Original Article

The Effect of Different levels of a Network Reinforced System and Curing Methods on Properties of Different Acrylic Resin Denture Base Materials

Mohammed A. Abdulla

Department of Prosthodontics, College of Dentistry, University of Mosul, Mosul, Iraq

ABSTRACT

Aims and objective: This study aimed to compare the effect of the addition of light-cured fibre SES mesh at different levels (near the polished surface, at the middle, and near the tissue surface) within different acrylic resin denture base materials on the transverse strength and the surface hardness. **Materials and Methods:** One hundred and twenty samples were prepared from three types of acrylic resin denture base materials (high impact heat cured, cross-linked heat cured, and microwaved cured acrylic resins) to test the transverse strength and surface hardness. The samples were divided into four groups: Group1(samples without fibre reinforcement, Control group, n = 30); Group 2 (samples reinforced using SES mesh network near the tissue surface of the acrylic resin sample, n = 30); Group 3 (samples reinforced using SES mesh network near to the polished surface of the acrylic resin sample, n = 30); Group 4 (samples reinforced using SES mesh reinforced network at the middle of the acrylic resin sample, n = 30). The data were statistically analyzed using one-way ANOVA and Tukey's post hoc test at a 0.05 level of significance (SPSS software, version 19.0). **Results:** One-way ANOVA showed a significant difference in the mean values of transverse strength between all levels of fibre mesh applications and without fibre mesh reinforcement ($P <$ 0.05). Tukey's post hoc test showed that mesh-reinforced fibre in Group 4 had the highest mean value, while the control group showed the lowest mean value. One-way ANOVA showed a significant difference in the mean surface hardness values between cross-linked heat-cured and microwave-cured acrylic resins ($P<$ 0.05). There was no significant difference in the mean surface hardness values between all levels of fibre mesh applications and without fibre mesh reinforcement for high-impact heat-cured acrylic resin ($P >$ 0.05). **Conclusions:** SES-reinforced glass fibre mesh at different levels significantly increased the transverse strength for different acrylic resin materials but had less effect on the surface hardness for all types of acrylic resin materials.

KEYWORDS: *Acrylic resin, fibre mesh reinforced, surface hardness, transverse strength*

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INTRODUCTION

Acrylic resins have many properties that make them a successful denture base material. These include excellent appearance, ease of processing and repair.[1,2] However, one of the drawbacks of using this material is its liability to crack or fracture during use.[1]

The factors predisposing to base fracture are low resistance to impact, low flexural properties, and

Address for correspondence: Dr. Mohammed A. Abdulla, Department of Prosthodontics, College of Dentistry, University of Mosul, Mosul, Iraq.
E-mail: mohammedaa2006@uomosul.edu.iq

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fatigue of the denture base polymer. Fatigue failure does not require heavy masticatory or bite forces. With time, relatively small stress may be generated through the masticatory system, which can finally lead to a small crack formation that would spread out through the denture, resulting in fracture.[3,4] Flexural fatigue of the material occurs intraorally after the flexing of a material, while impact fractures occur when force is applied extra orally. Many efforts have been made to enhance several weak properties related to acrylic resin denture base materials, like polymerization shrinkage after curing, lack of strength, and fatigue resistance.[5-9]

One of the approaches to address the lack of strength of acrylic resin denture base materials is the addition of a cross-linking agent of polyfunctional monomers such as polyethylene glycol dimethacrylate. Another approach is by reinforcing or modifying by incorporating silicon dioxide and nanoparticles,[10,11] blending polymers[12] or different fibres or rods like mesh reinforced systems, glass fibres, metal wires[13-15] and metal nets, which have also been shown to add to denture base strength. However, a few problems can arise, including the appearance of pores at the interface between the metal and resin matrix, corrosion in the metal and unaesthetic appearance.[16] Glass fibre has been used as a common reinforcement material in different applications because the fibre easily bends without breaking, has excellent strengthening properties, is chemically bounded to the resin materials, and is easy to manipulate in the dental laboratory.[17,18] Also, a removable prosthesis reinforced with glass fibre mesh was considered lighter in weight, aesthetically acceptable, less cytotoxic, and more beneficial for dental technicians, dentists, and patients than one using a metal framework.[18]

The null hypothesis to be tested in this research was that neither the level of the mesh network reinforced system nor the curing methods of different acrylic resin denture base materials would affect the transverse strength and surface hardness.

