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Effect on Mechanical Property of Polypropylene Mixed with Charcoal Waste Ash through Melt Compounding

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ABSTRACT

This study explores the use of charcoal waste ash, a by-product of human activities, as a filler in polypropylene matrices. The samples were mixed using the melt compounding method using an internal mixer at 1wt%, 2wt%, 5wt%, 7wt% and 10wt%. Tensile strength peaked at 29.85MPa at 2wt% while the flexural strength peaked well above pure PP at 45.5MPa at 7wt%. Charcoal waste ash is possible to enhance the mechanical properties of polypropylene, suggesting its potential as a sustainable material in polymer composites.

1. Introduction

The escalating concern over environmental waste has become a pressing issue in the 21st century. Rapid industrialisation and urbanisation have led to an exponential increase in waste generation, posing significant challenges to waste management and environmental sustainability [1,2]. Developing countries that depend on rapid industrialization for economic and improvement of well-being are equally important in order to avoid the mistakes of developed countries [2]. Tourism and human recreational activities are also seen as equally concerning. Proper management and framework would later result in intensive waste production [3,4]. Among these wastes, charcoal waste ash, a by-product of various human activities, has been largely overlooked and underutilized. Polymers on the other hand have been at the forefront in the quest for sustainable materials due to their versatility and wide range of applications. Therefore, the need to incorporate more sustainable and renewable materials into polymers has become increasingly important [4,5].

Charcoal waste ash, with its high carbon content and surface area, presents a promising alternative. Recent studies have shown that charcoal fines resulting from the pyrolysis of biomass are an efficient alternative for the production of green composites [6]. The use of charcoal waste ash

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as a filler in polymeric matrices would not only utilize a waste product but also offer the potential of working towards a zero-carbon emission in the future.

However, the use of charcoal waste ash in polymeric matrices is still in its early stages [7]. The potential of using charcoal waste ash as a filler for polymeric matrices is yet to be fully explored. This study aims to share by investigating the properties of charcoal waste ash and its effect on the mechanical strength of polymer composite.

2. Methodology

Raw materials used in this study; polypropylene was supplied from San Miguel Yamamura Plastic Films (M) Sdn. Bhd. Coal waste ash was collected from burnt charcoal briquettes. Charcoal waste ash was cleaned and removed larger bits and food fats were used in a mechanical sieve to collect only smaller particle sizes. Charcoal waste ash was later cleaned using isopropyl alcohol to improve dispersive properties, and then dried for 24 hours. For mixing, the melt compounding method was used using a HAAKE internal mixer machine. Tensile and flexural properties were studied using the Shimadzu Universal Testing Machine. The charcoal waste ash was also analysed for its particle size using a Malvern PANanalytical Mastersizer.

The formulation of samples is according to Table 1. 1wt% of stearic acid was added to each sample to improve the dispersion of charcoal waste ash in PP during mixing [8].

Table 1
Sample and wt% of CWA

Sample	Wt% CWA
1	0
2	1
3	2
4	5
5	7
6	10

3. Results

3.1 Particle Size

The particle size of charcoal waste ash was analysed using a Malvern PANanalytical Mastersizer. Figure 1 shows the resulting particle size of the charcoal waste ash. The particle size distribution of charcoal waste ash plays a crucial role in determining its potential applications and environmental impact. It revealed a bimodal distribution with peaks at approximately 25 µm and 50 µm (Figure 2). There are also finer particles of lesser than 5µm which is at 10% in volume. The finer particles, with a higher surface area, are likely to enhance the reactivity of the charcoal waste ash [9-14].

