



**Nathalia dos Santos Lopes Louzada**

**Experimental Study of Soils Reinforced  
with Crushed Polyethylene  
Terephthalate (PET) Residue**

**Dissertação de Mestrado**

Dissertation presented to the Programa de Pós-Graduação em Engenharia Civil of the Departamento de Engenharia Civil, PUC-Rio as partial requirement of Mestre em Engenharia Civil.

Advisor: Prof<sup>a</sup>. Michéle Dal Toé Casagrande

Rio de Janeiro  
March 2015



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### Bibliographic Data

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*I dedicate this Master Dissertation to my beloved  
parents Ubirajara and Vilma, and to my  
safe harbor, my sister Carolina.*

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## Abstract

Louzada, Nathalia dos Santos Lopes; Casagrande, Michéle Dal Toé (Advisor). **Experimental Study of Soils Reinforced with Crushed Polyethylene Terephthalate (PET) Residue**. Rio de Janeiro, 2015. 127 p. MSc. Dissertation – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

This study presents the behavior of soils reinforced with crushed PET (Polyethylene Terephthalate) residue through experimental study. Three soils were used: a coluvionar soil, a clean and poorly graduated sand and a bentonite. Physical characterization, chemical and mechanical tests (isotropically consolidated-drained triaxial and direct shear) were performed for each material and mixtures. The triaxial test was performed on samples of clayey soil compacted within the maximum dry density and optimum moisture content with ratios of 0, 10, 20 and 30% of fine crushed PET and 3,0 and 5,0% of PET flakes, by dry weight of soil. The triaxial tests on sand samples were made to a relative density of 50% and 10% of water content, and with 0, 10 and 20% fine crushed PET, by dry weight of soil. The direct shear tests with bentonite were made with ratios of 0 and 30% of fine crushed PET and 3,0 and 5,0% of PET flakes, by dry weight of soil. The results have shown that the PET content and level of confining stress have influence on the final mechanical behavior of the mixtures. With both residue of PET, the mixtures present a satisfactory behavior, increasing or maintaining the shear strength parameters similar to the pure soil. Thus, for the clayey mixtures, the fine crushed PET content of 30% and the PET flakes content of 5% are more effective, once they increase the strength parameters. For sandy mixtures the PET inclusions is more effective with 10% of fine crushed PET at lower confining stresses and the optimum content is 10%. For bentonite mixtures the PET inclusions is more effective for PET flakes and the optimum content is 5. Therefore, the use of PET waste for soil reinforcement could minimize the current problems of waste disposal, contribute with the reduction of consumption of natural resources and give a noble use for this material.

## Keywords

Triaxial tests; polyethylene terephthalate (PET); soil reinforcement; direct shear test; PET flakes; fine crushed PET.



## Resumo

Louzada, Nathalia dos Santos Lopes; Casagrande, Michéle Dal Toé (Advisor). **Estudo Experimental de Solos Reforçados com Resíduos de Politereftalato de Etileno (PET)**. Rio de Janeiro, 2015. 126 p. MSc. Dissertation – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

O presente estudo apresenta o comportamento dos solos reforçados com PET em pó e triturado, através de ensaios de laboratório. Foram utilizados três solos: um solo coluvionar, uma areia limpa e mal graduada e uma bentonita. Caracterização física, química e ensaios mecânicos (triaxiais CIU e cisalhamento direto) foram realizadas para cada material e misturas. O ensaio triaxial foi realizado em amostras de solo argiloso compactado com porcentagens de pó de PET de 0, 10, 20 e 30% de PET triturado de 3,0 e 5,0%, por seco peso de solo. Os ensaios triaxiais, em amostras de areia foram feitas a uma densidade relativa de 50% e 10% de teor de umidade, e com 0, 10 e 20% de pó de PET, em relação ao peso seco do solo. Os ensaios de cisalhamento direto com bentonita foram feitos com porcentagens de 0 e 30% de pó de PET e 3,0 e 5,0% de PET triturado, por peso seco de solo. Os resultados mostraram que o teor de PET e nível de confinamento têm influência sobre o comportamento mecânico final das misturas. Com ambos os resíduos de PET, as misturas apresentam um comportamento satisfatório, aumentando ou mantendo os parâmetros de resistência ao cisalhamento semelhantes ao solo puro. Assim, para as misturas argilosos, a mistura com 30% de pó de PET e a com 5% de PET triturado são mais eficazes, uma vez que nelas observou-se maior melhora nos parâmetros de resistência. Para misturas de areia a inclusão PET é mais eficaz com 10% de pó PET em tensões confinantes menores e umidade ótima de 10%. Para misturas bentonita, a inserção de PET é mais eficaz para o PET triturado na porcentagem de 5%. Portanto, o uso de resíduos de PET para o reforço do solo poderia minimizar os problemas atuais disposição do resíduo, contribuir com a redução do consumo de recursos naturais e dar um uso nobre para este material.

## Palavras Chave

Ensaio triaxial; polietileno tereftalato (PET); solo reforçado; cisalhamento direto; PET triturado; pó de PET.

