

MECHANICAL PROPERTIES OF RUBBER - AN OVERVIEW

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Abstract: *Several studies have been carried out to reuse scrap-tires in a variety of rubber and plastic products, incineration for production of electricity, or as fuel for cement kilns, as well as in asphalt concrete. Studies show that workable rubberized mixtures can be made with scrap-tire rubber. This paper presents an overview of some of the research published regarding the use of scrap-tire in cement concrete. The paper details the likely uses of rubberized concrete. In recent years, the production of elastomeric blends has markedly increased, due to their well balanced physical and mechanical properties, easy processability and relatively low cost.*

Key words: *rubber, tire, PET, HDPE, mechanical properties.*

1. Introduction

Global warming is a major environmental problem. The use of synthetic plastics results insignificant emissions of greenhouse gases.

Recycling involves processing used materials into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage and reduce air pollution and water pollution by reducing the need for “conventional” waste disposal.

Recyclable materials include many kinds of glass, paper, metal, plastic, textiles, and electronics. Several other materials are also commonly recycled, frequently at an industrial level. Tire recycling is also common.

The interest in recycling of rubber has been increasing over the last decade. This has been driven by the concern over scrap

tires and rubber products effects on the environment. Since 2004 the Romanian Government adopted a decision on the management of used tires, that includes collection and recovery of used tires, which has increased from 60% to the maximum recovery of 80%.

Used tires can be added to asphalt for producing road surfaces or to make rubber used on playgrounds for safety.

2. Tire Recycling

Tire recycling is the process of recycling vehicles tires that are no longer suitable for use on vehicles due to wear or irreparable damage (such as punctures).

These tires are among the largest and most problematic sources of waste, due to the large volume produced and their durability. Those same characteristics which make waste tires such a problem

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also make them one of the most re-used waste materials, as the rubber is very resilient and can be reused in other products.

2.1. Recycling Methods

At the present time the major methods of producing recycled rubber are reclaiming, ambient grinding and cryogenic grinding. Reclaiming of silicone and butyl rubbers is common and the resulting recycled products are useful for cost reduction and improved processing when added to virgin compounds.

2.2. Why Reclaim Or Recycle Rubber?

Rubber recovery can be a difficult process. There are many reasons, however why rubber should be reclaimed or recovered:

- Recovered rubber can cost half that of natural or synthetic rubber.
- Recovered rubber has some properties that are better than those of virgin rubber.
- Producing rubber from reclaim requires less energy in the total production process than does virgin material.
- It is an excellent way to dispose of unwanted rubber products, which is often difficult.
- It conserves non-renewable petroleum products, which are used to produce synthetic rubbers.

- Many useful products are derived from reused tires and other rubber products.

- If tires are incinerated to reclaim embodied energy then they can yield substantial quantities of useful power. In Australia, some cement factories use waste tires as a fuel source.

3. Research Findings

Sukanya S., et al. [6] studied the properties of thermoplastic elastomers from waste polyethylene (WPE) and reclaim rubber (RR). It is observed that the tensile strength decreases and the elongation at break increases with the increase in the RR proportion in the blend. WPE has a tensile MPa on incorporation of about 70 wt. % proportion of RR (WR70). This is expected as RR is a partially degraded rubber and contains carbon black as well as other additives in addition to the unperturbed sulfur crosslink.

As seen in Table 1, the elongation at break increases from 101% for WPE to 789% for the WR70 blend. This trend has also been reflected in the flexural strength and flexural modulus of the WPE : RR blends, which decreases with an increase in RR content. The tensile impact strength increases with the increase in RR content in the blend up to 20 wt. % of RR.

