Research Article

The effectiveness of hexagonal boron nitride as an additive in the enhancement of scleral acrylic resin properties subjected to artificial weathering

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Abstract: Background: A common material used to create ocular prostheses is scleral acrylic resin. However, this material's characteristics changed over time, necessitating the refabrication of the prosthesis. Numerous investigations were carried out to enhance these characteristics by adding nanoparticle reinforcement. Aims: This research attempted to assess the impact of hexagonal boron nitride nanoparticles (H-BN NPs) in a weight percentage of (0.050wt% and 0.075wt %) on the mechanical features of scleral acrylic resin (the impact strength, surface hardness and surface roughness) before and after being subjected to artificial weathering. Materials and Methods: 90 specimens were created and split into three groups, 30 for the impact strength test, 30 for the surface hardness test, and 30 for the surface roughness test, which is separated into 3 subgroups (n = 10) according to each test (Control group, 0.050 wt.%, and 0.075 wt.% modified groups). Specimen's microstructure and elemental examination for H-BN were quantified utilizing Izod's impact tester, Shore D hardness test machine, Profilometer device, field emission scanning electron microscope (FE-SEM), and energy dispersive x-ray (EDX) spectroscopy, respectively. Results: One-way ANOVA and post-hoc Tukey's tests were used to analyze the data; statistical significance was indicated by a p-value < 0.05. The FE-SEM test revealed that H-BN was equally distributed throughout the polymer matrix. A significant difference ($p < 0.05$) for impact strength and a non-significant difference effects were found regarding Shore D hardness and surface roughness before and after being subjected to weathering. Conclusion: H-BN–modified specimens exhibited superior resistance to mechanical degradation compared with the control group. These findings support the potential of H-BN NPs as an effective reinforcing additive for ocular prosthetic materials, although artificial aging negatively affected the material properties over time. Further investigations are recommended to assess long-term durability and optimize nanoparticle percentage for clinical applications.

Keywords: FE-SEM, H-BN NPs, Impact strength, Ocular prosthesis, Scleral acrylic resin, Shore D hardness.

Introduction

Anophthalmic patients have emotional, functional, and social suffering. The human mind is complex, and traumatic events can have profound impact on it. The lives of these individuals may be negatively impacted by alterations in their behavioral, mental, and emotional reactions (psychological), social interactions, and financial consequences (economic) [(1)]. A maxillofacial prosthodontist's job is to help these patients regain their sense of self-worth [(2)]. An ocular prosthetic is a type of maxillofacial prosthesis utilized to enhance the patient's looks and quality of life for social and psychological adaptability [(3)]. Scleral heat-cure acrylic resins are frequently utilized to create ocular prostheses due to their advantageous properties, which include stability in dimensions, light weight, tissue compatibility, durability, and cosmetic appeal [(4)].

Acrylic resin is the greatest material for eye replacement due to its special characteristics, which include being inexpensive, excellent adaptation, quick manufacture, strong biocompatibility, easy coloring, and good aesthetic effects [5]. Despite these benefits, the material deteriorates with time and has an impact on the longevity of the prosthesis and is linked to its mechanical, chemical, physical, and aesthetic qualities[6]. Regarding the mechanical and physical characteristics,

Surface hardness is the substances' ability to resist scratches, breaks, and permanent penetration. This quality is crucial to the lifetime of the prosthesis since it directly impacts its ability to withstand abrasive wear [7]. Another issue is Surface roughness, which has an impact on the user's comfort and physical attractiveness [8]. However, inadequate impact strength and fatigue resistance. Numerous investigations were carried out to enhance these characteristics by using nanoparticles (NPs) to reinforce this material [9, 10]. In the dental sector, some efforts have been made to enhance polymethyl methacrylate (PMMA) by adding various nano-sized fillers [11],

Andreotti et al. adding NPs (ZnO, TiO_2, and $BaSO_4$) at weight percentages of 1wt%, 2wt%, and 2.5wt%) to sclera acrylic resin, regarding the microhardness, flexural strength, and color stability of the resin before and after artificial weathering. The addition of NPs, particularly 2.5wt% TiO_2, assisted in preserving microhardness and color stability as the material aged. Even though the outcomes fell within the clinically reasonable range, the inclusion of NPs comparatively reduced flexural strength [12]. Oxides, metals, fibers, and ceramics were instances of NPs that improve the mechanical and physical characteristics of materials based on resin, resulting in the creation of nanocomposites with improved characteristics [13].

