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The Role of Boron Nitride Particles on Thermal Conductivity, Transverse Strength and Surface Hardness of Heat Cure Acrylic Resin

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Abstract

Objectives: The objective of this research was to investigate how boron nitride powder addition in percentages of 1% weight and 1.5% weight, affected the thermal conductivity, transverse strength, and surface hardness of heat cured acrylic resin denture base material. Methods: Ninety specimens were made from heat-cured acrylic resin and then divided into three groups based on the tests: a control group, a reinforced poly methyl methacrylate group with 1% weight boron nitride particles, and a reinforced poly methyl methacrylate group with 1.5% weight boron nitride particles. They investigated into the thermal conductivity, transverse strength, and surface hardness tests. Results: This research showed that 1% and 1.5% weight boron nitride particles significantly increased thermal conductivity and surface hardness in comparison to the controlled group. There was a highly significant increase in transverse strength compared to the control group; at the concentration of 1% weight boron nitride particles. Conclusion: Boron nitride particles enhance the thermal conductivity, transverse strength, and surface hardness when added to heat cure acrylic resin denture base material.

Introduction:

The invention of acrylic resin, which was made in 1936, was a significant development that impacted on contemporary dentistry. In clinical practice, acrylic resin is the preferred material for creating traditional removable dentures for edentulous patients[1] . Poly methyl methacrylate (PMMA) is a popular

material due to its optical characteristics, biocompatibility, and esthetic appearance. However, PMMA is not considered a perfect material due to its poor mechanical and physical qualities. The denture base is subjected to various effects during use, including masticatory forces, thermal changes, saliva, food, and water exposure, and mechanical impacts, all of which can lead to denture failure[2, 3]. However, PMMA base material has weak mechanical qualities against fatigue, impact, and bending and they may be modified to enhance PMMA denture base material[4]. PMMA is the material of choice for denture base, however a more perfect material is still in development [5]. Few studies have been done to improve acrylic resin's thermal conductivity, which is one of the material's drawbacks. In general, polymer materials are regarded as thermal insulators since their intrinsic heat conductivity is considerably less than that of ceramics and metals [6]. The denture with high thermal conductivity influence the acceptance of patient to denture, tissue protection, good tasting sensations[7]. Because the transverse strength measures more closely reflect the loading given to the denture in the mouth than do the tensile or compressive strength values, these tests used more frequently[8]. Due to these limitations, conductive particles can be inserted into the powder or liquid form of acrylic and polymerizing it in order to increase the material's heat conductivity[9]. Manufacturers have typically improved polymer with nano and micrometer-scale additives to increase stiffness and strength, boost solvent tolerance, and reduced cost[10]. Nowadays, more focus is being placed on incorporating various particles into PMMA to improve its properties [11]. Boron compounds are currently widely used in various fields, including medical chemistry[12]. As a fine-grained lubricant, hexagonal boron nitride (h-BN) is utilized in various applications, including paint, cosmetics, and dental cements[13]. Due to their biocompatibility, great thermal and chemical stability, outstanding mechanical strength, and electrical insulating qualities, they have potential applications in numerous fields, involving chemistry, pharmacy, and cosmetics [14].

Materials and Methods

A pilot study was done by using four concentrations of (1%,1.5%,3%,5%wt) boron nitride; the introduction of (1% by weight) and (1.5% by weight) of boron nitride powder resulted in the great values of thermal conductivity and transverse strength among the studied groups and were utilized to accomplish the main study. As a result, the concentrations chosen for the main study are (1% wt.) and (1.5% wt.).

