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The influence of light curing parameters on wear resistance of selected resin-based dental composites

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ABSTRACT

Purpose: The aim of the work was to test influence of curing time and distance of the light source on wear resistance of composite dental materials.

Design/methodology/approach: The following study provides an insight into factors influencing wear resistance of composite materials. Standardized samples were made of methacrylate-based material Herculite XRV and silorane-based material Filtek Silorane and were tested using two types of Light Curing Units (LCUs) – halogen and LED. The distance of light source and time of curing differed between samples.

Findings: Filtek Silorane composite compared to Herculite XRV composite guarantees higher wear resistance, regardless of the used LCU type. Using LED LCU compared to halogen LCU allows to obtain higher wear resistance both for Herculite XRV and Filtek Silorane composite. The lower the distance of light source the higher the wear resistance of composite material.

Research limitations/implications: Further studies will provide additional information on other properties such as compressive strength, and degree of conversion.

Practical implications: This article shows important comparison between older and newer composite technology. It provides practical information on polymerization methods.

Originality/value: Article shows broad spectrum of different curing methods, important to the composite material use in dentistry.

Keywords: Dental composites; Light-curing; Silorane; Methacrylate; Wear resistance

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PROPERTIES

1. Introduction

Dental materials used for restorations of missing hard tissues of teeth consist of materials with variety of functions and properties.

Polymerization using certain spectrum of light allowed to eliminate the time limit for shaping the restoration and also resulted in appearance of composites in a ready-to-use form [1-4]. This allowed dental composites to emerge as materials mostly used in direct restorations of damaged or lost hard tissues of teeth. They are also used for mounting braces and preparation of dental prosthetics [2-5]. Due to their esthetics and performance they are also used in esthetic dentistry [6].

Composite materials can be evaluated by various mechanical parameters. Most important mechanical properties of dental composites – influencing significantly the quality of restoration – are: hardness, compressive strength, wear resistance and resilience [1-4,7].

Regarding the size of filler, materials can be categorized into four groups [2-4,8]: macrofillers, microfillers, hybrid and nanofillers.

Content of filler in a dental composite has significant influence on material's wear resistance.

Wear resistance of a dental material should be comparable to wear resistance of the enamel. It can be achieved by adding glass, barium or zinc particles. Extensive and too hard particles e.g. quartz, can lead to premature wear of opposing teeth.

Wear of a material shows roughness in surface created due to wear of the matrix, falling off filler particles, crumbling of filler and matrix and exposure to air.

By definition, friction is a process of relative moving of two surfaces in contact, wear is defined as a process, in which the surface is exposed to mechanical effect of another surface or chemically active substance [1,9]. Increase of the degree of conversion of dental composite materials results in the increase of their hardness and tensile strength. It also increases elasticity modulus and wear resistance of a material [2,3,10,11].

2. Material and method

The research was performed on 70 standardized samples of Herculite XRV dental composite (KERR, shade A3) based on a methacrylate resin and 70 standardized samples of Filtek Silorane dental composite (3M ESPE, shade A3) based on silorane resin. The samples 7 mm x 3 mm x 3 mm were acquired by light-curing dental composites in a specially prepared silicone mold.

The materials were polymerized using Elipar Highlight halogen LCU (3m ESPE), 75 W with maximal irradiance of 700 mW/cm^2 and SmartLite LED LCU (DENTSPLY), 5W LED with maximal irradiance of 950 mW/cm^2. The distance of the LCU and the time of curing differed between the samples. The distance of the light-curing unit (LCU) was set with spacer rings 2 mm high.

The time of light-curing of the dental composite is the time of polymerization of unsaturated components. Polymerization of photoactive particles is initiated by the light emitted by the halogen and LED LCUs during the curing. The samples were cured for 10 s, 20 s, 30 s, 40 s, 50 s, 60 s or 70 s from a distance of 0 mm, 2 mm, 4 mm, 6 mm and 8 mm.

The coding for light-cured samples of dental composites used in the paper was as follows:

type of the material – distance in millimeters – time of light-curing in seconds – type of the LCU

The following codes were established:

H – Herculite XRV dental composite (KERR),
FS – Filtek Silorane dental composite (3M ESPE).

The numbers between 0 and 8 determine the distance between the LCU (halogen or LED) and the surface of cured dental composite during the curing.

The numbers between 10 and 70 determine the time of light-curing in seconds,
HAL – dental composite cured with halogen LCU,
LED – dental composite cured with LED LCU.

Example of sample coding:
H-0-40-HAL – Herculite XRV dental composite light-cured directly on the surface (0 mm) for 40 s with the halogen LCU.

Wear resistance of dental composites Herculite XRV by Kerr and Filtek Silorane by 3M ESPE was tested with use of TRN S/N 18-324 tribometer with TriboX v.2.96 system by CSM Instruments. Tribological test was performed with use of artificial medium replacing human saliva. The test was performed according to ASTM G99-05.

