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Polymeric composite based on waste material for high voltage outdoor application

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ABSTRACT

This paper presents the preparation of artificial reinforcement filler for polymeric composite insulation for high voltage outdoor application. The purpose of this study is to examine the possibility of waste material as filler for polymeric composite insulation that beneficial to our environment and economy. For this composite, a seashell ($CaCO_3$) and waste glass (SiO_2) were selected to produce an artificial wollastonite (calcium silicate-$CaSiO_3$) that use as filler and Polypropylene (PP) is utilized as a matrix. X-ray diffraction (X-RD) technique is applied to reveal the chemical composition of an artificial wollastonite (AW). Preparation method via melt compounding using a Haake internal mixer and a response surface methodology (RSM) statistical technique is used for sample preparation. Then, breakdown test complying with BS EN 60243-1:1998 is adopted to examine the breakdown strength of this newly polymeric composite. It was found that chemical compositions of the proposed materials similar with naturally wollastonite (calcium silicate-$CaSiO_3$) and the optimum compound is at 65/35 PP–AW wt% with 14.76 kV/mm breakdown strength. A step of processes to produce an artificial wollastonite (AW) is presented in this paper.

1. Introduction

In high voltage engineering or its applications, insulation is the most important part to prevent the flow of current to undesired paths. The dielectric strength and electrical field are a key properties of insulating material and they become the major factors that determine the failure of the insulation [1,2]. Insulation technology is still undergoing continuous development and improvement from time to time, from conventional ceramic type since the early 1900s, until the recent development of newly breed of insulation using polymeric composite materials [3].

The application of polymer composites has increased greatly because it is a relatively easy way to obtain new materials with balanced properties. Since polymeric composite insulation is accepted, a large number of studies and research activities for improvement on their performance had been made [3]. These include the development of new materials, the understanding of deterioration of chemical, electrical and mechanical over the stress, design and manufacturing process of material, and also development of practical testing, monitoring, reliability methods of measuring and service performance.

The Handbook of Electrical and Electronics Insulating Material [4] has summarized all of the requirements and categories covered such as electrical and electronic insulating materials and classification of electrical key properties for insulating material. It also comprises of definitions, steps of materials selection, classifications, requirements, test methods, recommended practices of electrical insulating materials and also type of reinforcement or filler to enhance the performance of polymeric or its composite material.

Reinforcements material or fillers are often used to improve the polymeric composite properties in terms of its electrical insulation properties, mechanical properties and chemical stability as well as to reduce the cost of material. Commonly used reinforcement and fillers for electrical application are calcium carbonate, alumina trihydrate, kaolin, mica flake and glass. Another reinforcement that widely used in electrical application is wollastonite. Wollastonite with chemical formula $CaSiO_3$-calcium silicate is a naturally occurring mineral with many unique characteristics and it is normally present in limestone. Wollastonite increases the performance of many products including plastics, paints, coatings, construction materials, friction product like brake pads, ceramic and metallurgical applications. In plastics or polymer, wollastonite improves the durability of the composite due to its acicular or needle-like structure. It also enhances electrical insulating properties, adds fire resistance, and improves dimensional stability. Refs. [5–8] reported on wollastonite, silica and calcium carbonate as reinforcement or filler in ceramic and polymer application, where United State and China are the main countries that produce this naturally mineral as a commercial product over the world.

The products of modern material research will impact our everyday lives, environment and economy. By these reasons this study is carried out. This study is attempted to discover a new valuable composite from a waste material with a concept of green technology the being beneficial to our environment, health and

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economy. It also concerning to global environmental issue to promote the use of renewable resources [9]. The aim of this study is to investigate the possibility of using artificial wollastonite (AW) as reinforcement for Polypropylene (PP) polymeric insulating material and their potential for high voltage insulation application such as for cable termination, insulator and bushing. It involves the seashell (calcium carbonate-$CaCO_3$) and glass (silica-SiO_2) as waste material which is put through an experimental process ($CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$) to produce an artificial wollastonite (calcium silicate-$CaSO_3$) as reinforcement for electrical application. The chemical composition of this newly artificial wollastonite (AW) is examined using X-RD approach. In order to ensure this newly polymeric composite is suitable for outdoor high voltage application, the statistical technique response surface methodology (RSM) is used for sample specimen preparation. Then dielectric strength of this polymeric composite is examined according to BS EN 60243-1 [10].

2. Material

A seashell or simply known as a shell is a part of mollusk and from a Cardiidae family. In this study, the shell from species of bivalves is selected and it is a highly elastic lightweight solid composite consisting of 98% calcium carbonate-$CaCO_3$ and 2% organic polymer proteins adhesive.

