Advanced Materials Research Vol. 1101 (2015) pp 361-367
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doi:10.4028/www.scientific.net/AMR.1101.361

Submitted: 06.01.2015
Accepted: 07.01.2015

Artificial Weathering Analysis and Mechanical Behavior of Geotextiles Used for Coast Erosion Control and Beach Restoration

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Keywords: Textile architecture; geotubes; mechanical properties; polymers.

Abstract. Nowadays geotextiles play a significant part in coastal protection and erosion prevention design and maintenance techniques. The growth in their use worldwide as geotubes for recovering damaged coastal due to its easiness of manipulation and excellent mechanical properties has been extraordinary. Considering that applications of geosynthetics are usually outdoors, the degradation of polymers must be taken in account when selecting polymeric textiles. There are many environmental factors, which influence aging mechanisms of geotextiles such as UV radiation, temperature, humidity, etc. However, a multiple exposures, such as a combination of moisture and heat or oxygen and light, can result in accelerated deterioration. This paper is related to mechanical behavior and durability consideration that geotextiles must withstand in order to be applied as geotubes for coast erosion and beach regaining. The paper provides an overview of the current erosion in the Yucatan coast and the solutions for shoreline protection as well as the effect of geotextile architecture on mechanical properties.

Introduction

Both natural and anthropic causes are very important to beach erosion. A consequence of beach erosion goes from environmental losses to consequences of great social, economical and political impact [1-3]. For this reason it is important to evaluate diverse causes of sandy littoral erosion and to find new techniques to recover damaged zones. Under these conditions and for critical points, geosynthetics were considered optimal for the beach-restoration project. Woven polypropylene geotextile tubes were designed to work as low-crested submerged structures. Their main function was to reduce the incident wave energy on the beach, by controlling the wave-breaking process, to the required level that maintains the dynamic balance on the shoreline. However, this geotextiles made up generally from polymers, need to be tested in its mechanical behavior under accelerated extreme climate conditions in order to understand and identify eventual degradation to predict durability while in service [4-6]. Natural weathering processes require testing over very lengthy durations and test replication is impractical, it is therefore desirable for practicality to use an accelerated method of testing to simulate the effects of natural weathering in a controlled environment using an artificial light source. The conditions of outdoor damage process on materials can be reproduced in a controlled environment at laboratory level. The exposure conditions use a combination of intense UV, heat and moisture to produce an acceleration factor, which is reliably correlated, from only days or weeks in the laboratory, to months or years of open-air exposure. Accelerated artificial weathering is particularly useful for determining the inherent environmental stability of a material by analyzing its degradation of properties such as mechanical behavior in relation to the time of exposure [7,8]. The mechanisms of degradation include oxidation, particularly at elevated temperatures during exposure to ultraviolet light, thermal degradation and photochemical action, irradiation, or mechanical action. These events can cause chain scission reactions involving the breakage of backbone bonds to yield free-radical segments, surface cracking, discoloration and most importantly reduction in molecular weight leading to a consequential loss in mechanical strength [9-11]. Over the past five years, coastal population pressure, extreme events and concerns over climate change and sea level rise have resulted in more emphasis being placed on shoreline protection systems. The beaches of the northern coast of Yucatan in Mexico have been in an erosion process that has dramatically increased in the past 15 years (Fig. 1). Changes in the littoral dynamics, mainly due to human action, have generated a coastline regression rate, estimated at 1m per year and more. There is a priority to establish monitoring in Yucatan coastal focused to minimize damages related to an exponential population growing that is the prime cause of environmental deterioration in the coastal zone among natural meteorological events such as hurricanes that follow a path through the Gulf of Mexico. Risk of destruction due to extraordinary wave conditions is a permanent threat. Coastline stabilization required a carefully designed project for controlling beach erosion, reducing as much as possible any changes to littoral dynamics that would have negative consequences in the long term [1-4]. The ASTM (1994) [15] defines geotextiles as "a permeable geosynthetic comprised solely of textiles. Geotextiles are used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of human-made project, structure, or system". Geotextile manufacturers have responded to the challenges put forward by design engineers and intensive research has been carried out in the field [12-14].

Figure 1.- Beach erosion, Chelem Beach, Yucatan Coast, April 2014.