Classification of specimens

Ninety heat-cured resin specimens were created. Based on tests that were accomplished, the samples were classified into three groups.
Every group comprised 30 specimens, which were further sub - divided into:
1) Controlled group of ten (10) specimens of PMMA without BN particles.
2) Ten (10) PMMA specimens containing 1% wt. BN particles
3) Ten (10) PMMA specimens containing 1.5% wt. BN particles

Addition of boron nitride particles

Measuring amount of BN powder **(**hexagonal, 99.99%, 3-4 um**)** (sky spring Nano materials, USA) was mixed with the monomer liquid to make the acrylic dough for the experimental groups. The BN was thoroughly dispersed using a probe sonicator apparatus for three minutes to ensure good BN dispersion and prevent agglomeration within the monomer [15-19].

preparation of an acrylic specimen

To produce a mould for acrylic specimens, different metal patterns were created using metal templates made by cutting metal plates with a turning machine into the needed shape and dimension. The separating medium is applied on the metal patterns and left to get dry. Following the instructions from the manufacturer, the dental stone is prepared using a mixture of 100 grams of powder and 20 milliliters of water, which is then poured to the lower member of flask and vibrated to eliminate any bubbles of air and heavy body condensation silicone is added above the

stone, after which the metal patterns are inserted to achieve the desired shape, the upper member can be put, loaded with stone, vibrated, and the flask lid was set. As recommended by the manufacturer, acrylic resin (Rodex-Turkey) was prepared in a proportion of 2.5 to 1 by weight (P/L) as illustrated in figure 1.

Research study tests

SEM analysis

A small piece of acrylic was trimmed and mounted on special SEM plates before being coated in gold with the help of a rotating pumping coater with tungsten gas (Quorum, Q150R ES, UK), and finally examining the acrylic samples with SEM device (Prisma E SEM, US).

FTIR Spectroscopy

To decide whether or not there is a chemical bond between BN and acrylic resin, a Fourier transform infrared test was performed on BN powder and the resulting powder after it had been blended with acrylic resin. A small amount of the material is scratched and applied directly on the FTIR special plate for testing (SHIMADZU, Japan).

Thermal conductivity

According to the specifications of the testing device, the test specimens are disks made of heat-cure acrylic resin, measuring 2.5 mm thick and 40 mm in diameter.

The thermal conductivity of acrylic samples was measured using thermal conductivity equipment (Lees disc) (figure 2). It is made up of three copper discs (A, B, and C), each with a hole to accept thermometers. A sixty-watt electrical plate heater was wedged between discs B and C, and the specimen was then positioned between copper discs A and B before tightening the clamp screw to hold all the discs together and turning on the heater. To reduce the effect of environmental temperature, the entire assembly was enclosed. To measure the ambient temperature, a fourth thermometer was placed within the enclosure near the apparatus. Because of the presence of a specimen that acts as an isolator, the temperature in the disc (C, B) began to rise faster than disc A when the heater was turned on. The temperatures in disc C and B were initially different, and readings were taken at 10-minute intervals until equilibrium was achieved. This means that after 30 minutes, the temperatures at disc C and B were equal, and the temperatures in all parts of the apparatus were stable to within 0.1°C. At this point, the reading is taken, and the thermal conductivity is calculated[20].

Transverse strength

Test specimen were created with dimensions of "65mm length x 10mm width x 2.5mm thickness". Before testing, each specimens are preserved in distilled water at 37°cellisus for 2 days according to ADA specifications[21] No.12, 1999.

As shown in figure 3, the test was carried out using an Instron universal testing machine (by a three-point bending approach). The specimens were loaded and put on bending fixture which consisted of two straight supporters spaced by 50 millimeters, across the head at a speed of 1 millimeter per minute through a rod positioned in the middle of the supports to cause create deformation till a fracture occurred. The following formula was used to determine the transverse strength:

$$T = \frac{3PL}{2bd^2}$$ ***(ADA specification No.12, 1999), where:***

T: Transverse strength (N/mm2)

P: Max specimen force (N)

L: The space that exists between each support (mm)

b: the dimension of the specimen (millimeter)

d: thickness of specimen (millimeter)

Surface hardness

The acrylic resin test specimens had the following measurements: 65 mm in length, 10 mm in width, and 2.5 mm in thickness. Before the test, we kept all the samples in 37 degrees Celsius and distilled water for 48 hours (ADA specification No.12, 1999)[21]. A (shore D) durometer hardness tester (*TLead,* China) was used to measure surface hardness by ADA specification No.12, 1999, which is appropriate for acrylic resin. The device comprised of a

spring-loaded indenter with a diameter of 0.8 mm connected to a digital scale with a range of 0 - 100 units; the maximum reading was recorded by pressing the indenter as shown in figure 4. There were three measurements taken to each specimen, one at each end and another in the middle, and the average was recorded.

