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Research Paper

Study the Effect of DBD Plasma on the Mechanical Properties of Polymer PMMA/HA

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Abstract

Recent studies on plasma generated at atmospheric pressure have become increasingly significant, with researchers intensifying their focus on its practical applications, particularly in industrial and medical fields. DBD plasma has been utilized in this study to examine the mechanical properties of compound materials (PMM/HA) synthesized in the laboratory. The compressive strength results indicate a gradual increase in stress and Young's modulus with increasing time before and after the plasma treatment, also hardness levels were found to have improved, before and after the plasma treatment (63.3, 71.3, 73, and 74.3) respectively. Either the bending test result increased post-impact, with a notable enhancement corresponding to extended time periods. DBD plasma had a much bigger effect on bending strength. The polymer and hydroxyapatite showed a rise from 63.31 MPa before impact to 74.4 MPa after 90 seconds. This shows that the samples' mechanical properties get better with longer plasma exposure. Method A base material made of PMMA polymer was added to with a nanomaterial made of hydroxyapatite (HA) to make a bioceramics compound. We conducted hardness, bending, and tensile tests to investigate the influence of DBD on the mechanical properties of nanocomposite materials. Nanosized materials (PMMA/HA) showed a big improvement in their properties after plasma treatment for three different lengths of time (30, 60, and 90 seconds). This shows that the samples' mechanical properties get better with longer plasma exposure.

Keywords

Plasma, Polymers, PMMA, HA, Mechanical Properties

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1. INTRODUCTION

Although modern advanced technology is constantly working to develop new materials and improve their specifications, they are suitable and can be used in a variety of industrial fields. This is typically accomplished by combining them with other materials that possess the necessary qualities to create a final product, as polymers, although having many benefits, have many drawbacks in their individual cases, including fragility, scratching, and ease of breaking (Bathe and Zhang, 2017; Al-Shboul et al., 2023). Modifying or activating the surfaces of soft materials and improving the qualities of materials like polymers used in medical applications without causing damage are two applications of DBD plasma that are especially crucial. These defects can be minimized or eliminated by combining them with other materials that possess desirable qualities, resulting in the material having the necessary new properties and characteristics (Jasim et al., 2025; Hussein et al., 2024).

Due to the simplicity and low cost of atmospheric pressure plasma discharge, it has been applied in practice Ahmed et al. (2024b). Since the last two decades, DBD plasma has been used due to the large number of scientific and industrial applications where the scientific and technological community made great efforts to produce, use and maintain ANTP (Buchanan et al., 2021; Ahmed et al., 2024a). It is possible to develop cold plasma technology in the atmosphere by doubling the scientific and technological use of ANTP to include the use of plasma in many important applications such as improving the properties of polymeric materials and increasing their physical properties, space engineering and biomedicine, and in improving the acceptability of materials in their cultivation inside the human body (Buchanan et al., 2021; Wang, 2024).

In the process of making polymers, which can show several upgrades or adjustments, physical property studies are crucial (Jasim et al., 2024a). Understanding the mechanical behavior of the materials is necessary for the design of medical materials used in the dental, filling, and orthopedic industries (Shirdar et al., 2021). Therefore, conducting laboratory trials is the sole method to determine how the materials respond to loads (Ran et al., 2020). This entails putting tiny material samples in test apparatuses, putting weights on them, and then calculating the deformations that ensue (Corsaro et al., 2021; Jasim et al., 2024b). The fundamental structure of the molecules that comprise the main chains determines the mechanical properties of polymeric materials; therefore, variations in the bonds between atoms and molecules, as well as across chains, will result in changes to the properties and indications (Falahat et al., 2018). The fundamental structure will be impacted by external factors including temperature, humidity, and radiation, which will alter the polymeric material's mechanical behavior (Falahat et al., 2018).

Tensile, bending, and hardness are some of the fundamental mechanical characteristics that we shall discuss (Rajan, 2013). It was found that surface modification and the addition of new functional groups by (DC) direct current plasma treatment resulted in a hydrophilic surface (Jasim et al., 2021a; Jasim et al., 2025). The fact that PMMA's surface modification preserves its superior bulk qualities while enhancing biocompatibility and lowering implantation risks is noteworthy (Freeman et al., 2013). According to this research, the combination of plasma processing's benefits such as its speed, environmental friendliness, solvent free processing, and cheap operating and maintenance costs has made it one of the most promising solutions (Mansour, 2015).

