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Flexural Strength of E - glass Fiber Reinforced Dental Polymer and Dental High Impact Strength Resin

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Fractures of denture base polymer material are one of the most frequent reasons for repair of removable dentures. Therefore, there is a continuous effort to strengthen them, and polymer materials of high resistance to fracture are being developed. The aim of this study was to determine the flexural strength of denture base polymers (pressure-heat polymerizing and auto polymerizing) reinforced with E -glass fibers and high impact strength resin (injectional polymerization) material using the "short beam" method. Specimens were tested after polymerization and after artificial ageing performed by storage at 37 ºC temperature during 28 days and thermocycling. Microscopic examination was performed to determine the quality of bonding between glass fibers and matrix. The study showed significantly higher values of flexural strength (130.1-163.88 MPa) of glass fiber reinforced specimens compared to the un-reinforced specimens (91.77 – 122.75 MPa) – control group, matching those of high impact strength resin (145.67 MPa). Between the groups of samples tested after polymerization and storage in water at 37 ºC during 28 days there was no statistically significant difference in flexural strength values while samples tested after thermocycling unexpectedly revealed significantly higher values. Fiber reinforced materials and high impact strength resin revealed similar results of flexural strength both being acceptable for clinical use. Obtained results suggest that the increase of temperature (during thermocycling) had the effect of prolonged polymerization which resulted in a decrease of residual monomer volume, enhancing polymer mechanical properties.

Usporedba savojne čvrstoće stomatoloških polimera ojačanih E-staklenim vlaknima i stomatoloških smola visoke otpornosti na udarac

Izvornoznanstveni članak

Lomovi polimernih materijala za izradu baza proteza jedan je od najčešćih razloga za popravak pomičnih proteza. Stoga se ulažu stalni napori kako bi se ti materijali očvrsnuli, te su razvijeni stomatološki polimerni materijali visoke otpornosti na lom. Cilj ovog istraživanja bio je odrediti metodom "kratke grede" savojnu čvrstoću polimera za izradu baza proteza (koji tlačno-toplinski polimeriziraju i auto-polimeriziraju) ojačanih uporabom E-staklenih vlakana, te stomatoloških smola visoke otpornosti na udarac (injekcijska polimerizacija) i to nakon polimerizacije i nakon skladištenja uzoraka u vodi temperature 37 ºC tijekom 28 dana, te termocikliranja. Izvršena je mikroskropska pretraga mikrostrukture kompozitnih uzoraka kako bi se ocijenila kvaliteta sveze između staklenih vlakana i matrice. Ispitivanje je pokazalo značajano više vrijednosti savojne čvrstoće vlaknima ojačanih kompozitnih uzoraka (130,1 – 163,88 MPa) u usporedbi s neojačanim uzorcima – samo materijal matrice (91,77 – 122,75 MPa) kontrolne skupine. Vrijednosti savojne čvrstoće vlaknima ojačanih kompozitnih uzoraka podudarali su se s vrijednostima savojne čvrstoće stomatoloških smola visoke otpornosti na udarac (145,67 MPa). Između skupina uzoraka ispitivanih nakon polimerizacije i skladištenja u vodi temperature 37 ºC tijekom 28 dana nije bilo statistički značajne razlike u vrijednosti savojne čvrstoće, dok su termociklirani uzorci neočekivano pokazali značajno više vrijednosti. Vlaknima ojačani stomatološki polimeri i stomatološke smole visoke otpornosti na udarac ostvarili su slične rezultate savojne čvrstoće koji su prihvatljivi za kliničku uporabu. Dobiveni rezultati navode i na zaključak kako je porast temperature (tijekom termocikliranja) izazvao efekt produžene polimerizacije koja je pak rezultirala snižavanjem volumena ostatnog monomera poboljšavajući mehaničke osobine polimernog materijala.

1. Introduction

Since the beginning of the 1940s, when it was used as denture base material for the first time, methyl metacrylate has proved to be the most reliable material. Despite many advantages, methyl metacrylate is prone to fracturing. Fractures of that denture base polymer material are one of the most frequent (64%) reasons for denture repair [1-4]. Theoretically, an edentulous patient would not be able to fracture a denture due to a reasonable high static rigidity of the denture construction and weak masticatory forces that are developed during the use of removable dentures [5, 6]. But with the ever-increasing use of implants, even for the anchorage of removable dentures, bite forces that are developing on the denture base are growing [7, 8]. Also, the influence of material fatigue on flexural strength of the material is decisive, which is one of the most significant reasons for denture fractures [9, 10]. Polymer dentures may be strengthened by modifications of material itself, or by incorporating various reinforcements into the polymer material that enhance the flexural strength and impact strength [11].