The overall performance of nanocomposites is influenced by the inherent features and kind of polymers utilized, the method of processing among the composites, concentration, size, and diffuseness of the NPs inside the matrix of polymers, and the compatibility at the point where the NPs meet the polymer matrix [14]. These additions' special qualities, such as their large surface area, significant chemical reactivity, polarity, and high surface energy, may be connected to the enhancement of reinforced polymers' mechanical and physical features [15].

In this research, Hexagonal Boron Nitride nanoparticles (H-BN NPs) were used as reinforcement substance for scleral acrylic resin. Among the several crystalline forms, H-BN NPs has the best level of thermal and chemical stability [16], which stays steady at temperatures below 3000 °C. At room temperature, its strong chemical stability prevents it from reacting with water, acids, or alkali. It has superior oxidation resistance, thermal conductivity, and thermal stability [17] . Due to its special qualities, H-BN has several uses in medicine, such as tissue engineering, antibacterial activity, and reinforcing medical equipment[18], and further research and possible applications across diverse fields are expected in the future years, such as an insulator in electronics, a semi-conductor substrate, a refractory mold coating, and in resins, ceramics, and plastics (to achieve self-lubricating qualities) [19].

The aim of this research is to assess the impact of hexagonal boron nitride nanoparticles (H-BN NPs) in a weight percentage of (0.050wt% and 0.075wt %) on the mechanical features of scleral acrylic resin (the impact strength, surface hardness and surface roughness) before and after being subjected to artificial weathering. The null hypothesis (H0) states that incorporating H-BN NPs into scleral acrylic resin will not have influence on the acrylic's mechanical features.

Materials and Methods

The World Health Organization's methodologies [20] for analyzing power were utilized to establish the research's sample size. The findings revealed a 5% significant level, a 5% marginal error, and an 80% study power. This was an *in vitro* study, and no human participants or animals were involved.

Nanocomposite mixture preparation

In this study, heat-cured scleral polymer (J-510) and non-crossed-linked scleral monomer (J-570) were combined by volume which was equal to 24.4gm (40 cc, single unit) of powder to 10ml of monomer by weight to create scleral acrylic resin (Techno Vent Ltd., South Wales, UK).

Scleral acrylic resin modified using hexagonal boron nitride nanoparticle (H-BN NPs) (China's Hongwu International Group Ltd., 99.8%, 45–200 nm) as the inorganic filler was used for creating the specimens for the nanocomposite material. The particle size measuring device (NanoBrook 90 Plus, Brookhaven, USA) confirmed that the effective diameter of the H-BN powder was 143.1 nm. H-BN NPs were added in 0.050 wt.% and 0.075 wt.% to scleral acrylic resin, while one group remained unmodified (without nanoparticles), representing the control group.

Initially, H-BN NPs were weighed using a digital device scale (Germany, sensitivity 0.0000g), integrated inside the monomer, and disintegrated into separate NPs for three minutes utilizing a sonication probe device (150 Soniprep, England) (NPs, they are considered potentially harmful to health when exposure occurs acutely or over prolonged periods in the workplace. The main risks are related to occupational exposure, where inhalation and skin contact are involved).

The container was put in a vessel packed with chilled water to cool the combination because the liquid may be overheated by sonication, which could harm the substance [21]. The monomers with H-BN NPs powder were quickly combined with powdered acrylic (the weight of H-BN NPs powder was taken away from the acrylic powder's weight) to lessen the chance of phase separation and aggregated particles. Blending was done for thirty seconds in a dry, clean glass cup, utilizing a wax blade. After that, the blend was covered up until the dough step was achieved [22].

A total of 90 specimens were made: 30 for the impact strength test, 30 for the surface hardness test, and 30 for the surface roughness test, which is separated into 3 subgroups (n = 10) according to each test (Control group, 0.050 wt.%, and 0.075 wt.% modified groups).

Specimens' preparations

Impact strength test specimens, with measurements of 80 × 10 × 4 mm, were created in line with ISO 179 (2000) [23], and for surface hardness and surface roughness test, specimens were made with measurements of 65 mm × 10 mm × 2.5 mm [24]. Using a laser cutting device to prepare molds, three different plastic forms were created by cutting plastic plates with dimensions and shapes in accordance with the necessary tests (Jinan Link Manufacturing and Distribution Co., Ltd., China, JL-1612).

Impact strength test

Impact strength was measured using TIME Group Inc.'s Izod Impact Tester. The specimen was held up vertically and hit by a pendulum that swings with a capacity of 5.5 joules. The impact energy value calculated in joules is provided by the measures. The Izod test is estimated using the following formula in kilojoules per square meter (KJ/m^2) [23]:

$$Impact\ strength = E/b \times d \times 10^3 \quad (1)$$

Where E is impact energy in (J), b is the specimen's width in (mm), and d is the specimen's depth in (mm).