2. EXPERIMENTAL SECTION

2.1 Materials

putting the material into the mold while keeping in mind that the materials must be uniform. Completely, hydroxyapatite (HA) is a ceramic powder once the samples are left for five days. MC: 502.31, particle size: 20 nm, purity: 99%, buffer: RT, mixed molar ratio: 1 mol, mixing ratio: 5%, polymer ratio: 95% PMMA, and eggshells were combined with PMMA polymer in the same proportion. The materials are mixed by magnetic mixing to create a completely homogenous liquid composite. After 30 minutes of magnetic vibration, the homogenous liquid is put in specially made molds from which glass is removed. This is an efficient mechanical mixing method that uses electric mixing, after that they are treated by the DBD plasma.

2.2 Method

Due to advancements in numerous scientific disciplines, particularly in medicine and industry, composite materials have been utilized to acquire high specification materials for modern technologies that are absent in older materials. To create a single substance, combine a base or matrix material with the precise weight or volume ratios of one or more reinforcement ingredients. This is what a composite material is. In material selection, it is essential that no chemical reactions occur between the components, ensuring that each material maintains its inherent properties. The characteristics of composite materials depend on the properties of their individual components, as well as their quantities and geometric configurations (support form, size, distribution, and orientation). The resultant material will exhibit qualities distinct from those of its individual components when utilized separately, particularly regarding lightweight and high durability (Jasim et al., 2021b; Normah et al., 2024). Consequently, to get the ideal characteristics in the composite materials, the components are selected to be significantly dissimilar. The improvement of materials happens when nanoparticles, microorganisms or inorganic substances, and minerals are mixed into the polymeric matrix.

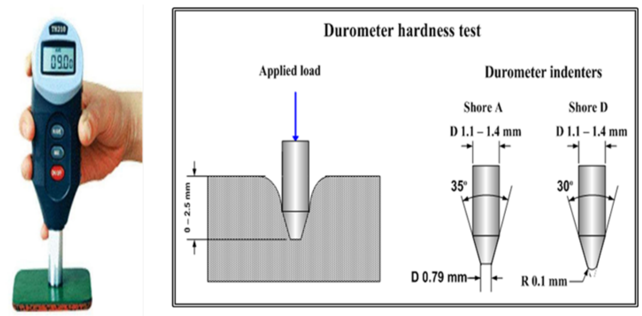

Figure 1. Hardness Test Device

This creates a new hybrid system that improves important properties like the bioelectric and mechanical properties of the polymers (Singh et al., 2010). In this study, hydroxylapatite nanoparticles were added to PMMA based materials. This makes them much less likely to wear down. The samples were fabricated utilizing a glass mold with dimensions of 1.5 cm in length, 1.5 cm in width, and a thickness of 1.5 mm. This was executed on a glass panel with a base area of 25 square centimeters and a thickness of 3 mm. Cut into 1.5 cm squares, the pieces were subsequently assembled on the surface of the glass base to form a 1.5 cm square mold. After that, the necessary parts for making the sampling material were made, specifically hydropeptite and PMMA polymer. Hydroxyapatite and weights were measured with a sensor. The mixture was then put through an electric mill for thirty minutes to make it more uniform. A polymer solvent was then added at a rate of 0.5 mL per gram of polymer. Subsequently, they are positioned on the magnetic vibration apparatus for thirty minutes; thereafter, they are placed within the mold and allowed to rest for five days at ambient temperature. Following the preparation of the samples, the DBD plasma treatment is administered for three durations: 30 seconds, 60 seconds, and 90 seconds, all under identical conditions. The examination of physical properties is crucial in the polymer production process, facilitating several enhancements or modifications.

2.2.1 The Hardness Testing

The hardness of all samples was tested using a diamond Vickers tool and groove spacing, as shown in Figure 1. This method is applicable to assessing the hardness of all polymers under a load of 0.4404 N, and the sample dimensions were 1.5 cm in diameter and 1.5 cm in height. We subjected each sample to the test in at least five separate locations, focusing on a new hardness location each time. Each application took 20 seconds to mitigate any potential uncertainties, as this constitutes a biomechanical assessment of the material's surface. Hardness is defined as the resistance of

