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MECHANICAL PROPERTIES OF POLYPROPYLENE-CALCIUM HYDROXIDE

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Abstract
The incorporation of fillers alters the physical and mechanical properties of the composite materials. This study focuses on the use of calcium carbide waste (CCW) as a filler for polypropylene to determine the mechanical properties of the resulting composite and aims to utilize waste material as a filler to reduce the cost of production and create job opportunities while reducing environmental pollution. The objectives of the study are to determine the effect of filler loading on the mechanical properties of the composites and investigate the distribution, orientation, and interaction of fillers in the composites. The methodology involves using a polymer injection moulding machine to process the composites, and samples are tested for tensile strength, flexural strength and hardness properties. The results helped to determine the potential of $Ca(OH)_2$ as a filler in polypropylene and its impact on the mechanical properties of the composites. The mechanical properties of polypropylene-calcium carbide waste composites were successfully determined in this study. The results showed that the tensile, flexural strength and hardness of the composites increased with increasing filler loading up to 10 wt%, but decreased beyond that point. This behaviour can be attributed to the agglomeration and poor dispersion of the fillers at higher loading. More research is required to optimize production conditions, investigate the effect of different coupling agents and study the composites' potential applications. Other waste materials should be investigated as fillers, and optimization techniques should be explored to determine the optimum filler loading for the best mechanical properties.

Keywords: Polypropylene, Calcium Hydroxide, Reinforcement, Composite Material, Fillers

Introduction

The wide spread of plastic products in various applications has attracted greater attention due to their unique properties, which include good mechanical properties, resistance to chemical attack and corrosion, ease of processing and recycling, cost-effectiveness, lightweight, and others. However, these properties are affected by many factors such as stress, temperature and environment when plastics are exposed to service or during processing. This leads to vehement objections to plastics in some specific applications. The attempts to overcome these obstacles led to the incorporation of fillers (inorganic and organic) into plastics to obtain a plastic composite whose constituents act synergistically to withstand the challenges, thereby making plastics more reliable during use or processing. Generally, the composite properties are influenced by many factors such as filler characteristics, filler content, and interfacial adhesion and dispersion due to the combination of more than one material (Nwanonenyi et al. 2013)

Since the early 1960s, there has been an increasing demand for materials that are stiffer and stronger yet lighter in fields as diverse as aerospace, energy and civil construction. The demands made on materials for better overall performance are so great and diverse that no one material can satisfy them. This naturally led to a resurgence of the ancient concept of combining different materials in an integral-composite material to satisfy the user's requirement. Composite rheology and processing can be considered as one of the interest areas in the polymer field that have attracted many researchers due to the need to develop and process new composite materials with desired physical and mechanical properties. Many recent developments in thermoplastic materials especially polyolefins have been taken into consideration, which include altering the existing polymer properties to meet end-user performance requirements, especially in the automotive industry. This alteration can be affected through changes in polymerization technique and chemistry, or by applying one of the most preferable techniques, which is the incorporation of a wide variety of additives such as organic and inorganic fillers. Leong et al. claimed that the incorporation of fillers (10–40 wt % filler loading), specifically talc, kaolin, and calcium carbonate hinders plastic flow and increases the viscosity of polymer melt. Apart from such studies on the incorporation of fillers in a polymer matrix, surface treatment of fillers has also been carried out extensively to offer better compounding and processing facilitation by enhancing filler dispersions and decreasing melt viscosity (Rahim et al., 2010).

Modification of organic polymers through the incorporation of additives yields, with few exceptions, multiphase systems containing the additive embedded in a continuous polymeric matrix. The resulting mixtures are characterized by unique microstructures that are responsible for their properties. Polymer composites are mixtures of polymers with inorganic or organic additives having certain geometries. Thus, they consist of two or more components and two or more phases. In addition to polymer composites, other important types of modified polymer systems include polymer-polymer blends and polymeric forms. Blending procedures have been employed since time immemorial. The principle of blending is geared towards achieving property averaging. A blend is, therefore, the physical mixture of two or more substances, without a chemical bond, (Aibu & Abubakar, 2016).