Mechanical properties of WPE : RR blends [1]

Table 1

Sample code	Tensile strength [MPa]	Elongation at break [%]	Flexural strength [MPa]	Flexural modulus [MPa]	Tensile impact strength [kJ/m ²]	Hardness (Shore D)
WR0	21.2 ± 0.2	101 ± 3	25.4 ± 0.5	1154 ± 10	144 ± 57	28
WR5	18.6 ± 0.4	390 ± 7	13.9 ± 0	334 ± 4	311 ± 15	41
WR10	18.3 ± 0.2	384 ± 4	14.1 ± 0	412 ± 18	382 ± 5	43
WR15	18.2 ± 0.3	383 ± 12	14.0 ± 0.6	418 ± 8	451 ± 25	45
WR20	16.3 ± 0.4	420 ± 4	12.8 ± 0.3	320 ± 3	461 ± 17	47
WR30	15.8 ± 0.5	456 ± 8	12.3 ± 0.2	311 ± 5	462 ± 16	47
WR40	13.6 ± 0.3	524 ± 10	11.8 ± 0.4	302 ± 8	463 ± 13	45
WR50	12.1 ± 0.9	630 ± 6	10.7 ± 0.1	304 ± 11	466 ± 5	44
WR60	11.9 ± 0.4	659 ± 10	10.2 ± 0.3	290 ± 13	525 ± 16	43
WR70	9.8 ± 0.1	789 ± 5	9.7 ± 0.2	278 ± 17	577 ± 19	42

Table 2
Variation in mechanical properties of WR15 blend with addition of treated and untreated fly ash [1]

Sample	Fly ash (FA) content	Si-69 content (CA)	Tensile strength [MPa]	Elongation at break [%]	Flexural strength [MPa]	Flexural modulus [MPa]	Tensile impact strength [kJ/m ²]	Hardness (Shore D)
WR15	0	0	18.2 ± 0.3	383 ± 12	14.0 ± 0.6	418 ± 8	451 ± 25	45
WR1510FA	10	0	18.7 ± 0.1	40.2 ± 3.6	16.3 ± 0.5	423 ± 10	156 ± 16	46
WR1520FA	20	0	18.9 ± 0	31.2 ± 2.4	18.5 ± 1.4	612 ± 50	130 ± 18	49
WR1530FA	30	0	19.2 ± 0.3	26.0 ± 1.2	18.7 ± 1.2	614 ± 45	130 ± 18	50
WR1540FA	40	0	19.6 ± 0.1	20.2 ± 2.2	18.7 ± 0.2	620 ± 30	128 ± 10	52
WR1550FA	50	0	21.8 ± 0.2	14.0 ± 1.3	19.0 ± 1.9	698 ± 60	127 ± 10	55
WR1560FA	60	0	-	-	20.0 ± 0.2	1087 ± 199	-	57
WR1550FA1CA	50	1	23.1 ± 0.4	13.2 ± 1.2	19.6 ± 0.9	700 ± 57	138 ± 10	56
WR1550FA3CA	50	3	24.8 ± 0.5	13.5 ± 0.7	23.9 ± 0.3	712 ± 26	166 ± 5	58
WR1550FA5CA	50	5	21.6 ± 0.1	17.7 ± 2.1	18.0 ± 0.3	665 ± 22	142 ± 8	60

Thereafter it becomes difficult to determine the tensile impact strength, as the samples do not break with further addition of RR due to higher elongation.

The Shore D hardness of the blends increase with addition of RR onto WPE and this increase is distinct up to 20 wt. % of RR, thereafter it levels off, or even decreases marginally at higher proportions of 50 to 70 wt. % RR content.

The elongation at break of the WR15 blend decreases drastically on incorporation of FA filler onto it. The results are shown in Table 2. The decrease is steady with increase in fly ash (FA) content. It is observed that the hardness of the blend increase from 45 to 55 Shore D as the FA filler loading increases to 50 wt.%. This is because FA consists of a mixture of inorganic metal oxides such as SiO₂, Al₂O₃ and Fe₂O₃, which are rigid in nature.

It can be clearly seen that the tensile strength increases with surface treatment of FA with Si-69 varying from 1 to 3% by wt. On increasing the concentration of Si-69 to 5% by wt. there is a decrease in the tensile

strength of the composite. This may be due to the plasticizing effect of Si-69 between the FA and the blend matrix at higher concentrations of the coupling agent [1].

