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Evaluation Mechanical Properties of Repaired Polyamide Dentures at Different Processing Techniques and Surface Treatment

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Abstract. *Background: Polyamide denture base materials have gained prominence in dentistry due to their superior attributes compared to traditional acrylic materials. However, the susceptibility of polyamide dentures to fractures necessitates exploration of repair, replacement, and reinforcement methods. Effective denture rehabilitation requires enhancing tensile and transverse strength.Methods: This study utilized 160 acrylic resin samples. The control group included 40 specimens with and without fusing material integration, representing fractured and intact scenarios. The remaining 120 specimens underwent meticulous repair through three approaches: Reinjection nylon repair (RiNR), Recycling Manual heating (spruing) repair (RcNHR), and Manual heating nylon (NHR) repair, each with American and Russian fusing materials. Rigorous tensile and transverse strength evaluations were performed. Results: Techniques augmenting tensile and transverse strength (RcNHR, NHR, RiNR) were significantly effective compared to untreated fractures (C2) for both fusing materials. The control group (C1) consistently exhibited higher strength than C2. RiNR exhibited paramount strength, with American-treated RcNHR showing lower tensile strength, and Russian-treated NHR showing reduced transverse strength. Russian and American treatments showed no significant differences in RcNHR and RiNR, but differences emerged in NHR. Conclusion: Implementing flexible materials enhances polyamide denture strength. Reintegration through reinjection and manual heating with sprue-material yielded positive outcomes. RiNR achieved the highest strength. Russian and American treatments showed no notable differences in RcNHR and RiNR, with variations seen in NHR. This study suggests potential for refining mechanical properties and methodologies, advancing denture restoration practices.*

Keywords: *Polyamide dentures, Mechanical properties, Tensile strength, Transverse strength, Denture repair techniques*

Introduction:

The field of dentistry has witnessed continuous evolution in the quest for ideal denture base materials that offer both functional efficiency and aesthetic appeal. From ancient materials like wood and ivory to the introduction of polymethyl methacrylate (PMMA) in the mid-20th century by Walter Wright, the journey of denture base materials has been marked by a relentless pursuit of improved properties and performance [1], [2]. With the emergence of innovative polyamide denture base materials, a new chapter in denture fabrication has begun, bringing forth a range of advantages and opportunities.

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Polyamide denture base materials have gained prominence owing to their distinct advantages over traditional options. These materials boast enhanced mechanical properties, lightweight nature, biocompatibility, and resistance to staining [3]. Moreover, their malleability under heat and the incorporation of additives like nylon fibers and silicon rubber contribute to their flexibility, enabling intricate designs for various dental applications [4]. Their ability to address patient concerns such as allergies, discomfort, and aesthetics has further fueled their adoption in modern dental prosthetics.

The utility of polyamide materials extends to a diverse array of applications within dentistry, encompassing orthodontic aligners, removable partial dentures (RPDs), soft denture liners, mouth guards, and temporary crowns and bridges [5]. This adaptability has positioned polyamide materials as a versatile solution catering to both functional and aesthetic demands. However, ensuring the durability and longevity of repaired polyamide dentures demands careful consideration of repair techniques and surface treatments.

The propensity of polyamide denture base materials to undergo fractures necessitates the development of effective repair strategies. Adhesive bonding and complete replacement of the denture base are common approaches, while reinforcement techniques involving metal wires are employed to prevent further damage [6]. Additionally, understanding the mechanical properties of these materials is pivotal for their successful application.

Tensile strength, a measure of a material's resistance to breaking and stretching, and transverse strength, indicative of its capacity to withstand bending or twisting forces, play a pivotal role in determining the suitability of denture base materials [7],[8]. These properties are particularly pertinent in the context of functional dentures, ensuring their ability to withstand the demands of oral function.

This study endeavors to comprehensively explore the influence of diverse surface treatments and repair materials on the tensile and transverse strength of repaired polyamide dentures. Through systematic investigation, the study aims to unearth optimal combinations that enhance the performance and longevity of ppolyamide-repaireddentures in the contemporary landscape of dental prosthetics. As dental practitioners strive to provide patients with functional and aesthetically pleasing solutions, an in-depth understanding of polyamide denture base materials and their mechanical attributes proves invaluable.

