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Enhancing Mechanical Performance of PMMA Resin Through Cinnamon Particle Reinforcement

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ABSTRACT

The article discusses an experimental procedure which involves impregnating cinnamon extracts into Poly Methyl Methacrylate (PMMA) resin with further purpose of utilizing it for dental prosthesis purposes. At normalized sampling rates and through manual molding using 53µm particle size, samples comprising of 8%, 6%, 4%, 2% and 0% volume fractions were evaluated. Mechanical properties such as hardness, impact strength, and tensile strength were also investigated empirically. The findings demonstrated an increase in hardness, reaching a maximum level of 8% with a value of 86 N/m². Also, impact strength coefficient marked rather a positive effect, with 0.93 KJ/m² being the highest peak noticed at the 6% volume fraction level. The peak value of tensile strength was successfully measured at 4% by volume fraction that gave 52 MPa, while additional ratios of reinforcement had a continuous trend of a decrease. This thorough study uncovers the future promising potential of cinnamon extracts as to the reinforcement of technical properties (mechanical properties), and this contributes to the improvement of modern biomaterials used in Dentistry.

1. INTRODUCTION

The composite materials are becoming more popular due to their specifications that the traditional materials, for example, metals and alloys, are being substituted, and therefore, they offer them strength and durability [1]. In composite materials, particular mixtures of various materials that are endowed with their own independent properties which upon the combination lead to the fabrication of a new material that may differ in its characteristics from the constituent materials [2]. Polymers are developed to meet specific needs that our age is conflicting with, hence we note multiple breakthroughs in different domains. The polymer is an easy-to-make material, compared to metal and ceramic ones, and is resistant to oxidation and corrosive solution containing acidic and alkaline acids [3]. Polymer piezotronics are made sourcing array of reinforcement and filler materials to get comprehensive material measurement requirements for various applications [4].

Polymethyl methacrylate (PMMA) resins are the major component in the manufacture of many dental bases providing with such positive attributes as lightweight, cheap in production, easy to repair, toxicity free, meeting color matchings and with perfect appeal to the tooth [5-7]. PMMA has been widely adopted in the dental industry due to these favorable characteristics. However, the major drawback of inter-facial flaw formation of dental base structure made of polymethyl-methacrylate (acrylic resin) is still to be identified, despite the dental compensations. Distinguishing the reasons for failure in dental bases is a complicated thing by taking different factors, like the type of dental treatments, problems with handling and usage, into consideration [8]. There are evidences that porosity or crack formation the key factors that cause fractures these days and consequently, there is huge demand to elucidate what is the root cause [9].

In order to overcome these issues, the latest research has been focusing onto the ways of improving the properties of PMMA based composites. One of the strategies that has been found has some guarantee is the use of natural reinforcing agents. The high costs of reinforcing materials create a barrier for researchers, and in this case, this must be creatively resolved by exploring of natural alternatives such as cinnamon, cloves, pomegranate and others in reinforcing polymeric materials [10]. Natural materials are advantageous since they can be obtained at low cost, are easily available and does not pose any threat to the environment.

A matter of fact is, cinnamon, a popular spice, is a bark of the cinnamon tree which, the color of the tree and it are same though. Cinnamon's nutritional composition includes substantial amounts of vitamins, minerals, essential oils, and other derivatives. Cinnamon is employed as an antimicrobial, anti-inflammatory, antidiabetic, anticancer, and cardiovascular diseases preventive agent, in addition to its lipid-lowering properties [11]. This property of it as a reinforcing agent in polymer composites, especially in PMMA has not been given much attention but holds benefits due to its physical properties.