Fig. 1. Charcoal waste ash

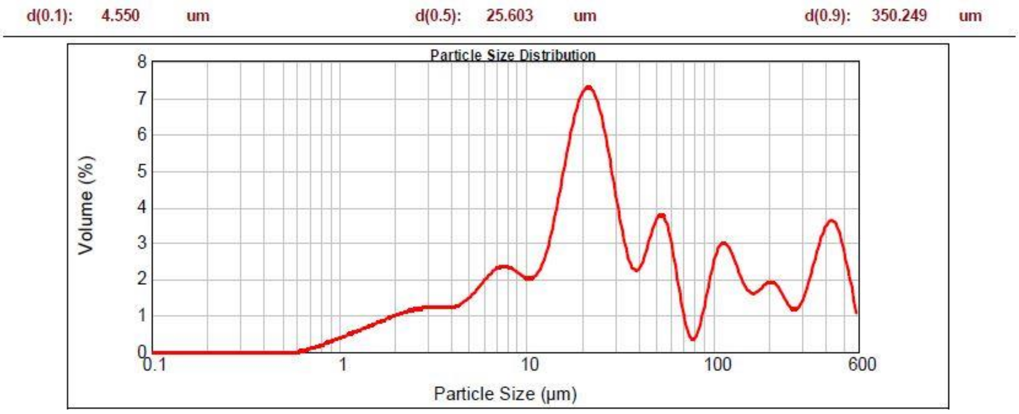
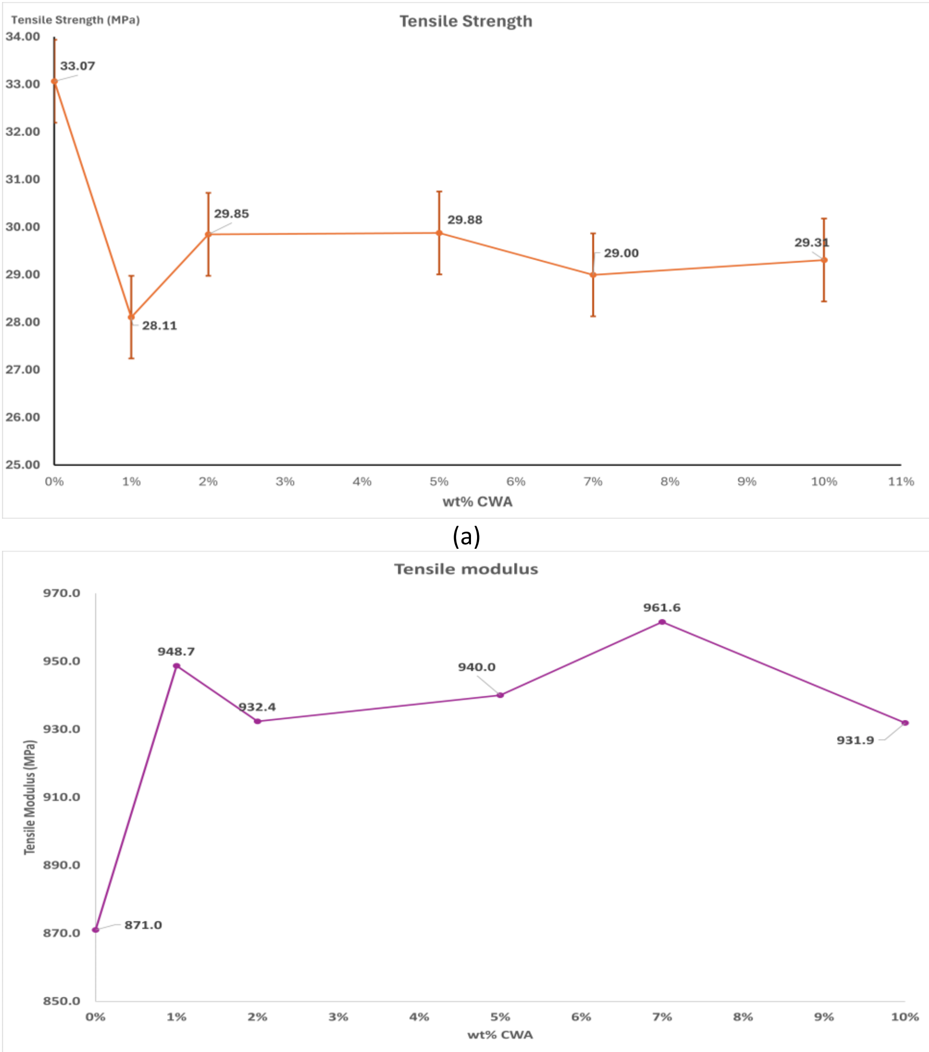


