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The Characterization of Eggshell Waste by using Polymeric Foam Replication Method

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Abstract

This study was carried out to investigate the potential using polymeric sponge replication method with eggshell waste as a raw material. Carboxymethyl Cellulose (CMC) and Polyethylene Glycol (PEG) as a binder were mixed with three composition eggshell waste powder (50%, 60% and 70%) by using the polymeric foam replication method. The sample was analyzed regarding to physical properties, density, porosity, shrinkage and sound absorption. Impedance Tube Method was used to measure sound absorption coefficient (α). The Measurements was done in accordance with ASTM E1050-98, which is the standard test method for impedance and absorption of acoustical. The results for porosity indicated that the higher content of eggshell waste the higher the value of porosity. While the result for sound absorption showed that 70% of the eggshell was good at the medium frequency to the highest of which from 1600 Hz to 5000 Hz with its range 0.88-0.94. These results indicated that 70% of eggshells showed a good potential in producing sound absorber.

1. Introduction

Daily, million tons of eggshell waste is being created around the world. This eggshell waste widely use in baking industries, cooking and an also in flower nursery. Eggshell generated after breaking eggs represent a significant waste because they become typically unusable after the use of egg contents and its derivatives. Such eggshell wastes are commonly disposed of in landfills without any pre-treatment. These activities are undesirable to the environment, especially from the perspective of green world. However, this waste can be converted to useful new materials for several industrial applications such as construction industries [1], biomedical application [2-5], biodiesel production [6] and fertilizer and calcium supplement [7].

Eggshells constitute 11% of the total weight of the egg and are mainly composed of calcium carbonate ($CaCO_3$) [8]. Several works have been done regarding the ability of eggshell waste to be employed as catalyst [9,10] and also as a good candidate for the eco-friendly filler material for the reinforced biopolymer composites, improving their mechanical properties and thermal stability [11].

As for the eggshell physical feature is the three hard protector layers which are 'Cuticle' (outermost layer) consists of calcium carbonate, 'Testa' located at beneath of the outermost layer and innermost layer, 'Mammillary'. Two layers of 'Cuticle' and 'Mammillary' that formed matrix which contained a protein fiber that lead to numerous circular openings (pores). The pore has been estimated between 7000 and 17000 pores [12]. Figure 1 shows the egg and eggshell structure. Moreover, the eggshell has two membranes which are inner and outer that maintains porous and fibril structure that help for good adsorption properties. It is composed of protein fiber and forms a semi-permeable membrane. The total thickness of these two membranes is about 100µm [13].

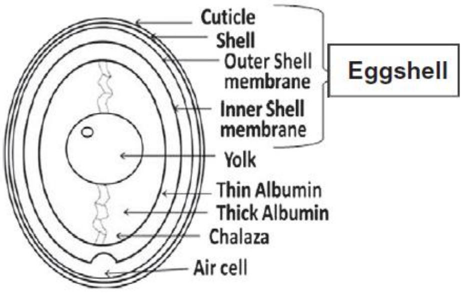

Figure 1. Egg and eggshell structure. [13]

To the best of our knowledge, no study has been reported about the polymeric foam replication method for the eggshell waste. Polymeric foam replication method involved coating of open-cell polymeric foam with ceramic slurry followed by burning out polymeric foam through sintering process which a replica of the original polymer foam in the ceramic foam structure [14]. Figure 2 shows the schematics process of foam replication method.

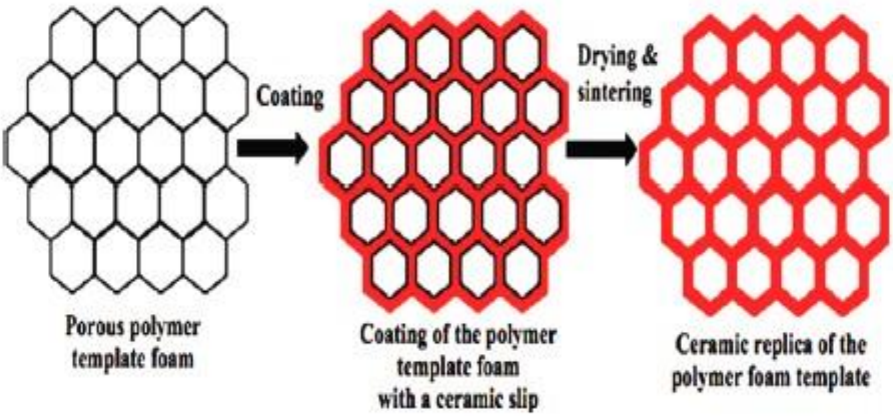

Figure 2. Schematic of foam replication technique [15].

