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Evaluating the Mechanical Properties of Maxillofacial Silicone Enhanced by Hexagonal Boron Nitride Particles

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RESEARCH ARTICLE

Evaluating the Mechanical Properties of Maxillofacial Silicone Enhanced by Hexagonal Boron Nitride Particles

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ABSTRACT

Maxillofacial silicone is the most popular and commonly used material for the construction of maxillofacial prostheses. However, the material failed to satisfy the expected features of a maxillofacial prosthesis due to major limitations, particularly in mechanical properties. The goal of this study is to evaluate the mechanical properties of the VST-50F silicone elastomer with the addition of hexagonal boron nitride (H-BN). A total of 120 specimens were prepared and divided into three groups control and two experimental (0.5 wt% and 0.7 wt% H-BN). Each group was divided into four identical subgroups. For each subgroup, 10 specimens were utilized for each test (tear strength, tensile strength, Shore A hardness, and surface roughness). The H-BN powder and specimens from each group were studied using field emission scanning electron microscopy (FE-SEM) and Fourier transform infrared spectroscopy (FTIR). The data were analyzed using one-way ANOVA and post-hoc Tukey's tests, and a P-value < 0.05 indicated statistical significance. The FE-SEM test showed evenly dispersed H-BN within the VST-50F silicon matrix. The FTIR test revealed no chemical interaction between the silicone and H-BN. Both experimental groups showed significantly increased tear strength and decreased Shore a hardness and surface roughness ($P < 0.05$). The 0.5 wt% group exhibited no significant decrease in tensile strength, but the 0.7 wt% group showed a significant decrease compared to the control group ($P < 0.05$). As the quantity of H-BN increased, tear strength improved, whereas tensile strength, Shore a hardness, and surface roughness reduced.

Keywords: Field emission scanning electron microscopy, Fourier transform infrared spectroscopy, Hexagonal boron nitride, Maxillofacial silicone, Mechanical properties

Introduction

Maxillofacial prostheses are used to rehabilitate patients with maxillofacial defects that are present from birth or are acquired through disease or trauma. They have been produced using silicone elastomer, polymethylmethacrylate, polyvinyl chlorides, chlorinated polyethylene, and polyurethanes. Silicone elastomers, on the other hand, are the most often utilized polymers in maxillofacial prosthodontics due to their favorable characteristics. Because the maxillofacial defects cause substantial psychological and social issues in these individuals, the prosthesis has to be as realistic and aesthetically pleasant as possible, its visual and tactile qualities are crucial. Because the mechanical and physical properties of silicone prostheses degrade quickly over time, and because such prostheses are particularly difficult to repair, they should be changed frequently.[1] The current research has focused on enhancing the mechanical and physical properties of silicone elastomers by incorporating different fillers into the silicones such as nanoparticles (NPs) and microparticles, the unique characteristics of these additions such as their huge surface area, high surface energy, and polarity or strong chemical reactivity, may be related to the

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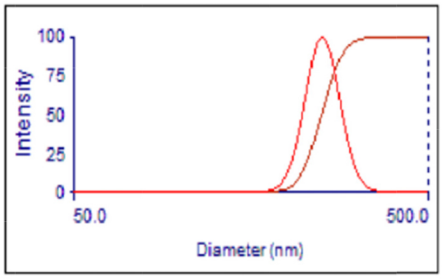
Brookhaven Instruments Corp.
90Plus Particle Sizing Software Ver. 5.34

Sample ID 63-1 (Combined)
Operator ID Unknown Operator
Notes

63-1 (Combined)

Effective Diameter: 252.1 nm
Polydispersity: 0.012
Baseline Index: 9.5
Elapsed Time: 00:00:50



