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Geotechnical properties of tire-sand mixtures as backfill material for buried pipe installations

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Abstract. Millions of scrap tires are discarded annually in Turkey. The bulk of which are currently landfilled or stockpiled. These tires consume valuable landfill space or if improperly disposed, create a fire hazard and provide a prolific breeding ground for rats and mosquitoes. Used tires pose both a serious public and environmental health problem which means that economically feasible alternatives for scrap tire disposal must be found. Some of the current uses of scrap tires are tire-derived fuel, creating barrier reefs and as an asphalt additive in the form of crumb rubber. However, there is a much need for the development of additional uses for scrap tires. One development the creation of shreds from scrap tires that are coarse grained, free draining and have a low compacted density thus offering significant advantages for use as lightweight subgrade fill and backfill material. This paper reports a comprehensive laboratory study that was performed to evaluate the use of a shredded tire-sand mixture as a backfill material in trench conditions. A steel frame test tank with glass walls was created to replicate a classical trench section in field conditions. The results of the test demonstrated that shredded tires mixed with sand have a definite potential to be effectively used as backfill material for buried pipe installations.

Keywords: tire rubber; backfill material; HDPE flexible pipe

1. Introduction

Developed and industrialized countries face a monumental environmental problem in terms of the need to dispose of millions of tires which are placed in landfills or stockpiled often in an uncontrolled way. One of the solutions to this problem has been to find ways in which the tires can be recycled, such as; tire-derived fuel for energy generation, ground rubber or engineering applications as crash barriers, creating breakwaters and reefs, and the use of crumb rubber in asphalt pavements. However, to date these efforts have not reduced the number of tires in landfills and the problem of the large amount of illegal dumping of used tires. Thus there is a need to develop additional practical uses for scrap tires. One possible application is to use tire shreds alone

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or mixed with soil as fills and backfills. Field and laboratory studies have confirmed that these tire shreds have very good frictional properties whether alone or mixed with soil. The tire shreds enhance the strength of the soil internally providing stability and inducing negligible differential settlement. In particular, for geotechnical applications shredded tires have great advantages because they have low density and high durability, are free draining and provide thermal insulation and in many cases they are also cheaper when compared with other fill materials. In the literature there are reports of many important experimental studies such as; Yoon *et al*. (2004), Edinçlilerand Ayhan (2010), Tafreshi and Norouzi (2012), Youwai and Bergado (2003), Zornberg *et al*. (2004), Bernal *et al*. (1996), Foose *et al*. (1996). They have all demonstrated that soil and shredded rubber-reinforced soil are potential composite materials which can be gainfully employed in increasing soil strength. There are also a few studies on pipe performance under shredded tire-soil mixture. Watkins and Roberts (2012) conducted a series of field tests to understand the effects the increase of soil cover on pipe performance. They evaluated deflections and stresses in the pipe cross section due to increase soil cover. Kawabata *et al*. (2013) investigated the behavior of a buried pipe installed in a non-uniform poor bedding layer. They used a laboratory test box which dimensions were $1600 \times 1200 \times 1400$ mm. Researchers were evaluated poor backfill conditions on the performance of a 600 mm diameter PVC flexible pipe. In order to simulate the poor backfill conditions they removed soil locally in particular sections of the trench. Masad *et al*. (1996) investigated the engineering properties of the Ottawa sand tire shreds mixture as lightweight backfill material. Lee *et al*. (1999) conducted a series of triaxial tests to investigate the stress strain relationship of tire chips and a mixture of sand and tire chips. Sheikh *et al*. (2012) investigated the hear and compressibility behavior of sand–tire crumb (S-TC) mixtures for their applications in civil engineering projects. They determined that, shear strength of the S-TC mixtures were decreased with the increasing the amount of the tire chips or tire shreds uses. Researchers were also observed that a larger proportion of plastic strain develops after the first cycle of unloading and hence the settlement associated with the application of the mixtures can be significantly reduced by preloading. Tsang *et al*. (2012), presented the preliminary research works on a potential seismic isolation method that makes use of scrap rubber tires for the protection of low-to-medium-rise buildings. These studies reflected the increasing popularity of using recycled materials, particularly waste tires, mixed with soil which is due to the shortage of natural mineral resources and increasing costs of waste disposal.

With waste tires being more frequently used in geotechnical applications there is a need to further understand of the behavior of these tire shred-soil mixtures. Thus, it was decided to carry out a series of tests in the Civil Engineering laboratories of Aksaray University.

The basic aim of the tests was to increase the understanding of the mechanical behavior of the pipe deformation pattern and to investigate the feasibility of using shredded tire and sand as the material for a trench backfill. To evaluate the performance of a buried flexible pipe a small scale physical test model was built to reproduce a plain-strain state within a trench that was backfilled with a shredded tire and sand mix. Although small-scale models are considered to have limited applications because some important similarity requirements cannot be met, these models can be a useful and low cost tool to study the behavior of geotechnical structures. From tests with small scale models experimental observations can be undertaken to provide a better insight into the deformation process occurring in various types of boundary problems. Thus, new research has recently been carried out on a physical test apparatus built to reproduce a plane-strain state within a backfill mixture.

