ARCHIVE OF MECHANICAL ENGINEERING

VOL. LXV 2018 Number 4

DOI: 10.24425/ame.2018.125440
Key words: acrylic materials, aging of a material, static strength, fatigue strength

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STRENGTH TESTS OF THE POLYMERS USED IN DENTAL PROSTHETICS

The functionality of a prosthesis is determined by clinical procedures, the manufacturing technology applied, the material used and its strength parameters. The aim of the paper is to evaluate the static strength and fatigue strength of acrylic construction materials directly after the process of polymerisation and for aged materials. It has been confirmed that the deformation speed of the tested materials has an evident impact on their mechanical characteristics. With greater deformation speed, a consistent increase in the material elasticity was observed in static compression tests, which was accompanied by a reduction in engineering stresses at the final stage of deformation. The greatest fatigue strength was observed for Vertex. It was by about 33% greater than the strength of Villacryl – the material that has the lowest fatigue properties. The resistance of acrylic polymers to cyclic loading applied with the frequency of 1 Hz may become an indication for the selection of the material to be used in the clinical procedures in which a patient is provided with full dentures.

1. Introduction

Acrylic polymers belong to the group of materials designed to be used in partial and full dentures, whose aim is to restore the functions of the stomatognathic system (SS) [1–7]. They are applied in patients with many missing teeth or in edentulous patients because of local or general contraindications or because of the patient's financial constraints which prevent implant prosthodontic treatment. Therefore, it is necessary to improve the traditional methods of prosthodontic restoration using

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improved materials and technological procedures. Artificial teeth in dentures, unlike natural teeth, are permanently fixed making a uniform construction with an extensive basic plate. During chewing, dentures mediate in the transfer and distribution of pressure on the bone, which is different than in physiological conditions. The pressure on the bone is transferred through the mucosa and periosteum. The denture construction must fulfil the biomechanical requirements of the masticatory organ determined on the basis of the analysis of occlusion, the level of tension and muscle work and the dynamics of the articulation conditions of the mandible [8, 9]. The denture functionality is determined by clinical procedures, its manufacturing technology, the material used and its strength parameters achieved when the construction is in use [10–12]. Considering the aforementioned aspects, it is justified to study new acrylic materials and determine their exploitation properties.

The aim is to evaluate the static strength and fatigue strength of acrylic construction materials directly after the process of polymerisation and for aged materials. The tests performed will make it possible to answer the questions regarding the quality and choice of the material of high fatigue strength in in vivo conditions.

2. Material and method

The test material includes cylindrical samples of the diameter of ø12 mm and the height of 15 mm made of 4 acrylic materials: Probase 0 (self-curing – polymerisation in room temperature), Probase (thermal polymerisation), Villacryl (thermal polymerisation), Vertex (thermal polymerisation under increased pressure). The polymerisation of samples involved the combination of many particles with multiple bonds into one macromolecular compound. It was performed according to the company formula using a programmable polymeriser. The samples of the above-mentioned materials were tested after a 7-year aging period. The Villacryl samples were also tested directly after polymerization [13–16].

The tests were carried out using the MTS 810 servohydraulic system controlled by FlexTest SE PLUS (Fig. 1). The system with the measurement accuracy of 0.5 makes it possible to carry out static and fatigue tests with a random loading sequence within the range of ±100 kN. The samples were compressed using the clamps which were part of the system.

The strength tests involved:

- static compression tests; the variables included: the kind of material and the speed of deformation,
- fatigue tests performed in the conditions of cyclic compression with a fixed value of the stress ratio $R = 50$, different stress amplitudes and two different frequencies of loading, $f = 1$ Hz and $f = 5$ Hz.

Stress ratio R describes the asymmetry of the stress cycle

$$R = \sigma_{\min}/\sigma_{\max},$$

where: $\sigma_{\min}$ – minimum cycle stress, $\sigma_{\max}$ – maximum cycle stress.

