Chapter 6

Waste and Recycled Textiles as Reinforcements of Building Materials

Patricia Peña Pichardo, Gonzalo Martínez-Barrera,
Miguel Martínez-López,
Fernando Ureña-Núñez and Liliana I. Ávila-Córdoba

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.70620

Abstract

Currently, the use of composite materials in the construction areas has had a great impact on the society; mainly, those related with sustainability and environment aspects. Daily proposals aimed at overcoming the properties of traditional materials that arise, which include emergent materials either from waste or recycled products. One of them is related to the textile materials, which include fibers such as wool, hemp, linen, and cotton. In the past decade, special attention has been focused on the used clothes, which represent a source of raw materials environmentally responsible and economically profitable. Textile materials are discarded daily around the world, representing approximately 1.5% of the generated waste. Blue jeans are the most used clothing in the world, and they are elaborated by one of the most commonly used natural textile fibers—cotton. Textile materials have been reused in different applications, for example, in the production of poor-quality wires, crushed to manufacture noise and temperature insulation materials, and as fillers or reinforcements of concrete. In this chapter, different topics are described that include: (a) environmental impact of textile waste—a result of massive consumption of clothing, (b) recycling and reuse of textile waste, and (c) waste and recycled textile materials used as building materials.

Keywords: recycling, waste, textiles, cotton, cellulose, composites, polymer concrete, gamma irradiation, mechanical properties

1. Introduction

As a consequence of the technology boom and global population growth, the environment is being seriously damaged by different types of waste. Large amounts of wastewater, polluting gases, and solid waste are being disposed of worldwide, which have degraded the ecosystem to an alarming extent. Concern about the environmental deterioration is leading science to design strategies to remedy the damages caused to some extent, which seek to generate in the population an ecological awareness, aimed at the reduction of waste, recycling of materials that can be reprocessed, and the reuse of objects or materials before proceeding to final disposal.

The use of waste materials or recycled materials for the creation of raw materials for the construction area is a topical issue, with a promising future and primarily aimed at environmental preservation. Concrete, wood, and steel have been the most used materials in the infrastructure of houses and buildings, but the high production costs of these are leading science to develop research aimed at developing composite materials that recycled materials, such as PET, polycarbonate, recycled tires, wood, textile fibers, etc. The use of plastics in the form of small particles to reinforce hydraulic concrete has been applied in several investigations, but the problem lies in the poor interface between the matrix and the reinforcement; which causes diminution of mechanical properties of the concrete, such as flexural and compressive strength.

The use of waste PET fibers, from bottles, as reinforcement in concrete has allowed improvement in mechanical properties. Other reinforcement materials in the processing of concrete are waste tyre particles, which contribute to diminution of the crack propagation effect and improvement of resistance to deformation of the concrete.

Some investigations are focused on the use of natural materials as reinforcements in Portland cement concrete. In special, natural fibers, such as jute, flax, coconut fiber, henequen, and cotton, as a reinforcement in building materials, which have great interest for their advantages when compared with synthetic materials, and one of their biggest benefits are the low environmental impact, low cost, and wide range of applications. Cellulose fibers mixed into the concrete improve the thermal and acoustic insulation.

In this regard, during the last decade, the construction industry is being innovated with a new material known as textile reinforced concrete (TRC): a combination of fine-grained concrete and multiaxially oriented textiles whose structural functionality, ease of production, applicability, and design are investigated [1], as a way to take advantage of the high amount of waste from the industry textile.

2. Environmental impact of textile wastes

At present, there is a growing need for textiles to make yarns, fabrics, and garments of different types, shapes, and colors. Demand increases with population and trends in international fashion being the reason why the rational exploitation of the necessary inputs for this purpose has become one of the main challenges for scientists and industrialists. Wastes from the production of textiles are undesirable but are inevitable byproducts in many manufacturing processes, which are often not given the recognition and economic value that they actually have [2].

In developed countries, each person produces on average 1.5–2 kg of solid waste per day and in Latin America 1 kg per day [3]. The urban waste percentages in Mexico are shown in **Figure 1**, in which textile wastes represent 1.2%, and this means 1100 tons are produced daily.

Actually, garments are discarded more quickly; which causes the industry to streamline its production and generate more textile waste. The production of textile fibers, both natural and synthetic, has been showing sustained growth, as a result of the increase in demand and population growth. The quantities of textile fibers used worldwide, between 1980 and 2000 are shown in **Figure 2**.

The different environmental aspects caused by the production, use, and disposal of garments are shown in **Table 1** [6]. In the textile production of garments, different impacts on health, land, water, and air are detected.

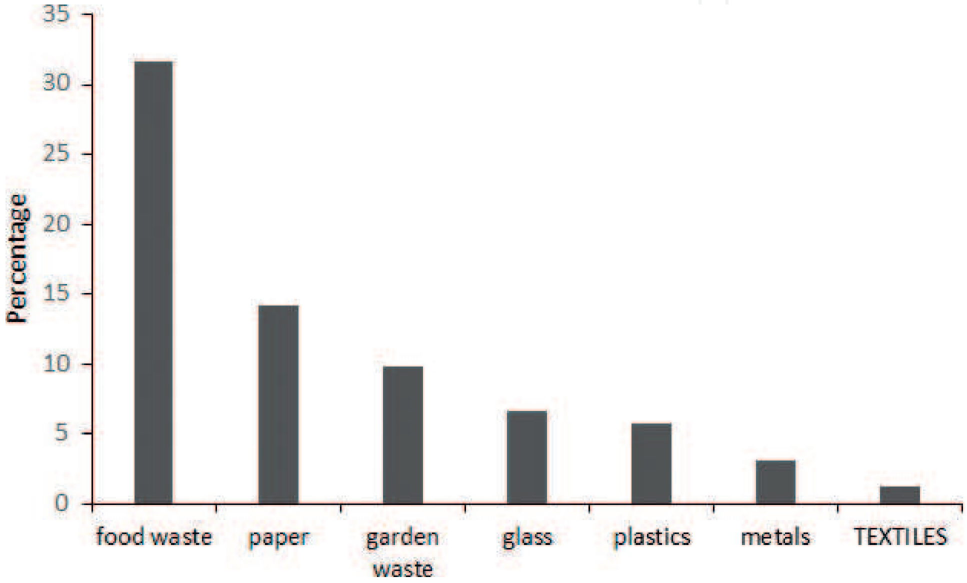

Figure 1. Solid urban waste in Mexico [4].

