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Mechanical and Thermal Analysis of Composites Based on Rubbers From Used Tires

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Summary: Reuse and recycling of tires at the end of their useful life is an environmental challenge owing to the huge volumes discarded all over the world. This paper tries to give a scientific contribution toward the mechanical recycling of elastomers derived from pre treatment of tires to produce anti-shock tiles and heat-insulating panels for civil applications. Thermal and mechanical results herein reported satisfactorily justify the interest devoted by now to this topic.

Keywords: anti-shock tiles; composite; rubber; thermo-insulation; tire

Introduction

Used tires do not break down in the natural environment and will accumulate indefinitely unless they are processed in some way. They take up valuable landfill space when stored in piles above ground, provide a perfect breeding ground for mosquitoes and are serious fire hazards. As a consequence, in order to reduce the environmental impact of used tires, they are further processed for other uses.

At this purpose, it is worth to note that recycling of tires is very difficult due to their complex structure including rubber formulations, metal end textile elements (see Fig. 1).

Huge amount of used tires are normally collected by authorised reclaimers who separate constituent materials and grind the elastomeric phase by using a mechanical or, rarely, a cryogenic approach.

Rubber particles, merely useful to toughen organic matrices, could be consolidated by using relatively low cost resins to obtain items for automotive, agricultural and civil applications.

Alternatively, tires become fuel for power plants and for manufacturing of cement, paper and other materials.

In this work, tire rubber granulates supplied from various reclaimers have been previously characterised in terms of microscopical features and then processed to obtain tile samples by adding commercial resins acting as linking agents such as polyurethanes (Voramer RF 1024 or Voramer RM 1007) and polyolefins (Hyfax, Adsyl). Products were analysed essentially in terms of compression and impact properties to verify their potential usefulness as anti-shock tiles.

Moreover, with the aim to use recycled rubber to produce thermo insulating panels, opportune tests have been carried out to determine the thermal conductivity of products. The aim was to evaluate this property as a function of sample density, type and content of resin. Preliminary results identified the density as the key parameter to monitor the thermal conductivity of rubber based items.

Experimental Part

Materials

Rubber powders or granulates coming from used tires were provided by local reclaiming

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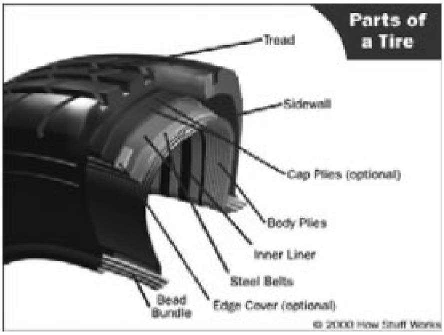

Figure 1.
Typical structure of a tire.

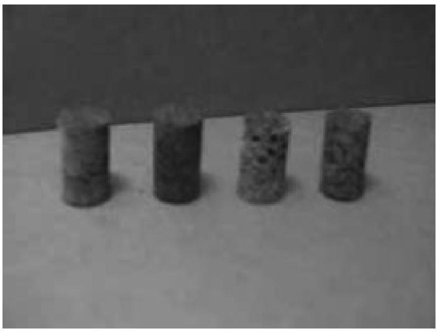

Figure 2.
Cylindrical samples for compression measurements.

sites and consolidated into tile samples with two kind of polymeric resins were considered: thermoplastic polyolefins such as Hifax CA02A, CA10A, CA60A and Adsyl 5C30F from Basell Polyolefins and polyurethanes such as Voramer RF 1024 and 1007 supplied by Dow Chemical.

In particular:

Hifax CA02A, Hifax CA10A showing an extremely high rubber content and characterised by an outstanding low stiffness, excellent low hardness and good impact resistance have been designed for extrusion, calendaring and blow moulding of very soft film and sheet;

Hifax CA60A has been developed for industrial application requiring a combination of good processability and excellent softness;

Adsyl 5C30F is a new thermoplastic polyolefin designed as a BOPP sealing layer material with exceptionally low sealing temperature (106 °C);

VORAMERs are industrial polyurethane based adhesives and binders normally used, among others, in a variety of recycling applications, bonding together different kinds of shredded materials such