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## List of Abbreviation

|        |   |
|--------|---|
| ABIPET | Brazilian Association of the PET Industry         |
| ABNT   | Brazilian Association of Technical Standard       |
| CBR    | California Bearing Ratio                          |
| CD     | Consolidated Drained                              |
| CEMPRE | Corporate Commitment to Recycling                 |
| CID    | Consolidated Isotopically Drained                 |
| CU     | Consolidated Undrained                            |
| EDXRF  | Energy Dispersive X-Ray Fluorescence Spectrometer |
| EPS    | Expanded polystyrene                              |
| LVDT   | Linear Variable Differential Transformer          |
| MR     | Resilience Modulus                                |
| MSW    | Municipal Solid Waste                             |
| MVV    | Volumetric Change Gauge                           |
| NBR    | Brazilian Standard                                |
| PE     | Polyethylene                                      |
| PET    | Polyethylene Terephthalate                        |
| PP     | Polypropylene                                     |
| PS     | Polystyrene                                       |
| PUC    | Pontifical Catholic University                    |
| PVC    | Polyvinyl chloride                                |
| RBV    | Relationship Voids Bitumen                        |
| RT     | Tensile Strength                                  |
| SEM    | Scanning Electron Microscope                      |
| SUCS   | Unified System of Soil Classification             |
| UCS    | Unconfined Compressive Strength                   |
| UU     | Unconsolidated Undrained                          |

## List of Symbols

|                      |   |
|----------------------|---|
| $G_s$                | Specific weight   |
| $e$                  | Void index  |
| $e_{max}$            | Maximum void index  |
| $e_{min}$            | Minimum void index  |
| $C_u$                | Coefficient of uniformity                                     |
| $C_c$                | Coefficient of curvature                                      |
| $D_{10}$             | Effective diameter  |
| $D_{50}$             | Mass-median-diameter  |
| $t_f$                | Minimum time of failure                                       |
| $L$                  | Specimen height   |
| $v$                  | Shear velocity  |
| $\sigma'$            | Relative to effective stress                                  |
| ”                    | Inches  |
| #                    | Number  |
| $\epsilon_a$         | Axial strain  |
| $\epsilon_v$         | Volumetric strain   |
| $\tau$               | Shear stress  |
| $\sigma_1, \sigma_3$ | Main stresses, major and minor                                |
| $\sigma'_c$          | Effective confining stress                                    |
| $\sigma_v$           | Deviator stress   |
| $\phi'$              | Friction angle  |
| $c'$                 | Cohesion  |
| $B$                  | Skempton parameter  |
| $p'$                 | $(\sigma'_1 + \sigma'_3)/2$ (Normal average effective stress) |
| $q$                  | $(\sigma'_1 - \sigma'_3)/2$ (Deviatoric stress)               |
| $h$                  | Final height of the specimen.                                 |
| $h_i$                | Initial height of the specimen.                               |

|   |                                    |
|---|------------------------------------|
| %   | Content                            |
| ml  | Milliliters                        |
| mm  | Millimeter                         |
| cm  | Centimeters                        |
| m   | Meter                              |
| t   | Ton                                |
| Kton  | Kilo ton                           |
| mm/min  | Millimeter per minute              |
| min   | Minute                             |
| gr  | Gram                               |
| g/cm <sup>3</sup>   | gram per cubic centimeter          |
| kg  | Kilogram                           |
| kg/m <sup>3</sup>   | Kilogram per cubic meter           |
| kgf/m <sup>2</sup>  | Kilogram force per square meter    |
| kN  | Kilo Newton                        |
| kPa   | Kilo Pascal                        |
| °C  | Degrees Celsius                    |
| Vvp   | Volume of voids                    |
| Vma   | Voids in the mineral aggregates    |
| H <sub>2</sub> O  | Water                              |
| SiO <sub>2</sub>  | Silica                             |
| Al <sub>2</sub> O <sub>3</sub>                                | Aluminum Oxide                     |
| Fe <sub>2</sub> O <sub>3</sub>                                | Iron Oxide (Hematite)              |
| SO <sub>3</sub>   | Sulfur Trioxide (Sulfuric Oxide)   |
| TiO <sub>2</sub>  | Titanium Dioxide                   |
| CaO   | Calcium Oxide (Lime)               |
| K <sub>2</sub> O  | Potassium Oxide                    |
| V <sub>2</sub> O <sub>5</sub>                                 | Vanadium Pentoxide                 |
| ZrO <sub>2</sub>  | Zirconium Dioxide (Zirconia)       |
| ZnO   | Zinc Oxide                         |
| CuO   | Copper Oxide                       |
| CH  | Organic Matter, PET, Carbon, Water |
| (C <sub>10</sub> H <sub>8</sub> O <sub>4</sub> ) <sub>n</sub> | Polyethylene Terephthalate         |

|                                |               |
|--------------------------------|---------------|
| Tm <sub>2</sub> O <sub>3</sub> | Thulium Oxide |
| Cl                             | Chlorine      |
| S                              | Sulfur        |
| Si                             | Silicon       |
| Ca                             | Calcium       |
| Fe                             | Iron          |
| Tm                             | Thulium       |
| Cu                             | Copper        |
| C                              | Carbon        |
| Al                             | Aluminum      |
| Ti                             | Titanium      |
| K                              | Potassium     |
| V                              | Vanadium      |
| Zr                             | Zirconium     |
| Zn                             | Zinc          |

*“Nobody's perfect enough, that cannot learn from the other  
and no one is totally devoid of values that cannot teach  
something to his brother”*

*- Saint Francis of Assisi-*