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The method of evaluation of the abilities of the lining soft materials to relieve the mucous membran

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ABSTRACT

Purpose: The presentation of a simple method of evaluation of the effectiveness to relieve the mucous membrane under thednture through soft lining materials, which is based on the analysis of creep curves and energy dissipated by the samples during the cyclic compression.

Design/methodology/approach: On the testing machine there were conducted studies of time characteristics and there was determined the energy dissipated by the samples during the cyclic compression. The results were subjected to the analysis of variation ANOVA (α=0.05) with the Newman-Keuls post-hoc test.

Findings: The presented method allowed to conduct the evaluation of abilities to relieve the mucous membrane of soft lining materials significantly different in hardness. The studies showed that the softer materials characterised with a greater ability to dissipate energy, nevertheless, after taking the load off, the return to the original form in case of materials with the lowest hardness lasted much longer. The samples of softer materials with large values of stress underwent much greater stiffening,

Research limitations/implications: Limitations not allow the full translation of the obtained results into the expected results of clinical trials. The demonstrated relations between the behaviour of the samples and the hardness of materials are proper for the tested materials, but not necessarily for other materials of a similar hardness.

Practical implications: The presented methodology of the research is even closer to the expected clinical reality, when the alveolar ridge is more uniform and flat, but in order to obtain an even fuller image of the situation in case of uneven or sharp alveolar ridges, one should conduct additional tests with the method consisting of the load of the samples with a properly shaped penetrator.

Originality/value: The advantages of the presented methods are: the possibility for a quantitative use of the comparison of energy dissipated by the samples and the estimation of the material reaction while maintaining the possibility to use the tests of variable values of stresses, what enables an easy association of the obtained results with the values of stresses, which cause pain sensations in the mucous.

Keywords: Soft lining; Efficiency; Retention; Denture; Mucous membrane

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PROPERTIES

1. Introduction

Materials to perform the permanent denture soft lining are intended for use in the oral cavity of the patients through the period exceeding 4 weeks. They are primarily recommended to all patients suffering from the total edentulism for example: when mucosa show a low tolerance for the load, in causes of pain sensations, injuries of mucosas, with immediate dentures, when dentures show poor retention and also to the reline post-operative obturators [1]-[6]. The aim of performing soft linings is the reduction of mechanical stresses transmitted to the mucosa and by the hard denture plate. Studies have proved the beneficial influence of the use of soft lining materials on the quality of life experienced by the dentures wearers [7]-[7]. Currently used materials are mostly silicone rubber, which characterise with the relatively good durability in oral cavity with a significant level of patient satisfaction [9]-[11]. However the basic problem connected with the use of these materials is their low resistance to the colonisation with microorganisms (mainly *Candida albicans*) [12]-[15].

The effectiveness of the long-time lining materials next to their traditionally tested functional properties, such as sorption, solubility, bond strength and hardness is mostly decided by their viscoelastic properties, which play a crucial role, because they allow the scattering of a significant part of energy transmitted to the prosthesis surface during chewing. These properties are usually tested with dynamic methods [17]-[20] or less sophisticated methods to achieve the results oriented towards the translation into the practical use with methods consisting of the progressive test with the time flow of the penetrator recess in the material during the load and unload of the samples [21]-[22]. In the paper there is presented a simple method of the evaluation of the relief of the mucous membrane found under the denture plate with soft lining materials, which is based on the analysis of the time characteristics and energy dissipated by the samples during the cyclic compression.

2. Materials and experimental procedure

Test samples were made of the material Ufi Gel SC (Voco, Germany) and experimental materials with the nanosilver concentration from 10, 20, 40, 80, 120 and 200 ppm obtained based on the material Ufi Gel SC described in the previous papers [15]-[16]. These materials created a range in terms of hardness, what is presented in Tab. 1. Hardness in the popular opinion decides about the comfort of use of the lined denture (softer materials are more comfortable).

Samples for all tests had the diameter of 15mm and thickness of 2.25 mm andwere die cut from cross-linked plaques with the dimensions of 60×60×2.25 mm. One plate was used to cut no more than 1 sample for one type of test (in total there were made 175 samples). Tests were accomplished on a universal test machine Zwick. Before each attempt, the stamps and samples were applied with a thin layer of olive oil to eliminate the sticking of the leading surface samples to the surface of stamps.

Analysis of time characteristics was conducted during the loading and unloading of samples. Samples were immediately loaded (one axis compression). There was applied the engineering stress of 0.1; 0.2; 0.4 and 0.6 MPa, referred to [21]:

$$\sigma_u = \frac{F}{A_0} \tag{1}$$

where A_0 - the initial cross-sectional area of the sample.