Surface hardness test

The specimen's Shore D hardness was measured using a durometer (HLX-AC). The durometer's indenter has a blunt point and a diameter of 0.8 mm. Pressure is applied to the specimen surface as quickly as possible while the durometer is kept perpendicular and supported by a solid surface to keep the device from being shocked. The specimens were subjected to a steady minor load of 44.5 N. Shore D hardness was calculated by taking three measurements of each specimen—one in the specimen's center and two on its periphery, and averaging the results [25]. The hardness value was digitally captured one second after making steady contact with the specimen.

Surface roughness test

The specimen's surface Ra is measured using a non-contact profilometer (Trane, United States). The Specimens underwent three distinct radial scans with a resolution of 0.08 mm at various locations. The device was positioned so that the stylus only made contact with the specimen surface three times, and each item had three measurements taken for each specimen, the average surface Ra (μm) was established. A digital scale readout appeared automatically.

Field Emission Scanning Electron Microscopy (FE-SEM) and Energy Dispersive X-Ray Spectroscopy (EDX)

A FE-SEM (FE.IS50) was used to examine the test specimen's damaged surfaces to ascertain the extent of consistent dispersion of H-BN NPs inside the resin matrix. The specimen was coated with gold and cut from an impact strength specimen in compliance with technical criteria; the accelerating voltage was 15 kV. The quantity and elemental distribution of each component of H-BNNPs were assessed using an EDX instrument (Axia Chem Sem, Thermos Scientific).

Artificial weathering or accelerated aging

The specimens underwent accelerated artificial aging within the accelerated aging apparatus (QUV; Q-Lab; Germany), It was set up for 8 hours of dry exposure to UVA-340 at 50 °C with an irradiance value of 0.76 W/m2, 0.25 hours of water spray, and condensation for 3.75 hours at 50 °C, with a 300-hour maximum age period. This is a widely recognized standard for accelerated weathering. Cycle No. 2 of ISO-4892-3:2024 [26].

Statistical analysis

The analysis of the data was done using version 29 of the Statistical Package for Social Sciences (SPSS). The descriptive statistics that were utilized to calculate the data's mean, standard deviation (SD), and minimum and maximum values. The Shapiro-Wilk test was carried out to confirm if the distribution of the data was normal. ANOVA (one-way analysis of variance) was used to compare group means. Tukey's Honestly Significant Difference (HSD) post hoc test was used to find specific group differences. A probability value (p-value) of 0.05 was used to ascertain the statistical significance. Non-significant differences ($P > 0.05$), while Significant differences were indicated by ($P < 0.05$). However, the homogeneity of the data was confirmed using the Levene test. Paired T-test was used to compare groups before and after being subjected to artificial weathering.

Results

FE-SEM and EDX, The FE-SEM results demonstrated noticeable differences in the microstructure between the treated and control (unmodified) groups by evaluating the interior morphology of the shattered surfaces of specimens subjected to impact strength testing at a field of view of 100 μm. Figure 1: (A) shows that the unmodified PMMA group exhibited an irregular surface with larger voids and defects; (B) demonstrates that the 0.050 wt.% H-BN NPs group exhibited a more homogeneous surface with better nanoparticle distribution and fewer surface irregularities; (C) the 0.075 wt.% H-BN NPs group showed a wide nanoparticle distribution; however, significant agglomeration was observed as the H-BN NPs loading increased. EDX displayed the chemical composition of (A) H-BN NPs, nitride is the most abundant element (76.4wt %); (B) Scleral acrylic resin without modification; (C) Scleral acrylic resin modified with H-BN NPs, it provides additional visualization of the elements' distribution across the acrylic. as seen in Figure 2.

