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# SURFACE MORPHOLOGY OF ORTHODONTIC BRACKET SLOTS AND ITS CLINICAL SIGNIFICANCE: A REVIEW OF SEM AND EDS RESULTS

**Słomion M.[1], Koczorowski W.[2,3], Mazurkiewicz A. [4], Wawroń W.[5]**

**Abstract:** *The effectiveness of treatment with a fixed orthodontic appliance largely depends on the condition of the bracket slot surface. A high surface roughness increases friction, causes greater wear, hinders tooth movement, and promotes bacterial biofilm retention. In this study, the surface condition of orthodontic bracket slots made of different materials (stainless steel, ceramic, and titanium) was analyzed using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). The research evaluated both the quality of the bracket slot surface and its chemical composition. The results show that brackets made of monocrystalline aluminum oxide (sapphire) have the smoothest surface, which helps reduce friction and plaque retention, thus improving treatment. Significant surface irregularities were observed in stainless steel and titanium brackets, potentially affecting archwire sliding in the slot and reducing oral hygiene, which can lower treatment effectiveness and prolong its duration.*

**Keywords: orthodontic brackets, SEM analysis, spectral analysis, surface morphology, material composition**

## 1. Introduction

In orthodontic treatment, precise force transfer from the archwire to the tooth via the bracket is crucial for treatment effectiveness and predictable outcomes. Since the bracket slot is the point of direct contact with the archwire, it plays a major role in determining friction levels, which can significantly influence treatment time. High slot surface roughness not only increases resistance to tooth movement but also promotes bacterial adhesion, which can lead to periodontal complications (Li, 2021; Mundhada, 2023; Ribeiro, 2012).

Advanced imaging and chemical analysis techniques, such as scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS), have become essential in both scientific research and clinical practice. These methods allow for qualitative surface topography evaluation and elemental composition assessment of orthodontic bracket slots (Liu, 2013; Mendes, 2014). This paper presents practical conclusions drawn from observations of slot surfaces made of different materials, with important implications for everyday orthodontic practice.

## 2. Materials and methods

### 2.1. Materials

The study included conventional orthodontic brackets intended for use in the upper arch (upper left central incisor, tooth 21), specifically:

[1] Dr Eng. Małgorzata Słomion: Faculty of Management, Bydgoszcz University of Science and Technology, 7 Kaliskiego Ave., 85-796 Bydgoszcz; PL, malgorzata.slomion@pbs.edu.pl

[2] Prof. dr. hab. Eng. Wojciech Koczorowski, prof. PP: Institute of Physics, Poznan University of Technology; Piotrowo 3; 60-965 Poznan; PL, wojciech.koczorowski@put.poznan.pl

[3] Prof. dr. hab. Eng. Wojciech Koczorowski, prof. PP: Center for Advanced Technology, Adam Mickiewicz University, Umultowska 89C, 61-614 Poznan; PL; wojciech.koczorowski@put.poznan.pl

[4] Prof. dr. hab. Eng. Adam Mazurkiewicz, prof. PBS: Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, 7 Kaliskiego Ave., 85-796 Bydgoszcz; PL, adam.mazurkiewicz@pbs.edu.pl

[5] Wojciech Wawroń: Student, University of Science and Technology, 7 Kaliskiego Ave., 85-796 Bydgoszcz; PL, wojwaw001@pbs.edu.pl

- 17-4 PH stainless steel brackets,
- monocrystalline aluminum oxide (sapphire) brackets,
- titanium brackets.

All brackets came from a single manufacturer and were taken from new, unused sets. They had not been subjected to any sterilization or disinfection processes, to exclude the influence of additional factors that could modify their surface.

### 2.2. Methods

Bracket slot surfaces were analyzed under a scanning electron microscope (SEM) to assess their topography and detailed microstructure. Elemental composition was determined using energy-dispersive X-ray spectroscopy (EDS). Samples were mounted on a conductive substrate, and for ceramic brackets, a thin Au/Pd layer was sputtered to improve electrical conductivity and imaging quality. SEM images were obtained using an ETD detector at an accelerating voltage of 10 kV. A magnification of 50,000× was used, with a horizontal field width (HFW) of 207 µm, under a pressure of 70 Pa. EDS spectra were acquired at an accelerating voltage of 30 kV, at a magnification of 2,000×, with an acquisition time of ~140–165 s, an Octane Pro detector, and a working vacuum of about $3.55 \times 10^{-3}$ Pa.