Initially, reinforcement of dentures was achieved by embedment of metal wires or nets, but that approach resulted only in partial improvement of flexural and impact strength. Subsequently, physical and mechanical properties of acrylic dentures were enhanced by integration of different fibers with different fiber architectures into the denture base polymer [12]. For that reason graphite, glass, and organic fibers, such as, aramide and polyethylene fibers, were used to improve the flexural and impact strength [12-16]. Today, the most commonly used fibers in dentistry are glass fibers, because of their acceptable esthetics [14,17-21] and good bonding with polymers via silane coupling agents [22-24].

Another approach to flexural strength improvement is incorporation of rubber phase in polymer pearls – thus producing materials known as high impact strength resins [25-30].

Another great disadvantage of polymer materials is a tendency to dimensional changes due to contraction of polymer material during polymerization. Therefore different attempts were made in order to compensate polymerization contraction and achieve complete reproduction of the modeled dental object in wax during dentures production and in that way enable better contact of the denture and its bearing tissues [28-30].

As outlined by the manufacturer of one dental high impact strength resin, their SR-IVOCAP (Ivoclar Vivadent, Schaan, Liechtenstein) procedure completely solves the problem of dimensional changes, with improved strength of the material itself [25]. Therefore, this procedure should be especially applicable to different dental appliances.

2. Aim of the study

Different strength and quality enhancers of polymer materials have been previously described in literature, both dental and technical. But the results are often contradictory, and instructions and explanations of the dental companies that produce denture base materials are usually biased and only rarely comply with the results of the objective investigations. Also, glass fibers produced especially for dental application by dental manufacturers are very expensive for wider clinical use especially in countries with lower living and health standards.

So, it is the aim of this study to assess the values of flexural strength of polymer materials commonly used for denture bases, but additionally reinforced with "industrial" E - glass fibers, and to compare them with the flexural strength values of dental high impact strength resin. In order to simulate the ageing process that occurs on the dentures placed in the mouth the samples were tested after: (I) material polymerization, (II) 28 days of storage in distilled water at 37 ºC, and (II) thermocycling procedure.The results should be statistically analyzed and compared in order to obtain statistical significance that would show which material is better for clinical use regarding investment/benefit ratio.

3. Materials and methods

Two hundred and ten quadratic specimens with smooth surfaces and dimensions of 18 x 10 x 3 mm, were made of Meliodent Heat Cure and Meliodent Rapid (Heraeus Kulzer, Hanau, Germany) polymer, the aforementioned polymers reinforced with E - glass unidirectional fibers (1200 tex, Kelteks, Duga Resa, Croatia) and net shaped fibers (ST-250, Kelteks, Duga Resa, Croatia), and high impact strength resin Ivocap "Plus" High Impact (Ivoclar, Schaan, Liechtenstein). Specimens were split across seven different groups with thirty specimens each. To obtain uniform specimens with glass fibers accurately placed, special metal cuvette, with two thick polished metal parts on the sides and two thin metal parts in the middle, was constructed. The middle metal parts had ten quadratic perforations of the size of a specimen (18 x 10 mm). One thin metal part was 1 mm thick, whereas, the other thin metal part was 2 mm thick, and placed together (3 mm thick) they also served as a placeholder for proper glass fiber alignment (1 mm from one side and 2 mm from the other side of a specimen). All metal parts of the cuvette were covered twice with a thin layer of Ivoclar Separating Fluid (Ivoclar Vivadent, Schaan, Liechtenstein). Non-impregnated E – glass fibers were cleaned with 1.6 mol sulphuric acid for 30 sec. They were rinsed in distilled water, and air dried at room temperature for 24 hours. After that they were dipped into 98 % γ-metacryloxypropyl-trimethoxysilane