Pin-on-disc test was chosen. The test was performed in the temperature of 23°C with a relative humidity of 45-55%. Samples were weighted before and after the test. Weighting was performed using AS/60/C/2 analytical balance by Radwag. The test was performed three times for each sample. Wear coefficient was calculated with following formula:

$$K = \frac{\Delta m}{F \cdot S}$$, where:

K – wear resistance coefficient,
Δm – mass loss, g,
F – force, N,
S – friction distance, m.

3. Statistical methodology

All calculations were performed with the use of StatSoft Inc. statistical software STATISTICA, version 10.0. and Excel calculation sheet.

Quantitative variables were expressed by: mean, standard deviation, median, minimal and maximal value (range) and 95% CI (Confidence Interval). The qualitative variables were expressed by numerical values.

The W Shapiro-Wilk test was used to check if the quantitative variable came from normally distributed population. The Levene's (Brown-Forsythe) test was used to check the hypothesis on equal variances.

The difference significance between two groups (independent variables model) was tested using significance differences test: t-Student or U Mann-Whitney test. Significant differences between more than two groups were tested with F (ANOVA) or Kruskal-Wallis test (in case of not complying with ANOVA test requirements).

The strength and direction of correlation between variables was tested using correlation analysis calculating Pearson and/or Spearman correlation coefficients. The statistical significance level was set at $p = 0.05$.

4. Results

Wear coefficient K of methacrylate-based dental composite (Herculite XRV) cured with halogen LCU (Tab. 1, Fig. 1) decreases from 10 s up to 40 s of curing, achieving the lowest value of wear at 40 s, hence the highest wear resistance. Longer curing (above 40 s) resulted in an increase of wear coefficient of Herculite XRV dental composite.

Table 1.
Wear coefficient K of methacrylate-based material (Herculite XRV) cured with halogen LCU in relation to time of curing and distance of the light source from the surface of the material

		Distance of the light source from the surface of the material, mm				
		0	2	4	6	8
Curing time, s	10	7.3	7.4	7.5	7.7	8.0
	20	7.1	7.3	7.4	7.5	7.8
	30	7.0	7.1	7.2	7.4	7.7
	40	6.8	7.0	7.1	7.3	7.6
	50	7.0	7.1	7.2	7.5	7.8
	60	7.1	7.3	7.4	7.7	8.1
	70	7.2	7.4	7.6	7.8	8.4

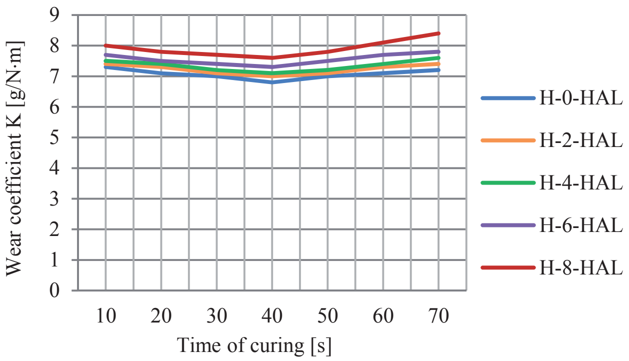

Fig. 1. Wear coefficients K of methacrylate-based material (Herculite XRV) cured with halogen LCU in relation to time of curing and distance of the light source from the surface of the material

Wear coefficient K of methacrylate-based material (Herculite XRV) cured with LED LCU (Tab. 2, Fig. 2) from a distance of 0 mm, 2 mm, 4 mm and 8 mm decreased between 10 s and 40 s of curing, achieving at 40 s lowest value of wear, hence highest wear resistance. Longer curing (above 40 s) at the same distances, resulted in the increase of wear coefficient of methacrylate-based dental composite (Herculite XRV).

Table 2.
Wear coefficients K of methacrylate-based material (Herculite XRV) cured with LED LCU in relation to time of curing and the distance of the light source from the surface of the material

		Distance of the light source from the surface of the material, mm				
		0	2	4	6	8
Curing time, s	10	7.0	7.2	7.4	7.6	7.8
	20	6.8	7.0	7.3	7.4	7.6
	30	6.5	6.8	7.0	7.3	7.4
	40	6.1	6.4	6.9	7.1	7.0
	50	6.2	6.5	7.1	7.0	7.1
	60	6.3	6.7	7.2	7.3	7.2
	70	6.4	6.8	7.4	7.5	7.3

The decrease of wear coefficient K of silorane-based dental composite (Filtek Silorane) was observed for curing with halogen LCU (Tab. 3, Fig. 3) for an extended period of time. The lower the distance of the light source from the surface of the sample, the lower the wear coefficient K.

