Recent Reviews on Hybrid Nano Reinforcements for Improving Mechanical Properties of Polymers for sustainable applications

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Abstract. The paper reviews the impact of hybrid nano particles in polymers that would enhance the mechanical properties. Various nano fillers have been used as reinforcements that would improve the mechanical properties of the composite materials. Poly methly methacrylate (PMMA) is preferred as the matrix material especially in denture bases as it overcomes the deficiencies that the other materials show. (PMMA) is an acrylic resin commonly used with a long heritage for prosthetic reasons. It can be classed as chemically or thermally polymerized material based on the causes that trigger the reaction. The nano fillers when used as reinforcements in PMMA have shown very good results. The microstructure behavior of the distribution of the nanofillers were studied through XRD, SEM, AFM and other techniques. Some studies have used optimization techniques to compare the results.

Keywords: PMMA; SEM; acrylic resins; denture materials.

1 Introduction

A wide range of materials have been utilized to make dentures over the ages. From the earliest dentures carved from stone, ivory, bone, and wood to the most recent polymer, the historical evolution of these materials has been researched. Nowadays, polymethyl

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methacrylate, or PMMA, is a common acrylic resin found in a variety of denture base materials. A significant issue is denture base fracture. Reinforcement with various fiber kinds is one of the methods that have been employed recently to strengthen the PMMA denture base resin. Prior research [Jawad Kadhim Oleiwi and Qahtan Adnan Hamad, 2018] indicates that high-strength metal marginally improves the flexural strength and impact strength of denture base polymer; however, its application is constrained due to its evident aesthetic influence [1].

Furthermore, there is little effect of metal wires on the resistance to external fatigue. Several fiber types, including carbon, aramid, and ultrahigh molecular weight polyethylene, have been studied recently as reinforcing materials. The results indicate that the fibers also improve the impact and flexural strength of the base polymer used to make dentures. Glass rods or fibers were researched in 2000 as a potential reinforcement for denture base polymer [2]. In a comparison of the mechanical properties of denture base polymer with glass fibers, carbon fiber, Kevlar fiber, and polyethylene fiber for reinforcement, the polyethylene fiber group produced the highest impact test values; however, there were no appreciable differences in transverse strength [Saleh Zidan et al. 2019).

Glass fibers have superior transparency over other fibers, making them a good choice for denture base polymer when utilized in light curing type resin. Glass rods can only be applied on thin palatal sections of denture base polymer, and it has proven difficult to integrate continuous long glass fibers into the dough of liquid methyl methacrylate (MMA) monomer and powdered polymethylmethacrylate (PMMA) in dental treatment.

Fig.1 depicts the evolution of polymers starting from Vulcanite in 1839, Celluloid in 1870, Bakelite in 1909, PVC in 1930 and then the PMMA in the year 1937.

Fig. 1. Development of polymers for the fabrication of denture base.

PMMA acrylic resin is the most widely used material for denture fabrication because it has a number of advantageous properties, including low weight, low cost of fabrication, non-toxicity, stability in the oral environment, and suitable aesthetic and color matching ability. It is not perfect in every way, though, and has a number of issues that need to be resolved, such as poor impact resistance and low thermal conductivity, which impair patients' ability to evaluate flavor and palatability.

It has been demonstrated that acrylic nanocomposites can stretch in function far more than one might anticipate. Thus, numerous changes were made to the traditional denture base resin to increase its strength in order to prevent such terrible outcomes. An attempt was made to improve the impact strength of acrylic resin by including rubber, namely butadiene styrene, through chemical alteration. This endeavor was effective. Impact forces and flexural fatigue are the two forces that cause denture fracture.

Research has indicated that several processing parameters, including temperature, mixing ratio, curing environment, length of curing regime, and water storage during postprocessing, can impact the mechanical characteristics of denture bases. [Rajender Sanjiv Dagar, 2017].Of all the properties of denture base resins, the flexural strength, hardness, and impact strength are the important properties which are used to evaluate the strength of the material [3]. Various studies have been done in the past evaluating the effect of P/L ratio. Previous studies demonstrated that the mixing ratio has an effect on the strength of unreinforced polymerized material. However, little is known about its effect on reinforced PMMA resin.

2 Literature Studies

2.1 PMMA used in Dentistry

Since Walter Wright first developed acrylic resin as the denture foundation material in 1937, the PMMA material has completely altered the techniques of preparation that have been employed up to now. Because acrylic resin could overcome many of the shortcomings of the materials available at the time, it became the material of choice for creating denture bases. On the other hand, removable dentures are used if the oral cavity is in a critical condition. [Ma. Concepción Arenas et. al]. There are approximately 500 microorganisms in the mouth that, in an acidic environment, produce a biofilm and can cause a number of disorders, including carious lesions in abutment teeth, denture stomatitis, and worsening of the periodontal health of the remaining teeth. As a result, selecting an appropriate material for dental prosthesis is crucial. Poly (methyl methacrylate) (PMMA) is an acrylic resin that has a long history of use in prosthetic applications [4]. Depending on the conditions that cause the process, the material might be categorized as thermally or chemically polymerized. Thermally polymerized polymers are utilized in dental prostheses, and heat can be produced using a microwave or a hot water bath.

