maximum size of the tire shreds ranges from 0.18 to 5.5 inches, and the hydraulic conductivity of the tire shreds was found to range from 0.0005 to 59.3 cm/s. The wide range of hydraulic conductivity values is attributed to the differences in shred size and composition, compaction level (initial density / void ratio), and normal stress.

The lowest hydraulic conductivity was found to be ranging from 0.002 to 0.0005 cm/s and this was measured by Masad et al., (1996) when the tire shreds were less than 0.18 inches in size. Reddy and Saichek (1998) also found a low hydraulic conductivity of 0.01 cm/s for larger tire shreds that were 0.5 to 5.5 inches in size but these tire shreds were under a very high vertical stress of 21.0 psf. For tire shreds greater than one inch in size and under a normal stress of 100 - 400 psf, which is expected in a final cover system, the hydraulic conductivity of tire shreds is always found to be higher than 1.0 cm/s (Reddy et al., 1998).

Hydraulic conductivity of tire shreds was measured using large scale constant head parameameter (Reddy and Saichek 1998 b). The hydraulic conductivity of tire chips under no vertical stress was too high to measure in the pereameter (Reddy et al., 1998).

Table 3: Hydraulic conductivity of different size tire shreds (After Redddy et al., 2001).

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Reference	Tire Shred Size (inch)	Hydraulic conductivity(cm/s)	Specific Test Conditions
Bressette1984	1-2.5	2.9-23.5	-
ASTM,1998	0.2-2.0	3.8-59.3	-
Hall,1991	1.5	1.43-2.64	Simulated overburden of 35 feet of MSW
	0.75	0.79-2.74	Simulated overburden of 25 feet of MSW
	0.4-2	7.7	Void ratio=0.9
Humphrey et al., 1992	0.4-2	2.1	0.488
Humphrey and Sandford, 1993	0.75-3	15.4	1.114
ASTM,1998	0.75-3 0.4-1.5 0.4-1.5	4.8 6.9 1.5	0.583 0.833 .414
Edil et al., 1992 Edil and Bosschcr,1994	2-3	0.6 0.45 0.4	Stress (psf) 1440 2881
Ahmed and Lovell, 1993	0.5-1.5	0.58 0.7	- 2500psf (40feetM)
Duffy, 1995	2	0.53 0.25 0.12 55.0	5000psf (80feetM) 10000psf (160feetM) 15000psf (240feetM) 1879
Narcjo and Shcttima, 1995	2.4-4.0	20.0 10.0 6.0	3132 7308 11484
Andrews and Guay, 1996	1-2	1.0	-
Masad et al., 1996	0.18	0.002 $5x10^{-4}$	3132 7308
Cecich et al., 1996	0.2-0.6	0.03	ASTM- D243
Bernal et al.,1996	2	1.2	-
Zimmerman, 1997	8-16 0.5-1.5	9.0 3.2 1.8 7.6	Void ratio=2.1 1.53 0.78 Void ratio=0.6
Lawrence et al, 1998	0.5-1.5 0.5-3 0.5-3 0.25-0.5	1.5 16.3 5.6 0.16	0.328 0.857 0.546 -
Chu,1998	0.5-1.0 1.0-1.5 0.5-5.5	0.18 0.18 0.65	- - 3400psf compression 21000psf
Reddy and saichek, 1998	0.5-5.5	0.01	Compression

9.3.8. Shear Strength

The shear strength between two particles is the force that must be applied to cause a relative movement between the particles (lambe and Whitman 1969) and it is a fundamental mechanical property that governs bearing capacity and slope stability (krishne, 1998).

The influencing parameters on shear strength characteristics of sand shred mixtures are normal stress, sand matrix unit weight, shreds content, shred width, and aspect ratio of tire shreds. With the selected widths of shreds; compaction efforts, shred content, and the variations of aspect ratios.

Ahmed (1993); Humphrey et al., (1993); Edil and Bosscher (1994), Foose et al., (1996) and Bernal et al., (1996) have reported that sand can be reinforced using tire shreds. They have shown that adding tire shreds increases the shear strength of sand with friction angles as large as 65° being obtained for mixtures of dense sand containing 30% tire chips by volume. however, that the strength decreases when the tire chip content increases beyond 30% because the sand–tire chip mixtures behaves less like reinforced soil and more like a tire chip mass with sand inclusions.

Edil and Bosscher (1994) studied the shear strength of mixture of tire shreds and sand in direct shear . They observed that the shear strength of mixture of sand and tire shreds was higher than that of pure dense sand at low and moderately high confining stresses but that at high confinements the benefit of adding tire shreds was not as evident. However, tire shreds and chips are also quite deformable, implying that bending of the tire shreds may reduce the need for particles to move around the shreds during shear. The shear strength of different tire shred sizes based on several reported studies is summarized in Table 4 .

