Journal of Dentistry 59 (2017) 41–47

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.intl.elsevierhealth.com/journals/jden

An approach to understanding tribological behaviour of dental composites through volumetric wear loss and wear mechanism determination; beyond material ranking

Asmaa Altaie[a], Nigel L. Bubb[a], Paul Franklin[a], Adam H. Dowling[b], Garry J.P. Fleming[b], David J. Wood[a,*]

[a] School of Dentistry, University of Leeds, Leeds, UK
[b] Materials Science Unit, Dublin Dental University Hospital, Lincoln Place, Trinity College Dublin, Dublin 2, Ireland

ARTICLE INFO

Article history:
Received 9 November 2016
Received in revised form 24 January 2017
Accepted 9 February 2017

Keywords:
Resin-based composite
Wear mechanism
Tribology

ABSTRACT

Objective: To investigate the fundamental wear mechanisms of six resin-based composite (RBC) formulations during short-term in vitro wear testing.
Materials: RBC materials were condensed into rectangular bar-shaped specimens and light irradiated using the ISO 4049 specimen manufacture and irradiation protocol. Wear testing ($n = 10$ specimens for each RBC) was performed on a modified pin-on-plate wear test apparatus and wear facets were analysed for wear volume loss using a white light profilometer. The wear tested RBC specimens and their corresponding antagonists were analysed using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS), respectively to determine the wear mechanism.
Results: Data generated using the profilometer showed variations in the mean total wear volume (mm^3) between the RBCs tested ($p < 0.05$). Abrasive wear was evident in all RBCs investigated with varying degrees of damage. Material transfer/deposition of the filler particles on the corresponding antagonists was evident in two RBC materials (Filtek Supreme and Kalore) indicative of a further adhesive wear mechanism.
Conclusion: It is proposed that the approach employed to use a combination of measurement and analytical techniques to quantify the wear facet volume (profilometry), wear trough (SEM) and material transfer (EDS) provides more useful information on the wear mechanism and the tribology of the system rather than relying on a simple wear ranking for the RBC materials as is routinely the case in dental research studies.

1. Introduction

The assessment of the wear performance of dental resin-based composite (RBC) restoratives has been determined frequently in the dental literature since the first in vitro studies were published [1,2]. Today using the identifiable Medical Subject Headings (MeSHs) of 'dentistry AND wear', almost 2000 manuscripts have been published in the dental literature in the last 10 years. To complicate wear performance data interpretation, a variety of in vitro wear testing devices have been advocated to replicate the in vivo masticatory process [3]. However, no single in vitro wear simulator available can simulate the masticatory cycle in the oral environment [4]. At best wear simulators can provide an indication of the relative ranking of potential novel dental RBC restorative formulations prior to market launch when compared with commercially successful formulations [5,6]. Variations in RBC materials arise from different manufacturing processing routes and RBCs often include different monomeric resin matrices, functioning silane coupling agents and filler technologies (filler volume fractions, particle size distribution and filler density) [5,6]. However, the most robust laboratory RBC wear studies in the literature are conducted on a range of commercial dental products, routinely from different manufacturers in the form of round-robin tests [7–9].

Until recently, confusion existed on whether wear depth, area or volume should be reported [10] although the volume of material removed due to the interaction of opposing surfaces was shown to be the parameter of choice for reporting the in vitro wear of RBCs [11] based on Archard's equation [12]. Too frequently in dentistry,

* Corresponding author at: School of Dentistry, University of Leeds, Worsley Building, Clarendon Way, LS2 9LU Leeds, UK.
E-mail address: D.J.Wood@leeds.ac.uk (D.J. Wood).

http://dx.doi.org/10.1016/j.jdent.2017.02.004
0300-5712/

Table 1
Manufacturers details for the six commercially available RBC materials selected.