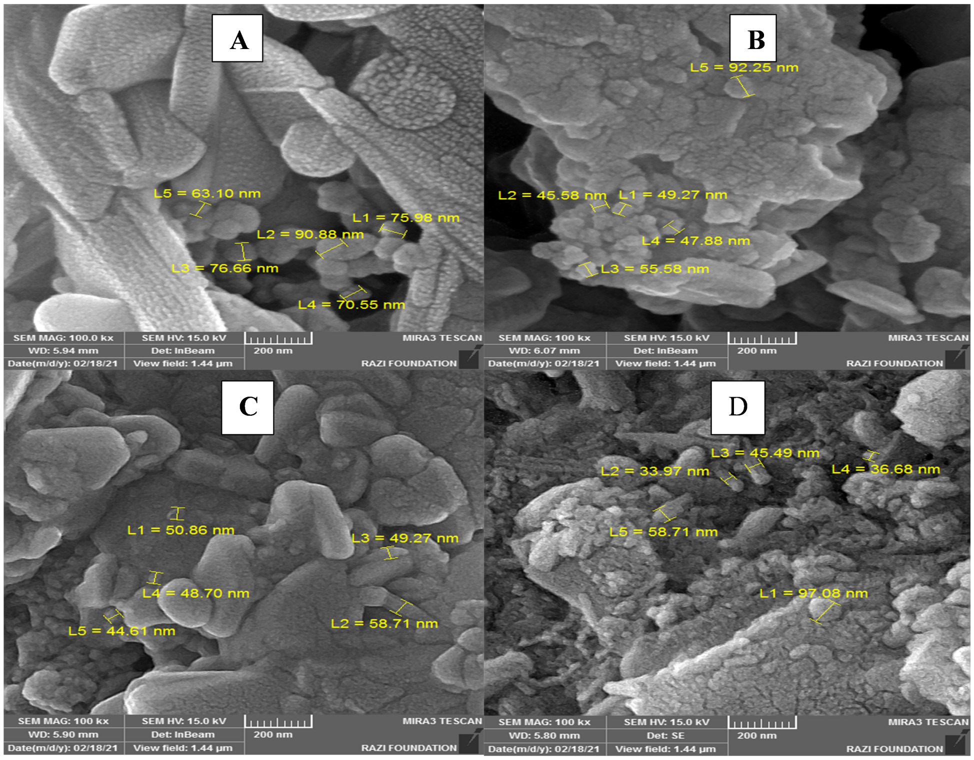

Figure 2. (SEM) Nanoceramic Image (HA-PMMA), Prior to Plasma Effect (A), After 30 Seconds (B), After 60 Seconds (C), After 90 Seconds (D)

Figure 3. Chirpy Impact Testing Apparatus

a material's surface to buckling. Compressive strength is the most important mechanical property of materials. High strength polymeric composites present significant challenges. As a structural assessment tool, compression testing of a composite sample demonstrates how localized failures and structural instability are intricately linked. During a compression test, various types of failure may occur simultaneously or simultaneously. These include fiber crushing, matrix failure, exfoliation, and longitudinal splitting (Shirdar et al., 2021). The Origin Lab 2024 program was used for the statistical plotting of all measurements.

The three point bending test was conducted utilizing an English-manufactured bending tester with a maximum operational capability of 220 V/50 Hz, as seen in Figure 2 his apparatus is equipped with a digital display meter and a plotter to document the load values applied to the specimen. The method involves connecting the sample at two points, putting a load on the middle point, and using the device diagram to get the current. This lets you figure out the stress values and show them in graph form. The graph depicts device stress, including both the modulus of unit stress at fracture and the strain at break. The machine is utilized for tensile testing.

3. RESULTS AND DISCUSSION

3.1 SEM Analysis

SEM analysis of PMMA/HA reveals that the particle size was 75.98 nm and 90.88 nm prior to treatment with DBD plasma, which is much larger than the samples following plasma treatment. The samples' particulate size rose to 55.5 nm and 49.2 nm after 30 seconds of plasma treatment. The surface particulate size was 48.7 nm and 44.61 nm after 60 seconds of plasma treatment; and finally, the samples' particulate size climbed to 90 seconds. Figure 2, it was discovered that the samples' surfaces had particle sizes of 33 and 36 nm.