Fig. 2. Particle size distribution for charcoal waste ash

3.2 Tensile Strength

The tensile strength of Polypropylene (PP) filled with charcoal waste ash was investigated at different weight percentages ranging from 0wt% to 10wt% (Figure 3). The tensile strengths obtained 0wt% (pure PP), and the tensile strength was the highest at 33.07 MPa. With the addition of 1wt% of ash, the tensile strength significantly decreased to 28.11 MPa. This could be due to the fact that the ash particles interrupt the continuity of the PP matrix, thereby reducing the load-bearing capacity of the material [15,16]. However, it was observed that the ash content was further increased. At 2wt% and 5wt%, the tensile strength increased to 29.85 MPa and 29.88 MPa respectively. This suggests that a certain amount of ash can actually enhance the tensile strength of the PP matrix, possibly due to improved interfacial bonding between the ash particles and the PP matrix [16-18]. Beyond 5wt%, the tensile strength started to decrease again, reaching 29 MPa at 7wt% and 29.31 MPa at 10wt% [15-17]. This indicates that too much ash can have a detrimental effect on the tensile strength of the material, likely due to the agglomerization of waste coal ash particles leading to stress concentration sites.



(a)

(b)

Fig. 3. (a) Tensile strength and (b) modulus of the samples at different wt% CWA loading

Waste coal ash affects the stiffness of the PP matrix. The tensile modulus of polypropylene (PP) filled with varying weight percentages of waste coal ash has an upward trend. The data indicates that the tensile modulus, a measure of stiffness, increases with the addition of waste coal ash up to 7%, after which it decreases [18]. It can be attributed to the stiffer nature of waste coal ash, which when added to the PP matrix, enhances its rigidity which is consistent with previous studies that have shown an increase in the modulus of elasticity for HDPE composites reinforced with fly ash [19]. The reduction of the modulus at 10wt% could also be likely attributed to the effect of agglomeration.

The optimal dispersion might be compromised at higher filler content (10wt%), leading to a decrease in tensile modulus [17].

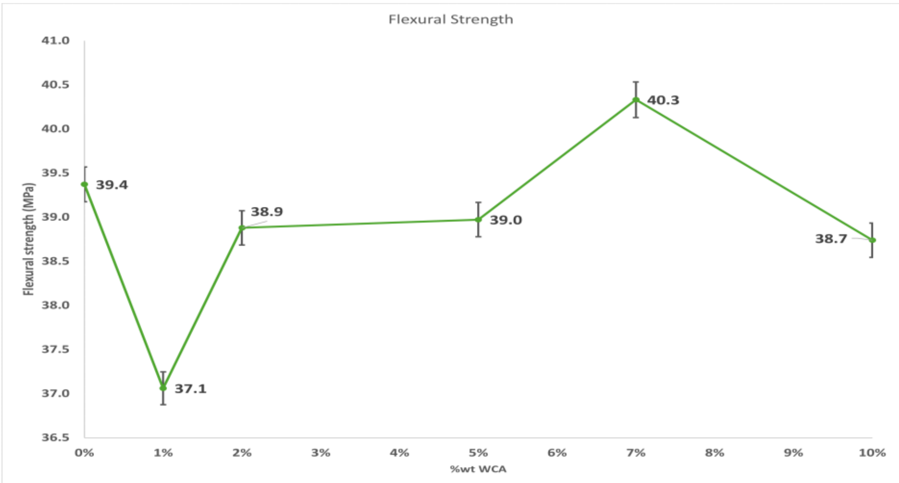
3.3 Flexural Strength

The flexural strength of polypropylene (PP) filled with charcoal waste ash at varying weight percentages (wt%) presents a trend as shown in Figure 4. The flexural strength values for 0wt%, 1wt%, 3wt%, 5wt%, 7wt% and 10wt% charcoal waste ash are 38.2MPa, 30.0MPa, 38.5MPa, 40.3MPa, 45.5MPa and 38.8MPa, respectively. The flexural strength initially decreases when the charcoal waste ash content increases from 0wt% to 1wt%. Again, the decrease suggests that the interfacial bonding between the charcoal waste ash and the PP matrix is affecting the matrix's load bearing ability.

