



Effect of Addition of Natural Wool Fibers on Some Surface Characteristics of Polymethyl Methacrylate Denture Base Material

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Article Info	ABSTRACT
Article type: Original Article	Objectives: Heat-cure acrylic resin is commonly used for the fabrication of denture base; however, it does not meet all the ideal requirements of a denture base material. This study was performed to assess the surface hardness and roughness of natural wool fiber-reinforced heat-cure acrylic resin as a denture base material.
Article History: Received: 15 Jul 2025 Accepted: 20 Jan 2026 Published: 18 Jul 2026	Materials and Methods: Sixty acrylic specimens were fabricated in this in vitro study; they were divided into three main groups. The first group (control) included acrylic specimens without fiber reinforcement, the second group (NW) included acrylic specimens reinforced with 0.25wt% natural wool fibers and the third group (SW) included acrylic specimens reinforced with 0.25wt% silane-treated natural wool fibers. Each group was further subdivided into two subgroups based on the tests performed, surface hardness test group and surface roughness test group. Surface hardness was measured by a Shore D hardness tester. A profilometer was used for measurement of surface roughness. The results were statistically analyzed using one-way ANOVA and Tukey's post-hoc test and $P \leq 0.05$ was considered statistically significant.
*Corresponding author: Department of Prosthodontics, College of Dentistry, University of Baghdad, Baghdad, Iraq Email: zahraa.abdulwahab1201a@codental.uobaghdad.edu.iq	Results: The SW group had the highest mean surface hardness value, followed by the NW group, whilst the control group had the lowermost mean value. However, the statistical significant difference was only evident between the SW group and the control group ($P=0.018$). Meanwhile, no statistically significant difference was found in surface roughness among the tested groups ($P>0.05$). Conclusion: The surface hardness of heat-cure acrylic resin can be improved by reinforcement with silane-treated natural wool fibers without significantly affecting its surface roughness. Keywords: Acrylic Resins; Hardness; Surface Properties; Wool

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INTRODUCTION

Despite the improvements in oral hygiene, many elderly people require full or partial dentures to replace their missing teeth [1]. Nowadays, acrylic resin is the typical material used for the fabrication of denture bases [2]. Optimal mechanical and physical characteristics are essential for denture base acrylic resin. Although acrylic resin denture bases are easy to process using inexpensive techniques and are esthetically pleasing, they

are not ideal [1]. The material of denture bases must possess adequate abrasion resistance in order to prevent excessive wear by food stuffs or abrasive denture cleaners [2]. Surface hardness indicates resistance of material to scratching and indentation [1]. Microhardness measurement of acrylic polymers reveals that they are relatively soft in comparison to alloys [2]. This exposes the acrylic denture base to abrasion, especially during brushing and application of abrasive cleansers, which can

adversely affect the function and esthetics of these prostheses [3]. Moreover, rough surfaces with indentations, projections and irregularities can contribute to denture stomatitis [4,5]. Furthermore, rough denture bases are more susceptible to discoloration than smooth surfaces and tend to prompt halitosis, thus decreasing patient comfort [6]. Denture base resins with adequate surface properties contribute to the longevity of denture and maintain the esthetic requirements.

Efforts have been made to enhance the properties of denture base acrylic resins [7,8]. An alternative approach to improve acrylic denture bases is the incorporation of fibers to produce a fiber-reinforced composite [9,10,11]. Natural fibers have gained popularity since concerns about environmental risks have grown [12]. Natural fibers embedded in thermoset matrices cause their reinforcement and create thermoset composites with improved properties. These fibers are distinguished by biocompatibility, low density, low cost, and sufficient mechanical properties [12,13]. Although natural fibers offer numerous advantages in the production of polymeric composites, the commonly inferior mechanical qualities of the resulting materials due to poor adhesion of the added fibers limit their usage as textile fibers. Thus, surface modification of natural fibers is strongly recommended to enhance the adhesion of fibers to the matrix to obtain the maximum benefit of added fibers [14]. However, the available literature mainly focuses on the use of natural cellulose-based fibers, and studies on natural keratin-based fibers for reinforcement are scarce [12].