Lognormal Distribution

Run	Eff. Diam. (nm)	Half Width (nm)	Polydispersity	Baseline Index
1	150.5	10.6	0.005	8.3
2	194.6	13.8	0.005	6.0
3	288.8	20.4	0.005	2.3
4	362.2	25.6	0.005	9.2
5	392.8	27.8	0.005	7.4
Mean	277.8	19.6	0.005	6.7
Std. Error	46.7	3.3	0.000	1.2
Combined	252.1	27.9	0.012	9.5

Fig. 1. Particle size analysis of H-BN.

improvements of the mechanical and physical properties of reinforced polymers. These features enable the interaction between the particles and the polymer chains, resulting in a three-dimensional composite with special properties.[2]

H-BN has the highest degree of chemical and thermal stability among the several crystalline forms. Due to its structural similarities to graphite, it is sometimes called "white graphite".[3] H-BN is more resistant to corrosion and wear than carbon materials, and in the upcoming years, more studies and potential uses are anticipated. H-BN has excellent thermal stability, oxidation resistance, and thermal conductivity, and it stays stable at temperatures below 3000 ˚C. Its high chemical stability precludes it from interacting with alkali, acids, or water at room temperature.[4] Because of its unique characteristics, H-BN has several applications in medicine, including tissue engineering, strengthening medical equipment, and antimicrobial activity. The H-BN can be mixed with various NPs that have antibacterial activity as an antibiotic.[5–7] The biocompatibility of H-BN particles incorporated with the maxillofacial silicone was verified concerning cytotoxicity and skin irritation.[8]

Materials and methods

The specimens were manufactured of VST-50F maxillofacial silicone elastomer (Factor II Inc., USA) and mixed with H-BN (Hongwu International Group Ltd., China, 99.8%, 45-200 nm) using a vacuum mixer. The particle size analyzer (NanoBrook 90Plus, Brookhaven, USA) confirmed that the H-BN powder's effective diameter, as depicted in Fig. 1, was 252.1 nm. The molds were created via a laser cutting machine (JL-1612, Jinan Link Manufacturing Trading Co, China) to custom-cut acrylic sheets (PT. Margacipta Wirasentosa, Indonesia) which were 2 and 7 mm thick. According to the manufacturer's guidelines, the VST-50F silicone was mixed at a ratio of 10:1 (10 parts base: 1 part catalyst) and the H-BN addition was mixed with the base to form the 10 parts. To avoid entangling air, the silicone was mixed using a vacuum mixer at 28 inches Hg with a mixing speed of less than 150 RPM. To prevent the suction of H-BN powder, the base, and H-BN particles were combined for 10 minutes, 3 minutes without any air being evacuated, and 7 minutes while under suctioning. The mixture was then allowed to cool for 5 minutes before