Results:

FTIR characterization

The IR spectrum of pure cement (acrylic) and modified cement show a strong band from the c=o group at the frequency of 1732.08 cm-1. The stretching vibration by the O-H band appeared at the zone of 3442.94 cm-1 as shown in figure 4[22]. There are significant enlarges in peaks of cement framework occurred after BN loading, the main bands correspond to structure of cement appear without significant changes after loading of BN in the percentage 1 and 1.5% , but the appear of new peak and some changes in peak position were observed especially in the frequency 2358.94 cm-1 confirmed the reaction band between nitrogen atoms with carbon group of carboxylic acid of cement to form C-N group in the modified cement as shown in figure 5 , suggesting that the modification of cement with boron nitride was almost complete. The nitrile group were transformed into =N-O from the oxime group.

Also after modified pure cement, some changes in peak position were observed especially for the peaks 1381.03-981.7 cm-1(the absorption peak observed at 1444.68 cm-1) contributed to the symmetric and asymmetric stretching of CO in COO[23, 24].

SEM

Figures 6 and 7 show scanning electron microscope images of control and experimental specimens with BN 1% and 1.5% wt. at 300 X magnification. The BN particles are spread equally across the material and do not aggregate in clusters inside the polymer matrix, as shown in figures 6 and 7.

Thermal conductivity test

The highest mean value of thermal conductivity appear in 1.5% wt. BN group, the control group had the lowest mean value (figure 8). One way (ANOVA) showed a high significant difference among groups as shown in table 1. Further investigation was conducted usingTukey HSD analysis (Honestly significant difference), as shown in table 2, which shows a highly significant difference among test groups at $p < 0.01$.

Transverse strength test

The 1% wt. BN group has the highest mean value, whereas the control group has the lowest mean value as seen in figure 9. One way (ANOVA) revealed high significant difference between groups (table 3). Tukey HSD analysis of the data, as shown in table 4, revealed a high significant increase across test groups ($P<0.01$) (table 4).

Surface hardness test

The mean value for the control group is the lowest, while the mean value for the 1.5%wt. BN group is the highest (figure 10). One way (ANOVA) test revealed high significant difference between the studied groups as seen in table 5. Tukey HSD analysis of the data revealed a high significant increase across test groups ($P<0.01$) (table 6).

Discussion:

Thermal conductivity

Thermal conductivity values increased significantly by addition of 1% and 1.5% wt BN particles. This might be because the BN particles eventually interact with one another to form chains or networks of structures called heat conductive pathways that overcome the polymer's insulating properties while allowing heat to flow from one side of the specimen to the other. Thus, The ability of the polymer to conduct heat will be high. The more filler there is, the more heat conduction paths there are, which improves the material's thermal conductive performance[25]. Porous structures were seen within PMMA in the control group's SEM images (figure 6). The porous areas of PMMA in

the BN-added group were packed with BN, and the PMMA was very well integrated, according to SEM pictures of that group, heat conduction paths are formed by this distribution.

Similar to this research, several other investigations found that adding micro and nano-fillers to the resin matrix improved thermal conductivity[26, 27]. In a study by **Ghaffari *et al.*,** the thermal conductivity of acrylic resin was improved by the addition of silver nanoparticles[27]. The result of our study are the same as those of Kamil and Al-Judy, who discovered that adding salinized SiC nanoparticles to a heat-cured acrylic resin improves the material's thermal conductivity in a concentration-dependent manner.[28].