(Sigma-Aldrich Co., St. Louis, MO, USA), and heated in dental sterilizer (ISO 400, Aesculap, Tuttlingen, Germany) at temperature 100 °C for 2 hours in order to be pre-impregnated. Afterwards they were impregnated with Meliodent Heat Cure polymer syrup (weight ratio polymer/monomer 10:8) for eight minutes. Pressure-heat polymerization polymer (Meliodent Heat Cure) was mixed according to the manufacturer's instructions and placed in both halves (one thick part + one thin middle part) of the special metal cuvette. Impregnated E - glass fibers, unidirectional or net shaped were then placed in-between. The unidirectional glass fibers were laid along the specimens, so that they were orthogonal to the force to be applied, whereas, the net shaped glass fibers were positioned at an angle of 45 °. The cuvette was closed and put in a hydraulic press (Zlatarne, Celje, Slovenia) under 200 bar. The cuvette was subsequently moved to a manual bench vice and the polymerization was performed in a polymerizing apparatus (Type 5518, KaVo EWL, Biberach, Germany) according to the manufacturer's instructions. Firstly, the cuvette was placed in boiling water and heating was stopped for 15 minutes, then heating was again turned on and the cuvette was boiled for 20 minutes. After boiling the cuvette was left to slowly cool down in water bath of polymerizing apparatus. A similar procedure was followed for the Meliodent Rapid auto polymerizing material, the difference being shorter impregnation time of glass fibers - two minutes in Meliodent Rapid polymer syrup – because of the auto polymerizing character of the material. As suggested by the manufacturer, auto polymerizing material was additionally polymerized in a pressure pot (Polyclav, Dentaurum, Pforzheim, Germany) through 10 minutes under 2 bar pressure at 45 °C temperature.

Given that the Ivocap "Plus" High Impact material (Ivoclar) required its own special flask and apparatus (SR-IVOCAP System, Ivoclar) these specimens were somehow differently produced. Firstly, wax patterns with the aforementioned dimensions were modeled and mounted on a wax profile (3 mm thick) providing the injection method of polymerization. One half of the original Ivoclar flask was filled with Moldano plaster (Heraeus Kulzer, Hanau, Germany), and wax patterns mounted on wax profiles were placed onto plaster surface at least 1 cm from the flask margin. After the plaster had hardened and wax patterns were half imbedded, plaster surface was covered once with a thin layer of Ivoclar Separating Fluid. Then the other half of the flask was placed on the first one, and filled completely with Moldano plaster. After hardening of that second portion of plaster the flask was opened and wax rinsed in the rinsing machine (Type 5522, KaVo EWL, Biberach, Germany) leaving the impressions of future specimens. The plaster surfaces were then isolated twice in a thin layer again using Ivoclar Separating Fluid. Both halves of the flask were joined together and tightened with Ivoclar bench vice. The injection method was executed in a manner in which the capsule containing Ivocap "Plus" High Impact material was initially prepared. The monomer from the bottle was poured in the capsule with polymer powder and then shaken for five minutes in a Cap vibrator (Ivoclar). The capsule with prepared polymer was attached to the flask and the system of pressurized air (6 bar) was connected for five minutes to inject polymer material into the flask. Later the flask was immersed in boiling water in a polymerization bath (Ivoclar) for 35 minutes, after which it was held in cold water for 20 minutes. Throughout this entire cooling process the flask with samples was still subjected to the 6 bar pressure.

After polymerization and cooling the cuvettes/flasks used for both methods were opened and the specimens were detached. Possible polymer excess on all the specimens was removed with a carbide bur (Ivomill, Ivoclar Vivadent). The margins were finished using sandpaper (Sianor 7/0B, Frauenfeld, Switzerland). The specimens of the stated dimensions were checked with calipers (Dentarium 042-751, Dentarium, Ispringen, Germany), with the maximum allowed deviation of 0.05 mm.

The specimens of all seven groups were further subdivided into three subgroups of ten specimens each that were further tested by the short beam method (Figure 1) [31]. The moving speed of the blade was set to 1.5 mm/min to determine the samples' flexural strength after (I) polymerization of the specimens, (II) immersion in distilled water with temperature at 37 °C (thermostat Btuj, Poznan, Poland) for 28 days, and(III) thermocycling of the specimens according to Hansson's method [32]. Fiber reinforced specimens were placed in a testing holder, in a position wherein the fiber reinforcements were closer to the posts (1mm away from the posts and 2 mm from the blade).The force causing breakdown was noted and the flexural strength was calculated according to the formula:

$$\sigma_{max} = \frac{F_{max} \cdot l}{4} \cdot \frac{6}{b \cdot h^2} \left(\frac{N}{mm^2} = MPa \right), \quad (1)$$

F_{max} – measured force of the loader (N),

l – distance between posts (here 15 mm),

b – width of the specimen (here 10 mm),

h – height of the specimen (here 3 mm).