This study aimed to compare the addition of light-cured fibre SES mesh at different levels (near the polished surface, at the middle, and near the tissue surface) within different acrylic resin denture base materials on the transverse strength and the surface hardness tests.

Materials and Methods

Materials used in the study are listed in [Table 1]. In this study, a total of one hundred and twenty samples were prepared from three types of acrylic resin denture base materials (high impact heat cured, cross-linked heat cured, and microwaved cured acrylic resin) for testing the transverse strength and surface hardness. Then samples were divided into four groups:

Table 1: Types of acrylic resin denture base materials and SES mesh

Products	Manufacturer	Specification No.
Implacryl, High impact heat curing acrylic resin	High Impact Acryl, Vertex dental, Netherlands	ISO 1567 Type 1 Class 1
VERACRIL®, Cross-linked (no cadmium) heat curing acrylic resin	Cross-linked, New Stetic S.A, Colombia	ISO 20795-1 Class 1
Acronacrylic resin,	microwavable GC-Japan	--------
SES mesh network mesh reinforced system	Keramos, Co./ INNO DENTAL Co., Korea	No.11-274

1. **Group 1**:30 samples fabricated without reinforcement (Control group).
2. **Group 2**:30 samples fabricated and reinforced using an SES mesh network (near the tissue surface of the acrylic resin sample).
3. **Group 3**:30 samples fabricated and reinforced using an SES mesh network (near the polished surface of the acrylic resin sample).
4. **Group 4**: 30 samples fabricated and reinforced using an SES mesh reinforced network (at the middle of the acrylic resin sample).

Transverse strength test

A-Specimen preparation

Sixty rectangular samples with a dimension of 65 × 10 × 2.5 (± 0.03) mm in (length, width, and thickness) respectively, were shaped according to American Dental Association Specification No.12.[19] The dimensions of all specimens were measured by using a digital calliper (LEZACO, ART. 2771, China).

B- Procedure

After conditioning the tested samples in distilled water for 24 hours, the transverse strength test of specimens was measured by using three-point loading on the device (Tensile testing machine, SJX-500N-200 mm electric push-pull test station 500N, Model; AEL.1000–400, China). The device was supplied with a loading plunger in the center and two support surfaces placed 50 mm apart supporting wedges, which represent the average inter-molar distance of the denture. The supports were fixed parallel to each other and perpendicular to the central line, the test specimen was held and stabilized at each end of the two supports, and the loading plunger was centered at midway between the two parallel supports. The transverse test was done with a

constant cross-head speed of 5 mm/min; test specimens were deflected until crack or fracture occurred. The following formula determined the ultimate flexural strength (MPa):

$$F.S \text{ (flexural strength)} = \frac{3 \times f \times I}{2 \times b \times h^2}$$

Where f= the maximum load applied (N), I= the span between the two supports (mm), b= specimen width (mm), h= specimen thickness (mm)

Indentation hardness test

A-Specimen preparation

Sixty samples with a dimension of 30 × 15 × 3 (± 0.03 mm) (length, width, and thickness) respectively were shaped according to American Dental Association Specifications No. 12.[19] The prepared samples were stored in distilled water at 37°C for 48hrs before testing. The test was done using a Durometer hardness tester (Shore D) testing machine (Shore Hardness Test, Model: LD-YJ, China). The device consists of an indenter 0.8 mm in diameter, which penetrates the surface of the tested sample by moving the tester down quickly and firmly, and then records the final maximum reading as the shore "D" hardness measurement. The reading was taken from the screen reading. The sample was supported by a rigid flat base, five readings were taken at five different sites of penetration.

Curing cycles

For the water bath technique acrylic resin sample was cured according to the manufacturer`s instructions, while for the microwave technique, the acrylic resin was cured at 500 watts for 3 minutes in a domestic microwave oven (Panasonic, Batch No. NN-GX36WF, Korea) according to manufacturer`s instructions.

Addition of fibre mesh

The network-reinforced visible light-cured SES mesh was prepared according to the dimensions of an acrylic resin sample to be tested for transverse strength and surface hardness tests, as mentioned previously. All the fibre meshes were polymerized for 4 minutes using a specially formulated curing device. The meshes were applied according to the divided groups of acrylic resin samples. Stoppers were made to each classified mesh to determine the level of the mesh within an acrylic sample: 2 mm, 1 mm, 1.5 mm (± 0.03 mm) (near to the tissue surface, near to the polished surface, at the middle of the tested sample) respectively.