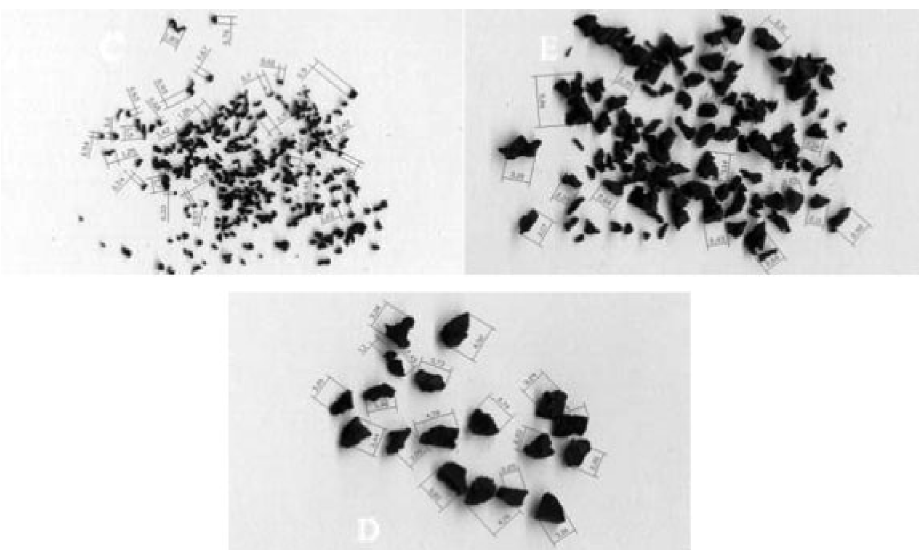

Figure 3.
Microscopic views of supplied ground rubbers.

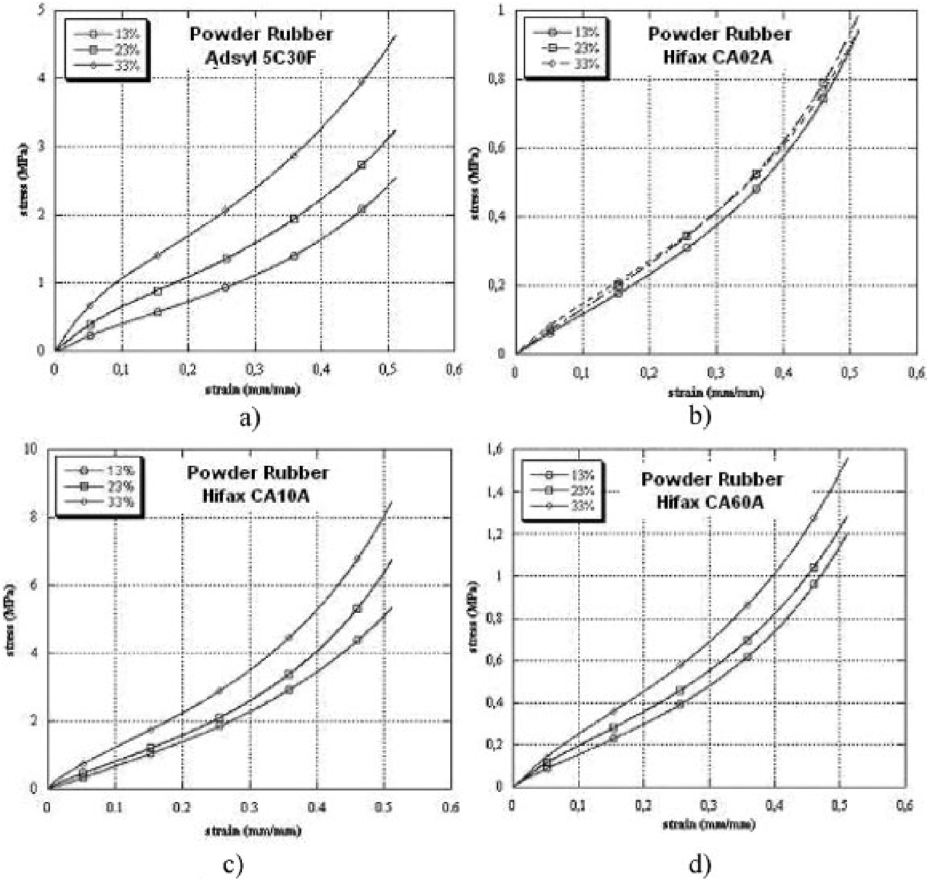

Figure 4.
Compression behaviour of samples based on powder rubber.

as rubber, flexible foams, EVA, cork and gravel.

