Simulation and evaluation of ageing effects on dental biomaterials using a novel hybrid metal-polymer bracket as an example

Sarah Burlein[1], Christiane Keil[1,2], Lukas Stepien[3], Franz Marquardt[3], Mehmet Aladag[4], Izabela Zglobicka[4], Krzysztof Kurzydłowski[4], Mihaela Pricop[5], Diana Jünger[1], Marit Gebelein[2], Torsten Sterzenbach[6], Günter Lauer[1] , Heike Meissner[1].
[1]Department of Oral and Maxillofacial Surgery, Faculty of Medicine "Carl Gustav Carus“, TU Dresden, Germany.
[2]Department of Orthodontics, Faculty of Medicine "Carl Gustav Carus“, TU Dresden, Germany.
[3]Fraunhofer Institute for Material and Beam Technology, Dresden, Germany.
[4]Faculty of Mechanical Engineering, Białystok University of Technology, Białystok, Poland.
[5]Department of Applied Mathematics, University Polytehnica of Bucharest, Romania.
[6]Policlinic of Operative Dentistry, Periodontology and Pediatric Dentistry, Faculty of Medicine "Carl Gustav Carus“, TU Dresden, Germany.

1 INTRODUCTION

Dental materials in the oral environment are exposed to numerous stressors that lead to ageing and fatigue. To predict material reliability, typical stress parameters are specifically simulated during ageing to reflect the conditions encountered throughout the intended clinical lifespan of the application.

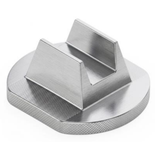
2 OBJECTIVE

Newly developed hybrid brackets (metal/polymer) were subjected to clinically relevant ageing procedures[5] to evaluate their influence on surface properties and shear bond strength to enamel, providing initial regarding their clinical viability.

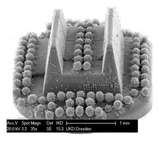
3 MATERIALS AND METHODS

48 brackets underwent thermal and abrasive stress. Surface characteristics were assessed stereomicroscopically in the initial state and after ageing, and surface roughness (Ra) was determined as a key quality metric (3D Confocal Laser Microscope). 16 samples were ultrasonically cleaned using Stammopur Z, 32 using Aqua dest.. All probes were subjected to thermocycling at 5 °C / 55 °C in water, as well as additional abrasion through toothbrushing simulation[4]. The number of cycles for both procedures corresponded to a clinical wearing period of one year.

1. Bracket body: Production of PANACEA stainless steel base bodies using *Model Injection Molding.*



2. Inter-locking Features: Additive application of 3D anchoring structures by *Direct Energy Deposition*.

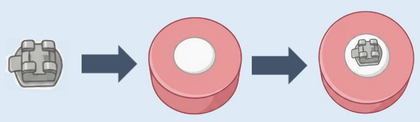


3. Polyamid Coating: *Injection molding* with Trogamid CX7323 (PA, Evonik).



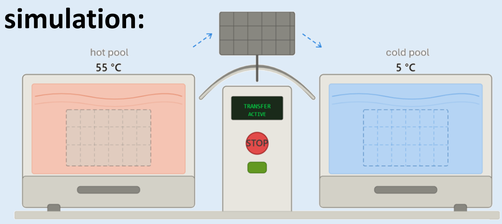
Sample Preparation

48 bovine enamel samples were embedded in Palapress acrylic resin. The brackets were bonded to the enamel surfaces using Transbond™ XT (3M Unitek) following standard orthodontic protocols.

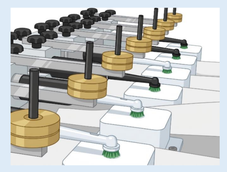


Ageing Protoco:l 1 year wear simulation:

1.Thermal ageing: Thermocycling at 5 °C / 55° C in H_2O



2.Mechanical ageing: Toothbrush simulation using electric / manual toothbrushes and toothpaste slury (1:3).



Shear bond strength (SBS)[3] and the Adhesive Remnant Index[1] (ARI) at the enamel-adhesive interface were evaluated by testing 8 aged and 8 non-aged samples.