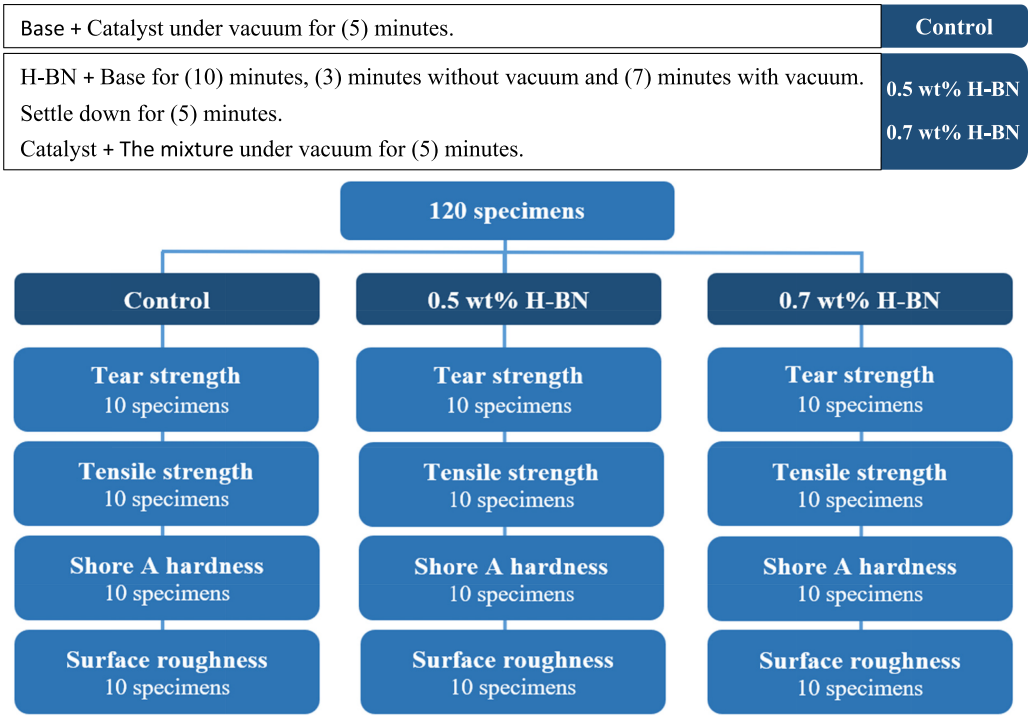


Fig. 2. Synthesis of the specimens.

the catalyst was added and the mixing was done under vacuum for 5 minutes to avoid air entrapment. Testing and vulcanization were more than 16 hours apart according to the manufacturer's instructions. During this time the silicone specimens were kept in a cooling box at 23 ± 2 ˚C and 50 ± 10% relative humidity according to ISO 23529.[9] The H-BN was used in two weight percentages (0.5 wt% and 0.7 wt%). A total of 120 specimens were prepared and divided into three groups: control and two experimental. Each group was divided into three identical subgroups. For each subgroup, 10 specimens were utilized for each test (tear strength, tensile strength, Shore A hardness, and surface roughness) Fig. 2. The H-BN powder and the specimens were analyzed using a field emission-scanning electron microscope (Quanta FEG 200, FEI, Netherland) and Fourier transform infrared spectroscopy (Iraffinity1, Shimadzu, Japan).

Tear strength specimens were prepared according to ISO 34-1.[10] The specimens were mounted in the clamps of a computerized universal testing machine (EBP manufacturer, China) at (60 ± 0.5) mm apart from the two clamps. The specimen was stretched at a constant crosshead speed of 500 mm/min until the specimen ruptured and the maximum force after a break was recorded by the computer software.

Tensile strength specimens were prepared according to ISO 37[11] with dumbbell-shaped and the same procedure of the tear strength test was done.

Shore A hardness specimens were prepared according to ASTM D2240-15[12] specifications. Specimens' dimensions are (25 × 25 mm) with (7 mm) thickness. The procedure is accomplished by a digital Shore A durometer (HS-A, Ezitown, China) with a blunt indenter of 1.25 mm diameter and a digital scale (0 to 100) to perform the hardness test. Within each specimen, five points were marked in the middle and at each corner of each specimen with a 6 mm distance apart between them and the lateral borders.

The surface roughness specimen dimensions are identical to those of the Shore A hardness test. A portable digital profilometer (TR200, China) with 0.001μm accuracy was used to conduct a surface roughness test. This device has a sensitive diamond probe (surface analyzer) to trace surface irregularities that will be adjusted such that the stylus touches the surface of the specimen at three spots to collect three readings from each specimen which is resting on a stable and rigid surface, once the stylus reaches the initial point it should proceed over the specimen surface for (11 mm). Later, the roughness value was given as the mean value of the three readings.[13]

Statistical analysis

Shapiro–Wilk test was performed to evaluate data distribution. Descriptive statistics including mean,