Numerical results of the flexural strength were analyzed with SPSS statistical package (SPSS Inc., Chicago, USA). Statistical analysis was performed using descriptive statistics, one-way analysis, and univariate analysis of variance. The statistical significance of difference between flexural strength values of the specimens was calculated using the Scheffe test.

To determine the quality of bonding between fibers and matrix, glass fiber reinforced specimens were randomly chosen, sealed in Durofix material (Struers, Rodovre, Denmark), ground, and polished according to the routine procedure [33], to obtain a smooth surface suitable for microscopic examination, which was performed with a light microscope, Olympus BH2-UMA (Olympus optical, Tokyo, Japan). Characteristic images were photographed through the microscope ocular using a camera, Olympus C-5050 Ultra Zoom (Olympus optical, Tokyo, Japan).

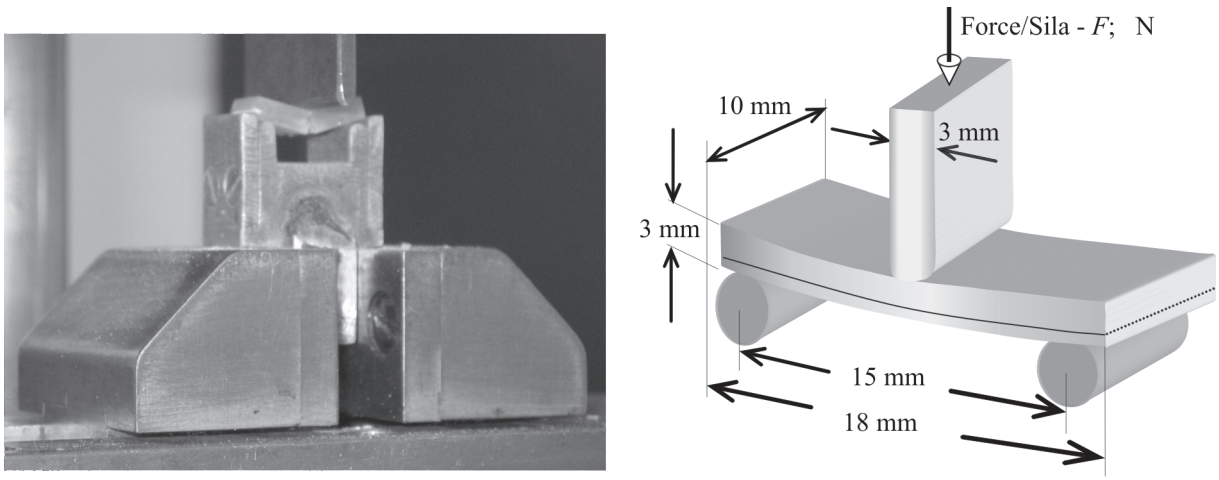

Figure 1. Specimen loading – scheme and dimensions
Slika 1. Opterećenje uzoraka – shema i dimenzije

