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Natural Fibers Reinforcement of Denture base materials: Natural Wool Reinforcement (A Review of Literature)

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Abstract

Heat-cured acrylic resin has been used to construct complete or partial edentulous denture bases for many years. However, it does not meet the ideal requirements of a dental prosthesis. Several researchers have studied the reinforcement of heat-cured acrylic resin with various fillers in order to enhance the properties of the acrylic. In this review of literature, the light will be concentrated on the role of natural fibers reinforcement with a focus on natural wool fibers.

Keywords Denture base, natural fibers, wool fibers, heat cure acrylic, fibers reinforcement.

Introduction

Full or partial denture is required to replace missing teeth by many elderly people despite the advancement in oral hygiene. Nowadays, the most common material used for the construction of a denture base is acrylic resin (McCabe, 2013; Aupaphong, 2022). It is inexpensive, has the desired aesthetic quality and easy to process. It does not have a single desirable property, but rather a combination of qualities that take into account its popularity and use. However, certain mechanical and physical properties are essential when fabricating a denture base. Therefore, despite fulfilling the aesthetic requirements, acrylic resin does not meet the mechanical demands of dental prosthesis (Noort, 2013; Aupaphong, 2022).

In practical applications, premature failure of denture base materials occurs as a result of different types of stresses, such as tensile, shear, and compressive. Intra orally, fatigue failure of the denture base can be caused by repeated mastication over a period of time. In addition, extra oral impact fractures can occur when dropped by accident, resulting in inadvertent denture damage (Scotti, 2010). Moreover, microhardness measurement revealed that acrylic polymers are relatively soft, particularly when compared with alloys. This predisposes the acrylic denture base to abrasion, especially during the use of brushes and abrasive cleansers, which can adversely affect the function and esthetics of these prostheses (McCabe, 2013; Shen, 2021). Furthermore, rough surfaces can contribute to denture stomatitis, induce halitosis, and are considered more susceptible to discoloration than smooth surfaces, thereby reducing patient comfort (Vongvachvasin, 2018; Al-Dwairi, 2019; Naser, 2023).

Researchers have made several experiments to improve the properties of denture base materials (Mawlood, 2020; Sabah, 2022; Abdul-Baqi, 2022; Alraziqi, 2022). Some of these attempts were made by adding fibers as reinforcement to PMMA and forming a new composite with better properties (Hameed, 2022; Harahap, 2022). The chief objective of using fibers as a reinforcement is to improve the elasticity and strength of the matrix, especially short fibers, which can provide significant reinforcement (Ouarhim, 2019).

Nowadays, as concern for the environment grows, bio-green composites are receiving more attention, and since the majority of composites are currently made from synthetic or glass fiber, which poses significant environmental risks (Fernandes, 2022). Therefore, recently natural fibers with low cost and high strength have been widely used to reinforce matrices. The excellent characteristics of the fibers, such as relatively low density, high strength, and high mechanical resistance, permit the creation of high-performance composites for imperative applications (Ouarhim, 2019; Fernandes, 2022).

Natural wool fibers are high performance fibers. They exhibit attractive properties, such as elasticity, flexibility, and null toxicity. From the point of chemical composition, wool fiber is mainly composed of keratins. Natural wool fiber properties have been reported to be closely related to keratin, where the existence of disulfide bonds regulates resistance, elasticity, flexibility, and biocompatibility (Satyanarayana, 2022; Fernandes, 2022). Furthermore, the cross linkages in wool fiber are hydrogen bonds, cysteine or sulfur linkages, which also contribute to strength, elasticity, and lateral resistance. In industry, when used as reinforcement, wool is reported to improve the mechanical characteristics of the matrix, such as flexural and tensile strength (Debnath, 2022).

The reinforcement of the heat-cured acrylic

Composite consists of a continuous phase called the matrix, a discontinuous phase called the reinforcements, and the interface. The matrix supports and holds the reinforcements in place. In addition, the matrix transmits loads between reinforcements and provides contour and surface quality to the composite component. Matrix also avoids mechanical and/or environmental damage to the reinforcement (Ngo, 2022). The primary benefits of composite materials are their superior stiffness, specific strength, and fatigue resistance compared to traditional materials (Ngo, 2018).

