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Recycled Polyethylene Terephthalate (Pet) As A Connector For Guadua Angustifolia Kunth Joints For Non-Structural Architectural Projects

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Abstract

This project consists of making T-connections from Kunth guadua angustifolia joints, focusing the research on determining their behavior under tensile stresses, changing the injection with mortar as proposed by NSR-10-chapter G-12, for a mixture of RPET (recycled polyethylene terephthalate) and PS (polystyrene) plastic material. This study is proposed to the extent that guadua as an engineering material is used in different types of construction for homes, bridges, support structures, among others. However, in Colombia the available research and information about the admissible tensile strength offered by this element for structural purposes can be considered deficient compared to the benefits offered by said material. Therefore, an investigation is developed with a quantitative approach of an experimental type, in which a dosage of model mixtures for the injection polymeric matrix was carried out; specimens from the department of Norte de Santander were taken; and the tensile stress tests were carried out on the samples, for which acting tensile strengths (ft) between 1.74 MPa and 3.20 MPa were reached, which compared to the modified allowable tensile stress (F't) that under coefficients of Modification of load duration and temperature yielded a value of 16.20 MPa; which indicates a positive result given that the criterion that ft ≤ F't set forth in Regulation NSR-10, chapter G-12 Structures in Guadua is met.

Keywords: Bamboo Guadua angustifolia Kunth; polymeric compounds; tensile strength.

1. Introduction

The use of guadua angustifolia, native to Colombia, has been characterized by its extraordinary physical-mechanical characteristics, its resistance to tension, compression, and added to the great flexibility it presents, make it a particularly interesting material for bioconstruction, being also catalogued as vegetable steel. In the specific case of the joints in this material, the NSR-10 regulation in its chapter G.12 - Guadua structures - specifies that it is necessary to fill the joints of the connection with a cement mortar mixture, but, exploring new possibilities, the research proposed the injection of plastic materials as alternative elements to replace the mortar, evaluating its admissible tensile strength.

To this extent, the reuse of plastic waste such as RPET and PS plays an important role, since within a sustainable approach, it seeks to generate a greater use of these wastes, since the amount of material that ends up in a landfill or dump is considerable compared to the amount that is recycled.

When talking about the dynamics of plastic recycling in the world, there are many countries that have advanced in this field, achieving the recovery and reuse for the production of new products. According to reports from the recycling industries, the countries that lead these processes are Japan, Switzerland, Germany, the United States, Mexico, Argentina and Brazil, improving over time the processes of collection, use and innovation in new technologies for recycling (Ortega Leyva, 2011).

urrently, plastic consumption in Colombia is 24 kg per person, which generates a volume of plastic waste of approximately 1,250,000 tons (Greenpeace, 2018). The country stops receiving around 2 billion pesos for not recycling plastic waste, a figure given by Juan Gutiérrez president of EkoRed; however, work has been ongoing on its utilization (Pastori, 2019).

On the other hand, on the subject of guadua, in Colombia there are about 55,000 hectares of guadua crops, which currently stands out not only environmentally, but is recognized as a sustainable alternative in areas such as construction, fiber production, among others. Jorge Montoya, president of Fedeguadua assures that 95 to 97% of the guadua crops in Colombia "nobody has planted them, they are natural, do not require maintenance and have grown due to soil and climate characteristics of the regions". (Faruk Simmonds, 2018). In the country, the departments with the greatest variety of bamboo forests are Norte de Santander, Cundinamarca, Cauca, Valle del Cauca, Antioquia, Huila, Nariño and Quindío. (Espinosa Pérez, 2004).

In 2004, Takeuchi (Takeuchi, 2004), after tests and analysis of Guadua angustifolia Kunth, showed its good structural qualities, based on its strong longitudinal fibers, large size, with heights up to 30 m and diameters up to 22 cm; strength/weight ratio with estimates of compressive strength ranging between 350 kg/cm2 and 500 kg/cm2, and great ductility.

Years later, due to the importance of guadua in the country, and thanks to the knowledge of its physical and mechanical properties and the solution proposed by Simón Vélez, who filled the canutos with mortar and used nuts and washers, significant advances were made in the material in question.

In the project under the name Determination of the tensile strength capacity in the joints of structures where the main resistant element is bamboo guadua (angustifolia Kunth), using high strength polypropylene (PPR) as filler material, Vargas and Niño (Vargas Barrera & Niño Fonseca, 2016), tested specimens with 3/8" reinforcing steel that when subjected to tension with said filler in the cannules reached an average tensile stress perpendicular to the fibers of 1.37 MPa.

On the other hand, in the monograph entitled Determinar la capacidad de fuerza a tensión en los entrenudos de estructuras en guadua angustifolia Kunth, utilizando polipropileno de alta resistencia (PP) como material de relleno para conexiones con bolno, (González Bonilla & Villamarín González, 2017), González and Bonilla in the tests applied to the specimens, obtained that the tensile stress for connections in rod No.3 was 5477 N and 7279 N for connections in No.4 rod, values lower than what is exposed in NSR10 chap. G-12. The considerable failures occurred in the rebar initially, then in the guadua, and finally the backfill did not present any visible failure. The researchers concluded that the filler used did not show adhesion with the guadua, nor with the rod; thus, the filler did not originate an important contribution to the connection, causing the rod to generate greater stress on it.