Microscopical examination

A fracture surface of the tested sample (controlled and reinforced) was taken from each group randomly. The fractured surface of each specimen was examined at 20X magnification under a stereomicroscope (Hamilton Altay, Italy). Images were captured using a computer program, then all findings were microscopically examined.

Statistical analysis

The collected data were analyzed statistically using the SPSS software (version 19.0; SPSS Inc., Chicago, IL, USA). One-way ANOVA was utilized to determine the significant difference between all different levels of SES mesh reinforcement within an acrylic resin-tested sample. Tukey's Post hoc test was used to compare the significant groups. *P*-values of ≤ 0.05 were considered statistically significant.

Results

Transverse strength test

The mean, standard deviation (SD), and transverse strength of the tested samples made from heat-cured and microwave cured with different levels of fibre mesh reinforcement and without fibre mesh reinforcement are listed in [Table 2]. The mean values of the transverse strength of high-impact heat-cured acrylic resin (118.887, 112.288, 81.246, and 78.145 MPa for groups 4,3,2,1 respectively) were significantly higher than that of the cross-linked heat-cured acrylic resin (86.124, 81.287, 69.280, and 63.376 MPa for groups 4,3,2,1 respectively), followed by microwave cured acrylic resin (84.407, 62.965, 56.167, and 47.527 MPa for groups 4,3,2,1 respectively) [Table 2]. For different acrylic resin materials, one-way ANOVA showed a significant difference in the mean values of transverse strength between all different levels of fibre mesh applications and without fibre mesh reinforcement ($P < 0.05$) [Table 2].

Tukey's post hoc test showed that SES-reinforced mesh fibre applied to the middle of the tested samples (group 4) had the highest mean value among the different levels of fibre mesh application, followed by mesh fibre applied near to the polished surface of the tested samples (group3), then the mesh fibre applied near to the tissue surface of the tested sample (group 2), while no fibre reinforced resin sample (control group) showed the lowest mean value [Table 2].

Indentation hardness test

The mean, standard deviation (SD), and surface hardness of the tested samples made from heat-cured and microwave cured with different levels of fibre mesh reinforcement and without fibre mesh reinforcement are listed in [Table 3]. Reinforcement with the fibre SES mesh framework system had little effect on the surface hardness of high-impact acrylic resin mean

Table 2: Mean, and standard deviation of the transverse strength of the four groups of different acrylic resins

Types of acrylic resin	Group	Transverse strength Mean (MPa)	SD	F-value	P-value
High-impact heat-curing acrylic resin	Group1 [d]	78.145	0.87	1935.626	.000*
	Group2 [c]	81.246	0.87		
	Group3 [b]	112.288	0.89		
	Group4 [a]	118.887	1.48		
Cross-linked heat-curing acrylic resin	Group1 [d]	63.376	0.75	506.241	.000*
	Group2 [c]	69.280	0.80		
	Group3 [b]	81.287	1.62		
	Group4 [a]	86.124	0.70		
Microwave curing acrylic resin	Group1 [d]	47.527	3.78	178.816	.000*
	Group2 [c]	56.167	1.95		
	Group3 [b]	62.965	2.53		
	Group4 [a]	84.407	1.78		

SD = Standard deviation, Number of samples = 5, Different letters are statistically different according to Tukey's test, * Significant differences at a level of 0.05.

Table 3: Mean, and standard deviation of the indentation surface hardness for the four groups of different acrylic resins

Types of acrylic resin	Group	Surface Hardness Mean	SD	F-value	P-value
High-impact heat-curing acrylic resin	Group1	86.00	3.39	2.022	.151
	Group2	85.40	1.51		
	Group3	82.20	1.64		
	Group4	84.80	3.34		
Cross-linked heat-curing acrylic resin	Group1[a]	88.60	1.51	3.704	.034*
	Group2[a b]	86.60	4.61		
	Group3[c]	83.60	1.14		
	Group4[a]	87.60	0.54		
Microwave curing acrylic resin	Group1[a]	77.20	1.09	15.620	.000*
	Group2[a]	74.60	4.50		
	Group3[b]	61.20	8.98		
	Group4[a]	82.60	1.94		

SD=Standard deviation, Number of samples= 5, Different letters are statistically significantly different according to Tukey's test, * Significant differences at a level of 0.05.

values (84.80, 82.20, 85.40, and 86.00 for groups 4,3,2,1 respectively), one-way ANOVA [Table 3] showed that there were no significant differences (p> 0.05). But a significant difference in the mean values of surface hardness (p< 0.05) was observed between the cross-linked mean values (87.60, 83.60, 86.60, and 88.60 for groups 4,3,2,1 respectively) and microwave-cured acrylic resin mean values (82.60, 61.20, 74.60, and 77.20 for groups 4,3,2,1 respectively).