Statement of Problem

Calcium carbide waste (calcium hydroxide) has been under-utilized, in composite formulation, as it is considered as waste material. Thus, there is a need to convert this waste to wealth meanwhile this conversion would serve as an environmental waste control.

Objective of Study

The main objective of this study is to determine the mechanical properties of polypropylene-calcium carbide waste components.

CONCEPTUALISATION

Composite Material

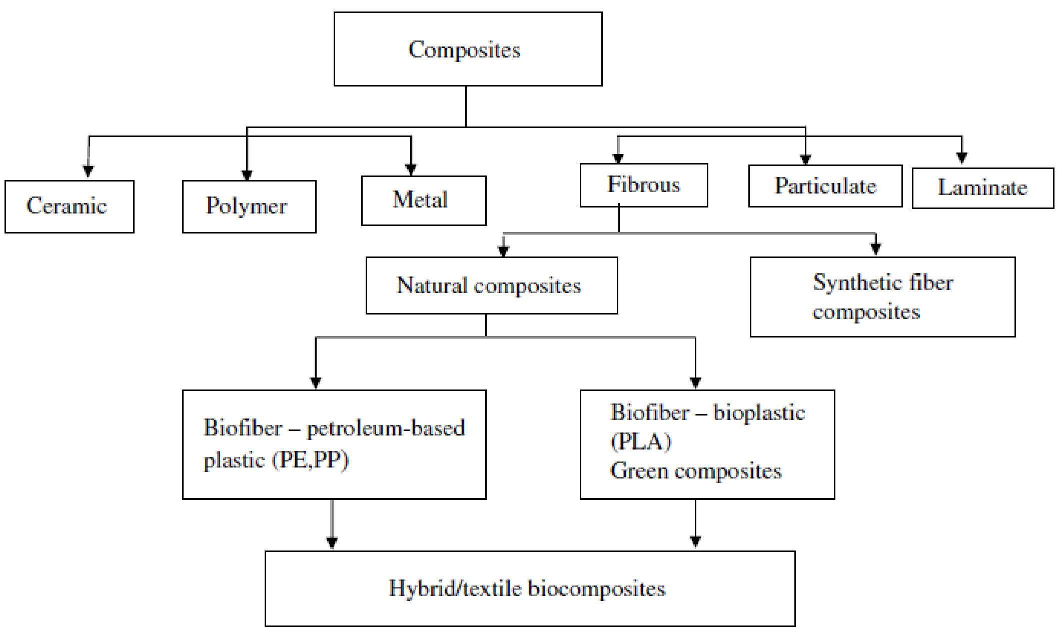
Composites can be defined as materials that consist of two or more chemically and physically different phases separated by a distinct interface. The different systems are combined judiciously to achieve a system with more useful structural or functional properties unattainable by any of the constituents alone. Composites, the wonder materials are becoming an essential part of today's materials due to their advantages such as low weight, corrosion resistance, high fatigue strength, and faster assembly. They are extensively used as materials in making aircraft structures, electronic packaging for medical equipment, and space vehicles for home building. Composites are combinations of materials differing in composition, where the individual constituents retain their separate identities. These separate constituents act together to give the necessary mechanical strength or stiffness to the composite part. Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different from those of any of the constituents.

Classification of Composites

Based on the matrix phase, composites can be classified into

i. metal matrix
ii. composites (MMCs),
iii. ceramic matrix composites (CMCs), and
iv. polymer matrix
v. composites (PMCs).

The classifications according to types of reinforcement are particulate composites (composed of particles), fibrous composites (Composed of fibres), and laminate composites (composed of laminates). Fibrous composites can be further subdivided based on natural/biofiber or synthetic fibre. Biofiber-encompassing composites are referred to as biofiber composites. They can be again divided based on matrix, that is, nonbiodegradable matrix and biodegradable matrix. Bio-based composites made from natural/biofiber and biodegradable polymers are referred to as green composites. These can be further subdivided into hybrid composites and textile composites. Hybrid composites comprise a combination of two or more types of fibres.



