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SOCIAL AND ENVIRONMENTAL IMPACT OF THE USE OF POLYETHYLENE TEREPTHALATE (PET) WASTE IN COLOMBIA USE OF RECYCLED PET AS AN ALTERNATIVE MATERIAL IN ROAD INFRASTRUCTURE

Ender J. Ordúz D.
Facultad de ingeniería. Programa de Ingeniería Civil
Universidad Católica de Colombia

Olga L. Atencia
Facultad de ingeniería. Programa de Ingeniería Civil
Universidad Católica de Colombia

Nancy C. Amaya C.
Facultad de ingeniería. Programa de Ingeniería Civil
Universidad Católica de Colombia

Juan S. Gilart P.
Facultad de ingeniería. Programa de Ingeniería Civil
Universidad Católica de Colombia

Abstract: The use of polymers for industrial use has proliferated in different contextsdue to its high consumption in multiple services for society. Mass production schemes for ítems made from Polyethylene terephthalate (PET) have considerably increased the amount of waste that must be disposed of. **[1]**. The low rates of recycled material generate a problem that many countries currently face**[2]**, particularlyifLatin American countries are analyzed, where the lowest percentages of reuse of polyethylene terephthalate are found**[3]**[**4**].Due to the above, vulnerability conditions can be identified around the final disposal of this type of waste and the repercussions from the environmental and social point of view that the disposal of PET waste has in a conventional way.**[5]**. In Colombia, recycling companies buy PET waste that can be recycled, such as bottles and caps, at convenient costs; Given the conditions under which this recycling process is carried out and its lack of regulation, this practice constitutes a high-value economic activity in the lowest socio economic levels.**[6]**. Among the technical proposals to review this process, there are alternative uses of these materials with their transformation into new materials, which helps to mitigate the environmental impact, considering the time required for the degradation of this type of waste. **[7]** **[8]**. This study seeks to address the issue of PET recycling from the technical context of engineering, in addition to identifying some actors that make up the Colombian social fabric linked to the issue, which isintegrated with a technical proposal for a new material that allows an impact social, political and environmental regarding its use. Likewise, technical elements and characteristics of the material are evaluated, as well as the environmental consequences derived from its use. For this, PET is proposed as a fundamental component for the development of a pavement structure that favors the social, environmental and technical environment in terms of functionality and service.**[9]**. In this sense, a numerical simulation model was developed using the finite element methodology, with the aim of carrying out a preliminary theoretical evaluation of the feasibility of using PET as a material for the construction of alternative pavements. In the same way, it was possible to identify that the structure subjected to light traffic loads may be able to support the applied stresses without reaching a permanent deformation according to the simulation models developed for different types of structures.**[10]**[**11**].It is concluded that in preliminary conditions, the PET presents characteristics that can guarantee the necessary resistance and functionality so that the simulated structures can be used as pavements for light traffic; In social and environmental terms, this guides the search for strategies to mitigate the impact that it generates on the environment and new possibilities for communities to generate business ideas with this type of waste.**[12]**.

Keywords: PET, recycling, sustainable material, modified pavements, uses of plastic.

INTRODUCTION

Polyethylene terephthalate (PET) is characterized by being resistant to corrosion, economical, lightweight, impermeable and easy to reuse compared to other materials; In addition, from an ecological point of view, PET takes between 100 and 1,000 years to degrade under natural conditions, which leads to paying special attention to the accumulation of waste that occurs in different parts of the world. Its high production and industrial use is due to its properties of transparency and resistance to chemical agents.

Recyclingis a dynamizer of employment and development, especially in communities that are in vulnerable conditions, from this

idea and considering that polyethylene terephthalate can be used from the technical context of engineering, and meshing this use with some of the needs that The Colombian social fabric linked to the subject is identified, social and environmental needs are integrated, a proposal for a new material that allows a social, political and environmental impact regarding its use in a technical way. For this, the use of PET is proposed as a fundamental component in the construction of pavement structures that favor the social, environmental and technical environment in terms of functionality and durability. In Colombia, the PET recycling activity has contributed not only to the use of this waste, seeking to reduce the waste that is disposed of in a sanitary landfill, but also contributes to the generation of employment for vulnerable populations, as is the case of trade recyclers, where through the decree 596 of April 11, 2016, trade recyclers from all municipalities of the country are allowed to formalize themselves to improve their quality of life and become recognized organizations, as well as that may have access to tariff resources.