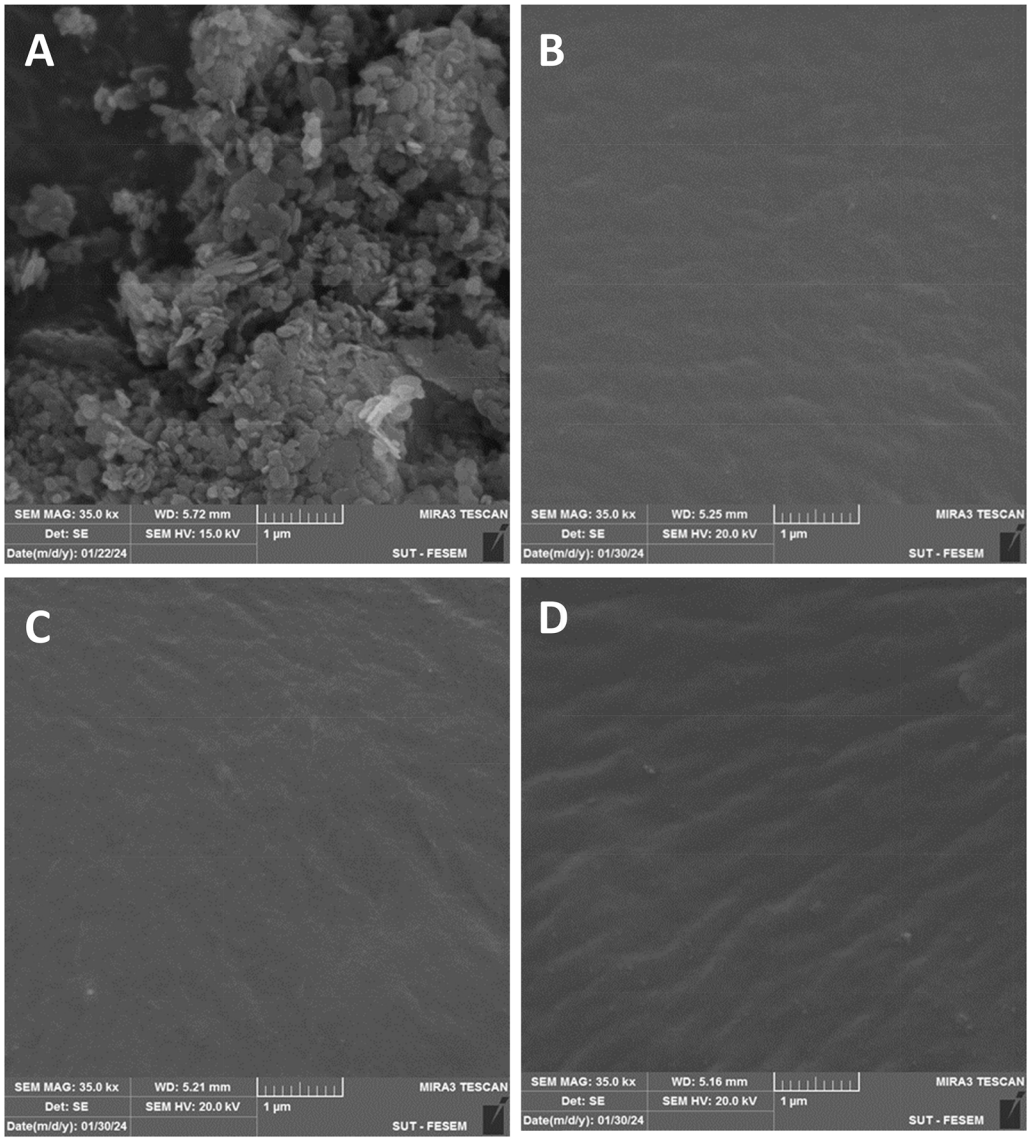


Fig. 3. Field emission scanning electron microscopy images: A. hexagonal boron nitride powder. B. Maxillofacial elastomer alone. C. Maxillofacial elastomer with 0.5 wt% hexagonal boron nitride D. Maxillofacial elastomer with 0.7 wt% hexagonal boron nitride.

standard deviation, minimum, and maximum were analyzed for each group. The obtained data were statically analyzed using one-way ANOVA and post-hoc Tukey's tests, where P-value < 0.05 was considered statistically significant.