It was proposed that the most crucial factor in determining the final PMMA for dental prosthesis qualities is the concentration of residual monomers. An understanding of the polymer arrangement can be gained from the discovery that the methylene groups are located in the inner layer of the PMMA surface, while the alpha methyl groups prefer to remain in the outer layer. Stated differently, PMMA has demonstrated a modest level of cytotoxicity both in its bulk and polymerized forms [36-40]. PMMA is an amorphous polymer that is created when MMA monomer is polymerized via a variety of techniques, including anionic, group transfer polymerization (GTP), free radical vinyl polymerization, and atom transfer radical polymerization (ATRP). To create PMMA, two methods are utilized: bulk or solution (homogeneous polymerization) and emulsion or suspension (heterogeneous polymerization). Suspension polymerization stands out as a viable method for yielding PMMA with a high molecular weight of 36,100, a high percentage of 83%, and a polydispersity of 2.4 (measured by Mw/Mn) [41-45].

(Mohammed A. Taha et. al 2023) in their study have considered two portions of nano materials being silicon carbide and fly ash to make a hybrid nano composite Cu-Matrix and in order to combine the two nano materials, powder metallurgy process was used [5]. The amount of both the nano materials used was varied. The nano materials were compressed at three temperatures in the presence of inert gas for over an hour. After the preparation of specimen, the microstructure was checked using the transmission electron microscopy and X-ray diffraction techniques. The mechanical properties that were tested in this study were electrical, wear, thermal and mechanical characteristics. Also, Young's modulus, microhardness, ultimate strength was also tested. The study concludes with the findings that significant improvement was seen in the mechanical characteristics such as Young's modulus, ultimate strength, wear rate by noticeable percentages. Also, the nano composites that had 16% Vol of ceramics showed good results on the mechanical properties such as electrical conductivity, value of density and coefficient thermal expansion.

The authors in their study have used two nano particles (A.M. Sadoun et. al, 2020) ZrO2 and GNPs to create the nano composite with CU based using the technique powder metallurgy. The experiment was carried out by keeping ZrO2 fraction constant at a specific percentage and varying fractions of GNPs to study the tribological properties and mechanical characteristics of the specimen produced [6]. For the purpose of mixing the two nano particles ball milling procedure was used with high energy, and for the purpose of consolidation of the specimen, the methodology used was sintering. The results in the study showed that the specimen with 0.5% GNPs showed good improvement in the tribological properties and mechanical characteristics. There was an increase in the hardness as compared with other mass fractions of GNPs. However, there was a decrease in the wear rate. The experiment showed increase in wear rate when the mass fraction of GNPs was also increased.

(Xin-feng Guo, 2024) in their study have carried out experiments to achieve the objective of removing the phenomenon of agglomeration of CrB2 particles and to exhibit the betterment of mechanical properties of CrB2/Cu composites. This was done by considering the high-volume fraction of CrB2 [7]. The study concentrates on change in mechanical properties and electrical properties. The authors in the study have used hot pressure sintering, hot extrusion and ball milling to fabricate the CrB2/Cu composite. The study highlights on the finding that there is direct proportionality between ball milling time and the mechanical properties however, inverse proportionality between ball milling time and electrical properties. Also, the composites exhibit improved characteristics like conductivity, elongation with 5% Vol of CrB2 particles. The authors also conclude that the main strengthening mechanisms are dislocation strengthening and refinement strengthening.

Milan Ferdinand et. al 2023, in their study have highlighted the advantages of preferring Polypropylene (PP). it has light weight, easy to recycle and cost is relatively low. The advantages can be further modified by adding a second component [8]. The materials HJ 120 UB grade homopolymer and the Daplen EE 050 AE grade hetero phasic copolymer were used for the study. BYK-MAX CT4270 grade was used as the nano filler, and was

compared with jet fine 3CA talc. The different weight of nano filler used were 0,1,3,5,7,10 % in the composites. The nanofillers which was a part of granules of the composites were dried at 110 degrees centigrade in vacuum for 4 hours. Four set of these materials were converted into 1A tensile bars of 4mm thickness by injection molding and four set of temperatures were used. The measurement was done using scanning electron micrographs (SEM) and transmission electron micrographs (TEM). Tensile strength test was measured using universal testing machine. The study concluded that the tensile strength of nanofiller is better when compared with talc. Characterization indicated the presence of sepiolite and laponite in the nano filler.