Polypropylene

Polypropylene is a semi-crystalline polymer that exhibits very attractive mechanical properties, like ductility and strength at room temperature or under moderate rates of deformation. However, under severe conditions it becomes brittle. This behaviour makes it interesting for the commercial and scientific fields to study methods for toughening these materials, also known as polypropylene—the thermoplastic polymer that is used in a wide variety of applications. An additional polymer made from the monomer propylene, it can be produced in a variety of structures giving rise to applications including packaging and labelling, textiles, plastic parts and reusable containers of various types, laboratory equipment, automotive components, and medical devices. It is a white, mechanically rugged material, and is resistant to many chemical solvents, bases and acids. Polypropylene is in many aspects similar to polyethene, especially in solution behaviour and electrical properties. The methyl group improves mechanical properties and thermal resistance, although the chemical resistance decreases. The properties of polypropylene depend on the molecular weight and molecular weight distribution, crystal, type and proportion of comonomer (if used) and isotacticity. In isotactic polypropylene, for example, the methyl groups are oriented on one side of the carbon backbone. This arrangement creates a greater degree of crystalline and results in a stiffer material that is more resistant to creep than both ataxic polypropylene and polyethene. The density of PP is between 0.895 and 0.92 g/cm^3. Therefore, PP is the commodity plastic with the lowest density. With lower density, moulding parts with lower weight and more parts of a certain mass of plastic can be produced. Unlike polyethene, crystalline and amorphous regions differ only slightly in their density. However, the density of polyethene can significantly change with fillers.

The Young's modulus of PP is between 1300 and 1800 N/mm^2. Polypropylene is normally tough and flexible especially when copolymerized with ethylene. This allows polypropylene to be used as an engineering plastic, competing with materials such as acrylonitrile butadiene styrene (ABS). Polypropylene is reasonably economical. Polypropylene has good fatigue resistance.

As polypropylene is resistant to fatigue, most plastic living hinges, such as those on flip-top bottles, are made from this material. However, it is important to ensure that chain molecules are oriented across the hinge to maximize strength. Polypropylene is used in the manufacturing piping systems; both ones concerned with high-purity and ones designed for strength and rigidity (e.g. those intended for use in potable plumbing, hedonic heating and cooling, and reclaimed water).

This material is often chosen for its resistance to corrosion and chemical leaching, its resilience against most forms of physical damage, including impact and freezing, its environmental benefits, and its ability to be joined by heat fusion rather than glueing. Many plastic items for medical or laboratory use can be made from polypropylene because it can withstand the heat in an autoclave. Its heat resistance also enables it to be used as the manufacturing material of consumer-grade kettles. Food containers made from it will not melt in the dishwasher and will not melt during industrial hot filling processes. For this reason, most plastic tubs for dairy products are polypropylene sealed with aluminium foil (both heat-resistant materials). After the product has cooled, the tubs are often given lids made of a less heat-resistant material, such as LDPE or polystyrene.

Calcium Hydroxide Ca $(OH)_2$

Calcium carbide waste (CCW) is a waste by-product from acetylene gas production. The main component of CCW is Ca $(OH)_2$. In this project, we synthesized CCW, Ca $(OH)_2$ being the reinforcement and polypropylene, being the matrix material through extrusion moulding technique and examined the important mechanical properties of the different sizes of the material containing different percentages amounts of Ca $(OH)_2$. Calcium carbide waste is a by-product obtained from the acetylene gas (C_2H_2) production process, as shown in the following equation:

$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$.

Increasing environmental concerns and legislation have resulted in significant pressure to reduce, reuse or recycle various waste products. Different methods can be used to dispose of or reuse calcium carbide waste, Ca $(OH)_2$. Calcium hydroxide is one of the materials which may be converted into several useful products. Acetylene (C_2H_2) gas is widely used for ripening fruit in agriculture and for welding in industry, while the by-product (CCW) is often discarded as waste in landfills and thus poses a threat to the environment. For example, in China, as much as 2500 tons of CCW is generated annually. CCW is mainly composed of calcium hydroxide with a mass fraction of above 92% and is highly alkaline (pH > 12).