Wool fibres are remarkable natural materials, they are distinguished by their multifunctional chemical groups and unique structure which extends from the outer cuticle layer to the inner helical arrangement of the cortex. Natural wool fiber has a characteristic cylindrical shape with a taper from the root to the tip. In a cross-sectional view proceeding from the periphery to the center, the wool fiber has a cuticle consisted mainly of proteins, lipids, and carbohydrates, and a cortex composed of approximately 90% keratinous fiber. It has

been reported that the characteristics of natural wool fibers are strongly related to keratin. In industry, wool has been reported to enhance the features of polymeric matrix when used as reinforcement [12].

To date, the effect of reinforcement of denture bases made of heat-cure acrylic resin material with natural wool fibers has not been studied. In this study, natural wool fibers were added with and without chemical surface treatment to evaluate their effect on some surface characteristics of heat-cure acrylic resin denture base material. The null hypothesis stated that natural wool fiber would not impact the surface properties of heat-cure acrylic resin.

MATERIALS AND METHODS

The protocol of this in vitro study was authorized on January 3, 2022 by the ethical committee of the Dentistry College at the University of Baghdad (Approval No. 13). Sixty acrylic specimens were fabricated and divided into three main groups. The control group included acrylic specimens without fiber reinforcement. The second group was the natural wool group (NW) and included acrylic specimens after reinforcement with 0.25%wt natural wool fibers. The third group (SW) was the natural wool group containing acrylic specimens reinforced with 0.25%wt silane-treated natural wool fibers. Each main group was further subdivided into two subgroups based on the test performed: the surface hardness test group and the surface roughness test group.

Natural wool fibers were obtained from the Iraqi local market. First, they were cut into pieces 2mm in length (Fig. 1A) [15]. Next, they were cleaned in an ultrasonic bath (Sofine, China) in order to eliminate the residual dirt from the fibers [14,16]. The ultrasonic bath container was filled with distilled water at 50°C and detergent (Persil, KSA). The concentration of the detergent in the bath was 0.5g/L. Then, the fibers were immersed in this bath and cleaned for 3 minutes. The fibers were then removed and the bath was cleaned and refilled with distilled water at 50°C. Next, the fibers were re-immersed in the bath and cleaned for



Fig 1. Natural wool fibers: (A) After cutting and before ultrasonic cleaning, (B) after ultrasonic cleaning and drying for 24 hours on filter paper, and (C) after silane treatment and drying for 14 days.

another 6 minutes [17]. Finally, they were distributed over a filter paper and left to dry for 24 hours at room temperature (Fig. 1B) [18].

Treatment with silane coupling agent (3-methacryloyloxy propyl trimethoxy silane; Sigma-Aldrich, China) was done for half of the cleansed fibers. Silane (10wt%) was dissolved in methanol/water/acetic acid in a ratio of 75v%:8v%:17% [19]. The fibers were added to the silane-containing mixture, stirred with a magnetic stirrer (IKA, Germany) for 30 minutes and then left for 14 days to dry at room temperature (Fig. 1C) [20].

Wool fibers without and with silane treatment were added to 0.25wt% acrylic powder in a glass container and stirred with a mechanical stirrer for 5 minutes at a speed of 400rpm [9,21]. Specimens for assessment of surface hardness were fabricated using the same conventional method of complete denture fabrication and measured 35mm in width and length, and 6mm in thickness [22]. Plastic molds with the specified dimensions were designed using hard putty silicone (Protechno, Spain) [23], and invested in type IV dental stone (Lascod, Italy) in a metal dental flask. The acrylic powder (Spofa-Dental, Kerr, Czech) was then mixed with the monomer according to the manufacturer's instructions. After reaching the dough stage, the mixture was packed in the silicone mold and pressed in a hydraulic press. Then the flask was placed in the clamp and fastened properly. The flask with clamp was placed in a water bath for curing in the short curing cycle according to the manufacturer's instructions as follows: First, it was immersed in water at room temperature; then the temperature was elevated to 70oC within 30 minutes, and subsequently the temperature

was fixed at 70oC for another 30 minutes. Next, the temperature was raised to 100oC within 30 minutes and maintained for another 30 minutes. Finally, the flask with the clamp was removed from the water bath and cooled on a bench to room temperature [24]. After cooling, the specimens were retrieved from the flask and finished according to ISO specification 20795-1, 2013 [25] by wet grinding using P500, P1000, and P1200 silicone carbide abrasive papers until smooth and flat surfaces were obtained. The specimen dimensions were continuously checked using a digital vernier caliper (China) with 0.01mm accuracy (Fig. 2). Then the finished specimens were conditioned prior to testing in accordance with ISO specification 20795-1, 2013 [25] in distilled water for 50+2 hours at a temperature of 37+1oC.