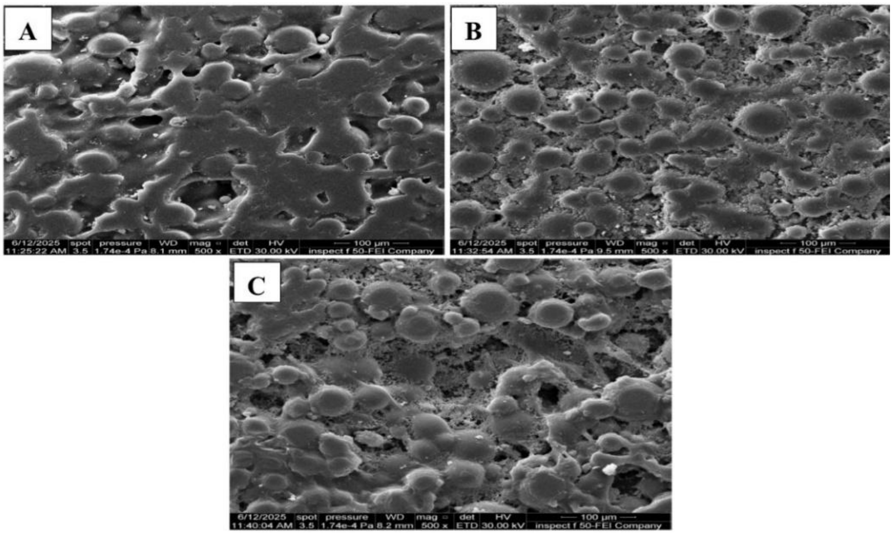

Figure 1: Morphology of the damaged surface of the specimens demonstrated by FE-SEM, scale bar = 100µm (A) unmodified group, (B) 0.050 wt.% H-BN group, and (C) 0.075 wt.% H-BN group.

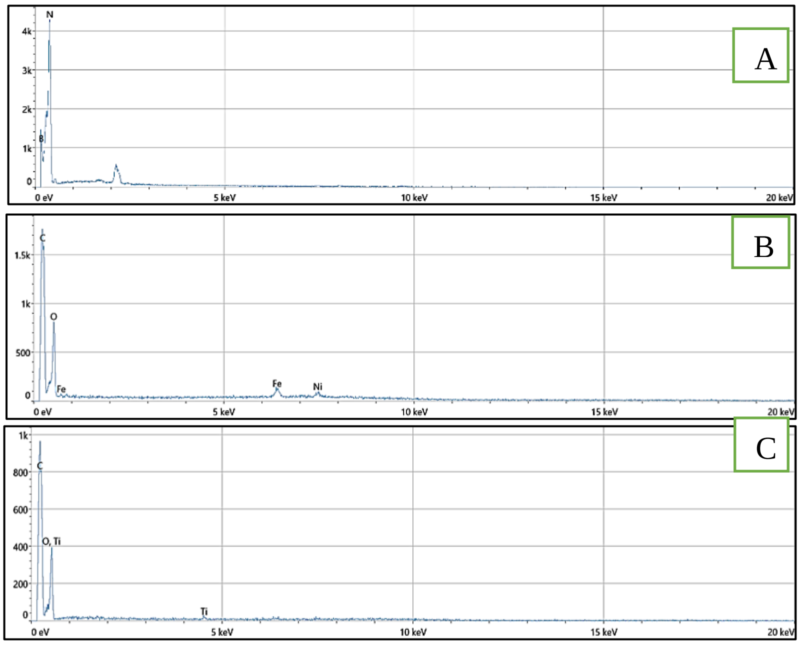

Figure 2: EDX analysis of (A) H-BN nanoparticles; (B) Scleral acrylic resin spesimens without modification; (C) Scleral acrylic resin spesimens modified with H-BN NPs.

Impact strength before and after being subjected to artificial weathering

The results of impact strength before weathering were demonstrated in Figure 3 and Table 1, 0.075 wt.% H-BN NPs had the highest average impact strength value (KJ/m²), while the least average value was for the unmodified group(KJ/m²),The homogeneity test was non-significant (p = 0.166), Tukey's HSD revealed a statistically significant (S) variation within the unmodified and 0.075wt.% groups ($p < 0.005$) and a non-significant (NS) difference between the 0.075wt.% and 0.050wt% ($p = 0.27$), and non-significant (NS) between the unmodified and 0.050 wt.% ($p = 0.009$).

The results of impact strength after weathering were demonstrated in Figure 3 and Table 1, 0.075 wt.% H-BN NPs, it also had the highest average impact strength value (KJ/m²), while the least average was for the unmodified group (KJ/m²), The homogeneity test was non-significant (*p* = 0.647), Tukey's HSD analysis revealed a statistically significant (S) difference between all groups.

Paired T-test for impact strength was done to compare groups before and after being subjected to artificial weathering (Table 1), analysis revealed a statistically significant difference between each two different groups (P<0.05).

Table 1: Descriptive statistics, normality test of impact strength (KJ/m²) before and after weathering, and F test by ANOVA, paired T test.

