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The formulation and study of the thermal stability and mechanical properties of an acrylic coating using chicken eggshell as a novel bio-filler

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ABSTRACT

The objective of this study was to evaluate the effect of chicken eggshell (ES) as a bio-filler on the adhesion strength and thermal stability of acrylic coatings. The influence of different particle sizes of ES on the performance of acrylic coatings was compared with commercial calcium carbonate filler by using thermogravimetric analysis (TGA), differential scanning calorimetry (DSC) and pull-off type equipment. The surface morphologies of the coatings were characterized through field emission scanning electron microscopy (FESEM). The resistance of the coating was also investigated using water immersion and freeze–thaw tests. Morphological studies revealed that the ES filler was well-distributed in the polymer matrix. Furthermore, it was observed that the adhesion strength, thermal properties, water and freeze–thaw resistance of the coating improved with decrease in particle size of ES filler. Overall, the best results were obtained from using ES bio-filler with the smallest particle, although the particle size was bigger than that of commercial calcium carbonate. The improvement in the properties of the coating was attributed to the even distribution of ES particles and better ES/matrix interface.

1. Introduction

The effective utilization of chicken eggshell (ES) biowaste is strongly encouraged in our society for environmental and economic reasons. ES which is a byproduct of the aviculture industry has been highlighted recently because of its reclamation potential. Unfortunately, most ES waste is discarded in landfills without further processing. It is known that eggshell waste contains valuable organic and inorganic components which can be utilized in commercial products by creating new value in these waste materials. This study presents a useful bio-filler derived from ES waste and its potential role in the coating industry.

The properties of ES have been extensively studied for various purposes by many researchers. It consists of two materials: the calcified eggshell made of calcite and calcium carbonate crystals and the ES membrane consisting of organic matter. ES contains about 95% calcium carbonate in the form of calcite and 5% organic materials such as type X collagen, sulfated polysaccharides, and other proteins [1–11]. Although there have been several attempts to use ES components for various applications [12–19], its chemical composition and availability makes ES a potential source of filler for polymer composites. Much attention has been given to the study of bio-filler reinforced bio-polymer composites [20] and its application as coating pigments for ink-jet printing papers [21]. Besides its chemical composition, ES is a potential source of bio-filler for coatings because it is available in bulk quantity, inexpensive, lightweight and environmental friendly.

The major components of coatings are the binder and filler combined with other additives. Several groups have reported the influence of particle morphology, fillers, dispersing agents and nature of the binder material on the performance of coatings [22–28]. The binder forms a continuous phase that provides the main characteristics (e.g. mechanical, chemical) to the coating, while the filler is the discontinuous phase giving additional or improved properties to the coating. The selection of the specific components will affect the general performance of the coating. The compatibility between filler and binder is a key factor to improve the mechanical properties of the coating. Addition of filler decreases the tendency of degradation of the system due to external factors like water ingress [29].

This paper focuses mainly on the effect of different types of fillers and particle sizes on the thermal stability and mechanical

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Table 1
Coating formulations: composite name, filler type, filler proportion, particle size and filler surface (BET) area.

Composite name	Filler			
	Type	Proportion (% w/w)	Particle size (μm)	BET area (m^2/g)
C1 = AR-CC	CC[a]	19.00	9.22	10.56
C2 = AR-ES1	ES1[b]	19.00	31.34	87.40
C3 = AR-ES2	ES2	19.00	22.99	148.41

[a] CC: calcium carbonate.
[b] ES: eggshells.

properties of acrylic coating. Acrylic resin has high heat and impact resistance, as well as good clarity and UV resistance. This polymeric coating system is widely used to provide protective and decorative functions to substrates due to its low cost, good adhesion and more durable resin [30,31]. The application of eggshell calcium carbonate as bio-filler for acrylic resin binder provides an excellent way of recycling eggshell waste. The influence of fillers on the thermal properties, surface morphologies and mechanical properties of coatings is studied by using thermogravimetry analysis (TGA), differential scanning calorimetry (DSC), field emission scanning electron microscopy (FESEM) and pull-off type equipment. This paper also comparatively analyzes the water resistance and freeze–thaw cycle resistance of the coatings.

Clearly, there are limitations of preparing eggshell particle size in this work unless the eggshell is ground to very fine particle size, it will exhibit high aspect ratio due to the thin plate like nature of a shell. Depending on the particle sizing technique this aspect ratio property will strongly influence the assumed particle size, particularly if sedimentation or air classification is used, or indeed if the wrong form factor is applied in light scattering methods. Furthermore, proteins exist which provide some limited elasticity to the shell structure. Therefore, before recommending this novel filler for improved properties the discussion would need extending to consider matrix linkage compatibility between filler and polymer and should explore the role of aspect ratio and filler deformation properties. This will be a subject of future work.