Transverse strength

Transverse strength measurements improved significantly for both experimental groups in this study in comparison to the control group; this improvement was noted for both 1% and 1.5% BN additions by weight. The enhanced transverse strength might be related to identical filler particle distribution within the matrix and transformation toughening. The transformation phenomenon occurs when sufficient stress starts to develop and micro cracks begin to propagate, depleting the energy for crack propagation. As a result, adequate filler distribution within matrix can prevent or deflect cracks[29]. Jasim and Harini et al. found a significant increase in transverse strength of heat cured acrylic by incorporating different percentages of surface modified aluminum oxide and unmodified titanium dioxide nano fillers, respectively[15,30]. As the percentage of BN particles increases, the distance between them decreases, increasing the possibility of particle agglomeration. This aggregation concentrates stress at the agglomerated particles, lowering mechanical properties, which explains the reduction in flexural strength at higher particle percentages(1.5%) wt[31]. versus lower particle percentages (1% wt.). Our findings contradict Grzegorz Chladek's findings that adding silver filler to PMMA reduces its transverse strength[32]. Kamil and Al-Judy demonstrated that the addition of silanized SiC nanoparticles resulted with no change in transverse strength in comparison to the control group[28]. Nejatian et al. showed that reducing the flexural strength of Polymer dentures by 10% by adding silanated ZrO2 to heat-cured acrylic[33].

Surface hardness

The introduction of boron nitride particles resulted in a highly significant increase versus the controlled group. The enhancement in the hardness is directly proportional to the amount of boron nitride present. The surface hardness improved till the appropriate level as the filler concentration increased. The reason behind this is that the composite aggregates less once the optimum filler level has been reached in the matrix, using magnetic stirrer and speed mixer [34]. These findings supported other studies on the influence of TiO2 particle reinforcement to enhance PMMA properties as hardness, fracture toughness, and flexure strength[35]. This result is similar with earlier research, which showed that surface hardness of PMMA was statistically increased when added TiO2 and ZrO2 filler particles at various concentrations[36].

Conclusions

The following conclusions were reached within the limitations of the study:

1. The thermal conductivity of the PMMA was improved with the incorporation of BN particles, additionally, conductivity improved as concentration increased.

2. The transverse strength with incorporation of BN to heat cured PMMA was significantly increased and concentration dependent.

3. Addition of BN particles to heat cured PMMA improved the surface hardness significantly.

Source of funding

This study received no specific funding from governmental, commercial, or not-for-profit funding entities.

Clinical relevance

Without changing other physical properties, the BN particles can be used to enhance the the thermal conductivity and thermal performance of acrylic resin.

Data Availability

The corresponding author can provide access to the data used to support the study's findings.

Conflicts of interest

The authors have not revealed any declared conflicts of interest.

Abbreviations: Poly methyl methacrylate (PMMA), Weight (wt.), Boron nitride (BN), Scanning electron microscope (SEM), Fourier Transformed Infrared (FTIR), hexagonal boron nitride (h-BN).

Figure 1: different mold samples preparation.

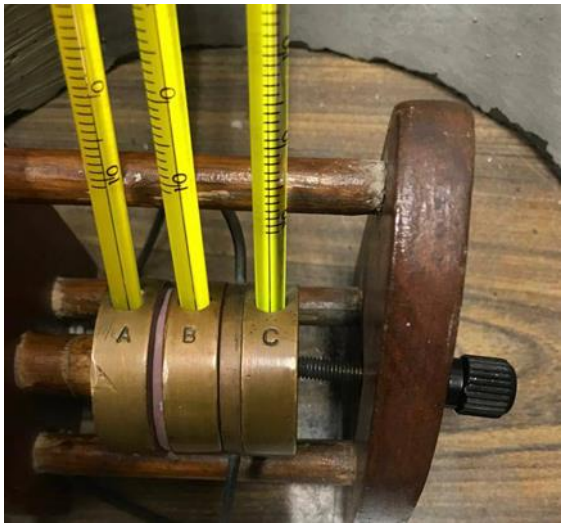


Figure 2: Thermal conductivity apparatus (Lee disc).