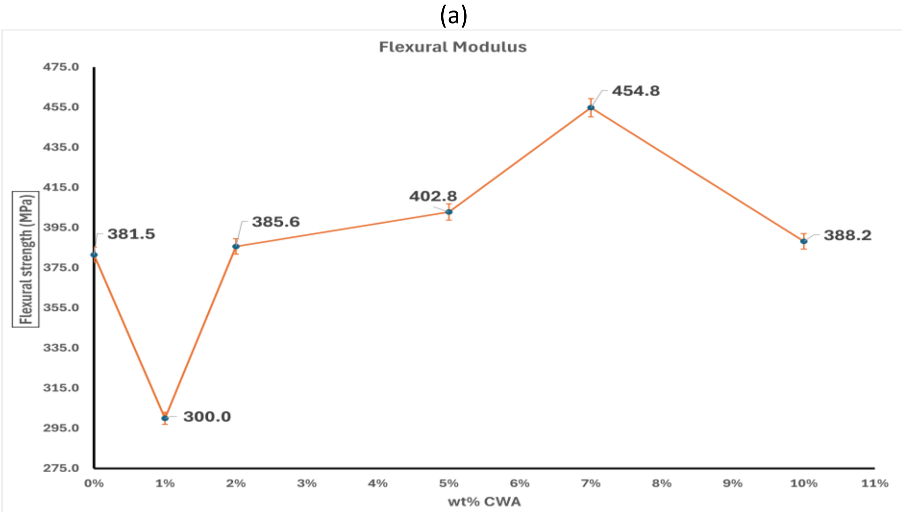
However, as the charcoal waste ash content further increases to 3wt%, the flexural strength improves, surpassing the strength of pure PP. This suggests that the charcoal waste ash may have a reinforcing effect on the PP matrix at this concentration. Interestingly, the flexural strength continues to increase with the addition of charcoal waste ash up to 7wt%, reaching a peak value of 45.5MPa. This is suggested due interfacial bonding of charcoal waste ash particles and the PP matrix, which in turn helps to act as resistance to the bending force. This leads to better stress transfer and, thus, enhanced flexural strength.

However, when the charcoal waste ash content increases to 10wt%, the flexural strength decreases slightly. This could be due to the overloading of charcoal waste ash, which may lead to agglomeration of the particles and create stress concentration points, thereby reducing the flexural strength [15-17].

For the flexural modulus of the PP, a similar trend with the flexural strength is observed. Though at 5wt% an increase of 4% was noticed which continued with higher wt% before its reduction at 10wt%. The waste coal ash likely helps with the resistance of bending, which showed the higher flexural modulus reported [17,18]. Agglomerization again could be attributed to the decrease in the flexural modulus at 10wt%.



(a)



(b)

Fig. 4. (a) Flexural strength and (b) modulus of the samples at different wt% CWA loading

4. Conclusions

This study successfully demonstrated the potential of charcoal waste ash as a filler in polypropylene matrices. The mechanical properties of the composite, specifically tensile and flexural strengths, were found to vary with the weight percentage of charcoal waste ash. The tensile strength peaked at 29.85MPa at 2wt% while the flexural strength peaked well above pure PP at 45.5MPa at 7wt%. The tensile and flexural modulus also peaked well above pure PP at 961.6MPa and 454.8MPa respectively. These findings suggest that charcoal waste ash can enhance the mechanical properties of polypropylene, thereby indicating its potential as a sustainable material in polymer composites. However, the study also found that an excessive amount of above 10wt% of charcoal waste ash can have a detrimental effect on the mechanical properties of the material. Therefore, further research is needed to optimize the loading of charcoal waste ash in the polypropylene matrix and also the bonding of waste coal ash with the PP matrix. This study hopefully opens up new possibilities for the use of waste materials in enhancing the properties of polymers thereby promoting sustainable practices and waste reduction.

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