New additively enhanced interface for multi-material orthodontic brackets

– analysis after one-year in-vitro simulated aging –

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Questions

Multi-material compositions, especially for dental applications, are critical due to the oral environment, which can alter the properties of combined materials and affect their bond. Micro-topologies can improve the interface for resin injection molding around metallic inserts by undercuts and surface-enlargements, thus improving the adhesion between the different materials.

The aim of the present study

was to analyse the structure and biocompatibility of multi-material brackets of different metal-plastic combinations for oral/dental application, characterised by an additively manufactured interface generated by Laser Metal Deposition (LMD).

Methods

Simplified bracket bodies (n= 51) formed by injection molding (P.A.N.A.C.E.A.) were delivered to an LMD-process for additively forming pin shaped structures (316L, <200µm) to improve composite-material interface (Fig. 1). For injection molding around metallic inserts with PEEK (polyether ether ketone; VESTAKEEP® DC4450 G, Evonik Industries AG, Essen, Germany; n=25) and polyamide (Trogamid CX 7323, Evonik Industries AG, Essen, Germany; n=26), respectively, giving the bracket the final shape, the build-up strategy with the best pull-off force results out of four formerly tested (different geometry and process parameters) was selected (build-up strategy V4; Fig. 2). Additionally, brackets out of metallic inserts without an additively enhanced surface were also produced and served as control groups (PEEK n=25; polyamide n=25). All test brackets were analysed by stereomicroscopy for insert molding defects and after one year simulated oral thermal (Thermocycler SD, Mechatronik GmbH, Feldkirchen-Westerham, Germany) and mechanical aging (Toothbrush simulator, Willitec GmbH, Munich, Germany); surface roughness of compound brackets was also measured by 3D confocal laser scanning microscopy (VK-X260K, Keyence, Neu-Isenburg, Germany). Statistics were performed by descriptive analysis and paired t-test (significance level: p≤0.05).

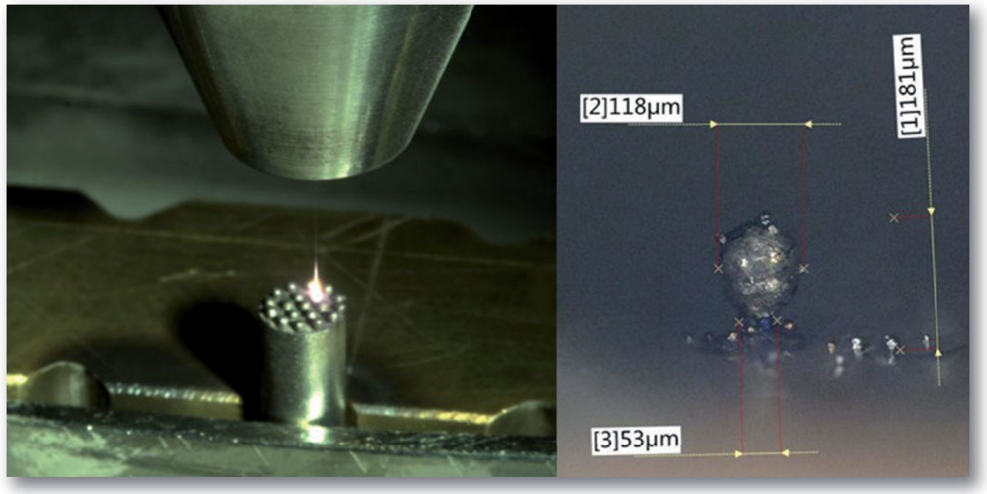

Figure 1: Additively formed pin shaped structures (316L, <200µm) on test tubes (P.A.N.A.C.E.A.) manufactured by Laser Metal Deposition (LMD) to improve interlocking of multi-material compound.

