Acta of Bioengineering and Biomechanics
Vol. 14, No. 3, 2012

Original paper
DOI: 10.5277/abb120311

Scanning electron microscope appearances of fretting in the fixed orthodontic appliances

LESZEK KLIMEK[1,2], ALEKSANDRA PALATYŃSKA-ULATOWSKA[3]*

[1] Institute of Materials Science and Technology, Technical University of Łódź, Poland.
[2] Restorative Dentistry, Division of Dental Techniques, Medical University of Łódź, Poland.
[3] Conservative Dentistry and Endodontics, Department of Endodontics, Medical University of Łódź, Poland.

Fretting is one of the types of a tribologic wear. It is a process that occurs at a nominally immovable junction of elements. In dentistry, such elements can be brackets and archwires of fixed orthodontic appliances. They meet all the criteria for fretting to occur, i.e., they are nominally immovable, are subjected to initial loadings and they work in aggressive environment. Chrome-nickel stainless steel Elite Opti-Mim brackets (Trachem) working *in vivo* in oral cavity environment in combination with NiTi and stainless steel archwires were investigated. Scanning electron micrographs of bracket's working surfaces showed the presence of fretting damaged areas. This research also confirmed that there were almost all the types of fretting wear on the elements of the orthodontic appliances under examination.

Key words: *fixed orthodontic appliances, fretting, scanning electron microscope*

1. Introduction

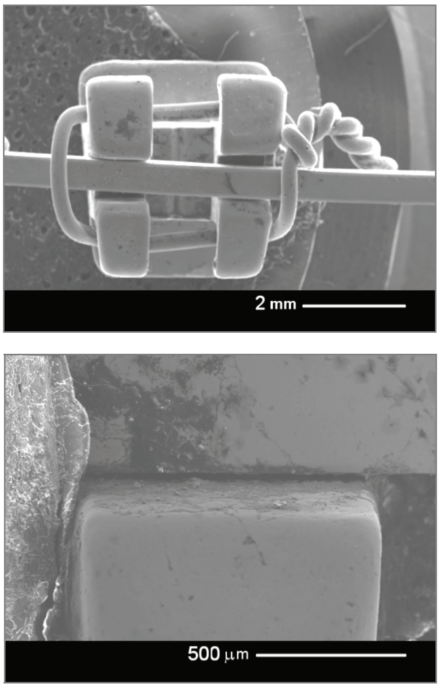
Fretting is considered as a specific type of tribologic wear. It comprises a group of mechanical, thermal, chemical or electric phenomena of micro-friction wear at loaded and nominally immovable junctions. Fretting damage was observed not only in the elements of a mechanical device and buildings, but also in an orthopedic implants [1] and elements of artificial heart [2]. These types of wearing can often have disastrous characteristics. Adjacent, nominally immovable surfaces contact only at peaks of roughness. Therefore, only a small fraction of nominal surface is a real contact surface. In contacts of roughness two types of areas can be distinguished: adhering areas, which are subjected to elastic deformations, and micro-displaced ones. Contact loadings with the normal force as well as with the tangential force can be a consequence of small contact surface displacements as a result of external cyclic loadings. Fretting occurs also during vibrations of the construction itself. Depending on the various loading conditions and exploitation, HOEPNER [3] differentiates between "fatigue by fretting" and " wearing by fretting".

The occurrence of adhering and microsliding areas is directly connected with two different mechanisms of wearing. Adhering area is subjected to cracking similar to a contact fatigue, while microsliding area is similar to adhesive wearing [4]. In both mechanisms, the formation of wearing products is observed. High hardness of those products works as an eraser and accelerates wearing process, especially in its final disastrous phase. A pure form of fretting (without chemical changes of surfaces) occurs very rarely and only in the case of precious metal contacts, in high vacuum or in inert atmosphere. A contact with an active environment causes fretting corrosion, which induces earlier and more intensive wearing changes. Fretting corrosion most often occurs when pairs of