Results and discussion

The FE-SEM images Fig. 3 showed that the H-BN particles were well-dispersed inside the VST-50F silicon matrix, with some agglomeration as filler loading rises. The FTIR test found no chemical interaction between the silicone and H-BN Fig. 4. FTIR results show that there is mostly physical contact between H-BN and the silicon matrix. Light transmission through the matrix and vibration absorption were probably slightly altered as a result of the fillers' interactions with the cross-linking mesh of the silicone. The Shapiro-Wilk test showed that data of all variables was normally distributed Table 1. Both experimental groups showed a significant increase in tear strength and a significant decrease in Shore A hardness and surface roughness ($P < 0.05$). The 0.5 wt% group showed a non-significant drop in tensile strength, however, the 0.7 wt% group showed a significant decline compared to the control group ($P < 0.05$) Fig. 5. The results of tear strength were similar to most of the previous studies that used different filler materials Table 2.

Fillers are added to silicone to achieve a specific level of enhancement in its performance. The polymer properties, filler characteristics (particle size or

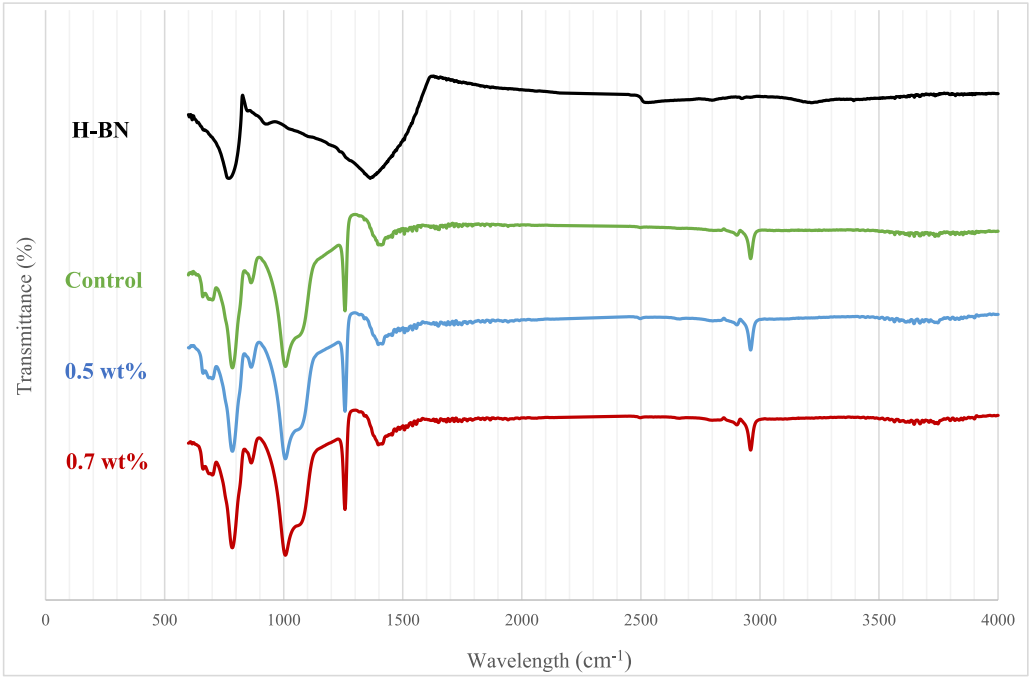


Fig. 4. Fourier transform infrared analysis.

Table 1. Shapiro-Wilk test for normality of variances.