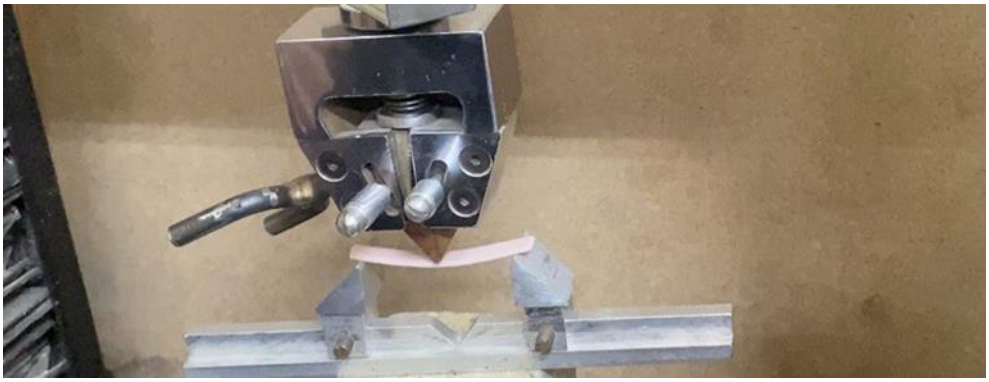
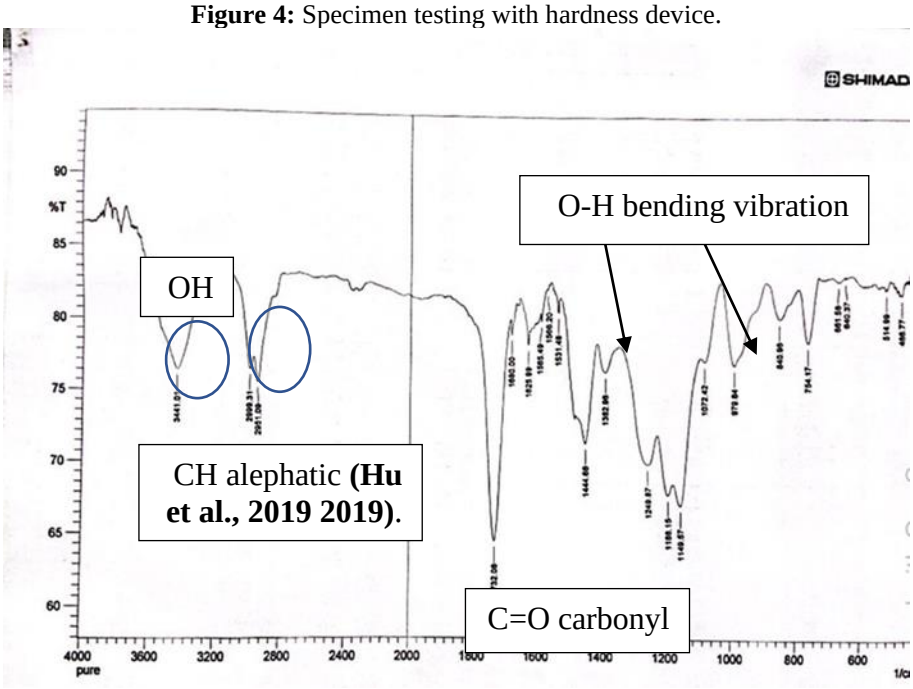
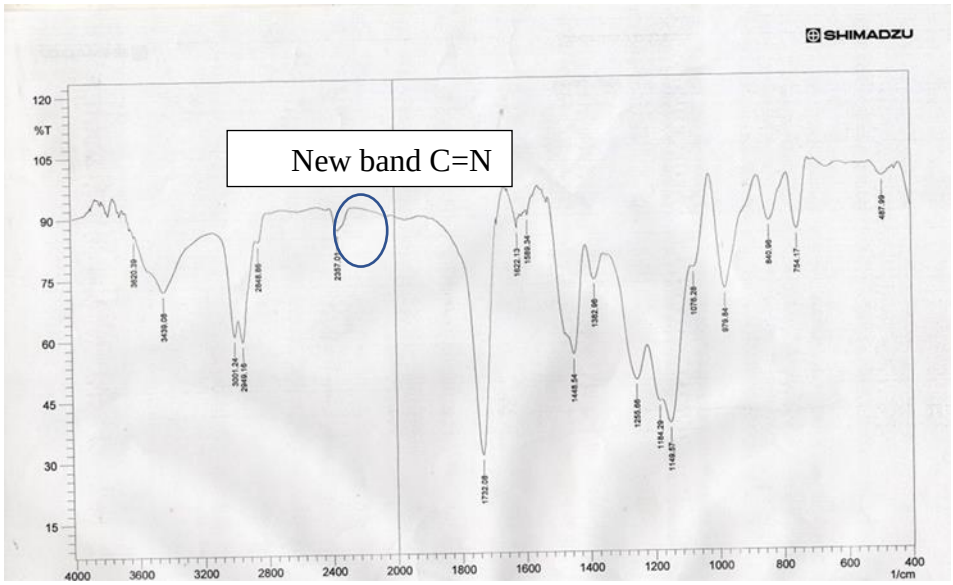


