METHOD OF EVALUATION OF DEGRADATION OF BIO-MECHANICAL TOOTH-COMPOSITE FILLING SYSTEM

Andrzej NIEWCZAS[1], Daniel PIENIAK[2], Agata M. NIEWCZAS[3]

[1] Technical University of Lublin, Department of Combustion Engines and Transport
Lublin 20-608, Nadbystrzycka Str. No 36, Poland, e-mail: a.niewczas@pollub.pl
[2] Department of Applied Mechanic, Main School of Fire Service
Warsaw 01-629, J. Słowackiego Str. No 52/54, Poland, e-mail: daniel60@poczta.fm
[3] Medical University of Lublin, Department of Conservative Dentistry
Lublin 20-081, Karmelicka Str. No 7, Poland, e-mail: agata.niewczas@umlub.pl

Summary

This paper describes a method of an enhanced life evaluation of dental fillings based on the observation of the enlargement of the marginal fissure between the filling and hard tissue of the tooth. A width of marginal fissure was considered as the functional parameter of the whole tooth-filling system in the conducted tests.

In this study development of the fissure influenced by the cyclic changes of thermal loads was analyzed. The extracted human teeth were used in the tests. In which a model lesions with micro-hybrid composite fillings were applied. All tests were conducted on the dedicated test stand. After performance of fatigue tests, measurements of the width of marginal fissure were taken by means of SEM electron scanning microscope and optical microscope with computer image analyzer.

On this basis a risk of functional unfitness of the tooth-filling system was estimated.

Keywords: reliability, laboratory tests, dental composite.

METODA OCENY DEGRADACJI SYSTEMU BIOMECHANICZNEGO ZĄB - WYPEŁNIENIE KOMPOZYTOWE

Streszczenie

W artykule opisano metodę przyspieszonej oceny trwałości wypełnień stomatologicznych na podstawie obserwacji rozbudowy szczeliny brzeżnej pomiędzy wypełnieniem a twardą tkanką zęba. W warunkach prowadzonych badań jako miarę zdatności czynnościowej całego systemu ząb – wypełnienie przyjęto szerokość szczeliny brzeżnej.

Autorzy przeprowadzili analizę rozwoju szczeliny pod wpływem cyklicznie zmiennych obciążeń cieplnych. Do badań wykorzystano usunięte zęby ludzkie. W zębach wypreparowano modelowe ubytki i założono wypełnienia z kompozytu mikrohybrydowego. Badania zostały przeprowadzone na specjalnie opracowanym stanowisku badawczym. Po wykonaniu testów zmęczeniowych przeprowadzano pomiary szerokości badanej szczeliny brzeżnej, wykorzystując elektronowy mikroskop skaningowy SEM. Na tej podstawie oszacowano ryzyko niezdatności użytkowej układu ząb – wypełnienie.

Słowa kluczowe: niezawodność, testy laboratoryjne, kompozyty stomatologiczne.

1. INTRODUCTION

Materials used in a conservative dentistry nowadays need to meet strict fatigue resistance requirements in the tooth-filling system. Fatigue resistance of dental fillings is limited by the development of marginal fissure between the lesion walls and the filling.

The consequence of the occurrence of marginal fissure is a microleakage. Bacterial microleakage consists in penetration of microorganisms and their proliferation in the space between the filling and the wall of lesion. Microleakage results in secondary caries occurring along the walls of filling, which ultimately leads to the physical and biological degradation of the filling and determines the end of the filling's life. Due to the time consuming testing of this phenomenon in clinical conditions, the development of marginal fissure was studied in laboratory conditions.

To fill the lesion a polymer photo-cured composite was used, always demonstrating polymerization shrinkage leading to the initiation of marginal fissure in the process of polymerization [3, 16, 20, 5, 14, 2]. In order to obtain a resistant bond of the filling with the wall of the lesion, bonding systems with indirect raisins or indirect liquids were applied [13, 15].