In the last decade, many researchers have developed and used biaxial, multi-axial soil boxes, test cells, large tanks, centrifuge models, and multipurpose test facilities to undertake experimental investigations on buried flexible pipes. Some of the studies are summarized below. Brachman *et al*. (2000), designed a laboratory facility to evaluate the performance of small-diameter pipes when buried under deep and extensive overburden material. They reported that reducing boundary friction to less than 5° and limiting the boundary deformation to less than 1mm at a vertical surcharge of 1000 kPa provided a good idealization of field conditions for a deeply buried pipe. Faragher *et al*. (2000) carried out a full-scale controlled field test to investigate the behavior of embedded flexible pipes under repeated loadings in real installation conditions. They observed that the vertical deformation of pipe increased rapidly during initial loading cycles while the rate of deformation was reduced markedly as further cycles of loading were applied. Hosseini and Tafreshi (2002) presented a laboratory work on small-diameter thin steel pipes subjected to repeated loads. They found that the soil density and the pipe embedded depth were the most important factors affecting the soil–pipe interaction. Arockiasamy *et al*. (2006) performed field tests on polyethylene, PVC, and metallic large-diameter pipes subjected to highway design truck loading. Tafreshi and Khalaj (2008) also examined small-diameter HDPE pipes buried in reinforced sand under repeated-load in laboratory conditions. They evaluated the pipe performance in relation to the sand tire rubber mixtures. Corey *et al*. (2014) discussed the laboratory results of shallowly buried steel-reinforced high-density polyethylene (HDPE) pipes subjected to static loads with or without geogrid. In their tests, static loads were applied to a steel plate seated on the ground with a 0.61 m diameter steel-reinforced HDPE pipe buried in a compacted-sand trench. Field test results indicated that the buried flexible pipes, embedded with highly compacted sand with silt demonstrated a good performance without exhibiting any visible joint opening or structural distress. They also found that; the geogrid reduced the longitudinal strains in the plastic shell of the buried pipe subjected to surface static loading. Lee *et al*. (2014), presented in their studies; the result of full scale field test for buried glass fiber reinforced thermosetting polymer plastic (GFRP) pipes with large diameter. Researchers mentioned that the long term vertical ring deflection up to 60 years is less than the 5% ring deflection limitations. They founded that; the value calculated by the Iowa formula tends to overestimate to a considerable extent. Rajeev and Kodikara (2011) investigated the pipe soil interaction for pipes buried in expansive soil when subjected to swelling soil movement due to increase in moisture content. They performed a laboratory experiment on a plastic pipe model in a large scale pipe box. They also performed a three dimensional numerical model to analyze the pipe response, using FLAC3D computer program. They reported a reasonably good agreement between the experimental results and model predictions. Chaallaletal *et al*. (2014) studied the short-term performance for shallowly buried flexible pipes to evaluate joint performance requirements, and verify AASHTO design assumptions in the light of field test data from in situ measurements. They presented the field test results in terms of the soil pressure distribution around the cross section, as well as the vertical and horizontal pipe diameter changes during construction and under the live loads.

2. Test equipmentand and test facility

In the experimental investigation presented in this paper; a series of tests were carried out on a small single pipe of 100mm radius that was buried in different tire shred-sand mixture contents that was subjected to surcharge loads. Tests were performed in accordance with the ASTM D2321

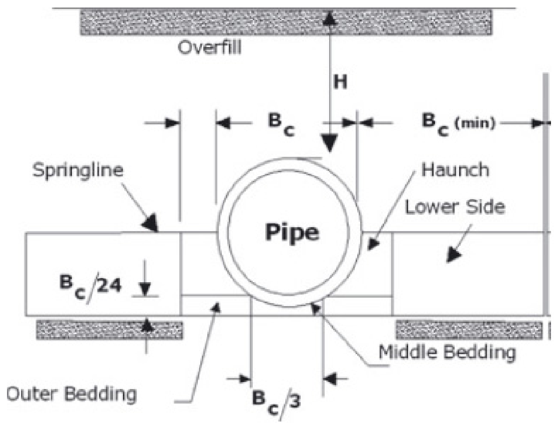


Fig. 1 A Conventional standard trench section (ASTM D 2321)

criteria given in Fig. 1. The testing program was designed to evaluate the role of the mixture content of backfill properties on the pipe deformation behavior. In each test, the vertical diameter change was determined on the basis that a 5% maximum vertical diameter change is considered to be the criteria for the service capability of the flexible buried pipe.

The test equipment consisted of four main parts; the test tank, strain gauge and LVDT instrumentations, data acquisition system. Buried pipes are included in the class of structures that can be treated in plane strain since they have a longitudinal length "*z*," much greater than the other two dimensions in the "*x*" and "*y*" directions. For this condition, it is assumed that the strain along the z-axis is zero. Normal planes to the "*z*" direction do not interfere with each other in the process of deformation. In a small-scale test, the plane strain condition can be achieved either by building the model with smooth "*x*–*y*" faces in order to prevent any friction that could cause distortion in the longitudinal direction or by taking the "*z*" dimension to be such that the end effects do not interfere with the behavior of the middle test section. On the other hand, a minimum trench width is maintained so as not to be less than either 1.5 times the outside radius of the pipe (100 mm) plus 305 mm or the outside diameter of the pipe plus 405 mm whichever is the greater ASSTHO (2003). Therefore, based on these recommendations, the width of the trench was selected as 700 mm, hence, and the testing rigid steel box schematic diagram given in Fig. 2 was designed to be 500 mm in length, 1000 mm in height, and 700 mm in width. The tank encompasses the reinforced soil, and the model pipe, which stood vertically along its square face while testing was in progress.

The vertical surcharge stresses from the weight of the backfill material can be simulated by applying a uniformly distributed pressure σ_v on the surface of the mixture backfill in the soil box test tank. In this study pressurized air membranes were used to simulate vertical surcharge stresses. The rigidity of the test tank was guaranteed using three stiff steel sections of U-220 on the sides and bottom of the tank. Extra stiffeners were used to restrict the excessive deflections of the sidewalls. The testing tank had smooth back and front faces with the back face of the tank consisting of a steel plate of 8 mm thickness permanently fixed to the channel plates.

The front face was a sheet of 40-mm-thick plexiglas that was supported by a strong solid beam of the box section of 30 mm × 60 mm to prevent any undesirable movement of the front side and thus maintaining plane strain condition. According to the preliminary test results, under maximum loading stress on the soil surface, the measured deflections of the back and front faces of the tank system and K_o conditions.

