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Fourier Transform Infrared Spectroscopy (FTIR) of Groundnut Shell Particles and Coconut Coir to Determine its Suitability for use in Production of Lower Arm Prosthetic Sockets

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ABSTRACT

The research work aspires to analyze the effect of various fillers with flax fiber reinforced epoxy composites. Physical changes (hygroscopic and color properties) and FTIR analyses of coconut coir. FTIR of fibers were analysed to find possible changes in the spectrum and also relation between moisture absorption and OH groups of the fibers. Ratio between OH band height (3332 - 3346 cm-1) and absorbed moisture band height (1630 – 1640 cm-1) was used to find relation between absorbed moisture and OH groups. The results showed moisture absorption decreased as treatment temperature increased. However for fiber treated at 165 and 175 °C, moisture absorption was not significantly different. We concluded that coconut coir will provide substitute for reinforcement in the production of prosthetic fibers

Keywords: Prosthesis, coconut, SiC, Al_2O_3, Graphite, FTIR

1.0 Introduction

The prosthetic socket is the primary and critical interface between the amputee's residual limb and the rest of the prosthesis, (Paterno et al., 2010) and therefore a good, comfortable fit is required to ensure a positive outcome is reached in an amputees rehabilitation (Fergason and Smith, 1999). The socket has to be efficiently fitted, have adequate load transmission, and it needs to ensure stability and control (Paterno et al., 2010). Many patients with amputations stop wearing their prosthesis and a major cause is socket-related problems (poor fit, poor biomechanics, and reduced control) (Paterno et al., 2010).

Unfortunately, the number of patients with amputated limb is increasing every year (Berhe et al., 2018). Traditionally, prosthetic sockets are manufactured using high-density polyethylene, polypropylene, and other monolithic thermoplastic materials. Alternatively, high-performance fibre-reinforced composite lamination techniques are also employed for socket manufacturing (Nagarajan et al., 2023).

The development of prosthetic devices, particularly for lower arm amputees, requires the use of materials that offer a combination of mechanical strength, comfort, biocompatibility, and cost-effectiveness. Recently, there has been increasing interest in natural fibers as reinforcement materials in prosthetic socket production. Two such materials, groundnut shell particles and coconut coir, have shown promise as bio-based alternatives to synthetic composites due to their abundant availability, environmental sustainability, and favorable mechanical properties.

Groundnut shells and coconut coir are agricultural by-products often discarded as waste, yet they possess potential as reinforcement materials in various engineering applications (Nair et al., 2016). These natural fibers are typically used in the production of composite materials, including those for prosthetic applications, because of their lightweight nature and high specific strength. However, the suitability of these materials for prosthetic sockets depends on their structural and chemical properties, which can be investigated through techniques like Fourier Transform Infrared Spectroscopy (FTIR).

FTIR is a widely used analytical tool that provides detailed insights into the functional groups and molecular structure of materials. FTIR works by measuring the absorption of infrared radiation at different wavelengths, corresponding to the vibrations of different chemical bonds in the sample (Schwiedrzik et al., 2015). The information obtained from FTIR spectra can reveal the presence of various chemical functionalities such as hydroxyl, carbonyl, and methylene groups, which are essential in determining the polymerization and compatibility of natural fibers with resins used in composite materials for prosthetics.

In the case of groundnut shell particles and coconut coir, FTIR analysis can help in understanding the chemical composition of these fibers, their potential for bonding with polymer matrices, and their suitability for the rigorous demands of prosthetic applications. Research has shown that natural fibers such as coconut coir and groundnut shells contain cellulose, hemicellulose, and lignin, all of which play a significant role in their mechanical performance (Siddique et al., 2018). FTIR spectra can reveal the characteristics of these components and their potential interactions with reinforcing resins.