Fluctuations of the conditions in the oral cavity (particularly changes of temperature and pH) may lead to the progress in the degradation of the tooth-composite filling system [6, 9]. The literature presents a common view that changes in temperature of the oral cavity environment may constitute the main factor affecting the placement of stresses and their changes in the bordering area of the filling and tooth tissues [19]. The previous tests have also demonstrated a relation between the temperature in which polymer composites based on resins are used and the loss of filling mass, as well as decomposition and depolymerization of its structure [1]. A consequence of this phenomenon is possible expansion of marginal fissure accompanied by the microleakage of liquids. The wedging activity of the liquids, during the act of chewing, leads to further expansion of the volume of fissure together with the weakening of its structure.

In vitro thermal fatigue simulation of the tooth-composite filling system should correspond to physiological conditions of the human oral cavity. The most important parameters of simulation environment are the following: 1) temperature of working liquid (in most cases it is an artificial saliva), 2) the retention time of working liquid in the vessel containing teeth specimens or the retention time of the examined specimen in the vessel with working liquid and 3) the number of thermal load cycles (thermal shocks).

In the previous studies, various different assumptions have been made with regards to the experimental parameters. Bottom temperature of working liquids used in the experiments varied between 2 and 24°C [7], while the temperatures of heated liquid ranged from 45°C to 60°C [21]. The applied retention time of conditioning liquid in the vessel containing specimens varied from 15 to even 180 seconds, and the number of cycles oscillated between 25 and 1 000 000 thermal cycles [7].

Today, the most frequently used experimental parameters are as follows:

- Temperature of cooled working liquid, 5 ºC,
- Temperature of heated working liquid, 55ºC,
- Retention time of working liquid in the vessel containing specimen, 30 seconds,
- Number of thermal cycles – from a few thousand to several dozen thousand cycles.

The evaluation of the influence of thermal cycles on resistance of the tooth-filling system was performed by the analysis of marginal untightness, mainly based on quality scales related to the enlargement of the marginal fissure. According to the authors' knowledge, up till now no quantitative evaluation of the process of degradation of the system resulting from the cyclic fluctuations of temperature has been made.

The examined tooth-dental filling system, based on the theory of reliability, is a series system [11]. Thus, its performance is determined by the functioning of all its elements such as tooth hard tissue, bonding layer and the body of the filling material.

The observed marginal fissure in the tooth-filling system indicates lack of continuity in the structure of specific size and shape. On the surface of these discontinuities the forces of atomic bonds do not act. In the unloaded state the edges of the fissure may contact with each other, whereas when loaded – they may spread or even move against each other [12].

In the presented studies it was assumed that the marginal fissure contributes to the functional unfitness of the tooth-filling system, while its parameters are the basis of evaluation of the limit state of the whole studied system.

2. METHOD

2.1. Objective of the study

The developed method consisted in application of the extracted human teeth (removed due to orthodontic reasons) as specimens in the fatigue degradation laboratory tests. In the specimens, model lesions were prepared of the identical size and lateral walls perpendicular to their bottoms (Fig. 1).

The lesions were filled with photo-cured composite with micro-filler according to manufacturer's instructions. In order to ensure a contact of the filling with the enamel and dentine, the lesions were 3 millimeter deep. The enamel and dentine were etched with 37% ortho-phosphoric acid. In the next stage, the bonding material was applied to all walls and the bottom of the lesion. Composite material was applied to the lesion as 2 millimeter layers and heated with halogen lamp for 40 seconds [8].

The tooth specimens were fixed in special holders.

Next, the tooth specimens were submitted to the thermal loads at the test stand simulating load cycles reflecting physiological processes in the oral cavity (Fig. 2).