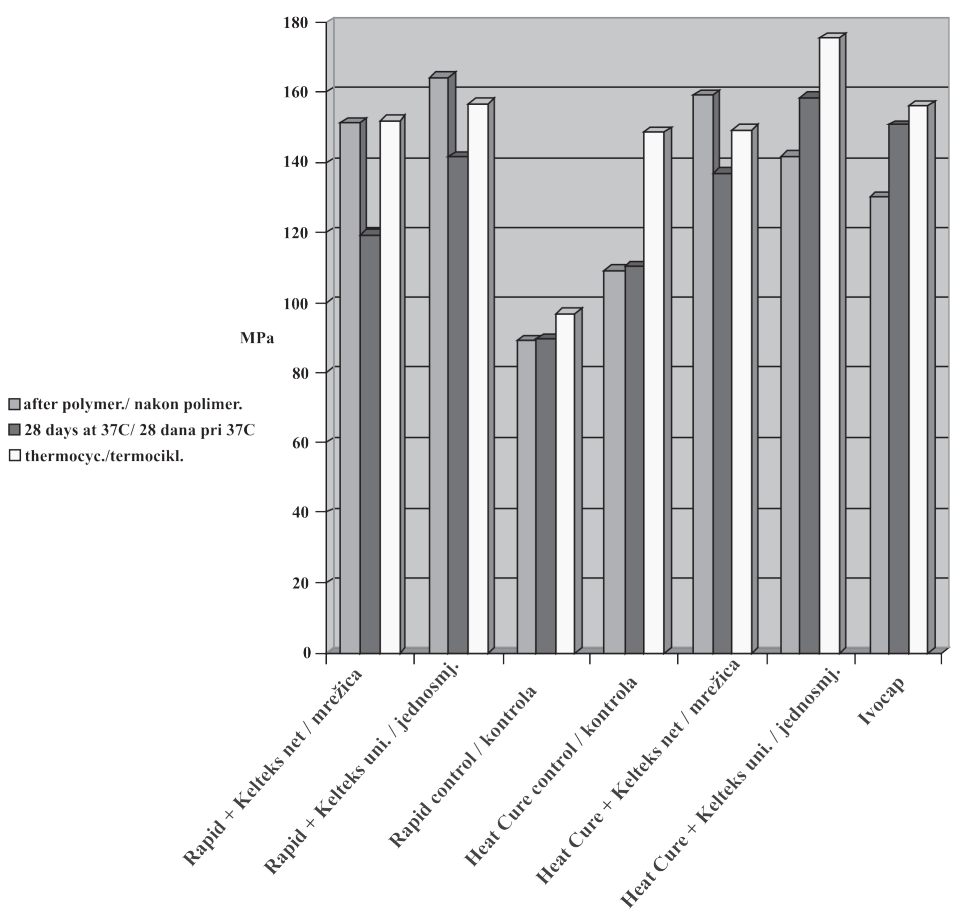

Figure 2. Arithmetic means of flexural strength
Slika 2. Aritmetičke sredine savojne čvrstoće

4. Results

Heat-pressure polymerizing Meliodent Heat Cure and auto polymerizing Meliodent Rapid polymer specimens (control groups) demonstrated the lowest flexural strength, whereas, the specimens reinforced with glass fibers showed higher flexural strength values, in addition to tested high impact strength resin (Figure 2). Scheffe's test applied across seven investigated groups of specimens revealed a statistically significant difference (P<0.05) between some of these groups, as shown in Table 1. The test between subjects effects revealed that ageing procedures (immersion in distilled water at temperature 37 °C for 28 days, thermocycling), and the type of polymer (heat cure, auto polymerizing, high impact strength resin) had a significant influence (P<0.05) on the achieved flexural strength values (Table 2). As expected reinforced auto polymerizing polymer material was weaker than reinforced heat-pressure polymerizing polymer (P<0.05), whereas, there was no statistically significant difference (P>0.05) between the reinforced heat cure polymer and the high impact strength resin (Table 3). Unexpectedly there was no statistically significant difference (P>0.05) between flexural strength values of unidirectional glass fibers positioned perpendicularly across the applied force on the specimen and net shaped glass fibers positioned at an angle of 45 °; neither was there any difference between these two groups of fiber reinforced specimens and the high impact strength resin.

Thermocycled specimens had the highest flexural strength (P<0.05), whereas, there was no statistically significant difference (P>0.05) between specimens tested after polymerization and after immersion in distilled water for 28 days (Table 3).

Microscope image analysis showed good bonding between fibers and polymer material (Figure 3), although existence of some voids at glass fibers - polymer matrix interfaces was also noticed thus revealing partial bonding between fibers and polymer material (Figure 4) at these places. After a short beam test was performed, some specimens also revealed adhesive type of breakdown, resulting in pullouts of glass fibers from the matrix.

Table 1. Descriptive statistics and Scheffe test (*=the mean difference significant at the .05 level) between the groups of specimens: 1=Meliodent Rapid polymer+Kelteks fibers (net); 2= Meliodent Rapid polymer+Kelteks fibers (unidirectional); 3= Meliodent Rapid polymer (control); 4=Meliodent Heat Cure polymer (control); 5=Meliodent Heat Cure polymer+Kelteks fibers (net); 6= Meliodent Heat Cure polymer+Kelteks fibers (unidirectional); 7= Ivocap.

Tablica 1. Deskriptivna statistika i Scheffe-ov test (*=razlika aritmetičkih sredina značajna na nivou .05) između skupina uzoraka: 1=Meliodent Rapid polimer+Kelteks vlakna (mrežica); 2= Meliodent Rapid polimer+Kelteks vlakna (jednosmjerna); 3= Meliodent Rapid polimer (kontrola); 4=Meliodent Heat Cure polimer (kontrola); 5=Meliodent Heat Cure polimer+Kelteks vlakna (mrežica); 6= Meliodent Heat Cure polimer+Kelteks vlakna (jednosmjerna); 7= Ivocap.

