Development of Granite-Filled Recycled LDPE Composites for Lightweight Military Helmet Applications

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Abstract
The development of a lightweight military helmet using granite particulate (GTP) reinforced recycled low-density polyethylene (RLDPE) was studied in an attempt to produce a light helmet with high strength and cost-effective material for military applications. This study utilised the abundant presence of granite in the ecosystem. The granite stone was washed using distilled water and detergent and sun dried, then ball milled for 72 hours. The process was followed by compounding the granite powder with recycled low-density polyethylene (pure water sachet) and compatibiliser (propylene glycol) in a two-roll mill compounder at a temperature of 150°C for 5 minutes. Six samples were produced by varying the composition of granite from 0 to 50 wt. % (at regular interval of 10%), one of the six samples is a control sample and it was used to compare the other samples. The samples were characterised using SEM and then tested for hardness, tensile, flexural and impact strengths, and density. The SEM images showed dispersion of the GTP. Additionally, mechanical properties improved with the addition of the filler while density depreciated mildly, especially at 10% loading.

Keywords: Granite, recycled low-density polyethylene, propylene glycol, military helmet, composite

Introduction

Military helmets have been essential in preventing head injuries among soldiers by shielding them from impact and ballistic threats during dangerous missions and warfare. Military helmets typically made of metals and monolithic polymers may offer enough protection from ballistic threats, but they frequently have issues with weight, comfort, and environmental sustainability (Siengchin, 2023).

As modern warfare demands more mobility and longer operating hours, lighter and more comfortable helmets are crucial to enhancing overall performance and ensuring the safety of soldiers in the field. The development of sophisticated composite materials to replace monolithic polymers in military helmets has attracted increasing attention in recent years in an effort to improve overall helmet performance and better protection for the safety of the armed forces. On the other hand, granite particles are used extensively in the building sector. These particles are used in the creation of road base materials, asphalt and concrete.

Granite is the perfect material for building strong and long-lasting infrastructure because of its excellent hardness and endurance. Concrete's compressive strength and resilience to wear and tear are improved by the inclusion of granite particles. Additionally, granite is a light weight material when finely powdered (Singaiah, 2020). Accordingly, in order to solve the concerns related to the military helmets, the goal of this work is to determine whether it is feasible to use Granite particulate as a reinforcing agent in RLDPE to create a novel composite material for military helmets.

Experimental Methods

Preparation of granite powder

The granite was first subjected to a meticulous cleaning process involving distilled water and detergent. Subsequently, it underwent thorough drying for an extended period to ensure complete removal of any residual moisture before being introduced into the ball mill. Five kilograms of the sun-dried granite were carefully loaded into the ball miller and subjected to a 72-hour milling process. This meticulous duration was aimed at achieving a finely-grained blend of granite powder, encompassing both nano-sized and macro-sized particles. The resulting milled powder was then meticulously sieved through a 75-micrometre sieve.

Fabrication of RLDPE/GTP

The compounding process occurred within a two-roll mill, where a six-sample mixture of RLDPE, GTP, and compatibiliser with varying compositions (as shown in Table 1). Components were carefully blended at a precise temperature of 150°C. Initially, RLDPE and compatibiliser were introduced into the mill and then melted. Afterwards, this signalled the opportune moment to incorporate the fillers. Meticulous mixing ensued until complete homogenization was achieved, at which point the paste was transferred to a compression moulding machine. Before moulding, the machine's temperature was meticulously set to 150 °C. Subsequently, the paste was poured into a mould with a thickness of 3mm and carefully placed inside the moulding machine. After a curing duration of 5 minutes, the curing process occurred at a pressure of 2.5 Pascal. Repeatedly, six distinct samples were created during this process, each with varying compositions. The final dimensions of the produced samples measured 120 × 150 × 3mm.

Table 1: Percentage composition of recycled low-density polyethylene, granite and polyethylene glycol.