* Corresponding author: Aleksandra Palatyńska-Ulatowska, Department of Endodontics, Medical University of Łódź, 92-217 Łódź, ul. Pomorska 251, Poland. Tel./fax.: +48 42 6757418, e-mail: aleksandra.palatynska-ulatowska@umed.lodz.pl
Received: January 21st, 2011
Accepted for publication: June 26th, 2012

elements work under some strain. Tension increases surface energy and enhances surface chemical reactivity [5]. In the case of fretting corrosion many products of wear, especially metal oxides, are formed. There can be oxides removed from the surface or formed because of the oxidation of the ground metal elements. The intensity of fretting depends on the kind and magnitude of forces directed to the junction, value of strains as well as aggressiveness of an environment.

In dentistry, junctions exposed to fretting include, among others, orthodontic fixed appliance elements. They are exposed to initial loadings. Despite nominal junction immovability there are some small movements of elements, for example, during mastication. Moreover, they work in a very aggressive oral cavity environment. In the appliances discussed, the places especially exposed to fretting are the inner surfaces of bracket slots being in contact with archwires (figure 1).



a) b)

Fig. 1. Bracket – archwire structure: (a) general view, (b) magnification of nominally immovable contact surface area

The objective of this study was to investigate in the 36 elements of four separate fixed orthodontic appliances the presence of wear qualified as fretting.

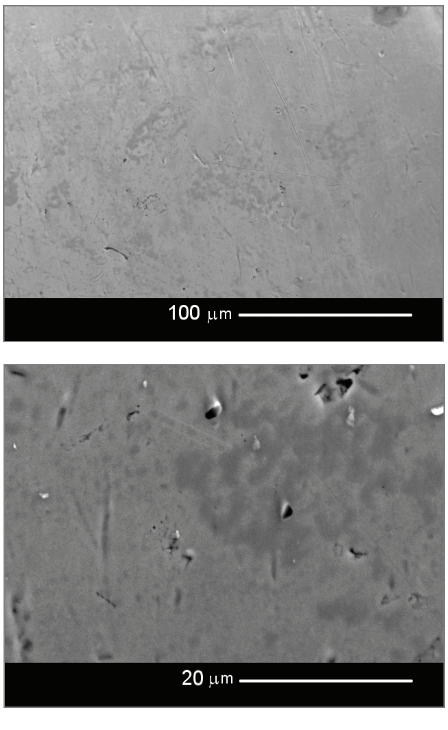
2. Materials and methods

The material consisted of 36 Elite Opti-Mim brackets (Trachem) taken out of four orthodontic fixed appliances cemented in the patients' oral cavity. Brackets were exposed to aggressive environment for two months.

Before the examination, half of each bracket was cut along its longitudinal axis for better visibility of surfaces. A scanning electron microscope (SEM) HITACHI S-3000N was used to investigate the samples. Magnifications from over a dozen times to several thousand times were used. For comparison, several new, unused brackets were investigated. The chemical composition analysis of the bracket material was conducted in SEM using the EDS method. Energy Dispersive Spectroscopy (EDS) is a method of quantifying the elemental constituents of a sample by measuring with a scanning electron microscope the number of X-rays produced by a solid sample when irradiated by electrons versus the energy of those X-rays. Energy analysis of characteristic X-ray radiation induced by electron beam in sample under investigation was performed at electron accelerating voltage of around 15 kV.

3. Results

The results of our investigation comprise images of bracket surfaces obtained in scanning electron microscope (figures 2 and 3), chemical analysis of the bracket material (table 1) and EDS spectrogram from the brack-



a) b)

Fig. 2. A scanning electron microscope appearances of the working surfaces of a new, unused bracket

ets (figure 4). Images presented a significant difference between the new elements and the used ones (compare figures 2 and 3). The surface of new brackets was quite smooth and only traces of mechanical processing during their formation were visible (figure 2). However, used elements showed explicit marks of wear, which were observed as crumblings of various sizes and cracks initiated crumbling of the material (figure 3c). In the bottom of some defects (figure 3e, f) products of corrosion were observed, which may give evidence of a complicated mechanism of wear – fretting and fretting corrosion.