METHODOLOGY

The development of a tread pattern for pavement is presented, as a different alternative to the conventional materials mostly used as asphalt or concrete. The Purpose is to mitigate the pollution produced by the waste generated, as well as the product of the use of conventional materials, this by using Polyethylene Terephthalate in a road structure with double benefit from the ecological point of view. For the above, the mechanical behavior of the proposed structure in reused PET is evaluated, subjected to type A traffic loads or light traffic. Some mechanical properties were evaluated with respect to the deformation presented in the wearing course of the loaded structure through the use of software using the finite element method, in order to determine the deformations resulting from the application of loads.

The simulation was carried out using the SAP 2000 software. The geometry of the proposed structure is three-dimensional with a length of 3 meters and a width of 3 meters; the dimensions comply with the parameters and specifications proposed by INVIAS for vehicular lane widths. The height of the elements of 0.5 meters resembling thickness currently used in typical pavement structures. The thicknesses of the elements are variable, thus leaving hollows paces that could be used in other functions (See Figure1). The structure is proposed in total polyethylene terephthalate (PET), on which a point load of 1,000 kilograms of force has been placed.

The properties defined for the numerical simulation of the structure correspond to material conditions that, according to the general conditions, are shown in tables of typical ranges for this material and are shown in table 1. These values are taken as a starting point to determine the technical possibility of using this material in the elaboration of the paving elements that were modeled.

In order to identify capacity conditions of the structure against the possibility of using PET, variable thicknesses of the elements that make up the proposed structure model were worked on, defined between 6.0 and 14.0 centimeters, with a variation of 2 centimeters. The general model of the proposed structure is modeled symmetrically to simulate homogeneity of the material, for which equal thicknesses of each of the elements (horizontal and vertical) were determined, so as to guarantee the symmetry conditions in the simulation. The load was applied in one of the nodes proposed in the division of the finite elements that were determined according to the general geometry of the model as an initial approximation to the real

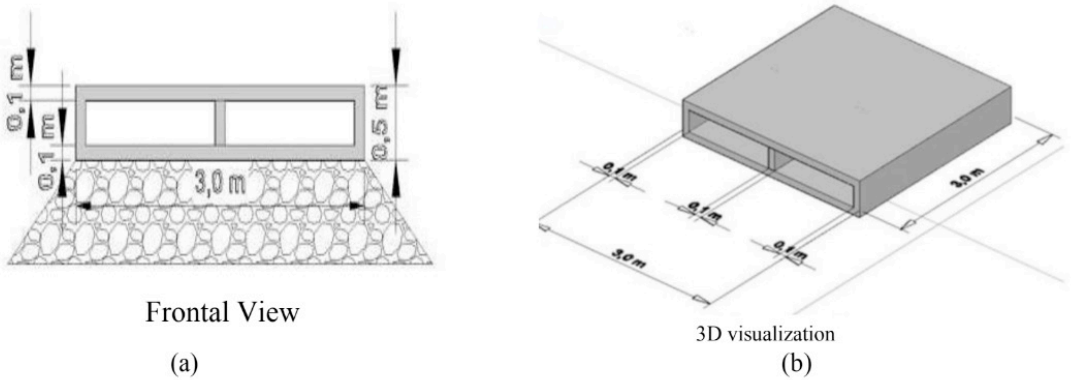

Figure1.Structuremodel a). Frontal section, b) Isometric scheme.

Source: Authors.

Characteristic	Defined value
Unit weight	1390kgf/m^3
Modulus of Elasticity	3,7x10^{8}kgf/m^2
Poisson's ratio	0,37
Coefficient of termal expansion	8x10^5°C^{-1}
Stiffness modulus	1,35x10^{8}kgf/m^2

Table 1. Main PET characteristics.

Source: Authors.