S/N	RLDPE (%)	Granite (%)	Polyethylene glycol (%)
1	100	0	0
2	90	10	10
3	80	20	10
4	70	30	10
5	60	40	10
6	50	50	10

Density Determination

The density of the different samples was ascertained through a meticulous procedure. Initially, the masses of specific specimen segments cut from each sample were meticulously measured in an air environment, employing a precision digital weighing balance located in the laboratory. Subsequently, these specimens were gently suspended in water. The volume of each sample was subsequently determined by measuring the overall volume of the composite material. Finally, the density was calculated using the following expression 1:

$$Density = \frac{mass}{volume} \quad (1)$$

Flexural Test

The measurement of the samples involves the precise use of a Vernier calliper to measure both the width and thickness of each specimen. Initially, the initial extension or deflection of the sample is recorded. Subsequently, the sample is carefully positioned within the three-point bending point of the machine, and hydraulic force is systematically applied. During this process, the samples fracture into two distinct pieces, and the final extension or deflection is meticulously measured, alongside the recorded load or force required to achieve this deflection. The calculation of both the flexural stress and modulus of elasticity is subsequently carried out using the following expression:

$$\text{Flexural stress} = \frac{3FL}{2bd^2}, \quad (2)$$

$$\text{MOE} = \frac{FL^3}{4bd^3D} \quad (3)$$

Impact Test

The specimens were initially notched, and then each sample was carefully positioned within the machine with the door securely closed. Subsequently, a force from a swinging pendulum was applied, resulting in the fracture of the samples at the notched cross-section. The final results were meticulously recorded and tabulated.

Tensile Test

The specimens are positioned between two sturdy jaws and securely clamped in place. Subsequently, tension is applied by gradually pulling the jaws apart until the specimens reach their fracture point.

Hardness Test

Hardness of the samples was determined using a Micro Vickers hardness testing machine model MV1-PC with a pyramidal diamond indenter and a load of 0.3 kgf, on HV scale according to ASTM E384.

Microstructural Characterization

The Scanning Electron Microscope (SEM) with model number JEOL JSM-6480LV was used to study the morphology of the material produced. The system is controlled by a PC running the dedicated mini analytical software. The pellet is loaded in the sample chamber of the spectrometer and a voltage of 15kv is applied to produce the X-rays to excite the sample for a preset time (30 sec in this case).

Results and Discussions

Density

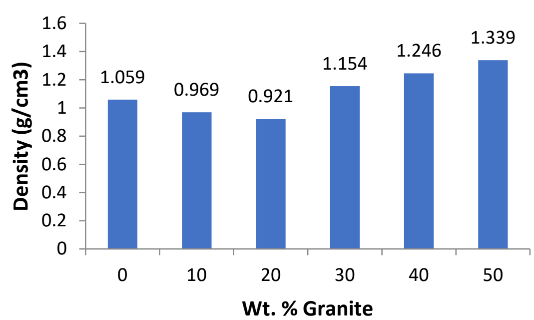

Figure 1: Variation in density with wt. % granite

From Figure 1, it can be seen that there is a progressive increase in density as the wt. % Granite increases, which can be attributed to the wide difference in densities between granite and RLDPE. This can be justified by the rule of mixtures of a composite. The 10 wt.% RLDPE/GTP shows a lower density value of about 0.969g/cm^3 which is a great improvement in the density of RLDPE, which is just about 0.925g/cm^3. The 10 wt. % RLDPE/GTP will be considered as a suitable choice for the application because it has the lowest density among other samples with regard to density. Similarly, Dodo *et al*., (2018) studied the effect of granite particle size on the properties of Al-7%Si-0.3%Mg/granite particulate composites and observed a similar trend of increasing density as the weight percentage of granite increases.

Flexural Strength

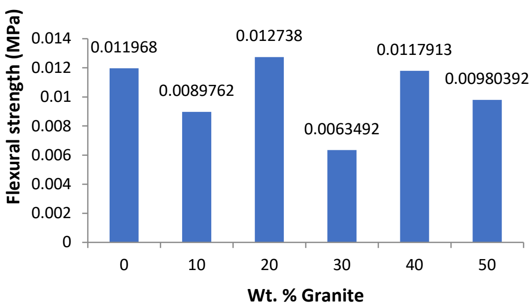

Figure 2: Variation of flexural strength with wt. % Granite

From Figure 2, it is seen that the flexural stress values do not show a consistent trend concerning the weight percentage of the GTP. Some compositions with higher percentages of granite exhibit lower flexural stress, for example, 30 wt. % GTP, while others with lower percentages have higher flexural stress (10 wt. %). This suggests that the relationship between flexural stress and granite content may be complex. However, similar research by Awad & Abdellatif, (2019) shows a progressive increase in flexural strength of the composite material as the percentage of reinforcement (Marble dust) increases in the composition of the composite material. The reason for the inconsistency from the result above may be due to uneven distribution of the filler material (granite particulate) in the matrix of the Low-density polyethylene.