Calcium hydroxide is an inorganic compound which has many applications, including food preparations such as juice clarification, alcoholic beverages, soft drinks, pickling, maize preparation, and a substitute for baking soda—also used in water and sewage treatment, pulp and paper pharmaceuticals.

Reinforcement

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different fibres used in composites have different properties and so affect the properties of the composite in different ways. For most of the applications, the fibres need to be arranged into some form of sheet, known as a fabric, to make handling possible. Different ways of assembling fibres into sheets and a variety of fibre orientations are possible to achieve different characteristics.

Filler Reinforcement

The term filler is very broad and encompasses a very wide range of materials. Fillers are arbitrarily defined as a variety of solid particulate materials (inorganic, organic) that may be irregular, acicular, fibrous, or plate-like in shape and that are used in reasonably large volume loadings in plastics. Pigments and elastomeric matrices are normally not included in this definition. There is a significant diversity in chemical structures, forms, shapes, sizes, and inherent properties of the various inorganic and organic compounds that are used as fillers. They are usually rigid materials, immiscible with the matrix in both molten and solid states, and, as such, form distinct dispersed morphologies. Their common characteristic is that they are used at relatively high concentrations (>5% by volume), although some surface modifiers and processing aids are used at lower concentrations. Fillers may be classified as inorganic or organic substances and further subdivided according to chemical family or according to their shape and size or aspect ratio. Wypych reported more than 70 types of particulates or flakes and more than 15 types of fibres of natural or synthetic origin that have been used or evaluated as fillers in thermoplastics and thermosets. The most commonly used particulate fillers are industrial minerals, such as talc, calcium carbonate, mica, kaolin, wollastonite, feldspar, and aluminium hydroxide.

Applications, trends, and challenges of fillers

Primary end-use markets are building or construction and transportation, followed by appliances and consumer products; furniture, industrial or machinery, electrical or electronics, and packaging comprise a small market segment. Flexural modulus and heat resistance are the two critical properties of plastics that are enhanced by the inclusion of performance minerals. Automotive exterior parts, construction materials, outdoor furniture, and appliance components are examples of applications benefitting from enhanced flexural modulus. Automotive interior and under-hood parts, electrical connectors, and microwave containers are examples of applications requiring high-temperature resistance. There are a significant number of technological advances that will undoubtedly contribute to the additional growth in the usage of certain functional fillers, For example, wood-filled plastics and, the introduction of specially configured counter-rotating twin-screw extruders with vent zones to remove moisture (Wood, 2007). Recent statistics (2007) estimate the U.S. demand for fillers and extender minerals to a total of 3.2 million tonnes per annum, (Blum, 2008). Annual growth rates were estimated to be 2-3% with much higher rates for fire retardant fillers.

Some new exciting application areas for composites containing certain functional fillers are; structural materials with improved mechanical, thermal and barrier properties, electrical conductivity, and flame retardancy, high-performance materials with improved UV absorption and scratch resistance, barrier packaging for reduced oxygen degradation, multifunctional fillers that could release in a controlled manner corrosion sensing additives, corrosion inhibitors, insecticides, active pharmaceutical ingredient, and so on bioactive materials for tissue engineering applications, (Ha *et al.,* 2009).