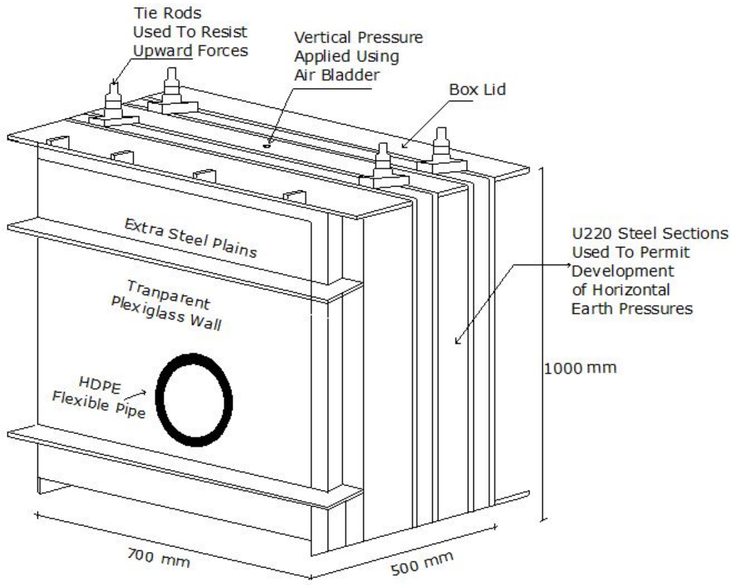


Fig. 2 Test equipment

In order to the non-linear load versus the displacement curve to be adequately defined, each load increment was maintained as constant until the pipe crown settlement stabilized. As shown in Fig. 3 the vertical and horizontal deformations and bending moments of the pipe inside section, were measured by using electrical resistance biaxial strain gauge rosettes and LVDTs. The strain measurements were obtained at the following eight points: crown, shoulders, springlines, haunches, and the invert of the pipe wall. All the locations of the LVDT and strain gauges were installed at the middle of the pile length. These locations correspond to the maximum stress locations (Ataoglu and Reddy 2001). The bending moments of the pipe wall were measured by the ratio between strains and the stiffness of the pipe wall.

Each gauge was 5 mm × 5 mm with a resistance of 350 ohm. To ensure an accurate reading, the data acquisition system and instrumentation, especially the strain gauges, were calibrated prior to each test. The strain gauges were calibrated using Eq. (1) which was created by Daley and Riely (1978).

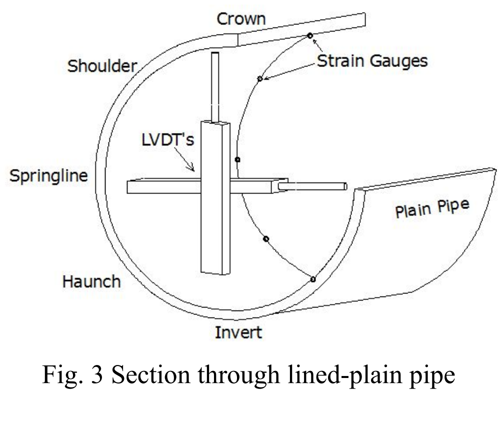


Fig. 3 Section through lined-plain pipe

$$CF = (1 - \upsilon_0 K_t)/(1 + K_t / \upsilon) \quad (1)$$

where CF is the calibration factor, υ_0 is the Poisson's ratio of gauge (0.285), υ is the Poisson's ratio of HDPE material (0.4), and K_t is the sensitivity factor of instruments (0.004). The biaxial strain gauge rosettes were glued to the inside of the pipe section, followed by a layer of silicone and finally protected by a layer of rubber sheeting to prevent the intrusion of external effects (Terzi *et al*. 2010).

3. Backfill properties

3.1 Sand properties

In the experimental studies, Sile sand was selected as the backfill material. The fine sand was, washed, dried, and sorted by a size into rounded to sub-rounded particles. The particle size distribution of backfill materials was determined using the dry sieving method and the results are given in Fig. 4. The specific gravity of the backfill particles was determined by the gas jar method. Three tests were carried out obtaining an average value of 2.657. Based on ASTM 4253 and ASTM 4254 test standards, maximum and minimum void ratios of Sile sand were determined as 0.87 and 0.52, respectively. Fig. 5 shows the subangular and angular shapes of the sand particles according to microscopic observations.

3.2 Shredded tire and mixture

The average scrap automobile tire weighs approximately 100 N this increases to 150 N to 1500 N for tires used by heavy trucks and for industrial purposes. Since 1983, all new car and light truck tires are steel-belted radials. A typical tire casing is composed of 83% carbon, 7% hydrogen, 1.2% sulfur and 6% ash. The primary constituents of tires include polymers, carbon black and softeners. The softeners are mostly composed of hydrocarbon oils which in combination with the polymers