Microscopical examination

The microscopic findings showed that in the non-reinforced tested samples, a pattern like river lines was noticed. Failure lines appeared vertically on the outer surface and were closely directed to the tissue surface [Figure 1]. In the reinforced tested samples, failure seems to be as a broom was noticed, occurring as crossed fibre blocks broke [Figure 2A]. A gap was observed, in which there is a space between glass fibres and the acrylic resin, and fractured acrylic resin was observed where the resin base and the glass fibres were bonded strongly [Figure 2B]. When this region was magnified, glass fibres inserted into the resin matrix had fractures at different locations [Figure 2C] cracks within the glass fibres were noticed.

Discussion

The results of the present study showed that fibre mesh-reinforced acrylic resin samples for heat and microwave-cured acrylic resin had a higher fracture resistance (transverse strength) than that of the non-reinforced acrylic resin sample (control group). All reinforced acrylic resin tested samples had enhanced fracture resistance compared with the unreinforced. While reinforcement with the fibre SES mesh framework system had little effect on the surface hardness of high-impact acrylic resin mean values.

Therefore, the null hypothesis of the present study was partially rejected. because the fracture resistances for

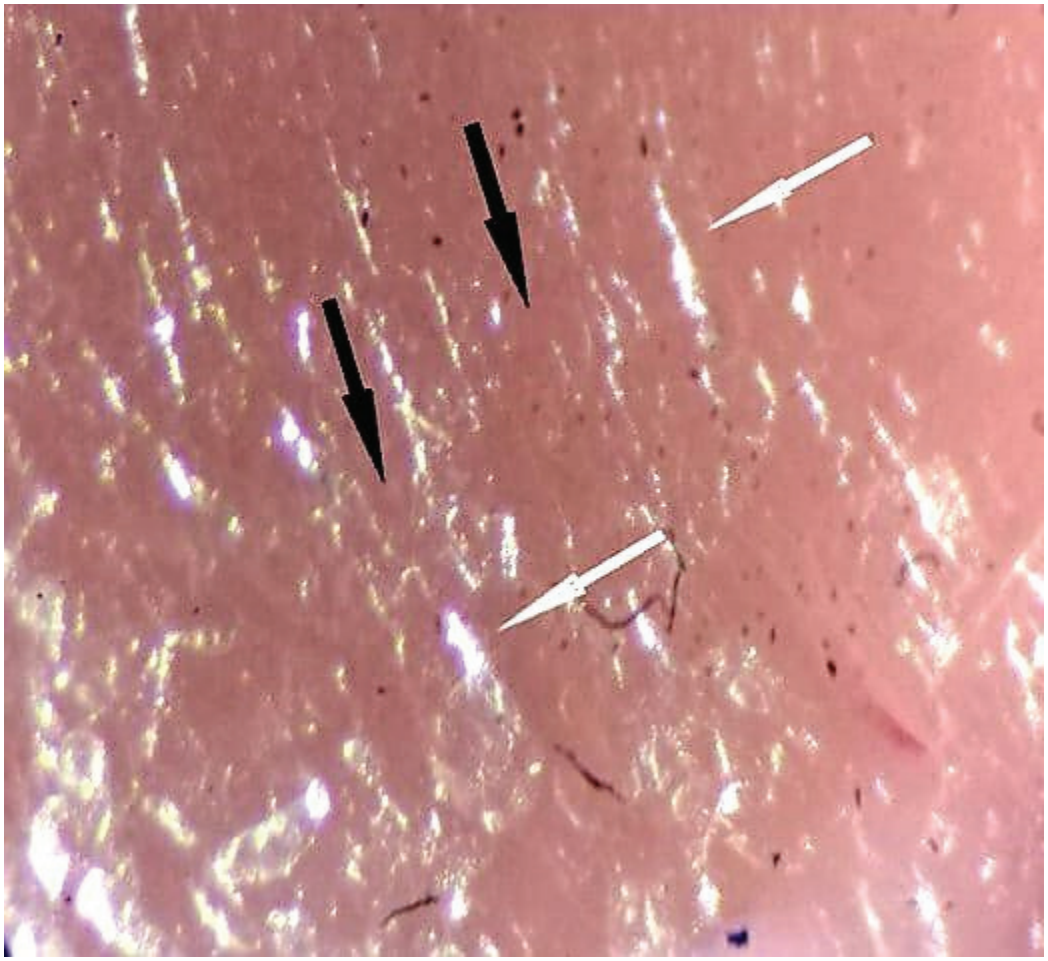

Figure 1: The fractured surface of the unreinforced resin sample. Black arrows indicate the) direction of the river line propagation. White arrows indicate scarps. (Original magnification X 20)

the transverse strength test were significantly different among the SES mesh reinforced and non-reinforced groups, but SES mesh fibre had little effect on the surface hardness test among the reinforced and non-reinforced groups.

The transverse strength of the materials is a combination of compressive, tensile, and shear strengths. It is a measure of the stiffness and resistance of a material to fracture.[20,21] Reinforcement of denture base resins with glass fibre is considered to be a proper method to increase fracture resistance[15] and give a greater toughness to the denture against breaking. The modulus of elasticity of glass fibres is high, which enables the fiber to absorb most of the stress without deformation. It also increases and improves the stiffness and dimensional stability of the materials during function.[22]

Compared to conventional polymer materials, fibre-reinforced polymers show better results during application.[23] During mastication, denture base materials with an adequate modulus of elasticity can withstand permanent deformation. Midline fractures of the upper and lower dentures mainly occur due to flexure leading to material fatigue. To resist fracture, denture base materials should have sufficient flexural strength after a period of time after wearing a denture.[24]

During the testing procedure, multiple factors affect the flexural transverse strength, including the distance between the two supporting coins, test speed, and dimensions (width and thickness) of the tested sample.[25]

This is due to the enhancement of the transverse strength of resin polymers, which may denote the proper interaction of the fibres with the monomer.[26] Another factor is that the fibres are pre-polymerized and contain a highly porous polymer that provides chemical bonding to the denture base resin.[27] Crack propagation can be prevented using a fibre mesh that controls the direction of cracks, resulting in smaller cracks created within the fibres.