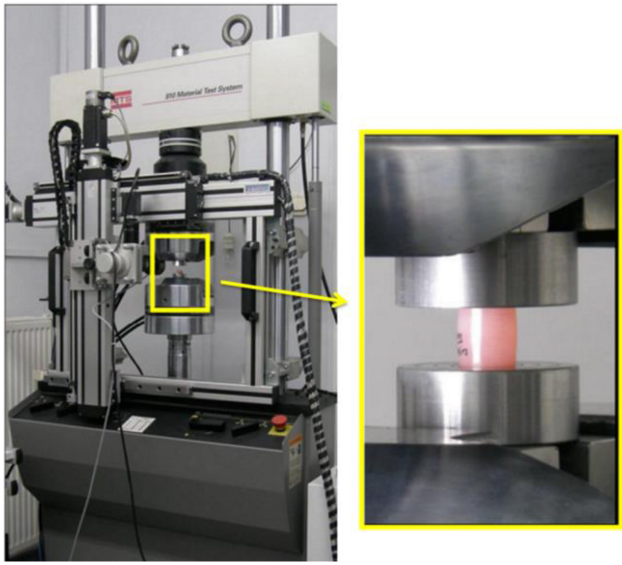


Fig. 1. The working station used in static and fatigue tests

3. Results and discussion

3.1. Static compression tests

Static compression tests were discontinued when the samples were shortened by 50%.

For the Villacryl samples, the impact of deformation speed on the mechanical properties determined on the basis of the compression test were evaluated at first. Together with the increase of deformation speed, a consistent increase of the material elasticity limit was observed and, at the same time, there was a reduction in engineering stresses during the final stage of deformation (Fig. 2, Table 1). An erratic change of the deformation speed during compression would result in a sudden, momentary increase of the material impact (Fig. 3).

Table 1.
Static properties of Villacryl determined on the basis of compression tests at a different speed of deformation

Speed of deformation $[min^{-1}]$	Young's modulus E [MPa]	Contractual yield strength $R_{0,2}$ [MPa]	Yield strength R_e [MPa]	Maximum stresses σ_{max} [MPa]
0.0667	2520	78.6	118.7	244.0
0.1333	2399	88.7	121.3	229.6
0.3333	2586	92.7	128.6	205.9
0.6667	2637	98.9	133.5	196.1

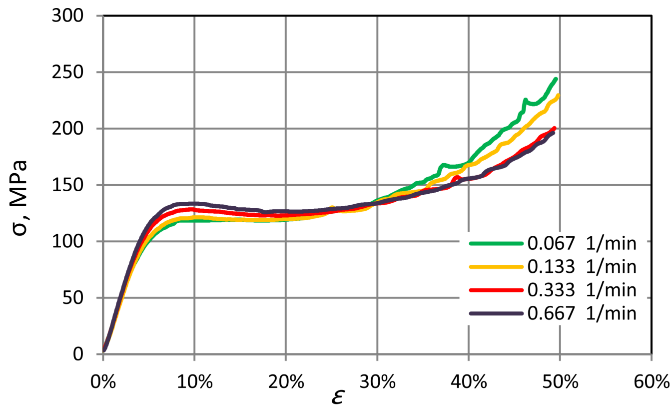


Fig. 2. The impact of the speed of deformation on the mechanical properties of Villacryl

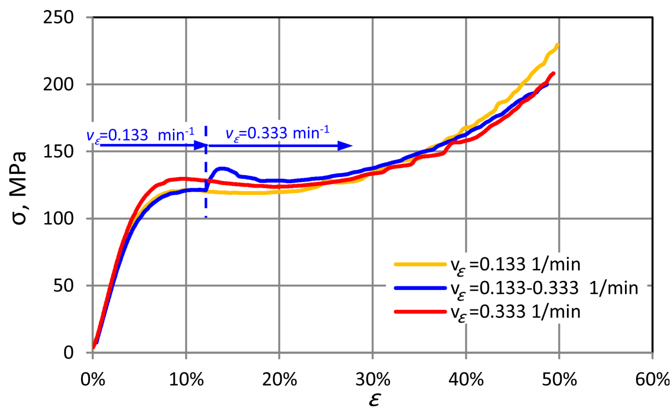


Fig. 3. The impact of the change of deformation speed on the stress response of Villacryl in a static compression test

Static properties of the materials were compared at the speed of the progressive motion of the cylinder equal to 5 mm/min, i.e., the deformation speed of v_ε = 0.33 min^{-1} (Fig. 4, Table 2).

