Pet bottle as a filling material for holes in paved roads.

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Abstract. The purpose of this work is to inform & raise awareness for search different potential applications for PET bottles, the Hypothesis proposed is to put PET bottles filling with sand into paved road holes with the purpose of gain filling volume, correcting the hole and use the less quantity of asphalt in this process.

It is known from studies conducted by different instances that the vast majority of PET bottles of various shapes have a high mechanical strength, low deformation. Previous studies show that the bottles for carbonated drinks and mineral water meet these specifications well. It has also been shown that these bottles increase their resistance significantly (up to 140%) to be filled with sand or polyethylene high and low density, in addition to having a greater resistance to cyclic static loads (passage of cars by the same point).

The test design that is intended to be tested, it is expected to have a deformation within a range of up to 20 millimeters and increase the useful life of the filled hole. The bottles must be in good condition since most of their resistance is provided by the sand or plastic material confined inside.

Keywords: PET Bottles, Paved road holes, Scour, Reduce Asphalt use, Second way to use PET.

Introduction

At present, environmental damage has been caused by the generation of solid urban waste, in Mexico year around 40 million tons of waste were generated, according to data reported by the Social Development Secretariat (SEDESOL) in 2004, an generation of 94,800 tons of waste per day. [4] In Mexico, 11% of urban solid waste are PET bottles. [4]

One of the plastics that has an indiscriminate use in our modern life, is the Tereftalato of Polyethylene or Polyethylene, tereftalato (PET by its acronym in English), is a very versatile material mechanically resistant, thermally stable, chemically inert to most of the acids, we even use it to pack products for human consumption, in Mexico as in most of the underdeveloped countries these virtues have made this product, an evil that is threatening the environment, our little culture of recycling and especially to that we have not had the capacity to give it another secondary use that gives added value.

The present work seeks to inform and raise awareness about the search for potential applications that PET containers may have in everyday life.

Polyethylene terephthalate (PET) is a polyester that belongs to the family of thermoplastics, with a high degree of crystallinity. It is obtained from a poly-condensation reaction between terephthalic acid and ethylene glycol. [1]

The physical properties of PET have been the reasons why it has reached a significant development in the production of a great variety of packaging. Among the most important features presented are:

- Good behavior to permanent mechanical stress.
- High resistance to wear and corrosion.
- High resistant rigidity.
- Good resistance to creep. [1]

PET is a light material that has certain characteristics that make it an option to be used in different applications within the field of civil engineering.

One of the applications that has been given to PET containers is the construction of low-cost housing with truly favorable results, these constructions represent an innovative system that optimizes the use of available resources obtaining resistant, durable and economic structures.

The construction system based on disposable PET bottles, allows to save up to 50% in materials. [1]

In addition this material is used to improve the conditions of the natural terrain due to its low volumetric weight. For this reason it is using PET containers for this project, which consists of the use *of PET containers filled with compacted sand in potholes or scouring to gain fill volume and correct these imperfections* seeking to reduce the use of asphalt to fill all the pothole and focus only on covering the surface exposed to the tires, with this proposal it is looking to give another use to plastic bottles and reduces consumption of the asphalt, since asphalt is a natural component of most of the oils and one of the oldest building materials that man has used. [2]. it is also preserved the integrity of the roads without losing their functionality and above all preserving the safety of the users.

It is intended to use PET containers as filling elements in the correction of potholes (refer with: Fig. 1), seeking to facilitate the filling process of the holes, that is not mechanically weakened over time and that less asphalt is used of the usual.

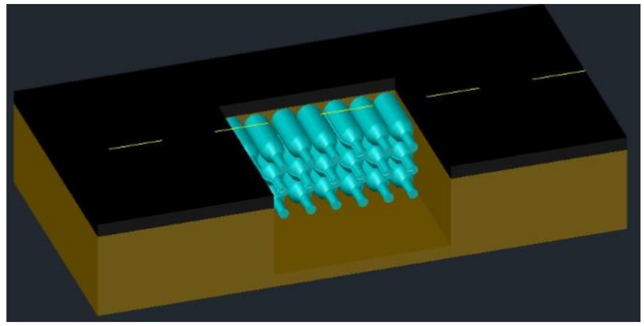


Figure 1. CAD simulation using the PET bottles in a pothole.