Experimental. Geotubes with different polypropylene textiles architecture were placed under water until its superior side was barely covered by water in locations of the coast damaged by erosion in order to diminish the wave energy and to recover sandy material (Fig. 2).

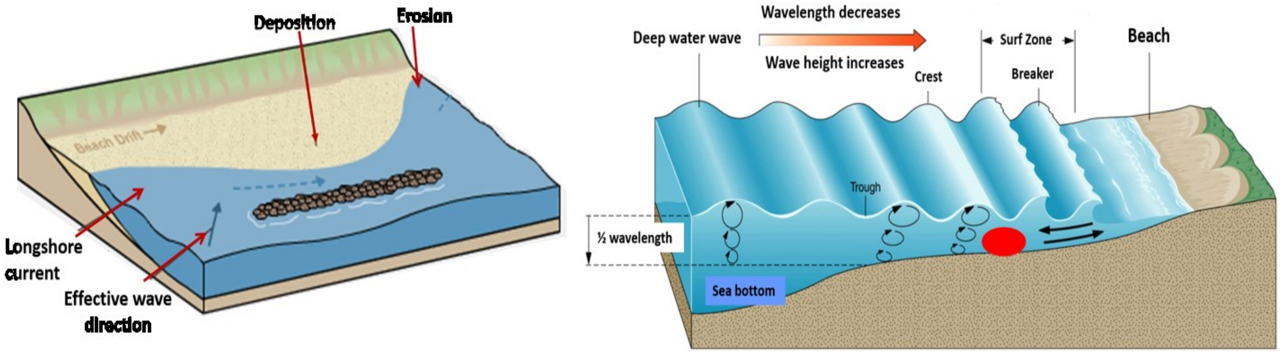


Figure 2.- Sand recovery by geotubes application.

Three different types of textiles used for the geotubes manufacture were mechanically characterized in order to understand the effect of interweaving and fibre geometry on its mechanical behaviour and environmental resistance. Figure 3 shows the studied textiles geometry in both sides since they posses different fiber arrangement. Mechanical tests were achieved under ASTM standard tests in a Shimadzu Universal Machine employing a 100 KN load cell at a crosshead velocity of 10 mm/min (tensile) and 50 mm/min (static puncture). Measurements of the mechanical parameters were analyzed in the textiles upon their two principal directions at 0^o and 90^o corresponding to machine direction (longitudinal) and transversal direction respectivelyof the mechanical parameters were analyzed in the textiles upon their two principal directions at 0 ° and 90 ° corresponding to machine direction (longitudinal) and transversal direction respectively.