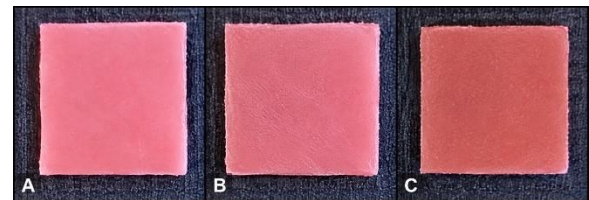


Fig 2. Finished surface hardness test specimens: (A) Control group, (B) natural wool group, and (C) silane-treated natural wool group.

Specimens for evaluation of surface roughness were fabricated according to ISO specification 20795-1:2013 [25]. They were disc-shaped and measured 0.5+0.1mm in thickness and 50+1mm in diameter. A stainless-steel mold and cover were invested in a type IV dental stone in a metal dental flask. After mixing the acrylic powder with the monomer, it was packed in the steel mold with a polyester sheet against the steel cover [25]. The flask was then pressed in a hydraulic press, positioned in the clamp, and properly fastened. Finally, it was cured in a water bath and cooled afterwards using the same method described previously for preparation of surface hardness specimens. The specimens were retrieved (Fig. 3) and conditioned prior to testing according to ISO specification 20795-1, 2013 [25] in distilled water for 50+2 hours at a temperature of 37+1°C.

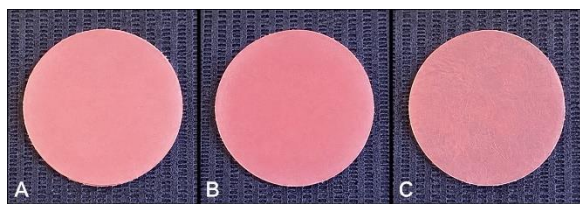


Fig 3. Surface roughness test specimens: (A) Control group, (B) natural wool group (C) silane-treated natural wool group.

The Fourier-transform infrared (FTIR) spectroscopy was utilized for chemical analysis of the wool fibers before adding them to the acrylic resin in order to evaluate the validation of silane treatment. It was done for the silane coupling agent and for the natural wool fibers before and after silane treatment. The FTIR spectrum was reported in a range of $4000\text{--}600\text{cm}^{-1}$ in the transmittance mode, and then the results of the three specimens were compared.

Field-emission scanning electron microscopy (FE-SEM) was done to evaluate the morphological characteristics of the external surface of the acrylic specimens for all study groups, such that we could observe the effect of wool fibers on the surface morphology of acrylic specimens.

The surface hardness test was performed according to ISO specification 868:2003 [22] using Shore D hardness tester (Elcometer, UK). The test specimen was placed on the surface of a hard horizontal plane. The durometer was held vertically, and the presser foot was then pressed on the test specimen by the durometer stand and a weight of 5kg was centered on the axis of the indenter as rapidly as possible, without shock. The foot was kept parallel to the surface of the test specimen; the highest durometer reading was recorded. The point of indenter was placed away from the edges of the test specimen by 9mm; five hardness measurements were made at different positions on each specimen 6mm apart and the mean reading of the measurements was calculated and reported.

The surface roughness test was performed by a contact profilometer (Beijing time Co, China) with an accuracy of $0.001\mu\text{m}$. The specimen was placed on a flat surface. Measurement was

performed with 5.5mm tracing length, 1mm/s stylus speed, and an end point cutting value of 0.8mm. Three measurements were made for each specimen, one at the center and two midway between the center measurement and the edge of the specimen on either side. The mean value of the three measurements of the surface roughness was calculated in micrometers (μm) [23,26].

The results were analyzed statistically using SPSS version 24 (SPSS Inc., IL, USA). Shapiro-Wilk test was used for testing the normality of variables distribution. Mean, standard error, and standard deviation values were reported for each test. Levene's test was utilized to test the homogeneity of variance of the variable among groups. One-way ANOVA was used for the comparison of the mean values of the study groups. Furthermore, pairwise comparisons between the study groups were done by the Tukey's HSD post-hoc test. Statistical significant was at $P \leq 0.05$.