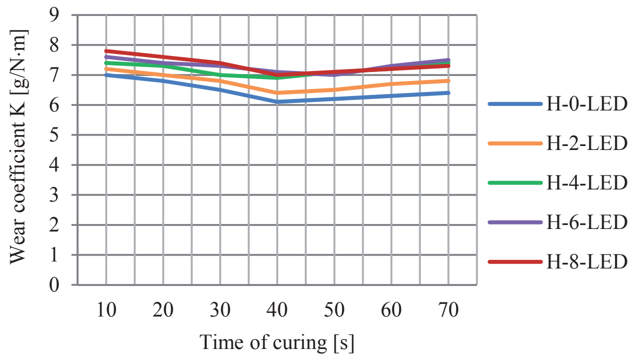

Fig. 2. Wear coefficients K of methacrylate-based material (Herculite XRV) cured with LED LCU in relation to time of curing and distance of the light source from the surface of the material

Table 3.
Wear coefficients K of silorane-based material (Filtek Silorane) cured with halogen LCU in relation to time of curing and distance of the light source from the surface of the material

		Distance of the light source from the surface of the material, mm				
		0	2	4	6	8
Curing time, s	10	7.0	7.2	7.3	7.5	7.9
	20	6.9	7.1	7.2	7.3	7.8
	30	6.7	6.9	7.1	7.2	7.7
	40	6.6	6.7	7.0	7.1	7.5
	50	6.4	6.6	6.8	7.0	7.3
	60	6.2	6.3	6.7	6.8	7.1
	70	6.0	6.1	6.6	6.7	7.0

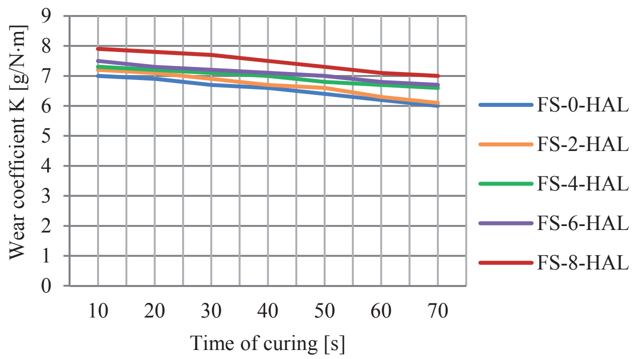

Fig. 3. Wear coefficients K of silorane-based material (Filtek Silorane) cured with halogen LCU in relation to time of curing and the distance of the light source from the surface of the material

With longer curing of silorane-based dental composite (Filtek Silorane) with LED LCU (Tab. 4, Fig. 4), values of wear coefficient K have decreased. The lower the distance of the light source from the surface of the material, the lower the wear coefficient K.

Table 4.
Wear coefficients K of silorane-based material (Filtek Silorane) cured with LED LCU in relation to time of curing and distance of the light source from the surface of the material

		Distance of the light source from the surface of the material, mm				
		0	2	4	6	8
Curing time, s	10	6.5	6.7	6.9	7.2	7.7
	20	6.4	6.5	6.7	7.0	7.6
	30	6.3	6.4	6.6	6.9	7.4
	40	6.0	6.1	6.4	6.7	7.2
	50	5.9	6.0	6.2	6.6	7.1
	60	5.7	5.8	6.0	6.4	6.9
	70	5.4	5.6	5.8	6.2	6.6

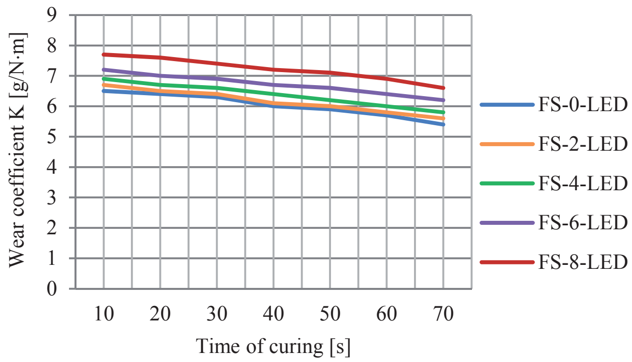

Fig. 4. Wear coefficients K of silorane-based material (Filtek Silorane) cured with LED LCU in relation to time of curing and distance of the light source from the surface of the material

Lowest values of wear coefficient K (the highest wear resistance) (Fig. 5) were observed after curing silorane-based dental composite (Filtek Silorane) with LED LCU for 70 s, by placing the light source directly on the surface of the sample. Silorane-based material (Filtek Silorane) achieved higher wear resistance than methacrylate-based material (Herculite XRV).

Mean wear coefficient (Tab. 5) of methacrylate-based material was 7.2 (0.4) and of silorane-based material was

6.7 (0.6). Wear coefficient of the silorane-based material was significantly lower comparing to wear coefficient of the methacrylate-based material (t-Student value t = 5.85, p = 0.0001).