Another study (Kamaljit Singh, 2022) suggests that the inclusion of nano materials increases the mechanicalproperties of pristine metals such as electrical conductivity and thermal conductivity. The authors selected Cu composites with few reinforcements, out of which graphite is one of them [9]. The study highlights on a very important finding that hybrid nano reinforcement has better mechanical behavior as compared to single 2D reinforcement material. The change in mechanical behavior makes the material adaptable to the changing conditions of environment.

(K.P.Srinivasa Perumal, 2023) in their study have tested the crystallographic and morphological behavior of epoxy composites as well as its mechanical properties. The nano reinforcement material used for this study is Zirconium. The nano fillers were mixed using ball milling at different percentages. In order to form the composite material, compression molding technique is used. To test the mechanical characteristics, the ASTM standards were maintained [10]. The crystalline structure of the nano filler was studied using X-ray diffraction. Out of the various % Wt. of the Zr nano filler, better improvement in the mechanical characteristics has been shown in 10%wt with the other nano filler. The study has concluded with the application of the above said composite in building if aircraft structure.

(HalilKarakoç, 2024) in their study used Al2O3 as the reinforcement particles. The composite that is functionally graded is fabricated using multi-layer about 6 to 7 layers of the Al2O3 reinforcement particles. Each of the layer of reinforcement was fabricated with different weight percentages. The distribution of reinforcement in the matrix was studied through compressive strength analysis and the intensity of the composite was checked through XRD test [11]. The structural behavior of the reinforcement in the matrix material was tested using compressive strength analysis. The test showed that the distribution was homogeneous throughout the matrix material. The study revealed that there was improvement in the mechanical characteristics of the composite material with one of the wt. %b of the reinforcements.

In another study (Isma Liza Ali et. al.) have tested the mechanical characteristics such as flexural modulus, flexural strength and other characteristics of base materials of dentures. These denture materials were cured using three methodologies. Also, the hardness of the specimen on both internal and external surface was tested. For the sake of specimen making, the materials used were Probase, Meliodent and Eclipse. Both cold cured and heat

cured resin material was used as the matrix material. After the fillers were mixed, a specific size of rectangular shapes was made. Before testing these specimens for their hardness, they were stored in water for approximately 30 days and at about 37 degrees centigrade. For the examination of surface hardness, Vickers Hardness was used, also were tested at different time intervals [12-16]. The study also carried out optimization techniques to check a comparison on all the mechanical characteristics. The optimization technique used was ANOVA one way. The hardness of both the internal and external surfaces of the specimen were compared using t-test. The tests revealed proportionality with different time frames with the mechanical characteristics and inverse proportionality with the varying Wt. % of the specimen with the mechanical characteristics. The study concludes that the matrix material gives better results when cured by two methods together rather than one method [17-21].

In the study carried for checking the surface defects of the denture base materials, a new method was developed (J.G. Robinson). The study highlighted that any surface defect would cause an effect on the strength of the denture base material made of acrylic material, some of the mechanical characteristics of the materials were tested such as flexural strength, toughness and other mechanical characteristics [22-27]. The study concludes by highlighting that the denture base material had less impact on the strength when the surface defects were less.

In the study carried out by (S.Srinivasan et.al, 2021) have analyzed a series of optimization techniques. The study highlights that there are many benefits when optimization techniques are used. Mechanical properties of the composite materials can be improved, quality of the composite materials, and so on. The various optimization techniques used in the study were Analytic Hierarchy Process, Taguchi Method, Gravitational Search Algorithms, Surface Methodology and other techniques [28-31]. The study highlights that the old method of convention does not work effectively for selection of parameters. However, the new and scientific method of processing have worked effectively for the selection of parameters. Also, the optimization techniques used in the study have helped in effectively in selecting the parameters for control factors. The results have been reliable according to the study and the study highlights that the results are better when combination of two optimization techniques are used. Along with the optimization techniques for selecting the control parameters, it was also based on machining process and the parameters that were considered were the speed of the machining process, feed of the machining process, depth of the cut etc. The study concludes by highlighting that different optimization techniques are effective for selecting control parameters [32-35].

3 Conclusion

The reviewed literature data clearly showed that there is improvement in the mechanical behavior and electrical characteristics of the composite material after the inclusion of nano fillers as reinforcements. These materials are preferred in few sustainable applications like solar panel parts, blades of turbines used in power plants, eco friendly biological system equipment parts and containers. The data has shown that there has been improvement in the

young's modulus, tensile strength, wear resistance and thermal conductivity with varying percentages of the nano fillers. Many studies have used ZrO2, CrB2, talc and many other materials as nano fillers. Most of the data revealed that the materials were prepared using powdered metallurgy and ball milling. The distribution of nano fillers in the matrix material were studied by Sem, XRD and XPS.

4 Abbreviations

TEM - Transmission electron microscopy
SEM - Scanning Electron Microscope
XPS - X-ray photon spectroscopy
XRD - X-ray diffraction
PMMA - Poly methyl methacrylate

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