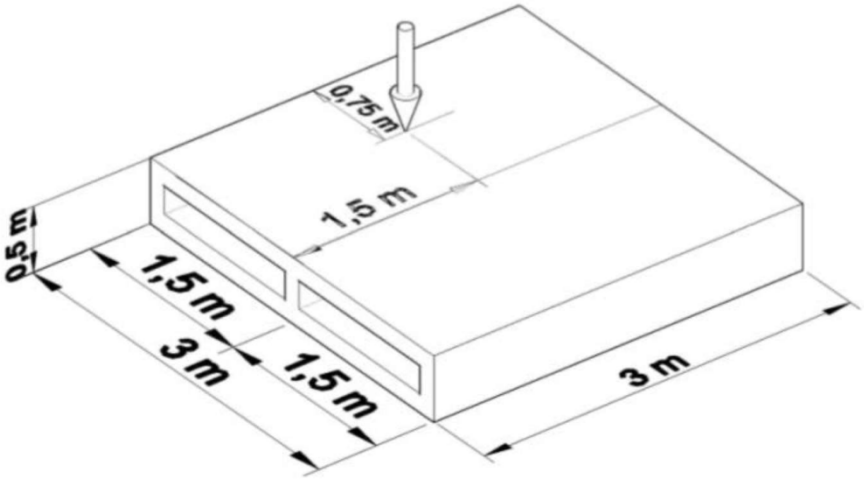

Figure2.Application model of instantaneous traffic loads.

Source: Authors.

conditions of the structure. Figure 2 shows the point of application of the load in the center of the span between the longitudinal supports and between the edges, directly affecting the element, and causing a critical focus that shows the greatest displacements, Analyzed later.

RESULTS AND ANALYSIS

According to the investigations in National entities, it was possible to identify that in Colombia only 17% of the 11.6 million tons per year is recycled, that is why one of the commitments acquired when joining the OECD (Organization for Cooperation and Economic Development) in the environmental framework in terms of waste management, is to comply with a plan that guarantees comprehensive management of container and packaging waste to prevent and reduce the impact on the environment. State documents such as CONPES 3874 of 2016 (National Council for Economic and Social Policy), through which the country adopted the National Policy for Integral Management of Solid Waste by 2030, with the objective of implementing the integral management of solid waste as national policy of social, economic, environmental and health interest, to contribute to the promotion of the circular economy and sustainable development.

This research is shown as a potential opportunity to use the residues from the analysis as raw material for other activities, products or services. It is important to carry out the classification at the source to prevent them from being mixed or contaminated with other waste, which demands variations in the regulations on the subject. In Colombia, recycling-oriented programs have been developed for companies, the residential and institutional sectors, to classify waste according to its composition, thus seeking to reduce, separate waste in order to take advantage of it and dispose of it separately in marked and colored containers, with the purpose that the inhabitants make a conscious and responsible consumption, implement the separation at the source, favoring the work of recyclers, through the proper disposal of elements such as plastic, paper, glass, cardboard, including special waste and debris, that can be reused, avoiding that much waste is disposed of in the sanitary landfill (See Figure 3)[5].

Currently in Colombia more than 2800 people benefit from the collection of bottles to the manufacture of the fiber [6]. This is one of the most common activities in the use of solid waste that is collected informally by workers who dedícate their lives to the waste recycling activity. The role played by the population of associated recyclers in the recycling activity is important, today many cities have become involved with the issue of solid waste, as detailed in Figure 4, making these a way of creating a company in an organized manner reaching the different generation points, making these a source of employment generation.

This aspect related to the generation of solid waste leads to generate adverse environmental impacts associated with soil alteration. Plastic materials take a long time to degrade, which causes the environment to not develop naturally. There is also contamination of watersources; studies suggest that *by the year 2050 it is estimated that the oceans will have more plastics than fish* [12]; bad odors are generated and with it air pollution that affects the human health of populations near the sanitary landfills. In Colombia, the majority of sanitary landfills have already fulfilled their useful life, and there are investigations that estimate that"*by the year 2030 there would be health emergencies in most of the country's cities*[12].