It has been demonstrated that the containers increase their resistance in an important way (up to 140%), although their weight increases drastically (up to 570%). In applications where the weight of the structure is not a limitation, the use of filled containers can be interesting since, in addition to having a greater mechanical resistance to cyclic static loads, passing of cars by the same point (refer with: fig. 2), it is also assigned a final disposal site to a greater amount of waste without affecting the environment.

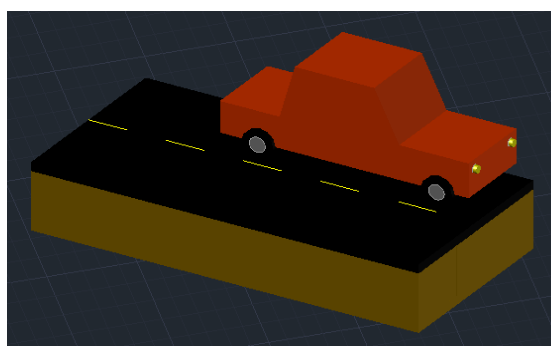


Figure 2. Simulation of cyclic static loads

Methodology or experimental section

A research question was asked which responds in the following way:

Is a new application the use of PET containers filled with sand as filler material in patching of underpasses on paved roads?

The variables to be measured are the following:

• Load capacity that the bottle receives when it deforms.

• Deformation of the bottle itself.

• Loading capacity of the bottles arrangement.

An exploratory study was conducted which establishes the following hypothesis:

600 ml PET soft drinks containers are useful as filling elements in the repair of potholes in paved roads as well as containers filled with compacted sand resist cyclic loads without being destroyed.

It is being considered this project for the highway section Cuitláhuac-Córdoba Veracruz, which is where the highest incidence of potholes occurs, it has been detected that the heaviest vehicles that can transit are those commonly known as "full cañero", which consists of a body enabled to load sugar cane in which they have reached to register weight of up to 30 tons.

Considering that the design of these vehicles accepts a configuration of 8 tires in total, it is understood that each tire exerts approximately 3,750 kiograms-force (See equation. 1)

$$\frac{30000\ kg}{8} = 3{,}750\ kg \quad (1)$$

Load study applied in the PET bottles (600 ml bottle).

Average weight of a car "full cañero".

1 Ton = 9,806.65 N
30 Ton * 9,806.65 N = 294,199 KN (2)

Average load exerted by a single carriage tire "full cañero" taking into account its configuration with 8 tires.

$$\frac{294{,}199.5\ N}{8} = 36{,}774.937N \quad (3)$$

Therefore each tire exerts a force of 36,774,937 N or 3,750 kgf.

It is well known that plastic bottles due to their nature are deformed, for the present project tests were performed in order to know the deformation when exerting an axial load on a 600 ml plastic bottle filled with compacted sand.

Based on a study carried out on 600 ml PET bottles, it is known that the maximum strength of these filled bottles subjected to pressure is 101 KN or equivalent to 10.29 tons. [3]

$$1\ ton = 9{,}806.65\ N$$
$$\frac{101{,}000\ N*1\ Ton}{9{,}806.65\ N} = 10.29\ Ton \quad (4)$$

Compression tests of bottles.

In the quality area of the company SISTELEC (Sistemas Electrour-banos), some general characteristics of the compacted sand-filled bottles were preliminarily evaluated. In the loading machine equipment brand DAVI (see figure 3)

Figure 3. Loading machine equipment brand DAVI, in the quality laboratory of SISTELEC.

A sampling was carried out with a total of 10 tests in filled bottles to know the average deformation that they present when applying an axial load, likewise to know what is the load capacity of this material without reaching the breaking point?

Subsequently, simple compression tests were performed, these tests were performed with the bottle lying down (See figure 4).

Figure 4. 600 ml PET bottle deformation test.

The results of the pilot tests carried out in the laboratory equipment (See chart 1) are shown below.

Results of the pilot test.

Sample	Load excerted (Tons)	Deformation (mm)
1	5.4	32
2	5.18	38
3	4.96	35
4	5.10	35
5	5	33
6	5.1	37
7	5.7	38
8	4.96	37
9	4.80	33
10	4.89	39

Chart 1. Results of the pilot test.