The inferior features of PMMA resins present an opportunity for more research to improve the resin's qualities. The most common method of improvement is through the addition of filler with PMMA resin. According to reports, the integration of filler with PMMA resin significantly improves composite characteristics (Ngo, 2022).

In reinforcing method, there different types of filler used. They are divided into two major sections: particle reinforcement and fiber reinforcement (Pavithra, 2021).

Particles reinforcement

Adding particles as reinforcement to acrylic resin denture base material is considered as reasonable and cost-effective method to improve the material's mechanical, physical, and thermal properties (Rajul, 2015). Reinforcement of PMMA with metal oxides has increased the material's physical and mechanical characteristics, as well as the sensation of heat and cold sensations in patient. Subsequently, the inclusion of metal fillers to denture-base resin was predicted to increase food sensation and healthier oral mucosa (Pavithra, 2021). Recently, it has been hypothesized that nanofillers can improve the characteristics of PMMA. PMMA thermal characteristics were enhanced by the large surface area, small size, and uniform nanofiller dispersion. Nanofiller-

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enhanced resin characteristics are dependent on particle size, shape, type, and concentration (Pavithra, 2021).

(Ahmed, 2016), stated that the addition of TiO2 nanoparticles into acrylic resins might have a negative impact on the material's flexural strength. This effect is directly proportional to the nanoparticle concentration. In contrast, concentrations of TiO2 nanoparticles over 5% had a beneficial effect on the microhardness of acrylic resin utilized in this investigation.

(Zidan, 2019) report that the incorporation of zirconium oxide nanoparticles into the heat-cured acrylic denture base material has a substantial influence on the mechanical qualities. At low filler loadings 3-5 weight percentage of zirconia, an improvement in the overall mechanical characteristics was found. However, as the filler loading was increased, the impact resistance was shown to decrease.

(Vikram, 2020), found that adding zinc oxide (ZnO) nanoparticles filler in different weight concentrations had improved the flexural strength of heat-cured denture base material.

Fibers reinforcement

Fiber reinforcements are the most popular type. They are either long fibers (also called continues), or short fibers (also called discontinues) (Callister, 2018; Ngo, 2022). There are various factors which may cause PMMA reinforced by fibers to perform in different ways (Sheng, 2018; Callister, 2018):

1. Types of fibers: To transfer stresses efficiently, fibers must have high mechanical qualities, be biocompatible, transparent, and bind well to denture acrylic; otherwise, the fibers behave as inclusion bodies and basically deteriorate the denture (Rickman, 2012).
2. Length of fibers: Effective fiber reinforcing requires the transmission of stress between the polymer matrix and the fiber. Which can be accomplished when the length of the fibers is equivalent or exceeding the critical fiber length. However, the critical fiber length relies on several elements such as the shear strength of the matrix, the interfacial bond strength, and the tensile strength of the fiber. However, it has been hypothesized that there is an optimal fiber length for preventing flow in the polymer and that the flow characteristics of the acrylic resin may be altered by changing the fiber length (Karacaer, 2003; Callister, 2018).
3. Orientation of fibers: Unidirectional continuous fiber-reinforced composites are called anisotropic, which have great strength and stiffness in a single direction. The utilization of randomly oriented fibers produces isotropic qualities, which are comparable in all directions. Clearly, continuous fibers give greater reinforcement to random fibers, but inserting continuous fibers at the weakest areas of the denture to achieve optimal reinforcement are challenging and needs extra technical steps (Karacaer, 2003). In addition, the manufacturing rates for short-fiber composites both aligned and randomly oriented are high, and complicated geometries are achievable, which are not possible with continuous

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fiber reinforcement. Furthermore, manufacturing costs are much cheaper than for continuous and aligned fibers (Callister, 2018).