This research aims to enhance the mechanical properties of Poly Methyl Methacrylate (PMMA) reinforced with cinnamon particles, commonly used in dental base structures. In view of the above, the specific objectives of this study are as follows: To analyze the mechanical properties of the PMMA/cinnamon particle composites with different volume fractions of the cinnamon particles in order to understand the viability of using natural materials as reinforcements in dental applications. The expected benefits would be the tensile strength, impact strength, and hardness of dental porcelain that are vital for the stability and performance of the prosthesis. This study does not only add to the development of biomaterial composites but also embraces sustainable production since fillers are derived from natural products.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 Base material

Thermally cured Poly Methyl Methacrylate (PMMA), denoted as PMMA, was employed as the base material. The used PMMA is a light pink powder transformed into a liquid state by adding a cold cure resin in a ratio of 1:2, with a density of 1.9 g/cm³.

2.2 Reinforcement materials

Cinnamon, known for its impact on oral health, was utilized for its properties in treating mouth infections, toothaches, and breath freshening [12]. The cinnamon (Figure 1(a)) preparation involved cutting and grinding using an electric grinder Figure 1(b) designed for this purpose. The ground cinnamon was then sifted through a wire mesh filter, as shown in, resulting in particles of granular size (53 μm) as illustrated in Figure 1(c).

Figure 1. Process of obtaining Cinnamon powder staring from a) cinnamon material and b) grinder and finally c) cinnamon after grinding

2.3 Sample preparation

The traditional method of hand molding, an easy and successful technique widely employed, was used for preparing polymer composites. PC-supported material was ground in volumetric ratios of 8%, 6%, 4%, 2%, and 0%. Cinnamon particles were gradually and slowly mixed with PMMA and the cold cure resin to ensure complete homogeneity and prevent bubble formation, which could affect the material's uniformity. The mixture was then poured into pre-prepared molds, left at room temperature for solidification, and subsequently placed in an electric oven for one hour at a temperature of 50 degrees Celsius. Afterward, the sample was allowed to cool. The heat treatment aimed to eliminate stresses generated during pouring and achieve maximum interlinking of polymer chains. The same steps were repeated for all samples according to the volumetric ratios.

3. MECHANICAL TESTS

3.1 Hardness strength test

The hardness of all samples was determined using the Shore-D method with the apparatus depicted in Figure 2(a), following the international standards of ASTM-D 2240 (Figure 2(b)). The apparatus consists of a needle located at the front. By inserting the needle into the sample under the influence of external force, the hardness value of the tested sample is obtained from the display indicator. The needle is planted in multiple locations within the sample surface, with the first reading taken at the center and four readings at the edges. The average of the readings for each sample is then calculated. Figure 2(b) illustrates the schematic structure of the hardness test sample according to the international ASTM dimensions for measurements [11]. Figure 2(c) shows the samples subjected to the hardness test.

