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Evaluation of the Mechanical Properties of Natural Rubber Composites Prepared from Hybrid Carbon Black and Ceramic Waste

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Abstract
Large amounts of ceramic waste produced in ceramic industries and by ceramic vendors do not have a proper method to reuse and mainly thrown away into landfills since fired ceramics have already been sintered and thus their utilization as a raw material is limited. Thus, a proper management of such industrial waste is eminent. This research is dedicated to evaluating the possibility of using such ceramic waste as a low-cost filler material in the manufacture of natural rubber based composites. Hybrid composites were prepared from the combination of ceramic waste with conventional filler, carbon black incorporated with natural rubber. Elemental analysis and composition of the phases of the ceramic particles were determined by X-ray fluorescence and diffraction respectively. Natural rubber based composites were prepared with different ratios of ceramic filler and carbon black filler loadings. The mechanical properties of the composites such as tensile strength, young modulus, abrasion resistance, flexural strength and hardness were evaluated. The composites were found to have an exciting enhancement of mechanical properties.

Keywords*: Ceramic waste, hybrid composite, carbon black, Natural rubber, mechanical properties*

1. INTRODUCTION

The demand of polymers in many applications has experienced steady growth over the years. In developed countries of Europe and America, the volumes of polymers used are more than that of metals or ceramics [1]. One of the most important phenomena in polymer science that has captured great research and industrial interest is the blending of polymers, since blending is a relatively simple way to create materials with significantly improved properties. Many people have tried to use various industrial by-products as fillers in compounding; these fillers are either used raw or modified.

In recent years, the interest in using industrial by-product in bio-composite has grown because they are light weight, combustible, non-toxic, low cost and easy to recycle. Industrial activities reveal a continuous demand of improved material that satisfy increasingly stringent requirement such as high physical, mechanical characteristics with cost reduction. This requirement can be achieved through the use of composite materials whose constituent synergistically comply with the need for specific application [2]. It is not surprising, therefore that more than 50% of all chemist, physicist, mechanical engineers and many material scientist are involved with research or development work with polymer composites. Materials from renewable resources are being sought as replacement and do not only act as reinforcement elements, but also the matrix phase of composite materials [3]. Considering the high performance standard of composite materials in terms of durability, maintenance and cost effectiveness, application of natural fillers reinforced composite as construction material in creating built environment holds the enormous potential and are critical for achieving sustainability. Hybrid composites are one of the emerging fields in polymer science that are gaining attention for application in various sectors such as buildings, aeronautic and automotive engineering. Advances are also being made into the use of industrial by-product, such as rice husk, groundnut shell, industrial waste such as nylon etc [4].

Natural rubber occurs naturally in form of isoprene. Milky natural rubber latex is extracted from Heveabrasilienses tree and is widely used to prepare many rubber products. The presence of NR in rubber products give the material beneficial technical characteristics such as considerable tensile strength, excellent resilience, high flexibility and resistance to impact and wear [5] and [6]. However, less resistance to oxidation, ozone, weathering, solvent and wide range of chemicals due to its unsaturated chain structure and polarity are some of its disadvantages [7]. These limitations hinder the use of natural rubber mainly for technical and engineering applications. However, these shortcomings could be overcome via chemical manipulation of the polymer chain or blending with other polymers and materials, for example, ceramics. Fillers represent one of the most important additives used in rubber compounding, they are added to rubber formulation in order to optimize properties needed for service applications. Reinforcement of rubber with particulate fillers is a subject that has captured the interest of large numbers of researchers. Property advantage obtainable from filler reinforced rubber vulcanizates includes design, flexibility, improved physical, mechanical properties, hardness and processing economy [8].

A considerable amount of research has been made over the last several years with a view to obtaining new polymeric material with enhanced specific attributes for specific application.Much attention is devoted to the simplest route for combining outstanding properties of different existing polymers that is, blending polymer [9].

In the compounding of hybrid composite, fillers are major additives; incorporation of such additives into the rubber matrix enhances properties such as tensile strength, modulus, tear strength, abrasion resistance, stiffness and processability. The cost of manufactured rubber product is also significantly reduced [10].

In the vulcanization of rubber, carbon black is the main filler used. However, because of the origin of carbon black from petroleum, carbon black causes pollution and gives the rubber a black color. The filler is also expensive [11]. The instability of prices of crude oil and its derivatives is also giving concern in the industries and so triggered the search for fillers that are obtainable from other sources.

Different materials have been used to reinforce natural or synthetic rubber such as clay [6], organo clay [12] coal shale-based fillers [13], recycled rubber powder [9], graphite [14], agricultural or industrial wastes. In addition, the processing of these composite materials is flexible and economical, it is also possible to use the same machinery employed with other traditional fillers.