Groups / Skupine	N	Mean / Aritmetička sredina (MPa)	Std. Deviation / Standard. devijacija	Std. Error / Stand. pogrješka	95% Confidence Interval / Interval pozdanosti		Min. / Najniža	Max. / Najviša	Scheffe test between groups / Scheffe-ov test između skupina 1 2 3 4 5 6 7
					Lower Bound / Donja granica	Upper Baund / Gornja granica			
1	30	140.9000	32.73348	5.97620	128.6771	153.1229	86.2511	196.25	*
2	30	130.6333	12.18530	2.22472	126.0833	135.1834	110.00	148.75	* *
3	30	91.7667	16.44517	3.00246	85.6259	97.9074	57.50	118.75	* * * * * * *
4	30	122.7500	32.32473	5.90166	110.6797	134.8203	28.75	160.00	* * * *
5	30	148.4667	15.66290	2.85964	142.6180	154.3153	117.50	178.50	* *
6	30	163.8833	26.21066	4.78539	154.0961	173.6706	119.00	236.25	* * *
7	30	145.667	20.39918	3.72436	138.0495	153.2838	85.00	166.25	* *

Table 2. Test of between subject effects on flexural strength. Subjects: type of fibers=unidirectional or net; polymer=Meliodent Rapid, Maliodent Heat Cure or Ivocap; ageing procedure=after polymerization, after immersion for 28 days in distilled water 37 °C, after thermocycling.

Tablica 2. Test između čimbenika koji utječu na savojnu čvrstoću. Čimbenici: tip vlakana=jednosmjerna ili mrežica; polimer=Meliodent Rapid, Meliodent Heat Cure ili Ivocap; umjetno ostarivanje=nakon polimerizacije, nakon pohranjivanja u destiliranoj vodi kroz 28 dana pri 37 °C, nakon termocikliranja

Source / Izvor	Type III Sum of Squares / Tip III suma kvadrata	df / stup slob	Mean Square / Kvadrat prosjeka	*F*	Sig. / Značaj.
Corrected Model / Korigirani model	33895.843	14	2421.132	7.358	.000
Intercept / Presretanje	298542.885	1	2985842.885	9074.724	.000
Ageing procedure / Umjetno ostarivanje	7428.074	2	3714.037	11.288	.000
Type of fibers / Tip vlakana	.252	1	.252	.001	.978
Polymer / Polymer	9443.002	1	9443.002	28.700	.000
Ageing procedure* type of fibers / Umjetno ostarivanje * tip vlakana	5377.329	2	2688.665	8.172	.000
Ageing procedure* polymer / Umjetno ostarivanje * polimer	1834.404	2	917.202	2.788	.065
Type of fibers* polymer / Tip vlakana * polimer	3105.919	1	3105.919	9.440	.003
Ageing procedure* type of fibers* polymer / Umjetno starivanje * tip vlakana * polimer	1455.113	2	727.556	2.211	0.114
Error / Pogrješka	44418.850	135	329.029		
Total / Ukupno	3225253.375	150			
Corrected Total / Korekcija ukupnog	78314.693	149			

5. Discussion

Dental material investigations require different procedures of artificial ageing, such as underwater storage and/or cyclic changes of temperature, in order to expose their influence on mechanical properties of materials in demanding environment of oral cavity [34].

The authors use different periods of underwater storage, and different water temperatures (usually room temperature or 37 ºC temperature). It should be emphasized that the important decrease of flexural strength values occurs during, the first four weeks of immersion, while the further period of storage does not present a statistically significant decrease [35]. That is the reason why four weeks immersion in water at 37 ºC temperature was used.

In this study most specimens made of auto polymerizing and heat-pressure polymerizing materials revealed only a slight decrease of flexural strength values after four weeks immersion in water at 37 ºC temperature. That was not observed in a group of Ivocap samples which values of flexural strength increased for even nearly 15%, but rather high values of standard deviations, usual for this type of experiment [34], have caused the lack of statistical confirmation. Decrease of flexural strength could be explained with water absorption. Water molecules penetrate into the areas between polymer chains, remain there and separate these chains. Water entry is primarily caused by diffusion, and partly by the polarity of polymer chains that is caused by unsaturated molecules and unbalanced intermolecular forces [36].

