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Cover system for roofs manufactured with recycled polyethylene and rubber

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Abstract. The intense waste generation moved by the urban and industrial activity and the wasteful consumption of natural resources, encourage the development of new technologies for the utilization of wastes and its reuse in new industrial processes, which decreases the environmental pollution and the removal of virgin materials. In this sense we work in the development of new materials and components from urban and industrial waste prepared by different techniques and with various applications.

We work on the development of a composite material made with recycled rubber from tires out of use (NFU) and recycled polyethylene, linked through the fusion of the plastic and the subsequent pressing of the material. In this article we present the partial results obtained in the physical and mechanical testing of the roof tiles, and the burning behavior of the components manufactured with flame retardants additives available in the market, to comply with the regulations in order to use these housing components. These components have as main advantages the high resistance to flexion and the hard impact, low thermal conductivity, and low water absorption by immersion in water. Despite the fact that the components do not meet all the points of the reference Norm in regard to its behavior when exposed to fire, further amendments in the formulation and the manufacture process have shown interesting results, with which roof tiles could comply with the regulation for the use proposed.

We developed a sustainable covering system for roof using two types of wastes in great abundance in all urban sites, which involve a simple manufacture process. Besides, due to its high flexibility and resistance to impact hard is presented as a good constructive alternative for housing covering in areas affected by the fall of hail or by the risk of blowing up and deterioration by strong winds.

Introduction

Environmental pollution is a serious problem that is in continuous growth, due to the intensive consumption that is reflected in a continual generation of waste. The wastes of low biodegradability, like the cases of the plastics and rubber, which are accumulated, buried or incinerated in landfills (legal or illegal) producing pollution, and irrationally wasted resources.

According the report from Secretary of Environment and Sustainable Development (SADyS), of Ministry of Healt and Environment of Argentine, our Country produces 12,325,000 tons of waste each year [1], which means an average of 1 Kg of garbage per person per day.

The plastics represent the 13.3 % of the total of urban wastes in Argentina, and from these wastes are recovered and recycled largely the polyethylene terephthalate (PET) and the polyethylene (PE) CEAMSE (2011) [2], but a significant amount has as destination the burial, with the consequent generation of a waste that takes between 150 and 600 years to degrade, depending on their chemical composition, and even more if it still buried.

On the other hand, the continuos generation of discarded tires from cars is a serious problem in Argentine, because they exceed the 100,000 tons a year INTI (2010) [3].These wastes are of difficult disposal because of its shape, the large volume occupied and the long time for its degradation (more than 600 years), besides if they are not properly disposed they generate a suitable habitat for the proliferation of rodents, pests and vectors of infections (mosquitoes). In addition with these wastes there is a danger of fire and pollution that the smoke of the burning generates in the environment.

In our country there is little awareness of the need for recycling, it is estimated that 70% of the garbage is recyclable, but only a 10 % of this amount is retrieved and enters again to the productive cycle, Agencia Córdoba Ambiente (2001) [4].

The decline in the production of wastes, the correct disposal of non-recyclable wastes and recycling of reusable wastes, are displayed as the best possible solutions to clean up the environment. Recycling is also the best way to avoid removal of virgin raw material.

One of the most appropriate targets to re-insert wastes to a new productive cycle are the construction materials, due to the large quantity of materials that are consumed and the diversity of possible applications. In this sense there are many examples about the development of construction materials and building systems, as the board manufactured with a mix o plastics (PVC, CPVC, PVDC, ABS, ASA y EVA), patented by Zhang in Europe (2001) [5], or the roof tiles developed in Brazil made up with long life packing developed by Fiorelli et all (2009) [6], the panels for roof developed with nylon fibers that simulate tiles, patented by Bacon in EEUU (2005) [7], the tiles "Tejalar" manufactured in the factory Recypack in Argentine, in addition to other examples of minor importance.