Flexural Modulus

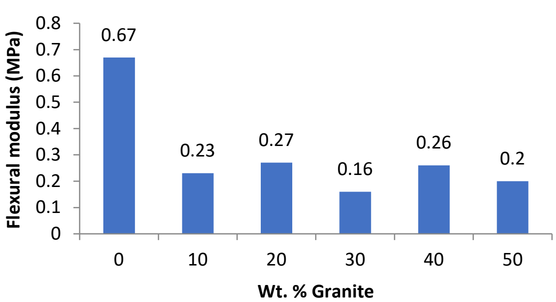

Figure 3: Variation of Flexural Modulus with wt. % Granite

The flexural modulus (Figure 3) values vary across the different weight percentages of granite. They are not consistent and fluctuate between different compositions. The results do not show a clear or linear relationship between the weight percentage of granite and the flexural modulus. In some cases, increasing the percentage of granite results in a higher flexural modulus, while in other cases, it results in a lower modulus. This indicates that the influence of granite content on flexural modulus is not straightforward and may be influenced by other factors.

Tensile Test

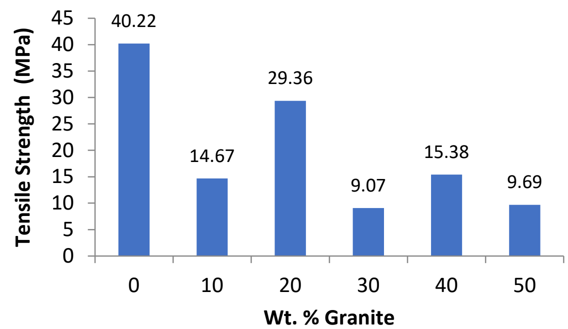

Figure 4: Variation in tensile strength with wt. % Granite for RLDPE/GTP composite.

Figure 4 indicates that tensile strength values vary significantly across the different weight percentages of granite. The results show that the influence of the weight percentage of granite on tensile strength is not consistent. In some cases, adding more granite appears to increase tensile strength (e.g., 20% granite), while in other cases, it results in a significant decrease in tensile strength (e.g., 30% granite). This suggests that the relationship between tensile strength and granite content is complex and influenced most likely by the production conditions.

Impact Test

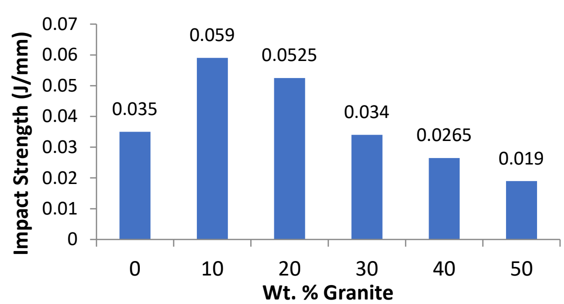

Figure 5: Variation of Impact strength with wt. % GTP

The impact strength values vary considerably across the different weight percentages of granite. There is a wide range of values, with some compositions exhibiting higher impact strength than others. The results suggest that the influence of the weight percentage of granite on impact strength does not follow a particular trend. In some cases, adding more granite appears to increase impact strength (e.g. 10% granite), while in other cases, it results in a decrease. However, if compared to the impact strength of RLDPE, the superior composite material is the one with 10% Granite reinforcement and would be the best candidate for this application.