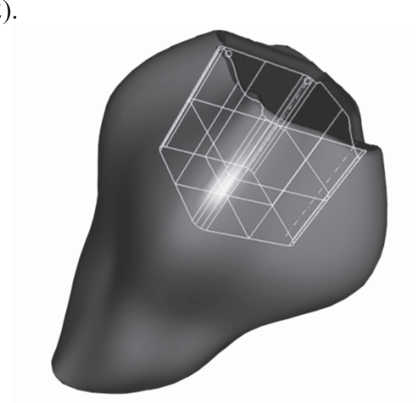

Fig. 1. Geometrical model of the tooth with the prepared lesion

2.2. Simulator of thermal loads

The test stand used for simulation of thermal shocks (Fig. 2) consisted of microprocessor control system and hydraulic system. The equipment assured the realization of thermal shocks in the specimens placed inside the measurement vessel, located in the mastication simulator. The operation of the simulator consisted in periodical pumping in and out of the working liquid into the measurement vessel with set temperature. The vessel was alternately filled with heated (temperature 328K) or cooled (temperature of 278K) working liquid from the two independent temperature conditioning systems.

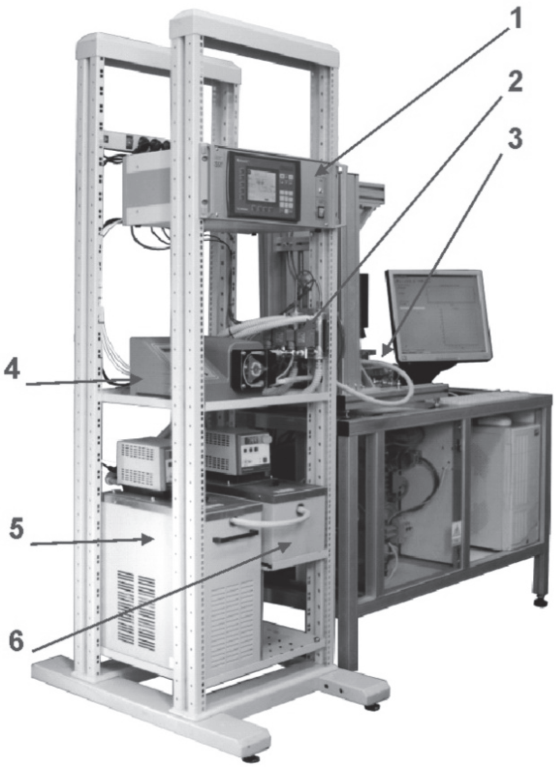

Fig. 2. Test stand for thermal shocks: 1 – microprocessor control module, 2 – control valves, 3 – mastication simulator, 4 – peristaltic pump, 5 – cooling thermostat, 6 – heating ultra thermostat

During thermal shocks performance, programmable times of the individual actions of the control were applied. Figure 3 presents the course of the procedure of one cycle of thermal shocks.

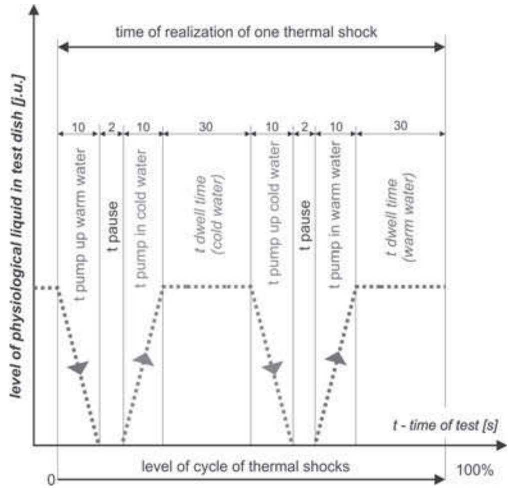

Fig. 3. Graphical presentation of thermal shock cycle with single pumping of working liquid

2.3. Microscope observations

After series of cyclic loads the teeth were cut along their long axis into two halves (Fig. 4).