Filament Winding

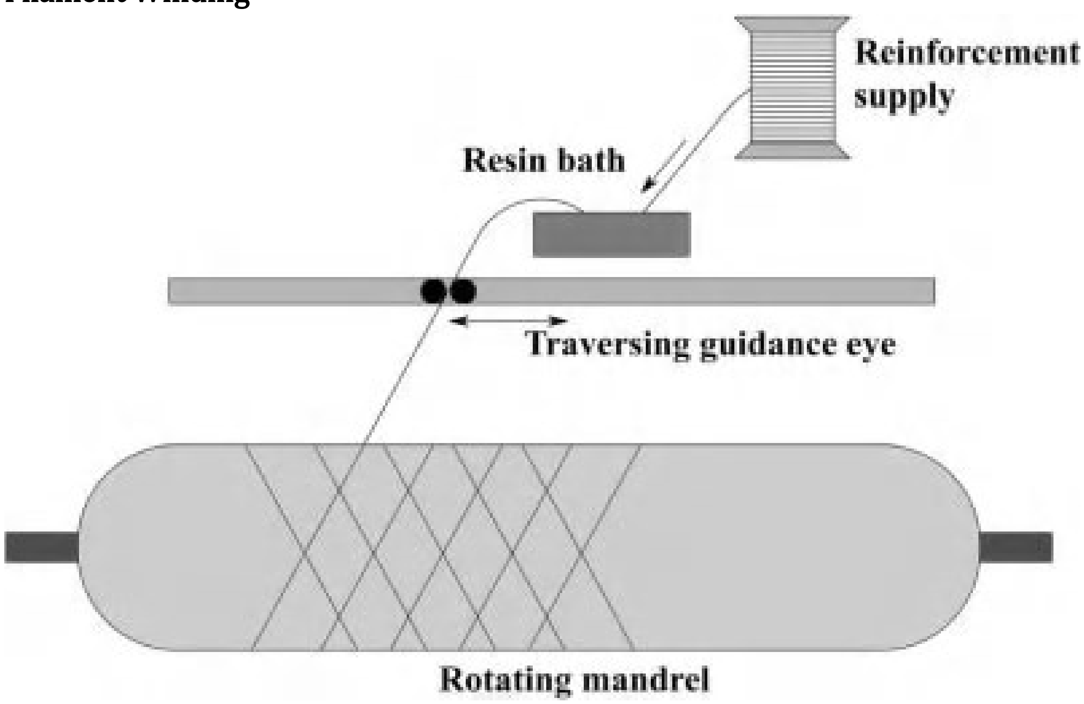


Figure 1. Scheme of filament winding process

The filament winding process is employed for the fabrication of a continuous fibre-reinforced composite structure having an axis of revolution. Continuous fibre strands or rovings are first coated with resin in a resin bath and then fed through rollers to squeeze out excess resin and finally wound, under constant tension, around a collapsible mandrel. The mandrel is usually made of steel. However, other materials like plastic foam and rubber are also used in the fabrication of some mandrels.

There are 2 types of filament winding patterns: helical winding and biaxial winding. After winding is complete, the mandrel is removed from the carriage and placed in an oven, if required, for curing. Filament wound products for aerospace applications are normally cured in an autoclave. Common examples are tubes, pipes, cylindrical tanks, pressure vessels, rocket motor cases, etc.

LITERATURE REVIEW

According to Mantia et al., 2005, the first fillers studied and used for polymer-based composites were inorganic. The main reason that led to their use was the need for cheaper materials or the significant improvement in some properties (rigidity, resistance to temperature, etc.) of the polymer matrix. A new type of filler has been recently investigated: organic ones. There are several reasons suggesting the use of these fillers for composites: low cost, environmental issues (in fact, organic fillers are biodegradable and come from renewable sources, which gives rise to less concern about their disposal), fewer hazards to the health of the operators, and low specific weight in comparison to mineral fillers (Sarraj et al., 2021). Furthermore, organic fillers other than wood are preferable because of the decreasing availability of natural resources (especially wood) and the increase in the cost of raw materials and energy. (Abd Rahman & Azahari, 2012)

The utilization of natural fibre in many industries has produced many exciting possibilities. Natural fibre is normally obtained from wood but due to the awareness of environmental problems associated with deforestation, people are looking for an alternative source of raw materials to obtain natural fibres.

The past decades have witnessed increasing interest in the use of fillers in the polymer industry. Fillers greatly enhance dimensional stability, impact resistance, tensile and compressive strength, abrasion resistance and thermal stability when incorporated into polymers. Fillers which merely increase the bulk volume, and hence, reduce price, are known as extender fillers while those which improve the mechanical properties, particularly tensile strength are termed as reinforcing fillers (Igwe and Onuegbu, 2012).

Nason *et al.*154 studied the effect of inorganic fillers on the photoinduced FP of a triacrylate. Not surprisingly, the front velocity decreased with increased loading of calcium carbonate or kaolin clay (Pojman JA (2012)).