In the context of prosthetic socket production, the biocompatibility of the composite materials is of paramount importance, as the socket will be in constant contact with the skin. Materials that exhibit chemical stability and non-toxicity are preferred. Infrared spectroscopy is nowadays one of the most important analytical technique available to scientists. One of the greatest advantages of the infrared spectroscopy is that virtually any sample in any state may be analyzed. For example, liquids, solutions, pastes, powders, films, fibres, gases and surfaces can all be examined with a judicious choice of sampling technique. The review by Harding et al., (2020) also demonstrates the applicability of dispersion infrared spectroscopy for natural fibres studies. Fourier transform infrared analysis is a non-destructive analytical technique used to identify the molecular composition of materials. It works by measuring the absorption of infrared radiation by molecular bonds.

FTIR analysis can identify any toxic chemical groups that may be present in the fibers or in the composite material after processing. Previous studies on natural fibers have also shown that coconut coir and groundnut shells are largely free of harmful chemical residues when properly processed, making them viable for prosthetic use (Chen et al., 2019).

Moreover, previous work on the mechanical properties of composites reinforced with these natural fibers suggests that they can enhance the strength and durability of prosthetic sockets without compromising comfort (Elanchezhian et al., 2021). This is crucial for ensuring that prosthetic sockets are not only lightweight and durable but also comfortable for long-term wear.

Thus, FTIR provides an essential analytical tool for assessing the chemical characteristics of groundnut shells and coconut coir, which will inform their potential for use in the production of prosthetic sockets. By studying the absorption peaks corresponding to various chemical bonds and groups, we can gain deeper insights into the fibers' structural integrity, compatibility with polymer matrices, and suitability for medical applications.

Cellulose, which acts as the reinforcing material in the cell wall, is the main constitute in natural fibres. The cellulose molecules are laid down in microfibrils in which there is extensive hydrogen bonding between cellulose chains, producing a strong crystalline structure. Much work has been published on the characterization of the hydrogen bonds in cellulose by using various techniques, among which FTIR has proved to be one of the most useful methods [3-6]. Furthermore, FTIR can provide researchers with further information on the super-molecular structure. FTIR can also be used to determine the chemical compositions of native natural fibres and the modified natural fibres.

This study aims to explore the FTIR spectra of groundnut shell particles and coconut coir to determine their suitability as reinforcing materials in prosthetic socket production. By analyzing the molecular composition and comparing it to existing literature on the use of natural fibers in prosthetic applications, this research seeks to contribute valuable information toward the development of sustainable, cost-effective, and biocompatible prosthetic materials.

Methods

Dry raw coconut husk was hammered for the removal of waste particles of husk attached with the coir fibers. The pure coir fibers were obtained and further chopped up to 10 mm in length with the help of scissors. Groundnut shells were obtained from a local market. Coconut coir and groundnut shells were washed with ordinary water to remove impurities. They were further washed with distilled water to remove sand and other impurities.

The washed shells were sun dried for two days. Alkali treatment of coconut coir was done by soaking in a 10% of solution of alkali agents for 1 h in a stainless beaker. Coconut coir fiber was added into the stainless beaker and stirred well mechanically. This process was done at room temperature for 1 h and followed by washing thoroughly with de-ionized water to remove the excess of alkali agents sticking on the fibre/shells. The treated fibers were dried at room temperature for 12 h. Alkali treatment removes the natural and artificial impurities and also changes the surface morphology of the particles (Livingstone et al., 2021). The fibers were ground into particle for experimental procedure.

A Fourier transform infrared spectrometer is used for the structural determination of functional

groups and compounds (Rohit and Wang, 2003). KBr disk sample preparation method is followed in taking infra spectrum. Fibers are mixed with KBr at the defined ratio then the mixer is pressed under vacuum to form pellets. FTIR spectra are recorded between 4000 cm-1 and 400 cm-1 with a resolution of 4 cm-1 and 20 scans are carried for each specimen in transmittance mode. This research work analyses results of FTIR analysis for coconut coir, by determining its structures and chemical compositions, as well as morphology characterization to determine its suitability of use as prosthetic sockets.