Composite samples containing 13, 23 and 33% by weight of consolidating additive were prepared under the conditions: 160 °C - 30 min - 1 Atm and 70 °C - 60 min - 1 Atm for polyolefin and polyurethane based ligands, respectively.

Microscopycal analysis

A preliminary investigation was devoted to reveal main morphological features of ground rubber coming from different local reclaimers. At this purpose a Nycon Eclipse E400 microscope was used by an image analysis approach having a resolution of 1200 dpi. For linear measurements an Autodesk CAD 2000 was employed.

Mechanical characterization

Compression tests have been carried out by using an Instron Machine (model 5800) according to the ASTM D695. At this purpose a steel mould was designed to prepare simultaneously, by pressure moulding, 3 cylindrical samples with controlled sizes (see Fig. 2). Measurements were performed at a cross-head speed of 1 mm/min using a load cell of 10 kN.

Moreover, impact tests have been performed according to the European standards UNI EN 1177.

The EN 1177 standard defines the requirements for bases used in children's playgrounds as well as the special requirements for those areas where impact absorbency is necessary. The standard explains

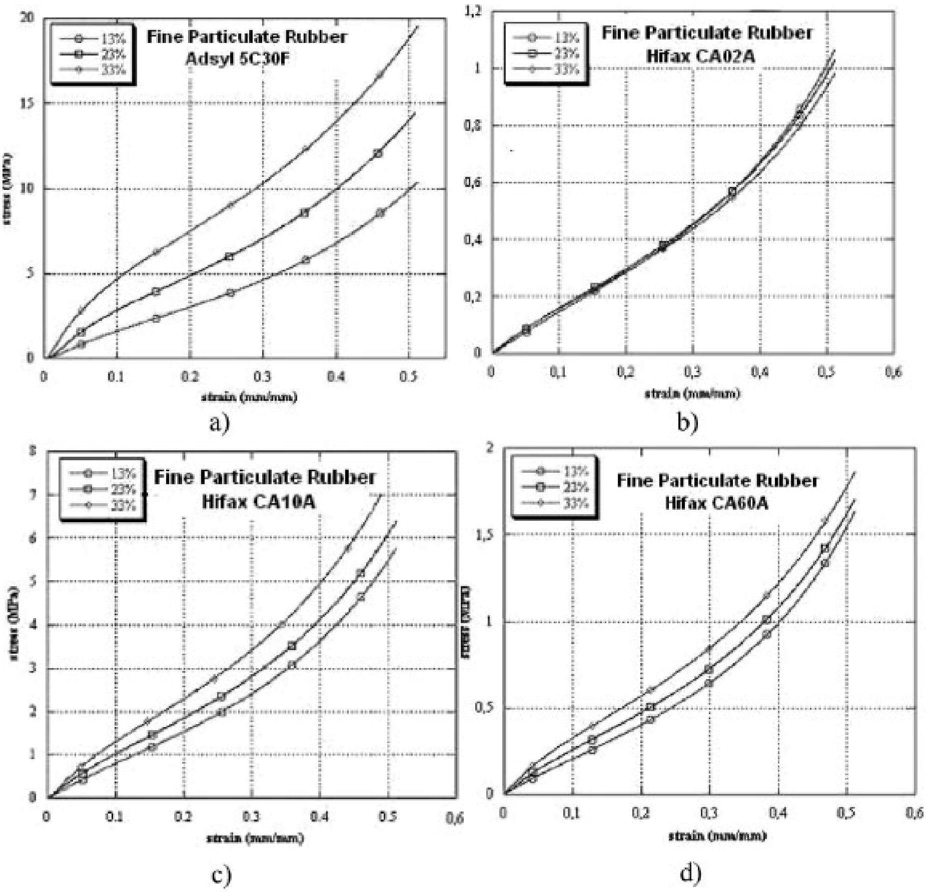

Figure 5.
Compression behaviour of samples based on fine particulate rubber.

the matters that need to be taken into consideration when choosing surface materials and it describes the test method for determining impact absorbency. The test determines the critical fall height of a base, i.e. the head injury criteria (HIC), which indicates the highest possible HIC value of the impact absorbency of a base in order to reduce head injuries when using playground equipment that complies with the EN 1176 standard.