It has been demonstrated to be a promising and effective method because of its possible in producing with high porosity, excellent interconnections between the macro pores and similar pore shape with that of cancellous bone [15]. Akil et al. [16] investigated the characterization of ceramic foam produced via polymeric foam replication method. The result showed that the properties of ceramic foam are greatly influenced by the density of ceramic slurry. An increase in the density of ceramic slurry enhances the strength of the foam as well as its density thus makes the foam denser. While, in research handling by *Sopyan and co workers*, a number of fabrication methods for developing a product based on porous ceramic material which involves impregnation of a polymeric sponge with slurries containing ceramics particles added with additives have been formed but among all these method, polymeric sponge method has received unusual recognition. This is because of porous ceramics is dealing with high specific surface area, high permeability, low density and low thermal conductivity. Consequently, the result showed that the sample had a good interconnection between pores, biocompatible and controlled degradation rate to the product

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[17]. Thus, this analysis is the nearest reference and is believed could be implied for eggshell.

Thus, the objective of this work is aimed to investigate the characteristics of eggshell waste and their influence on the physical, mechanical and sound absorption properties of eggshell waste foam by using polymeric foam replication method.

2. Methodology

2.1. Material

Material that had been used for this research is eggshell waste from the baking industries, Polyethylene Glycol (PEG) and Carboxymethyl Cellulose (CMC) as a binder and distilled water will be used as the solvent.

2.2. Sample preparation

Eggshell waste is washed for several hours to remove unpleasant smell and unwanted things. After wash, the eggshell dry naturally in the sun for 3 to 4 hours before crushing. Then, the eggshell was crushing by using plastic granulator machine before proceed for sieving process. The sieving process goes through until the mesh become into desired powder about size 45µm.

The composition of eggshells powder cover dust (50%, 60%,70%) with PEG (7%) and CMC (10%) was presented in the Table 1.

Table 1. Composition of the eggshell powder.

Eggshell waste (%)	CMC (%)	PEG (%)
50	10	7
60	10	7
70	10	7

2.3. Polymeric foam replication method

Polymeric Foam Replication method is used to provide foam by using polyurethane (PU) sponge as template and it has been cut in cylindrical shape with dimension 30 mm diameter. To fabricate the foam, 50 wt.%, 60 wt.% and 70 wt.% of eggshell waste were poured into distilled water and mixed with binders. The binders used in this method were 7 wt.% of polyethylene glycol (PEG) and 10 wt.% of carboxymethyl cellulose (CMC). The mixture of raw materials, binders and distilled water produced slurry solution for impregnation of PU sponge as a template in making porous material. The impregnated sponge was left for drying in oven at 80 °C before sintered at 800 °C, with 5 °C/min heating and cooling rate in programmable furnace.

2.4. Sintering process

The sintering was controlled under heating rate, temperature and time. Tube furnace and Argon gas are used during sintering process. The temperature used for the sintering profile is shown in Figure 3.

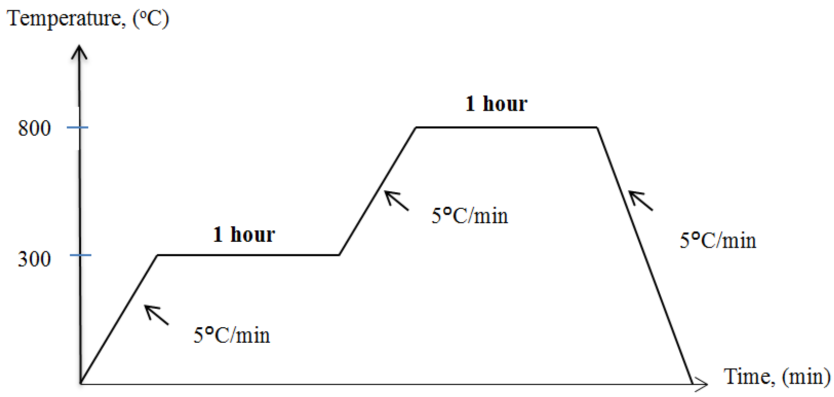

Figure 3. Sintering profile.