Hua Z., et al. [2] investigated the effect of NCG (nickel-coated graphite) conductive filler loading. It was found that NCG particles had poor mechanical strength that it can be ground into smaller particles during the blending process if the shear force was too large. The electrical conductivity of methyl vinyl silicone rubber master batch (VMQ)/NCG composites increased with the increase of NCG filler loading, and the threshold value of VMQ/NCG was lower than that of VMQ composites filled with silver-coated glass bead.

As seen in the Table 3, the stress at 100% elongation and shore A hardness increased with the increase of loading amount of the NCG powder, and the elongation at break decreased with the increase of loading amount of the NCG filler. The tensile strength first dropped drastically from 4.56 to 2.90 MPa, and then showed a slight increase from 2.90 to

Mechanical properties of VMQ/NCG [2]

Table 3

Compound	Stress at 100% elongation [MPa]	Tensile Strength [MPa]	Elongation at break [%]	Shore A Hardness
N0	1.03	4.56 ± 0.07	475 ± 6	30
N60	1.38	2.90 ± 0.03	240 ± 5	42
N80	1.66	3.12 ± 0.08	219 ± 7	49
N100	1.78	3.24 ± 0.06	205 ± 3	54
N120	2.22	3.53 ± 0.06	200 ± 3	59
N140	2.65	3.62 ± 0.08	172 ± 4	62
N160	2.75	3.68 ± 0.04	162 ± 9	65
N180	3.06	3.78 ± 0.09	149 ± 4	69
N200	3.26	3.87 ± 0.02	142 ± 6	73

3.87 MPa with the increase of NCG filler from 60 to 200 phr.

This phenomenon can be explained as following: The NCG-unfilled composites, namely the silica-containing rubber masterbatch KE-931U, showed high tensile strength because of the reinforcing action of silica. When the NCG particles were added to VMQ rubber, on the one hand, the tensile strength of the composites decreased sharply owing to the non-reinforcing effect of micron-scale filler. On the other hand, because of the high aspect ratio of NCG particles, the conductive filler showed orientation distribution in the VMQ rubber to a large extent.

It is worth pointing out that the slight increase of the tensile strength is very important for the practical applications, because the disadvantage of the high conductive rubber is low mechanical strength [2].

Abdelmouleh M., et al. [1] have worked on the use of cellulose fibers as reinforcing elements in thermoplastic low density polyethylene (LDPE) and natural rubber (NR) matrices.

It constitutes a good alternative to glass inorganic fibers commonly used as a reinforcing material. Four different cellulose fibers with different average lengths were used: avicel, technical, alfa pulps and pine fibers. Two thermoplastic polymers, LDPE and NR, were employed as matrices.

Cellulose fibers were incorporated into the matrices, as such or after chemical surface modification involving three silane coupling agents, namely *c*-methacryloxypropyl-trimethoxy (MPS), *c*-mercaptopyltrimethoxy (MRPS) and hexadecyltrimethoxysilanes (HDS). As expected, the composites treated with MPS and MRPS displayed good mechanical performances.

The evolution of tensile stress vs. strain curves at different fiber contents is presented in Figure 1. All the curves display a linear Hookean range at low strain (<20%) followed by a softening region which continues up to 40%. Then the plastic deformation under roughly constant stress

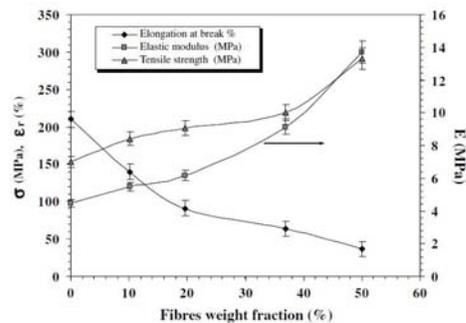


Fig. 1. Evolution of the Young Modulus (*E*), tensile strength, and elongation at break vs. cellulose fibers content for LPDE-based composite reinforces with untreated Tech-2500 cellulose fibers [3]

is maintained until the failure occurs. With the increase of the fibers content, both the modulus and the tensile strength increase, while the elongation at break decreases.