## 3. Results

### 3.1. Surface morphology of orthodontic bracket slots (SEM analysis)

Qualitative analysis of the SEM images revealed significant structural differences in bracket slots depending on the material. Example images of orthodontic brackets surfaces made from the tested materials are shown in Figure 1. Stainless steel (17-4 PH) brackets had more pronounced surface irregularities, including small pits and defects that can lead to increased friction (Fig. 1-B). Monocrystalline aluminum oxide (sapphire) brackets showed relatively smooth, homogeneous surfaces, offering minimal frictional resistance and reduced bacterial adhesion (Fig. 1-A). Titanium brackets demonstrated a non-uniform topography with numerous spherical defects (Fig. 1 -C), which may lead to increased friction and wear when in contact with the archwire.

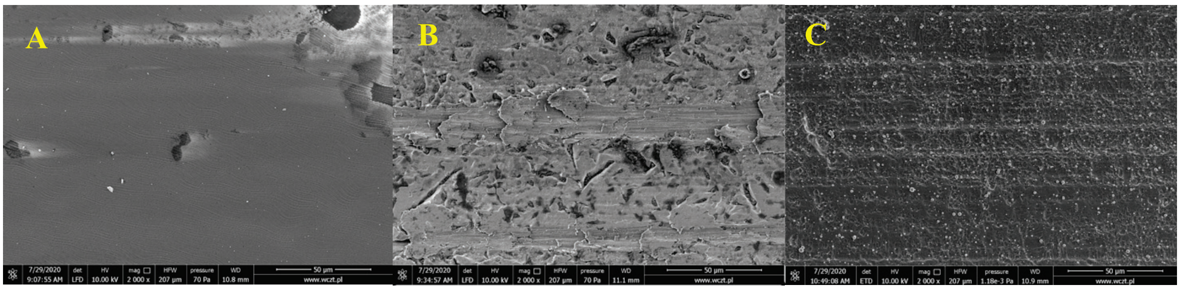


*Fig. 1: SEM images comparing bracket slot surfaces: A – sapphire slot bracket, B - 17-4 PH stainless steel slot bracket, C – titanium slot bracket*

### 3.2. Chemical composition of bracket slot surfaces (spectral analysis)

EDS analysis confirmed that the materials matched the manufacturer's specifications. The 17-4 PH stainless steel contained mainly Fe, Cr, Ni, and Cu, with traces of other elements (Si, Ca) likely originating from manufacturing processes (Fig. 2). The ceramic material ($Al_2O_3$) showed strong peaks for aluminum (Al) and oxygen (O), in typical proportions for this compound, without notable impurities. In the titanium bracket, Ti was the dominant element, with small amounts of Cr, Al, and trace contaminants (C, O).

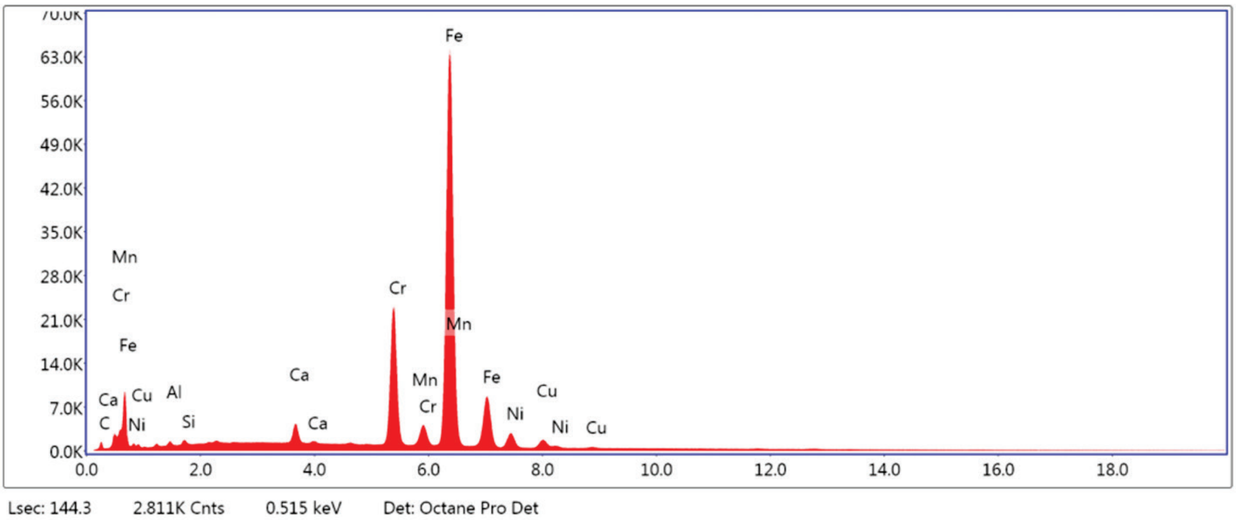


*Fig. 2: Example EDS spectrum of the stainless steel bracket, showing characteristic Fe, Cr, Ni, and Cu peaks*