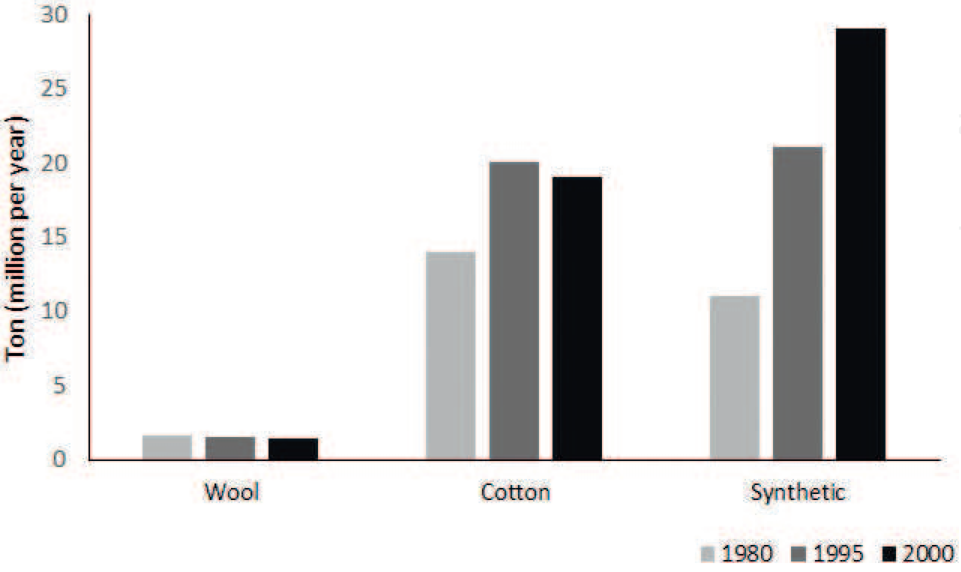

Figure 2. Worldwide production of textile fibers [5].

Fabric and cloth production		Impact		
Activity	**Environmental aspects**	**Health**	**Water**	**Air**
Ironing	Consumption of electricity and occupational diseases	X	X	X
Clothing sewing	Consumption of human energy, and textile and metal waste	X		
Cloth cut	Noise generation	X		X
Bleaching of tissues	Generation of liquid waste		X	
Cloth dyeing	Generation of liquid waste		X	
Cloth wash (Denim)	Water consumption		X	

Table 1. Environmental impacts generated by textiles (adapted from [6]).

Water contamination carried out through the dyeing of fabrics is produced by using synthetic dyes, which has become a common practice. Such toxic nature is a cause of concern for environmentalists [7]. It has a high content of sulfur, nitrates, acetic acid, soaps, enzymes, chromium compounds, and heavy metals such as copper, arsenic, lead, cadmium, mercury, nickel, and cobalt. Also used dyes are fixing agents that are based on formaldehyde, chlorinated stain removers, hydrocarbon softeners, and nonbiodegradable chemicals, which react with many disinfectants, especially chlorine, and form carcinogenic products.

In the research work carried out [8] was evaluated physicochemical parameters in waters coming from a textile industry, as well as the soil where they are arranged. The parameters such as pH, electrical conductivity, temperature, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), and total dissolved solids (TDS), as well as N, P, and K in soils were determined. The salinity and alkalinity of the soils changed; moreover, the food crops that were in these lands reported a very low yield and negative hygienic conditions.

The cotton cultivation requires large amounts of water. The amount of cotton fibers used for textiles is only one-third of the total production of raw cotton and the remainder consists of cotton seed (which are used for the extraction of oil) and weed which is used as food for livestock. The part of the fibers that does not have the necessary quality to enter into textile production processes is used for viscose raw material and cleaning cloths [9].

Requirements for the production of garments made from virgin materials were quantified [10]. They showed that for every kilogram of virgin cotton that is replaced by second-hand clothing, electric energy is saved. The reuse and recycling of used clothing reduces the environmental burden compared with the purchase of clothing obtained from virgin fibers. Rojas et al. [11] indicated the importance of minimizing waste produced in the textile industry.

The textile industry is one of the four most representative and polluting items in Latin America, because its processing employ a great amount of chemical compounds, water, and energy [11]. The indexes of pollutants from the cotton industry include yarns and cotton cloth (**Table 2**).

Types of pollution	Index
Air pollution	
Production of particles during the process	14 kg/ton cotton
Production of particles by incineration of waste	7.5 kg/ton residue
Production of SO_2 by incineration of waste	1.25 kg/ton residue
Production of nitrogen oxides by incineration of waste	1.0 kg/ton residue
Hydrocarbon production by incineration of waste	7.5 kg/ton residue
Water contamination	
Volume of wastewater	317 m^3/ton product
DBO5	155 kg/ton product
Suspended solids	70 kg/ton product
Total dissolved solids	205 kg/ton product
Solid waste	
Preparation of fibers and cotton thread	32 kg/ton product
Fiber fabric, thread, cloth	11 kg/ton product
Dyeing and finishing fabrics	7 kg/ton product
Dried fibers trapped in grids	0.8 kg/ton product
Natural fibers trapped in grids	2.8 kg/ton product
Residual sludge (not dehydrated or treated)	2300 kg/ton product

Table 2. Index of contamination for the cotton industry (Adapted from [11]).

The fact is undeniable that almost all human activities have an environmental impact; the textile industry is no exception, but as in many other productive processes, the population is increasingly acquiring an ecological awareness for recycling, reusing, and reducing (RRR).

At present, the consumption trend is due to the use of natural textile fibers, this as a response to the conservation of the environment, and that fashion is increasingly pronounced by comfortable, light, and friendly with the skin.

