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Evaluation of Some Mechanical Properties of Reinforced Acrylic Resin Denture Base Material(An In Vitro Study)

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ABSTRACT

Aims: To evaluate the effect of thickness of acrylic denture base resin on the transverse strength, also to evaluate the effect of metal and fiber reinforcements on the fracture resistance of denture base resin by four mechanical tests: Transverse strength; Charpy impact strength; Tensile strength and Rockwell Indentation Hardness. **Materials and methods** : Heat–cured resin, and three types of reinforcing metals were used which were: The cobalt–chromium alloy mesh, stainless steel wire and nickel alloy plate. Three forms of glass fiber also were used: Random, woven, and aligned unidirectional. The effect of these reinforcing materials on the mechanical properties of heat–cured resin had been evaluated by measuring the transverse strength by the Instron testing machine, tensile strength by the Textile tensile strength Tester, the impact strength by the Charpy type impact Tester and finally the hardness by the Rockwell hardness tester. Three hundred samples were prepared in this study. **Results:** Revealed a statistically significant effect of thickness on the transverse strength of heat–cured resin. Results also showed that all forms of fiber and metal reinforcements had a significant effect on the transverse strength, tensile strength , impact strength and hardness of denture base resin. **Conclusions**: The thickness significantly increased the transverse strength of denture base resin. All forms of metal and glass fiber reinforcement significantly improved the transverse strength, impact strength and tensile strength of denture base resin. All forms of metal and fiber reinforcement acted to reduce the hardness of denture base resin.

Key Words: Reinforcement, glass fiber, acrylic resin

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INTRODUCTION

Fracture of a denture is an important problem not only for patients but also for dentists and dental laboratory technicians. (1)

The failure of a denture base material may often involve either impact failure or fatigue failure. Impact failures involve rapid stressing of the material such as by dropping the denture on a hard surface. Fatigue failures occur after continued flexing of the base during function, which leads to crack development. Failure of this type in an upper denture commonly results in rupture along the midline. (2–4)

Fracture strength of denture base resin is of great concern, and various approaches have been suggested to strengthen acrylic resin dentures. These are include modifying or reinforcing the resin. (5)

Doubling the thickness of the denture one of the early attempts to increase the strength of acrylic dentures. (6)

Reinforcement has been attempted through the incorporation of solid metal forms and various types of fibers in fracture–prone areas. Metals can be added in the form of wires, plates, nets or fillers. (7)

The addition of fibers to acrylic resin has the potential to improve the mechanical properties of the material. Effective fiber reinforcement is dependent on many variables including the material used, the percentage of fibers in the matrix and their modulus and distribution, fiber length, fiber orientation and fiber form. Over the years various types of fibers such as carbon(8), aramid (9), polyethylene (10), and glass (11) have been added to acrylic resin in an attempt to improve its mechanical properties.

The aims of this study were to evaluate the effect of metal and fiber reinforcement on the mechanical properties of acrylic resin denture base material. The effect of thickness on the strength of denture base material has also been studied.

MATERIALS AND METHODS

Heat–cured acrylic resin (Major Prodotti, Italy) were used in this study. The reinforcing materials for heat curing resin were: Cobalt–chromium alloy mesh (Degussa, Germany), stainless steel wire(Ash, England) and nickel alloy plate (Shanghai,China).

Glass fiber was used as reinforcing material in the form of random, woven and aligned unidirectional (Pilkington, England).

Specimens were cured in the conventional denture flasking procedure. Three hundred samples were prepared, samples were divided into three groups: Control group, thickness group and reinforcing group. Samples were tested by four mechanical tests: Transverse strength, impact strength, tensile strength and hardness.

Two groups for thickness were prepared: Single thickness group and double thickness group.

Reinforcement groups were metal reinforcement of three types, which were: Wire reinforcement, metal plate and mesh reinforcement.

Glass fibers were used to reinforce acrylic samples in three different ways: Random, woven and aligned.

Generally the mould prepared by the conventional flasking technique for complete denture that were followed in the mould preparation.

The dough–mixture preparation, done when the acrylic resin at dough stage was made by mixing powder and liquid together in ratio of 3:1 polymer/monomer by volume or 2.5/1 by weight according to manufacturer's instructions, then the acrylic resin dough was placed in the mould and packed, the instructions of manufacturer's for curing were followed 1.5 hours at 74^{o}C + 30 minutes at 100^{o}C.

Finally the deflasking and finishing the acrylic samples were applicated and removed from the stone mould, the specimens were stored in distilled water.