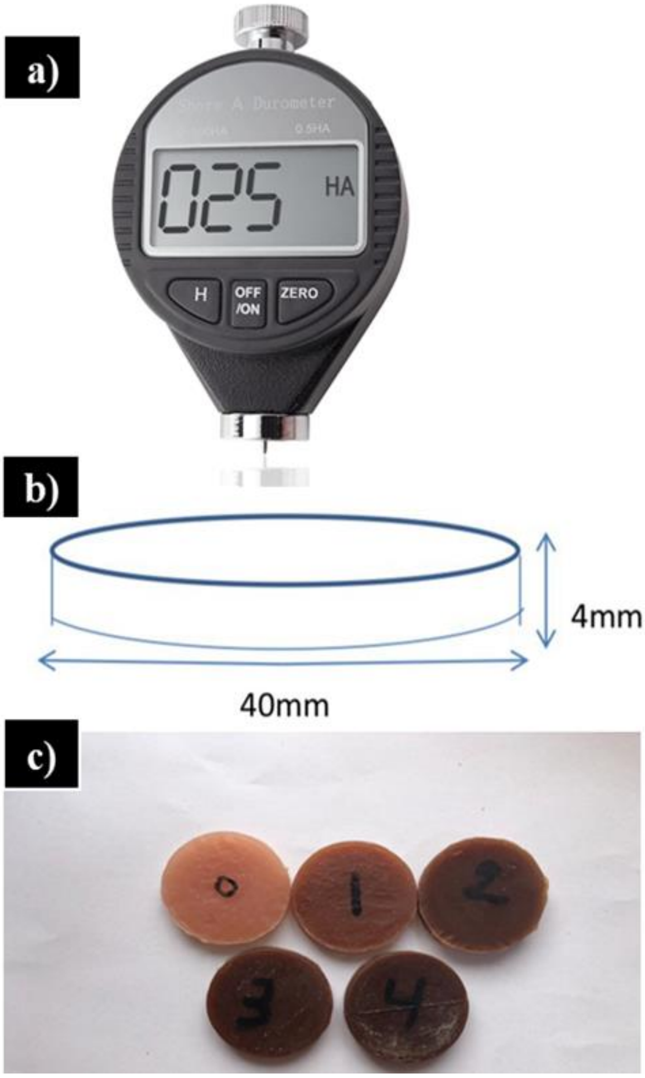

Figure 2. a) Hardness testing device, b) schematic drawing of a hardness test specimen according to ASTM international specifications, and c) sample subjected to hardness test.

3.2 Impact test

Impact samples were prepared following global standards, utilizing the Charpy impact test apparatus, as illustrated in Figure 3(a), for sample examination [13]. The samples were prepared according to international measurements, as shown in Figure 3(b). The Charpy method involves placing the sample in its designated location at the bottom of the device. The hammer is then raised and secured at the top of the device. Subsequently, the device is reset, and upon releasing the hammer, it impacts the sample, breaking it through a swinging motion. The potential energy in the hammer transforms into kinetic energy, and a portion of this energy is lost upon sample fracture. Readings are then taken using the device indicator. Figure 4(a) and Figure 4(b) illustrate impact test samples before and after the test.