The applied stress values correspond the loads found under the denture during the use, while the values 0.4-0.6 MPa correspond the stresses causing the local pain sensations [23]-[27]. The load of the samples was maintained for 120 s, recording the changes of the strain. After 120 s from the moment of the performance of the full load, the samples were unloaded immediately, leaving the residual load of 0.5 N and the changes of the strain were recorded for the next 120s. The analysis of results was performed based on the selected points of characteristics strain - time and the factors determining the size of strain changes over time. For the loaded samples the strain value was analysed at the moment of the performance of the maximal sample load (ε_0), the factor describing the growth of the strain after first five seconds of the sample load $\varepsilon_{5/0}$ was set (strain relation ε_5 after 5 s to ε_0) and the factor describing the growth of the strain in next 25 s of the sample load $\varepsilon_{30/5}$ (strain relation ε_{30} after 30 s to ε_5). Times were selected guided by the literature and the course of the mere characteristics. First five seconds imitated the first phase of the chewing cycle. The measurement of strain after 30 s is approximately equivalent to the reaction of material to the load during chewing: it was shown that crushing of food usually takes from 10 to 40 cycles [28]-[29] wherein the duration of 35 chewing cycles in the users of complete dentures is about 30 s [30]. Analysing the course of characteristics it was considered that the increase of the strain in next 90 s does not require analysis, due to the slight changes of strains with the low probability of such a long chewing cycle. Based on the curve imitating the strain changes during the unloading the strains were determined after 1 s from the removal of the load (ε_{1od}) and strain after 30 s from the removal of the load (ε_{30od}). There was also determined the factor $\varepsilon_{1od/120}$ (strain relation ε_{1od} to the strain preceding the beginning of the load), which describes the ability of the samples to recover the original form just after the beginning of the unloading.

Energy dissipated by the samples was determined based on the test consisting of the one axis, cyclic compression. In the samples there was evoked the stress calculated according to dependencies (1) with the value of 0.15 MPa. There were performed 7 full cycles. The number of the performed cycles was determined experimentally - in the seventh cycle there was obtained the overlapping loops, even for the worst material in this respect. Mechanical hysteresis loops were recorded in the stress-strain system. The loops of hysteresis determined experimentally (Fig. 1) are a simple method to examine the energy of dissipation [31] and their area is a measure of energy dissipated in one full cycle (load-unload), which is changed mostly into heat [32]-[35]. Dissipation energy (w_d) is calculated as the energy difference L_{ob} (energy consumed to strain of the sample, the area under the load curve) and L_{od} (energy given back during the unloading, the area under the unload curve) with is calculated from force - displacement characteristics [33]-[33]. For the first and seventh cycle w_d was determined.

Test results were statistically evaluated using the one-way analysis of variance ANOVA (α=0.05) for ε_0, $\varepsilon_{5/0}$, $\varepsilon_{30/5}$ and the two-way analysis of variance for factor $\varepsilon_{1od/120}$, ε_{1od}, ε_{30od} and for energy dissipated during the cyclic compression. The Newman-Keuls significant difference post hoc test was used to determine the differences between mean values. Statistical significance was defined at $p < 0.05$.

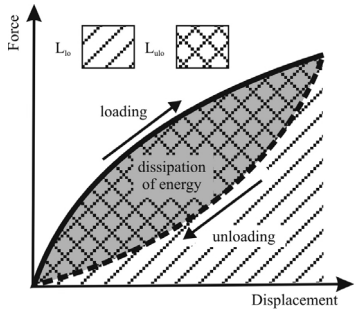

Fig. 1. Hysteresis loop of the curve of the power to displacement dependency

3. Results and discussion

3.1. Results

The obtained mean values ε_0 for the samples with various c_{Ag} differed from each other in a statistically important way ($p<0,05$) for all levels σ_e (Tab. 2). Mean values ε_0 are summarised in Tab. 3. Based on the post-hoc test it was stated that only two mean values ε_0 for UG do not differ from each other and nanocomposite c_{Ag} equal 10 ppm. Starting from c_{Ag} 20 ppm the increase of the concentration of silver nanoparticles caused the growth of mean values ε_0 (decrease of rigidity), and this tendency was particularly strong from c_{Ag} equal to 80 ppm.

The conducted statistical analyses showed the dependencies of coefficients $\varepsilon_{5/0}$ and $\varepsilon_{30/5}$ from c_{Ag} (Tab. 4). Values of coefficients $\varepsilon_{5/0}$ were set in Tab. 5. Test post-hoc showed that for the stress of 0.1 MPa the means of the coefficient $\varepsilon_{5/0}$ were statistically higher for the obtained nonocomposites, than for the UG material. With σ_e equal 0.1 and 0.2 MPa the samples of nanocomposites with c_{Ag} 120 and 200 ppm were characterised with a ratio $\varepsilon_{5/0}$ significantly greater, than the samples of materials with a lower c_{Ag}. With a tension of 0.4 MPa there was shown no statistical effect of c_{Ag} in the values of coefficients $\varepsilon_{5/0}$, but with a tension of 0.6 MPa nanocomposites with two highest c_{Ag} characterised with a ratio of $\varepsilon_{5/0}$ essentially lower than the materials with a lower c_{Ag}. Average values of the coefficient $\varepsilon_{30/5}$ are set in Tab. 6. These values changed similarly to the coefficient $\varepsilon_{30/5}$, but the power of the noted dependencies was weaker than for $\varepsilon_{5/0}$. Values of coefficients $\varepsilon_{30/5}$ were within the narrow range from 1.009 to 1.039. This indicates the necessity to maintain reserves in the interpretation of the statistical tests.