World cotton production in 2014 was 25.8 million tons and global production is expected to grow by 2.1% per year over the next 10 years. An important part of cotton produced worldwide is part of the textile fibers used for the production of Denim garments, which was created in 1873 by Jacob Davis, a friend of Levi Strauss, for the hard work of the mining time during the so-called gold rush in the USA. In the case of Mexico, 9000 million tons of Denim were produced in 2010. Jeans are the best-selling item in Mexico, representing 30% of the entire clothing market.

3. Recycling and reuse of textile waste

Textile waste is part of the solid waste that is generated by the population and also contains used clothing, footwear, curtains, sheets, etc. The theme of textile recycling should be taken as a means to obtain economic and environmental benefits for various reasons, as it contributes to the reduction of spaces required for landfills, reduces the need to produce virgin materials and reduces problems of water pollution. The textile recycling involves the reuse of used clothing, fibrous materials, and production losses of the manufacturing process of clothing.

Some products made from synthetic fibers do not decompose naturally, which causes soil and surface water contamination problems. Although cotton fibers decompose naturally, in doing so they produce methane, which contributes to the global warming.

Textile recycling strategies are based on the knowledge of their classification: (a) post-production materials, such as yarns, textiles, fibers, which come from the loss of the production process and (b) post-consumption materials, such as clothing, carpets, shoes, and furniture, which are discarded once its useful life expires.

The traditional recycling of textiles is based on introducing them back to a productive process that contemplates: (a) the classification is made according to the conditions and type of fiber; at this stage, it is decided whether garments can be reused, crushed, or used for reprocessing, and (b) re-classification, where the granulated material is separated according to its color, to be later crushed, carded, and finally spun.

The idea of using textile waste in applications that do not involve a new industrial process results in a novel research panorama, due to the economic and environmental benefits that can be achieved, as a novel investigation about home-use products obtained from waste textile materials [12]. **Table 3** shows the proposals and results of the recycling.

The results showed that eco-design is an effective tool, involving creativity and innovation, with environmental objectives. Recycling textiles are an excellent opportunity to reduce the environmental impact of commonly used products.

The use of textile waste to obtain ethanol was studied. Two types of textiles were used, one containing viscose, polyester, cotton, and modal and the other containing the cellulose contents that were between 70 and 94%. The textiles were cut from 2 to 5 mm in length and subjected to an alkaline pretreatment based on sodium hydroxide, and subsequently to an enzymatic hydrolysis process. The yields of ethanol obtained at 72 h were between 15 and 36% [13].

In a study carried out by Liang and Hota concerning to fiber-reinforced polymers and their use in engineering, they show a wide range of possibilities for their use within construction industry; due their characteristics, as: lower cost for maintenance (no paint, no decay, no insect infestation), lower heating and cooling costs and high structural strength [14].

Other researches focused on the use of recycled textile fibers in composites, as reinforcing materials [15], i.e., used carpet waste as a soil reinforcement material. The reinforcing fibrous strips were 5 × 5 mm and lengths of 5–45 mm. They were added to the soil in concentrations from 0.4 to 1.2%. The mechanical properties of shear forces were improved, is to say, composites without fibers have a value of 300 kPa, which was improved 25% when adding 1.2% of fibers (375 MPa). Moreover, the axial strain at yield point was improved, covering from 1% for composites without fibers to 4% for those with 1.2% of fibers.

Design alternatives matter virgin	Proposals reuse matter
1. Agglomerates	The fibers of fabrics that are considered as debris are separated by rippers, and the threads are joined together and under pressure and heat in the form of vapor to create textiles as felt.
2. Art objects	Textile waste considered to be waste is subjected to different procedures such as ripping or cut, to create artistic works such as paintings, sculptures, plastic art, etc.
3. Promotional objects	Fabric dolls consisting of materials of waste that promote institutions or campaigns around the type: felt bags made of textile waste that they bring logos, labels promoting congresses, or associations
4. Carpets made with T-shirts	Carpets made of T-shirts, second-hand clothing or scrap, which are cut into strips and woven by hand-form carpets for homes and offices
5. Bags made with pants	Wearing denim jeans that are no longer donated like second-hand clothes, their legs are cut off, sew holes, and debris are used to make the handle
6. Insulation	The same procedure is followed to make felt of but in thicker layers and then subjected to a cut for its adaptation in walls, in cars like acoustic and thermal insulation
7. Cleaning cloths	Used clothing, considered scrap made from cotton mainly, is cut or torn to be used like rags or tows for cleaning. Some fabric synthetics by their oleophilic and hydrophobic characteristics can be used for industrial cleaning
8. Bedspreads or bedding patchwork	Large textile fabric is selected for be subjected to cuts with patterns and form that will be joined with the help of a sewing machine to construct canvases based on pieces.

Table 3. Proposals for replacement of virgin materials by waste textiles (adapted from [13]).

Improvement on the reinforcement-matrix interface is one of the most important challenges for using textile fibers as reinforcements in composite materials. Some studies are concerning to the modification of reinforcing fibers, by means of chemical or physical techniques, that look for changes in the chemical structure and in consequence to improve the interface with the matrix.

There are several physical methods applied on fibers, as temperature plasma treatment, corona treatment, and a novel based on the use of gamma radiation. Physical methods of interface modification involve fibrillation on the fibers, causing structural and surface modification, and in consequence mechanical changes are obtained.

In an investigation about the effects of chemical treatment (with alkali) and gamma radiation on cotton fibers, structural modification of cellulose component was evidenced by a decrease in the degree of polymerization and an increase in carbonyl content [16]. In an other investigation, irradiated cellulose fibers (by using gamma rays) showed degradation from 6 to 12% up to an applied dose of 31.6 kGy; moreover, crystallinity decrease for dosages higher than 300 kGy and finally diminution of 1% in the crystallinity at dosages up to 1 MGy are observed. In general, gamma radiation causes degradation of cellulose in shorter chains and leads to “opening of microcracks” that are easily penetrable by water molecules. The complete degradation of cellulose is given up to 6.55 MGy, where amorphous zones along the length of the microfibrils are seen, which allows penetration of chemical substances in the microfibrils [17].