RESULTS

The FTIR test results are shown in Figure 4. The FTIR spectrum of the silane coupling agent (Fig. 4A) showed a characteristic band for the stretching vibration of C=O group of methacryloyloxy group at 1716cm^{-1} . The spectrum also exhibited two peaks at approximately 1635cm^{-1} and 1454cm^{-1} that are assigned to the stretching vibrations of C=C band and the deformation mode of the CH₂ groups of the silane, respectively. The spectrum also showed two medium-intensity bands at 2943cm^{-1} and 2839cm^{-1} of symmetrical stretching vibrations of -C-H groups. However, when comparing the FTIR spectra of the wool fibers before and after treatment with silane (Fig. 4B), the main difference was observed in the intensity of the bands, which were positioned at 1712cm^{-1} and 1631cm^{-1} . Furthermore, there was a slight modification in the section between 900cm^{-1} and 1400cm^{-1} of the stretching bands of -Si-O-R- and -Si-O-Si- groups. Additionally, formation of new bands was detected in the region of 2920cm^{-1} and 2850cm^{-1} of the silane-treated wool fibers.

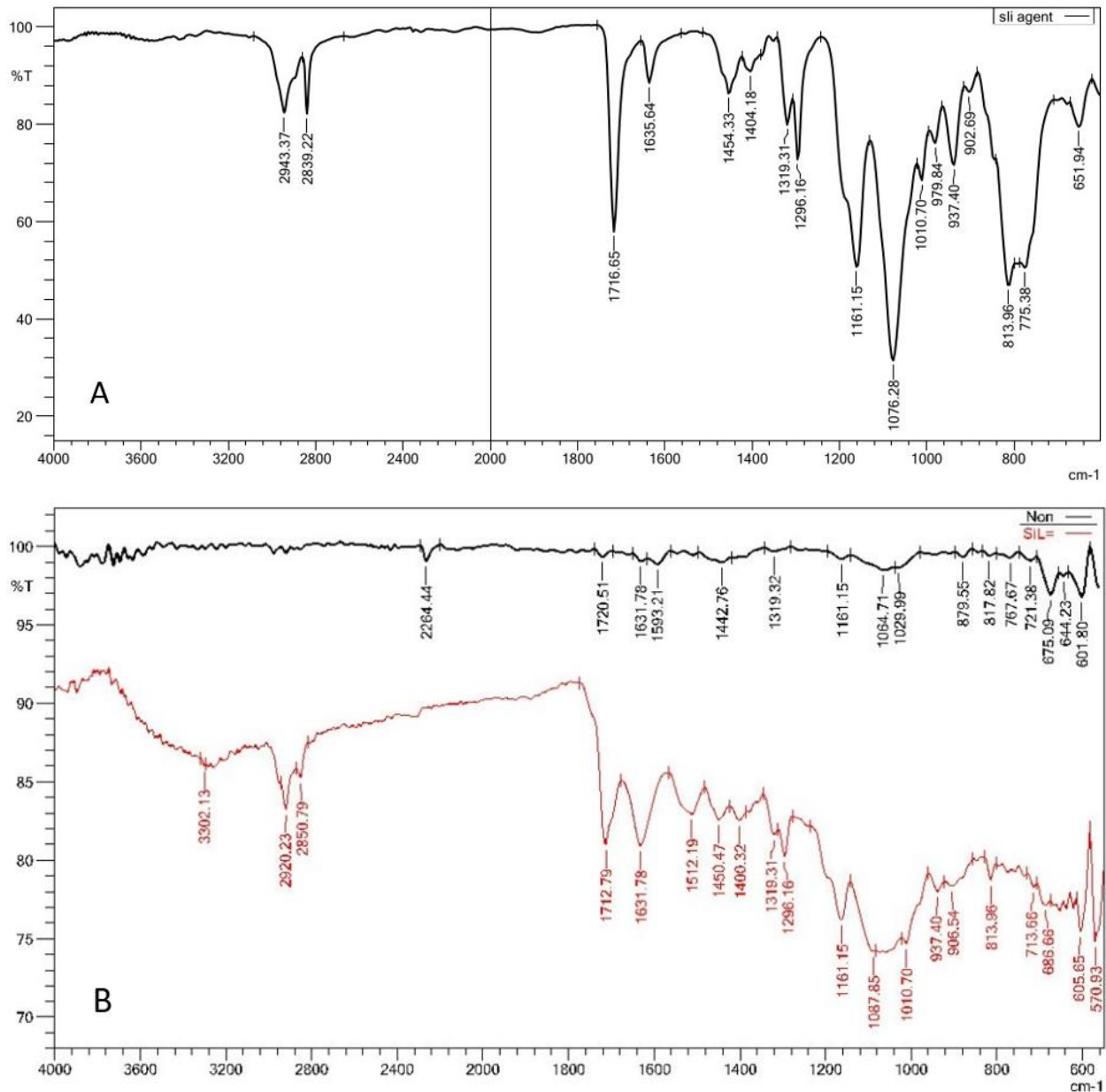


Fig 4. FTIR (Fourier-transform infrared) spectrum of (A) silane coupling agent (B) natural wool fibers; black spectrum before the silane treatment and red spectrum after the silane treatment.