There was presented the statistically important dependency between the average values of the coefficient $\varepsilon_{1od/120}$, and c_{Ag} and σ_e and a different reaction of the tested variable on one factor, with the change of the level of the second factor (Tab. 7). The influence of c_{Ag} on the obtained mean values $\varepsilon_{1od/120}$ was almost 15 times higher than the applied σ_e. Mean values of the coefficient $\varepsilon_{1od/120}$ (Tab. 8) grew with the increase of c_{Ag} for the specified values σ_e. On the basis of the conducted test post-hoc it was stated for σ_e equal 0.1 MPa that there were statistically essential differences of the coefficient between UG and the obtained composites. For σ_e equal 0,1 MPa in the range of c_{Ag} from 0 to 80 ppm and for σ_e equal 0.2; 0.4 and 0.6 MPa in the range of c_{Ag} from 0 to 40 ppm of the coefficient values obtained at the specified tension were very similar to each other. They ranged from 0,1 to 0,3, but higher values were noted with lower values σ_e (0.1 MPa). These results should be considered together with the results of measurements ε_{1od}, because higher obtained values of the coefficient with lower values σ_e result from the relatively low values of strain ε_{120}. Further enhancement of c_{Ag} caused a considerable increase of the mean values $\varepsilon_{1od/120}$ for all σ_e, while the differences of values of the coefficient $\varepsilon_{1od/120}$ obtained for the samples with various c_{Ag} were even higher, when the value of the applied σ_e was higher. There was shown a strong dependency between the mean values of ε_{1od}, and c_{Ag} and the value of the applied σ_u. Statistically essential was the interaction of two factors on the tested variable (Tab. 9). Increasing c_{Ag} and σ_e. caused the growth of the recorded values ε_{1od} (Tab. 10), while the growth of values ε_{1od} caused by the increase of one of the factors was greater with the simultaneous increase of the second factor. The graphic representation of the described dependencies is presented in Fig. 2. The conducted test post-hoc showed that UG and the nanocomposite with c_{Ag} equal 10 ppm and nanocomposites with c_{Ag} equal from 10 to 40 ppm did not differ in a statistically important way with mean values ε_{1od} for particular stress values. . Within the given c_{Ag} (from the above range) there was noted a difference between values ε_{1od} obtained with σ_e 0.1 and 0.6 MPa. Values ε_{1od} were in the range 2.24 to 4.3%, what means that already after the first second from the beginning of the unloading, the seemingly permanent strains were very small (on the level of a hundredth of a millimetre). Further enhancement of c_{Ag} caused a significant increase of the values of the coefficient ε_{1od}. In the range of c_{Ag} equal 80 to 200 ppm samples differed in mean values ε_{1od} between themselves and from the samples of materials with a lower mass share of silver nanoparticles. Also the size of the applied σ_e highly differentiated the means. The range of the mean values of ε_{1od} was from 5.15% (80 ppm, 0.1 MPa) to 36,90 % (200 ppm, 0.6 MPa).

There was shown a strong correlation between mean values ε_{30od}, and c_{Ag} a the value of the applied σ_e and the statistically important interaction of two factors on the tested variable (Tab. 11). The obtained results were set in Tab. 12. The graphic interpretation of the discussed dependencies is presented in Fig. 3. Based on the test post-hoc it was shown that samples made of the UG material and composites with c_{Ag} from 10 to 40 ppm, regardless of the previously applied σ_e, did not differ between themselves with mean values ε_{30od} (1.75 to 2.62 %). Further enhancement of c_{Ag} caused the growth of the recorded values ε_{30od}, while the reaction to the increase of the nanosilver share was smaller than the value of the applied σ_e was higher. The maximal mean values of ε_{30od} obtained for samples with c_{Ag} equal 200 ppm were 13%, so they were clearly smaller than after the first second.

Table 1.
Mean hardness values in Shore A units of investigated materials from [15]

Silver concentration, ppm	0 (Ufi Gel)	10	20	40	80	120	200
Hardness, Shore A units	31.2±0.6	28.±0.5	28.2±0.6	27.5±0.7	25.9±0.4	22.8±0.4	21.4±1.0

Table 2.
Results of the statistical assessment with the ANOVA test of the influence of c_{Ag} on the mean values of strain at the moment of the implementation of the maximal contractual stress

Engineering stress σ_e. MPa	Source of variance	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
0.1	c_{Ag}	1654.44	6	275.74	2051.23	<0.0001
0.2	c_{Ag}	2840.00	6	473.33	887.64	<0.0001
0.4	c_{Ag}	3620.59	6	603.43	833.23	<0.0001
0.6	c_{Ag}	4624.23	6	770.71	680.09	<0.0001

Table 3.
Mean values of strain at the moment of the implementation of the maximal sample load with the standard deviations for various values of the contractual stress σ_e*

Nanosilver concentration c_{Ag}. ppm	Strain at the moment of the implementation of the maximal sample load ε_0. %			
	σ_e = 0.1 MPa	σ_e = 0.2 MPa	σ_e = 0.4 MPa	σ_e = 0.6 MPa
0	8.70±0.15^a	14.77±0.46^a	24.34±0.41^a	31.6±60.86^a
10	8.93±0.18^a	15.53±0.54^a	25.06±0.95^a	31.50±0.41^a
20	9.77±0.28^b	17.15±0.48^b	28.78±0.73^b	34.03±1.20^b
40	10.50±0.43^c	18.91±0.68^c	30.56±1.09^c	36.33±0.97c
80	16.63±0.47^d	26.30±0.77^d	39.28±0.55^d	50.33±1.12^d
120	22.77±0.42^e	33.81±0.98^e	46.26±0.93^e	56.94±1.51^e
200	26.99±0.47^f	39.41±1.00^f	52.57±1.06^f	60.06±1.05^f