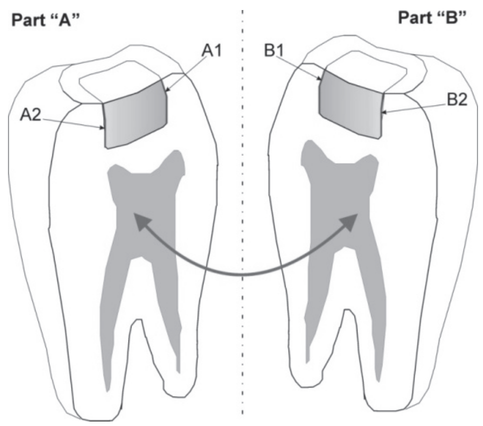

Fig. 4. Diagram of the tooth specimens: A1, A2, B1, B2 – marginal fissure observation areas

A surface of the prepared specimens was grinded with a few types of fine-grained abrasive paper, and next it was polished.

Fig. 5. Intersection of the tooth – the specimen for geometrical measurements of marginal fissure

The nature of the tooth tissue adherence to the surface of the composite filling was investigated by means of microscopic observation. Electron scanning microscope (LEO 1430 VP), optical microscope (Neophot 2) and image analysis software (Image-ProPlus, Media Cybernetics) were applied. Figure 6 presents the enamel, dentine and composite filling bordering area. Marginal fissure is visible between the enamel (2) and composite filling (1) and between dentine (3) and composite. The shape of the fissure is irregular along its whole length. The fissure ends with a crater-like lesion of parabolic intersection by the chewing surface (Fig. 6).

Figure 7 clearly shows irregular marginal fissure between the composite filling and the enamel on the chewing surface. The shape of the border line of the filling and the tooth hard tissue takes a different form. The border of the lesion is more linear, whereas that of the filling is more irregular.

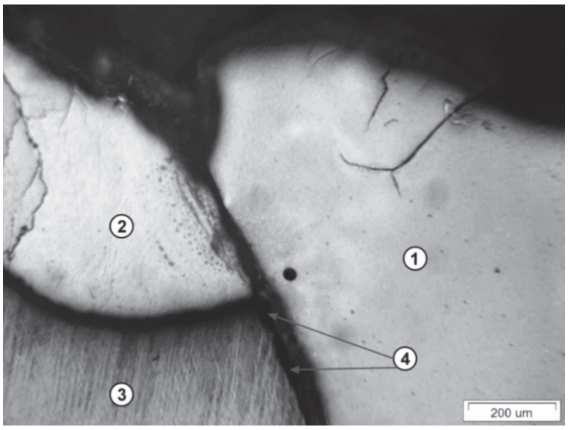

Fig. 6. Image of marginal fissure: 1 – polymer composite, 2 - enamel, 3 - dentine , 4 – marginal fissure

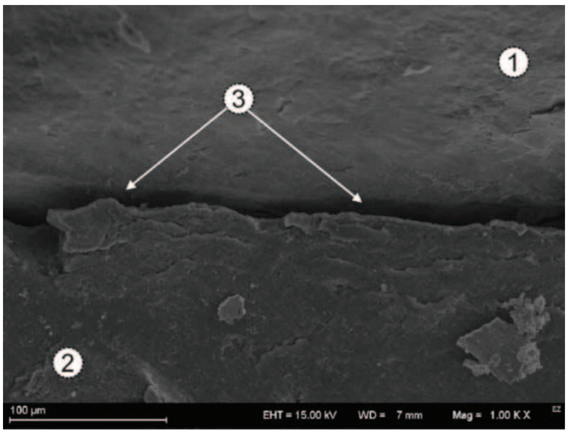

Fig. 7. SEM image of marginal fissure on the chewing surface: 1 – enamel, 2 – composite filling, 3 – marginal fissure

3. TESTS RESULTS AND RESULTS ANALYSIS

3.1. Parameters of marginal fissure

The results of the measurements of the marginal fissure width in *Heliomolar Radiopaque* material with regards to the number of thermal cycles are presented in Figure 8.