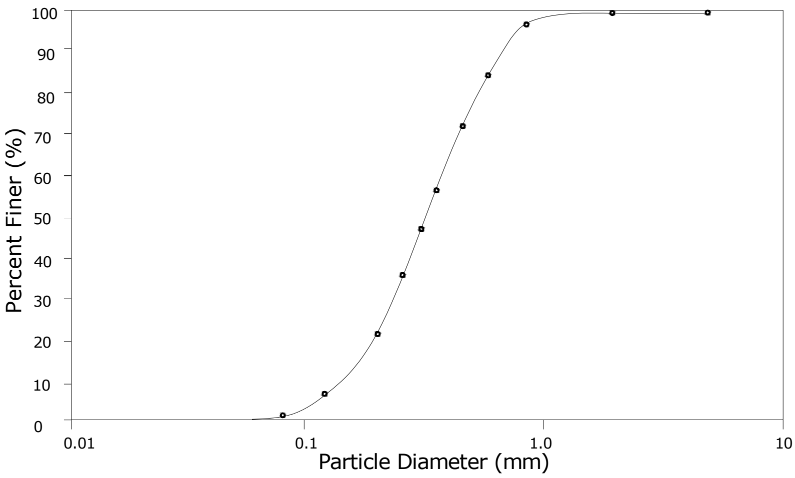


Fig. 4 Sieveanalysis of sandparticles

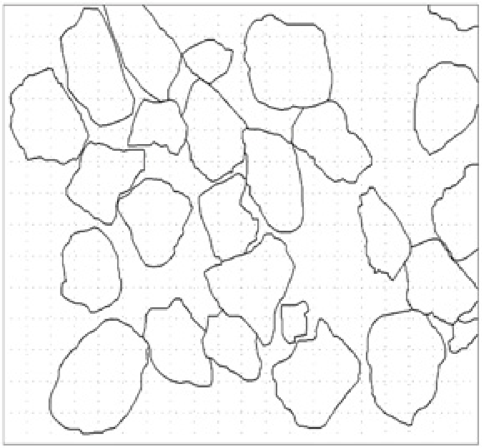


Fig. 5 Geometry of the sand particles

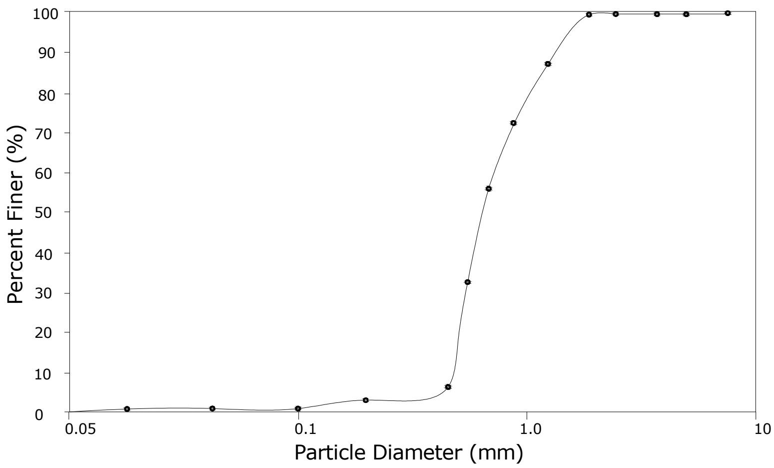


Fig. 6 Sieve analysis of tire shreds

give the tire a very high heating value Lund *et al*. (1993). In the laboratory studies as shown in Fig. 6, sieve analysis was performed in accordance with ASTM D422 to determine the particle size distribution (gradation) of the shredded tires.

The average dimensions of the tire shred particles are between 4-6 mm. They are angular and have a relatively even surface. Tire shreds are highly compressible because of their high porosity and high rubber content. When a load is applied the individual shreds compress, primarily due to the bending and orientation of the shreds into a more compact packing arrangement. Therefore, the sieve analysis was performed twice using two samples of the shredded tires. One test was carried out before compaction and the other after compacting in a proctor mold. Two sets were performed in order to verify the effects of compaction on the gradation of the shredded tires. Since shredded tires are comparable to sand and gravels, with the moisture effects being considered negligible, the tests were performed using samples of dry shredded tires. The unit weight of typical soils ranges from 18 kN/m^3 to 21 kN/m^3. The average unit weight of shredded tires of dimensions between 2 mm–20 mm without compaction is approximately 4 kN/m^3 to 5.2 kN/m^3, this unit weight value may increase to 7 kN/m^3 under standard compaction energy (Humphrey *et al*. 1992, Manion and Humphrey (1992). In the current study the unit weight and angle of friction of the pure shredded tires were found to be 5 kN/m^3 and 19 degrees respectively. The engineering properties of sand and shredded tire are given in Table 1.

A comparison of the results given in Table 3, below show that our results were in keeping with those found in the literature.

Pipe performance under surcharge loading is determined by the rigidity and engineering properties of backfill material. The backfill configuration (type and extend of soil materials) and the method of compaction can also impact on the nature of loading and support for the pipe. Dense backfill generally provides better soil support to the thermoplastic pipe walls but it is usually difficult to achieve uniform and well compacted backfill medium around the pipe, particularly when working in a single pipe trench of limited width, where the soil below the pipe haunch can not be accessed easily. Therefore non-uniformity and poorly compacted of the surrounding soil support can produce odd-shaped displacement and local bending problems on the pipe wall section. In particular, the lateral passive pressures of the soil near the pipe springlines and pipe haunches affect the lateral enlargement or expansion of the pipe culvert. In the literature there are numerous studies concerning tire shred sand mixtures. In most of them the tire percent in the haunches affect the lateral enlargement or expansion of the pipe culvert. In the literature there are numerous studies concerning tire shred sand mixtures. In most of them the tire percent in the reason for this choice was that using more tire shreds in the mixture leads to a decrease in the lateral passive earth pressure around the pipe medium. So, increasing the shredded tire ratio in the mixture creates poor haunch conditions and leads to additional pipe deformations. In other words; adding more than 7% tire shreds to the sand has an effect on the shear strength characteristics of the backfill mixture.

Table 1 Physical properties of the sand and shredded tire rubber used in the study

Physical properties of sand		Physical properties of shredded tire	
Description		Description	
Maximum void ratio	0,87	Unit weight (kN/m³)	5
Minimum void ratio	0,52	Thickness (mm)	4-6
Moisture content	0	Angle of internal friction (°)	19
Specific gravity	2,65	Cohesion (kPa)	0
Friction angle (°) at Dr 70%	32	Ultimate tensile strength (kN/m)	7,58

*The mixing ratios and the relative density of the mixtures are presented in Table 2

Table 2 Relative density of sand tire shreds mixture

Sand (%)	Tire shreds (%)	e_{max}	e_{min}
100	0	0,87	0,52
95	5	0,88	0,59
93	7	0,88	0,67
90	10	1,12	0,72
85	15	1,21	0,81

Table 3 Properties of shredded tires gained from the literature (Ravichandran and Huggins 2013)

Source	Compact unit weight (kN/m^3)	Friction angle (^{o})	Cohesion (kPa)	Poisson's Ratio
Cecich *et al*. (1996)	5,51-5,86	27	7,038	-
	6,97	22	5,746	-
Youwai and Bergado (2003)	6,72-7,37	30	-	0,33
Lee *et al*. (1999)	6,3	21	17,5	-
Moo-Young *et al*. (2003)	6,25	15	0,394	-
	7,25	32	0,3735	-
	6,5	27	0,3733	-
	6,25	29	20,3492	-
Shalaby and Khan (2005)		19-25	8-11	0,30
	5,89-6,87			0,30
Warith *et al*. (2004)	6,38-8,24		-	-
Humphrey *et al*. (1992)	6,06	23	8,6	0,32
	6,29	21	7,7	0,28
	6,07	19	11,5	0,20
Yang and Kjartanson (2002)	5,73	32	0	0,28
	5,73	11	21,6	0,28
	5,73	18,8	37,7	0,28
Average	6,39	23,4	9,19	0,29
Standard Deviation	0,659	5,87	5,87	n/a

This is mostly because a greater percentage of the tire shreds is distributed in the mixture resulting in more voids. These voids cannot be filled with sand uniformly, since the amount of sand is limited. The tire shreds thus trap the sand grains in the haunch zone. Therefore the friction between shred particles gradually governs the backfill medium and poor haunch conditions tend to occur around the pipe conduit. A zone of low stiffness soil placed under the haunch zone and bedding layer changes the distribution of strain around the pipe conduit towards the middle of the haunch zone. This fact was mentioned by Roger's *et al*. (1996). As the same problem as Rogers' *et al*. (1996) mentioned in their investigations, we also observed the same problems in our laboratory test series.