Table 2.

Average parameters of the tested materials determined on the basis of static compression tests at the deformation speed of $v_\varepsilon = 0.333$ min^{-1}

Material	Young's modulus E [MPa]	Contractual yield strength $R_{0,2}$ [MPa]	Yield strength R_e [MPa]	Maximum stresses $\sigma_{\max}$ [MPa]
Probase	2373 ± 163	95.1 ± 3.3	126.1 ± 0.5	191.8 ± 0.7
Probase 0	2015 ± 132	61.6 ± 7.0	77.4 ± 12.1	128.4 ± 13.2
Villacryl	2403 ± 36	87.4 ± 0.3	121.3 ± 0.4	182.3 ± 2.7
Vertex	2410 ± 24	87.2 ± 1.2	122.3 ± 3.2	185.5 ± 3.5

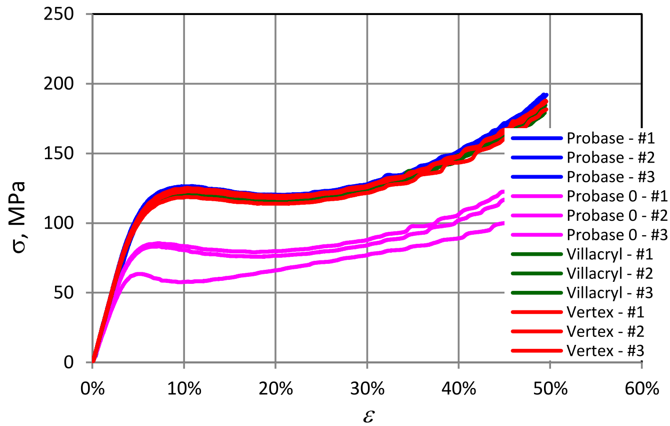


Fig. 4. Static compression curves for the tested materials at the speed of deformation of $v_{\varepsilon} = 0.333$ min^{-1}

All materials except for Probase 0 had similar static properties. For three materials: Probase, Villacryl and Vertex, compression curves (Fig. 4) as well as such basic mechanical parameters (Table 2) as contractual yield strength ($R_{0,2}$) or yield strength (R_e) were within the common spread pattern. Only the mechanical properties of Probase 0 were much lower than the remaining ones (R_e lower by about 36%) and they were characterised by a much greater spread of results.

The test results for the static properties of the tested materials confirm that polymerisation in room temperature causes a reduction in strength parameters [17, 18].

3.2. Resistance tests

The tests were performed for 4 samples made of the same materials for which static compression tests were carried out. The tests were performed in the conditions of cyclic compression with a fixed value of stress ratio $R = 50$, different stress amplitudes and two different loading frequencies, $f = 1$ Hz and $f = 5$ Hz. For Villacryl samples, the impact of the material aging on its fatigue properties was evaluated directly after polymerisation and after the period of 7 years. For the remaining materials, fatigue tests were carried out only for the aged samples.

It was observed that, in general, samples creep cyclically during fatigue tests with the intensity dependent on the stress amplitude applied. The destruction criterion adopted was a permanent shortening of the sample by 12%. It was observed that after this level of deformation was exceeded, the process of further permanent deformation and loss of the sample carrying capacity would progress very quickly (Fig. 5).