Eggshell and fishbone powder were utilized successfully in preparing polypropylene composites. The tensile strength, tensile modulus, flexural strength, impact strength, hardness, and specific gravity of the polypropylene composites were found to increase with the increase in filler contents and decrease in filler particle size. The elongation at the break of the prepared composites decreased with an increase in filler contents, and particle sizes. Except for talc-filled polypropylene, all the polypropylene composites of fish bone, and eggshell powder investigated showed significant water absorption in a 24-hour water absorption test, and the level of water absorbed was higher than that of unfilled polypropylene and considerably higher than those of mineral-filled systems (Igwe and Onuegbu, 2012).

Nwufo, (Griffin *et al.,*1984) studied the extrusion of starch-extended water-soluble poly (vinyl Alcohol) and asserted that the method is relatively faster in estimating the physico-mechanical properties of the virgin polymer and its composite, thereby enabling the prevention of the extrudate so produced during extrusion from water effects. While studying the microscopic arrangement/appearance of fractured surfaces and some mechanical properties of starch-extended poly (vinyl alcohol), Nwufo and Griffin (1985), with the aid of scanning electron microscopy (SEM), showed that the composite with 0% starch content reflected only fracture lines, whereas composites with 10% w/w starch content in Mowiol (an industrial plasticized poly (vinyl alcohol) showed fracture lines as well as some pitting, indicative of starch beds. The mechanical properties of the composites revealed that the impact strength decreases with an increase in starch content, in comparison to the matrix impact property. It was explained that the swelling of starch in the matrix brings about a further increase in the percentage of starch resulting in a break, however, the breaking strength decreased progressively with an increase in the starch content. Also, the flexural modulus showed an increase with the increase in starch content.

METHODOLOGY

Materials

The various materials used for the production of composite samples included:

1. Calcium carbide waste (CCW) - Calcium Hydroxide $Ca(OH)_2$ the (locally sourced material)

Figure 2.1 Calcium carbide residue

2. Other materials (tools and equipment) e.g Personal Protective Equipment, Polypropylene, Ball mill (medium-sized), Weighing pan, 150um Sieve,

Figure 2.2. 150um Sieve

3. Injection Moulding Setup: The injection moulding machine consists of

i. The hopper
ii. Heater setup
iii. Hand-operated lever

iv. Plunger Bench vice
v. Die cavity

The construction of the injection moulding setup is shown in the figure

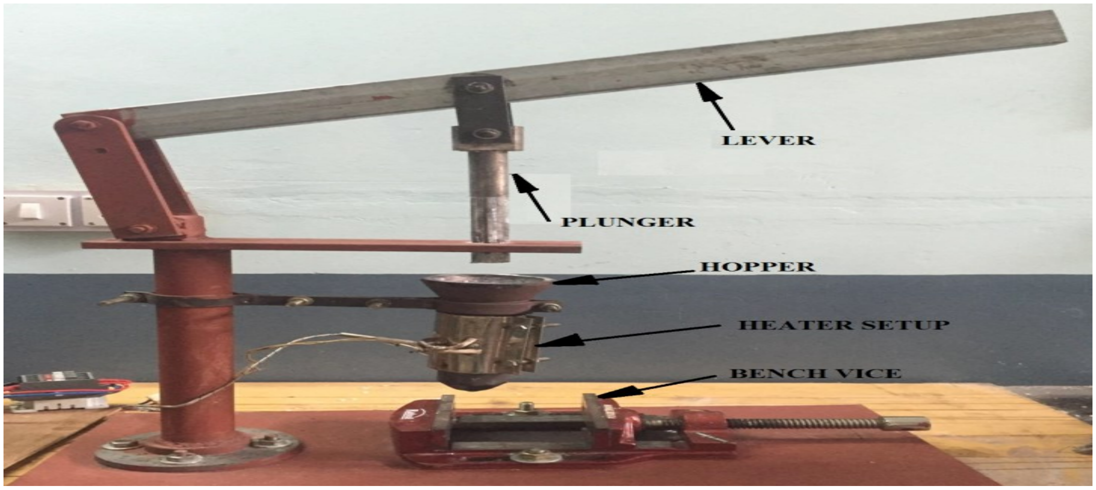


Figure 2.3. Injection Moulding Setup

Preparation of Test Samples

Test specimens are prepared as per ASTM standards. Five samples of each type were cut and prepared for the test. The list of ASTM standards used is mentioned in Table 3.2.