Absorbed water can act as poly(methyl metacrylate) plastificator, and may soften the polymer material of denture base, a fact that emanates from the interaction with the polymer structure. It that way water diminishes the mechanical properties of the material, resulting in lower flexural strength and lower modulus of elasticity [36].

Ivocap samples were produced with injection method of polymerization which results in lower polymerization shrinkage [37]. Lower polymerization shrinkage means less porosity and such polymer is more resistant to water

Table 3. Scheffe test for the significance between different factors (polymer, type of fibers, ageing procedure) influencing bond strength. * =The mean difference is significant at the 0.05 level.

Tablica 3. Scheffe test za začajnost razlike između različitih čimbenika (polimera, tipa vlakana, umjetnog ostarivanja) koji utječu na savojnu čvrstoću. *= Razlika aritmetičkih sredina je značajna na nivou 0,05.

(I) Factor / Čimbenik	(J) Factor / Čimbenik	Mean Difference / Razlika arit. sred. (I-J)	Std. Error / Stand. pogrješka	Sig. / Značajno.	95% Confidence Interval / Interval pozdanosti	
					Lower Bound / Donja granica	Upper Bound / Gornja granica
Meliodent Rapid	Meliodenti Heat Cure	-17.7417*	3.31174	.000	-25.9387	-9.5446
	Ivocap	-9.9000	4.05604	.054	-19.9393	0.1393
Meliodent Heat Cure	Meliodent Rapid	17.7417*	3.31174	.000	9.5446	25.9387
	Ivocap	7.8417	4.05604	.158	-2.1977	17.8810
Ivocap	Meliodent Rapid	9.9000	4.05604	.054	-0.1393	19.9393
	Meliodent Heat Cure	-7.8417	4.05604	.158	-17.8810	2.1977
Unidirectional fibers / Jednosmjerna vlakna	Net / Mrežica	-0.0917	3.31174	1.000	-8.2887	8.1054
	Ivocap	-1.0750	4.05604	.965	-11.1143	8.9643
Net / Mrežica	Unidirectional fibers / Jednosmjerna vlakna	0.0917	3.31174	1.000	-8.1054	8.2887
	Ivocap	-0.9833	4.05604	.971	-11.0227	9.0560
Ivocap	Unidirectional fibers / Jednosmjerna vlakna	1.0750	4.05604	.965	-8.9643	11.1143
	Net / Mrežica	0.9833	4.05604	.971	-9.0560	11.0227
After poymerisation / Nakon polimerizacije	28 days in distilled water / 28 dana u destiliranoj vodi	5.6100	3.62783	.306	-3.3694	14.5894
	After thermocycling procedure / Nakon termocikliranja	-12.2800*	3.62783	.004	-21.2594	-3.3006
28 days in distilled / 28 dana u destiliranoj vodi	After polymerisation / Nakon polimerizacije	-5.6100	3.62783	.306	-14.5894	3.3694
	After thermocycling procedure / Nakon termocikliranja	-17.8900*	3.62783	.000	-26.8694	-8.9106
After thermocycling procedure / Nakon termocikliranja	After polymerisation / Nakon polimerizacije	12.2800*	3.62783	.004	3.3006	21.2594
	28 days in distilled water / 28 dana u destiliranoj vodi	17.8900*	3.62783	.000	8.9106	26.8694

absorption and all of its consequences. Also, immersion in water could cause relaxation of the stress in the material that occurred during polymerization shrinkage [38,39], which has been proven to be a possible cause for an increase of the flexural strength values for the tested polymer materials.

Ageing procedure that imitates ingestion of cold and hot food/beverages, so called thermocycling, can also have a significant impact on mechanical properties of polymer materials [40,41], as well as on the color, surface smoothness and resistance to abrasion [41].

In this study thermocycling procedure did not cause a decrease of flexural strength values of samples. On the contrary, it resulted in an increase of values, especially in subgroups of pressure-heat polymerized samples which flexural strength was up to 35% higher. It seems that in this sample subgroups' increase of temperature during thermocycling resulted in the effect of prolonged

polymerization, which can, in turn, result in the decrease of residual monomer volume, enhancing mechanical properties of the material and increasing the flexural strength values.