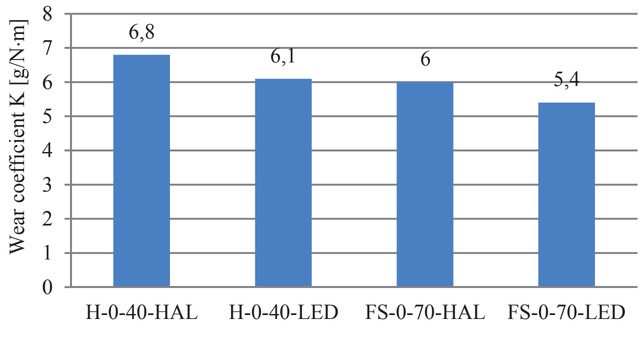

Fig. 5. Lowest values of wear coefficients K of methacrylate-based (Herculite XRV) and silorane-based (Filtek Silorane) dental materials in relation to type of used LCU, curing time and distance of the light source from the surface of the material

Table 5.
Comparison of wear coefficients of Herculite XRV and Filtek Silorane materials

	Herculite XRV	Filtek Silorane	p value
mean (SD)	7.2 (0.4)	6.7 (0.6)	**p=0.0001**
95%CI	[7.1;7.3]	[6.6;6.9]	
range (min-max)	6.1-8.4	5.4-7.9	
median	7.3	6.7	

Figure 6 show mean values and standard deviations of wear coefficients of methacrylate- and silorane-based materials.

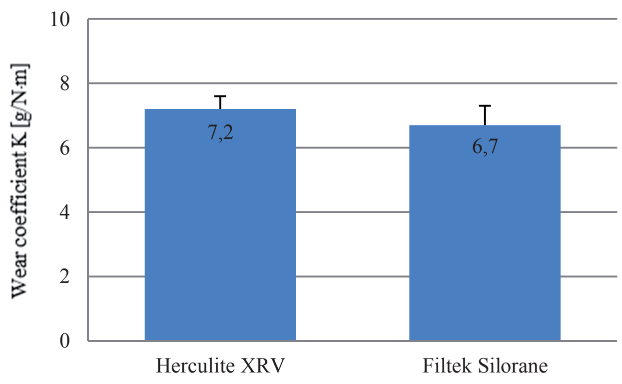

Fig. 6. Mean values and standard deviations of wear coefficients of Herculite XRV and Filtek Silorane materials

Mean wear coefficient (Tab. 6) of methacrylate-based material cured with halogen LCU was 7.4 (0.3) and of silorane-based material was 7.0 (0.5). Mean wear coefficient of methacrylate-based material cured with LED LCU was 7.0 (0.4) and of silorane-based was 6.5 (0.6).

Wear coefficient differed depending on material and LCU type (test value F = 24.31, p = 0.0001).

Wear coefficient of methacrylate-based material cured with halogen LCU was higher comparing to wear coefficient of methacrylate-based material cured with LED LCU (p = 0.0011) and wear coefficient of silorane-based material cured with halogen LCU (p = 0.0001).

Wear coefficient of silorane-based material cured with LED LCU was significantly lower than the wear coefficient of methacrylate-based material cured with LED LCU (p = 0.0001) and the wear coefficient of silorane-based material cured with halogen LCU (p = 0.0001).

Table 6.
Comparison of wear coefficients of Herculite XRV and Filtek Silorane materials in relation to type of the LCU used for curing

	Herculite XRV		Filtek Silorane		p value
	HAL	LED	HAL	LED	
mean (SD)	7.4 (0.3)	7.0 (0.4)	7.0 (0.5)	6.5 (0.6)	[1]0.0011
95%CI	[7.3;7.5]	[6.9;7.2]	[6.8;7.1]	[6.3;6.7]	[2]0.0001
range (min-max)	6.8-8.4	6.1-7.8	6.0-7.9	5.4-7.7	[3]0.0001
median	7.4[1.2]	7.1[1.3]	7.0[2.4]	6.5[3.4]	[4]0.0001

Figure 7 shows mean values and standard deviations of wear coefficients of methacrylate- and silorane-based materials in relation to a type of the LCU used for curing.

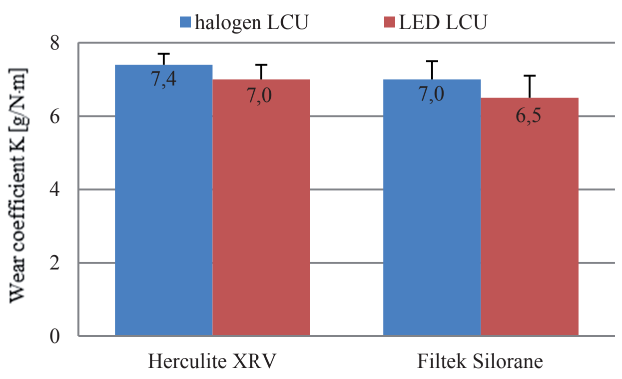

Fig. 7. Mean values and standard deviations of wear coefficients of Herculite XRV and Filtek Silorane materials in relation to type of the LCU used for curing

The correlation coefficient (Tab. 7) of silorane-based material was R = -0.58, p =0.0001 (with the increased duration of curing the wear has decreased) and for methacrylate-based material was R = -0.11, p = 0.3530.