One can notice that the modulus did not increase linearly with the fibers fraction and a discontinuity occurred at about 15 vol. %, composition above which a much faster increase is observed.

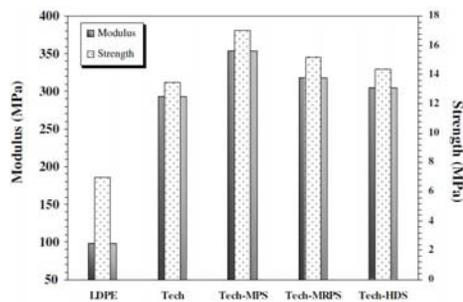


Fig. 2. *Young's modulus and tensile strength of LDPE-based composites reinforced with 50% Tech-2500 celulosic fibers submitted to different fiber surface treatment [3]*

For composites containing 50 wt% of Tech-2500 cellulose fibers, it reveals that both the modulus and tensile strength are

enhanced by the fiber treatment. However, this evolution depended on the silane structure. Thus, Figure 2 shows that the tensile strength and the modulus increased by 26% and 17%, respectively, for MPS and by only 12% and 6%, respectively, for MRPS. On the other hand, only a modest rise in tensile strength (about 6%) was observed after treatment with HDS silane [3].

Qinfu L., et al. [3] carried out investigations to study the properties of vulcanized rubber nanocomposites filled with nanokaolin (NK) and precipitated silica (PS), results presented in Table 4.

One kind of NK powder has been introduced into four types of rubber, specifically styrene butadiene rubber (SBR), natural rubber (NR), butadiene rubber (BR) and ethylene-propylene diene methylene (EPDM). Their reinforcing effects were evaluated by comparisons with those from PS.

The tensile strength given by NK is close to that of PS in SBR composites, and exceeds those from PS in NR, BR and EPDM composites. For the elongation at break and rebound elasticity (NK) is and tear strength, NK is dominant in NR, but there are some differences compared with

Mechanical properties of vulcanized rubber filled with PS and NK [4] Table 4

Testing item	NK	NR		Testing item	NK	EPDM	
		PS	NK			PS	NK
Shore A hardness	54	78	56	Shore A hardness	42	86	64
Tensile strength [MPa]	16.35	16.78	26.85	Tensile strength [MPa]	7.48	13.34	17.19
Elongation at break [%]	767.20	560.80	622.40	Elongation at break [%]	796.00	446.60	566.40
300% modulus [MPa]	2.63	6.31	7.07	300% modulus [MPa]	1.45	8.80	4.87
500% modulus [MPa]	3.75	13.72	17.74	500% modulus [MPa]	2.04	-	11.32
Tear strength [kN/m]	29.82	35.00	42.85	Tear strength [kN/m]	19.31	58.95	34.61
Rebound elasticity [%]	49	46	57	Rebound Elasticity [%]	58	52	49

PS in SBR, BR and EPDM. The structure and shape of materials are the main factors leading to the performance discrepancy of different reinforcing agents. The NK with sheet structure and flexibility contributes to good rebound elasticity obviously superior to PS.

The modulus and hardness are the most obvious properties to be influenced, and will be increased with increased cross-link density the hardness of the four kinds of rubbers filled with PS, and the 300% modulus of SBR and EPDM is seen to be higher than that of the comparative rubber filled with NK. The 300% modulus of NR/NK compound, however, is slightly higher than that of NR/PS compound. These phenomena indicate that PS improves the chemical cross linking of large rubber chains more effectively than NK in SBR rubber and EPDM, but NK seems better than PS in the NR rubber [4].

Shuguo C., *et al.* [5] studied the mechanical properties, flame retardancy, hot-air ageing, and hot-oil ageing resistance of ethylene-vinyl acetate rubber (EVM)/hydrogenated nitrilebutadiene rubber (HNBR)/magnesium hydroxide (MH) composites.

At room temperature the EVM and HNBR with different weight ratios were first mixed with auxiliary materials. Then MH with tricresyl phosphate (TCP) and A171 was added. Dicumyl Peroxide (DCP) was added in the end.