Understanding within a general context the use of Guadua angustifolia, and the plastic industry and recycling, important aspects in the development of this research; in particular, it is highlighted that for the execution of the project the Guadua angustifolia Kunth culms were obtained from the department of Norte de Santander, from which the orthogonal specimens were elaborated and subjected to the parallel tension test to the fibers, evaluating their behavior and performance.

2. Methodology

The objective of this research is to determine the tensile strength of guadua joints with injection of polymeric compounds as mortar substitutes. For the development of this research, an experimental methodology with a quantitative approach was used, where the study variables were the variability of the filler (plastic materials and mortar) of the joints, and the admissible tensile strength obtained.

2.1 Research Stages

2.1.1 Design of the polymeric compound for the injection of the guadua cannots

Since there is no standard or guide to define a mixture design with plastic materials, a model dosage has been experimentally taken, in order to look for an adequate design that guarantees an optimum tensile strength in the joints. In this section, it is important to highlight that the dosage worked in the project was taken from previous research carried out by students of the University with the support of Ms. Haidee Yulady Jaramillo. Haidee Yulady Jaramillo, who provided this information.

Table 1 shows the dosage in detail, specifying the quantities of plastic materials - recycled polyethylene terephthalate (RPET) and polystyrene (PS) - as well as the amount of styrene (diluting agent), resin (binding agent) and peroxide MEK (accelerating/hardening agent).

Table 1. Model dosage to be used in guadua joints

Materials	RPET + PS	Resin	Styrene	MEK peroxide
Units	grams (gr)	grams (gr)	grams (gr)	grams (gr)
Dosage model	730	1000	100	10

2.1.2 Elaboration of the guadua connections and injection of the corresponding filler material

For the process of making the guadua connections, the specimens were initially selected; then, as indicated in NTC 5407 "Unions of structures with Guadua angustifolia Kunth", a special fishmouth type cut was made for the coupling between the elements for the formation of the orthogonal joints; For the reinforcement of the same, threaded rod number 4 was used under a joint system between the rod, galvanized pipe, nuts and washers, making the corresponding total assembly; and finally, the injection of polymeric compounds was applied in the joint.

2.1.3 Tensile strength tests

After the curing process, and after 15 days had elapsed, tests were carried out to determine the tensile strength according to NTC 5525 "Determination of the physical and mechanical properties of bamboo culms. Test methods".

3. Results and discussion

Once the tension tests were performed, the specimens showed failures such as detachment between the vertical and horizontal elements (1), superficial cracking parallel to the fiber in the vertical element (2), and crushing in the lower zone where the longitudinal reinforcement was located (3), clearly identified in Figure 2.

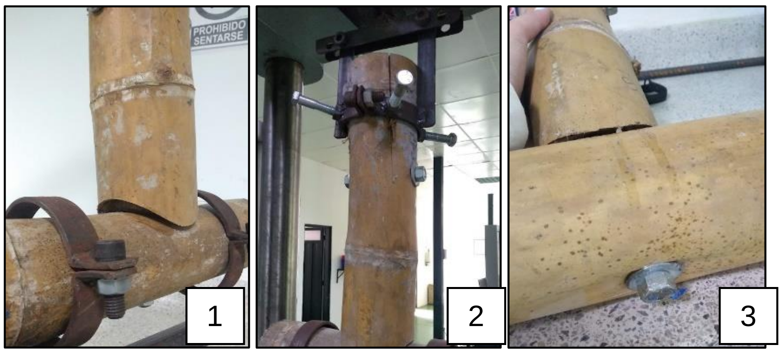

Figure 1. Failures evidenced in test specimens

Similarly, Figure 2 shows a superposition of the graphs given after the force vs. displacement tests of the rule of the plastic-filled joints, thus visualizing their behavior. The loads were chosen at the moment before observing noticeable slope changes, which indicated that the joint had started to fail.