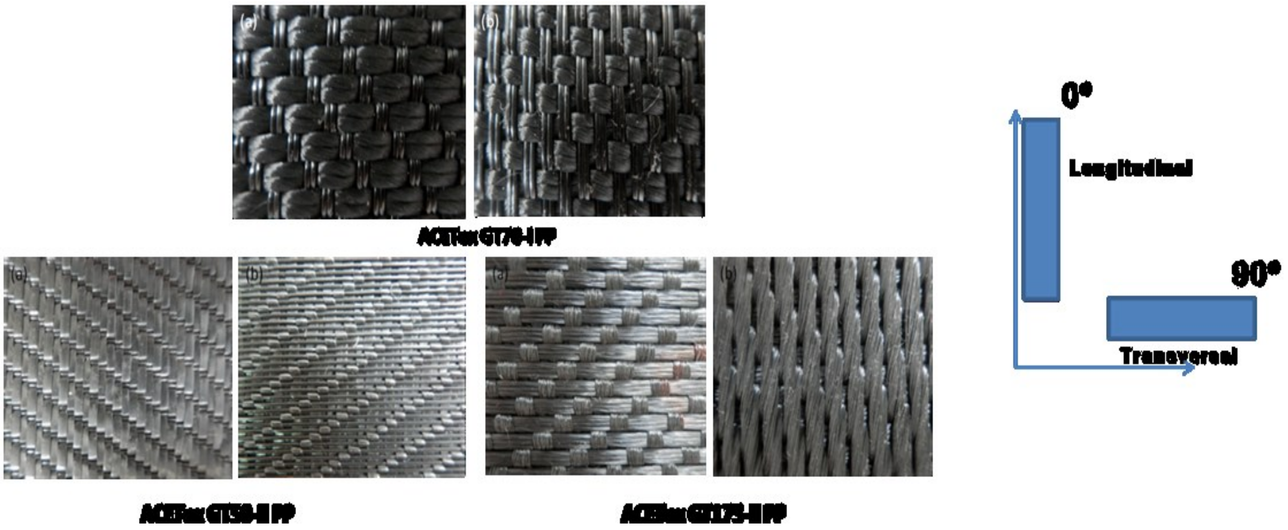
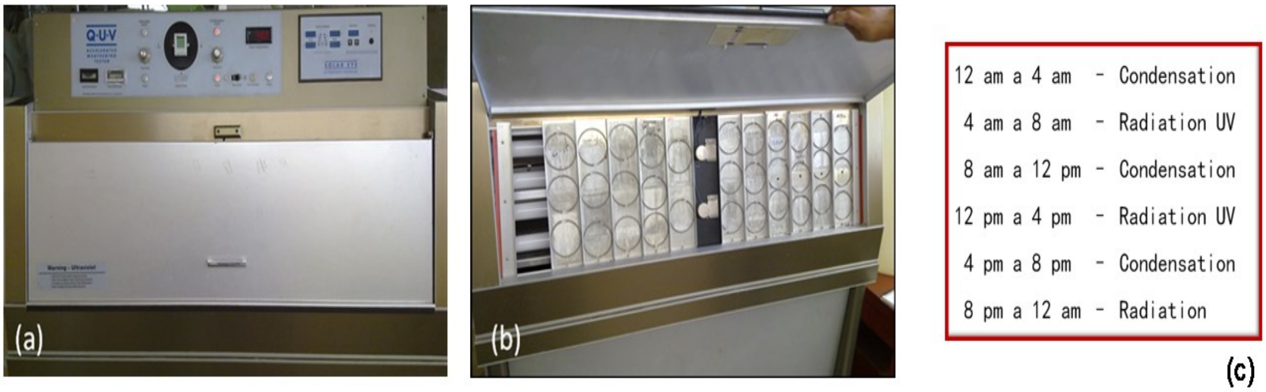


Figure 3.- Sand recovery by geotubes application.

Artificial weathering exposure was carried out in a chamber (Fig. 4) model QUV/SE at 130 Volts, 60 Hz and 1500 watts. Environmental artificial conditions were established according to the Yucatan Peninsula (Mexico) climate in cycles of condensation for 4 hours and 4 hours of radiation during 24 hours according to figure 4c.



12 am a 4 am - Condensation
4 am a 8 am - Radiation UV
8 am a 12 pm - Condensation
12 pm a 4 pm - Radiation UV
4 pm a 8 pm - Condensation
8 pm a 12 am - Radiation

Figure 4.- Weathering test chamber, a) exterior, b) interior, c) conditions.

Results

Geotube recovering effect:

Marine processes response: Geotextile tubes have been performing satisfactorily, working as parallel submerged breakwaters. As expected, energy dissipation is generated by wave breaking due to the presence of the tubes. Turbulence generated shoreward induces sand accumulation without interrupting littoral drift. It was observed a shoreline sandy recovery in 18 months as shown in figure 5. Further analysis is being undertaken in situ to correlate geotextiles properties with environmental effects.