Before weathering	**Shapiro-Wlik *P* value**	**Mean**	**SD**	**Min**	**Max**	**ANOVA F-test**	***P* value**
Control	0.103	18.29	1.708	16.38	20.68	17.866	< 0.001
0.050%	0.283	20.56	1.2130	18.69	22.52		
0.075%	0.251	22.50	1.748	20.00	24.74		
After weathering	**Shapiro-Wlik *P* value**	**Mean**	**SD**	**Min**	**Max**	**ANOVA F-test**	***P* value**
Control	0.699	14.18	0.9851	12.59	15.69	51.827	< 0.001
0.050%	0.442	16.59	1.477	14.67	18.90		
0.075%	0.901	20.23	1.487	18.00	22.80		

Shore D hardness before and after being subjected to artificial weathering

The results of surface hardness before weathering were demonstrated in Figure 3 and Table 2, The lowest average value (86.09) was for the 0.050wt% of HB-N, while the greatest average value (86.70) was for the unmodified group. While, the results of hardness after weathering were shown in Figure 3 and Table 2, The lowest average value (84.22) was for the 0.050wt% of HB-N, while the greatest average value (84.56) was for the unmodified group.

Paired T-test for surface hardness was done to compare groups before and after being subjected to artificial weathering (Table 2), analysis revealed a statistically significant difference between each two different groups (P<0.05).

Surface roughness before and after subject to artificial weathering

The results of surface roughness before weathering were demonstrated in Table 3 and Figure 3, the control group possessed the greatest average value (0.3478 μm), while the group containing 0.050 wt.% of H-BNNPs exhibited the lowest average value (0.2138 μm).

The results of surface roughness after weathering were demonstrated in Figure 3 and Table 3, the control group had the lowest average value (0.4897μm), while the group containing 0.075 wt.% of H-BNNPs exhibited the highest average value (0.6309μm).

Paired T-test for surface roughness was done to compare groups before and after being subjected to artificial weathering (Table 3), analysis revealed a statistically significant difference between each two different experimental groups (P<0.05), and non-significant between un-modified groups (P>0.05).

Table 2: Descriptive statistics, normality test of surface hardness before and after artificial weathering, and F test by ANOVA, paired T-test.

Before weathering	**Shapiro-Wlik *P* value**	**Mean**	**SD**	**Min**	**Max**	**ANOVA F-test**	***P* value**
Control	0.398	86.70	0.8028	84.9	87.9	1.285	0.293
0.050%	0.950	8609	0.8722	84.6	87.5		
0.075%	0.790	86.32	0.9004	84.6	87.6		
Before weathering	**Shapiro-Wlik *P* value**	**Mean**	**SD**	**Min**	**Max**	**ANOVA F-test**	***P* value**
Control	0.845	84.56	0.6620	83.3	85.6	0.695	0.508
0.050%	0.928	84.22	0.7177	83.0	85.3		
0.075%	0.681	84.53	0.7587	83.4	85.9		

Table 3: Descriptive statistics, normality test of surface roughness before and after artificial weathering, and F test by ANOVA, paired T-test.

Before weathering	Shapiro-Wlik *P* value	Mean	SD	Min	Max	ANOVA F-test	*P* value
Control	0.186	0.3478	0.1532	0.168	0.676	2.934	0.070
0.050%	0.176	0.2138	0.1054	0.100	0.433		
0.075%	0.119	0.2678	0.1089	0.126	0.459		
Before weathering	**Shapiro-Wlik *P* value**	**Mean**	**SD**	**Min**	**Max**	**ANOVA F-test**	***P* value**
Control	0.277	0.4897	0.2684	0.093	0.888	0.854	0.437
0.050%	0.406	0.6128	0.2201	0.334	0.975		
0.075%	0.222	0.6309	0.2941	0.219	0.995		