* Groups with the same upper case superscript letters (a-f) for each column are not significantly different at the p < 0.05 level

Table 4.
Results of the statistical assessment with the ANOVA test of the influence of c_{Ag} on the mean values of coefficients describing the changes of strains in the first 5 s of the load ($\varepsilon_{5/0}$) and after next 25 s ($\varepsilon_{30/5}$), (p< 0.05)

Coefficient	Engineering stress σ_e. MPa	Source of variance	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
$\varepsilon_{5/0}$	0.1	u_{AgT}	0.02	6	0.00	45.55	<0.0001
	0.2	u_{AgT}	0.01	6	0.00	10.32	<0.0001
	0.4	u_{AgT}	0.00	6	0.00	2.30	0.0621
	0.6	u_{AgT}	0.00	6	0.00	7.62	0.0001
$\varepsilon_{30/5}$	0.1	u_{AgT}	0.00	6	0.00	5.47	0.0008
	0.2	u_{AgT}	0.00	6	0.00	2.73	0.0324
	0.4	u_{AgT}	0.00	6	0.00	7.85	0.0001
	0.6	u_{AgT}	0.00	6	0.00	2.59	0.0399

Table 5.
Mean values with the standard deviations of the coefficient describing the increase of the strain after first five seconds of the load*

Nanosilver concentration c_{Ag}. ppm	The strain growth coefficient after first five seconds of the load $\varepsilon_{5/0}$			
	σ_e = 0.1 MPa	σ_e = 0.2 MPa	σ_e = 0.4 MPa	σ_e = 0.6 MPa
0	1.07±0.01^a	1.05±0.01^a	1.05±0.00	1.04±0.00^a
10	1.08±0.00^b	1.05±0.00^a	1.05±0.02	1.03±0.00^a
20	1.09±0.01^b	1.05±0.01^a	1.04±0.00	1.03±0.01^{ab}
40	1.09±0.01^b	1.07±0.02^b	1.05±0.02	1.03±0.00^{ab}
80	1.09±0.01^b	1.06±0.00^a	1.05±0.00	1.02±0.01^{bc}
120	1.13±0.01^c	1.08±0.00^b	1.04±0.00	1.01±0.00^c
200	1.13±0.01^c	1.08±0.00^b	1.04±0.00	1.01±0.00^c

* Groups with the same upper case superscript letters (a-c) for each column are not significantly different at the p < 0.05 level

Table 6.
Mean values with the standard deviations of the coefficient describing the strain growth between the fifth and thirtieth second after the implementation of the load*

Nanosilver concentration c_{Ag}. ppm	Strain growth coefficient between the fifth and thirtieth second after the implementation of the load $\varepsilon_{30/5}$			
	σ_e = 0.1 MPa	σ_e = 0.2 MPa	σ_e = 0.4 MPa	σ_e = 0.6 MPa
0	1.028 ± 0.004^{st}	1.016 ± 0.006^{t}	1.012 ± 0.001^{vyz}	1.010 ± 0.001
10	1.030 ± 0.003^{t}	1.013 ± 0.001^{x}	1.011 ± 0.001^{ux}	1.015 ± 0.010^{vx}
20	1.027 ± 0.004^{u}	1.020 ± 0.008^{uvx}	1.013 ± 0.000^{st}	1.009 ± 0.001
40	1.025 ± 0.004^{vx}	1.016 ± 0.002^{y}	1.013 ± 0.001^{uv}	1.012 ± 0.001^{yz}
80	1.025 ± 0.001^{yz}	1.017 ± 0.001^{z}	1.014 ± 0.001^{xyz}	1.011 ± 0.009
120	1.033 ± 0.015^{sxy}	1.019 ± 0.010^{v}	1.010 ± 0.002^{uy}	1.005 ± 0.001^{vy}
200	1.039 ± 0.007^{tuvz}	1.024 ± 0.001^{tuyz}	1.010 ± 0.002^{stvz}	1.005 ± 0.001^{xz}

* Groups with the same upper case superscript letters (*s*-*z*) for each column are significantly different at the $p < 0.05$ level

Table 7.
Results of the statistical assessment with the ANOVA test ($p<0,05$) of the influence c_{Ag} and σ_e on the mean values of the coefficient describing the ability of the samples to recover the original form in the first second of unloading

	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
σ_e	0.10	3	0.03	73.22	<0.0001
c_{Ag}	2.81	6	0.47	1078.55	<0.0001
$\sigma_e \times c_{Ag}$	0.38	18	0.02	48.93	<0.0001

Table 8.
Mean values with the standard deviations of the coefficient describing the ability of the samples to recover the original form in the first second of unloading*