FE-SEM analysis of the external surface of the specimens revealed no apparent differences among the groups tested (Fig. 5). All specimens showed the appearance of a mildly rough surface that contained narrow grooves. In addition, there was no evidence of wool fibers on the surface of the reinforced acrylic specimens.

The result of the Shapiro-Wilk test showed a normal distribution among the studied groups for

both surface hardness and surface roughness tests. The results of descriptive statistics of the surface hardness test indicated that the SW group had the highest mean surface hardness, followed by the NW group, whilst the control group had the lowermost mean surface hardness (Table 1). The results of Leven's test showed that there were no differences of variance in the studied group ($P=0.408$). The One-way ANOVA test indicated a

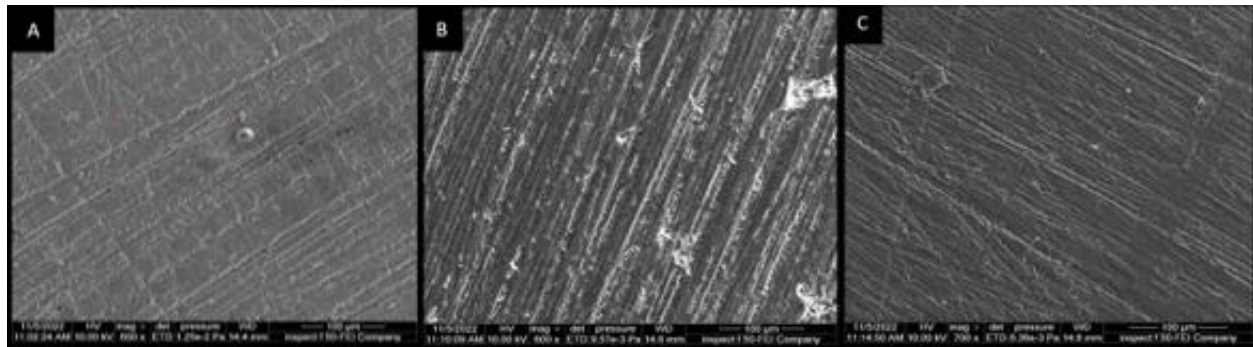


Fig 5. FE-SEM micrographs of the external surface of a (A) control specimen (B) NW specimen, and (C) SW specimen; NW: natural wool group; SW: silane-treated natural wool group.

Table 1. Descriptive statistics of surface hardness (Shore D) in the study groups (n=10)

Group	Mean	Standard deviation	Standard error
Control	80.340	1.710	0.541
NW	81.420	1.967	0.622
SW	83.010	2.165	0.685

NW: natural wool group; SW: silane-treated natural wool group.

statistically significant difference among the groups in surface hardness ($P=0.018$). Furthermore, a significant difference was found between the SW group and the control group as shown by the Tukey's HSD test ($P=0.014$). However, there were no significant differences between the NW and the control groups ($P=0.444$), or between the SW and NW groups ($P=0.183$). For the surface roughness test, descriptive statistics showed that the NW group had the highest mean surface roughness followed by the SW group, while the control group showed the lowest surface roughness (Table 2). The results of the Leven's test showed that there were no differences of variance in the studied groups ($P=0.627$). Moreover, one-way ANOVA found no statistically significant difference among the groups in this regard ($P=0.836$).

Table 2. Descriptive statistics of surface roughness (μm) in the study groups (n=10)

Group	Mean	Standard deviation	Standard error
Control	0.060	0.009	0.003
NW	0.063	0.009	0.003
SW	0.061	0.011	0.003

NW: natural wool group; SW: silane-treated natural wool group.