According to the findings, Colombia needs to improve waste management, encourage

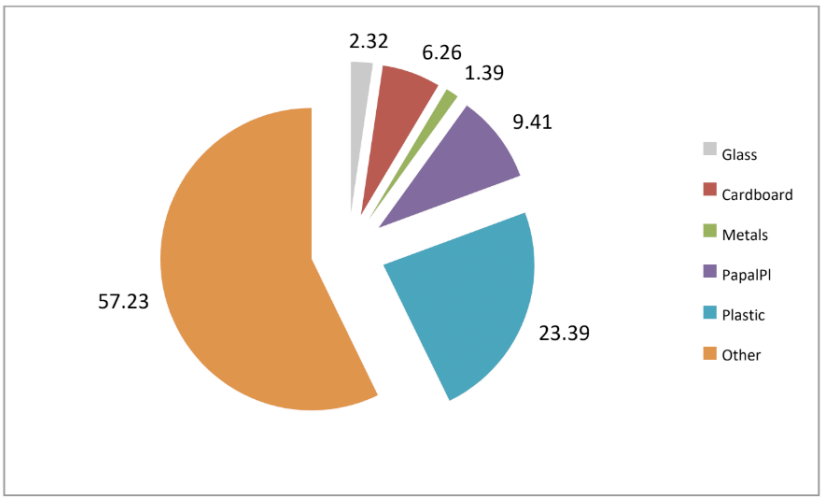

Figure 3. Percentage of waste arriving daily at the Doña Juana landfill Year 2016.

Source: CGR. Modified by the authors.

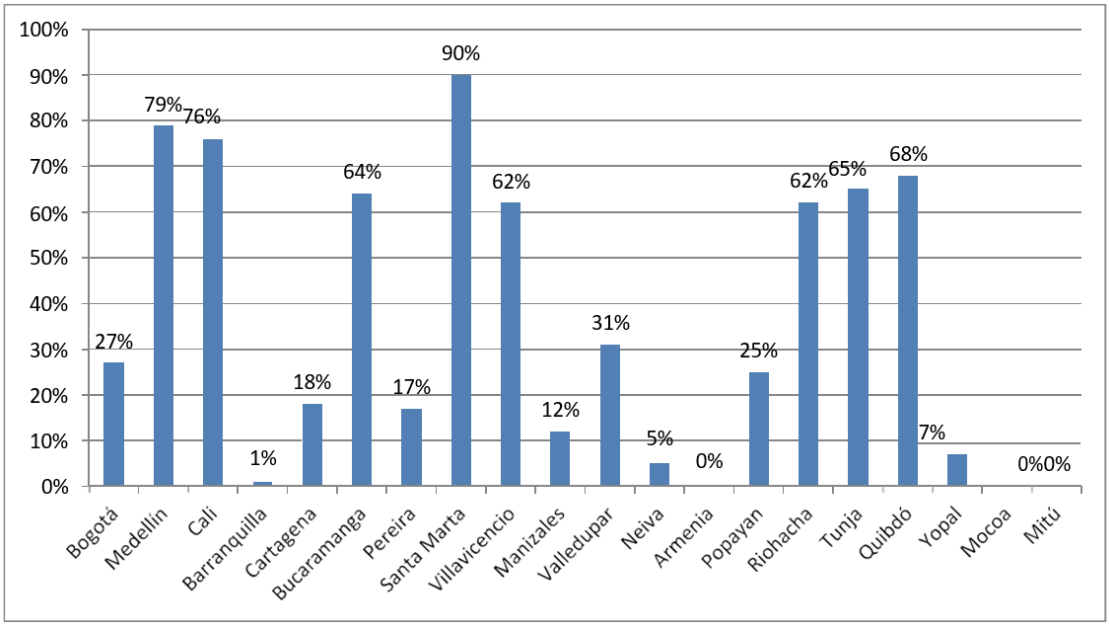

Figure 4. Population of associated recyclers.

Source: CGR. Modified by the authors

the circular economy through a model that seeks to keep the value of products, materials, and resources in the economy for as long as possible, and reduce the generation of waste by reincorporating it into the productive economic cycle[13].

Regarding PET Plastic (Polyethylene Terephthalate), as shown in figure 5, it is one of the plastics that is being disposed of in the largest proportion in the sanitary landfill of the country's capital (Bogotá, Doña Juana landfill) and in general in Colombia. According to National measurements, for every ten PET bottles that go on the market, in a sanitary landfill.[14].

The recovery of PET consists of making an adequate separation and reception, selection of the material, elimination of contaminants, tearing and/or cutting, grinding, agglutinating and pelletizing the ground material so that it is prepared for the transformation process into new materials. [fifteen]. The previously mentioned process makes the constitution of the proposed model in reused polyethylene terephthalate possible. In the same way, once the elements have been made according to the conditions shown in Table 1 from the mechanical point of view, it can be assumed that this material has the appropriate conditions for the development of paving elements of this style. Figure 6 shows the vertical displacements of the Rolling layer, measured in the direction parallel to the direction of traffic of the Shell-type element. The smallest vertical displacement was obtained for a thickness of 14 cm, product of a better defined distribution of stresses along the element, given the larger cross-sectional area of the structure, which translates into less stress in relation to the application. of the same magnitude of charge. The supports in each one of the nodes produce a lower vertical displacement in the lowerplate, due to the restriction that it presents in comparison with the upper plate that is subjected to load, the own weight of the element is analyzed in the general element.