Nanosilver concentration c_{Ag}. ppm	Sample ability coefficient to recover the original form in the first second of unloading $\varepsilon_{1od/120}$			
	σ_e = 0.1 MPa	σ_e = 0.2 MPa	σ_e = 0.4 MPa	σ_e = 0.6 MPa
0	$0.24\pm0.02^{A.a}$	$0.16\pm0.01^{B.a}$	$0.10\pm0.01^{C.a}$	$0.10\pm0.01^{C.a}$
10	$0.30\pm0.03^{A.b}$	$0.20\pm0.01^{B.b}$	$0.14\pm0.04^{C.b}$	$0.12\pm0.01^{C.a}$
20	$0.27\pm.02^{A.c}$	$0.20\pm0.01^{B.b}$	$0.12\pm0.00^{C.ab}$	$0.13\pm0.01^{C.a}$
40	$0.28\pm0.01^{A.bc}$	$0.18\pm0.02^{B.ab}$	$0.12\pm0.01^{C.ab}$	$0.11\pm0.01^{C.a}$
80	$0.28\pm0.02^{AB.c}$	$0.29\pm0.00^{A.c}$	$0.25\pm0.00^{BC.c}$	$0.24\pm0.03^{C.c}$
120	$0.41\pm0.03^{A.d}$	$0.41\pm0.03^{A.d}$	$0.46\pm0.02^{B.d}$	$0.48\pm0.02^{B.d}$
200	$0.47\pm0.04^{A.e}$	$0.46\pm0.02^{A.e}$	$0.64\pm0.03^{B.e}$	$0.60\pm0.03^{C.e}$

*Groups with the same upper case superscript letters (A-E) for each row and lower case superscript letters (a-e) for each column are not significantly different at the $p < 0.05$ level

Table 9.
Results of the statistical assessment with the ANOVA test ($p<0.05$) of the influence of c_{Ag} and σ_e on the mean values of strains in the 1 s of the removal of the load (ε_{1od})

	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
σ_e	1124.91	3	374.97	657.38	<0.0001
c_{Ag}	10832.76	6	1805.46	3165.27	<0.0001
$\sigma_e \times c_{Ag}$	1617.33	18	89.85	157.52	<0.0001

Table 10.
Mean values with the standard deviations in the 1s from the removal of the load*

Nanosilver concentration c_{Ag}. ppm	Strain after 1s from the removal of the load ε_{1od}. %			
	σ_e = 0.1 MPa	σ_e = 0.2 MPa	σ_e = 0.4 MPa	σ_e = 0.6 MPa
0	$2.27\pm0.11^{A.a}$	$2.53\pm0.23^{AB.a}$	$2.71\pm0.25^{AB.a}$	$3.35\pm0.33^{B.a}$
10	$3.08\pm0.29^{A.ab}$	$3.27\pm0.15^{AB.ab}$	$3.18\pm0.13^{AB.ab}$	$4.04\pm0.31^{B.ab}$
20	$3.04\pm0.25^{A.ab}$	$3.62\pm0.17^{AB.b}$	$3.74\pm0.17^{AB.b}$	$4.45\pm0.39^{B.b}$
40	$3.32\pm0.09^{A.b}$	$3.80\pm0.33^{AB.b}$	$3.96\pm0.38^{AB.b}$	$4.30\pm0.24^{B.b}$
80	$5.15\pm0.36^{A.c}$	$8.29\pm0.27^{B.c}$	$10.69\pm0.24^{C.c}$	$12.76\pm1.49^{D.c}$
120	$11.04\pm0.89^{A.d}$	$15.32\pm0.76^{B.d}$	$22.19\pm1.17^{C.d}$	$27.65\pm1.04^{D.d}$
200	$15.10\pm1.09^{A.e}$	$20.32\pm1.29^{B.e}$	$35.23\pm1.86^{C.e}$	$36.90\pm1.52^{D.e}$

*Groups with the same upper case superscript letters (A-D) for each row and lower case superscript letters (a-e) for each column are not significantly different at the $p < 0.05$ level

Table 11.
Results of the statistical assessment with the ANOVA test ($p<0.05$) of the influence of c_{Ag} and σ_e on the mean values of strains after 30s from the removal of the load (ε_{30od})

	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
σ_e	122.97	3	40.99	120.55	<0.0001
c_{Ag}	1117.79	6	186.30	547.88	<0.0001
$\sigma_e \times c_{Ag}$	180.78	18	10.04	29.54	<0.0001

Table 12.
Mean values with the standard deviations after 30s from the removal of the load*

Nanosilver concentration c_{Ag}. ppm	Strain after 30s from the removal of the load ε_{30od}. %			
	σ_e = 0.1 MPa	σ_e = 0.2 MPa	σ_e = 0.4 MPa	σ_e = 0.6 MPa
0	$1.75\pm0.15^{A.a}$	$1.83\pm0.30^{A.a}$	$1.71\pm0.22^{A.ab}$	$2.19\pm0.27^{A.ab}$
10	$1.90\pm0.20^{A.a}$	$1.79\pm0.26^{A.a}$	$1.58\pm0.13^{A.a}$	$2.22\pm0.06^{A.ab}$
20	$1.91\pm0.25^{A.a}$	$1.93\pm0.23^{A.a}$	$2.24\pm0.29^{AB.b}$	$2.62\pm0.56^{B.a}$
40	$1.84\pm0.19^{A.a}$	$2.33\pm0.22^{A.a}$	$1.81\pm0.36^{A.ab}$	$1.86\pm0.30^{A.b}$
80	$2.85\pm0.30^{A.b}$	$3.26\pm0.28^{A.b}$	$4.92\pm0.55^{B.c}$	$5.64\pm1.29^{B.c}$
120	$4.20\pm0.27^{A.c}$	$5.60\pm0.26^{B.c}$	$8.22\pm0.68^{C.d}$	$9.18\pm1.17^{D.d}$
200	$5.74\pm0.33^{A.d}$	$7.46\pm0.84^{B.d}$	$13.05\pm1.08^{C.e}$	$12.28\pm1.49^{D.e}$