Besides, there are same examples of roof systems using rubber, similar to the colonial tiles and panels for walls made with bowed pieces of tires patented by Garcia (1996) [8], the roof components made with polyethylene, polypropylene, rubber and arids patented by Boor (2009) [9], roof tiles made with lumps of rubber mixed with silicious materials by thermomoulding procedure patented by Crivelli (1993) [10], the products patented by Edson (2004) which involved the use of low density polyethylene as binder and some types of recycled rubber [11], bowed roof tiles made with plastics and rubber using a thermo moulding process, which have ridges and connectors to form a single piece that covers a roof, patented by Meyer (2004) [12], the composite material made with recycled rubber, thermoplastic microspheres and expandable conventional additives, which can be applied in roof tiles and other products, patented by Degerman (2002) [13], roof tiles made with powder rubber and different plastics developed by Liu, Yang y Hao (2009) [14], are some examples of application of recycled rubber in roof systems.

Technologies involving the use of waste are subject to regional availability waste that will ensure sustained productive processes over time and with a simple logistic for provision. In addition, the elements or constructive systems must be technically suitable for the proposed application and must respond to the social aspects of need and acceptance. In this sense, the developed system pretend to contribute in solving the problem of the frost which happens in winter and produces damage in the roof systems made with ceramics and traditional components, because of the expansion of frost water located in the interstices of the materials. By other hand, due to the characterisitcs of the developed material, might be a good alternative to solve the problem of hail which occurs frecuently in summer, with hailstones that reach 5 cm of diameter and produces economical damages each year [15].

These local problems raise the need to propose materials for the cover systems of housing, more suited to this climate phenomenon, which require constructive components with greater resistance to the hard impact than the traditional ones.

This work presents partial results on the housing covering system developed jointly by the Experimental Center for Economical Housing (CEVE) dependent of the National Council of Scientific and Technical Research of Argentina CONICET; and the Center for Research, Development and Transfer of Materials and Quality -CINTEMAC- dependent on the National Technological University, Regional Faculty of Cordoba.

At this stage of project we developed the roof tiles as the main component of the housing covering system, in order to evaluate the properties of the constructive component manufactured with recycled polyethylene and rubber by the technique of the thermo-molding. We performed several phisical, mechanical and thechnical tests to determine the characteristics and behavior of roof tiles. In this exploratory stage we found that the roof tiles have significant advantages with regard to the traditional ones, because they respond to the environmental requirements and weather needs for the region.

Experimental Section

Materials

We used shredded rubber from discarded tires (NFU) with particle size of 1-2 mm. Recycled Low density polyethylene -LDPE- in pellets of 2-3 mm of particle size was used as melt binder in the thermo-molding process. We also used Polyethylene terepthtalate -PET- in one of the formulations. We evaluate fire retardants applied over one of the formulations (the selected formulation). The fire retardants we applied were: powder of Sodium tetraborate (Borax); HT-E fire retardant provided by Fullchem and fire-retardant treatment surface (liquid) for wood panels provided by Venier.

Tiles roof manufacture

The rubber and the shredded plastic were mixed in a horizontal mixer during 2 min, and then the material was added to the extruder hopper. The extrusion zones were heated to temperatures between 250-270 °C. The extruded material was placed to the mold and pressed to 10 tons during 4 min. After that the constructive component was removed from the mold and cooled until room temperature in a special device type grid to avoid the deformation of the roof tiles.

Four different dosages were tested:

rubber 60 : LDPE 20 : PET 20
rubber 40 : LDPE 60
rubber 50 : LDPE 50
rubber 60 : LDPE 40

10 specimens of each formulation were prepared for mechanical tests. Then, flexural resistant tests and impact resistance tests were performed on them.

The formulation number 4 was selected, because it has lower viscosity facilitated the extrusion of the mixture. This formulation also incorporates, the highest proportion of rubber, which is desirable in order to improve the behavior of roof tiles exposed to weather conditions, without diminish the flexural resistance and hard impact resistance. All the technical tests were performed on formulation number 4 exclusively.

4 different temperatures of the extruder were tested: 270 ºC, 275ºC, 280 ºC and 290º.

With 270 ºC the mix was very difficult to put into the mould. With 290ºC the rubber started to decompose, spewing smoke. The best result was obtained with 280 ºC, so this temperature was chosen.