DISCUSSION

Heat-cure acrylic resin has been successfully used for the fabrication of complete and partial denture bases for many years. However, it does not meet the ideal requirements of a dental prosthesis [1]. Daily toothbrushing and foodstuffs can cause abrasion or wear of the denture base. Surface hardness is of primary importance to prevent abrasive wear of substrates [2]. In addition, increased surface roughness of a denture base has a negative impact on esthetic appearance and hygiene of dentures, as it facilitates bacterial plaque adhesion and staining of denture [6]. Thus, denture base material should be able to resist plastic deformation and have a smooth surface. Natural wool fibers are high-performance fibers with many desirable properties that synthetic fiber manufacturers are still unable to emulate. They are ecological, durable, and elastic [27]. However, there are also disadvantages associated with the usage of natural fibers especially when utilized as a reinforcement material; the interfacial adhesion between the fibers and the reinforced matrix may be problematic [12]. Thus, in order to improve the mechanical interactions of natural fibers with the matrix, surface treatment of the fibers has been suggested in some studies before using them as reinforcement [19,28]. Silane treatment is the most common chemical surface treatment especially for natural fibers. It enhances the interfacial adhesion of natural fibers with the matrix, where the bond between the fiber and the polymer matrix can be bridged by coupling agents. The hydroxyl

groups on the surface of raw natural fibers are inactive; therefore, silane treatment would lower the quantity of hydroxyl groups in natural fibers by reacting with the coupling agent. This in turn, reduces their water sorption and enhances their properties [12,13]. This study evaluated the impact of adding 0.25wt% natural wool fibers and silane-treated wool fibers on the surface hardness and surface roughness of heat-cure acrylic resin.

Characterization of natural wool fibers before and after silane treatment by FTIR indicated the success of silane treatment of wool fibers. The spectrum showed an increase in the intensity of bands located at 1712cm^{-1} and 1631cm^{-1} due to the overlap of the functional group of the fibers and the silane agent. In addition, modification of the stretching bands of $-\text{Si-O-R}-$ and $-\text{Si-O-Si}-$ groups indicates the release of active groups on the surface of silane-treated wool fibers [19]. Moreover, formation of new bands at 2920cm^{-1} and 2850cm^{-1} could be assigned to the presence of silane on the surface of wool fibers, which further indicates the success of the reaction between the wool fibers and the silane agent [29].

The observed FE-SEM test results could be due to the low percentage of the added fibers, which resulted in no evidence of the fibers in the area scanned. In addition, the scan was done only on the external surface, no scan was done on the bulk of specimen.

The surface hardness test results in the current study may be due to the fact that the hardness of a material is its resistance to permanent deformation or resistance to indentation [30], and wool fibers have a characteristic elastic recovery due to the presence of alpha helical cells before being permanently deformed [12]. Another reason is the enhanced adhesion between fibers and the matrix due to silane treatment, which may be the cause of significant improvement in surface hardness in the SW group in comparison to the control group [12,31]. On the other hand, poor adhesion between the reinforcement fibers and the matrix may be the cause of insufficient load transfer to the matrix causing insignificant difference in

hardness value between the NW group and the control group. The surface hardness findings in the present study were in agreement with the outcomes of earlier studies by Sharhan et al. [32] who added polyacrylonitrile fibers and Fatihallah et al. [11] who added polyester and polypropylene fibers to heat-cure acrylic resin. Both studies reported a significant improvement in surface hardness of acrylic resin after fiber reinforcement. However, these results conflict with the findings of Gad et al. [33] who added glass fibers to heat-cure acrylic resin; this may be due to the difference in fiber properties or the use of a higher percentage of fibers by weight in their study.

The results of the surface roughness test in the present study may be because of the uniform distribution of fibers within the acrylic resin and the low percentage of fibers used. In addition, surface roughness measures only the fibers on the surface; it does not measure the effect of presence of fibers inside the bulk of the material [32,34]. The present results regarding surface roughness agrees with those of Jassim [10] who added polyamide fibers treated with oxygen plasma gas, and noticed that surface roughness increased with increasing fiber concentration, but it was statistically insignificant. However, these outcomes were in contrast to those of Sharhan et al. [32] who added polypropylene fibers and Gad et al. [33] who added glass fibers to heat-cure acrylic resin. Both studies reported a significant rise in surface roughness, which was explained by the possibility of protruding the fibers from the surface and the fact that the test does not measure the bulk of the material, and only assesses the outer surface.