Hardness Test

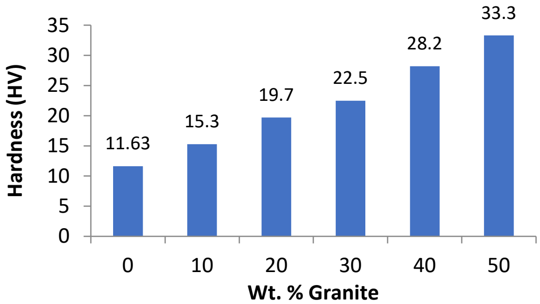

Figure 6: Variation of Hardness with wt. % Granite

From Figure 6, it is seen that the hardness values vary progressively with the filler loading. The values increase as the weight percentage of granite increases, indicating that the addition of granite reinforcement generally results in increased hardness. This indicates that the granite reinforcement has a positive effect on the material's hardness. Similarly, Awad & Abdellatif, (2019) observed the same phenomenon of increasing hardness in their research when they reinforced LDPE with marble dust; as the percentage of marble dust increased, the hardness value increased.

From plate 1a, it can be seen that there is an even distribution of fine particles of the granite in the RLDPE matrix if compared to the other wt. % samples (30wt. % and 10wt. % GTP). This might be the reason why their improved properties of the RLDPE material in terms of hardness and some other properties are due to the introduction of a more rigid material in the RLDPE matrix. Also, large amounts of granite particles can be observed in the microstructure as both RLDPE have an equal proportion in the sample. However, Plates 1b and c exhibit minimal dispersion of the granite particles within the recycled low-density polyethylene (RLDPE) matrix. This lack of dispersion may be attributed to the relatively low concentration of GTP in the sample. This lower loading leads to uneven distribution of the granite during the processing phase, which may affect the material's properties since the granite is not sufficient to cause a noticeable change in the properties of RLDPE. A Similar observation was reported from work done by Király & Ronkay, (2013).

Microstructural Characterization

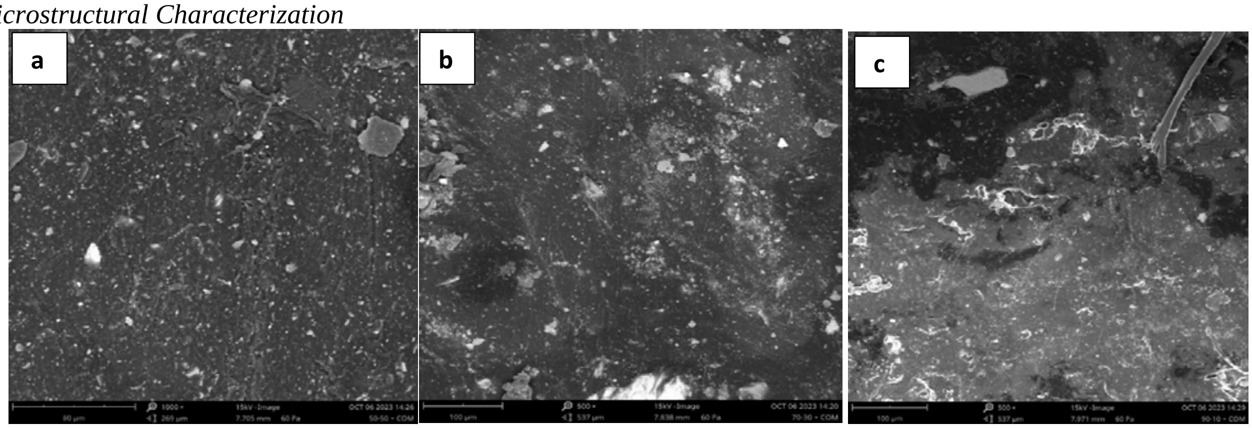

Plate 1: SEM Micrographs showing dispersion of GTP for (a) RLDPE/50wt%GTP; (b) LDPE/30wt%GTP; and (c) RLDPE/10wt%GTP.

Conclusion

In this work, the utilisation of a cheap material to improve the properties of recycled low-density polyethylene for use in military helmets was considered. The following can be concluded. The successful synthesis of fine particles of granite powder through a meticulous ball milling process was achieved. RLDPE/GTP samples with desired compositions and properties were fabricated using the compounding method. The 10 wt. % RLDPE/GTP depicted a good combination of properties and is therefore considered to be a suitable choice for the military helmet application.

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