Applying the highest recorded force (5.18 tons) at the time of testing, we noticed that the test pieces exceeded the elastic limit of the material but did not exceed the breaking stress, therefore a plastic deformation was generated in the material. To know the real deformation presented by the test object, the following formula should be applied: $\Delta L = Lo - Lf$, where the initial length (Lo) will be 68 mm, which is the dimension that the test piece presents before applying the load and The final length (Lf) will be the dimension that the test piece will present after the load has been applied.

$$\Delta L = 68\ mm - 32mm = 36mm \qquad (5)$$

Based on the tests carried out on the bottles, the following results were obtained (see chart 2), on average a PET bottle filled with compacted sand deforms 32.3 mm and supports an average axial load of 5,106 tons of force.

Results of deformations in the test object (600 ml PET bottles)

Sample	ΔL=Lo-Lf	Deformation (mm)
1	(68mm − 32mm)	36
2	(68mm − 38mm	30
3	(68mm − 35mm	33
4	(68mm − 35mm	33
5	(68mm − 33mm	35
6	(68mm − 37mm	31
7	(68mm − 38mm	30
8	(68mm − 37mm	31
9	(68mm − 33mm	35
10	(68mm − 39mm	29

Chart 2. Deformations for each of ones of the bottles using ΔL=Lo-Lf formula.

Results and discussion

Based on the results obtained from the axial compression tests, the corresponding calculations were made and the following results were obtained (See chart 3), an analysis of the variables was developed to study the dependence of one variable with the other.

Data of dispersión diagram.	
Deformation for bottle (mm)	Loading excerted for bottle (tons)
36	5.4
30	5.18
33	4.96
33	5.1
35	5
31	5.1
30	5.7
31	4.96
35	4.8
29	4.89

Chart 3. Results for axial load test.

The following chart (See chart 4) shows the calculations to make the correlation graph and explain the relationship of one variable with respect to the other.

N°	(Xi)	(Yi)	$(Xi)(Yi)$	$(Xi)^2$	$(Yi)^2$
1	36	5.4	194.4	1296	29.16
2	30	5.18	155.4	900	26.8324
3	33	4.96	163.68	1089	24.6016
4	33	5.1	168.3	1089	26.01
5	35	5	175	1225	25
6	31	5.1	158.1	961	26.01
7	30	5.7	171	900	32.49
8	31	4.96	153.76	961	24.6016
9	35	4.8	168	1225	23.04
10	29	4.89	141.81	841	23.9121
Total	323	51.09	1649.45	10487	261.6577

Chart 4. Calculations for the correlation graphic

In the first instance you must know the mean of the deformations (See equation 6) and the average of the load exerted on the bottles (See equation 7).

$$\bar{X} = \frac{323}{10} = 32.3 \tag{6}$$

$$\bar{Y} = \frac{51.09}{10} = 5.109 \tag{7}$$

Moving forward in our reasoning, the covariance (See equation 8) is calculated with respect to the variables X & Y and gives us a negative result which indicates that there is a decreasing relationship.

$$\sigma XY = \sum_{i=1}^{n} \frac{(Xi)(Yi)}{n} - (\bar{x})(\bar{y}) \tag{8}$$

$$\sigma XY = \frac{1649.45}{10} - (32.3)(5.109) = -0.0757$$

Continuing with the calculation, the variance of the variable X (See equation 9) and the variable Y (equation 10) are performed, the results are the following:

$$\sigma X = \sum_{i=1}^{n} \frac{Xi^2}{n} - (\bar{X})^2$$

$$\sigma X = \sqrt{\frac{10487}{10} - 32.3^2} = 2.3259 \tag{9}$$

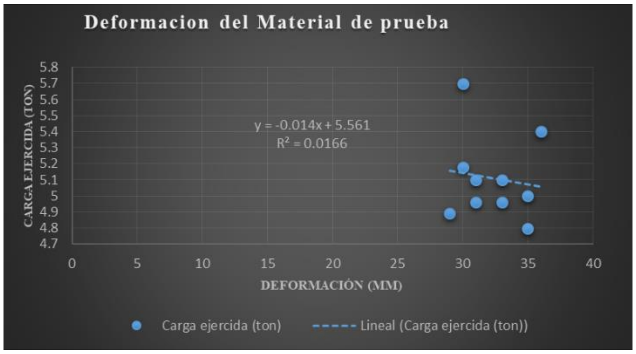
$$\sigma Y = \sum_{i=1}^{n} \frac{Yi^2}{n} - (\bar{Y})^2$$