Table 7.
Correlation of wear coefficients and time of curing of Herculite XRV and Filtek Silorane materials (R – correlation coefficient, p -statistical significance of the coefficient)

Herculite XRV		Filtek Silorane	
R	p	R	p
−0.11	0.3530	−0.58	**0.0001**

There was no statistically significant correlation of wear coefficient and time of curing of methacrylate-based material (Fig. 8).

With longer curing time the wear coefficient of silorane-based material has decreased (Fig. 9).

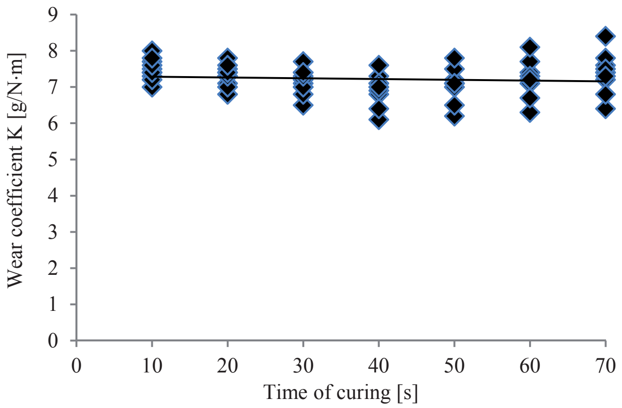

Fig. 8. Correlation of wear coefficient and time of curing of methacrylate-based material

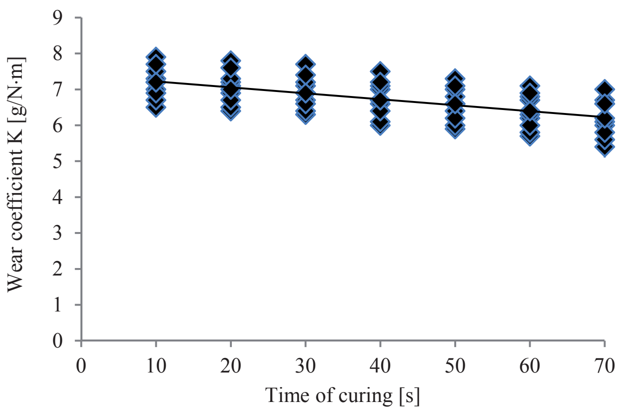

Fig. 9. Correlation of wear coefficient and time of curing of silorane-based material

Wear coefficient of methacrylate- and silorane-based materials increased with the increase of the distance of the light source from the surface of the material (Tab. 8). Correlation coefficient of methacrylate-based material was R = 0.70, p = 0.0001, whereas for silorane-based material was R = 0.66, p = 0.0001.

Table 8.
Correlation of wear coefficient and the distance of the light source from the surface of Herculite XRV and Filtek Silorane materials (R – correlation coefficient, p – statistical significance of the coefficient)

Herculite XRV		Filtek Silorane	
R	p	R	p
0.70	**0.0001**	0.66	**0.0001**

The increase of the distance of the light source from the surface of the methacrylate-based material, resulted in the increase of wear coefficient (Fig. 10).

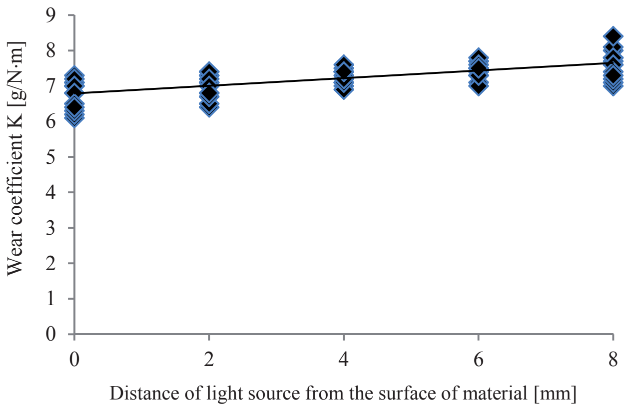

Fig. 10. Correlation of the wear coefficient and the distance of the light source from the surface of methacrylate-based material

The increase of the distance of the light source from the surface of the silorane-based material, resulted in the increase of wear coefficient (Fig. 11).

Wear coefficient of silorane-based material decreased with the increase of the time of curing (Tab. 9). Correlation coefficient of silorane-based material cured with halogen LCU was R = -0.69, p = 0.0001, Correlation coefficient of silorane-based material cured with LED LCU was R = -0.63, p = 0.0001.