2.5. Shrinkage linear test

Measuring linear shrinkage before and after sintering process was carried out using the Vernier calipers. It can be calculated using the formula in equation (1).

$$\text{Percentage of shrinkage} = \frac{L_w - L_d}{L_w} \times 100\% \quad (1)$$

2.6. Physical testing

The density and porosity of the specimen was done by using Archimedes' method. The aim for this test was to study the effect of binder on density and porosity each specimen. The value of density was directly got during the experiment and the percentage of porosity can be obtained by using equation (2).

$$\text{Porosity (\%)} = \frac{W_w = W_d}{W_w - W_s} \times 100\% \quad (2)$$

2.7. Tube impedance test

The acoustic property of eggshell waste studied in this work is sound absorption coefficient (α). Impedance Tube Method was used to measure the sound absorption coefficient in accordance with *ASTM E1050-98*. This method where placing the speaker at one end of the impedance tube and the small sample (28 mm) will be placed at the other end of the tube.

Subsequently, speaker generators, stationary random sound, and sound waves scattered through the impedance tube attack the reflected sample and produce a pattern of vertical wave interference. The measurement process is carried out from a frequency of 1000 Hz - 5000 Hz as shown in Figure 4.

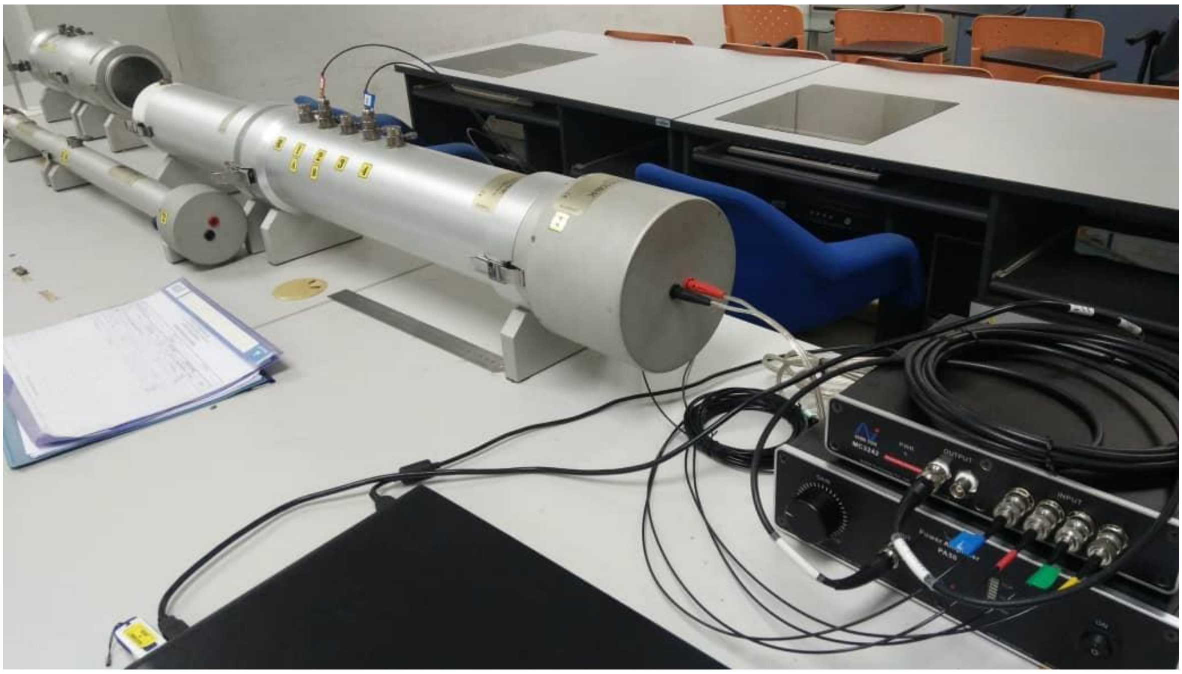

Figure 4. Sound absorption coefficient measurements.