Especially it is very hard to achieve uniform backfill conditions with the backfill that contents tire shredded materials in which they have a very light weight and very low stiffness properties. Furthermore it is much more difficult to provide at high percentage tire contents in the mixture. As the shred content increases in the mixture it is getting much more difficult to achieve uniformity and to maintain homogeneous density around the pipe walls. In our specific model trench test set up; the installation quality of the mixture is getting worsening after 7% tire shred portion. So we decided to restrict the adding portion of the tire shred as 7%.

The triaxial tests were performed on cylindrical specimens which were 38 mm in diameter and 6 mm high (H/D = 2.0). The tests were implemented in a dry deposition method with the quantity of dry shred-sand mixture of a targeted density (Dr; 70%) being placed in the split mold in three equal layers. After the specimens were prepared porous stone and a loading pad were placed on top of the mold and sealed with O-rings. Before applying a confining pressure a 25 kPa negative (back) pressure was applied to the specimens to reduce the disturbance during the removal of the split mould and triaxial cell installation. Each test was performed in dry conditions at the same axial strain rate of 2.5 mm/min. During the tests, for each of the confining pressure values, the load and deformation readings were recorded using a data acquisition system. The same test procedure was used to conduct the test on different mixtures as shown in Fig. 7.

Typical pattern of stress-strain curves gained from UU triaxial tests for a confining pressure of for a different percentage of shredded tire are given. The influence of tire particles is apparent in the significant change in the stress strain behavior. The peak shear strength was enhanced with the increase in shredded tire content in the backfill mixture.

A small direct shear test apparatus with rectangular mold of 60 mm × 60 mm and a thickness of 30 mm was also used to perform the shear tests. The tests were based on the procedure described in ASTM-D5321 and carried out on samples containing pure sand and four mixtures of sand and shredded tire crumbs at dry conditions. The samples were then tested at a constant rate of 2.5 mm/min. The stress-strain plot from the direct shear test for the 4 mm – 6 mm size tire shreds ; for all five percentages (of shred) and at normal stress of 100 kN/m^2 are given in Fig. 8. All mixture contents had a clear peak shear stress. The variation of volumetric strain against shear strain of mixtures at normal stress of 100 kN/m^2 is shown in Fig. 9. It can be observed in the figure that the samples were initially compressed and then dilate upon shearing. This behavior increases as the

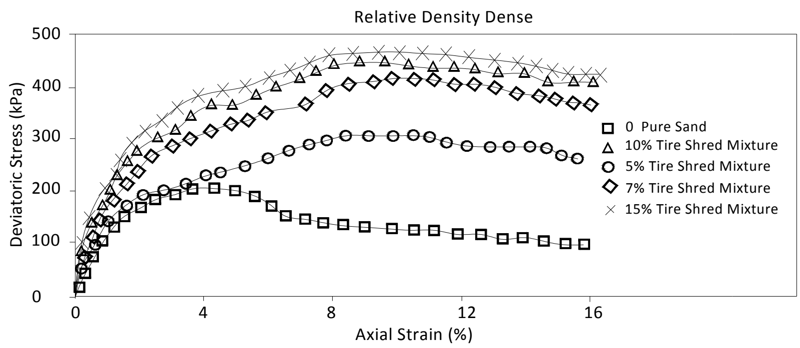


Fig. 7 Axial strain distribution under deviatoric stress

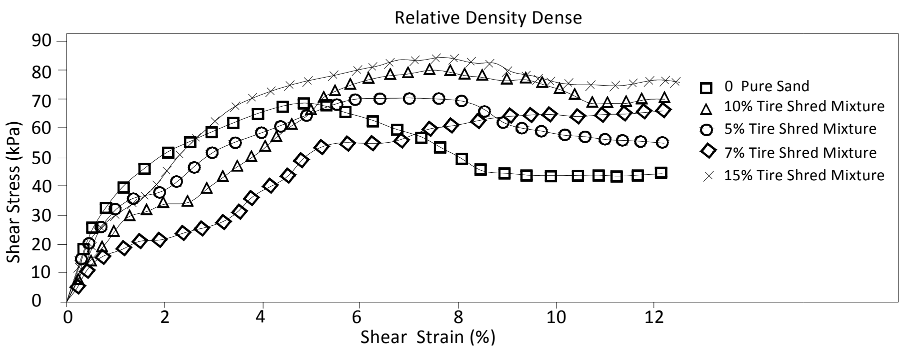


Fig. 8 Stress strain distribution

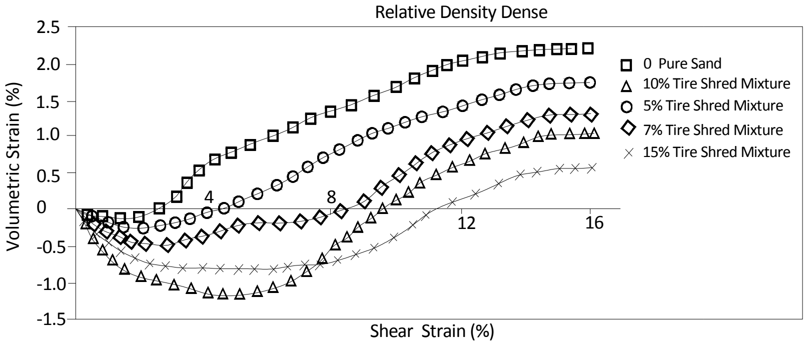


Fig. 9 Volumetric strain distribution

rubber content for all sizes of tire crumbs.