The fire retardant treatments includes the addition of 5% on weight of Borax; 5% on weight of HT-E, with regard to the total material during the mixing process. The surface treatment of Venier paint was applied twice once the roof tile was ready, with a dosage of 3% on weight regarding to the total weight of the roof tile.

The equipment used for manufacture the roof tile is showed in Fig. 1. The extrusion process and pressing are shown in Fig. 2.

Figure 1 – Equipment for the manufacture of roof tiles

Figure 2 – Extrusion process and pressing of roof tiles.

Mechanical and technical tests

Impact resistance and flexural resistance, were made according IRAM Norm 12528-1/2:2003 [16]. The informed observations correspond to the analysis of 10 tested specimens.

The water permeability was made according IRAM Norm 11632-1 [17].The informed behavior correspond to the observation of 3 specimens tested.

The air permeability was made according Swiss Norm SIA 262/2003 [18].The reported value corresponds to the average of 3 specimens tested with the coefficient of variation (CV), applying the Grubbs test with α=0.05 for discard outliers.

The water absorption was made according IRAM Norm 12528-2:2003 [16]. The reported value corresponds to the average of 6 specimens tested with the coefficient of variation (CV), applying the Grubbs test with α =0,05 for discard outliers.

The frost resistance was made according IRAM Norm 11632-2 [17] for concrete tiles. The observations informed correspond to the analysis of 3 tested specimens.

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The test of flame propagation was made according the UNE-EN Norm 13501-5:2005 [19]. The reported value was the result of one test performed on each type of specimen, based on formulation 4, with different fire retardants. The dimensions of each specimen were: 0,8 m width x 1,75 m lenght.

Four types of specimens were tested:

Panel without fire retardants additives.

Panel with powder of Sodium tetraborate (Borax), Analytical Grade, provided by Ciccarelli factory.

Panel with HT-E fire retardant provided by Fullchem Factory.

Panel with fire-retardant treatment surface (liquid) for wood panels provided by Venier Factory.

Thermal conductivity was made according IRAM Norm 11559:95 [20]. The reported value was the average of 2 specimens. The dimensions of each specimen were: 0,6 m width x 0,6 m length.

All the tests were made in the laboratory of the Center for Research, Development and Transfer of Materials and Quality -CINTEMAC - dependent on the National Technological University, Córdoba Regional Faculty; and in the Structures Laboratory, dependent on the Faculty of Exact, Physical and Natural Sciences, National University of Cordoba.

Results

The manufacture

The process for the manufacture of the roof tiles is simple. During the extrusion the mixture has to be heated to reach the melt temperature of polyethylene, but with the precaution of not to exceed the decomposition temperature of rubber. The extruded material has low viscosity, so it had to be extended into the mold manually, taking the precaution of distributing uniformly the material, and was observed that with higher temperature the viscosity is lower but the decomposition gases are higher. Completed the pressing of the component, it must be immediately removed from the mold and placed in a rigid structure to avoid deformations during cooling, due to the tensile forces that occur as a consequence of the temperature difference between the interior and exterior of the roof tile. The roof tiles obtained have a size of 40.8 cm of length and 23 cm of width. The average weigh is 1.7 Kg and the density of 1.03 g/cm^3. The roof tiles obtained is shown in Figure 3, and the small prototype for the coupling analysis between components is shown in Figure 4.

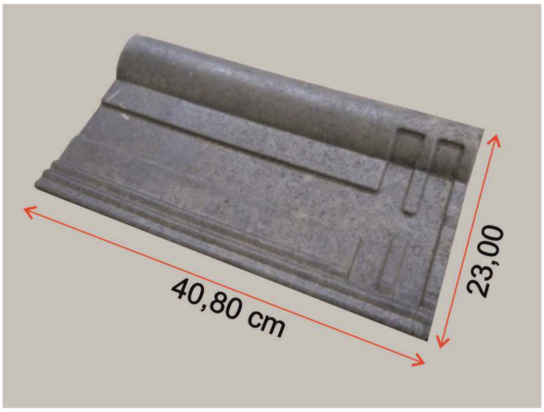

Figure 3 – Roof tiles made with recycled rubber and polyethylene.