Currently, different hybrid synchronization systems have been examined by numerous researchers. Carbon black-silica hybrid filler system glances to be the most popular and successful [15]. The carbon black-silica hybrid filler system recommends generally overall improved mechanical properties compared to individual one [16].

The purpose of this research is to study the effects of ceramics waste and carbon black fillers in hybrid composite on the properties of Natural rubber.

2. MATERIALS AND METHODS

2.1 Preparation of Ceramic Waste Powder and Characterization

Ceramics floor tile was collected domestically. It was washed to remove dirt particles, and then it was taken to a quarry factory where it was crushed and grinded using a mechanical method. The crushed ceramic waste was sieved using a stainless sieve of size 120 µm.

Elemental analyses and composition of the phases of the ceramic particles were determined by X-ray fluorescence spectrometer (model TEFA ORTEC, Phillip Pw 1210) and X-ray diffractometer respectively.

2.2 Compounding of Natural Rubber filled Ceramic Waste Composites

The Rubber mixes were prepared on a laboratory sized two roll mill and the vulcanization was done to prepare the final composites. Mixing follows ASTM D3184-8 standard.

Natural rubber based composite materials was prepared with different ratios of ceramic and carbon black hybrid filler loadings as shown in Table 1.

Table 1: Formulation for the Natural Rubber Composites

Ingredients	Pphr
Natural Rubber	100
Zinc oxide	5
Stearic acid	2
TMTD	2.4
TMQ	1.5
Sulphur	2.5
MBTS	2
Processing Oil	5
Ceramic waste/carbon black	00/00, 60/00, 50/10, 40/20, 30/30, 20/40, 10/50, 00/60

2.3 Determination of Mechanical Properties

Various mechanical property tests were carried out on the rubber compound to determine the effect of ceramic waste filler and carbon black filler on the properties of the rubber. The following mechanical properties were analyzed;

2.3.1 Determination of Tensile Properties

The tensile properties of samples were determined by a tensometer model zugfestingkeit 440gu Philips at a specified speed using a dumbbell test pieces of a specified dimension. The test sample was tested in the machine given straight tensile pulling without any bending or twisting. The machine measured both the tensile stress and tensile strain .The tensile stress is the strength of pull in the area. The tensile strength and modulus were determined by the tensometer [17].

2.3.2 Determination of Flexural Test

Flexural testing was performed in accordance with ASTM method D790 to measure the flexural strength. The flexural test measured the force required to bend a beam at a specific rate. Flexural modulus is an indication of a material stiffness when bent on a three point apparatus. The three points bending fixture support the specimen and the load is applied to the center by the loading nose producing three points bending at specified rate. The main parts of this test are specimen depth (thickness), the support span, the speed of the loading and their maximum deflection for the test.

2.3.3 Determination of Hardness

The hardness of the molded samples was determined using a hardness tester (Qualitest HP-AS Shore A Durometer). The test was performed on unstressed samples. Readings were taken after 10 seconds from the indentation as IRHD values.
Abrasion resistance property of ceramic waste and carbon black hybrid Natural rubber composites was carried out using standard procedures.

3. RESULTS AND DISCUSSION

3.1 Characterization of Ceramic Waste Powder

Table 2:Elemental analysis of ceramic waste powder obtained from XRF

Element	Mass %
SiO_2	55.10
Al_2O_3	15.10
Fe_2O_3	12.30
TiO_2	0.01
Na_2O	0.45
K_2O	0.50
MnO	0.22

According to Table 2, Si present as SiO_2 has a mass percentage of 55.10% and Al present as Al_2O_3 has a mass percentage of 15.10%. Elements like Fe, Ti, Na, k and Mn are present in small amount in the ceramic powder.
Fig 1 shows X-ray diffraction (XRD) of the ceramic sample. The sharp peak corresponding to SiO_2 indicates the presence of clusters of silicon. The result reveals that a high percentage of the particles are crystalline while a few of them are amorphous.