The results of chemical analysis indicated that elements of orthodontic appliances investigated were made of stainless steel.

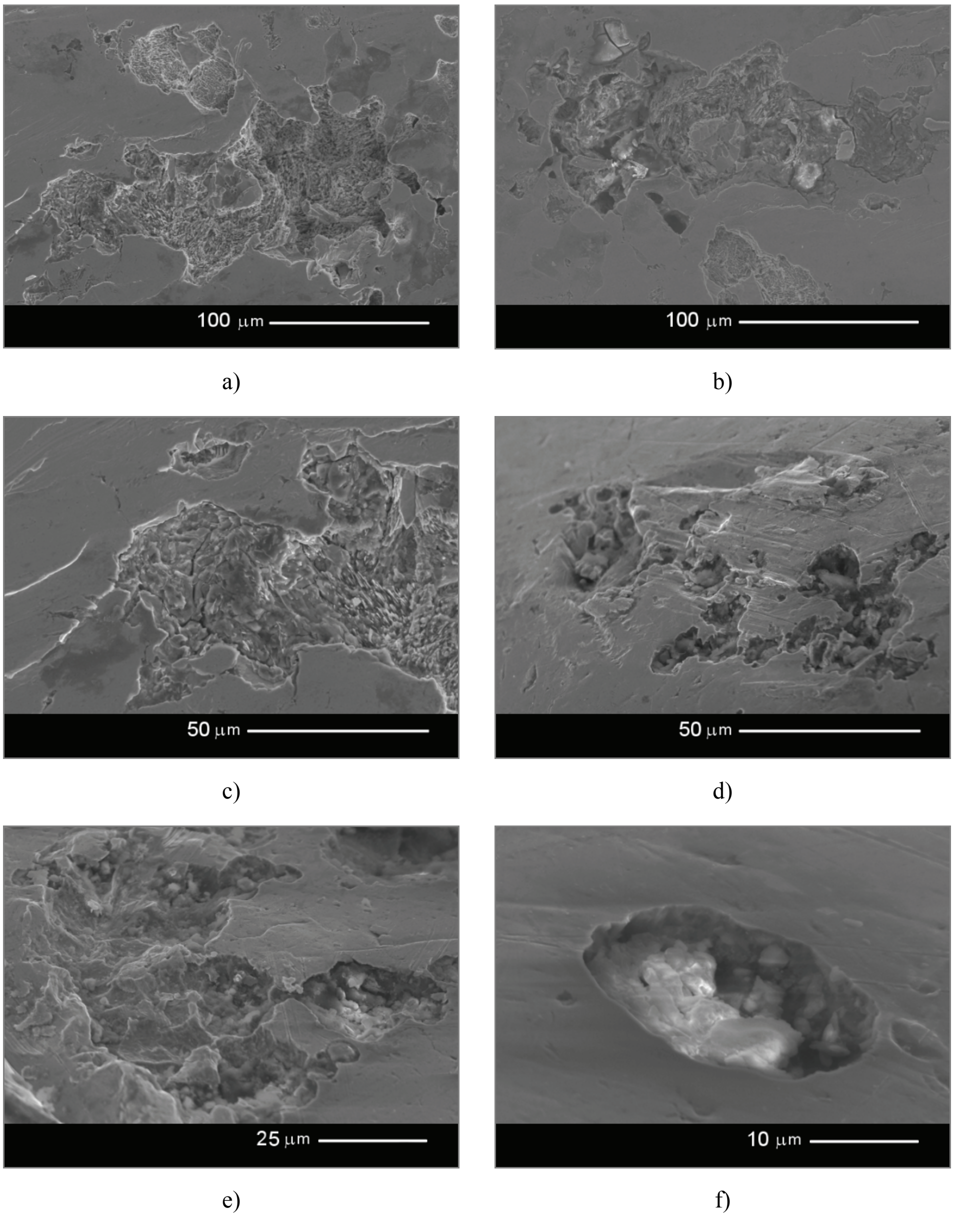


Fig. 3. Examples of wear on orthodontic bracket working surfaces.
(Description in the text)