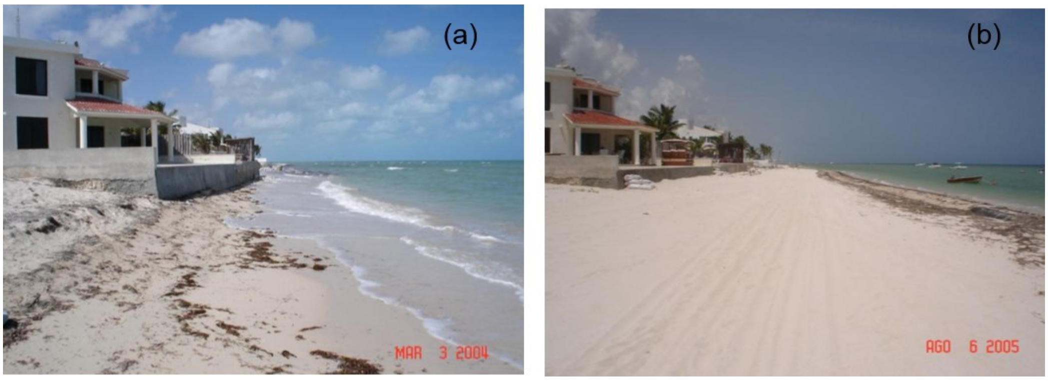
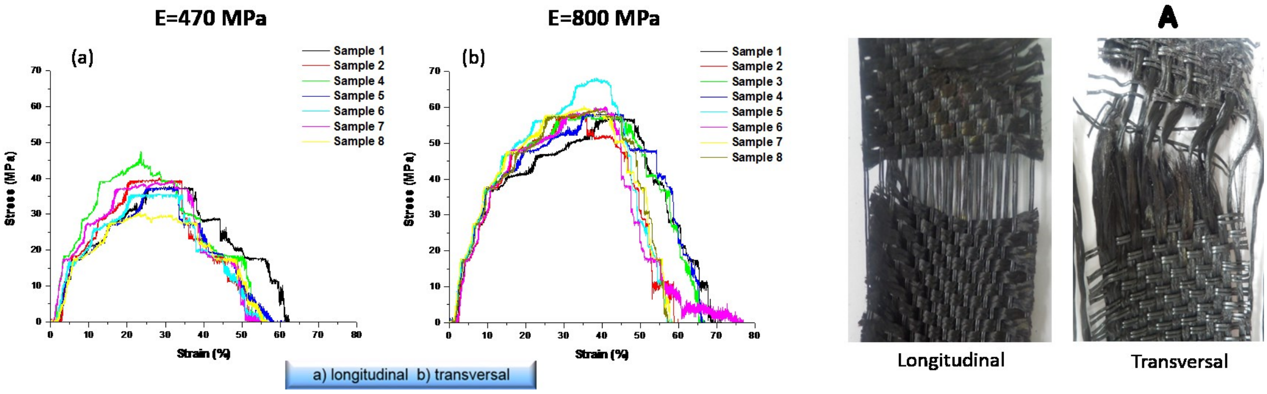


Figure 5.- Sand a) Eroded beach, Mar 2004, b) Recovered beach, August 2005.

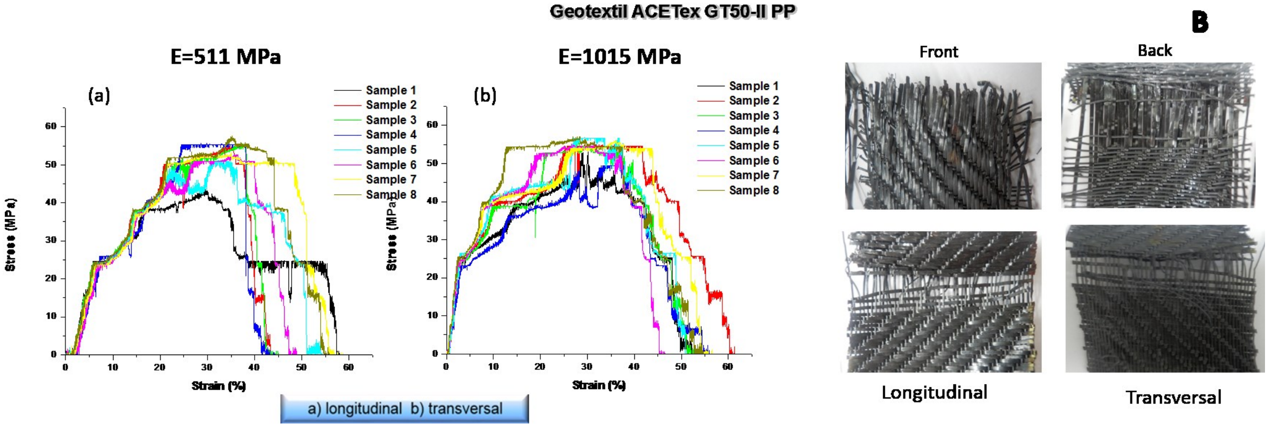
Mechanical properties:

Figure 6 presents stress-strain curves of the three textiles tested in tensile mode.