In the diagram (Fig.8) values from x1 to x10 show the depth of the measurement. Value x10 refers to the point of measurement by the chewing surface, whereas value x1 indicates the lowest point of measurement, near the filling’s bottom. The shape of the diagram demonstrates different dynamics of changes in the width of marginal fissure in various depth zones. The most significant variability of fissure parameters can be observed on the chewing surface.

3.2. Evaluation of differences between means

The evaluation of differences between the mean widths of the fissure in individual groups of measurements was carried out on the basis of T student test. Significance of differences in mean values of the fissure between the subsequent thermal load ranges was estimated (number of thermal cycles – TC): 2 000 cycles, 20 000 cycles, 40 000 cycles, 60 000 cycles, 90 000 cycles (Table 1).

Level *p* given in the results of T test represents error probability associated with the acceptance of the hypothesis on the existence of differences between the averages. This is error probability consisting in the rejection of the hypothesis about the lack of differences between averages in the two studied categories of observation belonging to the general population (represented by the studied groups) in the situation when actual state in the population is that this hypothesis is true [10]. Sign of *t* function, in the same way as in the case of standardized variable, indicates negative or positive deviation from the average [18].

Table 1. Comparison of values of the width of the fissure for the increasing number of thermal shocks

Gr. 1 vs. Gr. 2	*t*	*p*
2000 TC vs. 20000 TC	0,91452	0,361027
2000 TC vs. 40000 TC	-0,01398	0,988856
2000 TC vs. 60000 TC	-0,05215	0,958451
2000 TC vs. 90000 TC	-5,12049	0,000001
20000 TC vs. 40000 TC	-0,92713	0,354587
20000 TC vs. 60000 TC	-0,84739	0,397483
20000 TC vs. 90000 TC	-6,80944	0,000000
40000 TC vs. 60000 TC	-0,05115	0,959269
40000 TC vs. 90000 TC	-5,38188	0,000000
60000 TC vs. 90000 TC	-4,56952	0,000012

Figure 9 shows graphical presentation of variability measures and mean values of analyzed groups of variables.