4 RESULTS

Optical surface assessment:

- Simulated electric brushing: substantial abrasions and pronounced surface defects
- Simulated manual brushing: minimal wear with only minor, isolated defects.

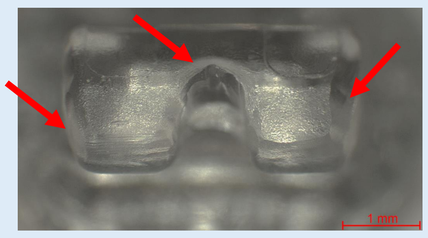


Figure 1: Stereo-microscopic image of hybrid bracket after thermal and abrasive stress (electric toothbrush). Arrows indicate areas of wear.

Adhesive Remnant Index:

- Thermomechanical ageing shifted the failure pattern from the bracket-adhesive interface (87.5% ARI 2) toward the enamel-adhesive interface (50% ARI 1), indicating a stable bracket-adhesive bond despite stress.

Surface roughness:

- Treatment effect: overall Ra was affected by procedures (RM-ANOVA, $p = 0.008$)
- Cleaning impact: Ra decreased significantly (0.56 µm to 0.50 µm, $p < 0.05$); water-only cleaning showed no effect.
- Material integrity: Hybrid brackets maintained topographic stability throughout 1-year wear simulation with no significant Ra changes following thermocycling or tooth brush simulation.

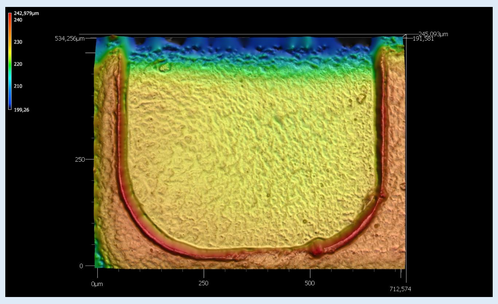


Figure 2.: 3D confocal laser microscopy topographical map of hybrid bracket surface.

Shear Bond Strength (SBS):

- Thermomechanical ageing led to a significant increase in SBS (6.73 ± 2.9 MPa to 15.7 ± 4.6 MPa, $p < 0.01$).
- Clinical requirement: initial values were within recommended 6–8 MPa[2]. Aged samples exceeded requirement.

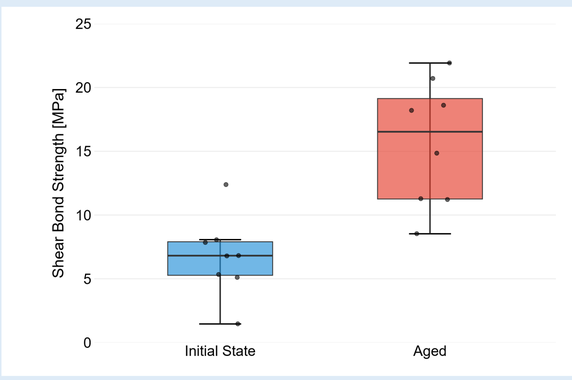


Figure 3.: SBS of hybrid brackets before and after thermomechanical ageing.

5 OUTLOOK

Standardised ageing protocols that better reflect clinical conditions would facilitate the evaluation of the rapidly expanding range of novel dental materials and benefit both clinicians and patients. Existing standards should serve as a reference and, as demonstrated, can be meaningfully extended and refined.

6 REFERENCES

[1]Årtun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid etching. Am J Orthod. 1984;85(4):333-340.
[2]Reynolds, I. R. (1975). A review of direct orthodontic bonding. British Journal of Orthodontics, 2(3), 171–178.
[3]DIN 13990 Dentistry Test methods for shear bond strength of adhesives for orthodontic attachments.
[4]DIN 13973-1 Dental materials Guidance on testing of wear Part 1: Wear by toothbrushing (ISO/TR 14569-1:2007).
[5]DIN EN ISO 22674 Dentistry Metallic materials for fixed and removable restorations and appliances.