Geotextil ACETex GT70-I PP



Geotextil ACETex GT50-II PP



Geotextil ACETex GT175-II PP

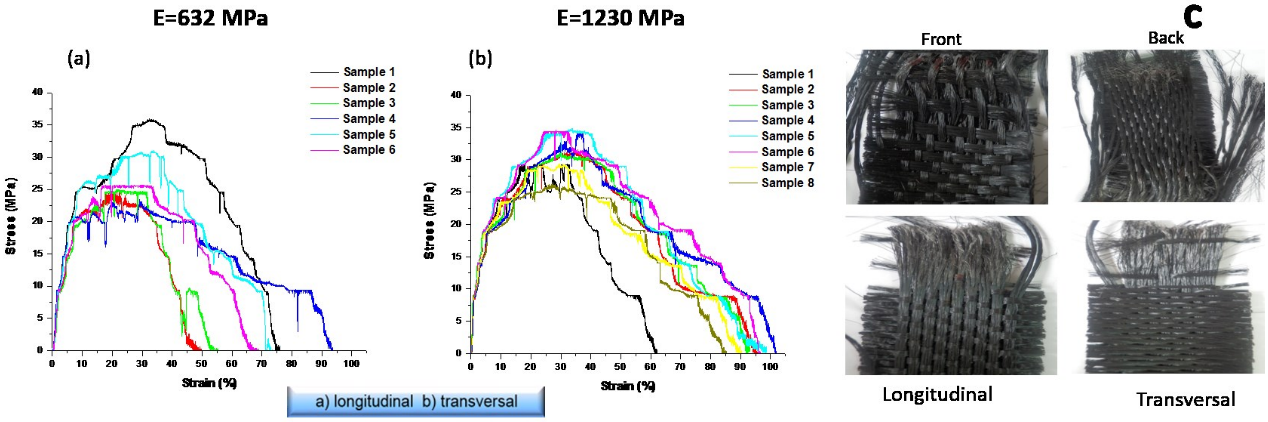
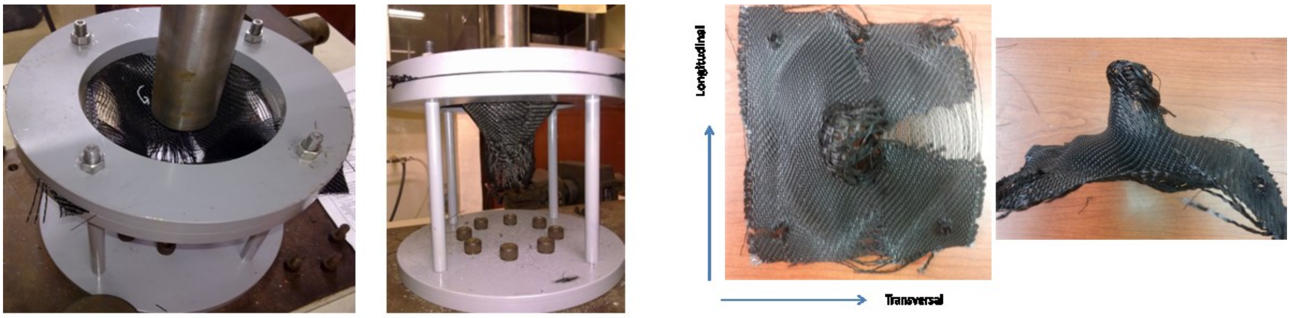


Figure 6.- Tensile test a) ACEtex GT70, b) ACEtex GT50, c) ACEtex GT175.

ACETex GT70-I PP is made up of broad filaments running on 0° but the threads at 90° are thicker (Figure 6a). On the other hand, figure 6a also exhibits the stress vs. strain curves for 8 samples for each direction. Samples at 90° showed better mechanical resistance with higher maximum stress and strain in comparison to 0°. It is evident that geometry of the textile fiber structure affects significantly the mechanical behavior under tensile stresses. In average, elastic modulus (E) was found to be the almost double at 90° (800 MPa) than the value observed at 0° (470 MPa). Fractographic examination carried out in tension indicates that in longitudinal direction parallel to the applied stress, failure deforms the textile by pulling apart the transversal thick strands with almost no fiber breakage. On the other when sample is tested at 90° (transversal) multiple fiber fracture is observed in the threads. Textiles ACETex GT50-II PP and ACETex GT175-II PP exhibited similar trend in having better mechanical properties in transversal direction (90°) doubling the value of Young's modulus (E). This is an indication of the high resistance induced to geotubes when stresses are applied transversally.