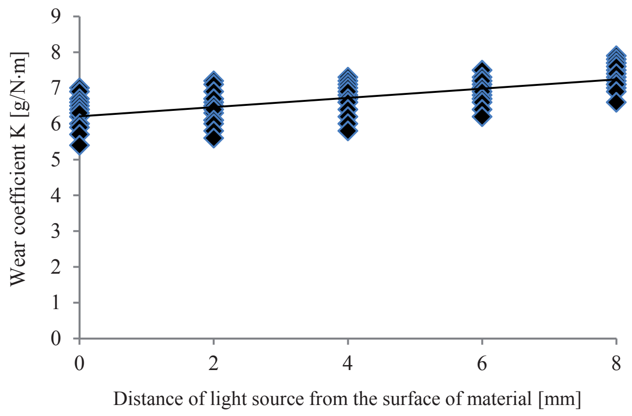

Fig. 11. Correlation of wear coefficient and the distance of the light source from the surface of silorane-based material

Table 9.
Correlation of wear coefficient and time of curing of Herculite XRV and Filtek Silorane materials in relation to type of LCU used for curing (R – correlation coefficient)

Herculite XRV				Filtek Silorane			
HAL		LED		HAL		LED	
R	p	R	p	R	p	R	p
0.05	0.7765	−0.27	0.1141	−0.69	**0.0001**	−0.63	**0.0001**

There is no statistically significant correlation of wear and time of curing of methacrylate-based material cured with halogen LCU (Fig. 12).

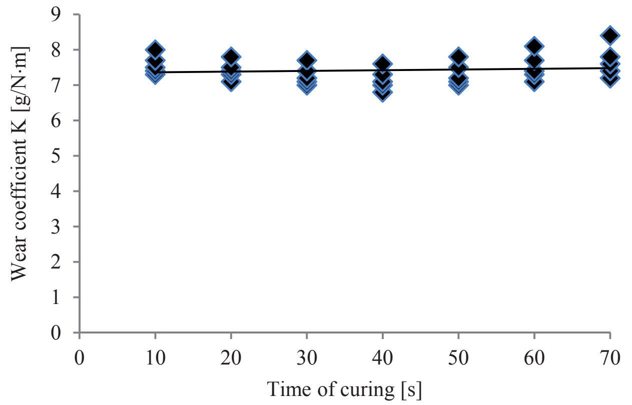

Fig. 12. Correlation of wear coefficient and time of curing of methacrylate-based material cured with halogen LCU

There is no statistically significant correlation of wear and time of curing of methacrylate-based material cured with LED LCU (Fig. 13).

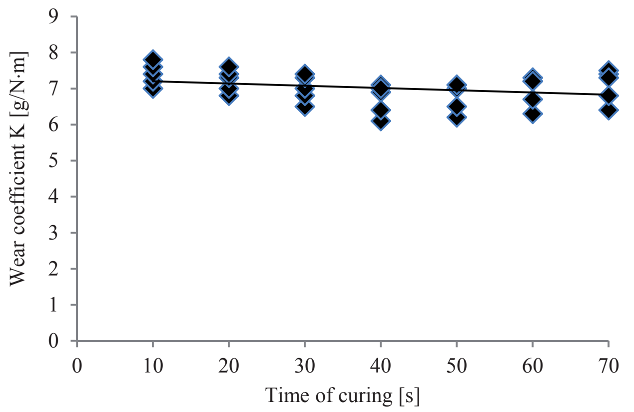

Fig. 13. Correlation of wear coefficient and time of curing of methacrylate-based material cured with LED LCU

The increase of the curing time of the silorane-based material cured with halogen LCU, resulted in the decrease of wear coefficient (Fig. 14).

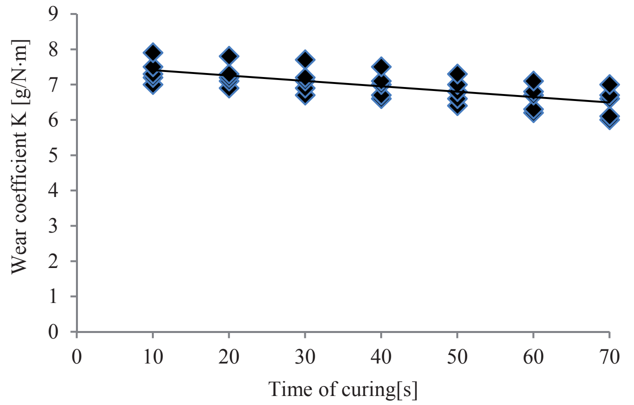

Fig. 14. Correlation of wear coefficient and time of curing silorane-based material cured with halogen LCU

Increase of the curing time of the silorane-based material cured with LED LCU, resulted in the decrease of wear coefficient (Fig. 15).

Wear coefficient of methacrylate- and silorane-based materials increased with the increase of the distance of the light source from the surface of material (Tab. 10). Correlation coefficient of methacrylate-based material cured with halogen LCU was R = 0.85, p = 0.0001, whereas of silorane-based material was R = 0.70, p = 0.0001. Correlation coefficient of methacrylate-based material cured with LED LCU was R = 0.76, p = 0.0001, whereas of silorane-based material was R = 0.74, p = 0.0001.

