Experimental investigation of the load-response and failure mode behaviour of modern dental implant materials

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Introduction

The growing availability of hybrid and metal-free materials in the dental industry, for both fixed and removable restorations, gives doctors a larger portfolio of material choices and facilitates the treatment of a wider range of indications [1]. However, determining the appropriate material for a particular indication requires an understanding of the material properties. This includes its ability to bond to acrylics and composites, the final aesthetic/translucence of the material, as well as other structural parameters [2]. This article summarises experimental results obtained on the flexural strength and modulus of elasticity of a number of commonly used material, as well as fibre-reinforced composites (FRC), in the context of full arch implant supported restorations. It also examines the failure modes of these materials and the to what extent the restoration can be subsequently repaired [3].

The conventional approaches to full arch implant supported restorations centre on the use either a titanium bar framework with a PMMA denture for final aesthetic, or a fully milled and sintered zirconia restoration. In the context of the full arch restoration, the prosthesis would be screw retained to the implants.

Figure 1: Examples of full arch dental implants, composed of internal titanium bar with PMMA finish (left) and full zirconia construction (right) [4].

The loading condition of the dentures in this experimental analysis, was to focus on 4-point loading, which simulated the arch-loading condition of a denture when a user bites on a non-compliant material and often is the cause of implant mechanical failures. An ASTM D790 4-point bending fixture was used to simulate the load, shown in Figure 2. This set-up was used for all materials considered in this study, with the same displacement control ramp of 1mm/min. There were seven different samples used, each composed of different materials. The samples were chosen to enable a comparison between the conventional material choices and the FRC alternatives. The samples of FRC, FRC Layered with additional composite finishing, PMMA, BIOHPP and Zirconia samples were milled using an Imes-icore 650i suite. FRC layered with composite was produced in a layered 3-stage milling process. The bar with PMMA and full PMMA denture were produced using standard production techniques.

Figure 2: Mechanical testing set-up for the 4-point loading of dental implant samples, in an Instron 5969 load frame using an ASTM D790 fixture.

The load-displacement history was collected for each sample, along with photographs of the fracture planes for post-test failure analyses.

Results

Mechanical tests were performed on each sample and have been summarised in Figure 3, illustrating the load-displacement history of each material. It can be seen that each material type has different ultimate loads, stiffnesses and failure loads, the latter of which are progressive in some samples (e.g. FRC), while brittle and catastrophic in others (e.g. Zirconia). It should be noted that all samples were configured structures in this test, so the results shown are not only indicative of the properties of the materials used, but also the manufacturing process used for each, resulting in nuances such as crystalline plane orientations that can either hinder or help the rapid propagation of cracks.

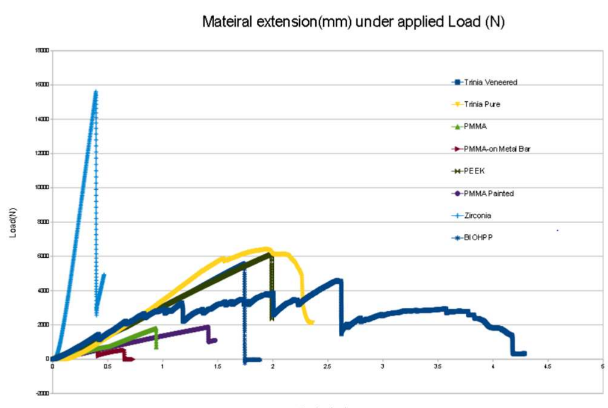

Figure 3: Load-displacement plot for Trinia veneered, Trinia pure, PMMA, PMMA on titanium bar, PEEK, PMMA painted, Zirconia and BIOHPP dentures.

A summary of material properties are given in Table 1 below. Related to the above note, these properties are also indicative of not only the material type, but associated manufacturing processes.

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Table 1: Summary of mechanical properties.

		Extension (mm) at		
	Mass (g)	**1500N**	**3000N**	**6000N**
Zirconia	50	0.08	0.12	0.19
PMMA Painted	10	1.11	N/A	N/A
Veneered FRC	15	0.49	1.11	N/A
Pure Trinia	15	0.56	0.91	1.68
BIOHPP	14	0.55	0.99	N/A
Milled PMMA	10	0.80	N/A	N/A
PEEK	12	0.52	0.98	1.94
PMMA-Ti Bar	12	N/A	N/A	N/A

Investigations of sample failure modes has led to increasingly valuable conclusions about the relative strengths of each material, both from a purely structural point of view, as well as that from the view of patients. The latter is particularly important, in how patients may effectively communicate questions or concerns about dentures, with their practitioners and in turn, how practitioners may effectively understand structural issues and implement remedies. Figure 4 shows two distinct failures of similar polymer dentures.

Figure 4: Failure modes of (left) PEEK and (right) PMMA. The PEEK experienced a significantly higher failure load than the PMMA, likely in part due to the manufacturing process used.

In this example, the fracture plane of the PMMA sample was clean and indicated an amorphous structure, which resulted in a catastrophic failure (as with the Zirconia sample too). In contrast, the PEEK sample was highly crystalline and contributed towards a higher surface area fracture plane and higher failure strain energy. Figure 5 shows the non-catastrophic failure of the FRC sample, which exhibited delamination on the back-face and local crushing failure on the load-supporting teeth. This illustrates the nature of the discontinuous FRC material and how patients may experience different thresholds of failure for different denture materials. Similarly, Figure 6 shows the titanium bar-reinforced PMMA denture, where the pure PMMA teeth fractured and sacrificially prevented damage of the substrate denture.

Figure 5: FRC sample shown in (left) top and (right) back-face orientations. The crack did not render the sample fully failed, with fibres bridged between the fracture planes for residual strength.

Figure 6: Titanium bar-reinforced PMMA denture, where the PMMA teeth failed and were removed before the main substrate was catastrophically damaged.

Results and Conclusions

An experimental investigation into the material properties and failure modes of various dental implant materials has been summarised in this article. It has been shown that all samples tested have different failure loads, failure strains, as well as modes. These are coupled with the materials used in each sample, the manufacturing process, in addition to the form of the dentures themselves. The industrial partners of this study shall benefit from helping dental practitioners communicate with patients to better identify denture failures and corrective courses of action.

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All denture restorations were produced at Perfit Dental. For more information visit www.perfitdental.com

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