2. Experimental work

2.1. Materials

Chicken eggshells (ES) were used as a bio-filler in this study. The ES membrane was removed and discarded. The ES were then cleaned thoroughly and dried at 90 °C for 12 h in the oven. The dried eggshells were mechanically triturated to a powder form and then milled at a milling speed of 280 rpm for 20 h and 48 h, respectively in a four-roll mill to obtain mean particle sizes of 31.34 μm and 22.99 μm. The Mastersizer Micro Particle Size Analyzer was used to measure the particle sizes and the particle size distribution profiles of the fillers are shown in Fig. 1.

In this research, acrylic resin was used as a binder. Acrylic resin is a 100% solid thermoplastic substance derived from acrylic acid, methacrylic acid, esters of these acids, or acrylonitrile and is a general purpose polymer with good hardness, broad compatibility and good weather-resistance. Acrylic resin in the form of acrylic copolymer (M_w = 60,000) was purchased from Mitsubishi Rayon Co., Ltd (Tokyo, Japan). The components of the coating formulations are listed in Table 1. The acrylic resin was mixed with mineral filler (calcium carbonate) or ES fillers until homogenous using a high-speed disperse mixer. The solvent used for acrylic resin was toluene.

2.2. Film preparation method

The polymer films were prepared by casting the solution on a glass leveled support plate. The solvent was then allowed to

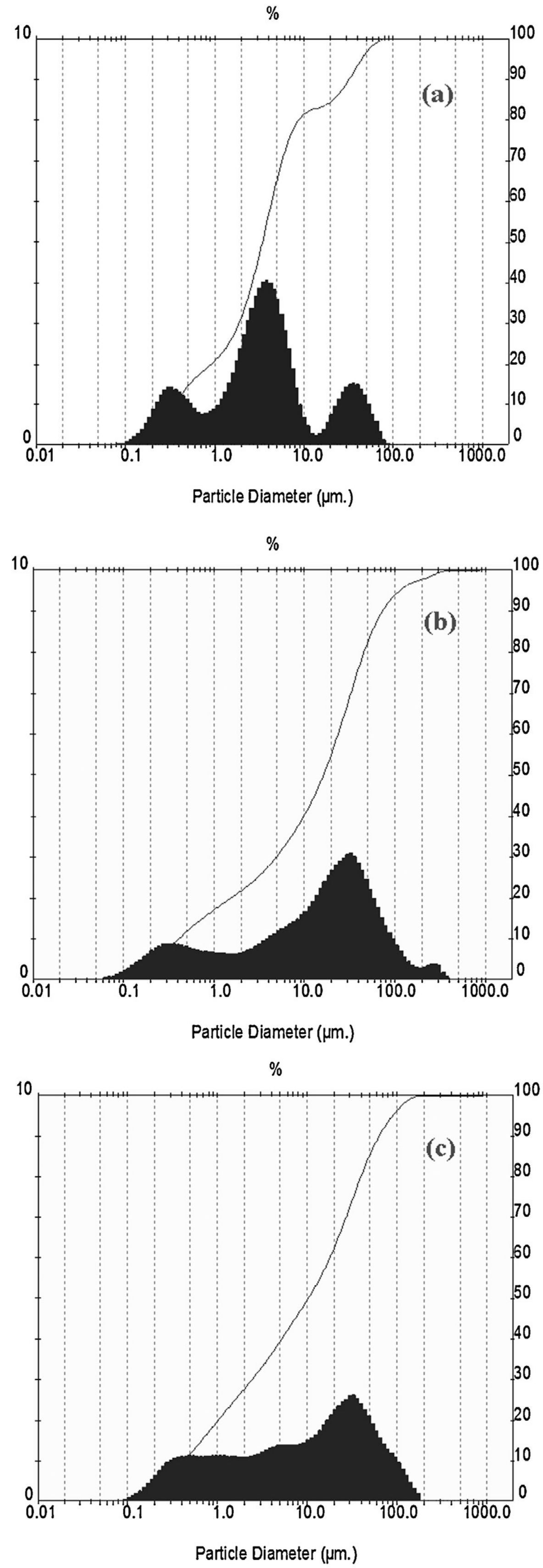

Fig. 1. Particle size distribution profiles of the different fillers (a) CC, (b) ES1 and (c) ES2.