*Groups with the same upper case superscript letters (A-D) for each row and lower case superscript letters (a-e) for each column are not significantly different at the $p < 0.05$ level

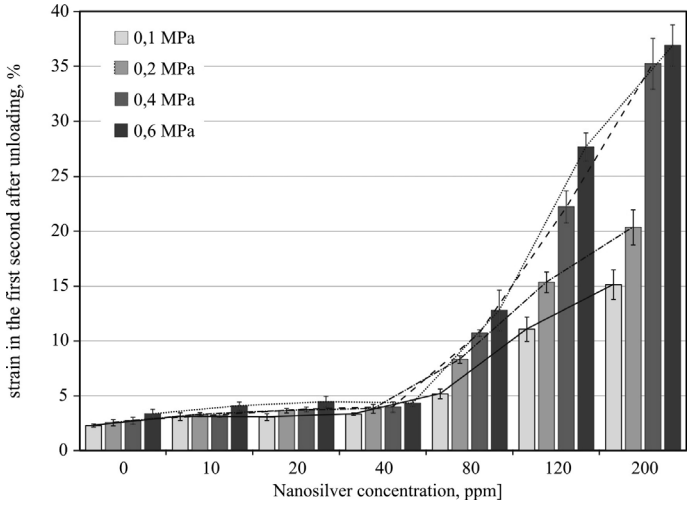

Fig. 2. The influence of the mass share of silver nanoparticles on the values of strains in the first second from the beginning of unloading for various contractual stress values; the confidence range is indicated with markers

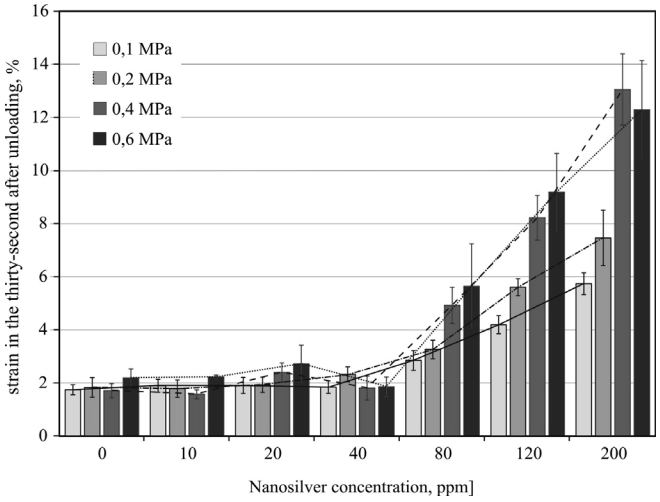

Fig. 3. The influence of the mass share of silver nanoparticles on the strain values in the thirtieth second from the beginning of unloading for various contractual stress values; the confidence range is indicated with markers

The statistical analyses (Table 13) showed the dependence of the energy of dissipation w_d on c_{Ag} and on the cycle number, while the influence of c_{Ag} was about thirty times stronger in the direction of the increase of the value w_d, than the cycle number. Statistically significant was also the influence on the values w_d of the mutual interaction of c_{Ag} and the number of cycles. In Table 14 there are presented the mean values of w_d calculated based on the hysteresis loop from the first and seventh cycle. The graphic illustration of the discussed dependencies is presented in Fig. 4. The conducted test post-hoc showed that samples of the UG material and composite with c_{Ag} 10 ppm did not differ from each other in a statistically significant way with mean values w_d, while the mean values of w_d were also not differentiated by the cycle number, in which the measurement was taken. Starting from the concentration of silver nanoparticles 20 ppm value of w_d increased with the growth of c_{Ag}. For example, composite with c_{Ag} equal 40 ppm dissipated almost twice as much energy than UG material. This increase was especially clear for nanosilver concentrations from 80 ppm the increase c_{Ag} from 40 to 80 ppm allowed to dissipat more than two and a half times, and from 40 to 200 ppm more than six time more energy. Mean values of w_d in the first and seventh cycle differed among themselves in a statistically significant way, while in case of c_{Ag} 20 to 40 ppm these differences were slight and ranged from 2 to 5%, while for c_{Ag} 80 to 200 ppm there was noted the decrease of mean values of energy of dissipation by 12 to 16%. The comparison of the process of load curves of the stress-strain characteristics in 1 and 7 of the obtained nanocomposites with c_{Ag} equal 80 to 200 ppm indicates the increase of the stiffness of samples in subsequent cycles.