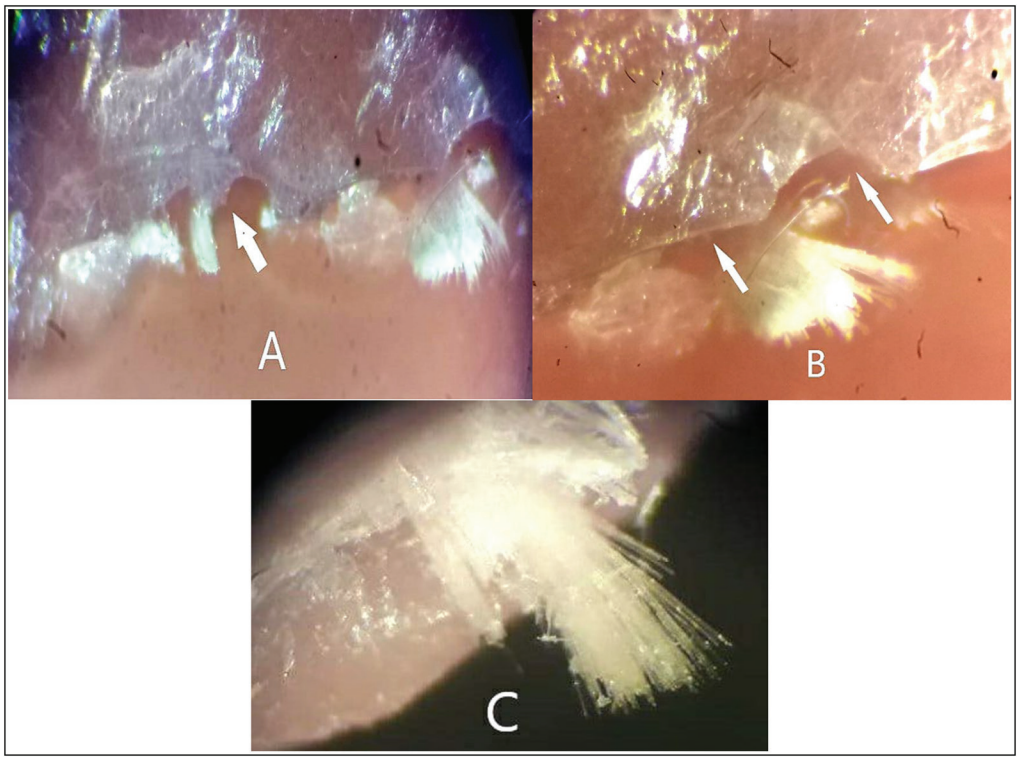

Figure 2: The fractured surface of the fibre mesh-reinforced resin sample. (A) Crisscross fibres are fractured. (B) Fractured resin and broom-like fibre end. The white arrow represents the gap between the fiber and resin matrix (C) Fractured glass fibers. (Original magnification X 20)

The reinforced groups (Group 2,3,4) bent less and maintained their shape better than the unreinforced control group (group 1). The fibre mesh-reinforced resin denture base clinically maintains its shape to some degree even when damaged, affecting both surfaces of the upper and lower dentures during chewing and mastication.

The use of prefabricated well-oriented fibre mesh is an important step in reducing the difficulty arising from the incorporation process of continuous fibres in a specific part of the tested sample[28] It also prevents the lateral spread of fibres during the packing procedure

The improvement of transverse strength was attributed to the direction and aligned orientation of the glass fibres within the polymer matrix. When fibres were placed perpendicular to the loading force, the reinforcement of the acrylic resin was obtained. Unidirectional alignment of the glass fibre (mesh pattern) reinforcement produced the highest transverse strength of the resin material. This is due to the larger volume of fibre mesh within the resin matrix[29-31] This made the transverse strength values of the reinforced conventional acrylic resin similar to those of the improved high-impact strength resin.

During the transverse test, stresses were generated at the midpoint of the upper polished surface of the tested sample, where the vertical loading force was applied; thus, tension stresses were generated at the lower surface (tissue surface) of the tested sample. The bending and fracture of the tested sample occurred due to the gradual propagation of small cracks created at the tension site on the lower surface (tissue surface).[2] This is identical to the direction of fracture progression suggested by a river line pattern.[18]

The fibre fracture started at the initiation site of the sample (concentrated on the fibre mesh within the tissue surface or the polished surface); therefore, the fracture advanced through the adjacent areas in the resin matrix to the opposite fibre level, leading to faster strength deterioration when crack occurred in fibre mesh-reinforced.