The elongation at break, angle tear strength, and trousers tear strength shown in Figure 3 increase with increasing HNBR fraction. The elongation at break, angle tear strength, and trousers tear strength increase from 223%, 40.7 N/mm, 8.9 N/mm for EVM/MH composite to 255%, 44.9 N/mm, 13.0 N/mm for EVM/HNBR/MH (75/25) composite.

The shore A hardness and tensile set modulus decrease with increasing HNBR fraction, indicating the crosslinking density

decreased in the blends. The low-temperature bending property becomes better when HNBR content is more than 25 phr, indicating HNBR is more feasible than EVM.

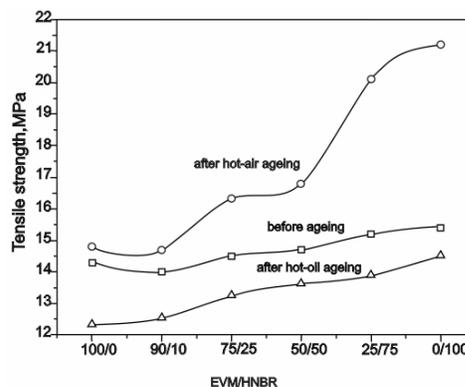


Fig. 3. The tensile strength EVM/HNBR

EVM/HNBR/MH composites have higher elongation at break and tear strength than EVM/MH composite, which can attribute to that HNBR with excellent flexibility is superior to EVM in tensile strength, elongation at break, and tear strength, as well as the good compatibility and heterogeneous co-vulcanizing between EVM and HNBR as both of them are polar rubber two rubbers (such as EPDM/NBR20 and NBR/SBR21) are not compatible, they would show best mechanical properties with a special ratio, due to their relative uniform distribution of components. The hot-oil ageing resistance and hot-air ageing resistance of EVM/HNBR composites are summarized in Figure 4.

Although in EVM/HNBR blends, the mechanical properties changed regularly with increasing HNBR fraction, indicating the EVM and HNBR are compatible with each other; the flexibility and elasticity of the rubber chains were more when HNBR was incorporated into EVM, which also resulted in less rigid rubber vulcanizates and a decrease in hardness [5].

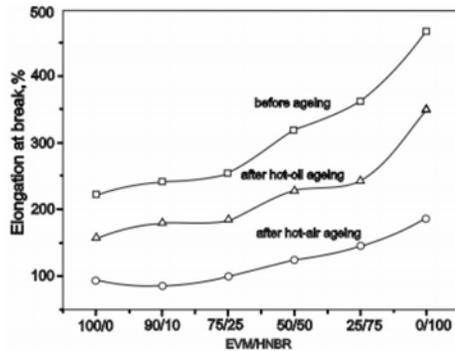


Fig. 4. The elongation at break for EVM/HNBR [5]

Rattanasom N., et al. [4] carried out investigations to study NR vulcanizates containing various fillers were prepared to have the same hardness level, and their mechanical properties were compared and related to the degree of filler dispersion.

The results presented in Figures 5 and 6 show that modulus, hardness and tear strength of NR filled with conventional fillers and clay are superior to those of the gum. Hardness and modulus increase noticeably when 6 phr (parts of hundred ratio) of clay is added.

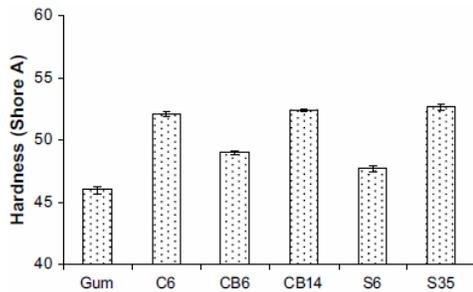


Fig. 5. The hardness of composites [6]

At equal loading of fillers, clay-filled NR vulcanized exhibits higher modulus, hardness, tensile strength compression set but lower heat build-up resistance and crack growth resistance than those of NR vulcanized containing conventional fillers. However, their tear strength is not much different.