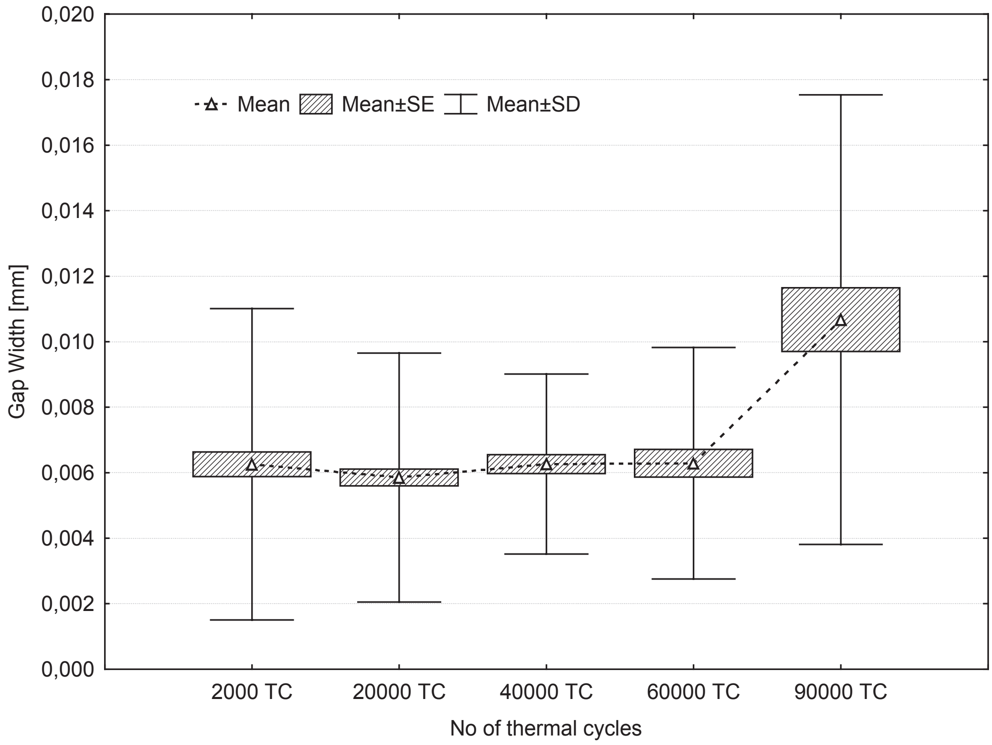

Fig. 9. Box & whiskers diagram of the width of marginal fissure for different number of thermal cycles

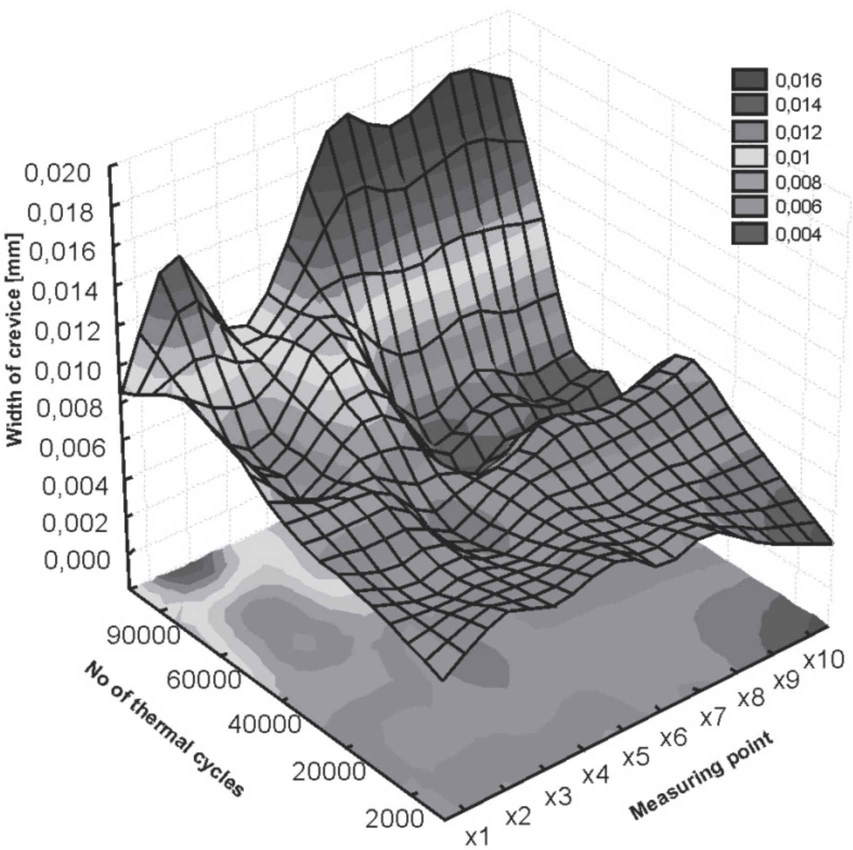

Fig. 8. The width of marginal fissure

3.3. Analysis of the predicted durability („survival time")

In order to determine predicted durability („survival time"), so-called life table was prepared (Table 2). It is an expanded table of the quantity distribution. Distribution of survival times was divided into a certain number of ranges. For each range a number and proportion of cases which did not reach the limit state were calculated as well as the number and proportion of the cases reaching the limit state.

The percentage of the specimens reaching the limit state (Fig.10a) constitutes the proportion of the observed cases – specimens. This proportion was calculated as the ratio of the number of cases reaching limit state in a given range to the number of cases observed in this range. After initial number of the load cycles (2000TC), 37.5% of specimens reaching limit state were identified. In the subsequent ranges the percentage of those specimens was decreasing. After 90 000 load cycles, the highest percentage of cases reaching limit state was noticed.