Table 1 Product Data of Polypropylene

S.I NO	PROPERTY	UNIT	ASTM STANDARD
1	Tensile	kg/ cm2	D 638
2	Hardness (Rockwell Hardness)		D785 A
3	Flexural Strength	kg/cm2	D790 B

Conclusion

Based on the results obtained from the mechanical tests carried out on the polypropylene-calcium carbide waste composite (PPCCWC), it can be concluded that the addition of calcium carbide waste significantly affected the mechanical properties of the composite. The tensile strength of a material is its ability to withstand a stretching force without breaking. In this study, we measured the tensile strength of polypropylene-calcium carbide waste composite, which is a type of composite material made from polypropylene and calcium carbide waste.

We found that the tensile strength of the composite was about 24.50 N/mm^2 without the addition of calcium hydroxide. When we added calcium hydroxide to the composite, it was found that the tensile strength increased slightly up to a certain point (less than 10% calcium hydroxide), and then decreased rapidly as the amount of calcium hydroxide increased beyond that point. This decrease in tensile strength was due to a weakening of the intermolecular forces within the internal structures of the composite, which made it less stable and less resistant to stretching forces. Based on this test we concluded that the optimal amount of calcium hydroxide to add to the composite is less than 10%, to maintain or increase its tensile strength. The flexural strength of a material is its ability to resist bending without breaking. In this study, we measured the flexural strength of the polypropylene-calcium carbide waste composite with varying amounts of calcium hydroxide. We found that the flexural strength of the composite increased slightly with the addition of up to 10% calcium hydroxide, but then decreased as the amount of calcium hydroxide increased beyond that point. The increase in flexural strength with lower amounts of calcium hydroxide was due to the smaller size of the calcium hydroxide particles, which filled the tiny gaps between the polypropylene in the composite and made its internal structure more compact and dense. However, as the amount of calcium hydroxide increased beyond 10%, the increase in flexural strength became less significant and eventually gave way to a decrease, likely due to the same weakening of intermolecular forces seen in the tensile strength tests. The hardness of a material is its resistance to deformation, usually measured by its ability to resist indentation or scratching. In this study, we used a rebound hammer to measure the hardness of the polypropylene-calcium carbide waste composite with varying amounts of calcium hydroxide. We found that the addition of up to 5% calcium hydroxide increased the hardness of the composite, likely due to the toughening effect of the calcium hydroxide on the polymer. However, as the amount of calcium hydroxide increased beyond 5%, the increase in hardness became less significant and was eventually outweighed by the decrease in other mechanical properties seen in the tensile and flexural strength tests.

Recommendations

i. The use of calcium carbide waste as a filler in polymer composites is a promising avenue that should be further explored. This waste material is not only cost-effective but also environmentally friendly, making it an attractive alternative to commercial fillers. As such, researchers should investigate the properties of the composites produced with calcium carbide waste and compare them to those made with other fillers to determine the best applications for this material.

ii. It is essential to evaluate the suitability of calcium carbide waste as a filler in other polymer matrices to understand its potential applications in different fields. This will require researchers to explore the effects of the waste material on various mechanical, thermal, and electrical properties of the composites. Additionally, the results of such studies will provide a broader understanding of the potential of this waste material in industrial applications.

iii. To optimize the use of calcium carbide waste as a filler in polymer composites, researchers must investigate the effect of surface treatment on the mechanical properties of the composites. Surface treatment can significantly impact the compatibility between the filler and the polymer matrix, affecting the strength and durability of the resulting composites. Researchers should experiment with different surface treatments and evaluate their effects on the mechanical properties of the composites.

iv. Researchers should also explore the use of other waste materials as fillers in polymer composites to reduce the cost of production and control environmental pollution. By using waste materials, researchers can develop sustainable materials with minimal environmental impact, promoting a circular economy. Investigating the properties of composites produced using different waste materials will also inform the development of new and innovative materials for industrial applications.

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