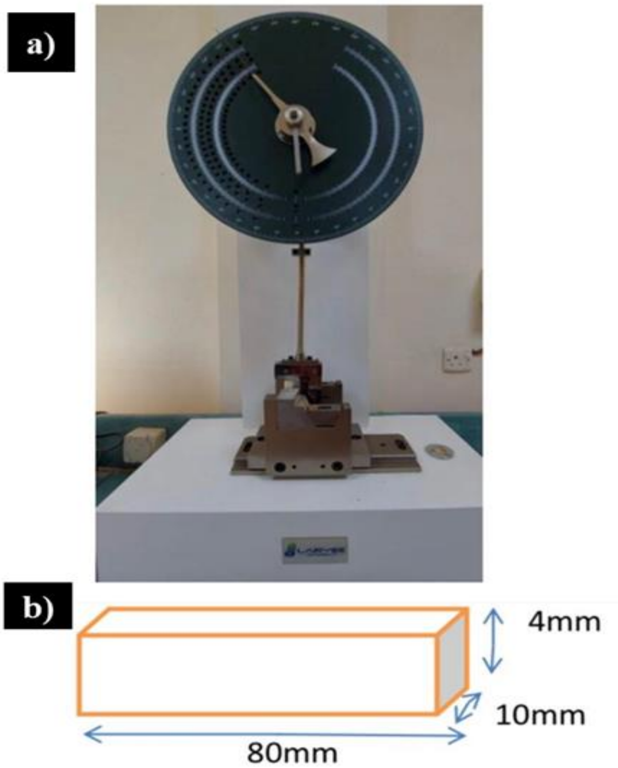

Figure 3. a) Impact testing device, and b) Schematic diagram of impact specimens

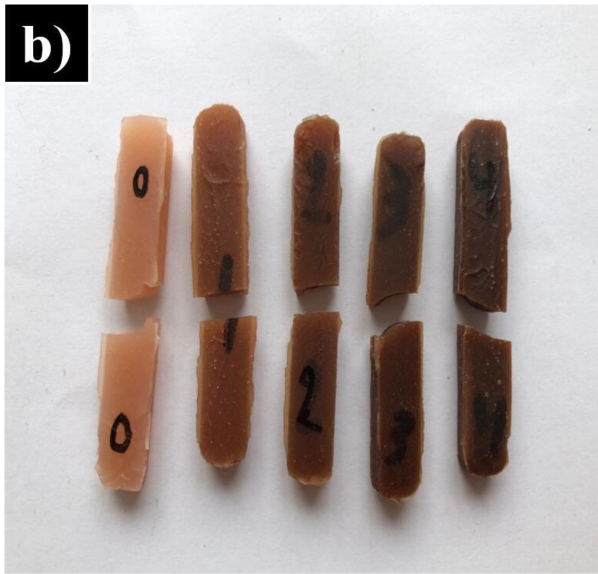

Figure 4. Impact test samples a) before and b) after testing

3.3 Tensile strength test

Tensile samples were prepared according to the required standard dimensions and the adopted ASTM D638-03 specifications [14]. Tensile tests for the prepared samples were conducted using the LARYEE Yaur Tasting Solution tensile testing machine, as illustrated in Figure 5(a). The sample was placed between the grips for secure handling, ensuring no movement during the test. When the machine was activated, the grips started to pull the sample from the top and bottom until it collapsed. The plotted sample diagrams generated from this test provided stress-strain curves, enabling the calculation of tensile strength. Figure 5(b) represents the standard dimensions for tensile test samples according to international standards, and Figure 6 depicts tensile test samples before and after testing.

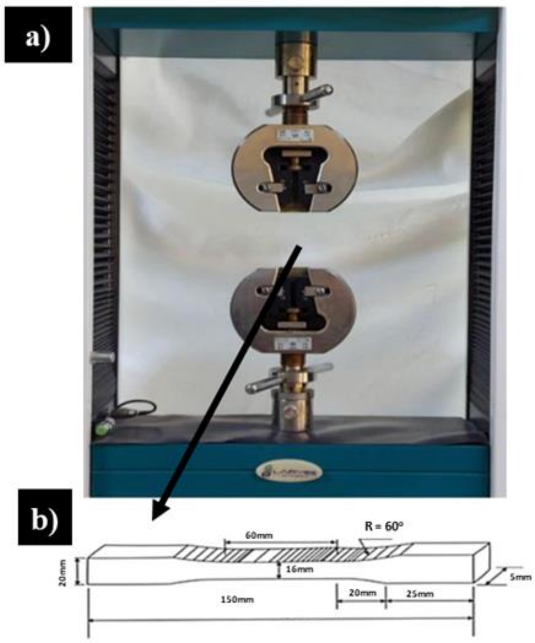

Figure 5. a) Tensile testing device, and b) schematic drawing of tensile specimens according to ASTM international standards