Materials and Methods:

Materials:

The materials used in this study are detailed in Table.1, highlighting their origin and expiration dates. The components encompass hard die stone, separating medium, fusing liquids, sprue wax of varying dimensions, and medium standard pink cartridges

Table (1) The materials used in the study

No	Materials	Made in	Expiration
1.	Hard die stone type 4	Germany	7/202
2.	Separating medium Zeisol	Italy	11/2023
3.	Fusing liquid evidsun	Russian	6/2024
4.	Fusing liquid TCS	USA	4/2025
5.	Sprue wax 4mm	China	1/2025
6.	Sprue wax 2mm	China	1/2025
7.	25 medium standard pink cartridges	China	3/2023

Equipment and Instruments:

The equipment and instruments employed in the study are listed in Table 2, emphasizing their origin. These include items such as brushes, flasks, pneumatic injection molding machines, heat gun devices, heat tubes, clamps, wax knives, and lacron carvers.

Table (2) Equipment and instruments used in present study

Equipment and instruments	origin
brush	China
Flask	England
Pneumatic injection molding machine (ROKO)	Europe
Heat gun device	China
Heat tube	China
Clamp	England
Wax knife	China
Lacron carver	China

Method:

Distribution of the Samples:

A total of 160 acrylic resin samples were carefully prepared for the study. These samples were organized into three distinct sets, each serving a specific purpose. Within these sets, 40 specimens were assigned to the control group, equally divided into two subgroups: 20 were subjected to transverse strength testing, while the remaining 20 underwent tensile strength testing. Among these, 10 samples were intact (control positive C1), and the other 10 had fractures (control negative C2). It is important to note that none of these 40 specimens received any additional fusing material.

Furthermore, three groups of specimens were repaired using three distinct methods: reinjection, recycling through sprue material, and manual heating with flexible cartilage. Among the repaired specimens, 20 were allocated for each method. These repaired specimens were then further categorized into two subgroups of 10 samples each, based on the type of surface treatment applied: either ICS fusing material or evidsun fusing material.

In total, all 160 specimens, repaired using reinjection, sprue, and flexible cartilage methods, and featuring the two aforementioned surface treatment types, were subjected to testing for both tensile and transverse strength.

Pilot Study:

The pilot study aimed to select suitable flexible components and surface treatments to enhance adhesion. Evaluation of tensile and transverse bond strength between acrylic resin and base followed the addition of materials to experimental groups (liquid nylon polyamide) using an ultrasonic homogenizer. Standard clamping, finishing, and polishing stages were carried out before testing.

Preparation of Specimens:

Transverse and tensile strength specimens were prepared according to specific dimensions for testing as listed below

-Transverse specimens (65x10x2.5±0.03mm), length, width, and thickness, respectively parameters needed for the transverse strength test in accordance with ADA Specification No.12,1975. 19 as shown in Figure (1).

- Tensile strength specimens: Dimensions of specimen was according to ISO 527:1993 was Gauge length: 60 ± 2 mm, Width: 12 ± 1 mm, Thickness: 2.0± 0.2

Preparation for Mold:

The process of creating molds for specimens involved die stone placement, wax pattern addition, and die stone application, culminating in the creation of solid models.

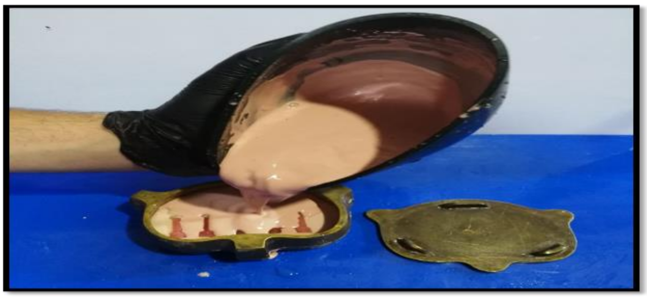

Figure. 1 coating of mold by stone

Flexible Polyamide Specimen Preparation:

Flexible resin specimens were prepared using an injection molding machine at specified settings. Rectangular metal patterns and sprue wax were used to facilitate material flow see Figure 2

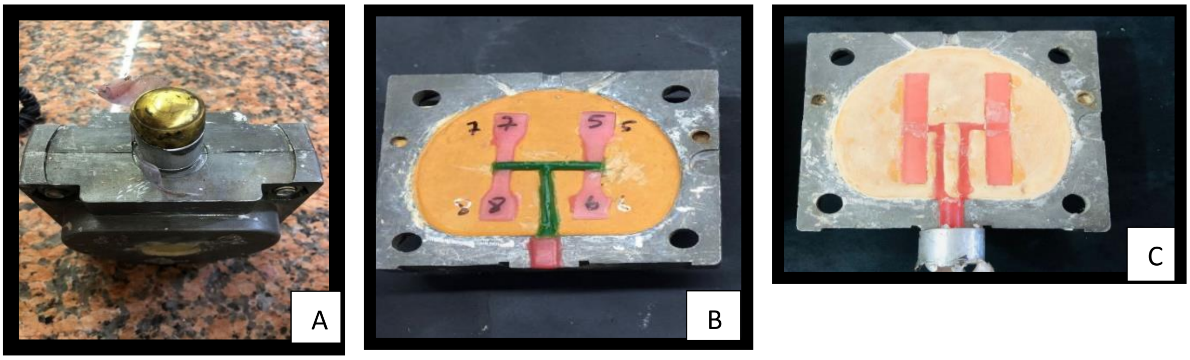

Figure 2. A. Sprue Molding B. Cartilage Placed on the Flask, C. Flask was closed and tightened with the screws

Preparation of Repaired Polyamide Specimen:

Three different repair methods were employed on the specimens: reinjection, manual heating using flexible cartilage, and recycling manual heating (spruing). The repaired specimens were then subjected to further processing, finishing, and polishing.

Methods for Tensile Test:

Tensile strength testing was conducted using an Instron universal machine, and bond strength was computed using relevant formulas. Based on the load (F) in (N) at fracture and the adhesive surface area (S) in (mm2), the tensile bond strength was computed and translated to Map for samples.[9]

$T.\ S = F/S$ ……… (1)

$S = \pi /4.\ D2$ where $\pi = 22/7$

D (diameter) =5 mm, S= 19.64 mm2
T. S= tensile strength (N/mm2)
F=force at failure
S= area of cross section

Transverse Strength Test:

Transverse strength testing involved using a three-point bending test setup and an Instron machine to calculate bond strength. The load cell was set at 100 kg, and the force at fracture (F) and the sticky surface area (S) were computed and converted to Mpa [10] as in the following.

B.S = F /   ………. (2)
B.S = Bond strength (N/mm^2) or (MPa)
F=force at failure $S= (\pi / 4) \times D^2$; π =22/7 or 3.14
D (diameter) = 5mm, S = 19.64 mm^2.

Statistical Analysis:

Data collected from the different techniques and controls were analyzed using SPSS software. Descriptive statistics were computed, and parametric tests (t-test and Welch ANOVA) were used. Significance was determined at $p \leq 0.05$.

By comprehensively investigating the impact of diverse repair techniques and surface treatments on the mechanical properties of polyamide dentures, this study seeks to provide valuable insights into enhancing the longevity and performance of these materials in the context of contemporary dental prosthetics.

Results

Tensile Strength Test:

The study identified significant differences (F=77.107, p-value < 0.0001) among the means of tensile strength for various American processing techniques and controls. The highest mean value was observed in Control/ Nylon Non-repair (C1) at 23.813 ± 3.390 MPa, while the lowest mean value was in Control/ Nylon Repair (C2) at 5.657 ± 0.715 MPa. Post hoc analysis revealed that the tensile strength was significantly higher in C1 compared to C2 and all different processing techniques (RcNHR, NHR, RiNR). Additionally, RiNR showed higher tensile strength than both RcNHR and C2. (Refer to Table 3 A and Figure 4.2)

Table 3 A) Comparison of Means for Tensile Strength in different America's processing techniques (Recycled Nylon-manual heating repair (RcNHR), Nylon-manual heating repair (NHR), and Re-injection nylon repair (RiNR)) and both studied controls (C1 and C2) using ANOVA statistical test.