Figure 4 – Small prototype for the study of coupling between components.

Technical and mechanical properties.

The mechanical properties are discussed below:

Impact resistance: After the test there were no surface defects such as: cracking, blistering, chipping, craters, malfunction, superficial fissure, micro-cracking of the enamel surface or glaze (quartering) or burrs, which shows that the component is an excellent alternative to cover system in the areas affected by falling hail, and provide a solution to the damage suffered by the cover systems of traditional ceramic roof tiles.

Flexural resistance: The loaded charge supported is <500 N, the component has high flexibility and it was not broken with the maximum load applied. With increased loads the component does not break but the greater deformation could contact the roof tile with the mounting strips. We assume that the flexibility is an excellent and innovative property in cover systems, and it might be a good alternative for buildings in areas affected by strong winds and hurricanes, conditional to a good system for fixing.

Frost resistance: After the successive cycles of freezing, there were no damage of the surface, therefore we consider that the behavior of roof tile is satisfactory, and the component is suitable for climates with high thermal amplitude and temperatures under 0 °C.

Water permeability: There was no leaking water at the bottom of the tile during the test. The test was conducted within 7 days after the end of the thaw test. The roof tiles meet with the reference Norm.

Air permeability: The result obtained for air permeability is 0.0010 KT [10-16m^2] with a CV= 9.5%. The component meets with the reference Norm and is classified as very low permeability material.

Water Absorption: The roof tiles immersed in water for 24 h absorb 0.42 % of water (on weight), with a CV=15%, which is far below what suggests the Norm (15% of their dry mass). The low value of water absorption of roof tile is due to its low porosity and the waterproof characteristics of the raw materials.

Thermal conductivity: The value determined was 0.810 W/m K with a CV=10%. These values are very similar to the ceramic roof tiles (0.76 W/m K) and lower than the traditional mortars (1.7 W/m K). Considering that panels of high density Polyethylene (with density of 1 g/cm^3) show a thermal conductivity of 0.5 W/m K and tiles of rubber (with density of 1 g/cm3) show a thermal conductivity of approximately 0.12 W/m K, the value observed in roof tiles made with recycled rubber and polyethylene (with density of 1 g/cm^3) is a little high and it could be decreased modifying experimental parameters and diminishing the porosity of the material. Data of thermal conductivity was extracted from IRAM Norm 11601:02.

Behavior of roof tiles exposed to fire: The test of behavior of the component exposed to fire, shows that the roof tiles do not meet with same requirement of the norm, related to the superficial spreading of the fire and the shedding of particles. These parameters do not meet for the reference material and neither for the material with the fire retardant treatments, although it is noteworthy that the roof tile with the surface treatment showed a better behavior than the others.

In this sense we are studying the addition of an inert powder during the mixing process (kaolin, ground quartz from industrial waste process, etc.), in order to make more absorbent the surface, which could improve the effect of surface flame retardant treatments. On the other hand, this powder additive will fill the interstitial sites between the rubber and polyethylene, with which will diminish the porosity of the material and hence will decrease the potential of the fire due to the minor availability of air. So far, in non-standardized tests performed in our laboratory on the roof tiles made with these inorganic additives, we obtained encouraging results that might allow the component comply with all the requirements of the reference Norm.

Conclusion

We developed roof tiles made with recycled rubber and recycled polyethylene, which have good technical and mechanical properties and they are an alternative to the traditional covering systems.

From an environmental point of view, this component is presented as an alternative of sustainable construction, due to the fact that involves the use of two types of waste that exist in all urban sites and that must be incorporated into new productive cycles to reduce the environmental pollution that they generate

Some technical properties, as the flexural strength and impact resistance, permit to propose this covering system as an excellent alternative for areas affected by hail fall and strong winds

The addition of an inert powder into the material, might improve some properties as the behavior of roof tiles exposed to fire, allowing the component be suitable for the proposed use.

We are working in the design of a prototype of approximately 30 m^2, in order to evaluate technical properties as workability of the component and thermal behavior of the covering system. On the other hand, complementary components as ridge cap and lateral spread are in the development stage, study of the coupling between components and design of matrix for its manufacture.

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