The addition of glass fiber: Amount of fibers, polymer and monomer are presented in Table (1)

Table (1) : Summary of the Amount of Fibers and Monomer Used in the Study

Specimen	Wight of Polymer (gram)	Weight of fiber (grams)	Weight of Monomer (grams)	Polymer/ monomer ratio By weight
Control	7.5	0	3	2.5/1
Random fiber	7.125	0.375	3.75	2/1
Woven fiber	7.125	0.375	3	2.5/1
Aligned fiber	7.125	0.375	3	2.5/1

The Mechanical Tests Used in This Study, were:

1. Transverse Strength Test: Rectangular samples with dimensions of 65x10x2.5$\pm$0.03 mm in length, width and thickness respectively.

The transverse strength of specimens was measured in air by using Three–point loading on an Instron testing machine.

2. Charpy Impact Strength Test: Specimen made from acrylic resin with dimensions of 80x10x4 mm in length, width and thickness respectively, following the ISO standard 179–1:2000. [12]

The impact strength test was carried out with a 15 J Charpy pendulum. The Charpy impact strength of notched specimen was calculated using the following equation:

$$I = \frac{A}{X.Y} \times 10^{3}$$

I = Impact Strength in KJ/m^2

A = Absorbed Energy (J).

X = Specimen Thickness (mm).

Y = Remaining Width at the Notch Base (mm). [12]

3. Tensile Strength Test: A dumbbell–shaped specimen was prepared from wax in a metal mould in dimensions of 75x12.75x2.5±0.03 mm in length, width and depth respectively.

The tensile strength was tested using a Textile Tensile testing Tester sets at a cross–head speed of 150 mm/min.

The true tensile strength value was calculated by the following formula :

$$T.S = \frac{F\,(N)}{A\,(mm^2)}$$

F= Force at Failure (N)

A= Area of Cross Section at Failure

The units were then converted to MPa.

4. Indentation Hardness Test (Rockwell Hardness): Acrylic resin specimens were prepared with dimensions of 30x15x3±0.03 mm in length, width and thickness respectively.

The indentation hardness of the specimen was tested by means of the Rockwell hardness tester equipped with an indenter in the form of round steel ball of 6.350 mm in diameter and a dial gauge for recording the Rockwell hardness number.

After data collection, the results of the present study were analyzed statistically by the use of: Descriptive Analysis including Means and Standard Deviations (SD), analysis of Variance (One–way ANOVA) to show if there were significant differences among groups, and Duncan Multiple Range Test (DMRT) to compare between significant groups.

RESULTS

Generally as the thickness of the acrylic samples increased the transverse strength also increased.

One way analysis of Variance (ANOVA), at Table (2) showed very highly significant differences in the transverse strength among the groups of thickness.

Table (2) Analysis of variance (ANOVA) for the effect of thickness on the transverse strength.

Source of Variation SOV	Degree of freedom DF	Sum of square SS	Mean square MS	F–value
Thickness	2	1750.00	875.00	20.91**
Error	27	1129.95	41.85	
Total	29	2879.95		

** Highly significant $p \leq 0.01$

The means and standard deviation of the transverse strength of the control group (2.5mm thickness), single thickness group (1.5mm) and double thickness group (3mm) were presented in Table (3); the same table showed Duncan's Multiple Range Test which reveled that acrylic samples of (3mm) thickness had the highest Transverse Strength.

Table (3) Duncan's Multiple Range Test (DMRT) for the effect of Thickness of acrylic samples on Transverse Strength.

Thickness (mm)	Transverse strength Mean ±SE	Duncan Group*
2.5	80.55 ± 1.50	B
1.5	73.55 ± 2.53	C
3.0	92.08 ± 1.98	A

Different letters vertically mean significant difference at $p \leq 0.05$; * Means with the same letters are not significantly different; SE = Standard Error; MPa = Mega Pasca.

One way analysis of variance (ANOVA), with Table (4) showed that there were highly significant differences between the reinforcement groups.

Table (4) Analysis of Variance (ANOVA) for the Effect of Different Reinforcement on the Transverse Strength.

Source of Variation SOV	Degree of freedom DF	Sum of square SS	Mean square MS	F–value
Reinforcements	6	13048.52	2174.75	30.02**
Error	63	45612.64	72.44	
Total	69	17612.64		

** Highly significant *p* ≤0.01

Table (5) showed the effect of metal and fiber reinforcements on the transverse strength of acrylic denture base material, by means and standard deviation of the tested groups, also showed Duncan's Multiple Range Test which explained that acrylic samples reinforced with mesh had the highest Transverse Strength.