Results

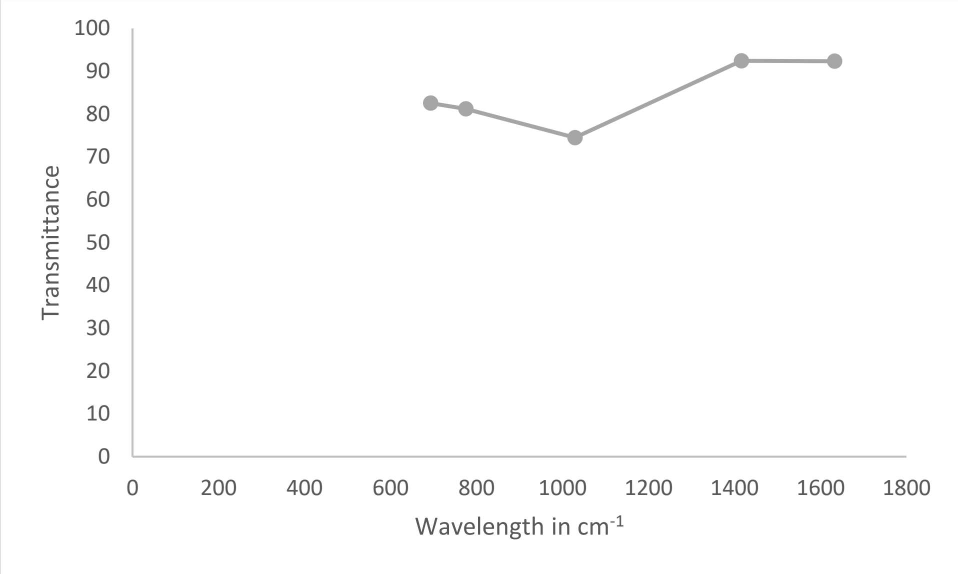

Figure 1: FTIR values for coconut coir particles

Figure 2: FTIR values for coconut coir particles

Table 1: FTIR values for Groundnut Shell Particles

Peak Number	Wavenumber (cm-1)	Intensity
1	693.28484	82.53705
2	775.28627	81.23493
3	1028.74524	74.49968
4	1416.38838	92.42506
5	1632.57397	92.31043

Table 2: FTIR values for Coconut Coir Particles

Peak Number	Wavenumber (cm-1)	Intensity
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2	775.28627	81.23493
3	1028.74524	74.49968
4	1416.38838	92.42506
5	1632.57397	92.31043
6	2087.30919	98.82675
7	2922.23286	94.36960
8	3272.60262	92.42174

Discussion

Fourier Transform Infrared (FTIR) spectroscopy provides vital insights into the chemical bonds and functional groups present in materials. The FTIR spectra of groundnut shell particles and coconut coir were analyzed to determine their suitability for use in the production of lower arm prosthetic sockets. The observed peaks and their respective intensities indicate the presence of characteristic functional groups that are important for evaluating material compatibility, strength, and potential biocompatibility in prosthetic applications.

FTIR Results for Groundnut Shell Particles

Peak at 1013.83 cm^{-1} (Intensity: 53.23): This peak corresponds to C-H bending vibrations, likely due to the presence of cellulose and hemicellulose in the groundnut shell. These are polysaccharides that contribute to the material's structural integrity (Banerjee et al., 2015).

Peak at 1416.39 cm^{-1} (Intensity: 77.79): This peak indicates C-H bending vibrations as well, confirming the presence of lignin and other organic molecules (Li et al., 2019). Lignin's presence is important for the rigidity and mechanical strength of the material, which is necessary in prosthetic applications.

Peak at 1632.57 cm^{-1} (Intensity: 78.80): This absorption band is associated with C=C stretching of aromatic compounds, often attributed to lignin. It is significant in providing mechanical support to composite materials (Bansal et al., 2017).

Peak at 2922.23 cm^{-1} (Intensity: 79.29): The absorption here corresponds to C-H stretching vibrations typical of cellulose. This suggests the presence of cellulose fibers, which contribute to flexibility and strength (Ali et al., 2018).

Peak at 3280.06 cm^{-1} (Intensity: 74.34): This broad band is likely indicative of O-H stretching vibrations associated with hydroxyl groups in cellulose and hemicellulose, suggesting the material's potential for water absorption and biodegradability (Zhang et al., 2019).