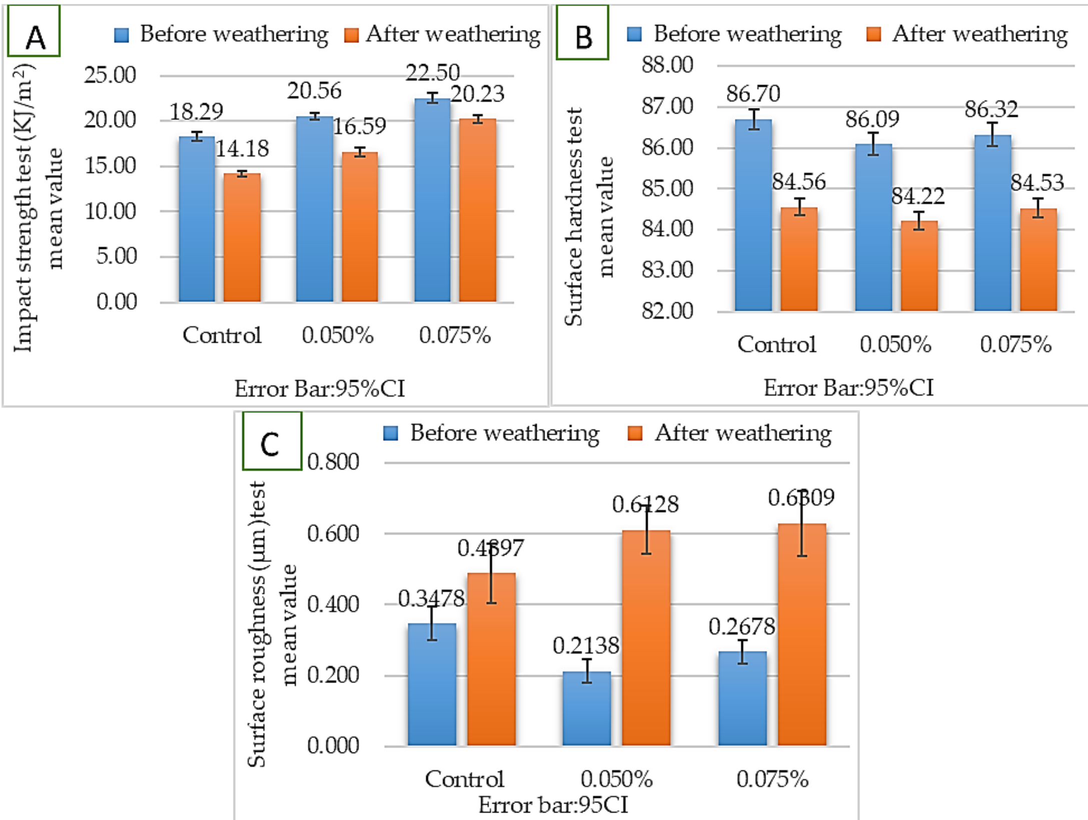

Figure 3: Bar chart of A: Impact strength test (KJ/m²); B: Surface hardness test; C: Surface roughness test (µm), and stander error before and after subjected to artificial weathering.

Discussion

The most recognizable and distinctive aspect of the face is the eyes. Eye loss, either inherited or acquired, adversely impacts patients' quality of life. Rehabilitating a missing eye can be done using both custom-made and prefabricated eye prostheses [27]. A prosthetic replacement helps patients regain their social and psychological well-being and boost their self-esteem. Heat-cured scleral acrylic resins are frequently utilized to create ocular prostheses since they have appropriate properties [4]. The ocular prostheses made from scleral acrylic resin need to be refabricated because of potential changes in the material's chemical and physical characteristics. Numerous initiatives have been implemented to include inorganic NPs in PMMA to improve the physical and mechanical features.

The inclusion of NPs enhanced this material's characteristics [28]. Along with enhancing the qualities of polymers, it's been proposed that adding (NPs) to an organic polymer may offer it resilience to aging and cracking brought on by environmental stress [29]. Artificial weathering this kind of testing (conditioning) is mostly used to mimic the aging process of natural daylight using an aging chamber called a Weather-

Ometer or weathering chamber, which forecasts the material's durability while it is in use. The primary benefit is the consistency and repeatability of the necessary conditions since the temperature, thermal cycle, moisture, and water exposure may all be applied to their maximum (within the permitted limits). Andreotti et al. evaluated the influence of adding various nanoparticles to the ocular acrylic and concluded that after 1008 hours of artificial aging, adding 2.5% TiO_2 helped to maintain microhardness and color [12].

This research assessed the impacts of H-BN NPs on the mechanical properties of scleral acrylic resin, before and after being subjected to artificial weathering. A significant variation ($p < 0.05$) between the H-BN-containing group and the control group was found for impact strength, both the lower and the higher percentages showed improved mechanical qualities as relative to the unmodified group before and after subject to artificial weathering. Non-significant effects were found regarding shore D hardness and surface roughness before and after being subjected to weathering.

The Impact strength test results for this study, before weathering, showed that the scleral acrylic resin improved significantly. The enhancement is attributed to the fine particle size and well-dispersed NPs [30]. Furthermore, the excellent interfacial connection between the polymer matrix and nanofiller is expected to play a role in impact strength improvement as nanoparticles fill spaces between polymer chains, avoiding displacement and dissipating energy that causes crack propagation [31]. This suggests that NPS serve as reinforcing agents, strengthening the material's ability to withstand fractures brought on by stress [32]. NPs at low percentages can interact effectively with the polymer chains and improve load transfer within the composite, thereby enhancing impact resistance [33].

The FE-SEM investigations showed that the HB-N NPs were evenly distributed throughout the substance, which may enhance the impact strength. However, after artificial weathering, a noticeable reduction in impact strength was observed for all groups. This decline is consistent with the well-documented effects of ultraviolet exposure on PMMA, where UV light causes chain scission and oxidative photodegradation in the polymer matrix, resulting in embrittlement and loss of mechanical integrity [34]. Despite this reduction, PMMA/H-BN composites retained higher impact strength readings in relation to the control group, indicating that a low percentage of H-BN was effective in mitigating, although not completely preventing, the deleterious effects of aging [33].