Glass is a very solid material that possesses of an amorphous or non-crystalline material. Glass is typically brittle, optically transparent. It is normally made of silica-SiO_2 and several minor additives are added for chemical stability. In this study, a waste window commercial colorless amorphous glass is selected as a silica-SiO_2 source for this AW. This commercial glass or named as soda-lime glass has roughly chemical composition of 75% silica (SiO_2) and 25% composition of sodium carbonate (Na_2CO_3), calcium oxide (CaO) and some magnesium oxide (MgO).

According to the Handbook of Electrical and Electronics Insulating Material [4] there are 18 thermoplastic polymers based that applicable for electrical insulation. And referring to the tests results, have no any polymer perform excellent for all of tests key properties. But among of these polymers, Polypropylene (PP) is the most good balance of electrical and mechanical properties. PP also highly versatile resin suitable for processing in molding or extruded part and it is one of the lowest in cost since it can be synthesized from low-cost petrochemical raw materials by using a Ziegler-type catalyst [11,12]. A wide range of the polypropylene material can be obtained depending on their grade such as homopolymer, copolymers or terpolymers [4]. In this study, homopolymer grade 211 is selected due to it high purity of material and will give excellent dielectric properties. It supplied by Polypropylene Malaysia Sdn Bhd.

Alumina Trihydrate (ATH) is used as fillers and it is also known as Hydrated Alumina, Aluminum Trihydrate, and Aluminum (III) Hydroxide. At present, ATH is generally used in polymeric material for outdoor application. With the proper size and amount of ATH, it will improve flammability properties of the polymeric compounding in terms of tracking and erosion resistance as well as ageing performance. From the previous studies, it has been shown the ATH filled above the optimum level will affect the hydrophobicity of the insulating material [13,14] as well as it dielectric strength. And according to Mohamed Afendi [15], typically industries use 50–150 in part per hundred (pph) of formula by weight of ATH in compound or equivalent to 40–60% of the compound total weight [8]. ATH with chemical formulation $Al(OH)_3$ is selected and was produced by Hamburg Chemical, Germany.

3. Experimental works

3.1. Preparation of artificial wollastonite (AW)

In this study, the developments of AW have been prepared by the following processes. The naturally seashell is cured by the heater (Memmert). The seashell is placed in a cleaned container and the heater is operated at 80 °C for 24 h. Next, Crusher Machine is used to break the waste glass material and cured seashell into granulate form. The following process is to fine grind the waste glass and seashell samples to make it into powder form. In this step, Planetary Mill Machine (Insmart System) is used with two opposing cycle. The machine is carried out at 30 min for each cycle at 400 rpm, with 15 min resting time in the between. The waste glass and seashell in a powder form is then subjected to Sieve Shaker Machine (Fritsch) for particle size separation purpose and Particle Size Distribution Machine (Mastersizer 2000) is applied for sizing range and precision confirmation. Referring to [16], it was mentioned that size of filler will influence the particle dispersion and distribution with the matrix. For the preliminary study, the powder between 43 μm and 65 μm is selected for samples preparation.

There are two main constituents that form the mineral of wollastonite; Calcium Oxide CaO and Silica SiO_2. In a pure wollastonite $CaSiO_3$, each component forms nearly half of the mineral by weight: 48.3% of CaO and 51.7% of SiO_2 [6]. In this stage the ratio of seashell (Calcium Carbonate) and waste glass (Silica) is weighed with Weighing Machine (Metter Toledo) into this particular ratio for calcinations purpose. Then, the Ball Miling Machine (RS-1S) is utilized for synthesization process of these materials. The machine

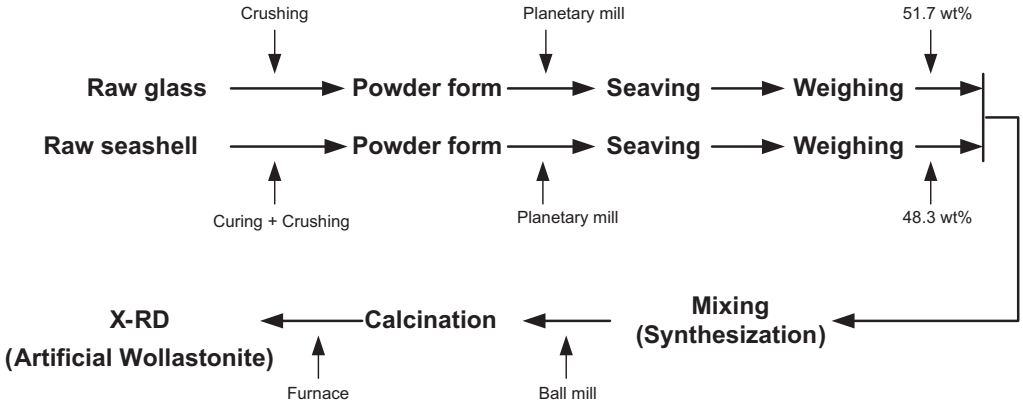

Fig. 1. Preparation of artificial wollastonite.