The impact of an acrylic material on its fatigue properties was presented on the example of Villacryl (Fig. 6). With time, the material fatigue properties would

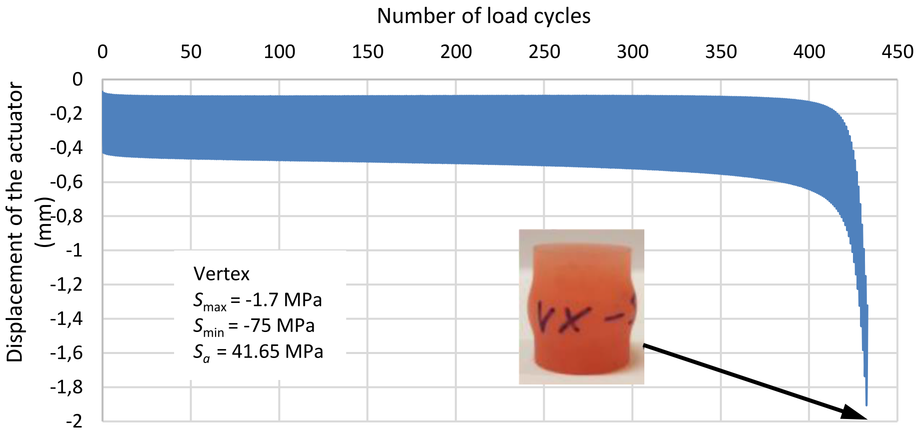


Fig. 5. An example diagram of the change of extreme positions of the cylinder of the resistance system during the fatigue test of the Vertex sample at a fixed amplitude (S_a = 41.65 MPa)

improve, both in terms of limited resistance at both loading frequencies and because of an evident increase of the fatigue limit observed for the low loading frequency of f = 1 Hz. At the frequency representative for SS in chewing conditions (f = 1 Hz), the fatigue strength of Villacryl aged was at the level of 34 MPa, and the new one at the level of 30 MPa. Such a situation may result from the fact that a residual polymerization process takes place in the material. At the same time, both for Villacryl (Fig. 6) and for the remaining materials tested (Figs. 7–9), significant differences in the fatigue properties of the materials were observed at different loading frequencies. For most of the loading range, the dominant trend was a reduction in fatigue properties accompanied by an increase in loading frequency. This applied, in particular, to evidently lower values of the fatigue limit at the loading frequency of f = 5 Hz as compared with the frequency of f = 1 Hz, which

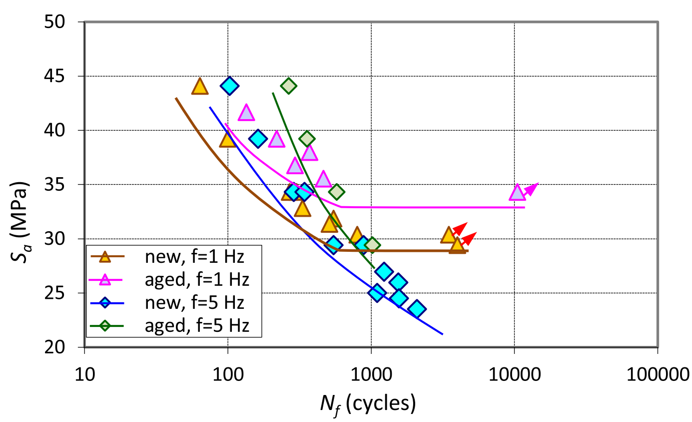


Fig. 6. The impact of aging and loading frequency on the fatigue properties of Villacryl in the conditions of cyclic compression with the stress ratio of R = 50

were observed for all materials (Figs. 6–9). Only for the highest loading levels applied (amplitude $S_a > 45$ MPa), fatigue lives were higher for the greater loading frequency tested (Figs. 6–8). In the Probase material at the frequency $f = 1$ Hz, fatigue strength was 41 MPa, and for frequency $f = 5$ Hz it was 26.5 MPa. In the Probase 0 material, at the frequency $f = 1$ Hz, the fatigue strength was 39.7 MPa, and for the frequency $f = 5$ Hz – 26.5 MPa. Material Vertex at the frequency $f = 1$ Hz had a fatigue strength of 41.5 MPa, and at a frequency $f = 5$ Hz – 27 MPa.