In contrast to the behavior observed in the UU triaxial tests, the percentage of shredded tire does not strongly influence the shear strength characteristics of sand-tire mixtures. In both of the tests (UU and direct shear test) the addition of shredded tire particles to sand increased slightly with increasing shredded tire content. However, after 7% this pattern was reversed.

3.3 Pipe properties

Although there is a great range in pipe diameters, there is a common small pipe diameter which is used for urban services (drainage, sewer, and gas mains, etc.). Therefore, based on the dimensions of the model test, the plastic pipes used in this research were 100 mm external diameter, approximately 10 mm thickness, and 500 mm length. The PE 100 type HDPE plastic pipe with a production standard of DIN 8074.16 was supplied by the Dizayn Pipe Corporation with a production standard of DIN 8074.16. The elastic modulus, stiffness and Poisson's ratio of the pipe material were 900 MPa, 720 kN/m and 0.40, respectively. The mass per unit area and ultimate tensile strength of the pipe material were 0.802 kg/m^2 and 6.1 kN/m, respectively. The length of the pipe was 1cm less than the length of the stiff tank to prevent binding against the end walls. Also, in order to prevent sand particles entering the pipe and to reduce friction between the pipe and the front and back faces of the tank, the two ends of the pipe were closed with strip foam before placing it in the tank.

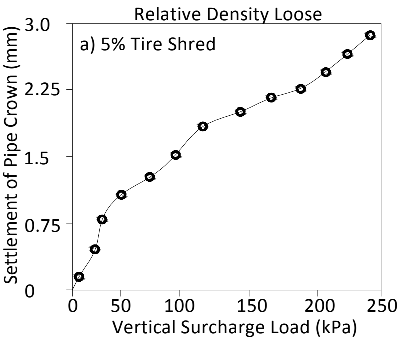
4. Experimental studies

Atotal of 15 series of loading tests were performed on tire shred-sand backfill material mixtures containing 5%, 7%, 10% and 15% tire shredded particles by weight.

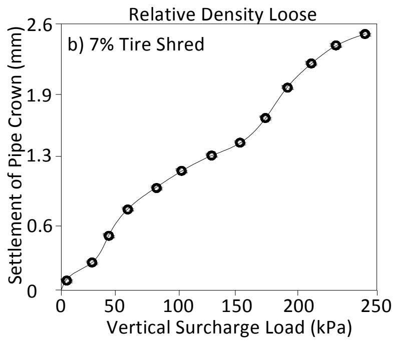
The entire process of mixing the tire shreds and sand was carried out by hand. The whole process of the test was conducted under dry conditions. One of the factors that may influence the basic characteristics of the mixed composite is segregation since, if the shreds are larger than the sand particles, sand particles may tend to settled at the bottom of the trench, however in our tests the sand contents remained unsegregated. Edil and Bosscher (1994), and Bosscher *et al*. (1992) conducted experiments on a sand shred mix and observed that when the ratio of sand to tire shreds in the mixture was low (for example less than 30% based on volume) segregation occurred and the sand tended to settle at the bottom of the soil box. They found that when the amount of sand was high segregation did not happen. Based on these studies, the importance of the segregation issue was considered. To avoid segregation, care was taken to continue the mixing and observe the mixture from the beginning until it was poured into the soil box trench model. In this way the sand contents in our installations remained segregated.

In order to determine the targeted relative densities of the mixtures, we adopted the method given by Adalier *et al*. (1998) which was developed by taking into account; ASTM 4253 and ASTM 4254.This method was also used by Terzi *et al*. (2010, 2012).

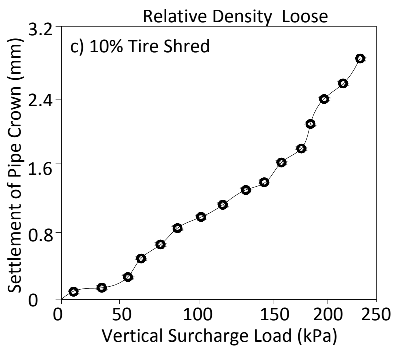
The process of the test began with the installation of bedding layer. After the bedding layer was established and the pipe installed carefully, the mixed materials were poured steadily into the model trench box. In order to prepare the backfill in a particular density the materials were poured into the shear box from a very low height to create the loosest densification. To achieve the expected relative density a cylindrical wooden plate with a diameter that was slightly less than the box mold was located on the top of the sample. Then a weight with a mass of 100 N was dropped three times from a height of 15 cm on the plate. After the backfill mix was poured the pipe tests were begun by applying a load onto the pressurized air membrane until the first loading step (10 kPa) was achieved. The loading was stopped and the deformation of the pipe section was obtained synchronously. After completing each test, the soil box was discharged and the sand-shred backfill mixture was weighed. The relationship between the weight of the backfill and the volume of the soil box gives the relative density and compaction quality of the embedment in the model trench.



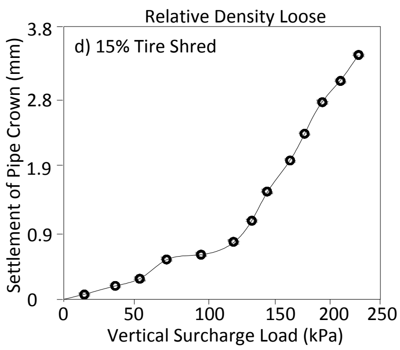
(a) 5% tire shred



(b) 7% tire shred

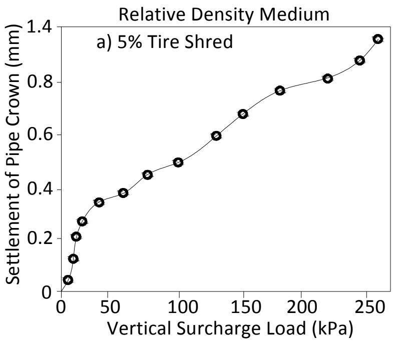


(c) 10% tire shred

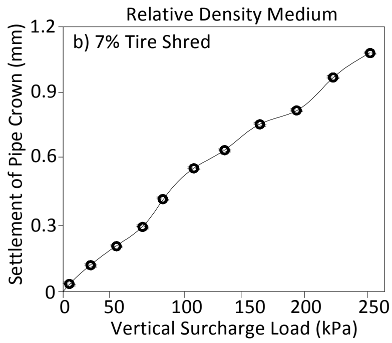


(d) 15% tire shred

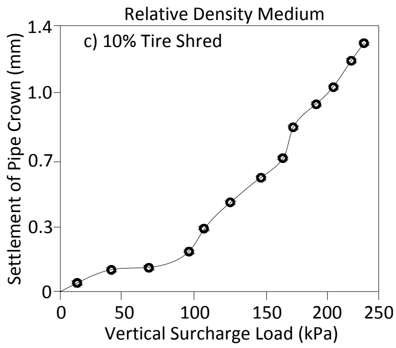
Fig. 10 Vertical deflection of pipe crown in loose backfill condition