Figure 7 presents the vertical displacements of the element measured perpendicular to the direction of traffic in the Analyzed structure. It is observed that the greatest displacement is reflected at the point where the load isapplied, generating a smaller displacement for the thickness of 14 centimeters in comparison with the other thicknesses and showing, in turn, in 1.5 meters, the intermediate support of the Displacements, product of the own weight of the element, generates a point of distinction in terms of the efforts supported by both spans, presenting in the Right span a tendency to zero in each of the models.

The vertical displacements for the 14.0 centimeter thickness are reduced by up to 90.4% compared to the relevant results for a 6.0 centimeter thickness. The use of material with a thickness of 10.0 centimeters reveals vertical displacements for the load of 1,000 kilograms of less than 1.0 millimeters, which reflects a behavior that is perceived as adequate to give way to new, more detailed simulation models. and with characteristics of the materials analyzed in the laboratories, seeking to guarantee conditions that better approximate the behavior that the material may have with load tests and test sections in future research.

The use of PET in conditions of unused material, can be of great mechanical utility, but they do not allow collaborating with the mitigation of the environmental problems generated by the considerable consumption of this material, so to use recycled PET, analysis must be carried out through Laboratory tests that determine the characteristics of the material that govern its mechanical behavior and with it the proposed structure, with the aim of contrasting the results obtained through simulation in software that was

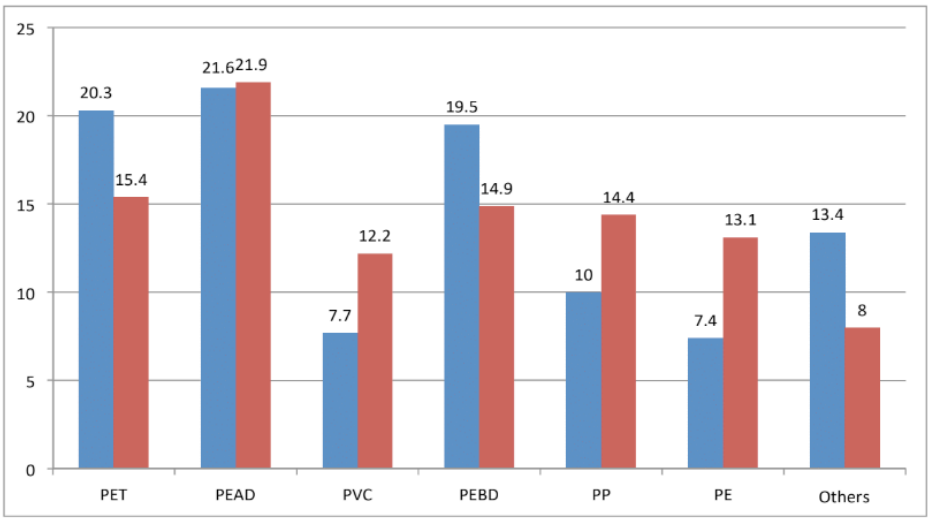

Figure 5. Percentage by type of plastics between 2015 and 2016.

Source: CGR Modified by the authors

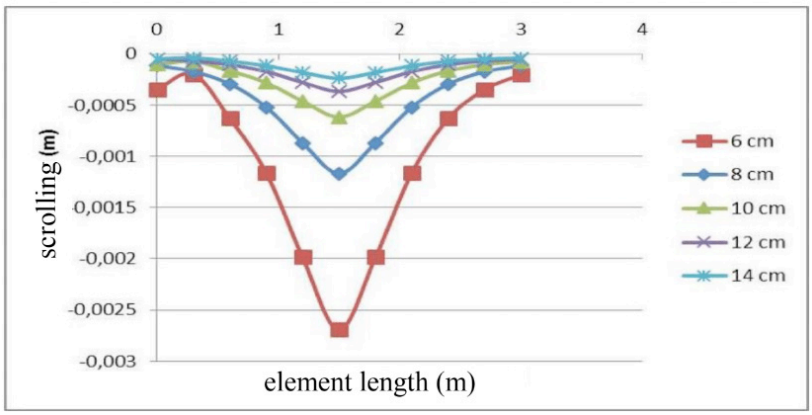

Figure 6. Vertical displacements at the load Application point for different thicknesses.