Compared to carbon black (CB), a higher amount of silica is needed to achieve the same hardness as that of the clay-filled sample. At the same hardness value, CB-filled vulcanizate gives the better overall mechanical properties followed by the clay-filled and silica-filled vulcanizates, respectively.

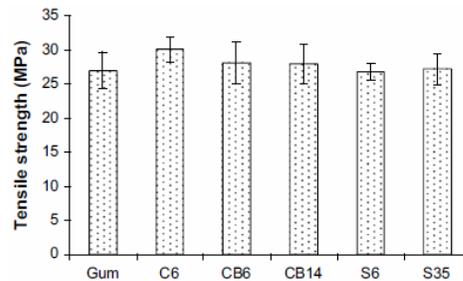


Fig. 6. The tensile strength of composites

The poor silica dispersion and lower crosslink density of silica-filled vulcanizate (S35) are thought to be the causes of its poorer properties compared to the other vulcanizates [6].

Upinder P.S., et al. [7] studied some parameters by adding wollastonite mineral as filler into polypropylene (PP). The silicon rubber was used to reduce stiffness and to improve the flexibility and where as malicanhydride used as compatibilizer.

Some novel polypropylene composites having wollastonite at different compositions of 10%, 20%, 30% and 40% were prepared by compounding with and without 5% silicon rubber. Subsequently, mechanical properties and heat deflection temperatures were evaluated for all the composites to provide a database for the probable industrial applications of these composites.

An increase of wollastonite amount in the polypropylene, in general, resulted in a reduction in unnotched impact strength as well as tensile strength, and an increase in notched impact strength, heat deflection temperature (HDT), flexural strength and flexural modulus.

Addition of 5% rubber in the polypropylene composites having wollastonite at different compositions of 10%, 20%, 30% and 40% provided, in general, enhanced HDT, notched impact strength and flexural strength, but, reduced unnotched impact strength, tensile strength and flexural modulus [7].

Conclusions

The factors affecting the properties of blended polymers are:

1. Particle size, size distribution and filler content.
2. Particle shape and surface structure.
3. Mechanical properties of the mineral (stiffness, strength etc.).
4. Compounding and molding methods used.
5. Bond strength between mineral and polymer. This will be influenced by the type of dispersion aid or coupling agent used.
6. Polymer properties, ductile polymers will behave differently than brittle ones when adding minerals to polymers.

References

1. Abdelmouleh, M., Boufi, S., et al.: *Short Natural-Fiber Reinforced Polyethylene and Natural Rubber Composites: Effect of Silane Coupling Agents and Fibers Loading*. In: *Composites Science and Technology* **67** (2007), p. 1627-1639.
2. Hua, Z., et al.: *Study on the Structure and Properties of Conductive Silicone Rubber Filled with Nickel-Coated Graphite*. In: *InterScience* (2009), p. 2710-2717.
3. Qinfu, L., et al.: *Properties of Vulcanized Rubber Nanocomposites Filled with Nanokaolin and Precipitated Silica*. In: *Applied Clay Science* **42** (2008), p. 232-237.
4. Rattanasom, N., et al.: *Comparison of the Mechanical Properties at Similar Hardness Level of Natural Rubber Filled with Various Reinforcing-Fillers*. In: *Polymer Testing* **28** (2009), p. 8-12.
5. Shuguo, C., et al.: *Mechanical Properties, Flame Retardancy, Hot-Air Ageing, and Hot-Oil Ageing Resistance of Ethylene-Vinyl Acetate Rubber/Hydrogenated Nitrile-Butadiene Rubber/Magnesium Hydroxide Composites*. In: *Wiley InterScience* (2009), p. 3310-18.
6. Sukanya, S., et al.: *Thermoplastic Elastomers from Waste Polyethylene and Reclaim Rubber Blends and Their Composites with Fly Ash*. In: *Process Safety and Environmental Protection* **118** (2010), p. 1-11.
7. Upinder, P.S., et al.: *Evaluation of Mechanical Properties of Polypropylene Filled with Wollastonite and Silicon Rubber*. In: *Materials Science and Engineering A* **501** (2009), p. 94-98.