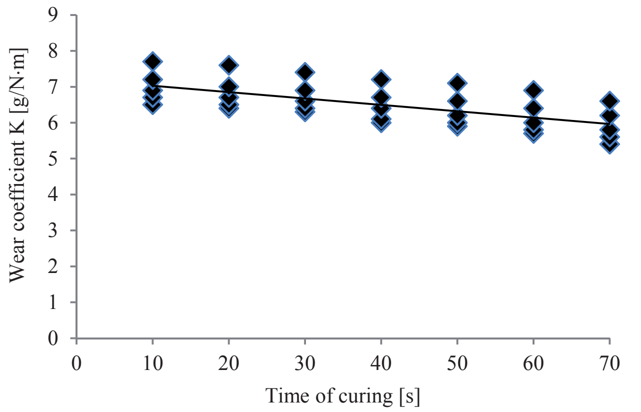

Fig. 15. Correlation of wear coefficient and time of curing of silorane-based material cured with LED LCU

Table 10.
Correlation of wear coefficient and the distance of light source from the surface of Herculite XRV and Filtek Silorane materials in relation to type of LCU used for curing (R – correlation coefficient)

Herculite XRV				Filtek Silorane			
HAL		LED		HAL		LED	
R	p	R	p	R	p	R	p
0.85	**0.0001**	0.76	**0.0001**	0.70	**0.0001**	0.74	**0.0001**

The increase of the distance of the light source from the surface of the methacrylate-based material cured with halogen LCU, resulted in the increase of wear coefficient (Fig. 16).

Increase of the distance of the light source from the surface of the methacrylate-based material cured with LED LCU, resulted in the increase of wear coefficient (Fig. 17).

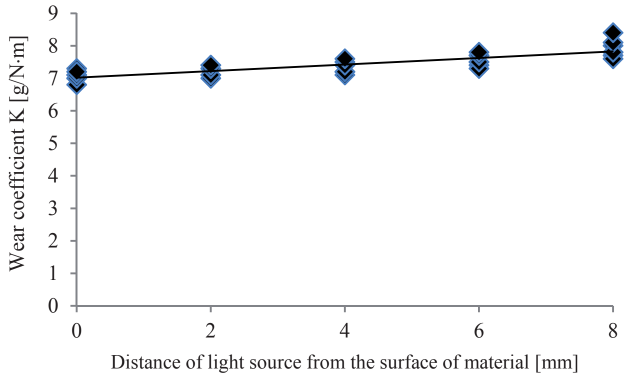

Fig. 16. Correlation of wear coefficient and the distance of light source from the surface of methacrylate-based material cured with halogen LCU

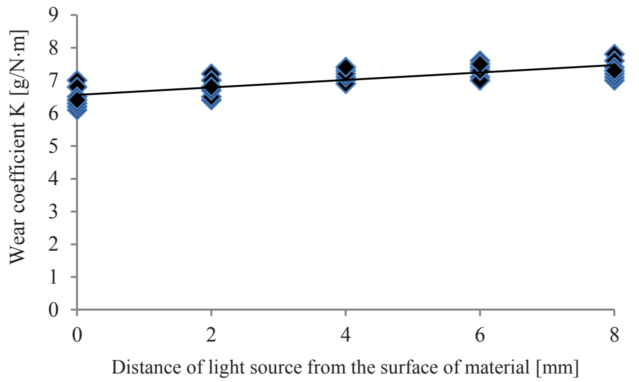

Fig. 17. Correlation of wear coefficient and the distance of the light source from the surface of methacrylate-based material cured with LED LCU

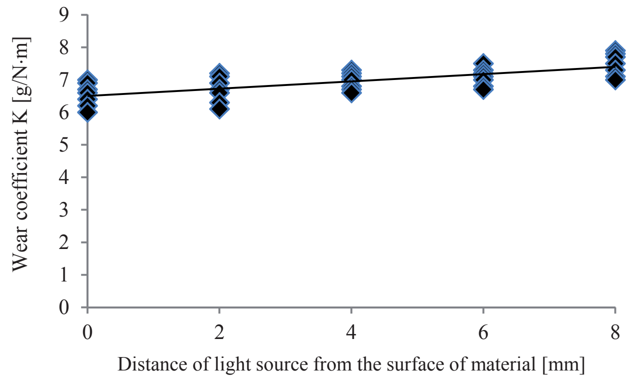

Fig. 18. Correlation of wear coefficient and the distance of the light source from the surface of silorane-based material cured with halogen LCU

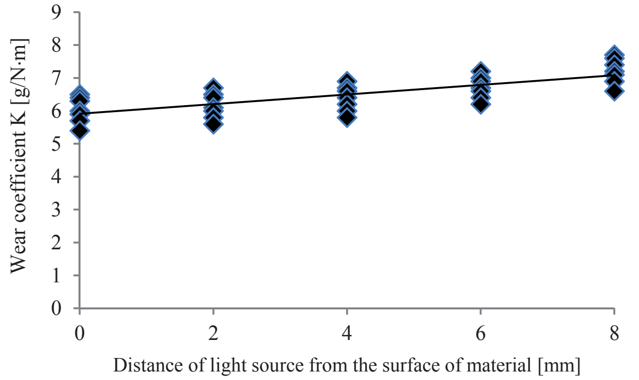

Fig. 19. Correlation of wear coefficient and the distance of light source from the surface of silorane-based material cured with LED LCU

Increase of the distance of the light source from the surface of the silorane-based material cured with halogen LCU, resulted in the increase of wear coefficient (Fig. 18).