Groups / Tests	Control		0.5 wt% H-BN		0.7 wt% H-BN	
	Statistics	*P*-value	Statistics	*P*-value	Statistics	*P*-value
Tear strength	0.902	0.232	0.920	0.360	0.951	0.676
Tensile strength	0.936	0.513	0.900	0.220	0.969	0.879
Shore A hardness	0.932	0.472	0.984	0.984	0.972	0.904
Surface roughness	0.894	0.188	0.891	0.176	0.952	0.753

specific surface area, structure, and surface activity), filler loading, and processing conditions all have an important influence on the enhancement.[14]

Alanssari and Khalaf[15] introduced a mixture of polyamide fiber microparticles and silica oxide NPs to the VST-50F silicone. The addition increased surface roughness, hardness, and tear strength but decreased tensile strength and elongation percentage.

Ibrahim and Abdul - Ameer[16] revealed that adding kappa-carrageenan powder to VST-50 maxillofacial silicone elastomer significantly decreased the bacterial cells adherent to enhance the antibacterial activity of silicon against *Staphylococcus epidermidis* in the 1 wt% and 2 wt% groups.

Chemically, there is no interaction between H-BN particles and VST50F maxillofacial silicone since the spectral range of the silicone remains unchanged after the addition of the H-BN, which could be because the silicone is saturated. The well dispersed and good interfacial performance of H-BN with the silicon matrix is consistent with the work of Rakaa and Obaid[22] who discovered silver NPs that had been well-dispersed inside the silicon substrates.

Nanoparticles (NPs) and microparticles frequently aggregate. Thermodynamics controls the agglomeration process. Ensembles consist of either highly agglomerated or poorly agglomerated particles, depending on the nature of the interaction.[23] As the

Table 2. Comparative of the tear strength results with other fillers.

The filler	The result	The filler	The result
Alumina NPs[17]	Significant increased	Silver NPs[18]	Unchanged
Alumina and silica NPs[19]	Significant increased	Silver and silica NPs[20]	Reduced
Zinc NPs[20]	Significant increased	Zirconia nanopowder[21]	Significant increased