Processing Techniques	No.	Mean	SD	SE	Min.	Max.	WF-Statistic	P-value	*Post-hoc* analysis $^{\psi}$
C1	10	23.813	3.390	1.072	17.390	28.760	77.107	<0.0001 (HS)	A B
C2	10	5.657	0.715	0.226	4.590	6.962			A B
RcNHR	10	7.980	0.633	0.200	6.930	8.910			A B
NHR	10	8.274	1.733	.548	5.540	10.500			A
RiNR	10	15.486	4.452	1.408	9.790	24.450			B

Abbreviations: **WF=** data were analyzed by using the Welch-Fisher ANOVA test; **ψ=** The Dunnett C method was used for *post hoc* comparisons and similar letters were statistically significant; **C1=** Control/ Nylon Non-repair; **C2=** Control/ Nylon Repair; **RcNHR=** Recycled Nylon-manual Heating Repair; **NHR=** Nylon-manual Heating Repair; **RiNR=** Re-injection Nylon Repair; **SD=** standard deviation; **SE=** standard error; **Min.=** minimum, **Max.=** maximum and **HS=** High significant.

Table 4.4 B) Multi-comparison of Means for Tensile Strength in different America's processing techniques (Recycled Nylon-manual heating repair (RcNHR), Nylon-manual heating repair (NHR), and Re-injection nylon repair (RiNR) and both studied controls (C1 and C2) using Dunnett C statistical test.

		Mean Difference	SE	p-value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
C1	C2	-18.157*	1.096	<0.0001	HS	-21.777	-14.537
	RiNR	-9.829*	1.426	<0.0001	HS	-14.574	-5.085
	RcNHR	-2.323*	.302	<0.0001	HS	-3.238	-1.409
	NHR	-2.617*	.593	0.006	HS	-4.507	-.727
C2	C1	18.157*	1.096	<0.0001	HS	14.537	21.777
	RiNR	8.327*	1.770	0.002	HS	2.937	13.718
	RcNHR	15.833*	1.091	<0.0001	HS	12.217	19.450
	NHR	15.539*	1.204	<0.0001	HS	11.765	19.314
RiNR	C1	9.829*	1.426	<0.0001	HS	5.085	14.574

	C2	-8.327^{*}	1.770	0.002	HS	-13.718	-2.937
	RcNHR	7.506^{*}	1.422	0.003	HS	2.764	12.248
	NHR	7.212^{*}	1.511	0.004	HS	2.374	12.050
RcNHR	C1	2.323^{*}	.302	<0.0001	HS	1.409	3.238
	C2	-15.833^{*}	1.091	<0.0001	HS	-19.450	-12.217
	RiNR	-7.506^{*}	1.422	0.003	HS	-12.248	-2.764
	NHR	-.294	.583	0.985	NS	-2.170	1.582
NHR	C1	2.617^{*}	.593	0.006	HS	.727	4.507
	C2	-15.539^{*}	1.204	<0.0001	HS	-19.314	-11.765
	RiNR	-7.212^{*}	1.511	0.004	HS	-12.050	-2.374
	RcNHR	.294	.583	0.985	NS	-1.582	2.170

Abbreviations: **C1=** Control/ Nylon Non-repair; **C2=** Control/ Nylon Repair; **RcNHR=** Recycled Nylon-manual Heating Repair; **NHR=** Nylon-manual Heating Repair; **RiNR=** Re-injection Nylon Repair; **SD=** standard deviation; **SE=** standard error; **HS=** High significant; **S=**significant; **NS=** Non significant; ***=**The mean difference is significant at the 0.05 level**.**