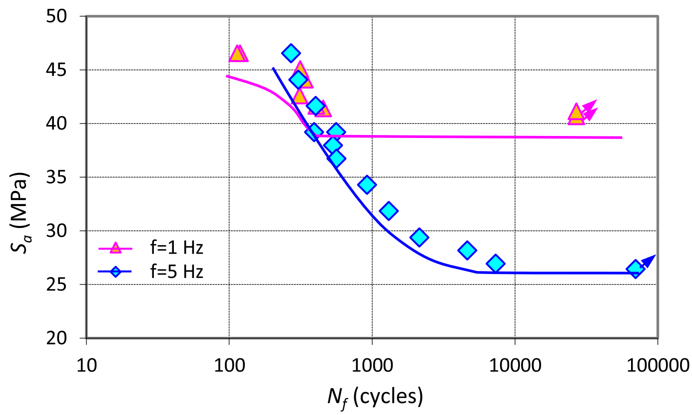


Fig. 7. The impact of loading frequency on the fatigue properties of Probase in the conditions of cyclic compression with the stress ratio of $R = 50$

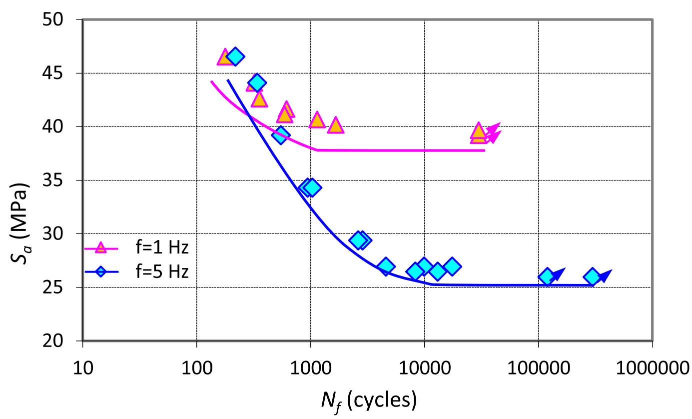


Fig. 8. The impact of loading frequency on the fatigue properties of Probase 0 in the conditions of cyclic compression with the stress ratio of $R = 50$

The differences in the fatigue properties of the tested materials presented as S-N curves determined for the loading frequencies of $f = 1$ Hz and $f = 5$ Hz can be found in Fig. 10.

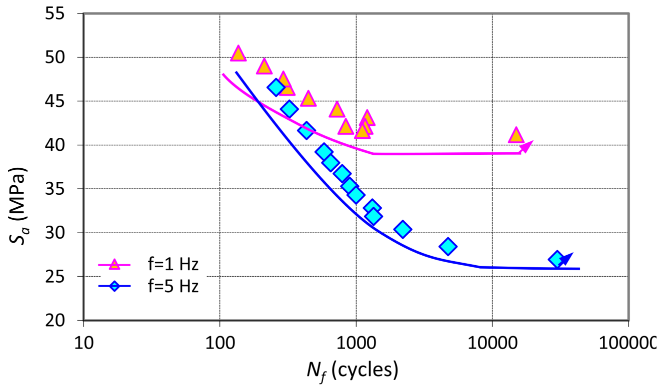
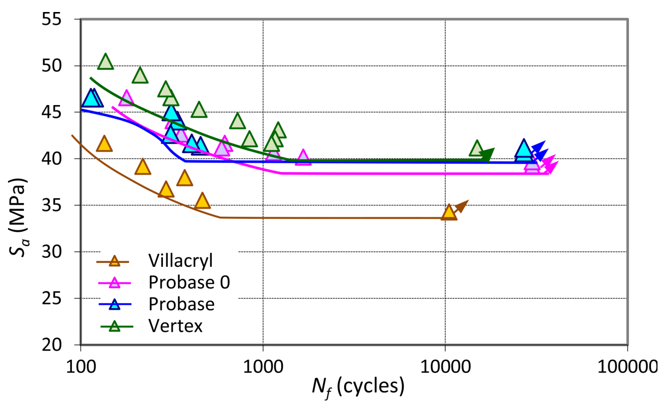
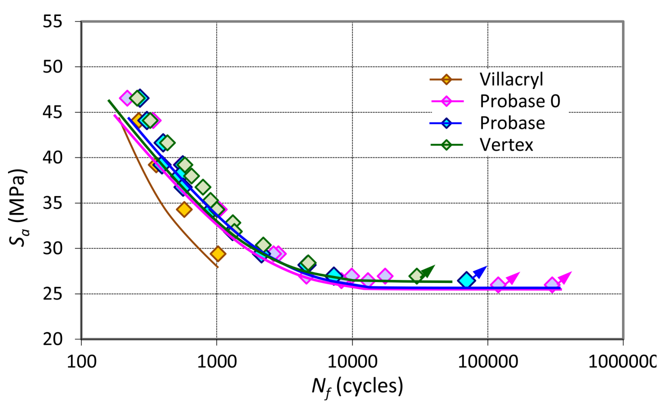