Hardness is a surface feature of a material that indicates the level of polymerization and, by being resistant to indentation, acts as an indirect measure of material strength [35]. In the current study, before weathering the non-significant findings could be clarified by the limited diffusion of the free radicals [36, 37]. This outcome may be described by the comparatively low percentage of H-BN NPs added to the PMMA matrix. The improvement was percentage dependent, so the best results were obtained from the higher percentage of NPs. For surface hardness, the decreased value because microhardness (wear resistance) is closely correlated with both flexural strength and impact strength [38], the material becomes more prone to fracture as its microhardness increases due to its friability [39].

The filler particles are smaller in size and tend to agglomerate, resulting in reduced mechanical properties because the agglomerates themselves are weaker [40]. The degree of polymerization directly influences surface hardness, a measurement of a substance's resistance to indenting, and indirectly determines its strength [41]. These outcomes are consistent with previous outcomes stated by Alshaikh et al., indicating that incorporating ZrO_2 NPs into the resin led to a modest drop in the hardness of the surface as compared to the unchanged resin. This discrepancy implies that the material's composition, the kind of NPs employed, and their percentage could all have a role [42].

After artificial weathering, the decline in hardness can be ascribed to ultraviolet-induced degradation of the polymer matrix, where UV irradiation leads to structural changes and chain scission, which diminish the material's capacity to withstand surface deformation. Despite the initial reinforcement effect, the aging process reduced hardness in all groups, demonstrating the dominant role of photodegradation on surface mechanical properties (34).

Surface roughness is a characteristic that refers to the minute deviations from a perfectly smooth surface that are naturally present in materials. The surface texture of small irregularities must be measured to determine the surface roughness (35).

In this study, the surface roughness value dropped after incorporating 0.05 wt% of H-BN NPs. This can be clarified by filling the gaps between the polymer matrix and the additive of NPs, thus diminishing the surface irregularities and voids (43), while increasing the percentage of the H-BN NPs to 0.075wt% results in a slight rise in the roughness ratings, but still less than the control group, the study's findings are compared with those of Cevik et al., who reported increased mechanical properties in acrylic resin with a higher filler percentage (44). These results before subject to weathering due to the material's small size, which allows it to be widely distributed and to seal the holes in the matrix of resin (44).

Furthermore, surface roughness is calculated from the composite's exterior rather than its interior. The specimens show little particles on surfaces when utilizing tiny percentages of NPs (21). The results conform to earlier studies conducted by Sadoon and Abd Alwahab et al. (45, 46). While the roughness value increases after being subjected to artificial weathering because there is a clear correlation between the hydrophobicity of the composite system and surface smoothness (47).

Interestingly, the control group displayed a smaller rise in surface roughness after weathering compared to the H-BN–containing groups. This may be attributed to filler–matrix interfaces in nanocomposites acting as stress concentration sites, which are more prone to debonding and microcrack formation under UV and moisture exposure. Such interfacial degradation accelerates surface deterioration around NPs, resulting in greater roughness than in neat PMMA, where degradation occurs more uniformly. Differences in thermal and mechanical behavior between H-BN and PMMA may further intensify this effect (48).

The association between impact strength, surface roughness, and surface hardness tests was complicated, as each test evaluates distinct properties. The energy that the material absorbs during an abrupt load was measured by the impact strength (32). The resistance of a substance's surface to indentations is quantified by its hardness (49). Enhancing one feature might not always result in enhancing another (50).

The potential for cytotoxicity resulting from the materials' leaching of nanofillers is particularly worrisome since it may have detrimental effects on the surrounding tissue. Further *in vitro* and *in vivo* research is essential to guarantee the safety and effectiveness of resin treated with H-BNNPs before it is used in clinical settings. Up to 1wt% of the H-BN was incorporated into the silicone elastomer former to make maxillofacial prostheses, which was thought to be safe. But before being utilized on humans, the remaining biocompatibility testing must be completed (35).

The hypothesis outcome

The inclusion of H-BN NPs at 0.050 wt.% and 0.075 wt.% resulted in alterations in some physical and mechanical features of Scleral acrylic resin. Subsequently, the null hypothesis was rejected and the alternative hypothesis was accepted.

This study has several limitations:

It was conducted under *in vitro* conditions, which may not fully simulate the complex environmental and clinical conditions encountered by ocular prostheses in vivo. The only selected percentages of H-BN were evaluated; other percentages may yield different outcomes. Artificial weathering was performed for a limited duration and may not precisely represent long-term clinical aging. The only one commercially available scleral heat-cure acrylic resin was tested, limiting the generalizability of the findings.