4. Fiber percentage and position: For optimal strengthening, the concentration must be high. The reinforcing fibers with high tensile strength are more effective when positioned close to the region of maximum tensile stress during functional loading of a denture, such as near the oral surface of a maxillary full denture and perpendicular to the midline (Rickman, 2012).

Numerous researches have evaluated the various factors that control the properties of fiber-reinforced PMMA (Gad, 2017; Sheng, 2018; Callister, 2018). In order for these fibers to successfully transfer stresses, they must possess excellent mechanical qualities, be biocompatible, transparent, and adhere well to denture acrylic (Gad, 2017).

(Abdulrazzaq, 2015), added glass flakes to heat-cured acrylic denture base material. The results showed significant improvement in surface hardness after flakes addition in percentages of 5% and 7%.

(Singh, 2016), revealed that reinforcement of denture base with 2% and 5% glass fibers have statistically significant enhancement in the flexural strength of PMMA.

(Kannaiyan, 2020), evaluated the addition of nylon fibers with 2% by weight on denture base acrylic. The results showed that reinforcement of conventional denture base resin with nylon fibers showed statistical significance in the flexural strength values.

(Yerliyurt, 2022), added carbon and polypropylene fibers with 3, 6 and 12 mm lengths, in concentrations of 0.25, 0.50 and 1.0 percentages by volume as reinforcement of PMMA denture base resins. This study's testing and analysis demonstrated that all fiber kinds may improve mechanical qualities such as modulus of elasticity and flexural strength.

Natural fiber reinforcement

Natural fibers are defined simply as fibers that are neither synthetic nor manufactured, and are classed according to their origin from animals, plants, or minerals. Natural fibers are the material that might be used to substitute synthetic materials and their derivatives in applications that need reduced weight and energy conservation (Ngo, 2018).

Natural fiber has several benefits compared to synthetic fiber in terms of its comparatively renewable resources, include: excellent relative mechanical qualities, as for tensile and flexural modulus, low weight, its abundance, low cost, less damage to processing equipment, and enhanced surface finish of composite molded parts. For these reasons, these bio-composites are becoming increasingly popular, and a substantial quantity of scientific information has already been developed (Ngo, 2018; Ouarhim, 2019).

(Okeke, 2018), studied natural hibiscus sabdariffa fiber-reinforced PMMA acrylic resins. They had significant improvement in impact strength at 7.5% by weight of fibers.

Oleiwi 2018), added alkali-treated natural bamboo fibers to denture base acrylic. However, the result revealed reduction in impact strength after the addition of the fibers compared to the unreinforced acrylic.

(Harahap, 2022), reported an improvement in impact strength of heat-cured denture base material after reinforcement with natural banana stem fibers of 2 mm long and in 1.5 % by weight.

(Salih, 2017), investigated the influence of fiber length and weight fraction of alkali-treated natural siwak fiber, with the selected length of 2, 6 and 12 mm and weight fraction of 3, 6 and 9 %

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by weight on tensile strength of PMMA. The result showed that the highest value was for 12 mm long with 9 % fibers group.

(Hameed, 2022), added silane-treated natural sisal fiber to heat cured acrylic. They reported a significant increase in tensile strength after fibers reinforcement.

(Johari, 2021), reported that kenaf natural fibers with 6 mm length and in 2% by weight significantly increased the flexural strength of heat-cured acrylic resin.

Natural wool fibers

The most significant animal hair utilized as a fiber in the world is wool. Wool fibers look cylindrical, each fiber has a gradual tapering from the root to the tip. In cross-section, the wool fiber has an external cuticle consisting mostly of proteins, carbohydrates, and lipids, and internal cortex constituted of around 90 percent keratinous fiber, also occasionally air-filled vacuoles called medulla. The cell membrane complex splits the cuticle from the underlying cortex. Furthermore, it splits the cortical cells from one another (Das, 2022).