Table (5) Duncan's Multiple Range Test (DMRT) for the Effect of different Reinforcement on Transverse Strength

Groups	Mean ± SE	Duncan Group*
Control	80.55 ± 1.50	D
Random fiber	98.25 ± 2.48	C
Woven fiber	96.60 ± 2.48	C
Aligned fiber	110.85 ± 3.08	B
Metal wire	106.20 ± 3.89	B
Metal plate	93.15 ± 1.06	C
Metal mesh	127.05 ± 3.23	A

Different letters vertically mean significant difference at $p \leq 0.05$; * Means with the same letters are not significantly different; SE = Standard Error; MPa = Mega Pascal.

One way analysis of variance (ANOVA) revealed a highly significant difference between the tested groups, as shown in Table (6).

Table (6) Analysis of Variance (ANOVA) for the Effect of Different Reinforcement on the Impact Strength.

Source of Variation SOV	Degree of freedom DF	Sum of square SS	Mean square MS	F–value
Reinforcements	6	29503.81	4917.30	391.0**
Error	63	792.31	12.57	
Total	69	30296.12		

** Highly significant $p \leq 0.01$

Table (7) presented the means and standard deviations of impact strength of reinforcement groups, with Duncan's Multiple Range Test that showed the acrylic samples reinforced with metal wire had the highest impact strength.

Table (7) Duncan's Multiple Range Test (DMRT) for the Effect of Different Reinforcement on Charpy Impact Strength

Groups	Mean + SE	Duncan Group*
Control	8.3 + 0.30	E
Random fiber	6.0 + 0.11	E
Woven fiber	5.4 + 0.30	E
Aligned fiber	32.4 + 1.26	C
Metal wire	58.3 + 2.09	A
Metal plate	24.2 + 1.52	D
Metal mesh	53.0 + 0.59	B

Different letters vertically mean significant difference at $p \leq 0.05$;* Means with the same letters are not significantly different.

One way analysis of variance (ANOVA), Table (8) showed that there was a highly significant differences observed among the tested groups.

Table (8) Analysis of Variance (ANOVA) for the Effect of Different Reinforcement on Tensile Strength.

Source of Variation SOV	Degree of freedom DF	Sum of square SS	Mean square MS	F–value
Reinforcements	6	18586.88	3097.81	53.82**
Error	63	3626.2	57.55	
Total	69	22213.08		

** Highly significant $p \leq 0.01$

For the effect of metal and fiber reinforcement on tensile strength of acrylic resin denture base material, Table (9) explained the mean values and standard deviation of tested groups and the Duncan's Multiple Range Test which showed that acrylic samples reinforced with metal wire had the highest Tensile Strength.

Table (9) Duncan's Multiple Range Test (DMRT) for the Effect of Different Reinforcement on Tensile strength

Groups	Mean + SE	Duncan Group
Control	52.6 + 4.48	D
Random fiber	59.6 + 0.65	D
Woven fiber	54.5 + 0.52	D
Aligned fiber	72.6 + 2.35	C
Metal wire	96.5 + 0.95	A
Metal plate	85.0 + 3.43	B
Metal mesh	88.0 + 1.15	B

Different letters vertically mean significant difference at $p \leq 0.05$.

One–way analysis of variance (ANOVA), Table (10) showed highly significant differences among tested groups.

Table (11) showed the means and standard deviations for the effect of different reinforcement on hardness and the Duncan's Multiple Range Test which showed that acrylic samples reinforced with Aligned fiber had the least Hardness.

Table (10) Analysis of Variance (ANOVA) for the Effect of Different Reinforcement on Hardness (Rockwell).

Source of Variation SOV	Degree of freedom DF	Sum of square SS	Mean square MS	F–value
Reinforcements	6	2497.74	416.29	10.03**
Error	63	2614.60	41.50	
Total	69	5112.34		

** Highly significant $p \leq 0.01$

Table (11) Duncan's Multiple Range Test (DMRT) for the Effect of Different Reinforcement on Hardness

Groups	Mean $\pm$ SE	Duncan Group*
Control	97.2 $\pm$ 5.94	A
Random fiber	81.0 $\pm$ 2.21	D
Woven fiber	83.6 $\pm$ 2.43	CD
Aligned fiber	80.2 $\pm$ 1.77	D
Metal wire	83.1 $\pm$ 2.12	CD
Metal plate	88.3 $\pm$ 2.87	BC
Metal mesh	93.0 $\pm$ 5.12	AB

Different letters vertically mean significant difference at $p \leq 0.05$;
* Means with the same letters are not significantly different.

DISCUSSION

The results showed that thickness of acrylic resin denture base material was a significant factor in determining the strength of the denture.

The thickness of denture base resin approved by **A.D.A.** [13] is 2.5 mm, this thickness was considered to be as a control group in this study, and it was compared with 1.5 mm thickness (which represents single thickness group) and also compared with 3 mm thickness (which represents double thickness group).