Conclusion

The outcomes of this investigation showed that the inclusion of (H-BN NPs) at low weight percentages can beneficially modify the mechanical performance of the material in a percentage-dependent manner. Specifically, the addition of 0.075 wt.% H-BN NPs yielded the most significant improvement in impact strength, both before and after being subjected to artificial weathering, indicating enhanced resistance to mechanical degradation and environmental aging. Conversely, surface roughness was optimally reduced at 0.050 wt.% before aging, while higher NPs loading caused a gradual increase in roughness, the values were still less than those of the control group. Despite the observed reduction in surface hardness with increasing H-BN content, the overall balance of mechanical properties suggests that low NPs of H-BN NPs can be effectively utilized to enhance impact resistance and surface characteristics without compromising long-term performance. These findings displayed the promise of H-BN NPs as functional nanofillers for optimizing advanced polymer-based materials in dental applications.

Conflict of interest

No conflicts of interest have been revealed by the writers.

Author contributions

AJ; Study design and idea, data gathering, methodology, statistical analysis and result interpretation, creation of the first draft of the manuscript, writing and editing, and supervision , FA; Methodology, statistical analysis and interpretation of results, original draft manuscript preparation, writing & editing, supervision. NL; Supervision. Every author examined the outcomes and gave the go-ahead for the manuscript's publication.

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فاعلية نيتريد البورون السداسي كمادة مضافة في تحسين خصائص راتنج الأكريل الصلبي المستخدم في الصُّلبة عند تعريضه للشيخوخة الصناعية

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المستخلص

الخلفية: يُعدّ راتنج الأكريل الصلبي من المواد الشائعة الاستخدام في تصنيع التعويضات العينية. إلا أن خصائص هذه المادة تتغير مع مرور الزمن، مما يستدعي إعادة تصنيع التعويض. وقد أُجريت العديد من الدراسات لتحسين هذه الخصائص من خلال تدعيمها بالجسيمات النانوية. الهدف: تهدف هذه الدراسة إلى تقييم تأثير إضافة جسيمات نيتريد البورون السداسي النانوية (H-BN NPs) بنسب وزنية (0.050% و0.075%) على الخواص الميكانيكية لراتنج الأكريل الصلبي (مقاومة الصدم، الصلادة السطحية، والخشونة السطحية)، قبل وبعد تعريضه للشيخوخة الصناعية .المواد وطرائق العمل: تم تحضير ما مجموعه 90 نموذجاً، قُسمت إلى ثلاث مجموعات لإجراء الاختبارات المختلفة. تم تقييم الخواص الميكانيكية، إضافةً إلى دراسة البنية المجهرية والتحليل العنصري لجسيمات H-BN باستخدام جهاز اختبار الصدم من نوع Izod ، وجهاز قياس الصلادة Shore D ، وجهاز قياس الخشونة (Profilometer) ، والمجهر الإلكتروني الماسح بانبعاث المجال (FE-SEM) ، والتحليل الطيفي للأشعة السينية المشتتة للطاقة (EDX) ، على التوالي. النتائج: تم تحليل البيانات باستخدام اختبار تحليل التباين الأحادي (One-way ANOVA) واختبار Tukey البَعدي، واعتُبر الفرق ذا دلالة إحصائية عند قيمة $p < 0.05$. أظهرت نتائج فحص FE-SEM توزعاً متجانساً لجسيمات H-BN داخل مصفوفة البوليمر. لوحظت زيادات معنوية في مقاومة الصدم وانخفاض في كل من الخشونة السطحية والصلادة السطحية (Shore D) في المجموعتين التجريبيتين قبل تعريضها للشيخوخة الصناعية. في المقابل، وبعد 300 ساعة من اختبار الشيخوخة الصناعية، لوحظ انخفاض ملحوظ في مقاومة الصدم والصلادة السطحية، مع زيادة في الخشونة السطحية. الاستنتاج: أظهرت النماذج المعدلة بجسيمات نيتريد البورون السداسي مقاومة أفضل للتدهور الميكانيكي مقارنة بمجموعة السيطرة. تدعم هذه النتائج إمكانية استخدام جسيمات H-BN النانوية كمادة تدعيم فعّالة لمواد التعويضات العينية، على الرغم من أن الشيخوخة الصناعية تؤثر سلباً في خصائص المادة بمرور الوقت. ويوصى بإجراء دراسات إضافية لتقييم المتانة طويلة الأمد وتحسين النسبة الوزنية المثلى للجسيمات النانوية لأغراض التطبيق السريري.