The increase of the distance of the light source from the surface of the silorane-based material cured with LED LCU, resulted in the increase of wear coefficient (Fig. 19).

5. Discussion

The quality of composite restorations depends mainly on the mechanical properties of used materials. Use of a high class materials reduces the risk of damaging the restoration under masticatory force. Wear resistance of a restoration depends significantly on hardness of a material it is made of. Materials that are too hard may cause increased wear of opposing teeth.

Wear resistance – one of the most important property of dental materials – depends mostly on hardness [12-14].

Research conducted by Santos Jr et al. [13] showed, that the highest wear resistance have materials with average hardness and elasticity.

Properties of composite materials depend greatly on type, size, space between particles and volume of filler. The composition of organic matrix plays also a great role in acquiring material with best characteristics [15-17].

Zheng et al. [18] studied friction and wear of enamel and dentin against titanium balls in the presence of artificial saliva. Their research showed that enamel exhibited a lower friction coefficient than dentin and the hardness and tooth wear decreased with depth of wear.

In comparison to materials containing big particle filler (>1 μm), microfillers and hybrid composite materials have higher wear resistance due to smoother surface, smaller spaces between particles and lower friction on the surface in contact with the food [14,18,19].

Decrease of conversion degree by shortening time and intensity of curing light can lower mechanical strength of a material. Proper degree of conversion of a resin not only increases hardness of a composite but also determines the wear resistance.

Application of insufficient amount of energy for the activation of catalyst system of a composite material during the restoration of damaged hard tissues of teeth, can result in insufficient polymerization of the composite, hence decrease in quality [20]. It occurs due to decrease of the amount of monomers bonded in the polymer network, which results in inhomogeneous crosslinking of the matrix. This can occur, in case of insufficient curing time of the material or extensive distance of the light source from the surface of cured composite.

Wear resistance of light-cured dental composites is an important mechanical property and is used to evaluate their performance [21]. Our research showed that the highest wear resistance, exhibited as wear coefficient K was achieved for Herculite XRV and Filtek Silorane dental composites cured directly on the surface of the material. Regardless of the used LCU type, wear resistance of Herculite XRV dental composite at first increased, decreasing afterwards and reaching the peak after curing for 40 s. Filtek Silorane composite achieved highest wear resistance after curing for 70 s, regardless of used LCU type. Both composite materials exhibited higher wear resistance after curing with LED LCU.

Comparing results of own research, Filtek Silorane exhibits higher wear resistance (lower values of wear coefficient K) than Herculite XRV. It was noticed that increase of the distance of the LCU from the surface of a material results in loss of wear resistance of both materials.

Use of LED LCU for curing of studied materials increases their wear resistance, comparing to halogen LCU.

Wear resistance, exhibited as wear coefficient K, of dental composite Herculite XRV cured with LED or halogen LCU, increases with the time of curing – between 10 s and 40 s. Longer curing of the composite resulted in decrease of its wear resistance. It may be a result of its chemical composition; Herculite XRV contains mostly multifunctional methacrylate monomers. The curing process in Herculite XRV composite is caused by polymerization of double bonds in methacrylate groups. The process runs according to radical mechanism, which due to a high polymerization shrinkage caused by curing time necessary for conversion of unsaturated bonds, can result in decreased of wear resistance. The polymerization process of silorane-based composite Filtek Silorane runs by opening of reactive oxirane group ring. Composites polymerized according to cationic mechanism through oxirane groups exhibit lower polymerization shrinkage than composites polymerized according to radical mechanism. The wear resistance, exhibited as wear coefficient K, of Filtek Silorane composite cured with LED or halogen LCU decreased with the increase of time of curing in the whole time interval – from 10 s to 70 s.

Clinical success of dental restorations made with composite materials depends mostly on their proper polymerization, because mechanical strength of dental composites depends on conversion degree of a resin.

Studies related to curing methods and LCUs used for curing of dental composites allow to choose most efficient techniques.

6. Conclusions

1. In the curing process Filtek Silorane and Herculite XRV composites increased their wear resistance with the decrease of the distance of the light source from the surface of material.
2. Methacrylate-based dental composite Herculite XRV achieved the highest wear resistance after curing directly on the surface of the sample for 40 s. Silorane-based dental composite Filtek Silorane achieved the highest wear resistance after curing for 70 s also directly on the surface of the sample.
3. Using LED LCU for curing of silorane-based Filtek Silorane and methacrylate-based Herculite XRV dental composites allowed to achieve higher wear resistance than using halogen LCU for the same exposure time.

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