Table 13.
Results of the statistical assessment with the ANOVA test ($p< 0.05$) of the influence c_{Ag} and the cycle number, in which the measurement was taken, on the value of the dissipation energy

	Sum of squares	Freedom levels	Average squares	Value of the Fisher statistics	p
c_{Ag}	29911.43	6	4985.24	4504.95	<0.0001
cycle number	169.51	1	169.51	153.18	<0.0001
c_{Ag} × cycle number	218.10	6	36.35	32.85	<0.0001

Table 14.
Mean values of the dissipation energy (w_d) with standard deviations in the first and seventh load cycle*

Share of silver nanoparticles in composite	Dissipation energy w_d. $\times 10^{-4}$. J	
u_{AgT}. ppm	1th cycle	7th cycle
0 ppm	$6.15\pm0.22^{A.a}$	$5.93\pm0.14^{A.a}$
10 ppm	$6.95\pm0.31^{A.a}$	$6.52\pm0.13^{A.a}$
20 ppm	$9.31\pm0.33^{A.b}$	$9.12\pm0.21^{A.b}$
40 ppm	$11.75\pm0.48^{A.c}$	$11.14\pm0.39^{A.c}$
80 ppm	$27.24\pm0.93^{A.d}$	$22.99\pm0.91^{B.d}$
120 ppm	$51.02\pm1.25^{A.e}$	$44.83\pm1.94^{B.e}$
200 ppm	$66.64\pm1.97^{A.f}$	$56.74\pm1.96^{B.f}$

*Groups with the same upper case superscript letters (A-B) for each row and lower case superscript letters (a-f) for each column are not significantly different at the $p < 0.05$ level

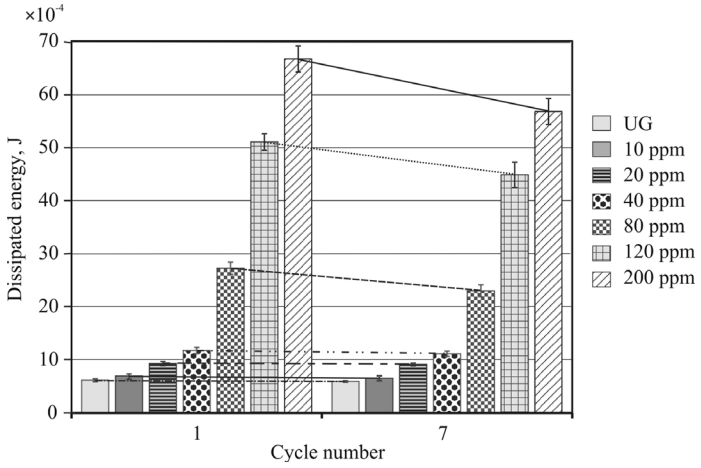

Fig. 4. The influence of the mass share of silver nanoparticles on the value of the dissipation energy in the first and seventh load cycle; the confidence level is indicated with markers

3.2. Discussion

Dentures in use are subjected to cyclic impact of the chewing forces. The basic task of soft linings is the reduction of the load of the mucous membrane and to prevent the mechanical injuries. The proper functioning of soft linings is conditioned by the elastic properties as well as viscoelastic ones of the materials. For the users of dentures what is important is the value of the energy dispersed by the linings and the ability of the lining material to a quick reaction to the loads/unloads encountered while chewing. It is believed that the softer material will distribute the loads on the soft tissue better and that the lining material should absorb as much energy transmitted to the mucous membrane while chewing a possible. However, this is not fully true, because many materials with viscoelastic characteristics dissipates the energy during the load, but at the same time experiences seemingly permanent strains, connected with the long-time of the duration of the return strain. These types of strains, especially in case of soft materials, can very adversely affect the functioning of dentures, causing in practice the "light off" of the response of the material on the applied, cyclic loads. Therefore, in this paper there was studied the influence of the introduction of silver nanoparticles to the commercially used silicone on the process of the strain-time characteristics of the samples, which is considered together with the values of the energy dissipated by the samples during the cyclic compression.

On the basis of time characteristics during the load, there was determined the strain value ε_0 at the moment of the implementation of the maximal sample load, coefficient describing the increase of the strain after first five seconds of the sample load $\varepsilon_{5/0}$ (strain sample ε_5 after 5 s to ε_0) and the coefficient describing the increase of strain in next 25 s of the sample load $\varepsilon_{30/5}$ (ration of strain ε_{30} after 30s to ε_5). While during the unloading there were determined strain after 1 s from the removal of the load (ε_{1od}) and strains after 30 s from the removal of the load (ε_{30od}) and the relation of the strain ε_{1od} to the strain preceding the beginning of the unloading ($\varepsilon_{1od/120}$), describing the ability of the samples to recover the original form already after the beginning of the unloading. It has been shown that samples with c_{Ag} higher than 10 ppm in comparison with the UG material characterised with the lower stiffness. The decrease of stiffness was significantly above c_{Ag} equal 80 ppm. At the same time, coefficients $\varepsilon_{5/0}$ and $\varepsilon_{30/5}$ determined during the load reached low values, what is a desired feature, because this proves a very fast response of the material to the applied load. Low values of coefficients mean that although the statistically significant differences have been shown, they are of no great practical importance. Nonetheless, what is interesting is the trend noted in case of the highest stress values, reducing the mean values of the coefficient $\varepsilon_{5/0}$ for the composites with the highest shares of silver nanoparticles. It results from great values of strains ε_0, which the moments underwent at the moment of the implementation of the load. Considerably deformed material has more limited abilities for the further strain, than almost twice more stiff materials with lower c_{Ag}. The introduction of the silver nanoparticles to the lining material influenced also the reaction of composites on the loads. Starting from c_{Ag} equal 80 ppm, there was noted an unfavourable change of values of the coefficient $\varepsilon_{1od/120}$ and strains ε_{1od} and ε_{30od}, which for two highest shares of nanosilver was very clear. With the increase of c_{Ag} there grew the values of the seemingly permanent strains in 1 and 120 s after the removal of the load, which were higher when the greater load was applied. This unfavourable effect is caused by the increase of the viscosity of the samples, with the simultaneous decrease of their elasticity. The cause of this situation is the lowering of the level of conversion of composites [15]. Particularly high were the values of ε_{1od} and coefficient $\varepsilon_{1od/120}$, proving the limited capacity of the recovery of the original form by the material during the chewing cycle. The observed severe loss of elastic properties with the greatest stress values may lead in the clinical values to the increase of pain sensations experienced by the patients. Based on the conducted studies it was stated, however, that despite the decrease of the stiffness with the increase of c_{Ag}, the sample of composites with the shares of nanosilver equal 10 to 40 ppm, similarly to the material available commercially, they characterised with the desired values, guaranteeing the almost immediate reaction of the material to the application or removal