In the current study, the null hypothesis was partially rejected, since the addition of natural wool fibers only resulted in a significant enhancement in surface hardness of the acrylic resin after being treated with silane coupling agent, yet it did not affect the surface roughness. According to the results of this study, an acrylic denture base can be reinforced with natural wool fibers in order to obtain a denture base with enhanced surface hardness. However, one limitation of this in vitro study was that the specimens used did

not physically replicate the shape of an actual denture base. Also, only one length of the added fibers was used. Therefore, further studies are recommended to assess the use of heat-cure acrylic resin reinforced with natural wool fibers of different lengths with physical fabrication under more closely simulated conditions.

CONCLUSION

Natural wool fibers in 0.25wt% concentration can significantly enhance the surface hardness of heat-cure acrylic resin after treatment with silane coupling agent. At the same time, they did not significantly affect the surface roughness. Natural wool fibers of the same concentration without surface treatment did not produce significant effects on surface hardness or roughness of heat-cure acrylic resin.

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CONFLICT OF INTEREST STATEMENT

None declared.

GENERATIVE AI IN SCIENTIFIC WRITING

None declared.

REFERENCES

1. Van Noort R, Barbour M. introduction to dental materials-E-book 4th edition. Elsevier Health Sciences; 2014. Ch. 1.6, P. 35, Ch. 3.2, P. 175-177.
2. McCabe JF, Walls AW, editors. Applied dental materials 9th edition. John Wiley & Sons; 2013 May 7. Ch. 13, P. 110-123.
3. Anusavice KJ, Shen C, Rawls HR, editors. Phillips' science of dental materials 12th edition. Elsevier Health Sciences; 2012 Sep 27. Chapter 11, P. 247.
4. Cerci BB, Roman LS, Guariza-Filho O, Camargo ES, Tanaka OM. Dental enamel roughness with different acid etching times: Atomic force microscopy study. *Eur J Gen Dent*. 2012 Sep;1(03):187-191.
5. Vongvachvasin K, Thaweboon S, Churnjitapirom P, Kaophun S, Chotprasert N. The physical properties of PMMA denture base resin incorporated with vanillin. In *Key Engineering Materials* 2018 Sep;773:338-43.
6. Al-Dwairi ZN, Tahboub KY, Baba NZ, Goodacre CJ, Özcan M. A comparison of the surface properties of CAD/CAM and conventional polymethylmethacrylate (PMMA). *J Prosthodont*. 2019 Apr;28(4):452-7.
7. Alraziqi ZN. Water temperature effect on hardness and flexural strength of (PMMA/TiO₂ NPs) for dental applications. *Baghdad Sci J*. 2022 Aug;19(4):922.
8. Khalaf BS, Abass SM, Jassim TK. Dimensional stability of heat-activated acrylic resin at different time intervals by different flask cooling methods. *Mustansiria Dent J*. 2008;5(3):274-80.
9. Gad MM, Al-Thobity AM, Rahoma A, Abualsaud R, Al-Harbi FA, Akhtar S. Reinforcement of PMMA denture base material with a mixture of ZrO₂ nanoparticles and glass fibers. *Int J Dent*. 2019 Jan;2019:2489393.
10. Jassim RK. Studying the properties of heat cure acrylic resin after reinforced with polyamide fibers treated with plasma (oxygen gas). *Iraqi Dent J*. 2015 Dec;37(3):83-9.
11. Fatihallah AA, Mohammed MR, Taha YT, Salih ZS. The effect of incorporation of two different fibers on some mechanical properties of heat cure acrylic resin. *Mustansiria Dent J*. 2014;11(1):48-56.
12. Thomas S, Jose S, editors. Wool fiber reinforced polymer composites. Woodhead Publishing. 2022. P. 1-71, 179-196, 227-254.
13. Ouarhim W, Zari N, Bouhfid R. Mechanical performance of natural fibers-based thermosetting composites. In *Mechanical and physical testing of biocomposites, fibre-reinforced composites and hybrid composites*. Woodhead Publishing 2019. p. 43-60.
14. Pawlak F, Aldas M, Parres F, López-Martínez J, Arrieta MP. Silane-functionalized sheep wool fibers from dairy industry waste for the development of plasticized PLA composites with maleinized linseed oil for injection-molded parts. *Polymers*. 2020 Oct;12(11):2523.
15. Harahap SA, Yudhit A, Wardani FK. Potency of banana (*Musa acuminata* Linn.) stem fiber as a reinforcement material for heat cured acrylic resin. *Mater Sci Forum*. 2022 Sep;1069:129-34.
16. Aldas Carrasco MF, Rouault NJ, Ferri Azor JM, López-Martínez J, Samper Madrigal MD. A new bio-based fibre-reinforced polymer obtained from sheep wool short fibres and PLA. *Green Mater*. 2020 Jun;8(2):79-91.
17. Pan Y, Hurren CJ, Li Q. Effect of sonochemical scouring on the surface morphologies, mechanical properties, and dyeing abilities of wool fibres. *Ultrason Sonochem*. 2018 Mar;41:227-33.
18. Braniša J, Jomová K, Porubská M. Scouring