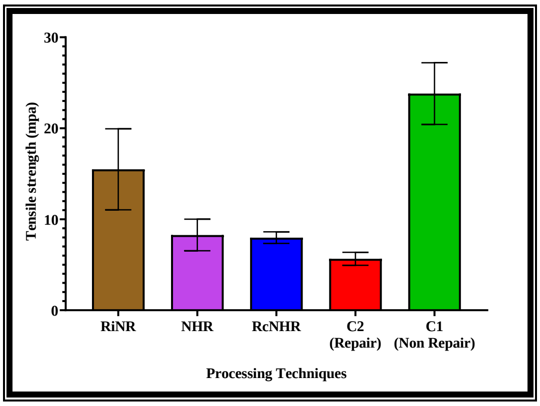

Figure (3) Bar chart for Tensile Strength in different America's processing Techniques (Recycled Nylon-manual heating repair (RcNHR), Nylon-manual heating repair (NHR), and Re-injection nylon repair (RiNR)) and both studied controls (C1 and C2).

Transvers Strength Test:

The transvers strength test also showed significant differences (F=25.991, p-value < 0.0001) among the means of transvers strength for various American processing techniques and controls. Similar to the tensile strength results, Control/ Nylon Non-repair (C1) exhibited the highest mean value at 107.748 ± 33.692 MPa, while Control/ Nylon Repair (C2) had the lowest mean value at 8.637 ± 1.430 MPa. Post hoc analysis demonstrated that transvers strength was significantly higher in C1 compared to C2 and all different processing techniques (RcNHR, NHR, RiNR). RcNHR, NHR, and RiNR did not show significant differences among themselves. (Refer to Table 4.10 A and Figure 4.7)

Table (4) A) Comparison of Means for Transvers Strength in different America's processing techniques (Recycled Nylon-manual heating repair (RcNHR), Nylon-manual heating repair (NHR), and Re-injection nylon repair (RiNR) and both studied controls (C1 and C2) using ANOVA statistical test.

Processing Techniques	**No.**	**Mean**	**SD**	**SE**	**Min.**	**Max.**	**WF-Statistic**	**P-value**	***Post-hoc* analysis** $^{\psi}$
C1	10	107.748	33.692	10.654	39.790	169.360	25.991	<0.0001 (HS)	A B
C2	10	8.637	1.430	0.452	6.483	10.452			A B
RcNHR	10	19.491	3.233	1.022	15.760	26.530			A B
NHR	10	25.309	3.614	1.143	20.130	30.550			A
RiNR	10	25.906	4.342	1.373	17.130	31.640			B

Abbreviations: **WF=** data were analyzed by using the Welch-Fisher ANOVA test; **ψ=** The Dunnett C method was used for *post hoc* comparisons and similar letters were statistically significant; **C1=** Control/ Nylon Non-repair; **C2=** Control/ Nylon Repair; **RcNHR=** Recycled Nylon-manual Heating Repair; **NHR=** Nylon-manual Heating Repair; **RiNR=** Re-injection Nylon Repair; **SD=** standard deviation; **SE=** standard error; **Min.=** minimum, **Max.=** maximum and **HS=** High significant.

Table 4.11 B) Multi-comparison of Means for Transvers Strength in different America's processing techniques (Recycled Nylon-manual heating repair (RcNHR), Nylon-manual heating repair (NHR), and Re-injection nylon repair (RiNR) and both studied controls (C1 and C2) using Dunnett C statistical test.