Bresette (1984) tested two scrap tire samples. One sample was termed "2-inch square" and it had a cohesion intercept of 540 psf and ф=21°, whereas the other sample was termed as" 2-inch shredded" and it had a cohesion intercept of 660 psf and ф=14°.

Ahmed and Lovell conducted different tests on tire shreds with a maximum size of 0.5 inch and 1 inch. Using a 20% axial strain as failure criteria, they found that cohesion intercepts ranged from 694 to 818 psf and friction angles ranged from 20° to 25° degrees.

Humphery et al., (1993) investigated the shear strength of three separate tire shred sizes that had maximum sizes of 1.5 inches, 2 inches and 3 inches. These experiments were performed under different normal stress conditions, and they found that these shreds possess frictional angle values of 19° to 26° and cohesion values of 90 to 240 psf. Foose (1993) and Foose et al., (1996) performed tests to investigate the shear strength characteristics of a tire shred mixture (sizes ranging from 2 to 6 inches). Several factors, including normal stress, tire shred size, and orientation of tire shreds were considered in their study, and they found angle of friction of 30 and cohesion of 0-62.6 psf.

Edil and Bosscher (1994) conducted tests on 2 to 3 inch size tire shreds and found that the angle of repose or internal friction angle was in the range of 37° to 43°; however, it was as high ; under compacted conditions. Black and Shakoor (1994) Duffy (1995), Cosgrove (1995), Bernal et al., (1996), Cecich et al., (1996), and Andrews and Guay (1996), also performed tests under different initial density and normal stress conditions. These investigators found that 0.04 to 3-inch size tire shreds had angle of internal friction values ranged from 17° to 38 ° and values ranged from 0 to 150 psf.

Gebhardth (1997) investigated the shear strength properties of large tire shreds containing 1.6 to 55 inches in size using the two failure criteria: peak failure and 10% failure. This investigation showed that the shear strength of the shredded tires does not depend on the shred size and ф=38° was found for all the tire shreds.

All of the above studies were conducted using the direct shear testing apparatus and procedures. But, Masad et al., (1996) and Wu et al., (1997) conducted tests using triaxial testing apparatus and procedures to determine shear strength of tire shreds. Masad et al., (1996) conducted tests on tire shreds smaller than 0.18 inches, and they found that the angle of internal friction ranged from 6° to 15° and the cohesion ranged from 1462 psf to 1712 psf. Wu et al., (1997) conducted tests using four different tire shreds with different maximum tire shred sizes of 0.08,0.37,0.74 and 1.5 inches, respectively, and they found that all of these tire shreds possess angle of internal friction of 45° to 60° with cohesion value of zero. It should be noted here that Masad et al.,(1996) showed very low friction angles and very high cohesion values as compared to those reported by other investigators, even in studies involving comparable tire shred sizes, but the reasons for such large differences were not explained. Nevertheless, it is uneconomical to use very small size tire shreds (<1 inch), so the results of the study conducted by Masad et al., (1996) are of limited use in evaluating the feasibility of using tire shreds as drainage material in landfill covers.

Table 4: Shear strength of different size tire shreds (After Redddy et al., 2001).

Reference	**Tire Shred Size (inch)**	**C (psf)**	**ϕ°**	**Specific Test Conditions / Normal stress (psf)**
Bresette,1984	2-inch square	540	21	
	2--inch	660	14	
	0.5	747	20.5	Standard compaction & 20%. strain as failure
		818	24.6	Modified compaction energy & 20%. strain as failure
Ahmed and Lovell,1993	1.0	694	25.3	Standard compaction energy & 20%. strain as failure
	<1.5	779 180	22.6 25	50% Standard compaction energy &20%. strain as failure
Humphery et al.,1993	<2.0	90-160	21-26	Normal stress range 400-1500 psf
	<3.0	240	19	
Foose, 1993	<2			
Foose et al., 1996	2-4 4-6	0.6–0.62	30	146-1460psf
Edil and Bosscher,1994	2-3	-	37-43	0
	<0.04	- 100	35 30	Compacted condition
Black and shakoor,1994	0.04-0.16 0.16-0.27	70 130	31 27	Tested at dry unit Weight of 33 pcf
Duffy,1995	2	150	27	-
Cosgrove, 1995	1.5 3	69 90	38 32	Saturated
Bernal et al., 1996	2	0	17-35	17 at 5% strain; 35 at 20 % strain
		1462	6	10% strain
Masad et al., 1996	0.18	1482 1712	11 15	15% strain 20% strain
Cecich et al., 1996	0.2-0.6	147	27	ASTM- D3080
Andrews and guay, 1996	1-2	80	27.5	-
Wu et al., 1997	<0.08 <037 <0.74	0 0 0	45 47-60 54	Tire shreds without Steel - triaxial tests under confining pressure of
	<1.5	0	57	1148-720 psf
	1.5-55.1	65	38	115-585 psf
Gebhardt,1997	-	-	-	Peak failure criterion 115-585 psf
	1.5-55.1	0	38	10 % failure criterion

9.3.9. Interface Shear Strength

The Interface shear strength between the shredded tires and the other materials such as the soils that they come contact within landfill cover systems is necessary to ensure slope stability. Table 5 summarizes the reported interface shear strength between the shredded tires and the soils, respectively.