Flexural strength values in the Ivocap sample subgroup (produced by injection procedure) only slightly increased (4%) when compared to the Ivocap samples immersed in water. This fact could be attributed to the already low residual monomer volume in these specimens, which could not be significantly lowered with "prolonged polymerization" during the thermocycling procedure. It can be stated that flexural strength values remained stable during artificial ageing procedures. Archadian et al. [42] in their study also reported stable flexural strength values, although they were somewhat lower (around 100 MPa) than in this study (130-156 MPa). The results of flexural strength in our study are higher than in the study of Karacaer et al. [43], which used Palajet injection method for the production of specimens.

Figure 3. Microscopic image of a specimen section – good bonding between glass fibers and polymer matrix (magnification 1000x).

Slika 3. Mikroskopska slika presjeka uzorka - dobra veza između staklenih vlakana i polimernog matriksa (povećanje 1000x).

Control groups of heat-pressure (Meliodent Heat Cure) and auto polymerizing (Meliodent Rapid) polymer revealed the lowest values of flexural strength, whereas, specimens made of the same polymers but reinforced with glass fibers showed higher flexural strength values (P<0.05) (Figure 2, Table 1). Glass fiber reinforcements strengthened the basic polymer material, because testing load was shared between polymer matrix and the fibers on account of the in-between established bond. As expected auto polymerizing material was weaker than heat-pressure polymerizing (P<0.05) regardless of the details of fiber reinforcements. Between the high impact strength resin and auto polymerizing and heat-pressure polymerizing polymer there was no statistically significant difference in flexural strength values (P>0.05) because of the strengthening effect of glass fiber reinforcements used in these two polymers (Table 3). Unidirectional glass fibers equally strengthen polymer material as net shaped glass fibers due to the larger volume amount of fibers used in net shaped reinforcements. Both of these reinforced specimens have flexural strength values similar to those of high impact strength resin specimens (P<0.05) (Table 3).

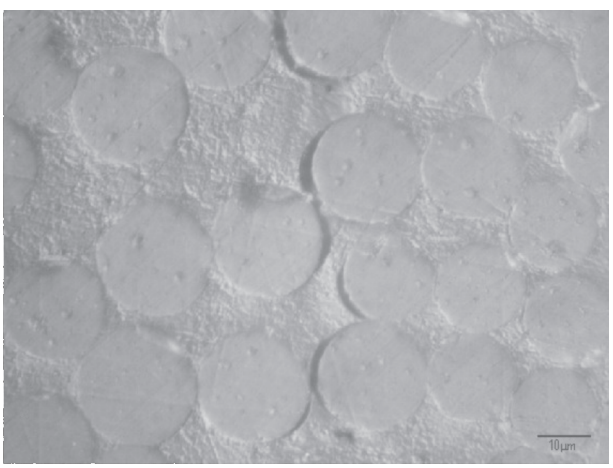

Figure 4. Microscopic image of a specimen section – existence of voids between glass fibers and polymer matrix (magnification 1000x).

Slika 4. Mikroskopska slika presjeka uzorka – prisutnost šupljina između staklenih vlakana i polimernog matriksa (povećanje 1000x).

Interfaces between glass fibers and polymer matrix with the existence of some voids are the result of established dental laboratory routine production, without idealization of procedure conditions, such as vacuum mixing of the polymer material, etc. That is because the main intent of the present study is generation of reproducible results comparable to the general dental laboratory practice. But even such "imperfect" reinforcements were good enough to significantly increase the flexural strength of the investigated glass fiber reinforced specimens to match that of the high impact strength resin.

6. Conclusions

Based on the results of this study, it could be concluded that Ivocap "Plus" High Impact injection polymerizing material has constantly high values of flexural strength, without regard to artificial ageing procedures and can be safely used in clinical work. The pressure-heat polymerizing material Meliodent Heat Cure gave higher values after thermocycling. Therefore, one should propose a prolonged polymerization of this material, disregarding the manufacturer's instructions on the (short) duration of

the polymerization, in order to achieve better mechanical properties of the material.

Reinforcements of polymers using dental laboratory pre-impregnated "industrial" E - glass fibers increased their flexural strength, which was then comparable to that of the tested high impact strength resin Ivocap "Plus" High Impact, and therefore can be recommended for clinical usage. Since these fiber reinforcements are relatively cheap, contrary to the "special" glass fibers for dental use, but obviously with good reinforcement effect, their clinical use would also be more cost effective.

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