In this work the effect of the tile design and density on the HIC values have been investigated.

Thermal conductivity measurements

Tests have been carried out according to the ASTM C177-85 Standard (steady state heat flux method). In this way surfaces of a flat, homogeneous specimen are in contact with solid, parallel boundaries held at constant temperatures. The test apparatus designed for this purpose is known as a guarded-hot-plate apparatus.

Results and Discussion

In order to emphasize any effect coming from the dimension of particle rubbers on the final performances of items based on, all raw materials were subjected to a preliminary microscopic analysis. Figure 3 shows optical micrographs of grinded used tires marked in terms of their major size. Results allowed us to classify raw materials

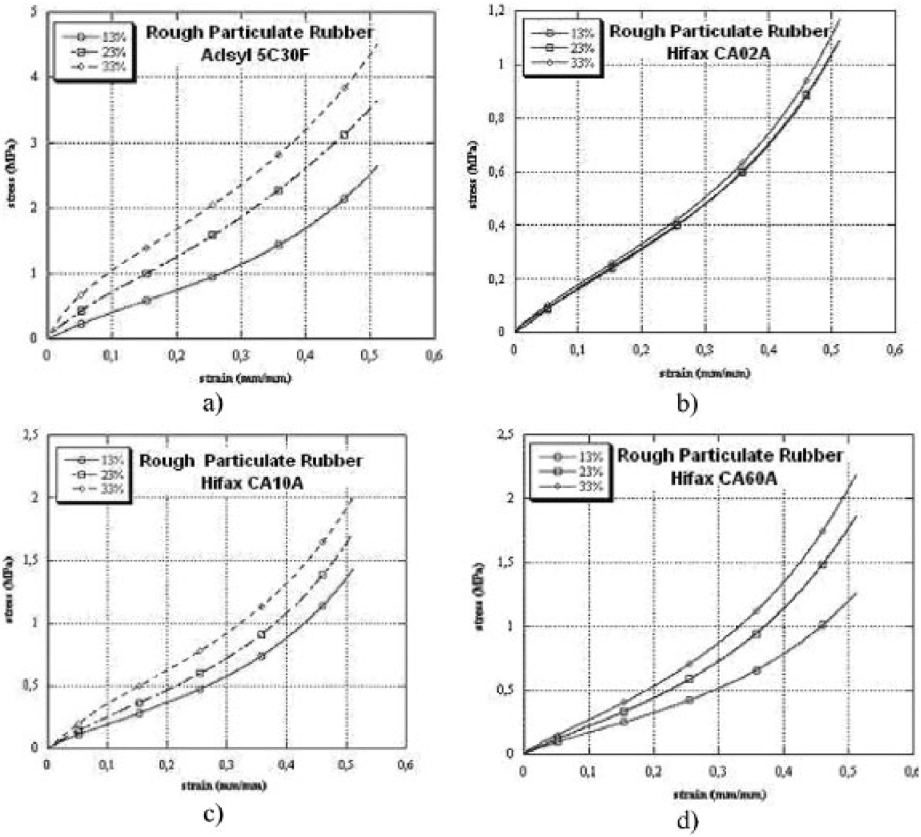

Figure 6.
Compression behaviour of samples based on rough particulate rubber.

in three categories: powder (rubber particle dimension <2 mm), fine particulate (from 2 to 3 mm) and rough particulate (from 3 to 5 mm).

Compression results have been summarised in typical stress-strain plots in Figs. 4, 5, and 6 where it is possible to note the effect of nature and content of the consolidating resin and, on the other hand, the influence of the rubber particle size on the mechanical behaviour of products.

Clearly, the compression behaviour of samples based on Adsyl 5C30F is strongly influenced by the resin content. This effect, although in a slight way, is evident for samples containing Hifax CA10A and Hifax CA60A, too. On the contrary, using Hifax CA02A, the stress-strain trend appear independent from the resin content, at least on the investigated concentration range. In general, the last consideration seems to be valid for samples obtained from fine or rough particulate rubber while for samples based on powder rubber a slight improvement of the ultimate compression performance is achieved by increasing the resin content. This observation could be explained considering that lower the mean size of particle rubber wider the interface between rubber and consolidating resin.