Industrial development and the need to protect the environment are placing escalating demands on the natural resources and improved technologies. Radiation technology has been used to produce high performance polymeric materials with unique physical and chemical properties. Now, this technology can successfully be utilized to upgrade natural polymers as well, yielding value-added products for diverse applications.

Cellulose is the most abundant natural polymer around the world, and its high abundance and the presence of reactive hydroxyl groups in the chain promise an array of potential applications. The modified celluloses like carboxymethyl cellulose (CMC) or hydroxyethyl cellulose (HEC) are more useful in producing specialized polymers due to their solubility in water. CMC is the most promising derivative of cellulose that can be used for the production of hydrogels, since it has an ionizable carboxyl group.

The natural polymers are presently being exploited for industrial use. However, by judicious use of radiation, these polymers can yield high value products with interesting applications. Possibility of blends of polymers with natural polymers opens up a new avenue for novel applications.

4. Waste and recycled textile materials used in building materials

Fibers recovered from various waste streams are suitable for concrete reinforcement. The advantages of using such recycled fibers generally include lower cost to process than virgin fibers and the elimination of the need for waste disposal in landfills.

Recent studies about composites with textile fibers as reinforcement materials have opened great chances of success. For example, textile cutting waste has been mixed with epoxy resin and foundry sand for producing a unique composite material that can be used for lightweight construction. In general, textile fibers do not increase flexural and compressive strength of polymer concrete, but their addition to the mixture eliminates the signs of brittleness behavior. The use of textile fibers, in specific applications, may solve two problems, namely, elimination of an environmental pollutant and provision of an alternative material for the construction industry.

A significant amount of fibrous waste from the textile industry and postconsumer product is disposed worldwide. This is not only a cause for environmental concern but also represents a waste of useful resources. The textile cuttings are usually disposed of as a waste product that become an environmental nuisance because of its nonbiodegradability or burned in heaps thus releasing highly toxic fumes in the surrounding air. Turning them into useful materials serves a dual function: elimination of wastes and introduction of a new product.

Polymer concrete is elaborated by combining polymers and minerals. The most important parameters in its elaboration include type and size of the minerals, as well as percentages of the components, in order to obtain improved properties. In general, polymer composite materials are brittle in nature but show an increase in both ductility and strength when adding fibers. Nevertheless, fibers have not been widely used in polymer concretes. Moreover, interface between fibers and polymer matrix influences the strength and toughness of composite materials. When an interfacial failure happens, fibers are pulled out from the polymer matrix and bridging forces are developed on the crack surface. The bridging forces shield the crack and hence reduce the stress intensity factor at the crack tip. Interfacial shear strength plays a dominant role since the bridging pressure from fiber pull-out is governed mainly by shear stress resistance between fibers and the polymer matrix.

Mechanical behavior of polymer concrete with textile residues was investigated. Textile wastes were recovered from lingeries, which are elaborated with cotton, polyester, silk, and rayon fibers. Two sets of resin, fine aggregate and textile fibers were elaborated, and 1 and 2 wt.% of recycled textile fibers were added. The results show diminution on the flexural strength of polymer concrete when increasing the fiber concentration. However, flexural strength values are higher than those obtained for cement concrete. Polymer concrete without fibers failed and was broken into pieces; in contrast, all fiber-reinforced specimens after reaching the maximum load remained as an integral piece, with hold fibers to polymer matrix [18].

Polymer concrete with olive oil from vegetable solid wastes was elaborated; for its use in the construction industry or in the manufacture of furniture. Polymer concrete specimens had from 10 to 60 wt.% of residues, and a silanized process was used to improve the interface characteristics. Silanized was made with untreated alpha-mercaptopropyltrimethoxysilane. The results show that olive oil improves the mechanical properties, and even more silanized process allows improvements on interface and in consequence higher mechanical values [19].

In the search to include textile waste materials in construction materials, an investigation was carried out in which we evaluated the feasibility of using residuals and subresidues of fabrics, for thermal insulation in the construction industry [20]. This was done by making an outer double wall with an air box filled with such debris by placing two heat flow meters and four surface temperature sensors on the wall surface to determine the thermal conductivity of the waste. The results show that the application of fabrics in the external double wall increases its thermal behavior between 30 and 56%.

In the construction industry, one of the most demanding items is the construction of floors for roads and highways, which must be able to withstand the constant impact of the traffic of people and transports. In an investigation, we used recycled carpet waste fibers to make composites of lightweight cements in a 20% fiber ratio. The flexural, tenacity, and impact properties were characterized. The results show that in the three-point flexural test, a ductile behavior and an increase in flexural strength were observed. Nevertheless, density decreases with increasing fiber concentration. Energy absorption was also measured by the weight drop impact test, but this was not very significant due to the total absorption of the impact energy of the specimens [21].

The importance of the concentration of the load of reinforcing material in a composite is evidenced in an investigation in which it developed a polymer concrete elaborated with polyester resin, sand, and textile glass fibers (1, 2, and 3 wt.%). The properties of fibers were weight (160 g/m^2), thickness (0.47 mm), mesh (3.5 × 3.5 mm), and tensile strength (1200 N/cm^2). Load-displacement curves for different reinforcement contents were obtained. The results show that after to reach the maximum load this suddenly decreases the matrix cracking completely. Two important factors affect the fracture toughness, fiber pull-out and the bridging effect [22].

In the next section, we show a study concerning to polymer concrete elaborated with polyester resin, marble particles, and waste cotton fibers carried out by our research team. The cotton fibers were obtained from waste blue jeans (Denim).

5. Polymer concrete: experimental results

5.1. Polymer concrete without textile fibers

In a first stage, test specimens were made with different concentrations of polyester resin and marble to determine those with better compressive and flexural strength. The compressive strength results are shown in **Figure 3**, as it can be seen, the values increase when the resin concentration increases too (or marble particles diminish).

In **Figure 4**, it is observed a similar behavior as compressive strength, is to say, flexural strength values increase when increasing resin concentration. Thus, it was decided to work with the specimens with 30% of polyester resin and 70% of marble particles. Results that are in agreement with other investigations where using marble residues as an aggregate in concrete, in order to improve the durability [23].