Survival function (Fig.10b) describes the ratio of the number of teeth specimens, remaining in the state of usability during the operation time *t* to the initial number of specimens. This is a cumulated proportion of cases which did not reach limit condition from the initial moment till the analyzed moment.

In the next stage of durability analysis hazard function *h(t)* was determined. Hazard function is described by the probability per unit of time, that the case which "survived" since the beginning of the tests will undergo failure in the studied interval of time. Hazard function *h(t)* was estimated according to the following formula:

$$h(t) = \frac{\frac{dF}{dt}}{R(t)} \qquad (1)$$

where:
F(t) -unreliability,
R(t) – reliability,
t - generalized usage time (No of thermal cycles).

Figure 10c presents the hazard function which takes the shape of bathtub curve. Thus, a failure risk (reaching limit condition) is the highest in the initial and final periods of usage.

Durability of the filling was approximated by the Weibull distribution, in which density of probability was described by the following relation [11]:

$$a = \frac{c}{b}\left(\frac{t}{b}\right)^{c-1} exp\left(-\left(\frac{x-\theta}{b}\right)^{c}\right) \qquad (2)$$

Whereas distribution function (with positive parameters *b*, *c* and *θ*) is given by:

$$F(t) = 1 - exp\left(-\left(\frac{x-\theta}{b}\right)^{c}\right) \qquad (3)$$

where:
x – time,
b – scale parameter,
c – shape parameter,
θ – location parameter,
e – constant (e = 2.71828...)

Hollander-Proschan test was used in order to estimate the most probable shape of reliability function *R(t)* of the examined fillings (Fig. 10d). On the basis of *R(t)* function the durability of the fillings described in this paper can be determined. Assuming a probability criterion of 0.9 (90%), in the sense of not exceeding the limit value of marginal fissure (0,015 mm [17]), predicted durability of fillings can be estimated to 58 000 thermal cycles.

Table 2. Life table of the examined dental fillings

Parameters	Parameter values						
Load level	0	15000	30000	45000	60000	75000	90000
Central point	7500	22500	37500	52500	67500	82500	-
Interval width	15000	15000	15000	15000	15000	15000	-
Number of the observed	32	16,5	13	12	12	9	9
Number of reaching limit condition	12	2	1	0	3	0	9
Proportion of reaching limit condition	0,375	0,1212	0,0769	0,0416	0,25	0,055556	0,9444
Proportion of the surviving	0,625	0,8787	0,9230	0,9583	0,75	0,944444	0,0555
Cumulated proportion of the surviving	1	0,625	0,5492	0,5069	0,4858	0,364401	0,3441
Probabilisty density	0,000025	0,000005	0,000003	0,000001	0,000008	0,000001	0,000024
Hazard	0,000031	0,000009	0,000005	0,000003	0,000019	0,000004	0,00002