Regarding samples obtained with polyurethanes (VORAMER), analogous comparisons in Fig. 7 show a more marked effect of Voramer RF with respect to Voramer RM resin. This behaviour, only slightly influenced by the mean size of used particle rubber, maybe is related to different degree of chemical interactions

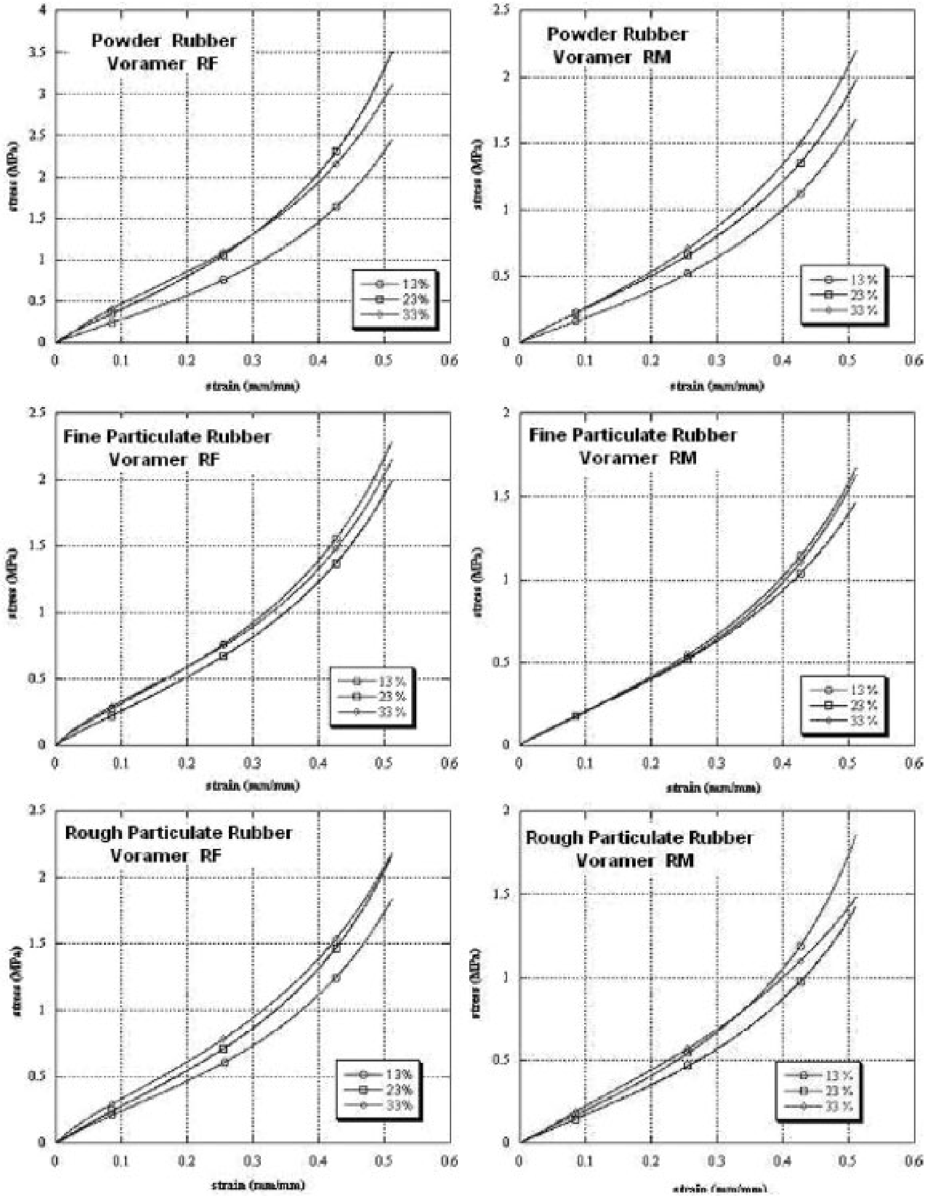

Figure 7.
Stress-strain compression behaviour of samples based on polyurethanes.

occurring at the interface. Anyway, a thorough analysis of these aspect could be the goal for further investigations.

Finally, besides the particle size of recycled rubber, the better performances of samples consolidated by using Adsyl 5C30F and Voramer RF are presumably due to strong chemical interactions at the interface rubber-resin. Work is in progress to assess interactions at the interphase and to confirm these considerations.