5.2. Polymer concrete with waste textile fibers

In a second stage, textiles were cut in pieces of approximately 1.0 × 1.0 cm, and then they were crushed in a windmill. The obtained fibers were added to the blend of polyester resin and

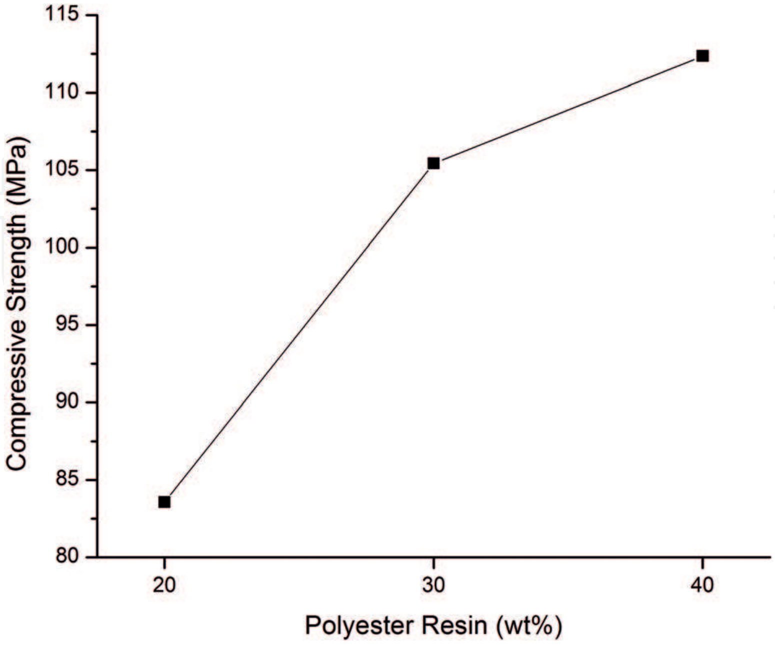

Figure 3. Compressive strength of polymer concrete.

marble particles (without applying them any treatment). The concentrations of cotton fibers were 0.5, 1.0, and 1.4% by weight. The specimens were obtained through the casting method according to the European norm EN-196-1, with dimensions of 4 × 4 × 16 cm. The results are shown in **Figure 5**.

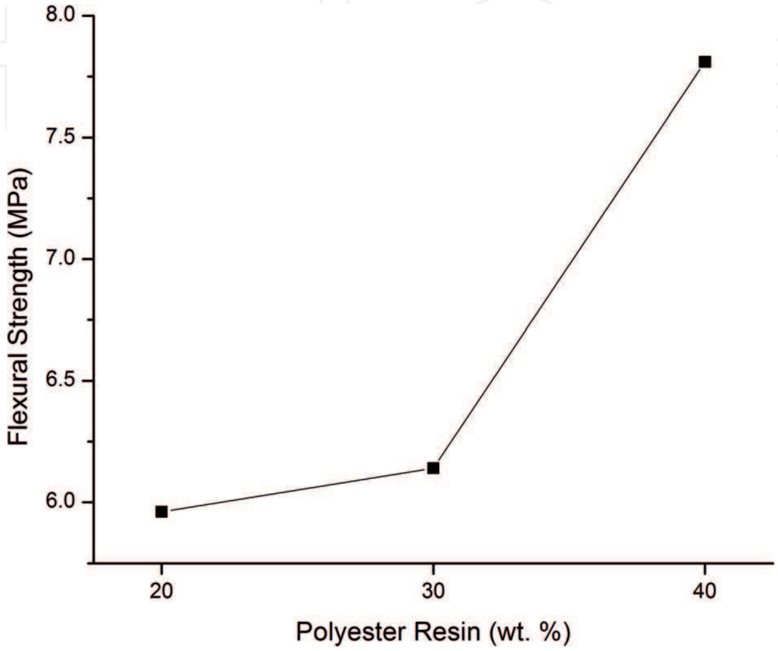

Figure 4. Flexural strength of polymer concrete.

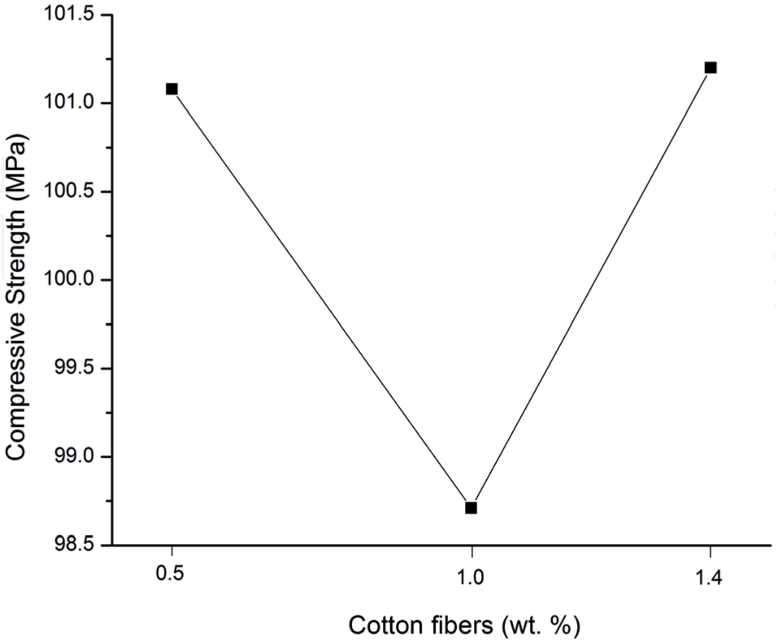

Figure 5. Compressive strength of polymer concrete with recycled cotton fibers.

Compressive strength values show a peculiar behavior; since at a lower concentration of cotton fiber (0.4%), a value of 101 MPa is obtained; however, for a higher fiber concentration (1.0%), the value decreases up to 98.7 MPa, and finally they increase again up to 101 MPa for 1.4% of cotton fibers; such behaviors can be due to the inherent properties of the fibers, i.e., whether they agglomerate or interact with the polymer matrix.