3. Results and discussion

3.1. Shrinkage linear analysis

Figure 5 shows the eggshell waste foams sample before and after the sintering process of the sample 60 wt. % composition of eggshell waste. In this analysis, the diameter for each sample was being measured before and after the sintering process. The shrinkage of the sample was measured by digital calliper to observe the shrinkage effect for each of the sample.

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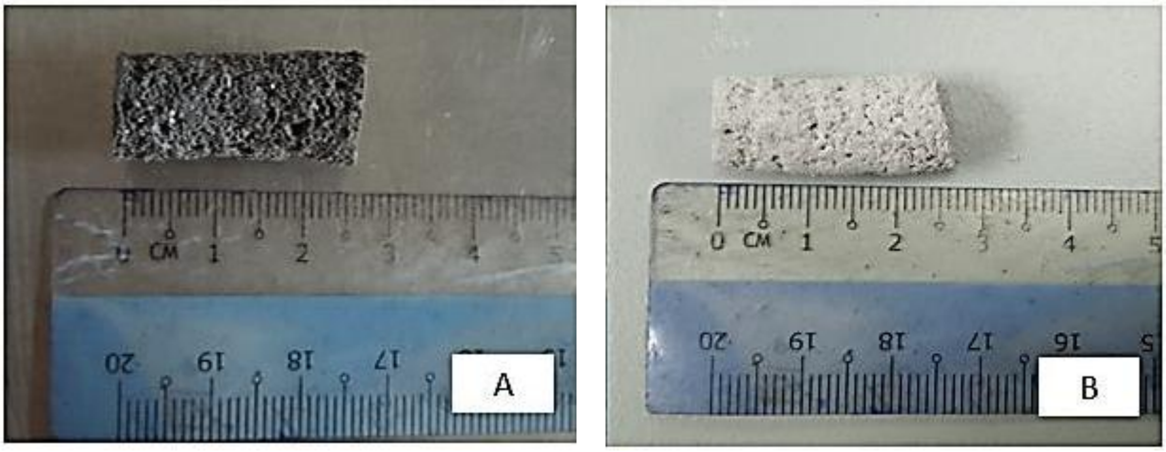

Figure 5: Eggshell waste foams sample before (A) and after (B) the sintering process.

While Figure 6 depicts the different composition of eggshell waste after sintering process. Based on the figure shown, it can be seen that the sample still have an original shape after the sintering process although it have different shrinkage.

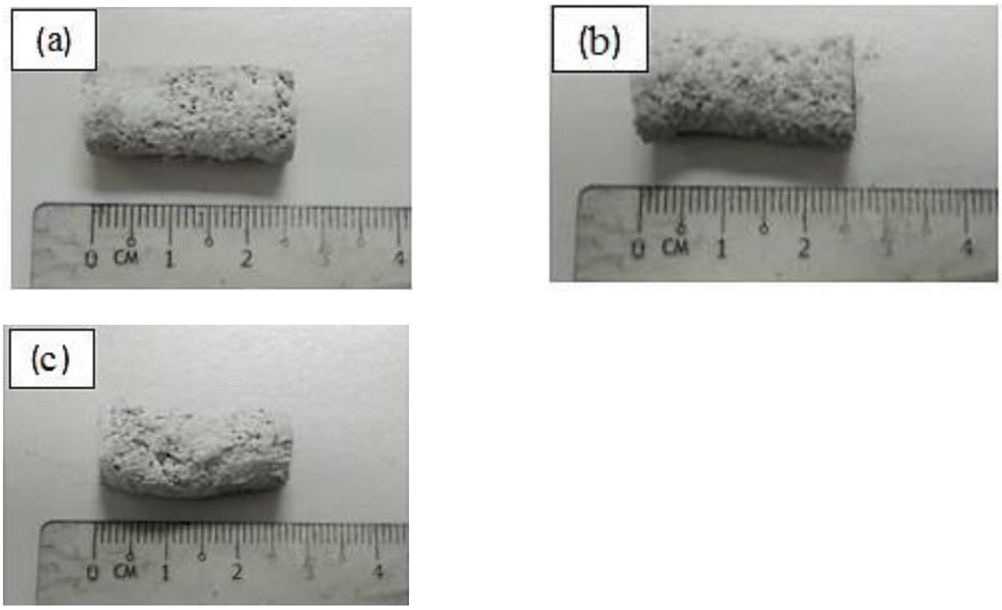

Figure 6: Eggshell waste foam sample with different composition (a) 50 wt. %, (b) 60 wt. %, (c) 70 wt. %