test of sheep wool intended for sorption. *Fibres Text East Eur.* 2019;27(2(134)):24-9

19. Conzatti L, Giunco F, Stagnaro P, Patrucco A, Tonin C, Marano C, et al. Wool fibres functionalised with a silane-based coupling agent for reinforced polypropylene composites. *Compos Part A Appl Sci Manuf.* 2014 Jun;61:51-9.

20. Zaidan NM, Jassim RK. The Impact of Adding Silanized Microcrystalline Cellulose on Some Properties of Heat-Cured Acrylic Denture Base Material. *J Res Med Dent Sci.* 2022 Aug;10(8):11-8.

21. Xu J, Li Y, Yu T, Cong L. Reinforcement of denture base resin with short vegetable fiber. *Dent Mater.* 2013 Dec;29(12):1273-9.

22. International Organization for Standardization. ISO 868:2003 – Plastics and ebonite – Determination of indentation hardness by means of a durometer (Shore hardness). Switzerland: ISO; 2003.

23. Melo CB, Feitosa MD, Maia SD, Barreto JO, Peixoto RF, Regis RR. Effect of a continuous mechanical polishing protocol on the color stainability, microhardness, mass, and surface roughness of denture base acrylic resin. *J Prosthet Dent.* 2021 Dec;126(6):796-802.

24. Chhabra M, Nanditha Kumar M, RaghavendraSwamy KN, Thippeswamy HM. Flexural strength and impact strength of heat-cured acrylic and 3D printed denture base resins- A comparative in vitro study. *J Oral Biol Craniofac Res.* 2022 Jan-Feb;12(1):1-3.

25. International Organization for Standardization. ISO 20795-1:2013 – Dentistry – Base polymers – Part 1: Denture base polymer. Switzerland: ISO; 2013.

26. Atalay S, Çakmak G, Fonseca M, Schimmel M, Yilmaz B. Effect of thermocycling on the surface properties of CAD-CAM denture base materials after

different surface treatments. *J Mech Behav Biomed Mater.* 2021 Sep;121:104646.

27. Millington KR, Rippon JA. Wool as a high-performance fiber. In: Bhat G, editor. *Structure and properties of high-performance fibers.* Woodhead Publishing; 2017. p. 367-408.

28. Okeke KN, Vahed A, Singh S. Improving the strength properties of denture base acrylic resins using hibiscus sabdariffa natural fiber. *J Int Dent Med Res.* 2018;11(1):248-54.

29. Tham DQ, Chung I, Kim T, Kang J, Tan MM, Kim Dung NT, et al. Preparation, stabilization and characterization of 3-(methacryloyloxy) propyl trimethoxy silane modified colloidal nanosilica particles. *Colloids Surf A Physicochem Eng Asp.* 2020;585:124066

30. Herrmann K, editor. *Hardness testing: principles and applications.* ASM international; 2011 (P. 69).

31. Alhotan A, Yates J, Zidan S, Haider J, Silikas N. Flexural strength and hardness of filler-reinforced PMMA targeted for denture base application. *Materials.* 2021 May;14(10):2659.

32. Sharhan HA, Alraziqi ZN, Oleiwi JK. Effect of polypropylene (PP) and polyacrylonitrile (PAN) fibers reinforced acrylic resin on compression, hardness and surface-roughness for denture applications. *Key Eng Mater.* 2022 Mar;911:9-16.

33. Gad MM, Rahoma A, Al-Thobity AM. Effect of polymerization technique and glass fiber addition on the surface roughness and hardness of PMMA denture base material. *Dent Mater J.* 2018 Sep;37(5):746-53.

34. Abdulrazzaq HT, Ali MM. The effect of glass flakes reinforcement on the surface hardness and surface roughness of heat-cured poly (methyl methacrylate) denture base material. *J Baghdad Coll Dent.* 2015;27(2):6-10.