		Mean Difference	**SE**	**p-value**	**Sig.**	**95% Confidence Interval**	
						Lower Bound	**Upper Bound**
C1	C2	-99.111*	10.664	<0.0001	HS	-134.941	-63.281
	RiNR	-17.269*	1.446	<0.0001	HS	-21.949	-12.588
	RcNHR	-10.854*	1.118	<0.0001	HS	-14.399	-7.308
	NHR	-16.672*	1.229	<0.0001	HS	-20.603	-12.741
C2	C1	99.111*	10.664	<0.0001	HS	63.281	134.941
	RiNR	81.842*	10.742	<0.0001	HS	45.969	117.715
	RcNHR	88.257*	10.703	<0.0001	HS	52.407	124.107
	NHR	82.439*	10.715	<0.0001	HS	46.582	118.296
RiNR	C1	17.269*	1.446	<0.0001	HS	12.588	21.949
	C2	-81.842*	10.742	<0.0001	HS	-117.715	-45.969

	RcNHR	6.415*	1.712	0.012	S	1.194	11.636
	NHR	.597	1.787	0.997	NS	-4.824	6.018
RcNHR	C1	10.854*	1.118	<0.0001	HS	7.308	14.399
	C2	-88.257*	10.703	<0.0001	HS	-124.107	-52.407
	RiNR	-6.415*	1.712	0.012	S	-11.636	-1.194
	NHR	-5.818*	1.533	0.010	S	-10.461	-1.175
NHR	C1	16.672*	1.229	<0.0001	HS	12.741	20.603
	C2	-82.439*	10.715	<0.0001	HS	-118.296	-46.582
	RiNR	-.597	1.787	0.997	NS	-6.018	4.824
	RcNHR	5.818*	1.533	0.010	S	1.175	10.461

Abbreviations: **C1=** Control/ Nylon Non-repair; **C2=** Control/ Nylon Repair; **RcNHR=** Recycled Nylon-manual Heating Repair; **NHR=** Nylon-manual Heating Repair; **RiNR=** Re-injection Nylon Repair; **SD=** standard deviation; **SE=** standard error; **HS=** High significant; **S**=significant; **NS=** Non significant; *****=The mean difference is significant at the 0.05 level**.**

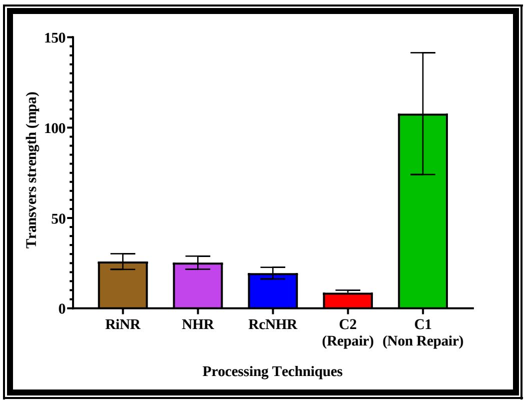

Figure (4) Bar chart for Transvers Strength in different America's processing Techniques (Recycled Nylon-manual heating repair (RcNHR), Nylon-manual heating repair (NHR), and Re-injection nylon repair (RiNR)) and both studied controls (C1 and C2).

Comparisons Between American and Russian Processing Techniques:

A comparison of processing techniques between American and Russian materials was also performed. While differences were observed, some of the mean differences did not reach statistical significance. For instance, there was no statistically significant difference in the means of tensile strength between America's RcNHR and Russia's RcNHR (t=1.801, p-value = 0.089). However, the mean difference in transvers strength between these two materials was not statistically significant (t=1.33, p-value = 0.20). Similar findings were observed for the comparison of NHR and RiNR between the American and Russian materials.

the results of the research highlight the significant differences in tensile and transvers strength among different processing techniques for the American material. The comparisons between American and Russian materials suggest some differences in specific processing techniques, although not all differences were statistically significant. The detailed statistical analysis can be found in Tables 4.1-4.13 and the corresponding figures presented in the paper.

Table (5) Comparison of Means for Transvers Strength between America's NHR and Russia's NHR using independent t-test.

Processing Techniques	No.	Mean	SD	SE	Min.	Max.	t-test	P-value	Sig.
America's NHR	**10**	**25.309**	**3.614**	**1.143**	**20.130**	**30.550**	**2.538**	**0.021**	**(S)**
Russia's NHR	**10**	**21.274**	**3.496**	**1.105**	**14.200**	**25.420**			

Abbreviations: **NHR=** Nylon-manual Heating Repair; **SD=** standard deviation; **SE=** standard error; **Min.=** minimum, **Max.=** maximum and **S=**Significant.