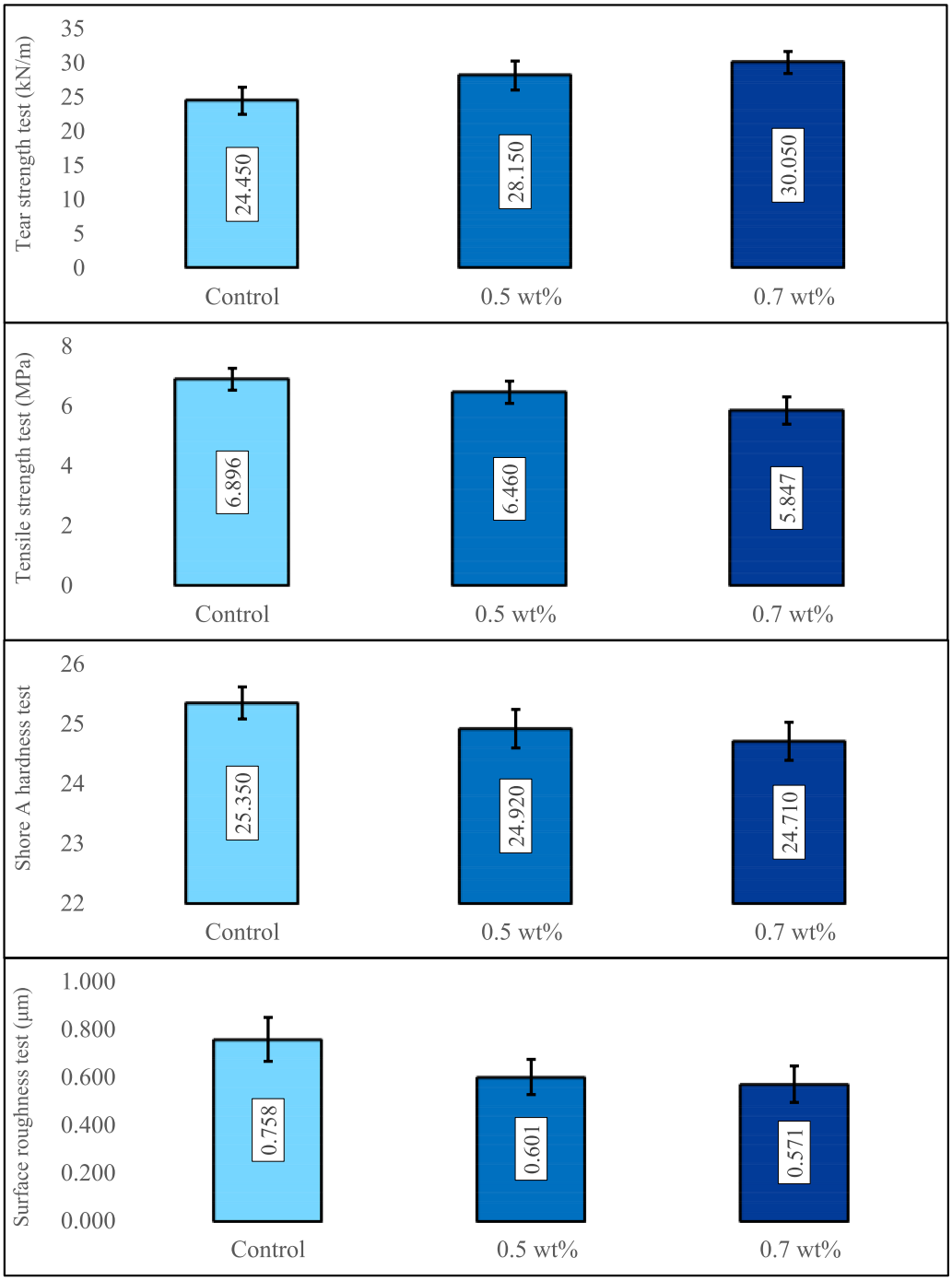


Fig. 5. Bar charts of the mean and standard deviation of tear strength, tensile strength, Shore A hardness tests, and surface roughness.

H-BN loading increased in this study, some agglomerations developed on the silicone specimens' surface. Although H-BN particles were well-dispersed inside the VST-50F silicon matrix. It is possible to speculate that when NPs concentration rises, there is a greater chance of their aggregating together, which would reduce their mechanical attributes like tensile strength and hardness.

The reason for the increase in tear strength can be attributed to the H-BN particles' fine dispersion and their physical bonding with the VST-50F silicon matrix. In terms of physicality, by creating 3D networks inside the polymer matrix, the filler particles can raise the density of the polymer. Polymer chains may become stronger as a result of this interaction between the particles and the polymer matrix.

Consequently, an increase in density and an increase in tear strength occurs.[24] Furthermore, rubber materials disperse the strain near the fracture's propagation tip. The material's resistance to tearing can then be increased by the added filler particles, which can disperse their energy as the crack spreads and absorb strain energy in the silicon matrix.[25] The results are consistent with the study of Tukmachi et al.[21] which showed a considerable improvement in tear strength when zirconia NPs were added to VST-50 maxillofacial silicone elastomer.

Because there was no chemical interaction between the filler and the matrix, the size of the voids that formed in the polymer matrix increased dramatically as filler loading increased. These voids cause the primary fracture, which reduces tensile strength.[23] The results are consistent with the work of Alanssari and Khalaf[15] who used a combination of polyamide fiber microparticles and silica oxide NPs to VST-50F silicone.

The decrease in Shore A hardness mean value indicates that the filler particles are smaller in size and tend to agglomerate, resulting in reduced mechanical properties due to the lower strength of the agglomerates themselves.[23] The low friction coefficient of H-BN is a result of there being no boron–nitrogen bonding between the layers, and large interplanar distances separate the H-BN 's neighboring layers.[26] The soft, smooth particles are the outcome of this coefficient of friction. The addition of these soft particles to the polymer might decrease the polymer's hardness. The test results agreed with Sonnahalli and Chowdhary[18] who found a reduction in hardness after the addition of silver NPs.