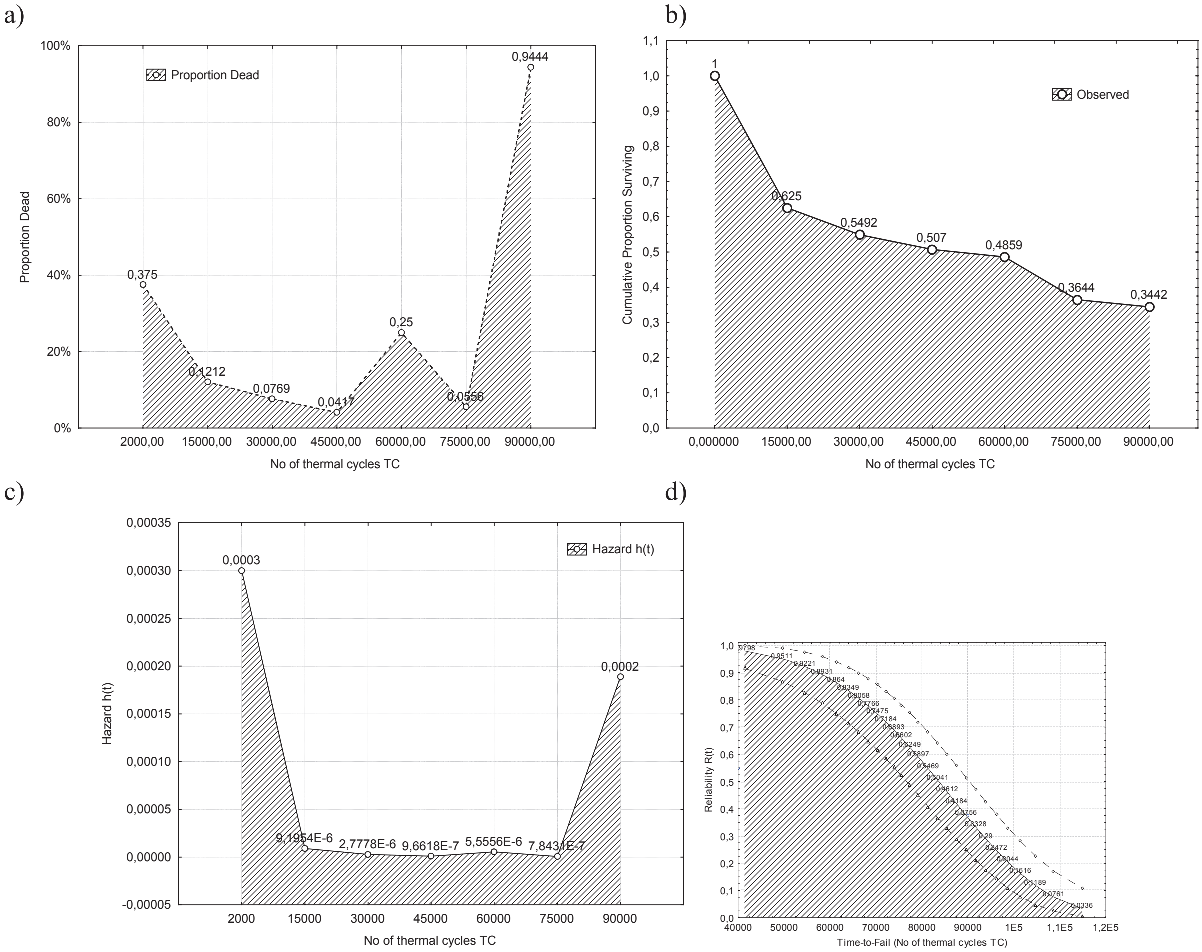

Fig. 10. a) Percentage of specimens reaching limit state, b) Survival function, c) Hazard function of dental fillings, d) Reliability function of greatest significance

4. SUMMARY

The tests have demonstrated that the marginal fissure in the bio-mechanical tooth-composite filling system, resulting from the polymerization shrinkage, grows under the influence of cyclic changes of temperature. Furthermore, the enlargement of the fissure has a multi-stage character. After exceeding the limit number of cycles (in the test conditions the limit was about 60 000 thermal cycles) a rapid growth of fissure width occurs, accompanied by the formation of micro-cracks in the enamel and filling material.

The observed shape of the hazard curve *h(t)* (Fig. 10c) indicates a significant increase in the probability of functional degradation occurrence (reaching critical marginal fissure width in the tooth-composite filling system) after 75 000 thermal cycles.

It can be concluded that the developed method shows high applicability for evaluating durability of the filling as well as testing new dental materials.

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Andrzej NIEWCZAS
Prof. PhD eng., is the Head of the Department of Combustion Engines and Transport at the Technical University of Lublin.

Daniel PIENIAK
PhD eng., he works at the Department of Applied Mechanic at the Fire Safety Engineering Faculty at Main School of Fire Service.

Agata NIEWCZAS
MD PhD, she works at the Department of Conservative Dentistry, Medical University of Lublin.