Figure 7 illustrates the shrinkage percentage of the eggshell waste composition. The highest percentage of shrinkage occurred in the mixture of the eggshell waste composition of 50% wt. while the lowest shrinkage value was about 2.67% with 70% wt. composition of eggshell waste. Based on these results, it is possible to conclude that the percentage of eggshell foam shrinkage decreases as the sample composition content increases from 50% to 70%. According to Sufizar et al., this shrinkage was also due to the removal of pores during the sintering process [18]. This is supported by Fazimah et al., in the research, mentioned that after sintering process, no open pores produced and the sample become densified [19].

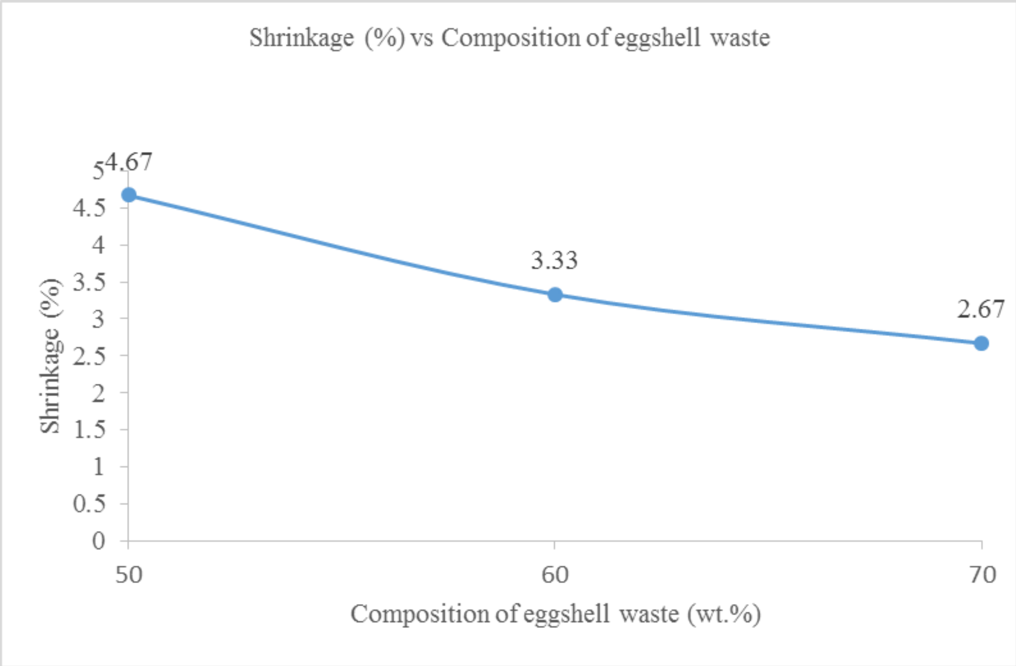

Figure 7. Shrinkage percentage (%) vs Composition eggshell waste

3.2. Porosity and density

Table 2 show the result of porosity and density for different composition of eggshell waste. The effect of different composition eggshell waste on the density and porosity can be clearly seen. From Figure 8, the density decreased while porosity increased as the eggshell waste composition has been increased from 50 wt.% to 70 wt.% . The density of the samples with 50 wt.% and 70 wt.% eggshell waste were about 2.63 g/cm^3 and 1.75g/cm^3 respectively. While the porosity for the sample with 50 wt.% eggshell waste are 58.4% and sample with 70 wt.% eggshell waste are 81.3 %. According to Leitao et al. [20], open pore foams are widely used for noise control in the fields such as building and transportation owing to their capability of dissipating sound energy in wide frequency range.

Table 2. Porosity and density result.