Specimens with fibres in close approximation to a polished surface generally fracture readily during flexion. Clinically, polishing a fibre-reinforced denture base is expected to weaken the finished prosthesis drastically.[22]

In the present study, fibre reinforcement was more effective when the fibre mesh was placed in the middle of the tested sample (group 4) and had the highest mean values compared with other levels of fibre mesh reinforcements within the tested samples. This is due to the fact that the stress transferred from the polymer

matrix (in the polished surface) to the fibres within the middle of the sample leads to the maximal reduction of the deformity of resin samples.

In the early stages of flexural testing, the lower surface of the test specimen lengthened slightly, but the inner glass fibre mesh (in the middle of the tested sample) did not change. When a fibre mesh fracture occurs, this leads to a final complete fracture of the tested specimen. This means that the tensile strength of the glass fibre is taking part in the flexural strength of the test specimen.[2]

The fibre mesh controlled the flexion of the test specimen because the mesh had a certain degree of thickness, which shifted from the neutral axis of the specimen and prevented the spread of delamination within the tested specimen. This means that during the testing procedure, the increased polymer matrix length, caused by the flexural test, stopped in the fibre mesh within the middle level of acrylic resin samples.

The present study is in agreement with the results of a study conducted by Im *et al.*[18] supported the results of the current study: the unreinforced complete dentures (control group) showed bending when loading was applied, whereas the fibre mesh reinforced groups did not show visible changes and preserved their original structure even after fracturing. Other experimental findings by Fonseca *et al.*[26] explained that a better interaction between glass fibres and acrylic resin results in a higher transverse strength than groups of non-impregnated glass fibres. Moreover, Tsue *et al.*,[32] evaluated the fracture resistance of denture reinforcement of unidirectional glass fibres, and Yu *et al.*[33] explained that the fracture load and toughness of fibre mesh-reinforced groups were significantly higher than those of the control group and metal mesh-reinforced group. Yu *et al.*[34] demonstrated that the fracture resistance of the SES fibre mesh group was significantly higher than that of the reinforced metal mesh groups.