The results of this study showed that increasing the thickness to 3 mm significantly increased the transverse strength of denture base resin and decreasing the thickness to 1.5 mm decreased the strength significantly.

This was because thicker denture bases had a greater flexural strength and have a decreased deflection under loading. The results obtained in this study were in agreement with Woelfel [14] and ohers. [15]

The results also agreed with McCabe [6] who concluded that the flexural stress required to cause fracture depends on the square of the thickness of the denture.

It was found that acrylic resin reinforced with unidirectional aligned glass fiber presented the highest transverse strength when compared to the other two forms of fiber reinforcement, this was because the transverse strength of fiber composite depends on the direction of fiber in the polymer matrix and the aligned orientation of glass fiber placed perpendicular to the loading force provide the most effective reinforcement of acrylic resin. This finding was in agreement with the theoretical efficiency of reinforcement the Krenchel's factor: which was one for aligned unidirectional fibers and half for woven fibers Morris *et al*., Holliday. [15, 16] These findings were also in agreement with the results obtained by Vallittu and others. [18, 19, 21]

By the results, all groups of metal reinforcement significantly increased the transverse strength of acrylic resin. This finding was in agreement with previous studies of Carroll and others.[21– 26]

The result may be attributed to the fact that the reinforcing metal embedded in the acrylic sample became the principle load bearing constituent that resist all forces subjected to the sample.

The impact strength for conventional unreinforced heat–cured acrylic denture base material reported in this study was 8.3 KJ/m^2, this was in agreement with previous studies, [27, 28] the addition of 5% by weight glass fibers in random form reduced the impact strength.This reduction could be the result of clustered fibers and void spaces that may act as stress concentration point in the polymer matrix and thus decrease interfacial bonding between fiber and matrix.

These findings were in agreement with Al–Momen and others.[19, 29] These results disagree with those obtained by Salem[30], probably due to different concentration of fibers and nature of fibers.

The incorporation of glass fiber in woven form also showed a high reduction in the impact strength when compared to unreinforced samples. This could be related to the poor adhesion between the woven mat and polymer matrix. This result was agreed with Braden *et al.* [31], but this results disagreed with the results obtained by Kim *et al.* [32], probably due to different type of resin and different type of test to measure impact strength.

The addition of aligned unidirectional glass fiber produces showed a remarkable increasing in impact strength (290%). This result was in agreement with Ladizesky [33], this may be due to the arrangement of fibers in a strategic direction as many fibers were parallel to the surface of the samples as possible, so the fibers take the mechanical load and the matrix transfer the load to the fibers.

Specimens reinforced with metal wire and metal mesh produced a remarkable increasing in impact strength, this may be attributed to the form of the metal and due to its placement perpendicular to the line of fracture. This was agreed with Ruffino. [22]

The mean tensile strength of the unreinforced test specimens in this study was 52.6 MPa, this value was similar to the result obtained by Phillips. [34]

The increase of tensile strength for the fibers that reinforced the samples was due to the high tensile strength of glass fiber used in this study. This result agreed with Vallittu. [11]

Samples reinforced with aligned unidirectional fibers produced significant increasing in tensile strength, this increasing was due to the fiber architecture which provide the highest strength. This was agreed to Goldberg *et al.*, and others.[35–37]

The explanation for the increasing of the tensile strength for aligned unidirectional fiber reinforcement, could be attributed to the transfer of stress from the weak polymer matrix to the fibers that have a high tensile strength Nohrstrom *et al.* [38], but he increase in tensile strength of wire reinforced samples was due to the high tensile strength of metal wire made from stainless–steel when compared to the tensile strength of the other metals used in this study, this was in agreement with Anusavice. [39]

The decreased of surface hardness for the bulk reinforced acrylic resin may be caused by both the effect of the incorporated fibers or metals and the reduced proportion of the resin matrix. This result was in agreement with the study applied by Chen *et al.* [40] The results of this study showed that randomly oriented and aligned glass fibers produced the lowest indentation resistance, this could be attributed to the higher percentage of residual monomer content, because surface hardness was affected by high levels of residual monomer which has a plasticizing effect that reduces interchain forces so that deformation could occur more easily under load. This had agreement with Arab *et al.* [41]

CONCLUSION

The thickness was significantly increased the transverse strength of denture base resin.

The aligned unidirectional glass fiber reinforcement produced the highest transverse strength, impact strength, and tensile strength when compared to other forms of fiber reinforcement.

The Co–Cr mesh reinforcement produced the highest transverse strength when compared to other forms of reinforcement.

All forms of metal reinforcement significantly increased the impact strength and tensile strength and the metal wire reinforcement produced the greatest increasing in impact strength and tensile strength.

All forms of metal and fiber reinforcement acted to reduce the hardness of acrylic denture base resin.

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