Table 1. Chemical analysis of the bracket material

Chemical composition of alloy examined									
Al		Si		Cr		Ni		Fe	
% mass.	% weight	% mass.	% weight	% mass.	% weight	% mass.	% weight	% mass.	% weight
0.47	0.23	1.54	0.8	23.32	22.27	2.40	2.58	rest	rest

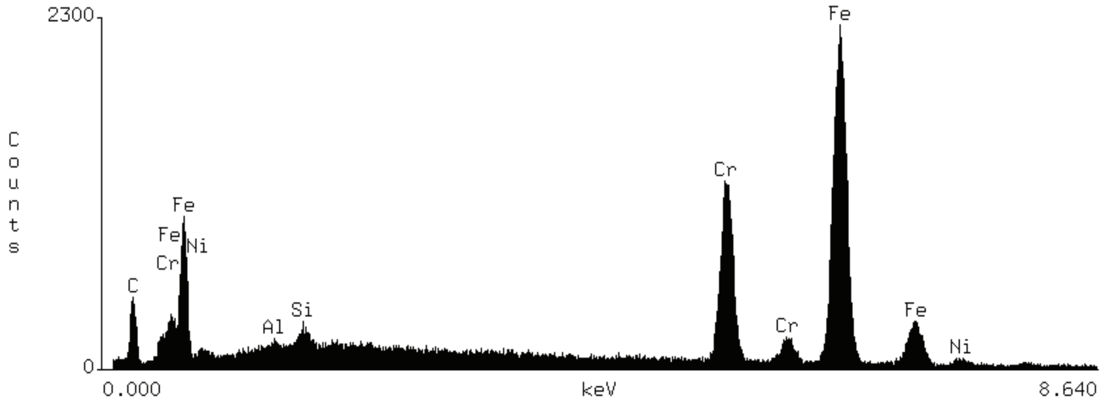


Fig. 4. EDS spectrogram from the bracket material

4. Discussion

So far in the literature, only the occurrence of friction forces between orthodontic brackets and archwires was mainly discussed [6]–[8]. The majority of articles in this field were reported by KUSY et al. [8]–[11]. Researchers conducted their investigations in the experimental dry, water, and human or artificial saliva environment [11] and did not mention wear by fretting in those elements. Only the friction movement model in experimental environments was observed, without other wear types of bracket slot surfaces, working *in vivo* in the patients' oral cavity.

Fretting destruction on bracket working surfaces, observed in this study, is manifested by the loss of material. There are distinct differences between surfaces of a new and working *in vivo* brackets (compare figures 2 and 3). In most cases (figure 3(a)–(d)) there are material defects of significant size reaching several dozen micrometers. Various sizes of the defects observed (compare figures 3(a) and 3(f)) are probably due to the observation of the different phases of wear. Also various characteristics of such destruction seem to be different. There are mostly cracks of the material. Cracks found in this area (figure 3(c)) can provide evidence of the material fatigue (contact fatigue). Some fragments of destruction seen in figure 3(e) are similar to material pulling out, being an effect of adhesive wear. Lack of the cracks in this case might be a confirmation of this kind of destruction.