Wool is a copolymer composed of 18 amino acids, while synthetic fibers are copolymers composed of 2 monomers. Wool fiber's distinct amino acid composition contributes to its chemical characterization. Sulfur-containing cysteine is an essential wool fiber characteristic. A greater sulfur content in wool results in improved processing qualities, increased resistance to chemical effects, and enhanced physico-mechanical properties (Allafi, 2020).

Raw wool includes between 25 and 70 percent contaminants, including: wool grease, vegetable matter, for example burrs and seeds, suint (residuals from perspiration), and dirt. Wool grease is a combination of esters and fatty acids, whereas suint is made up of potassium salts of fatty acids, in addition to sulfate, phosphate, and nitrogenous substances. By scouring, debris, wool grease, and suint are eliminated. While the vegetable matter has to be eliminated through carding and combing (Millington, 2017).

Chemical and physical structure of wool fibers

The chemical constituent of wool fibers is the fibrous protein called keratin. In addition to several kinds of amino acids, wool fibers contain mineral salts, carbohydrates, lipids, nucleic acid residues, and sulphur containing groups (Erdogan, 2020).

Encircling the cortex is a sheath composed of cuticle cells, which make up around 10 percent of the fiber's mass. Cuticle cells, which overlap around and all sides of the boundary of each fiber similar to roof tiles, are visible under scanning electron microscope (SEM) (Figure 1). This organization distinguishes wool from other textile fibers. The cuticle cells are crucial for the capacity of wool to felt, especially when disturbed in wet circumstances. Fine wool typically has a cuticle that is one cell thick, and around 15 percent overlap. Cuticle cells have a thickness between 0.3 to 0.5 µm, a width approximately 20 µm, and a length of 30 µm. Cross-section segments of cuticle cells reveal an upper high sulfur zone called the exocuticle and a lower sulfur-containing underlying region called the endocuticle. Based on chemical and physical examination of cuticle cell components, it has a greater amorphous structure comparing to the remaining portion of the fiber. In addition, due to a greater concentration of cystine, it has a lower extensibility compared to the cortex, thus has a greater crosslink density. When wool fibers are stretched, the reduced extensibility causes the cuticle cells to crack. However, cracking does not result in the separation of the cortex from the cuticle cells, which is extremely crucial for the mechanical processing of wool (Millington, 2017).

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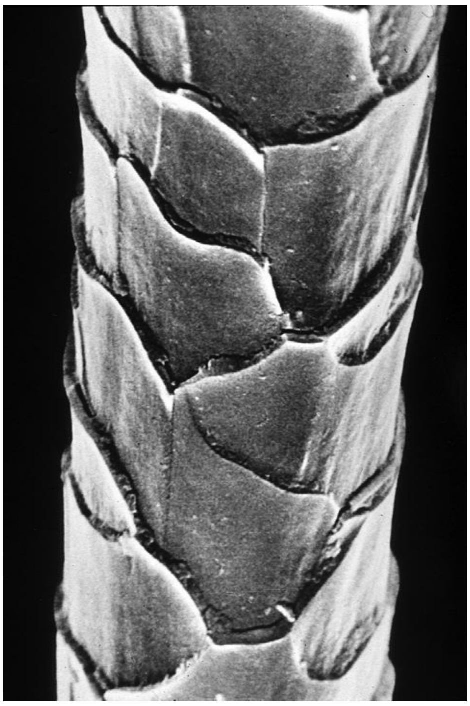

Figure 1: SEM picture of a clean wool fiber (Millington, 2017).

A chemically resistant membrane surrounds each cuticle cell. This membrane is between 2 and 7 nanometers thick; it contributes about 0.1 percent of the fiber mass. The lower side of this membrane which formulates part of the cell membrane complex, partitions the cuticle from the cortex of the fiber. This protective membrane on the external surface of cuticle cells is known as epicuticle. Even though the epicuticle composed of protein, grease-free wool fibers are hydrophobic (Das, 2022).