Source: Authors.

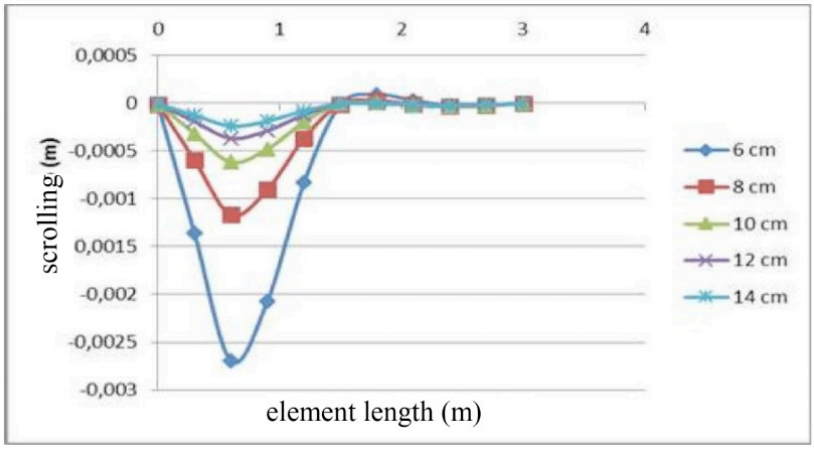

Figure 7. Transversal displacements at the load applicationpoint.

Source: Authors.

shown in this article and the projection of this material as posible work material in the field of environmental and social economics in countries with highrates of economic vulnerability of the inhabitants.

CONCLUSIONS

Usable solid waste, such as PET, is disposed of in sanitary landfills in the best of cases, or in natural sources and environments that harm the quality of life of the inhabitants and ecosystems. These materials can be recycled, reused or transformed to give them uses as useful materials in Engineering projects, whose alternative contributes to the reduction of green house gases.

The recycling activity contributes to the generation of employment for vulnerable populations. Trade recyclers, through thre decree 596, of April 11, 2016, are allowed to formalize themselves in all the municipalities of the country, so that they improve their quality of life and become recognized organizations. These new legislations guarantee viable opportunities in the collection and commercialization of solid waste that can be reused, as is the case of PET.

In the research, the aim is to contribute through Sustainable road projects. For 1 km of track according to the proposed model with a thickness of 10.0 cm, approximately 1,668 tons of PET are required, in otherwords, 116,760,000 one-liter PET bottles can be used for the construction of one kilometer of street in this material. In accordance with the above and considering the data from environmental studies, evidencing that 15.4% of the waste arrives in PET per day in Bogotá, this represents around 995.9 tons per day. This relationship suggests that in less than approximately 2 days with the use of all the PET that reaches the landfill, 2.0 km of street can be paved in a structure like the one analyzed in the investigation.

The results obtained by means of the SAP2000 software in the modeling and simulation of the structure in recycled polyethylene that allow us to affirm that the vertical displacements are admissible in most cases of the location of the load. From the proposed models, it is found that the structure was simulated with a continuous subgrade support of excellent quality and that prevents displacements in the three axes of space, so that making the model closer is proposed for future research to simulate on a with typical soil conditions that allow settlement.

The loads contributed by the structure to the soil or to the structure that supports it must be evaluated, this allows determining the need for the base and sub-baselayers, or if, on the contrary, it can be applied directly on the subgrade, being this improved or not. This iswhy the Research project has a considerable scope because it has various factors that can be linked in the analysis for the development of this type of plastic structure, in addition to the fact that it can be achieved with or without intermediate support. In the same way, different geometries can be considered to identify the most favorable conditions for the development of this type of material.

Vulnerable communities may have a space for economic strengthening; work in recycling activities under current conditions does not have the best guarantees, but the development of projects of this type can demand high consumption and therefore the possibility for recycling workers to improve the market for this type of material and with it the growth of the productivity of a country in which the companies that develop this type of material as the suppliers of the raw material, which in this case are the recyclers.

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