Surface roughness may be reduced as a result of sequential polymerization, which promotes polymer chain formation and complementarity, resulting in fine, smooth silicone surfaces. H-BN fillers can operate as nucleating agents, providing sites for polymer chain initiation and speeding up the process. The filler particles with a low friction coefficient have fewer irregularities or rough spots as a result of their smooth surface.[27] Which may reduce the surface roughness of the modified silicone. The test results agreed with Hasan and Fatalla.[28]

Conclusion

Tear strength improved as the amount of H-BN grew, whereas tensile strength, Shore A hardness, and surface roughness decreased as the filler quantity increased. The addition of 0.5 wt% of H-BN to the maxillofacial silicone was the ideal amount since the tensile strength did not decrease significantly.

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Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for republication, which is attached to the manuscript.
- Authors sign on ethical consideration's approval.
- No animal studies are present in the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at University of Baghdad.

Contribution

M. S. A. contributed to the design and implementation of the research and to the analysis of the results. F. M. A. contributed as a supervisor on the manuscript's writing.

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تقييم الخواص الميكانيكية لسيليكون الوجه والفكين معزز بجزيئات نيتريد البورون السداسية

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قسم التعويضات الاصطناعية، كلية طب الأسنان، جامعة بغداد، العراق.

المستخلص

الخلفية: يعد سيليكون الوجه والفكين المادة الأكثر شيوعًا والأكثر استخدامًا في بناء الأطراف الاصطناعية للوجه والفكين. ومع ذلك، فشلت المادة في تلبية الميزات المتوقعة من بدلة الوجه والفكين بسبب القيود الرئيسية، وخاصة في الخواص الميكانيكية. الهدف: الهدف من هذه الدراسة هو تقييم الخواص الميكانيكية لمطاط السيليكون مع إضافة نيتريد البورون السداسي. المواد والطرق: تم تحضير 120 عينة وتقسيمها إلى ثلاث مجموعات: ضابطة وتجريبية (0.5% بالوزن و0.7% بالوزن). تم تقسيم كل مجموعة إلى اربع مجموعات فرعية متطابقة. لكل مجموعة فرعية، تم استخدام 10 عينات لكل اختبار (قوة التمزق، قوة الشد، الصلابة و خشونة السطح). تمت دراسة مسحوق نيتريد البورون السداسي والعينات من كل مجموعة باستخدام المجهر الإلكتروني لمسح الانبعاث الميداني و التحليل الطيفي للأشعة تحت الحمراء. تم تحليل البيانات باستخدام تحليل التباين الأحادي واختبارات توكي اللاحقة، وأشارت القيمة $P < 0.05$ إلى دلالة إحصائية. النتائج: أظهر المجهر الإلكتروني الماسح للانبعاث الميداني وجود نيتريد البورون السداسي مشتتًا بالتساوي داخل مصفوفة السيليكون. أظهر اختبار التحليل الطيفي للأشعة تحت الحمراء عدم وجود تفاعل كيميائي بين السيليكون و نيتريد البورون السداسي. أظهرت كلا المجموعتين التجريبيتين زيادة ملحوظة في قوة التمزق وانخفاض في الصلابة و خشونة السطح. لم تظهر مجموعة 0.5% بالوزن أي انخفاض ملحوظ في قوة الشد، لكن المجموعة 0.7% بالوزن أظهرت انخفاضًا كبيرًا مقارنة بالمجموعة الضابطة. الاستنتاج: مع زيادة كمية نيتريد البورون السداسي ، تحسنت قوة التمزق، في حين انخفضت قوة الشد والصلابة و خشونة السطح.

الكلمات المفتاحية: المجهر الإلكتروني الماسح للانبعاث الميداني، التحليل الطيفي للأشعة تحت الحمراء، نيتريد البورون السداسي، سيليكون الوجه والفكين، الخواص الميكانيكية.