Composition eggshell waste (%)	Porosity (%)	Density (g/cm^3)
50	58.4	2.63
60	65.2	2.25
70	81.3	1.75

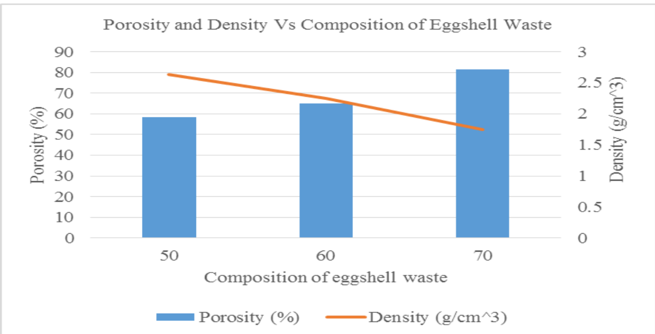

Figure 8. Porosity and density against composition of eggshell waste.

3.3. Sound absorption coefficient of eggshell waste

The sound absorption coefficient of eggshell waste was measured from the impedance tube test on three different composition of eggshell waste are shown in Figure 9. It shows that 70 % composition of eggshell waste obtained optimum sound absorption coefficient which is 0.92 at frequency 5000 Hz. While the lowest sound absorption coefficient obtained at composition 60% wt, at 0.51 which is higher than 0.5. This result agreed well with the result found by the previous researcher [21, 22]. Generally, the thicker material exhibits a maximum sound absorption coefficient at high frequencies [23].

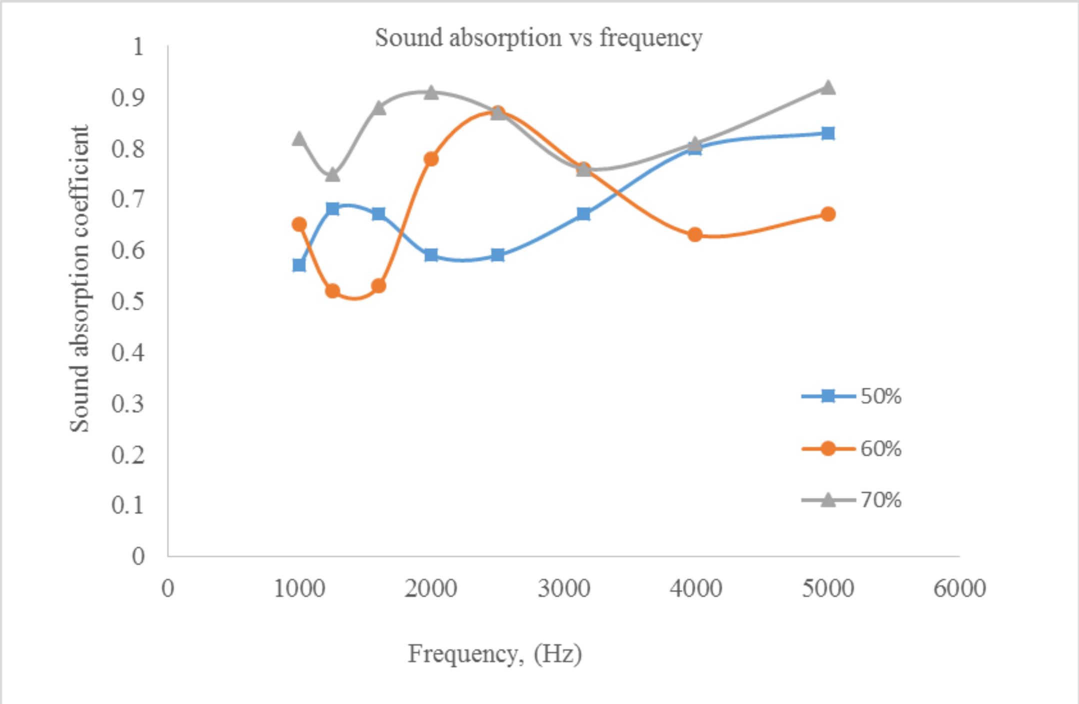

Figure 9. Sound absorption coefficient of eggshell waste.

4. Summary

An investigation on eggshell waste fabrication with different composition was carried out to identify the relationship between polymeric foam characteristics and the physical properties such as shrinkage and porosity. The sound absorption also was investigated and the result of sound absorption coefficient shows comparable with another natural fiber result. The result of the methods studied found that eggshell waste can be new candidate materials for eco-friendly filler material. However in order to ensure the potential of this eggshell waste, further investigation should be explored.

5. Acknowledgement

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