of the load, regardless of the value of the applied contractual stress.

These results should be considered in connection with the results of measurements w_d by the samples in 1 and 7 cycle of compression. The conducted analysis showed very good dissipation properties of the tested materials. Especially from the point of view of the use of soft linings there is a small difference between the values of work dissipated in 1 and 7 cycle obtained for nanocomposites with the shares of nanosilver equal 10 to 40 ppm. These results correspond well with the results of measurements of strain ε_{1od}, where with the stress values equal from 0,1 to 0,2 MPa strains did not exceed 4%. Both experiments proves that these materials during the chewing cycle will be stable, almost without losing their original dissipated properties. It should be emphasised that the samples of material with the share of nanosilver equal 40 ppm had almost twice as big value w_d, than the samples of the UG material, while they maintained other properties, such as hardness, bond strength, sorption and solubility [15]. Therefore, it can be said that they have much improved properties in comparison to the starting material. Further enhancement of c_{Ag} allowed to obtain a several times greater values of the dissipation energy, however, the differences between the first and last cycle have clearly increased. This is consistent with the expectations, because of the behaviour of the samples during the load in the tests of the time characteristics. At the same time the potentially better dissipation properties of these composites, connected with the increase of the internal viscosity of the material as a result of the worse cross-linking of the materials, are depreciated by the negative consequences of the increase of c_{Ag} described in the previous work [15] and great values of the coefficient $\varepsilon_{1od/120}$, and strains ε_{1od}, ε_{30od}. It was therefore considered that in case of composites with shares of silver nanoparticles 80 to 200ppm, the growth of the dissipation work is only a seemingly positive effect, resulting from the generally negative changes of the properties. Moreover, the obtained high values ε_{1od}, with stress ranging from 0.4 to 0.6 MPa prove that the use of higher stress values would still lower the high values of the dissipation work obtained in the last cycle.

The presented method allows the laboratory evaluation of the effectiveness of the unloading of the mucous membrane through the soft lining materials. In the light of the presented studies during the loading the greatest importance for the effectiveness of the material falls on the strain value ε_0, determining the stiffness of the sample with the specified stress value. Although the obtained coefficients $\varepsilon_{5/0}$ and $\varepsilon_{30/5}$ could significantly differ from other soft lining materials (especially acrylic) [20],[22],[36]-[40], however, if we take into account the frequency and the average cycle of chewing in the denture users ranking from 10 to 40 cycles during approx. 30 s [28]-[30] their analysis does not bring any interesting information.

Important in the light of the conducted studies are the values of strains and coefficients $\varepsilon_{1od/120}$, ε_{1od}, ε_{30od} describing the behaviour of the material during the unload, which decide how fast the material recovers its original properties both during the chewing cycle (ε_{1od}) and after it is finished or in the intervals separating the next chewing cycles. The greater the values of strains and coefficients, the worse the material, because it undergoes slower regeneration losing for a moment some of its rehabilitation properties. The complementary study which allows to quantitatively compare the samples of materials in terms of energy absorption, which will not be transferred to the tissues under the denture plate, is the determination of the energy dissipated by the samples during the cyclic compression. These studies showed that more viscous materials, which in the analysed cases were also very soft, clearly dissipated more energy, however to a greater degree during the chewing cycle they underwent stiffening and lost the original dissipation properties. It should also be noted that softer materials with the increase of the stress values were stiffened in a greater extent. Such material in case of great load focused on a small area (e.g. with great inequalities of the appendicitis or in case of acute appendicitis) can undergo the temporary strain, which is so large that its layer in the loaded place will be too thin to properly fulfil its role.

The presented methodology of the research is even closer to reality, when the appendicitis is more uniform and flat, close to the plane of stamps. In order to obtain a fuller picture of the situation we should conduct studies with a methodology previously described by McCabe et al. [21] consisting of the loading of samples with the properly shaped penetrator, which gives better results in respect to the local compliance and viscoelasticity of denture soft linings. In contrast, the advantages of the presented simple methods are: the possibility to use the quantitative comparison of energy dissipated by the samples and the estimation of the reaction of material with more even distribution of loads. Furthermore, the presented method provides the possibility to use the variable stress values, what enables the easy connection of the obtained results with stress values, which cause pain sensations in the mucous membrane. It should be noted that the relations between the behaviour of the samples and the hardness of the materials shown in this paper are appropriate for the tested materials, what does not mean that the same results will be obtained for other materials of similar hardness.

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