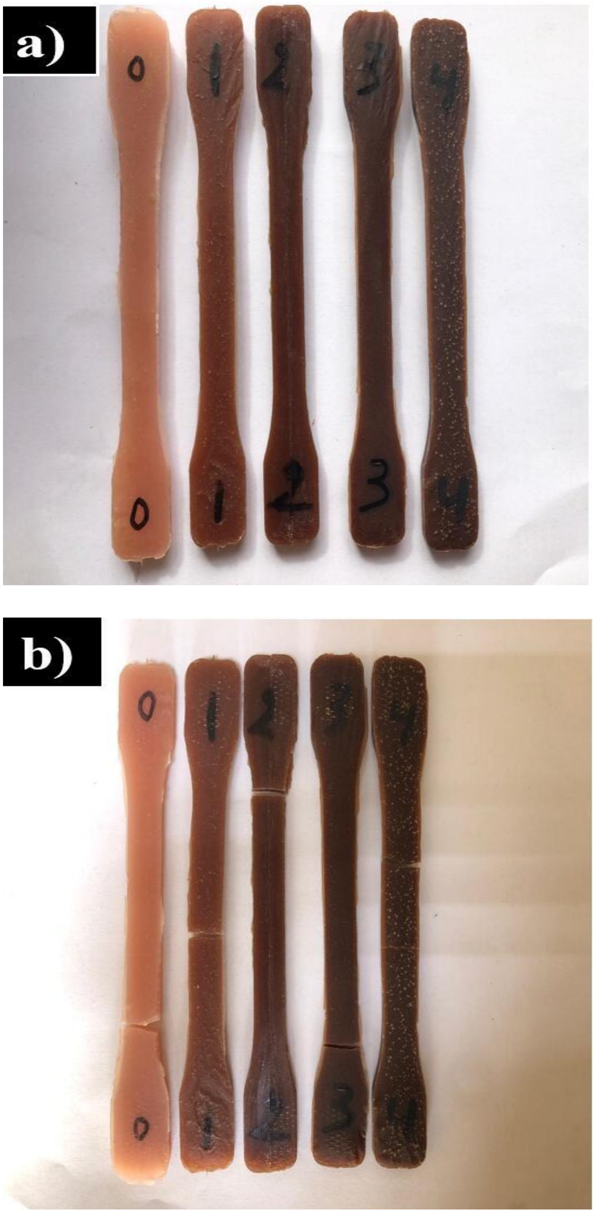

Figure 6. Tensile test samples a) before and b) after testing

4. RESULTS AND DISCUSSION

4.1 Hardness test results

Hardness tests were conducted using the Shore-D method for all prepared samples and various ratios. Figure 7 illustrates the hardness values for all prepared samples. The results show a significant improvement in hardness values for all samples gradually with an increase in the quantity of cinnamon particles.

The highest value was recorded at a volumetric ratio of 8%, reaching 86 N/mm². This improvement can be attributed to increased compactness, where the dimensions between polymer chains are reduced, enhancing resistance to scratching or penetration. The use of cinnamon particles as a reinforcing material facilitated their penetration and dispersion in the Poly Methyl Methacrylate (PMMA) resin during the molding process, reducing interparticle distance. This led to increased compactness between the components of the composite samples. Furthermore, the added cinnamon particles prevented the movement of the polymer molecules, thus providing increased scratch endurance and hardness [15]. Cinnamon particles occupied comparably large areas of space within the ant holder of PMMA which resulted in enhanced stress distribution. This improved stress distribution added mechanical suitability to the composite part thus having an added resistance to the forces that might be placed on it.

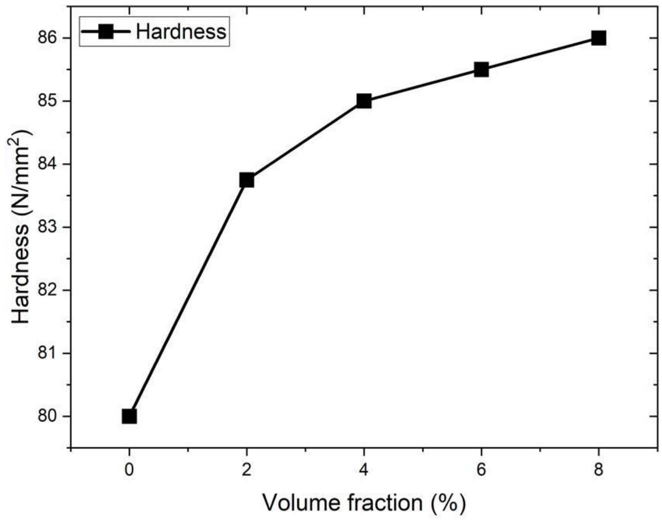

Figure 7. Influences of volume fraction on the composite hardness

4.2 Impact testing results

Impact testing would be the most important mechanical testing where a sample is bombarded with a rapid load. At the end, amount of energy absorbed will be determined by the sample itself upon the fracture. The impact test was a test that was conducted at the laboratory temperature. The impact strength (I.S) which was calculated for all prepared samples was divided by the cross-sectional area for the amount of energy required for sample fracture. The study determined the improvement to the extent where the impact strength was recorded as 0.93 KJ/m^2 corresponding to the 6% volume fracture, which indicated a high impact strength as revealed in Figure 8.