Figure 3: Specimen bending before fracture.

Figure 4: Specimen testing with hardness device.



(A)



(B)

Figure 5 A: FTIR of heat cure acrylic resin.
B, FTIR of heat cure acrylic resin modified with BN.

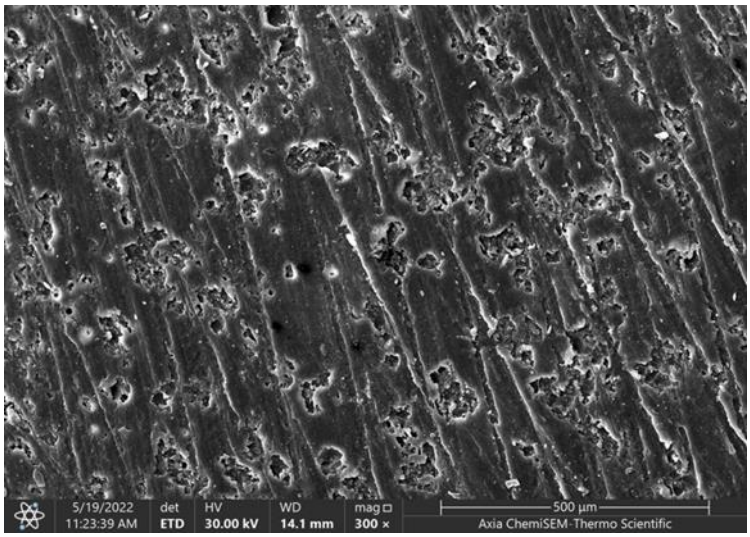


Figure 6: Scanning electron microscope of control specimen.