The results agree with early investigations, concerning to mix recycle fibers with the concrete in order to improve their mechanical properties and concomitantly reduce wastes, while minimizing the cost of the raw material. Environmentally, the benefit is also considerable, since natural resources are conserved and the presence of these residues in landfills is reduced [24].

Such compressive strength behaviors of the composites depend on the cotton fiber concentrations, as we know at 1.0 wt.%, lowest values were found. Nevertheless, other important parameter is fiber sizes; cotton fibers were analyzed by using scanning electron microscopy (SEM), as shown in **Figure 6**, where fibers have 10 μm diameter in average and lengths of some millimeters. Then, the mechanical performance of composites depends on the combination of concentration and size of the fibers.

Based on the previous results for composites with different concentrations of cotton fibers, it was determined the proportion ratio of 30% polyester resin/69% marble/1.0% cotton fiber, for the next stage.

5.3. Polymer concrete irradiated with gamma rays

According to the concentrations, composite specimens were elaborated and after they were submitted to different radiation dosages from 100 to 1000 kGy. After irradiating mechanical tests (including compressive and flexural strength) were carried out. The compressive strength results are shown in **Figure 7**; it can be seen that compressive strength results are almost constant, ranging between 120 and 140 MPa, even at highest dose of radiation. The lowest value is obtained at 200 kGy.

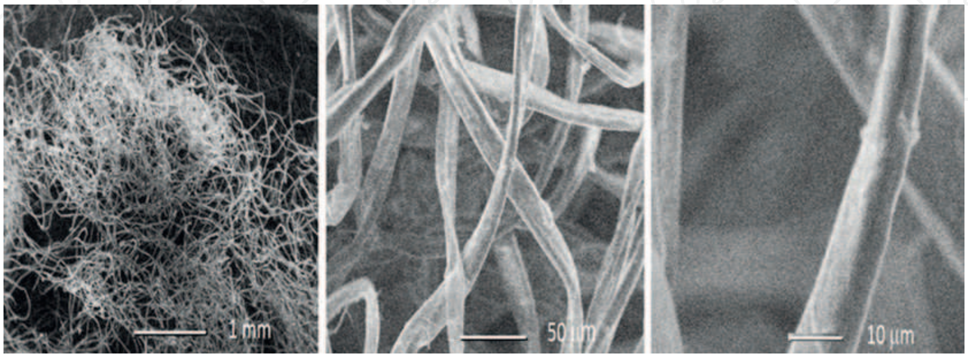

Figure 6. SEM images of cotton fibers, at different amplifications.

Structural modifications of gamma-irradiated cotton fibers were analyzed by using scanning electron microscopy, as it is shown in **Figure 8**. Gamma irradiation causes modifications on the composite as a whole and in each component (polyester resin, marble particles, and cotton fibers). Diminution of the compressive strength at 200 kGy is due in part to surface modifications of the fibers, as it is observed in **Figure 8**. For higher doses, at 600 kGy, fiber surfaces are rougher and the presence of detached particles on them is observed, such characteristics give to composite higher compressive strength values, which holds for the highest dose, at 1000 kGy, where cotton fibers show more deterioration.

In contrast, the flexural strength increases to 200 kGy (7.76 MPa), which can be explained by two causes: an improvement in the interface due to the superficial alterations caused by the

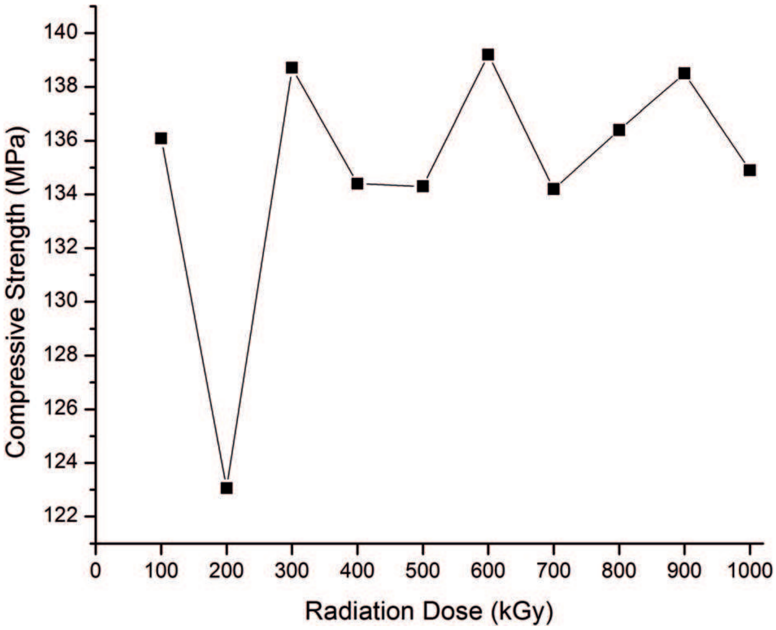

Figure 7. Compressive strength of irradiated polymer concrete at different doses.

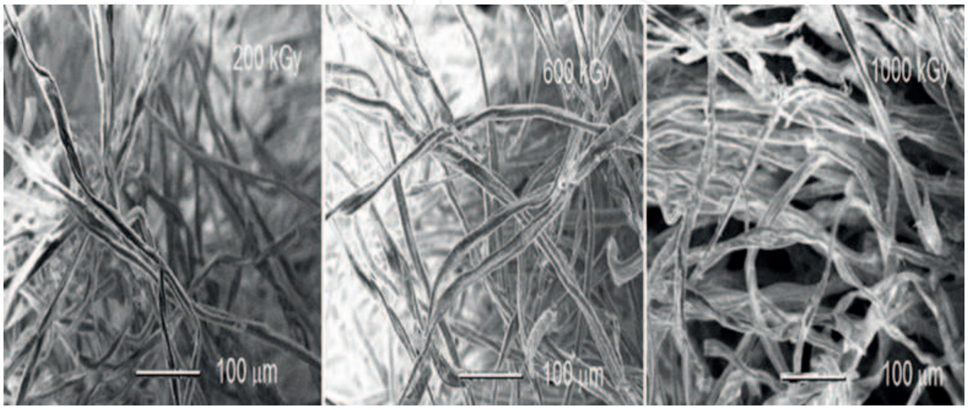

Figure 8. SEM images of irradiated cotton fibers.

irradiation in the cotton fibers, and on the other hand, as a consequence of the way the textile fibers are distributed within the polymeric concrete. At values greater than 200 kGy, the changes were minimal (**Figure 9**).