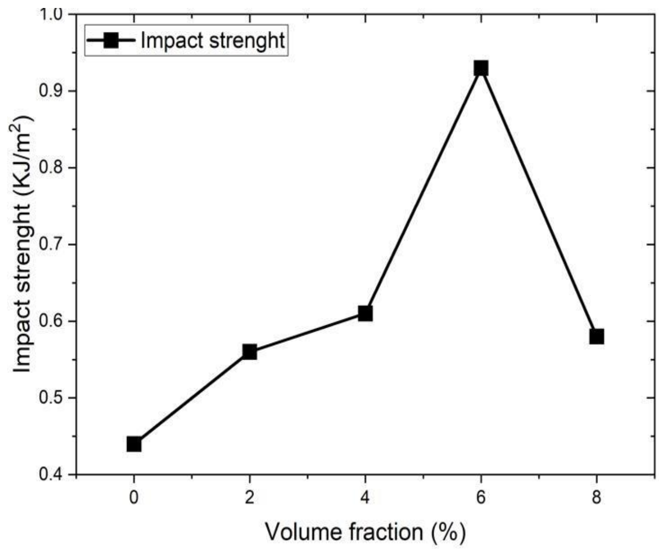

Figure 8. Influences of volume fraction on the composite impact strength

This improvement should be explained with the presence of the cinnamon particles in the sample as these compounds are considered to be extremely hardy and resistant to mechanical shocks. Due to the addition of cinnamon particles, new stresses formed and it resulted to dispersion of the stress across the area, thus preventing formation of high spots where failure might occur and also hindered the growth of cracks. It is due to the presence of these particles; the crack shape and direction was changed because the energy utilized by the crack to overcome the barriers posed by the cinnamon particles were more complex. This longitudinally enhanced elevated path also helped deliver dynamic stresses across most area of the sample accessible. As a result, the static characteristics of the sample increased, which is in accordance with the literature review where it has been shown that natural reinforcements help to increase the mechanical characteristics of composite materials [16, 17].

4.3 Tensile testing results

The mechanical properties of the mixture of cinnamon particles and PMMA resin were tested via tensile tests as shown in Figure 9. The tensile strength raised gradually as the volume fraction up to cinnamon 4% and achieve the maximum of 52 MPa. However, the effect started to decline slowly as the volumetric fractions of cinnamon content went on rising. This implies that the additional cinnamon particles possess high tensile strength and more elasticity. The cinnamon particles dispersed into the binding material of the used resin, especially in the right particle size, work gradually to heal failing points in the matrix of the binding material [18]. Moreover, it has been demonstrated that when particles are added in the composite materials, the composites are not solely dependent on the characteristics of the constituting components of the composites.