Foose (1993) and Foose et al., (1996) reported interface friction angles between tire shreds and Portage sand. They conducted different experiments using 2, 4, and 6 inch size tire shreds. During the testing, the surface of the tire shreds was set level with the shear plane by mounting the tire shreds on a piece of plywood. The average interface friction angle were found to be 34° & 39° for the sand of unit weight of 97-100 and 107 pcf respectively. This study reported an adhesion value of zero.

Table 5: Interface shear strength of tire shreds (After Redddy et al., 2001).

Reference	**Tire Shred Size (in)**	**Type**	**Soil Dry Unit Weight (pcf)**	**Moisture Content (%)**	**C_a (psf)**
Foose, 1993	2,4,6	Portage Sand	97-100	Dry	C_a=0.8
Foose et al., 1996	2,4,6	Portage Sand	107	Dry	C_a=0.8
Gebhardt, 1997 (Peak failure criterion)	1.5-55.2	Glacial till	92	8	C_a=12.5
Gebhardt, 1997 (10% failure criterion)	1.5-55.2	Glacial till	92	8	C_a=0.8
Gebhardt, 1997 (Peak failure criterion)	1.5-55.2	Glacial till	92	18-22	C_a=43.8
Gebhardt, 1997 (10%failurecriterion)	1.5-55.2	Glacial till	92	18-22	C_a=14.6

Gebhardt (1997) investigated the interface shear strength of large tire shreds (1.5 inches to 55.2 inches in size) in contact with glacial till (a clayey soil). Direct shear tests were conducted under five different normal loading conditions with the soil at moisture contents that were dry and wet of optimum Table 5. Moreover, two different failure criteria of maximum stress and 10% failure were considered. For the failure criterion defined at maximum shear stress, a friction angle 39° with adhesion of 12.5 psf was found for all tire shreds with the soil at dry of optimum condition. However, for the same soil and tire shred conditions, but using the 10% failure criterion, a friction angle of 37° with zero adhesion was found (Reddy et al., 1998).

9.3.10. Environmental Considerations

Tire shreds are considered by the State of California to be non-hazardous material (CRWQCB, 1988). A number of leach ability tests were performed on tire shreds using both tap water and landfill leachate. The results of these tests indicate that tire shreds do not leach volatile organic compounds (VOCs) or, when leaching does occur, these compounds are found at very low concentrations, i.e., below the primary drinking water standards or action levels. Additionally, the same tests indicate that concentrations of tested metals were below their primary or secondary drinking water standards with the exception of iron and manganese (Duffy, 1996; Humphrey, 1996b; Humphrey et al., 1997). The source of the manganese is thought to be the exposed steel belts, which are composed of 2% to 3% manganese by weight. Iron leaches more rapidly in below ground-water table applications than in above ground-water table applications. Laboratory studies suggest that metals leach more readily under acidic conditions and organic compounds leach more readily under basic conditions (Minnesota Pollution Control Agency, 1990). The source of the zinc may be zinc oxide in the rubber or the zinc in the coating on the bead and belt wires (Humphrey et al., 1997).

9.3.11. Physical Compatibility Considerations

Tire shreds with metal wires removed are fully compatible with other materials, including geosynthetics, of the landfill containment system. However, bead wire protruding from tire shreds may puncture geosynthetics materials if used of the underlying containment system (Jesionek et al., 1998)

9.3.12. Permeability

The coefficient of permeability of tire shred was found to rang from 1.5 to 15 cm/sec, depending on their void ratio. This is equivalent to the permeability of a clean gravel soil.

Permeability testing can be accomplished using a 305 mm (12 in) diameter by 0.96 meter (38 in) long pvc pipe and following the constant head testing procedures of the California department of transportation . A 38 mm (1.5 in) diameter water inlet was fixed to the center of the end cap. A 101 mm (4 in) wide by 50 mm (2 in) deep slot was cut into the top of the pvc pipe to allow water to flow out the top of the apparatus .The initial length of the tire shreds sample is about 600 mm (24 in)

10. CONCLUSION

Based on the review present in this paper; there are many different approaches to develop appropriate strategies to enhance the efficiency of waste polymer. Its application extends beyond conventional civil engineering works. It also can be applied in different ways as measures to prevent ground subsidence.

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