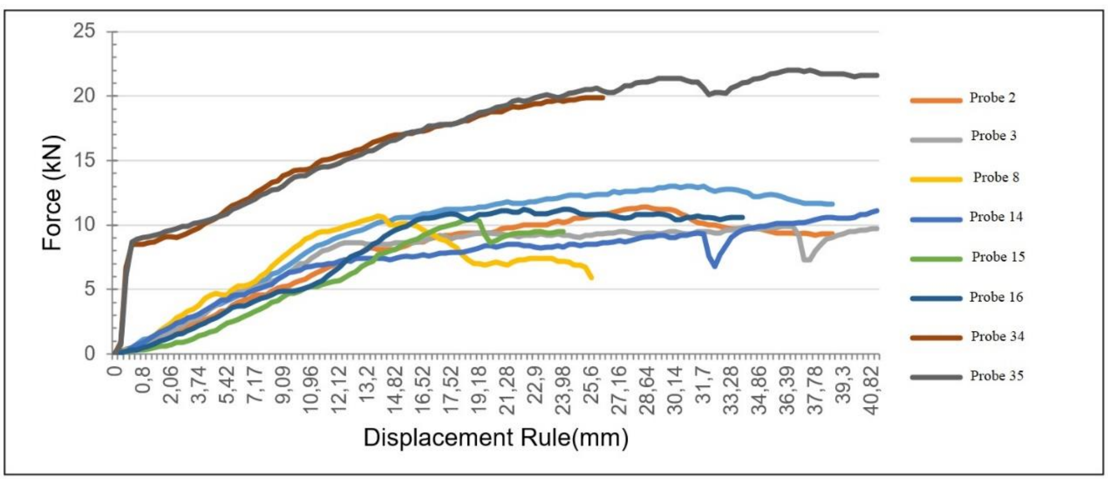

Figure 2. Superimposition of force vs. displacement plots of the tension test ruler.

3.1 Modified allowable tensile stress (F't)

After performing the tests, the allowable tensile stresses were determined. First, the modified allowable tensile stress was calculated according to formula G.12.7-3 of NSR-10 Chap. G-12, which, under the permanent tensile load duration coefficients with a value of 0.90, and a temperature modification coefficient (T ≤ 37°C) at tension of 1.0, resulted in a stress of 16.20 MPa.

3.2 Acting tensile stress (ft).

Acting tensile stresses were calculated for the joints filled with plastic materials and for the joints filled with mortar in order to establish a comparison between the two. Tables 2 and 3 show the results of these calculations, taking into account equations G.12.8-1 and G.12.9-1 of NSR-10, chapter G-12 Guadua Structures.

Table 2. Calculation of the acting tensile stress in polymer matrix connections

N° of Probeta	N° of Reinforcement	Diameter (mm)	Thickness (mm)	Net area (mm^2)	Force T (N)	Acting tensile stress f_t (MPa)
1	4	100,00	14,00	3782,48	10200	2,697
2	4	100,40	15,22	4072,89	8200	2,013
3	4	99,87	17,00	4425,84	8600	1,943
8	4	95,50	17,94	4371,29	10700	2,448
14	4	100,20	15,59	4143,98	7200	1,737
15	4	101,70	11,35	3221,62	10300	3,197
16	4	99,22	18,78	4745,89	10900	2,297
34	4	91,00	16,85	3925,19	8500	2,165
35	4	92,48	15,81	3808,09	8700	2,285

Table 3. Calculation of the acting tensile stress in mortar-filled joints.

N° of Probeta	N° of Reinforcement	Diameter (mm)	Thickness (mm)	Net area (mm^2)	Force T (N)	Acting tensile stress f_t (MPa)f_t (MPa)
6	4	99,70	18,50	4719,30	9000	1,907
11	4	91,86	13,29	3280,44	8100	2,469
12	4	89,53	13,99	3320,05	9000	2,711
13	4	99,72	19,02	4822,07	8900	1,846
21	4	97,12	13,48	3542,04	11800	3,331
22	4	97,50	15,11	3911,01	9900	2,531
23	4	90,57	12,19	3001,64	9100	3,032
24	4	91,92	13,40	3305,48	9100	2,753
25	4	100,85	12,91	3566,67	9800	2,748

From the data presented in Table 2, for joints filled with plastic materials, a load variation between 7200 - 10900 N is established, with a minimum tensile stress of 1.74MPa and a maximum of 3.20MPa; on the other hand, from Table 3, for joints filled with mortar, a load variation between 8100 - 11800 N is observed, with a minimum tensile stress of 1.85MPa and a maximum of 3.33MPa.

Comparing the modified allowable tensile stress with the acting stresses in both types of joints, the criterion according to NSR-10, formula G.12.9-1 that ft ≤ F't regardless of the variability of the backfill is met, to this extent, it is important to clarify that it is the decision of the structural engineer, taking into account the loads, use and environmental conditions of the project, to evaluate this factor according to the resistance specified in the designs.

On the other hand, it is highlighted that the bonding with injection of polymeric compounds presents similar values to the bonding with mortar filling, so that the use of alternative strategic elements such as the use of plastic materials can become viable as mortar substitutes.

4. Conclusions

A model dosage was experimentally carried out, specifying the amounts of RPET plastic plus PS, resin, styrene and peroxide MEK, optimizing the alternative filler used in the joints of guadua structures, also contributing to the reuse of plastic waste and therefore contributing to the care of the environment.

From the results it was observed that the connections with mortar filler were the ones that yielded the highest admissible resistance to tensile stresses; however, it is important to point out that the connections with plastic filler obtained similar resistances to these, so they can become optimal from the use of such alternative materials, also seeking the promotion of bioconstruction.

Finally, a comparison was made between the specimens according to their filler variability, for which it was obtained that the joints injected with plastic had an average admissible stress at tension of 2.31 MPa, but not higher than the joints with mortar that showed average resistances of 2.59 MPa, which indicates that the substitution of mortar by plastic elements yields very close resistances at tension, thus innovating with the use of these materials, and at the same time generating an important contribution and new knowledge regarding the connections in guadua.

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