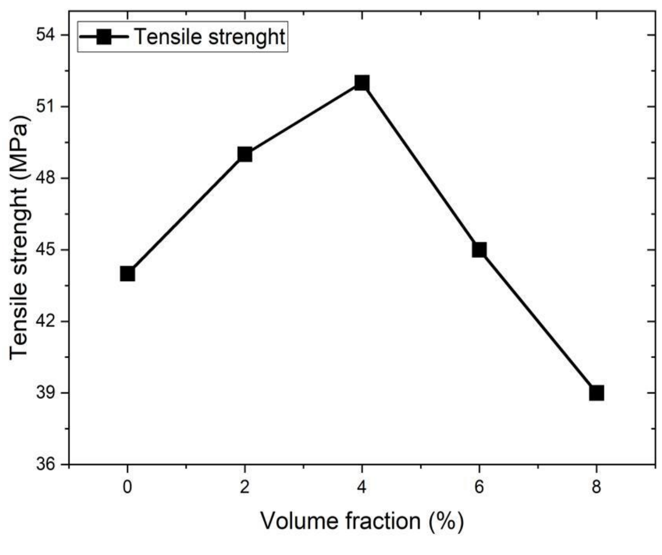

Figure 9. Influences of volume fraction on the composite tensile strength

There is, first of all, the role of the interfacial surface nature between the two components and the geometric form and volume concentrations of the particles involved. Therefore, the ability to interact with Cinnamon particles and the bonding between cinnamon particles and the PMMA matrix is very important to enable efficient stress transfer and reinforcement. With the increase in the volumetric fractions, the tensile value steadily decreases to face failure and complete structural collapse due to the higher quantity of cinnamon particles. This can be attributed to the confined interfacial surface area available for the binding material to react with the particle particles with the increase in volumetric fractures of the particle material resulting in weakened forces holding the composite materials together. This results in the load bearing capacity of the composite material reducing though it experiences stress due to the different load bearing cinnamon particles within the matrix. For this reason, many internal defects may develop leading to the condition where the material is overstressed and, in this case, it collapses when the imposed stress is greater the permissible limits. This is a testament to the fact that the increase and optimization of the volume fractions of the reinforcing particles have the potential to give composites the right mechanical characteristics [20].

5. CONCLUSIONS

Using poly methyl methacrylate (PMMA) resin reinforced with cinnamon particles, it is evident that tensile strength, impact strength, and hardness were improved, where the increase in volume fraction of cinnamon particles determined the magnitude of those improvements. This effect is evidence of the intense strength of cinnamon particles within the PMMA matrix, which makes for a very strong argument towards the prospect that such composite materials may be found useful in many situations. The consideration of cinnamon microstructure on mechanical performance is crucial. In fact, the investigation of whether the buildup of cinnamon particles causes the alteration of microstructure that led to the improved resistance of the material to the penetration and the scratches deserves more attention. This work is not just to emphasize the possible yields that could be accomplished by blending cinnamon dusts but also to let the researchers have more extensive deliberation about the complexity of the interactions that are involved with the base polymer matrix. These achievements are essential for maturing the knowledge on the polymer composites and they provide a basis for discovering new innovative strategies that will be applicable in a wide range of engineering and biomedical fields.

REFERENCES

[1] Thonon, H.H. Hussein, N.A. (2019). Mechanical and physical properties of epoxy and unsaturated polyether complexes reinforced with glass fiber and nanomaterial alumina powder. Journal of Education and Science, 28(1): 273-293. https://doi.org/10.33899/edusj.2019.161055

[2] Faisal, R., Bdaiwi, W. (2021). Exploiting environmental waste) plastic medical syringes) to prepare structural sections. Annals of the Romanian Society for Cell Biology,. 25(6): 4967-4975. http://www.annalsofrscb.ro/index.php/journal/article/view/6357.

[3] Mohsoun, E.H., Ahmed, A.R. (2019). Study of etiquettes behavior and some physical and mechanical properties of a polymeric basic composite. Journal of University of Babylon for Pure and Applied Sciences, 27(4): 58-65. https://journalofbabylon.com/index.php/JUBPAS/article/view/2319.

[4] Turki, A., Bdaiwi, W. (2022). Exploiting the waste of pistachio shells to reinforce the unsaturated polyester. NeuroQuantology, 20(2): 107-112.