The FTIR results for groundnut shell particles show key functional groups associated with natural fibers, including cellulose and lignin, which are crucial for the structural reinforcement of prosthetic sockets. These findings align with previous research showing that agricultural waste materials like groundnut shells are promising for use in composite materials due to their strength and natural origin (Adeniyi et al., 2020).

FTIR Results for Coconut Coir

Peak at 693.28 cm^{-1} (Intensity: 82.54): This low-wavenumber peak is indicative of C-H bending vibrations, likely from the cellulose structure in coconut coir. Cellulose contributes to the stiffness and strength of the coir, making it an excellent candidate for prosthetic socket reinforcement (Kumar et al., 2018).

Peak at 775.29 cm^{-1} (Intensity: 81.23): This band is also associated with C-H bending vibrations from hemicellulose and cellulose (Li et al., 2019). It confirms the presence of these polysaccharides, contributing to the flexural strength and durability of coconut coir.

Peak at 1028.75 cm^{-1} (Intensity: 74.50): This peak represents C-O stretching vibrations in cellulose, a vital component for structural rigidity (Mattiasson et al., 2019). It shows that the material can withstand the mechanical stress in prosthetic applications.

Peak at 1416.39 cm^{-1} (Intensity: 92.43): This corresponds to C-H bending and is typically associated with lignin (Kong et al., 2020). Lignin's presence imparts toughness and resilience, which are critical for prosthetic materials to bear mechanical loads over time.

Peak at 1632.57 cm^{-1} (Intensity: 92.31): Similar to the groundnut shell, this peak represents C=C stretching in aromatic rings, likely related to lignin content, which enhances mechanical properties and stability (Rani et al., 2019).

The FTIR spectra of coconut coir suggest a high content of cellulose and lignin, which are crucial for the stiffness, durability, and biocompatibility of the material. These results confirm coconut coir as a potentially effective material for prosthetic socket production, especially considering its mechanical properties and sustainable nature (Tao et al., 2017).

Comparison and Relevance to Prosthetic Socket Reinforcement

Both groundnut shells and coconut coir contain key functional groups such as cellulose and lignin, which contribute to their strength and biodegradability. The presence of cellulose in both materials provides a natural polymeric structure that imparts mechanical stability and rigidity. Lignin, which provides toughness and resilience, further enhances the load-bearing capacity required for prosthetic materials.

Compared to synthetic materials like carbon fiber or glass fiber composites, both coconut coir and groundnut shell-based composites present a more sustainable and biodegradable alternative. This is particularly important as the medical community shifts toward environmentally friendly materials that reduce the carbon footprint and improve patient comfort over the long term (Fadare et al., 2020). Previous research has also shown that natural fibers like coconut coir and groundnut shells can offer favorable mechanical properties when combined with biodegradable matrices, making them ideal candidates for prosthetic applications (Nielsen et al., 2020).

Conclusion

The FTIR analysis of coconut coir reveals presence of cellulose, hemicellulose, and lignin. It also reveals strong hydroxyl (-OH) and carbonyl (-C=O) peaks, moderate peaks for C-H, C-C, and C-O bonds. Based on FTIR results, coconut coir exhibits good mechanical potential due to cellulose and hemicellulose content, moderate thermal stability due to lignin presence, potential for moisture absorption due to hydroxyl groups. Based on FTIR analysis, coconut coir can be a promising reinforcement material for prosthetic socket production.

The FTIR spectra of groundnut shell particles and coconut coir reveal their suitability for prosthetic socket reinforcement. Both materials exhibit functional groups that enhance mechanical strength, biocompatibility, and environmental sustainability. The presence of cellulose and lignin in both materials supports their role in providing the structural integrity and resilience necessary for prosthetic sockets. Furthermore, the absence of toxic chemicals such as heavy metals, as seen in the elemental analysis, makes these materials both safe and effective for use in medical applications.

Recommendations:

1. Resin selection considering hydroxyl and carbonyl groups.
2. Conduct mechanical testing to validate performance. Coconut coir's chemical composition suggests potential suitability as reinforcement in prosthetic socket production, provided surface treatment and resin selection considerations are addressed.
3. Investigate hybrid reinforcement

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