Corrosion, as an electro-chemical reaction between metal and its environment, intensifies through the inner strains of the metal, non-homogenous alloy structure and the contacts with other metals in the oral cavity environment (bracket – archwire) with the formation of the corrosion products. In particular, nickel ion releasing during stainless steel corrosion is clinically important. The presence of the metal oxides in the oral cavity can lead to different allergic reactions. Figures 3(b) and 3(f) show that there are places in defect area where oxides can be observed. Brackets are made of Fe–Cr alloy, and that is why chromium oxides should rather appear because of their better chemical affinity to oxygen than the ion of iron. Despite the fact that the scanning electron microscope in this research was equipped with the X-ray microanalysis detector it was impossible to prove the presence of these oxides on the surfaces observed. The difference between the values of characteristic radiation energy $L\alpha$ for chrome and $K\alpha$ for oxygen was below the detector's distribution capability. There is no possibility to differentiate an element from which the signal comes. The presence of these oxides confirms fretting corrosion in the elements of orthodontic appliances being observed. No signs of abrasive wear with corrosion products or other products of wear were observed.

An orthodontic appliance fastened to the enamel works through activated archwires inserted and fixed in the bracket slots. Orthodontic brackets, different for each tooth, with a defined torque and angulation give a desirable tooth position in the dental arch. Wear by fretting on the bracket slot surfaces can probably influence the magnitude and direction of the forces transferred to teeth by brackets. This research proves that there is fretting and there are almost all types of fretting wear on the elements of the orthodontic appliances under examination. ARTICOLO [12] in his research put forward a theory of notch formation, in which a vertical movement from tooth or wire during mastication caused fretting wear, and horizontal movement during orthodontic procedures such as space closure, tipping or bodily movement caused sliding wear. Undoubtedly, there is a necessity to continue further research to establish the influence this kind of bracket surface wear can have on the duration and the final result of a treatment with fixed orthodontic appliances.

References

[1] CRISTOFOLINI L., SAVIGNI P., TEUTONICO S.A., VICECONTI M., *In vitro load history to evaluate the effects of daily activities on cemented hip implants*, Acta Bioeng. Biomech., 2003, 5, 77–88.

[2] LISKIEWICZ T., FOUVRY S., WENDLER B., *Impact of variable conditions on fretting wear*, Elsevier Science B.V. Surface and Coatings Technology, 2003, 163–164, 465–471.

[3] HOEPNER D.W., *Mechanism of fretting fatigue. ESIS 18*, edited by R.B. Waterhouse and T.C. Lindley, Mechanical Engineering Publications, London, 1994, 3–19.

[4] KULA P., *Outer layer engineering*, Monografie, Łódź, 2000.

[5] HEBDA M., WACHAL A., *Trybology*, WNT, Warszawa, 1980.

[6] NISHIO C., da MOTTA A.F., ELIAS C.N., MUCHA J.N., *In vitro evaluation forces between archwires and ceramic brackets*, Am. J. Orthod. Dentofac. Orthop., 2004, 125, 56–64.

[7] WILLEMS G., CLOCHERET K., CELIS J.-P., VERBEKE G., CHATZICHARALAMPOUS E., CARELS C., *Frictional behavior of stainless steel bracket–wire combinations subjected to small oscilating displacements*, Am. J. Orthod. Dentofac. Orthop., 2001, 120, 371–377.

[8] KUSY R.P., WHITLEY J.Q., *Resistance to sliding of orthodontic appliances in the dry and wet states: Influence of archwire alloy, interbracket distance, and bracket engagement*, J. Biomed. Mater. Res., 2000, 52, 797–811.

[9] KUSY R.P., WHITLEY J.Q., *Friction between different wire–bracket configurations and materials*, Semin. Orthod., 1997, 3, 166–177.

[10] THORSTENSON G.A., KUSY R.P., *Resistance to sliding of orthodontic brackets with bumps in the slot floors and walls: effects of second-order angulation*, Elsevier Science Academy of Dental Materials, 2004, 20, 881–892.

[11] THORSTENSON G.A., KUSY R.P., *Comparison of resistance to sliding between different self-ligating brackets with second-order angulation in the dry and saliva states*, Am. J. Orthod. Dentofac. Orthop., 2002, 121, 472–482.

[12] ARTICOLO L.C., *Influence of ceramic and stainless steel brackets on the notching of archwires during clinical treatment*, Eur. J. Orthod., 2000, 22, 409–425.