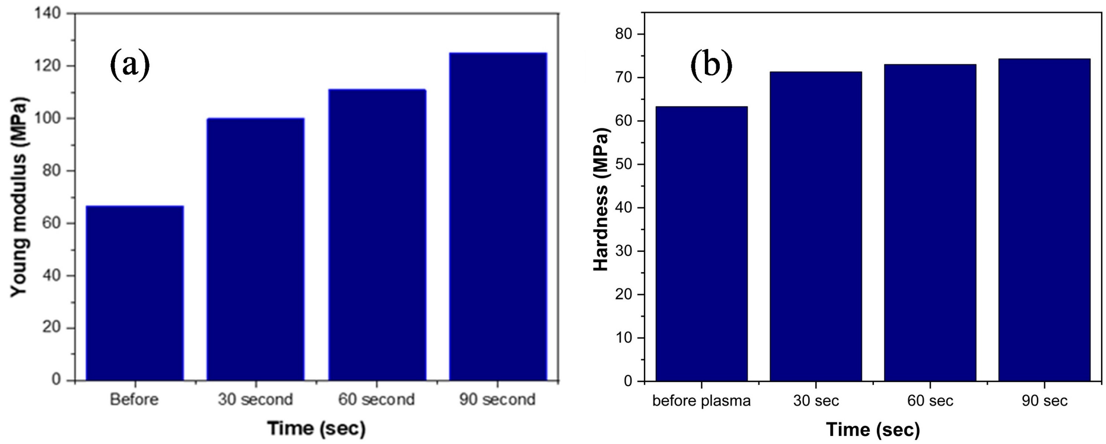

Figure 4. Young Modulus (a), Stress Before Effect with Plasma and Under Influence with Different Time Periods (b)

Table 1. Stress and Young Modulus

Samples	Stress (MPa)	Young Modulus (MPa)
Before	3.59	66.61
30 Seconds	5.12	100
60 Seconds	5.85	111
90 Seconds	6.48	125

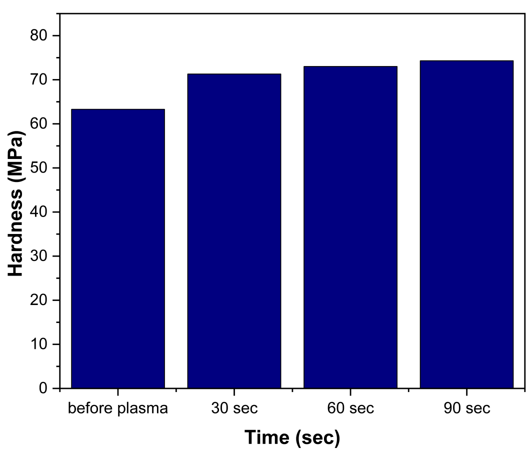

Figure 5. The Hardness for Samples Prepared Before and After Plasma

3.2 Mechanical Properties

The examination of physical properties is crucial in the polymer production process, facilitating several enhancements or alterations. Polymers have unique mechanical properties, such as being very strong and able to deform under different forces. These properties are mostly due to the interaction of two types of forces: strong chemical bonds and secondary interactions between molecules. This group significantly influences its mechanical properties. Mechanical properties describes the behaviour of polymeric materials and their compounds under the influence of effective forces, since there are several methods by which these properties can be verified.

3.2.1 Compression Strength

A thorough testing apparatus was used to measure the pressure in order to evaluate the materials. The empirical findings of the pressure resistance test for PMMA-HA and related materials are shown in Table 1 Young's modulus was determined. The bending resistance test differs from the tensile test regarding the forces applied to the sample during assessment. In this instance, both the compressive and tensile strengths will be provided together, as depicted in Figure 3 and Table 1. The image and the table indicate that the Young's modulus varies for samples prior to and subsequent to the exciters in the plasma. The duration of the exciter correlates positively with the Young's modulus. Strengthening the intermolecular interactions among the molecular chains of the base material enhances flexibility and substantial strain, leading to prolonging the effect by 90 seconds enhances the bending strength and improves the Young's modulus, and it was also clarified statistically in the Figures (4a and 4b). The improvement is due to the aforementioned causes and the variation in the bonds linking the molecular chains. Thus, this explains the fluctuation in values related to the duration of the action in the plasma, in accordance with references Navarro-Pardo et al. (2015) and Corsaro et al. (2021).

Table 2. The Samples Hardness Prior to and Following Plasma Preparation

Sample	VH (MPa)
Before Plasma Treatment	63.3
After Plasma Treatment 30 Seconds	71.3
After Plasma Treatment 60 Seconds	73
After Plasma Treatment 90 Seconds	74.3

3.2.2 The Hardness Measurement

The samples were prepared both before and after the plasma treatment. Hardness levels were found to have improved, as indicated by Table 2 and Figure 5.