Almost 90 percent of the wool fiber is composed of the cells of the interior cortex, which are significantly responsible for its mechanical qualities. The length and width of spindle-shaped cortical cells are around 100 µm and 3 to 6 µm, respectively. They are lined along the axis of the fiber with overlapping and dense arrangement. Cortical cells are composed of intermediate filaments, which are rod-shaped components made of highly organized, crystalline proteins. Some of the intermediate filament proteins are helical and crystalline. These proteins give the wool fiber its resilience, elasticity, in addition to the excellent wrinkle recovery (Das, 2022).

The matrix and intermediate filaments are arranged into collections referred to as macro-fibrils. These cylindrical units have a length that range between 10 µm to the whole length of a cortical cell and have a diameter around 0.3 µm. On average, each macro-fibril comprises 19 intermediate filaments (Millington, 2017).

Macro-fibrils are clustered to produce two principal cortical cells forms called ortho and para. Generally, paracortical cells are better defined than orthocortical cells, with non-keratinous material localized in prominent areas known as nuclear remnants. In the orthocortex cells, there are less nuclear remains because the non-keratinous substance is spread more uniformly across the macro-fibrils, as opposed to being localized in specific locations. Therefore, the connection of inter macro-fibrillar substance clearly distinguishes orthocortical macro-fibrils from paracortical cells. Furthermore, the ortho and paracortex cells vary in the percentage of matrix material and intermediate filaments inside the macro-fibrils, as well as the packing arrangement of these constituents. Despite the fact that the proteins of the intermediate filaments are identical in both types of cells, the matrix proteins differ, with the paracortex containing proteins with the largest sulfur concentration. The variations in the chemical and physical structure of the ortho and

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paracortical cells affect the amount and degree of chemical absorption, and are thus crucial to the processing of wool. Generally speaking, the orthocortical cell has greater susceptibility to reagents and is chemically active more than its paracortical counterpart (Das, 2022; Millington, 2017).

Natural wool fibers as a reinforcement fiber

In several sectors, fiber-reinforced composites are frequently employed. Compared to unreinforced plastics and metals, the composites of animal fiber bring superior flexibility, strength, and corrosion resistance (Allafi, 2020). The complex structure of wool both physically and chemically, as mentioned above, renders it with a wide variety of valuable qualities not obtained in any other textile fiber. Wool is more chemically reactive than other textile fibers. In addition, developments in the understanding of wool's fine structure and chemical content have led to strategies for further enhancing its chemical and physical qualities (Millington, 2017).

(Conzatti, 2012), studied the effect of adding wool fibers to the polyester matrix; the elastic modulus and the yield tensile strength of polyester improved after wool fibers reinforcement.

(Kim, 2013), studied polypropylene reinforced with wool fibers. It was concluded that the incorporation of wool fibers in a percentage of 15 % by weight enhanced the tensile modulus and tensile strength compared to polypropylene alone.

Furthermore, (Chang, 2017), investigated the poly (propylene carbonate) natural wool composite in a percentage of 0.5, 1, 2, and 4 % by weight; the results showed an increase in tensile strength and young modulus with increasing wool concentration.

(Das, 2017), studied the biochar based hybrid composites with waste wool. The results revealed that wool enhance certain mechanical properties, including flexural and tensile strength. In addition, it aids in improving the limit oxygen index.

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تعزيز قاعدة أطقم الأسنان بالألياف الطبيعية: التعزيزبألياف الصوف الطبيعي

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المستخلص
تم استخدام راتينج الأكريليك المعالج بالحرارة لبناء قواعد اطقم الأسنان الكاملة أو الجزئية لسنوات عديدة. ومع ذلك، فإنه لا يفي بالمتطلبات المثالية للأطقم الاصطناعية للأسنان. درس العديد من الباحثين تعزيز راتينج الأكريليك المعالج بالحرارة باستخدام حشوات مختلفة من أجل تعزيز خصائص الأكريليك. في هذا البحث، سيتم تركيز الضوء على دور تعزيز الألياف الطبيعية مع التركيز على ألياف الصوف الطبيعية.

الكلمات الدالة :- قاعدة طقم الأسنان، الألياف الطبيعية، ألياف الصوف، الأكريليك المعالج بالحرارة، التقوية بالألياف
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