Static puncture strength:

Textile samples were uniformly held in the static puncture device and compressed by a piston in order to induce a deformation in the sample (Fig. 7a). All textiles were punctured until maximum load, total fracture or rupture due to penetration was observed. ACETex GT70-I PP textiles exhibited excellent stability to deformation until failure appeared in the internal fibers of the textile (Fig. 7b). Samples were noticed to have more stability in the transversal direction.



(a) (b)

Figure 7.- a) Static puncture strength device test, b) Deformed ACETex GT70-I PP textile .

Figure 8 shows the load – displacement curves obtained during static puncture test. Samples exhibited similar trend having an average maximum load of about 8.1 kN and a displacement of 57.3 mm. ACETex GT50-II PP presented total fracture of fibres during penetration by stretching considerably along the longitudinal direction originating the progress of failure perpendicularly. On the other hand ACETex GT175-II PP exhibited the lowest load value since presented a wide deformation by glide of the multifilament yarns in both directions.

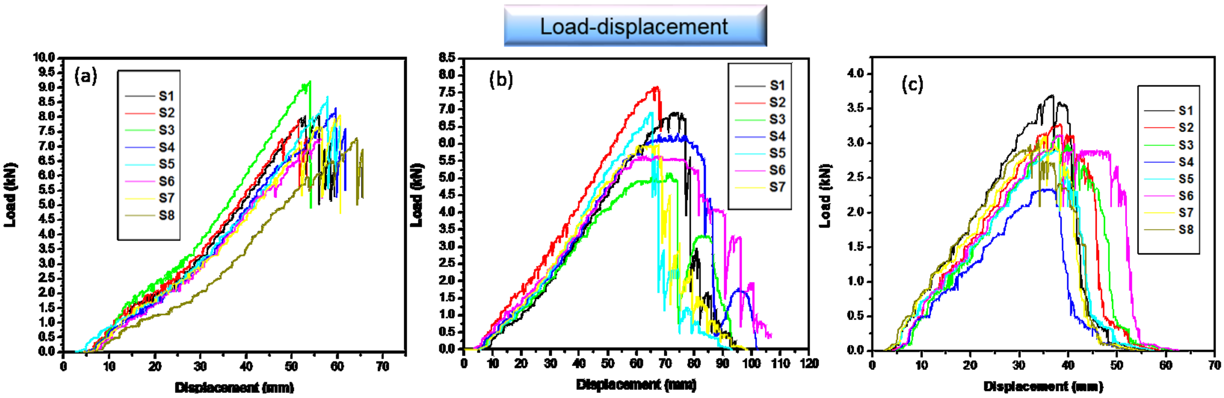
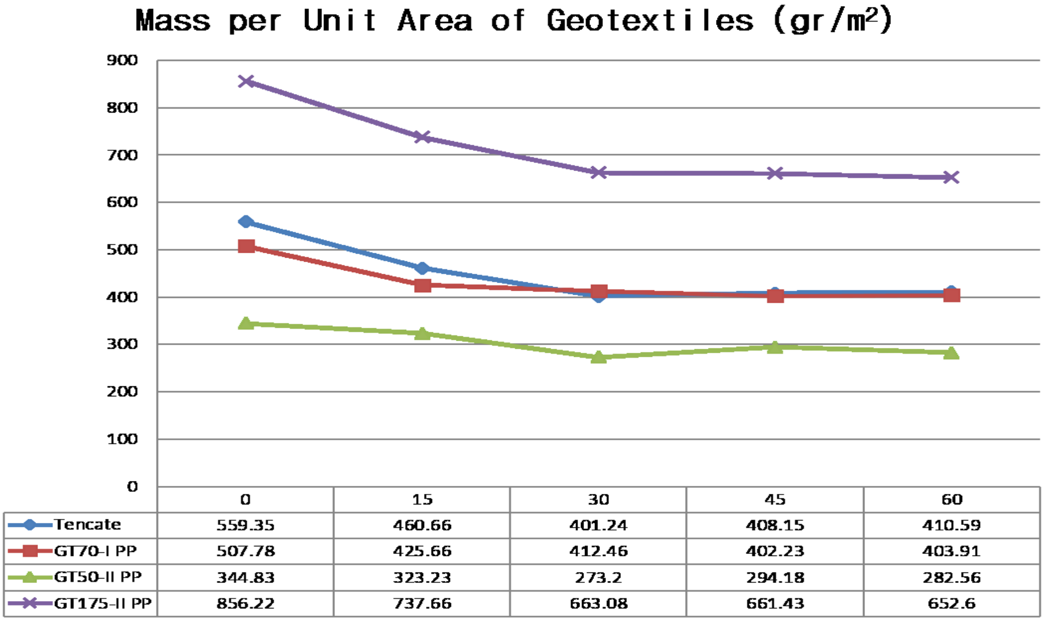