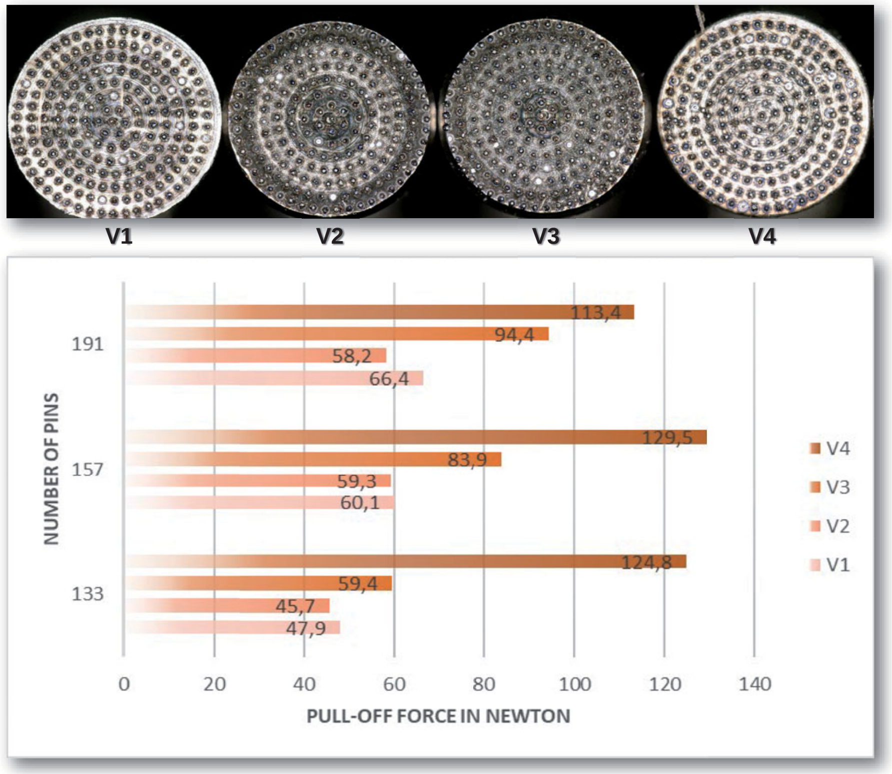

Figure 2: Results of pull-off test at test tubes with different pin arrangement (V1-V4) infiltrated with polyamide (n=5 each, median values).

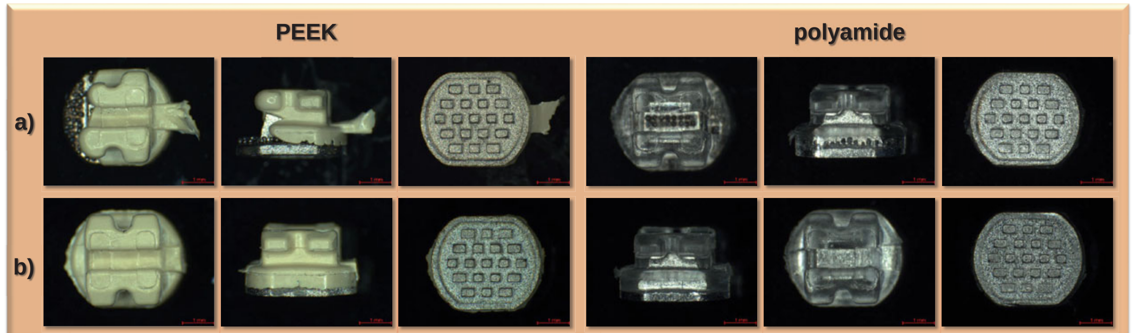

Figure 3: Steromicroscopy images of infiltrated brackets with PEEK (left) and polyamide (right) before simulated aging, a) with additively enhanced interface, b) without interface enhancement. PEEK samples with marked filling defects (a) were excluded during quality analysis (scalebar: 1mm).