$$\sigma Y = \sqrt{\frac{261.6577}{10} - (5.109)^2} = 0.2527 \tag{10}$$

To finish with the calculation of the correlation of the variables, the following mathematical operation is performed, which consists in evaluating the relationship between the two variables (equation 11).

$$r = \frac{-0.0757}{(0.2527)(2.2959)} = -0.1287 \tag{11}$$

There is a negative correlation (See graphic. 1) between the two variables, 12% of the time the deformation values are given by the applied load, when the load increases the deformation decreases and vice versa.



Graphic 1. Results deformation vs axial load excerted.

Based on the results obtained, it is proposed to carry out a pilot test in the field to study the deformation of the asphalt and the test object (600 ml pet bottles filled with compacted sand) when exercising a static cyclic load, which consists of simulation of a bump or undercut that will be filled with the test material (600 ml PET bottles filled with compacted earth) and covered by a cold asphalt mixture that will provide the user with a uniform rolling surface no greater than 4 cm. [5]

A wooden box was fitted to simulate the pothole in question (See figure 5).

Figura 5. Simulation ofrectangular repared pothole.

Afterwards, the first layer of 600 ml pet bottles filled with compacted sand was placed to replace the asphalt used to increase the filling volume (See figure 6).

Picture 6. First layer of PET bottle filling with sand.

After placing the first layer of bottles sand is added to completely seal the missing spaces for reasons of symmetry in the bottles (See figure 7)

Picture 7. Filling the space between bottle with sand.

Then the same procedure was carried out for the placement of the second bed (layer) of 600 ml pet bottles filled with compacted sand, the purpose is the same, this consists of gaining filling material and reducing the use of asphalt (Figure 8).

Figure 8. Placing the second layer of PET bottle.

Finally, the asphalt mixture was placed cold (See figure 9) due to the benefits it offers, these are some of the benefits: it can be mixed on site or off site and then transported to the location, it is strong enough to withstand temperature fluctuations, it is easy to maintain and recycle, due to this it is used as a temporary patch in the repair of potholes, it should be properly compacted since this makes it improve the properties of mechanical behavior (Resistance, deformability , permeability, flexibility and resistance to erosion). [6]

Figure 9. Placing the asphalt layer at the end of the pothole repair.

It is expected to reach a deformation in the potholes of up to 60 mm, counting that the bottles filled with sand reach to deform with an average load of 5 tons up to 30 mm each.

References in spanish.

[1] Muñoz, L. (2012). *Estudio del uso del polietileno de tereftalato (PET) como material de restitución en suelos de baja capacidad de carga* (tesis de pregrado). Universidad Nacional Autónoma de México, México D.F.

[2] MAXIL COYOPOTL, R. Y SALINAS HERNPANDEZ, M.A. *Ventajas y desventajas del uso de polímeros en el asfalto.* Tesis Licenciatura en Ingeniería Civil. Universidad de las Américas Puebla. Cholula, Puebla, México 2006.

[3] Ruiz, D., López, C., Cortes, E., Froese, A. (2012). *Nueva alternativa de construcción: Botellas PET con relleno de tierra*. En: Apuntes 25 (2): 292 - 303.

[4] El Medio Ambiente en México en resumen. Gobierno Federal, SEMARNAT 2009. Sistema Nacional de Información Ambiental y de Recursos Naturales.

[5] Secretaría de Comunicaciones y Transporte (S.C.T) (2013). *Normas para la construcción de capas de Rodadura con Mezcla Asfáltica en Frio. Libro CTR Contrucción, México.*

[6] RICO, DEL CASTILLO. *La Ingeniería de Suelos en las Vías Terrestres: carreteras, ferrocarriles y aeropistas.* Volumen 1. Editorial Limusa, 2005. México, D.F.