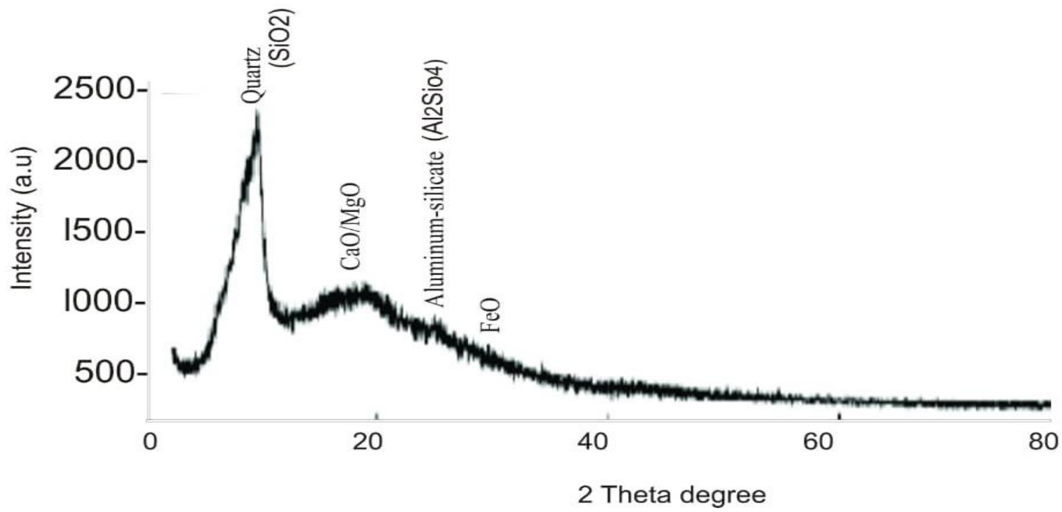

Figure1: X-ray diffractogram of ceramic powder

3.2 Mechanical Properties of the NR Composites

Table 2:Mechanical Properties Test Results

Properties	**Hybrid Filler Loadings (pphr) Carbon black/Ceramic waste powder**							
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**
	00/00	**60/00**	**50/10**	**40/20**	**30/30**	**20/40**	**10/50**	**00/60**
Tensile Strength (MPa)	36.67	37.00	35.67	40.00	37.33	33.67	36.00	37.33
Young Modulus (MPa)	331.33	436.00	353.67	347.33	338.00	434.33	355.67	356.00
Flexural Strength (MPa)	21.67	27.67	23.33	26.67	21.00	20.33	23.00	27.00
Hardness (IRHD)	15.00	21.00	30.00	37.00	42.00	47.00	46.00	39.00
Abrasion Resistance (%)	98.80	98.25	98.28	98.21	97.89	98.26	98.28	98.21

3.2.1 Tensile Strength

The tensile strength of hybrid composites is revealed in Table 2. The incorporation of carbon black and ceramic waste powder in their relevant hybrid NR composite improved tensile strength at filler loading amount 40/20 pphr better than only ceramic, carbon black and the unfilled vulcanizate. This could be attributed to adequate interaction of carbon black as well as ceramic waste powder with NR. The filler reinforcement level improves with reduced amount of ceramic waste in the hybrid composition.

3.2.2 Young Modulus
The result for young modulus indicate that the highest value of modulus for hybrid composite was obtained at 20/40 pphr carbon black/ceramic filler composition. It was observed that the modulus of the composites improved with the increasing carbon black in the individual hybrid composites. This is due to the small particle size, carbon black and its aptitude to have excellent dispersion within the matrix as compared to ceramic waste powder that increased the rigidity of composites [18].

3.2.3 Flexural Strength
Flexural strength of the hybrid filler composites is lower than that of the composite filled with only ceramic and carbon black. This may be due to the polar nature of ceramic and may influence the compatibility and dispensability of filler in the rubber matrix. The filler compatibility in rubber composites depends on particle size, the structure of filler particles and surface activity [19]; [20].

3.2.4 Hardness
As shown in Table 2, hardness increases with the increase of ceramic filler across the hybrid composites and gave the highest value at 20/40 pphr carbon black/ceramic filler composition.

3.2.5 Abrasion Resistance
The abrasion resistance of the hybrid filler composites did not show any marked difference from the composites filled with only ceramic and carbon black as well as the unfilled vulcanizate. However, it was observed that the composites have very high abrasion resistance.

4. CONCLUSION
The main aim of this work is to access the effect of ceramic waste as filler on the mechanical properties of rubber vulcanizates. The mechanical properties of Natural rubber filled with hybrid ceramic waste and carbon black fillers was studied as a function of filler loading. The preliminary work showed that ceramic waste powder exhibit high reinforcing properties as filler for natural rubber compound.The results showed that the mechanical properties of the composites are greatly influenced by filler loading and the adhesion of the hybrid fillers to the rubber matrix and are therefore significant factors in determining the application in rubber compounding. The results also showed the potential application of ceramics waste filler as low cost filler in natural rubber products exhibiting high quality characteristics at moderate hybrid filler loadings of carbon black and ceramic waste powder.

This assessment revealed that ceramic waste powder can be utilized as a co-filler with carbon black. It was observed that the optimal mechanical properties of the composites are present at moderate loading of the ceramic waste powder and carbon black fillers.

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