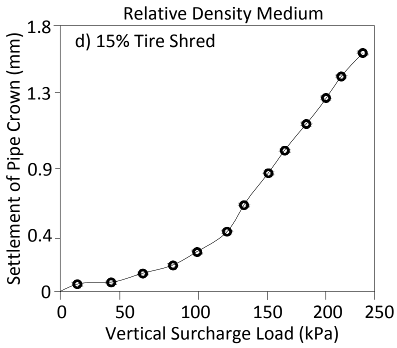
(a) 5% tire shred



(b) 7% tire shred



(c) 10% tire shred



(d) 15% tire shred

Fig. 11 Vertical deflection of pipe crown in medium backfill condition

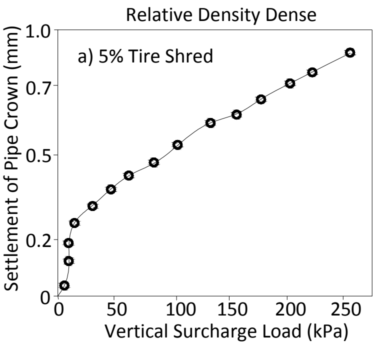
In the use of this type of different composite mixtures; the main concern is the segregation and discrete behavior of the materials Mahboub and Massie (1996) reported that particle segregation is an expected problem for mixtures using two materials with a significant difference in specific gravity. However, in all tests no evidence of segregation was observed for comparatively low tire shred contents.

For the first phase of the experimental studies as shown in Fig. 10(a), (b), (c), (d), the backfill mixture was poured into the trench model in a loose condition. For a 250 kPa surcharge load, the total deformation of the pipe conduit was 2.9 mm, 2.5 mm, 3.1 mm and 3.7 mm for 5%, 7%, 10% and 15% backfill conditions, respectively.

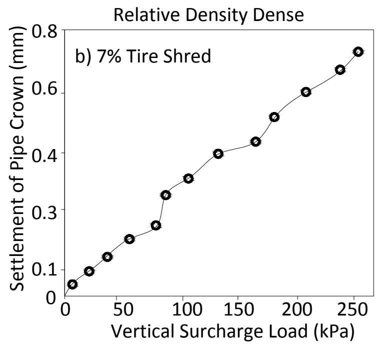
In the second phase of the study, as shown in Figs. 11(a), (b), (c), (d) the mixture was installed into the trench model in a medium dense condition. The final deformation of the pipe crown under 250 kPa was 1.3 mm, 1.0 mm, 1.2 mm and 1.7 mm for the 5%, 7%, 10% and 15%, respectively in the medium backfill condition.

Many flexible buried pipes have been known to deflect up to 20% from their original diameter without structural failure; however, a 5% initial deflection design limit is recommended Spangler (1941), Jeyapalan and Boldon (1986)for the following reasons:

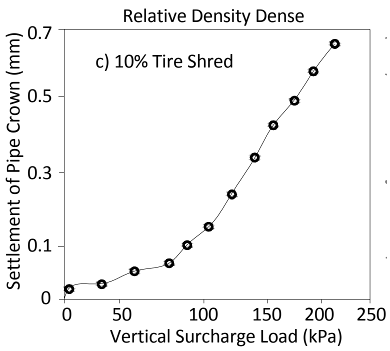
(1) If the pipe is poorly restrained laterally (e.g., poor compaction or weak embedment material used), failure may occur due to excessive deformation.



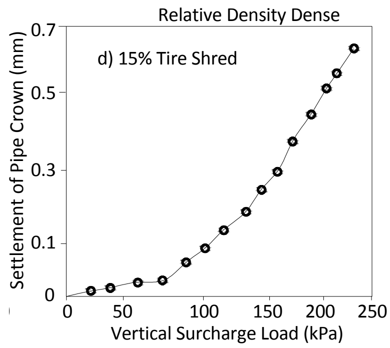
(a) 5% tire shred



(b) 7% tire shred



(c) 10% tire shred



(d) 15% tire shred

Fig. 12 Vertical deflection of pipe crown in dense backfill condition

(2) Flexible plastic pipes will continue to deflect over time due to the creep characteristics of pipe.
(3) Excessive deflection could cause infiltration and exfiltration to occur as joints become unsealed.

As shown in the Figures above, the deflections at the vertical axes of the pipe wall in all the backfill mixtures were less than 5%. Therefore, the performance of the flexible pipe under the shredded rubber-sand backfill was quite satisfactory. Although a minimum deflection measured in the 15% and 10% mixtures, the deformation gap for the 7% mixture and 15% mixture was very close. Therefore, a 7% rubber content should be accepted as the optimum mixture content for sandy trench conditions. As mentioned before; shred content more than 7% has occurred poor hunch conditions at the bedding layer of the trench. But we have to emphasise that this restriction is not a general statement. The limitation is strongly related with the set up dimensions, pipe properties, and index characteristics of the sand and tire shreds. In order to make a general statement about tire mixture proportion, the tests have to be conducted in the field conditions with considering the other parameters such as trench width, pipe wall section, shredded tire properties, loading steps etc.