Hardness refers to the material's resistance to penetration when indented by a hard object, a part from scratch, or abrasion resistance. For polymer-based materials, several factors influence the hardness values, including the time and speed of elastic recovery, the presence, size and quantity of filler particles.[35] The reduction in the mean values of surface hardness could be attributed to the residual monomer content within the samples. The surface hardness of the resin materials was affected by the residual monomer content, which has a plasticizing effect, reduces, and causes relaxation of the inter-chain forces. Finally, deformation was formed more easily under load that lowering the hardness of the acrylic resin. This is in agreement with the published literature.[36-38]

Consequently, water absorption into the acrylic resin replaced residual monomer particles. Because water molecules are smaller than the inter-chain distance in the resins, they can cluster at the polar center that exists in polymer resins. The secondary chemical bonding forces between these chains decreased, leading to a change in the material's stiffness. The mechanical properties of the resin are negatively influenced by the plasticizing effect of water molecules which differ in each resin.[39,40] Plasticizer molecules can fill microvoids or cavities, thereby excluding water uptake. The fibre mesh incorporated within the reinforced acrylic resin and the reduced proportion of the resin matrix may also reduce the surface hardness of acrylic resin materials.[15]

The amount of water absorbed by resins during immersion of the tested samples in distilled water can be reduced, and the surface hardness of resin materials can be enhanced by adding cross-linking agents[41] This can be noticed for all groups of cross-linked acrylic resin samples [Table 3].

In [Figure 1] the river line pattern shows that the direction of the crack or fracture begins and progresses from the polished surface towards the tissue surface.[18] The gap between the acrylic resin and fibre mesh is shown in [Figures 2 A and B]. If water enters these gaps, they undergo hydrolysis. There is a reduction in the cohesion between the glass fibre and resin matrix due to the hydrolysis of silane coupling agents[42] which leads to faster strength deterioration, a crack occurred in the fibre mesh-reinforced resin sample. Broken fibres had different lengths giving the pattern of a broom-like failure also noticed.[18]

These data are in agreement with those reported by AL-Omari[43] explained that SES fibre meshes increased acrylic resin denture base resistance to fracture without affecting the surface hardness, while disagreement with Alhotan *et al.*[44] showed that the addition of glass fibre to PMMA delivered the greatest improvement in surface hardness property.

The results of the present study demonstrate that reinforcing the tested sample with an SES mesh reinforced network is much better than that of the non-reinforced tested sample on the stress side of a flexural loaded material increases its flexural strength and flexural modulus. Therefore, to obtain the best fracture resistance results, the SES mesh reinforced network must be placed within the middle area of the prosthesis during the laboratory processing procedure to obtain

the maximum reduction of the deformity and control the flexion of the prosthesis.

The present study helps select the best application of fibre-reinforced mesh during prosthesis construction; and improves the mechanical properties using different types of acrylic resin denture base materials. The application of a fiber-reinforced mesh system is recommended as a reliable method to increase the fracture resistance of denture bases.

As this study is an *in vitro* study that provided data on the mechanical properties of acrylic resin denture base materials, but these data differ from the dental prosthesis used intraorally, which is affected by the presence of artificial teeth, the resiliency of the oral mucosa, and supporting bone played an essential role in load distribution while wearing the prosthesis. Therefore, further studies are required to measure the fracture resistance of reinforced denture prostheses under simulated oral conditions.

Conclusions

Within the limitations of this study, the following conclusions can be determined:

1- The transverse strength of the reinforced acrylic resin denture base materials with SES-reinforced fibre mesh at different levels was significantly higher than that without reinforced acrylic resin denture base materials.
2- The SES-reinforced fibre mesh at different levels had little effect on the surface hardness for high-impact heat-cured acrylic resin, but it produced a significant difference in surface hardness between cross-linked heat-cured and microwave-cured acrylic resin.

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Conflicts of interest

There are no conflicts of interest

Authors contributions

Not applicable.

Ethical policy and institutional review board statement

The study was approved by the Research Ethics Committee board (the University of Mosul, College of Dentistry, REC reference No. 6, 24/6/2018), and there are no biohazardous and toxic materials/substances. This study was in accordance with institution guidelines.

Patient declaration of consent

Not applicable.

Data availability statement

Not applicable.

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