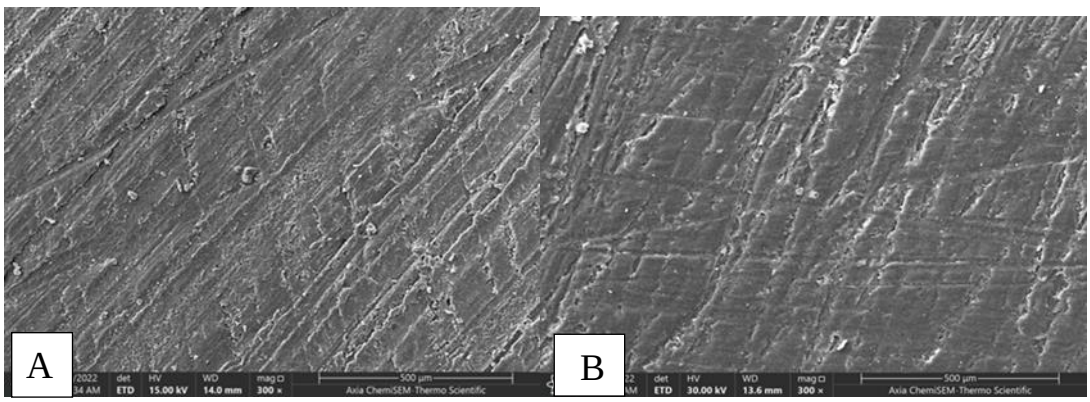


Figure 7 A and B: Scanning electron microscope of the experimental specimen with 1% and 1.5% wt. BN powder.

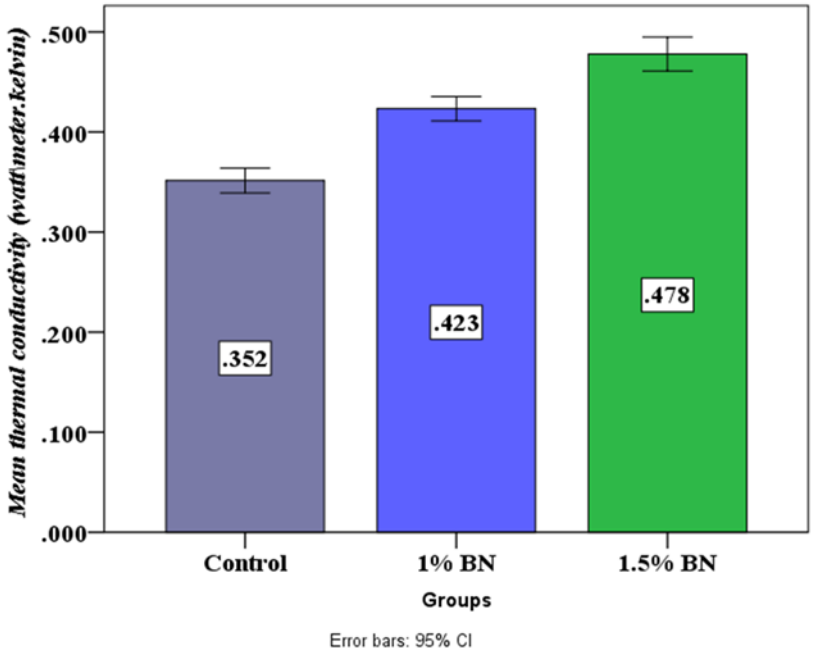


Figure 8: A bar graph showing the average thermal conductivity values for the study groups .

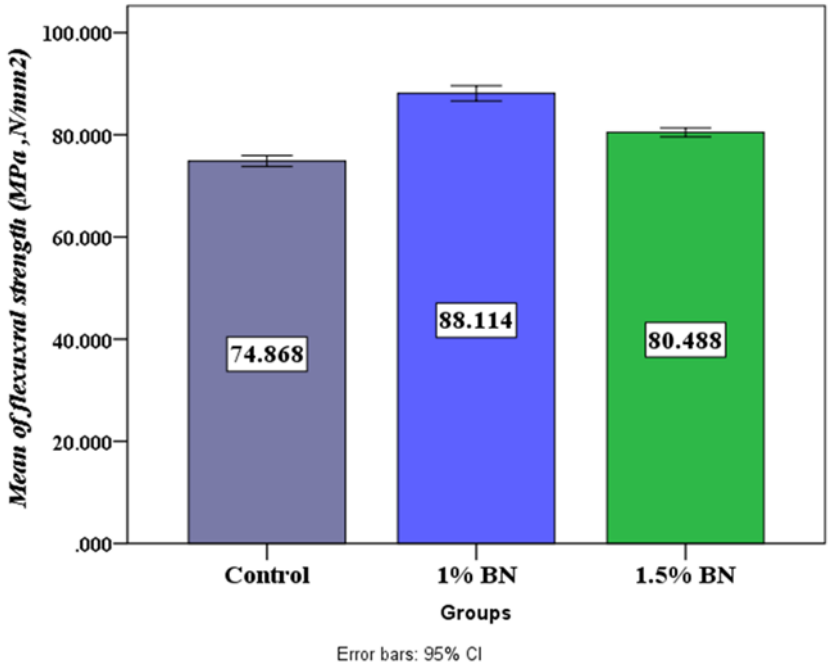


Figure 9: A bar graph showing the average transverse strength test results for the groups under study.