About impact measurements, with particular interest to recycle tire rubber in antishock tiles for playground application, it is necessary to note that disadvantages of tile systems include tile to tile separation, limitation in graphic design potential, and stringent requirements for base preparation. Moreover, the design of the tile surface directly in contact with the base is expected to play a relevant role about the damping of impulsive stress applied. Thus, a specific attention has been paid considering the use of nine different stainless steel moulds opportunely designed (see example in Fig. 8).

Further interest has been devoted to the tile density testing samples, all obtained starting from rough particulate rubber, characterised by a density value of 0,67 and 0,75 kg/dm^3, under the same base surface configuration.

Results, for a critical falling height equal to 1.5 m, show HIC values significantly altered by the mould geometry as shown in the following Table 1.

Moreover, tests revealed that safety of tiles is improved by decreasing their density. This effect could be explained considering that the damping is expected to be proportional to the void degree of tiles and clearly higher is the density, lower is the void content.

Regarding the recycling of tire rubber to obtain thermo insulating panels, preliminary tests performed on samples based on rough rubber granulate showed an almost linear negative relationship between thermal conductivity and density (Fig. 9). Although the reported graph is related to samples consolidated by Voramer RF resin this consideration seems to be verified besides the consolidating agent used.

Figure 8.
Mould with concentric squares.

Table 1.
HIC comparison of tiles with density 0,67 Kg/dm^3-Falling critical height 1,5 m.

Mould geometry	HIC values
Circles and cross	1.47
Five circles	1.38
Curves and circles	1.48
Hexagons with curved edges	1.40
Nine hexagons	1.48
Concentric squares	1.49
Network	1.48
Rhombs	1.28
Twentyfive circles	1.37

Conclusions

Tire rubber granulates previously characterised in terms of morphological observations were consolidated into compression moulded samples by testing the use of two kind of polymeric resins. With the main goal to explore civil applications to recycle tires at the end of their useful life, specific interest was devoted to obtain anti-shock tiles or panels with low thermal conductivity. In this context, products were subjected to mechanical and thermal tests, respectively.

Compression measurements emphasised that the final performance of rubber based compounds is slightly influenced by the resin content unless it is considered the use of particles with very low mean size or the addition of Adsyl 5C30F or Hifax CA10A, perhaps owing to chemical interactions at the interphase.

Impact tests performed according to the European normative for the safety of playgrounds UNI EN 1177 indicated that the impact response of tile samples is clearly influenced by the base design configuration as well as on their density.

Finally, for thermo insulating applications preliminary results have demonstrated that final performances are again essentially determined by the density of panels improving with lowering of this parameter.

As a whole, promising alternatives to the combustion approach could be foreseen to reduce the environmental impact of used tires. Future work could be dedicated to

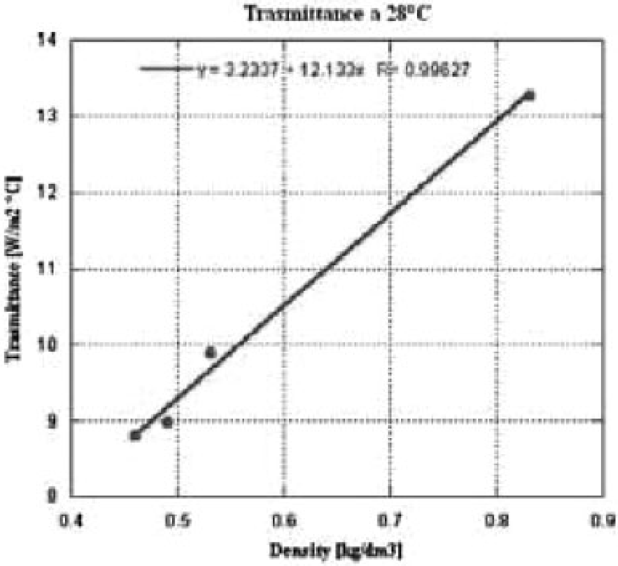

Figure 9.
Thermal conductivity vs tile density.

optimize the processing conditions and further improve specific ultimate characteristics. Moreover interest could be dedicated to investigate the effect, on the same properties herein discussed, of both any preliminary chemical activation at the interphase and the use of recycled resins to consolidate rubber particulates.

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