The behavior of flexural strength and the compressive strength, as we say before, the structural modifications are caused by gamma irradiation, which are observed by scanning electron microscopy (SEM) (as shown in **Figure 10**). In the images, smooth surfaces of nonirradiated fibers can be clearly seen, but when applying 400 kGy, the fibers exhibit rough surfaces and some detachment of particles, such characteristics allow lower flexural strength values. For higher irradiation dose, at 700 kGy, appearance of cracks is observed and, in consequence, diminution of the flexural strength.

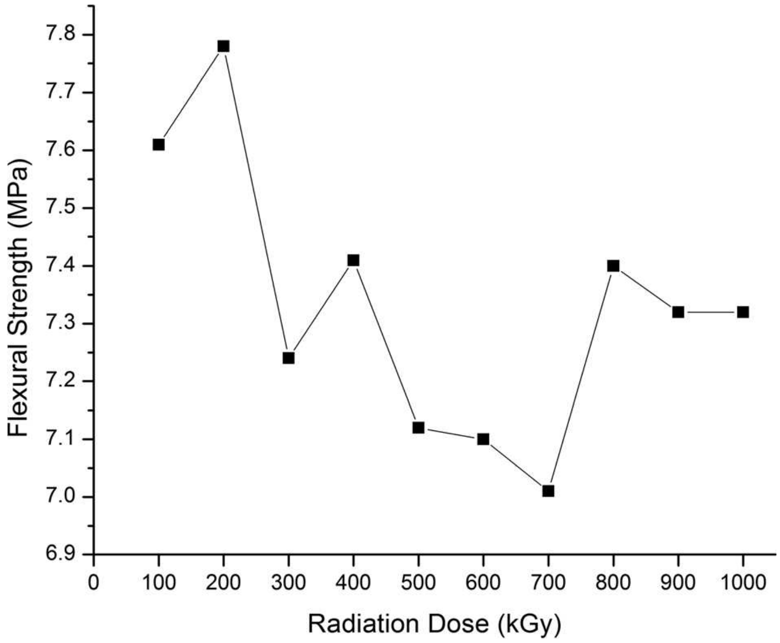

Figure 9. Flexural strength of irradiated polymer concrete at different doses.

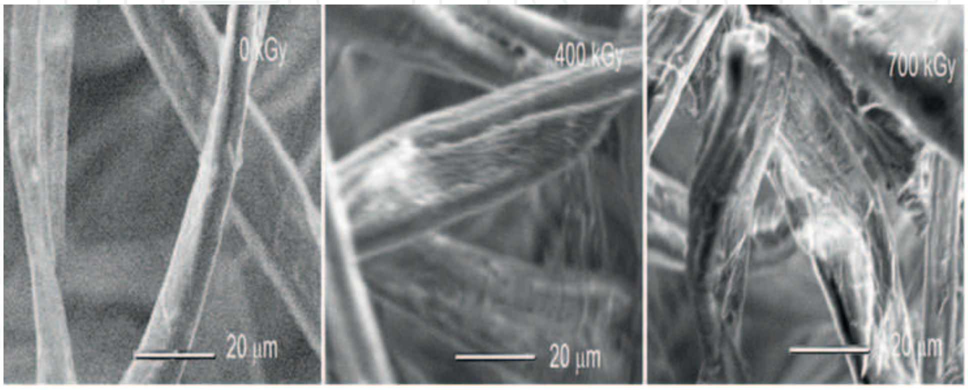

Figure 10. SEM images of irradiated cotton fibers.

Author details

Patricia Peña Pichardo[1], Gonzalo Martínez-Barrera[1]*, Miguel Martínez-López[2], Fernando Ureña-Núñez[3] and Liliana I. Ávila-Córdoba[4]

*Address all correspondence to: gonzomartinez02@yahoo.com.mx

1 Laboratorio de Investigación y Desarrollo de Materiales Avanzados (LIDMA), Facultad de Química, Universidad Autónoma del Estado de México, Toluca, México

2 Departamento de Construcción e Ingeniería de Fabricación, Universidad de Oviedo, Gijón, España

3 Instituto Nacional de Investigaciones Nucleares, La Marquesa Ocoyoacac, México

4 Facultad de Ingeniería, Universidad Autónoma del Estado de México, Toluca, México

References

[1] Williams N, Lundgren K, Wallbaum H, Malaga K, Malaga K. Sustainable potential of textile-reinforced concrete. Journal of Materials in Civil Engineering. 2015;**27**:1-12. Available from: http://ascelibrary.org/doi/pdf/10.1061/(ASCE)MT.1943-5533.0001160 [Accessed: 11 April 2017]

[2] Dinesh B, Ankush S, Urvashi M. Recycled fibers: An overview. International Journal of Fiber and Textile Research. 2014, 2014;**4**:77-82. Available from: http://www.academia.edu/14454205/Recycled_fibers_An_overview [Accessed: 23 March 2017]

[3] Hoornweg D, Bhad Tata P. What a Waste. A Global Review of Solid Waste Management. Washington DC: Urban Development & Local Government Unit Word Bank; 2012. 98 p. Available from: https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf. [Accessed: 23 March 2017]

[4] SEMARNAT. Informe de la Situación del Medio Ambiente en México Compendio de Estadísticas Ambientales Indicadores Clave y de Desempeño Ambiental. Capìtulo 7; 2012. p. 318-361. Available from: http://apps1.semarnat.gob.mx/dgeia/informe_12/pdf/Cap7_residuos.pdf [Accessed: 16 April 2017]