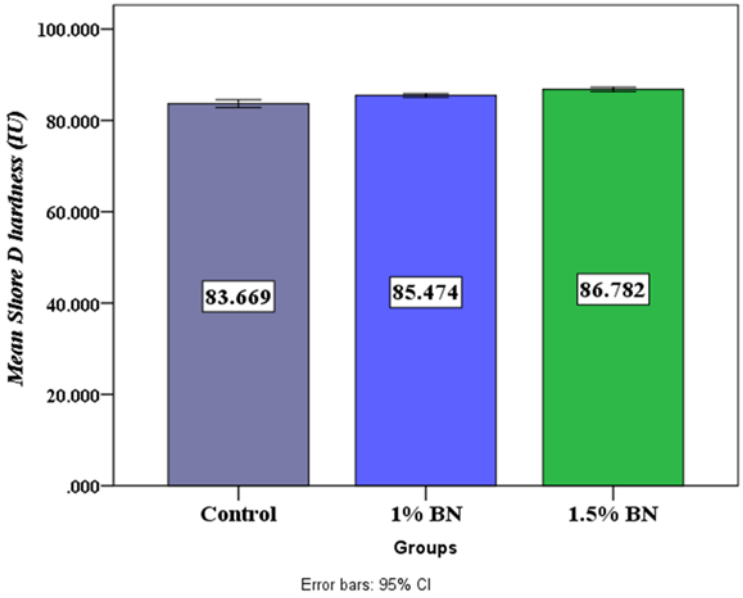


Figure 10: A bar graph showing the average test results for hardness among groups.

Table 1: One-way ANOVA for thermal conductivity among groups.

	Sum of Squares	df	Mean Square	F	P value
Between Groups	**0.080**	**2**	**0.040**	**104.553**	**0.00000 Sig.**
Within Groups	**0.010**	**27**	**0.000**		
Total	**0.091**	**29**			

Table 2: Tukey HSD comparisons of the thermal conductivity between various groupings.

Groups		Mean difference	p value	
Control	**1% BN**	**-0.072**	**0.00000**	**High Sig.**
	1.5% BN	**-0.126**	**0.00000**	
1% BN	**1.5% BN**	**-0.055**	**0.00000**	

Table 3: One-way analysis of variance (ANOVA) performed to compare groups' flexural strength.

	Sum of Squares	df	Mean Square	F	P value
Between Groups	**883.989**	**2**	**441.995**	**164.412**	**0.00000 Sig.**
Within Groups	**72.585**	**27**	**2.688**		
Total	**956.574**	**29**			

Table 4: Several Comparisons of flexural strength across groups by using (Tukey HSD).

Groups		Mean difference	p value	
Control	**1% BN**	**-13.246**	**0.00000**	**Sig.**
	1.5% BN	**-5.620**	**0.00000**	
1% BN	**1.5% BN**	**7.626**	**0.00000**	

Table 5: One-way ANOVA for surface hardness among groups.

	Sum of Squares	df	Mean Square	F	P-value
Between Groups	**48.866**	**2**	**24.433**	**33.776**	**0.00000 Sig.**
Within Groups	**19.531**	**27**	**0.723**		
Total	**68.397**	**29**			

Table 6: Several Shore D hardness comparisons among groups by using (Tukey's HSD).

Groups		Mean difference	p-value	
Control	**1% BN**	**-1.805**	**0.00017**	**Sig.**
	1.5% BN	**-3.113**	**0.00000**	
1% BN	**1.5% BN**	**-1.308**	**0.00526**	

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