The experiences gained from the application of HDPE flexible pipe prove that, in most cases, the appearance of local plastic strains does not indicate any risk of the transition of a pipeline system into a limiting state followed by the loss of its load-carrying capacity. The investigation of pipes utilized in conditions where there are stress–strain relationships and bending moment distributions becomes quite important for both practical and academic studies. In a general case of a dead surcharge loading located on the trench surface, normal and tangential stresses induced by a bending moment and longitudinal forces are observed. In analyzing the stress–strain state, it is customary to neglect the tangential stresses caused by the transverse forces and assume that the components of stresses and strains are constant across the thickness of the wall. Rigid pipes carry surcharge loads on their crown and invert point of the pipe culvert; however, flexible pipes carry these loads on their springline points. Therefore, the maximum bending moment on flexible buried pipes occurs on the sidewalls of the pipe culverts. In this study, the strain measurements were obtained at springlines, haunches, shoulders, invert, and crown of the pipe wall. The maximum bending moments obtained in the springlines of the flexible pipe culvert were as predicted. The maximum bending moments at different mixture backfills and conditions are given in Figs. 13-14 and 15.

The pipe bending moment distribution and pipe response to the applied pressure are almost linear, leading to an elliptical deformation. It is evident from the results that increasing the backfill quality afforded the pipe greater protection in terms of bending moment distribution and maximum circumferential strain. Additionally, flexible pipes resist deformation with the help of lateral shear strength of backfill material. Therefore, of crucial importance are the deformation characteristics and shear strength parameters of backfill material that installed around the haunch of the pipe conduit. If the shredded tire content in the mixture is higher than 7%, then elastic deformation

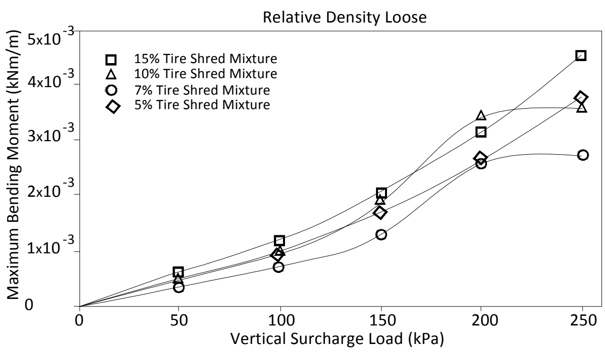


Fig. 13 Maximum bending moment at loose backfill condition

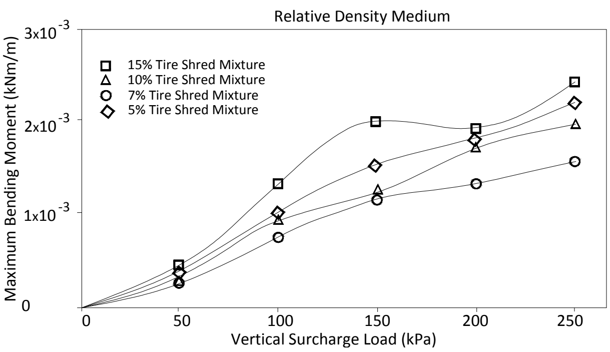


Fig. 14 Maximum bending moment at medium backfill condition

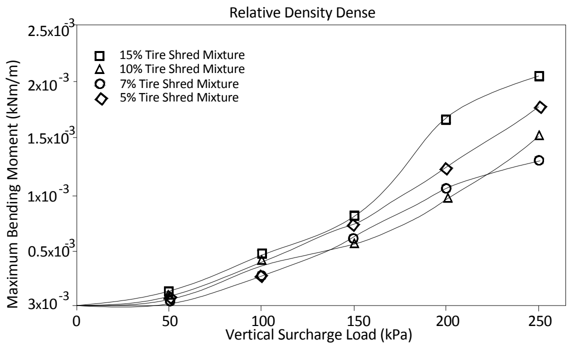


Fig. 15 Maximum bending moment at dense backfill condition

characteristic of the whole mixture increases and thus the lateral deflection of the flexible pipe increases. As a result in order to maintain the elastic deformations of a flexible pipe conduit at an appropriate level then shredded tire content must be carefully mixed with sand. It is important to recognize that the shear parameters are regulated mostly by the sand not the shredded tire material.

5. Conclusions

Backfill is the main and most important component of flexible buried pipe applications. In such kind of special situations, as the pipe installations are more deeply buried, there has to be additional concern to maintain the service capability of the flexible buried pipe. In this situation tire shreds sand mixture can be used. In this study the effect of different sand-shredded tire mixtures were analyzed to determine whether they are suitable for use as a lightweight filling material. For the analysis purposes; in the first part of the test procedure the shear strength parameters of the tire-sand mixtures were evaluated using the simple direct shear test and triaxial UU tests. On the results of the direct shear tests showed that for most of the tests the shear the stress displacement curves were almost nonlinear and with no well-defined peak stress. Samples compressed at low horizontal displacements reached a minimum volume then dilated after about a 10% horizontal displacement. For the triaxial tests the stress strain response was linear up to 10% strain but exhibited strain softening beyond 10% strain. The results from the direct shear test and triaxial test were shown that, shredded tire sand mixture seems to have a remarkable effect on the structural rigidity under 10% mixture content. The structural skeleton of the composite mixture improved as the quantity of the tire content was increased in the mixture. From the test results it was clearly seen that randomly distributed shreds in compacted and mixed with fine sand can create an important backfill material for flexible buried pipes in trench conditions. The presence of shredded tires in sandy backfill changed pipe deflection pattern and the strain distribution at the pipe wall. However, as mentioned above, adding more than 7% by weight tire shreds in a backfill, leads to the mixture becoming more compressible than sand alone, which allows greater deflection, poor haunch condition and extra pipe settlement on the bedding layer. Based on the findings, the best performance observed for sand-shreds mixture is 7% which produces minimum values of pipe deformation and pipe wall strains. This results shows that; the use of shredded waste tires in geotechnical applications along with the fine sandy soils will have an overall net positive impact on the environmental since large quantities can be consumed.

This study should provide encouragement for tire shred-sand mixtures to be used as backfill material. The parameters and evaluations resulted from this experimental studies were conducted on dry shredded tire-sand mixtures. In practical applications flexible buried pipe behavior in tire shred- sand mixture under moist or wet conditions needs to be investigated.

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