[5] Rodríguez E, Lupín B, Lacaze V, González J. Sustainable production of textile fibers. In: A Viable Alternative for Argentina? Mar de la Plata: Universidad Nacional de Mar de la Plata; 2011. 136 p. Available from: http://nulan.mdp.edu.ar/1559/9/fibras_textiles.pdf [Accessed: 02 August 2017]

[6] Parada-Gómez A, Pelupessy W. The environmental effects of the global clothing chain in Costa Rica. Ibero-American Journal of Ecological Economics. 2006;**3**:63-79. Available from: http://cro.ots.ac.cr/rdmcnfs/datasets/biblioteca/pdfs/nbina-5930.pdf [Accessed: 08 April 2017]

[7] Kant R. Textile dyeing Industry an environmental hazar. Natural Science. 2012;**4**:22-26. DOI: 10.4236/ns.2012.41004

[8] Kanan A, Marine S, Raihan F, Redowan M, Miah M. Textile effluents changes physiochemical parameters of water and soil: Threat for agriculture. African Journal of Agronomy. 2014;**2** (10):219-223. Available from: http://internationalscholarsjournals.org/journal/aja/articles?index=5 [Accessed: 22 April 2017]

[9] Kalliala E, Pertti N. Environmental profile of cotton and polyester-cotton fabrics. AUTEX Research Journal. 1999;**1**:8-20. Available from: http://www.proyectaryproducir.com.ar/public_html/Seminarios_Posgrado/Material_de_referencia/LCA%20for%20Cotton%20and%20Polyester-cotton%20fabrics.pdf [Accessed: 26 March 2017]

[10] Woolridge A, Ward G, Phillips P, Gandy S. Life cycle assessment for reuse/recycing of donated waste textiles compared to use of virgin material: An UK energy saving perperctive. Resources, Conservation and Recycling. 2006;**46**:94-103. DOI: 10.1016/j.resconrec.2005.06.006

[11] Rojas I, Wetter C, Veloso C, Garcia G, Bedregal C, Robayo C, García C. Technical report on the minimization of textile waste. Lima Peru: Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente. Organizacion Mundial de la Salud; 1994. p. 77. Available from: http://www.bvsde.paho.org/bvsacd/scan/029704.pdf [Accessed: 02 April 2017]

[12] Viveros-Eulogio B, Ramirez-Angulo J, Ramirez-Portillo A. Ecodesign applied to household products. In: 30th International Conference on Case Method Research and Application-WACRA; 7-11 July; Berlin, Germany. pp. 1-8. Available from: http://diva-portal.org/smash/get/diva2:767421/FULLTEXT01 [Accessed: 11 April 2017]

[13] Menéndez-Ramirez Z, Jeihanipour A, Thaerzadeh M, Zumalacárregui-de CL. Posibilidad de aprovechamiento de residuos textiles para la obtención de etanol. Revista CENIC Ciencias Biológicas. 2010;**41**:185-188. Available from: http://revista.cnic.edu.cu/revistaCB/sites/default/files/articulos/Articulo%20No%206%20B31 [Accessed: 30 April 2017]

[14] Liang R, Hota G. Fiber-reinforced polymer (FRP) composites in environmental engineering applications. In: Hodzic A, Shanks R, editors. Handbook of Natural fibre Composites: Materials, Processes end Properties. Oxford, United Kingdom: Woodhead Publishing; 2014. p. 410-468. DOI: 10.1533/9780857098955.2.410

[15] Ghiassian H, Poorebrahim G, Gray D. Soil reinforcement with recycled carpet wastes. Waste Management and Research. 2004;**22**:108-114. DOI: 10.1177/0734242X04043938

[16] Takács E, Wojnárovits L, Földváry C, Hargittai P, Borsa J, Sajó I. Effect of combined gamma-irradiation and alkali treatment on cotton-cellulose. Radiation Physics and Chemestry. 2000;**57**:399-403. DOI: 10.1016/S0969-806X (99)00409-0

[17] Martínez-Barrera G, Ávila-Córdoba L, Martínez-López M, Herrera-Sosa E, Vigueras-Santiago E, Barrera-Díaz C, Ureña-Nuñez F, González R. Gamma radiation as a recycling tool for waste materials used in concrete. In: Nenio M, editor. Evolution of Ionizing Radiation Research. Rijeka Croatia: In Tech; 2015. p. 259-279. DOI: 10.5772/60435

[18] Reis J. Effect of textile waste on the mechanical properties of polymer concrete. Materials Research. 2009;**12**:63-67. DOI: 10.1590/S1516-14392009000100007

[19] Gharbi A, Bel Hassen R, Boufi S. Composite materials from unsaturated polyester resin and olive nuts residue: The effect of silane treatment. Industrial Crops and Products. 2014;**62**:491-498. DOI: 10.1016/j.indcrop.2014.09.012

[20] Briga-Sá A, Nascimento D, Teixeira N, Pinto J, Caldeira F, Varum H, Paíva A. Textile waste as an alternative thermal insulation building material solution. Construction and Building Materials. 2013;**38**:155-160. DOI: 10.1016/j.conbuildmat.2012.08.037

[21] Ucar M, Wang J. Utilization of recycled post-consumer carpet waste fibers as reinforcement in lightweight cementitious composites. International Journal of Clothing Science and Technology. 2011;**23**:242-248. DOI: 10.1108/09556221111136502

[22] Arikan H. Fracture behavior of textile glass fiber reinforced polymer concrete according to mixed-mode. Journal of Thermoplastic Composite Materials. 2011;**25**:63-677. DOI: 10.1177/0892705711412649

[23] André A, De Brito J, Rosa A, Diogo P. Durability performance of concrete incorporating coarse aggregates from marble industry waste. Journal of Cleaner Production. 2014;**65**:38 9-396. DOI: 10.1016/jclepro.2013.09.037

[24] Heniegal A, El-Habiby F, Hafez R. Physical and mechanical properties of concrete incorporating industrial and agricultural textile wastes. International Journal of Research in Engineering and Technology. 2015;**4**:166-176. Available from: http://esatjournals.net/ijret/2015v04/i07/IJRET20150407026.pdf [Accessed: 25 April 2017]