[5] Aziz, H.K. (2018). TiO2-nanofillers effects on some properties of highly-impact resin using different processing techniques. The Open Dentistry Journal, 12: 202. https://doi.org/ 10.2174/1874210601812010202

[6] Gad, M.M., Abualsaud, R., Rahoma, A., Al-Thobity, A.M., Al-Abidi, K.S., Akhtar, S. (2018). Effect of zirconium oxide nanoparticles addition on the optical and tensile properties of polymethyl methacrylate denture base material. International Journal of Nanomedicine, 13(2018): 283-292. https://www.tandfonline.com/doi/full/10.2147/IJN.S152571.

[7] Greig, V. (2012). Craig's restorative dental materials, 13th edition, British Dental Journal, 213(2): 90-90. https://doi.org/10.1038/sj.bdj.2012.659

[8] Alqutaibi, A.Y., Baik, A., Almuzaini, S.A., Farghal, A. E., Alnazzawi, A.A., Borzangy, S., Aboalrejal, A.N., AbdElaziz, M.H., Mahmoud. I.I., Zafar. M.S. (2023). Polymeric denture base materials: A review. Polymers (Basel), 15(15): 3258. https://doi.org/10.3390/polym15153258.

[9] Hammed, M.G., Al-Fahdawi, I.H., Motlak, M. (2018). Enhancement of the tensile and the compression properties for heat-cured acrylic resin denture base materials. Baghdad Science Journal, 15(4): 0449-0449. http://doi.org/10.21123/bsj.2018.15.4.0449

[10] Zwawi M. (2021). A review on natural fiber bio-composites, surface modifications and applications. Molecules. 26(2): 404. https://doi.org/10.3390/molecules26020404.

[11] Meena Vangalapati, M.V., Satya, N.S., Prakash, D.S., Avanigadda, S. (2012). A review on pharmacological activities and clinical effects of cinnamon species. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 3(1): 653-663.

[12] Chaudhary, S.S., Tariq, M., Zaman, R., Imtiyaz, S. (2013). The In vitro anti-acne activity of two unani drugs. Ancient Science of Life, 33(1): 35-38. http://doi.org/10.4103/0257-7941.134594

[13] Izod impact (unnotched) ASTM D4812, ISO 180. Intertek. (n.d.). https://www.intertek.com/polymers-plastics/testlopedia/unnotched-izod-impact-astm-d4812/#:~:text=Test%20Procedure%3A,is%20used%20until%20failure%20occurs.

[14] Plastics tensile testing for ASTM D638 (no date) Intertek. Available at: https://www.intertek.com/polymers-plastics/tensile-testing/astmd5083/ (Accessed: 17 June 2024).
http://www.astm.org.

[15] Yaseen, M. (2020). An investigation of the mechanical properties of PMMA-based composites reinforced with PZT ternary nanoparticles. NeuroQuantology, 18(2): 56-61. https://doi.org/10.14704/nq.2020.18.2.NQ20125

[16] Sabah, S., Bdaiwi, W. (2023). The use of cigarette butts residues to reinforce unsaturated polyester for the manufacture of structural sections. AIP Conference Proceedings, 2839(1): 020025. https://doi.org/10.1063/5.0171958

[17] Mohammed, M.B., Saleh, W.B. (2021). Manufacturing of structural sections made of papyrus cane with unsaturated polyester adhesives for building eco-friendly houses. in AIP Conference Proceedings, 2372(1): 130002. https://doi.org/10.1063/5.0068717

[18] Chawla, K.K. (2012). Composite Materials: Science and Engineering. Springer New York, NY. https://doi.org/10.1007/978-0-387-74365-3

[19] Vinson, J.R., Chou, T.W. (1977). Composite materials and their use in structures. Journal of Applied Mechanics, 44(1): 189. https://doi.org/10.1115/1.3424003

[20] A.hassan, H.A.S., Kdhim, K.K., (2013). Effect the grain size on the polymer matrix composites reinforced by reenia particles. (2013). Al-Khwarizmi Engineering Journal, 9(2): 94-102. https://alkej.uobaghdad.edu.iq/index.php/alkej/article/view/172.