Table 3. The Samples Bending Prior to and Following Plasma Preparation

Samples	F.S (MPa)
Before Plasma Treatment	63.31
After Plasma Treatment (30 Seconds)	71.32
After Plasma Treatment (60 Seconds)	73.20
After Plasma Treatment (90 Seconds)	74.40

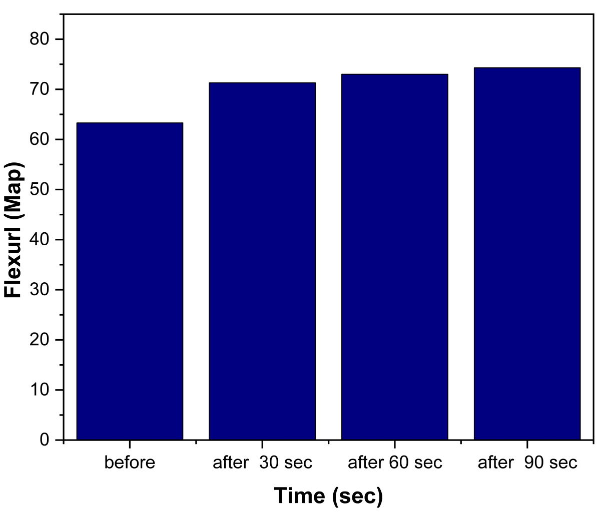

Figure 6. Bending of Prepared Samples Prepared Before and After Plasma

This section presents the outcomes obtained from the testing of hydroxyapatite materials and PMMA polymer models. It improved in samples as before plasma effects DBD and after effects, as explained above, because the hardness depends on the strength of the binding, the more the binding strength increases, the harder the samples become, and the harder the samples get, the longer the effect lasts. Additionally, as plasma effects increase, atoms and molecules converge and materials become more homogeneous, increasing the strength of the bonding between atoms and molecules of substances which have strong ionic interatomic bonds. These findings are significant for both the medicinal materials and the bone industry because the hardness of bones varies depending on where they are located within the body, which correlates to bone structure and limb manufacturing, dental filling and other medical applications these results are consistent with Farjamfar et al. (2023).

3.2.3 Bending Test Result

The bending test is a crucial evaluation for composite materials, designed to ascertain their elasticity and ductility. This test assesses a material's resistance to bending forces exerted perpendicular to its longitudinal axis. The complexity comes from the interaction of different types of stress, especially tensile stress in the lower layers and compressive stress in the upper layers. Often, one type of stress takes over, which causes the material to break. Critical parameters affecting the bending test encompass the loading type and rate, the span between the supports, and the specimen's cross-sectional dimensions. The changes in the curvature values of hydroxyapatite and PMMA polymer before and after DBD plasma treatment are shown in Table 3 and Figure 6.

The preceding tables and illustrations indicate that the bending strength increased post-impact, with a notable enhancement corresponding to extended time periods. To be more specific, DBD plasma had a much bigger effect on bending strength. The polymer and hydroxyapatite showed a rise from 63.31 MPa before impact to 74.4 MPa after 90 seconds. The effect of the plasma is what makes the material last longer. Long term exposure increases the bonding forces between the molecular chains, which makes the material less flexible. Additionally, variations in bending strength are observed in bone material within the human body, contingent upon its anatomical location. It can handle shocks and influences from the outside, which lets us measure its bending strength, which changes depending on where it is and what time it is when the DBD plasma hits it. Similarly, the bending values change because of the different bonds between the molecular chains. This is one reason why the bending strength values change as the DBD plasma impact lasts longer (Ahmad, 2012; Li et al., 2015).

4. CONCLUSIONS

A novel composite material exhibiting superior mechanical properties was synthesized by combining 95% polymer as the base with 5% hydroxyapatite. The bending strength demonstrated an enhancement post-impact, with the effect of DBD plasma intensifying the bending strength over time. This signifies a notable improvement in durability. The bending strength increased from 63.31 MPa prior to impact to 74.4 MPa after a duration of 90 seconds post impact. The stiffness, tensile, and bending characteristics of this superposition are crucial due to its applications in orthopaedics, dental fillings, and other medical fields. Numerous studies have demonstrated that the plasma effect significantly enhances surface qualities and roughness while augmenting physical and mechanical characteristics. In the future, researchers are encouraged to extend the duration of the effect, as a longer period yields more favourable outcomes.

5. ACKNOWLEDGEMENT

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