Figure 8.- Load-displacement curves a) ACETEX GT70, b) ACETEX GT50, c) ACETEX GT175.

Weathering exposure test.

Artificial weathering exposure was carried out for the three textiles in a chamber model QUV/SE at 130 Volts, 60 Hz and 1500 watts. Environmental artificial conditions were established according to the Yucatan Peninsula (Mexico) climate in cycles of condensation for 4 hours and 4 hours of radiation during 24 hours. They were mechanically tested after 0, 15, 30, 45 and 60 days in artificial weather conditions. The results showed that mechanical properties suffer a decrement bye the effect of UV light on polypropylene behaving more as a brittle polymer. In a period of 15 days, textiles exhibited a slightly augmentation in the elastic modulus value which is possibly originated by a crosslinking of the polypropylene. At longer periods of permanence, 30, 45 and 60 days mechanical parameters value present a diminishing with a consequent detriment in textile mechanical behavior. Figure 9 shows the effect of artificial weathering on the mass per unit area of the textiles. It is possible to notice a loss of mass after 30 day of exposure and then the materials seems to be stable. During the firsts days, volatile substances such as oils, lubricants and plasticizers are lost by the effect of intense exposure.



	0	15	30	45	60
Tencate	559.35	460.66	401.24	408.15	410.59
GT70-I PP	507.78	425.66	412.46	402.23	403.91
GT50-II PP	344.83	323.23	273.2	294.18	282.56
GT175-II PP	856.22	737.66	663.08	661.43	652.6

Figure 9.- Mass per unit area of textiles evaluated.

Conclusions

The early geotextile containers consisted predominantly of tubes of varying length and circumference manufactured predominantly from woven geotextiles (depending on the manufacturer). As a result, the technology until recently has relied on manufacturers' design suggestions based on monitoring of actual structures. Nowadays it is fundamental to take in account the architecture/geometry of the textiles when used in a specific application in order to enhance the performance and extend the service life of geotextiles. Textiles fiber architecture/geometry is very important to consider an application since it has a great influence in mechanical properties when considering the external stress applied. Geotubes used in Yucatan Coast demonstrated great applicability in recuperating eroded zones of the beach. It was noticed a uniform sand recovery along the geotube length. To be employed as geotubes, it is important that the strength in the transverse direction is higher. All the textiles studied in this work achieved excellent mechanical properties at 90^o (transverse). Threads and filament are arranged in a design to confer high strength in the desired direction. SEM analysis identified better fiber proportion in transverse direction augmenting the resistance. On the other hand mechanical tests showed textile geometry limitations and advantages in relation to the fibers orientation while in loading.

This is significant information to understand failure generation, propagation and development in the textiles. The effect of artificial environmental photodegradation and humidity affected significantly the mechanical behavior of textiles by gradually diminishing its properties. The damage to geosynthetics from UV exposure can be evidenced through changes in both the physical appearance and material mechanical performance. Some of the most easily observed changes are partial strength loss and loss in material density over time (Mass per unit area). The UV spectrum wavelength between 300 nm and 400 nm appear to be the most aggressive in damaging geosynthetic polymers, which occurs on a molecular structure level. Finally There are a number of factors that will help to determine the durability of a geotextile; the physical structure of the fabric, the nature of the polymer used, the quality and consistency of the manufacturing process, the physical and chemical environment in which the product is placed, the condition in which the product is stored and installed and the different loads that are supported by the geotextile

Acknowledgements

The authors are grateful to the Mexican Council for Science and Technology (CONACYT) for the provision of grant 60204/ CM0042.

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