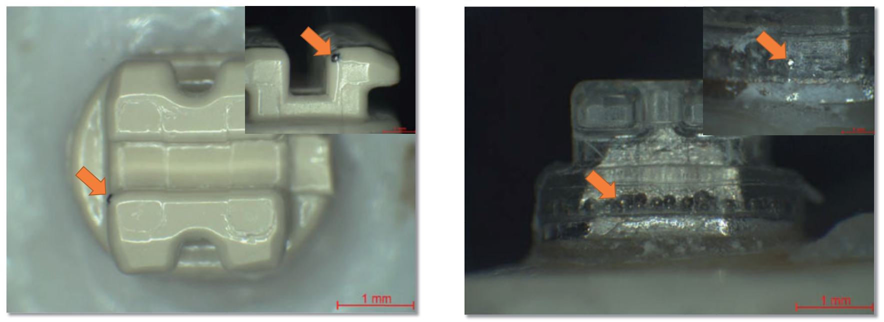

Figure 4: Stereomicroscopy images of PEEK (left) and polyamide (right) samples with exposure of interface after one year simulated thermal and mechanical aging (marked by orange arrows, scalebar: 100µm).

Results

Regardless of interface, stereomicroscopy analysis of infiltrated brackets revealed numerous filling-defects in PEEK (n=13/36%) compared to polyamide samples, where no filling-defects could be detected (Fig. 3). However, PEEK infiltration was much better at additively enhanced surfaces (n=8/32% vs. n=5/45% defects in the test compared to the control group, respectively), whereas n=14 (56%) samples in the control group had to be excluded from the outset and were not taken further into account since no compound could be reached. In none of the samples still under consideration (test groups: PEEK n=17, polyamide n=26; control groups: PEEK n=6, polyamide n=25) a detachment of the compound could be found after simulation of one year thermal and mechanical aging, and an exposure of the interface could only be detected in the test groups with one sample each (Fig. 4). Independently of the interface, surface roughness of both plastic materials significantly decreased with aging (0.2-0.3µm vs. 0.5-0.6µm beforehand; p<0.0001). While PEEK initially had somewhat lower Ra values compared to polyamide samples (p=0.01), this reversed for materials after aging (p<0.0001) (Fig. 5).

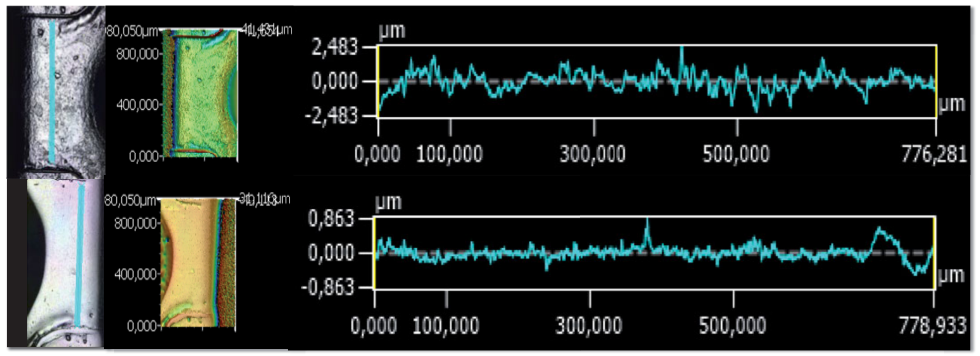

Figure 5: Exemplary images and roughness profile of polyamide samples before (Ra 0,513µm; upper line) and after (Ra 0,152µm; lower line) one year simulated thermal and mechanical aging, recorded by confocal laser scanning microscopy (VK-X260K, Keyence, Neu-Isenburg, Germany).

Conclusions

Additive manufacturing is a favourable technique to modify the interface of complex geometries and enhance composite material properties for oral clinical use. The material compound was not compromised at one year simulated oral thermal and mechanical aging, but surface roughness significantly decreased with aging, and substance abrasion was critical with exposure of micro-topologies in some, but clinical negligible cases, so that the weak point was not the interface but laid in the material properties of the resins used for final bracket shaping.

Acknowledgement

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