According to the manufacturer (Tab. 1), 17-4 PH steel mainly consists of iron (Fe, "balance"), chromium (Cr 15.0–17.5%), nickel (Ni 3.0–5.0%), and copper (Cu 3.0–5.0%), along with small amounts of other elements (e.g., C, Mn, Si). The EDS results from this study confirmed the presence of these same components in similar proportions (Tab. 2), indicating that the actual chemical composition of the steel used in the orthodontic brackets aligns with the manufacturer's claims. No significant discrepancies were found between the actual material composition and the data provided by the manufacturer.

*Tab. 1: Chemical composition (wt. %) of 17-4 PH alloy*

| Carbon | Manganese | Silicone | Chromium | Nickel | Iron | Other |
|---|---|---|---|---|---|---|
| 0.07 % | 0.05 % | 1.00 % | 15.0-17.5 % | 3.0-5.0 % | balance | P 0.04 %, S 0.03 %, Cu 3.0-5.0 %, Nb 0.15 – 0.45 % |

*Tab. 2: Quantitative elemental analysis results using eZAF Smart Quant, showing weight and atomic percentages of detected elements along with net intensity, error, Kratio, and Z, R, A, and F correction factors*

| Element | Weight [%] | Atomic [%] | Net Int. | Error [%] | Kratio | Z | R | A | F |
|---|---|---|---|---|---|---|---|---|---|
| C K | 6.32 | 23.4 | 92.47 | 9.65 | 0.0177 | 1.2424 | 0.846 | 0.2253 | 1.0 |
| AlK | 0.77 | 1.27 | 76.6 | 11.68 | 0.0018 | 1.0944 | 0.9192 | 0.2123 | 1.0049 |
| SiK | 0.48 | 0.76 | 72.81 | 11.45 | 0.0017 | 1.1221 | 0.9278 | 0.3071 | 1.008 |
| CaK | 1.58 | 1.75 | 460.13 | 3.89 | 0.0163 | 1.0772 | 0.9738 | 0.8721 | 1.0999 |
| CrK | 13.65 | 11.68 | 3648.51 | 2.55 | 0.1657 | 0.9765 | 1.0001 | 0.9787 | 1.2706 |
| MnK | 0.0 | 0.0 | 0.01 | 99.99 | 0.0 | 0.9585 | 1.0061 | 0.9849 | 1.0938 |
| FeK | 71.36 | 56.84 | 12312.91 | 1.55 | 0.6824 | 0.9764 | 1.0119 | 0.9481 | 1.0331 |
| NiK | 3.53 | 2.68 | 440.66 | 4.35 | 0.0295 | 0.9925 | 1.0228 | 0.8082 | 1.0396 |
| CuK | 2.32 | 1.62 | 257.47 | 4.98 | 0.0193 | 0.9456 | 1.0278 | 0.8413 | 1.0495 |

## 4. Clinical conclusions

Bracket slots with smoother surfaces—particularly monocrystalline (sapphire) brackets—show the least resistance in the bracket-archwire system. This improves biomechanical control and can result in faster, more predictable tooth movement (Bhat, 2022). With lower frictional forces, the orthodontist can more precisely adjust and control the forces and moments applied to the teeth, optimizing crown and root movement (e.g., controlling the path of movement and preventing unwanted tipping or rotations). Additionally, a smoother bracket slot surface helps reduce bacterial biofilm adhesion, leading to more stable tribological and mechanical conditions throughout treatment (Bhat, 2022; Li, 2021 Premchind, 2019).

Over the long-term use of an orthodontic appliance, surface irregularities also play a role in wear processes. Higher friction and numerous microscopic defects can lead to gradual material abrasion, especially where the bracket is in intense contact with the archwire. As a result, changes in slot topography and the formation of microscopic damage may worsen biomechanical properties and reduce the bracket's clinical durability (Fidalgo, 2011). A smoother surface (such as monocrystalline ceramic) is much less prone to such wear, minimizing the risk of premature material degradation during the extended stages of orthodontic treatment (Liu, 2013).

The observed differences in surface finishing quality and material composition of the brackets may lead to modifications of the forces acting within the bracket–archwire system, ultimately influencing both the biomechanics of treatment and the precision of orthodontic tooth movement (Joch, 2010).

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