Fig. 9. The impact of loading frequency on the fatigue properties of Vertex in the conditions of cyclic compression with the stress ratio of $R = 50$



(a) $f = 1$ Hz



(b) $f = 5$ Hz

Fig. 10. The comparison of the S-N curves determined for the different acrylic materials tested at the frequency of a) $f = 1$ Hz, b) $f = 5$ Hz

For the higher loading frequency (Fig. 10b), all the materials tested showed almost identical fatigue properties, except for Villacryl whose fatigue strength was slightly lower than for the remaining ones and this difference increased with the reduction of the loading level. But the comparison of the S-N curves determined for the loading frequency of $f = 1$ Hz (Fig. 10a), i.e., close to the frequency that may occur in the conditions of use for dentures, produces completely different results. In these conditions, the fatigue properties of individual materials were significantly different from each other [19–24]. Vertex was characterised by the highest fatigue strength, which was by about 33% greater than that of Villacryl. i.e., the material with the lowest fatigue properties. The properties of Probase and Probase 0 were somewhere in the middle of the spectrum, very close to each other. It is surprising because Probase 0 was far beyond the rest in terms of static strength (Fig. 4). These results prove that neither static tests nor comparative fatigue tests carried out at the loading frequency other than the frequency of use can serve as a basis for the indication of the material that will have the highest resistance to cyclic loading in the real conditions of exploitation [25, 26].

4. Conclusions

The static strength parameters determined, in particular the high value of the modulus of longitudinal elasticity, make it possible to compare and select the material that can be used to manufacture thinner plates that would be stiffer and well-adjusted to the prosthetic base – which would improve the patient's comfort of use.

It was confirmed that the speed of deformation of the tested materials had a definite impact on their mechanical characteristics. When the deformation speed during static compression tests was higher, the material elasticity limit would increase consistently and, at the same time, engineering stresses would be reduced at the final stage of deformation. An erratic change of the deformation speed during compression resulted in a sudden, momentary increase of the material impact.

The resistance of acrylic polymers to cyclic loading in the clinical procedures in which a patient is provided with full dentures may be an indication for the choice of the adequate material. Because of the biomechanics of SS, non-physiological conditions of the occlusion loading transfer, in particular during chewing, the construction made of the material of high fatigue strength with the loading frequency close to the real conditions may be an optimal solution.

Considering the results obtained for fatigue resistance, the tests should be expanded by the ability of the materials to absorb energy as this property will secure the constructions of dentures against cracks and fractures.

It was confirmed that, in the case of visco-elastic materials, such as the acrylic materials under examination, neither static tests nor comparative fatigue tests performed at a different loading frequency than the frequency of use, provided a basis for the evaluation of the material resistance to cyclical loading in real conditions of work.

The tests that were carried out provide an answer to the question regarding the improvement of polymers and the technological methods used to manufacture full and partial dentures.

Manuscript received by Editorial Board, June 18, 2018;
final version, October 12, 2018.

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