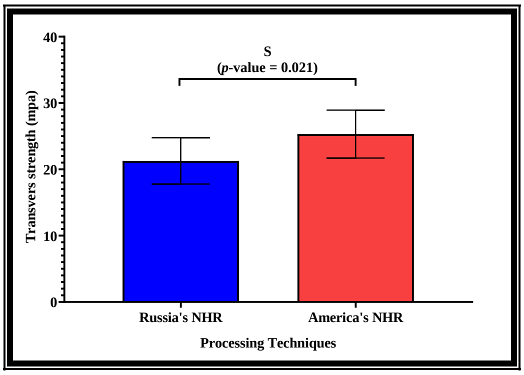

Figure (5) Bar chart for Transvers Strength between America's NHR and Russia's NHR

Discussion

Tensile Strength:

Tensile strength is a critical measure of a material's resistance to breaking under tension. The study employed a 200 kg tensile bond strength test to evaluate this property. Repairing dentures is a common practice to avoid the expense and time of creating new ones. However, fractures in repaired dentures often occur at the interface between the original base and the repair materials, where stress is concentrated. Surface treatments involving chemical and physical techniques were explored to improve the bonding strength between the base and repair material.

The study found highly significant differences in tensile strength among various processing techniques for both the American and Russian materials. Control samples without repair had higher tensile strength compared to repaired samples, regardless of the processing technique. Among the American techniques, Control/ Nylon Non-repair (C1) showed the highest mean tensile strength, while Control/ Nylon Repair (C2) showed the lowest mean. This trend was consistent across all different processing techniques (Recycled Nylon-manual heating repair, Nylon-manual heating repair, and Re-injection nylon repair).

Comparing American and Russian processing techniques, the study found no statistically significant difference in the means of tensile strength for Recycled Nylon-manual heating repair (RcNHR) and Re-injection nylon repair (RiNR). However, differences were observed between Nylon-manual heating repair (NHR) techniques.

Transverse Strength:

Transverse strength is crucial for materials subjected to bending or twisting forces. The three-point bending test was employed to measure transverse strength. Just as with tensile strength, repairing dentures aims to restore strength while avoiding fracture propagation. Fractures in repaired dentures often occur at the interface junction between the original base and the repair materials.

The study found highly significant differences in transverse strength among various processing techniques for both the American and Russian materials. Control samples (C1) exhibited higher transverse strength compared to repaired samples (C2) for both American and Russian techniques. Among the American techniques, Control/ Nylon Non-repair (C1) had the highest mean transverse strength, while Control/ Nylon Repair (C2) had the lowest mean.

Post hoc analyses revealed significant differences in transverse strength between different processing techniques and controls. Additionally, the study compared transverse strength between American and Russian processing techniques. For Recycled Nylon-manual heating repair (RcNHR) and Re-injection nylon repair (RiNR), no statistically significant differences were found between the American and Russian materials. However, differences were observed for Nylon-manual heating repair (NHR) techniques.

The results indicate significant differences in both tensile and transverse strength among different processing techniques and controls, both for the American and Russian materials. The study also highlighted the importance of surface treatments in improving the bonding strength between the base and repair materials. These findings contribute valuable insights into enhancing the mechanical properties of denture base materials, aiding dentists and dental technicians in making informed repair and enhancement decisions.

Conclusion

This study focused on American polyamide denture bases, yielding key findings. Application of flexible materials notably improved tensile and transverse strength, with highest values in C1 and lowest in C2. Repair processing technique significantly impacted mechanical properties. Promising outcomes were observed with Reinjection and sprue-material methods, while flexible cartilage and reinjection showed potential. Notably, Re-injection nylon repair (RiNR) excelled in both treatments. Transverse strength mirrored tensile strength trends. While Russian and American treatments showed no significant differences in RcNHR and RiNR groups, NHR group displayed disparities. This research guides denture repair strategies, hinting at potential for enhancing mechanical properties with flexible materials and specific techniques.

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