RBC	Description	Manufacturer	Resin	Filler type/size	Content	Special characteristics
Filtek Silorane	Universal Microhybrid	3M ESPE, USA	Siloxanes and Oxiranes	Quartz, YF 0.1–0.2 μm	76 wt% 55 vol%	Ring-opening monomers
Filtek Supreme	Universal nanofilled	3M ESPE, USA	BisGMA, $BisEMA_6$ UDMA, TEDMA PEGDMA	ZrO_2, SiO_2 0.6–1.4 μm	72 wt% 55 vol%	"True" nanotechnology unique clusters of nano-sized particles
Kalore	Universal nanohybrid	GC America, USA	UDMA DX-511 co-monomers, Dimethacrylate	F-Al-Si, SiO_2 0.4–0.7 μm	82 wt%	Does not contain BisGMA, DuPont's new monomer technology
Venus Diamond	Universal nanohybrid	Heraeus Kulzer Hanau, Germany	TCD-DI-HEA, UDMA	Ba-Al-F, SiO_2 0.5 nm to 20 μm	65 wt% 41 vol%	New cross linker technology. TCD-urethane cross linker
Tetric Ceram HB	Universal nanohybrid	Ivoclar-Vivadent Liechtenstein	BisGMA, UDMA, BisEMA	Ba-F-Al-B-Si mixed oxides, SiO_2, YbF_3, PPF 0.4–1 μm	76 wt% 55 vol%	Containing BisEMA Monomer
Clearfil Majesty Posterior	Universal nanofilled	Kuraray, USA	BisGMA, TEGDMA	Alumina and glass-ceramic 20 nm to 1.5 μm	92 wt% 82 vol%	Nano Dispersion Technology High filler content

BIGMA: Bisphenol A diglycidal ether dimethacrylate; TEGDMA: tri ethylene glycol dimethacrylate; BISEMA: Bisphenol A polyethylene glycol diether dimethacrylate; $BISEMA_6$: hexa ethoxylated Bisphenol A polyethylene glycol diether dimethacrylate; PEGDMA: poly ethylene glycol dimethacrylate; UDMA: urethane di methacrylate; TCD-DI-HEA: 2-propenoic acid, (octahydro-4,7 methano-1H-indene-5-diyl) bis(methyleneiminocarbonyloxy-2,1-ethanediyl) ester; PPF: pre-polymersied fillers.

wear depth or wear area are reported but wear in the mouth is dependent upon occlusal factors which change continuously with time and the progression of wear [10]. In addition, authors that claim to assess the wear volume often fail to examine the wear facet sufficiently [13] or ensure the accuracy and precision of the wear measurements reported [5,6,11,14]. From a tribology perspective, there are four fundamental wear mechanisms that can exist, namely abrasion, adhesion, fatigue or corrosion [15,16] and wear facets are infrequently assessed following testing to elucidate the wear mechanisms operative during testing.

The aim of the current study was to investigate the short-term in vitro wear resistance and wear mechanism operative during testing six RBC formulations. The null hypotheses stated were that there would be no differences in the (1) in vitro mean total wear volume data and (2) wear mechanisms operative, for the commercial RBC formulations investigated.

2. Materials and methods

2.1. Materials

Six commercially available RBC materials with innovative claims in terms of monomer chemistry, filler content, filler type and/or filler size and produced by a range of dental manufacturers, for both anterior and posterior clinical use were selected (Table 1).

2.2. Specimen manufacture

The RBC materials was condensed into rectangular bar-shaped specimens (25.0 ± 0.1 mm length, 10.0 ± 0.1 mm width and 3.0 ± 0.1 mm thickness) using a custom made Perspex holder. A constant excess of uncured RBC was placed into the mould, covered with a cellulose acetate strip and a glass microscope slide and a weight of 1 kg was applied for 20 s to ensure consistent and reproducible packing of the specimens. The weight and microscope slide were removed and the specimen was light irradiated using a light emitting diode (LED) light curing unit (LCU) (Demi Plus, Kerr, Orange Co., CA, USA) at ambient room temperature (23 ± 1 °C) with a spectral range of 450–470 nm and an irradiance of 1200 mW/cm^2. The irradiance was checked prior to use by employing a checkMARK (Bluelight Analytics Inc., Halifax, Canada). The entire length of each specimen was light irradiated using the ISO 4049 specimen manufacture protocol by placing the tip of the light guide in direct contact with the cellulose acetate strip in the centre of the specimen [17]. Both the top and the lower surface of the specimens were light irradiated to produce six groups of 10 specimens by overlapping the exit window by half the LCU tip diameter along the specimen [17] so that areas received twice the irradiation of adjacent areas using the 8 mm LCU tip diameter.

Following light irradiation, the cellulose acetate strip was discarded, the mould dismantled and the specimen removed and checked for surface imperfections. The specimens were wet ground by hand lapping using P400, P600, P800, P1000 and P1200 grit silicon carbide (SiC) abrasive papers (Struers, Copenhagen, Denmark) under copious water irrigation to remove the oxygen inhibited, resin rich layer and produce a planar surface with a consistent surface topography. The specimens were stored in a light-proof container and placed in a water-bath maintained at 37 ± 1 °C for seven days prior to testing and analysis.

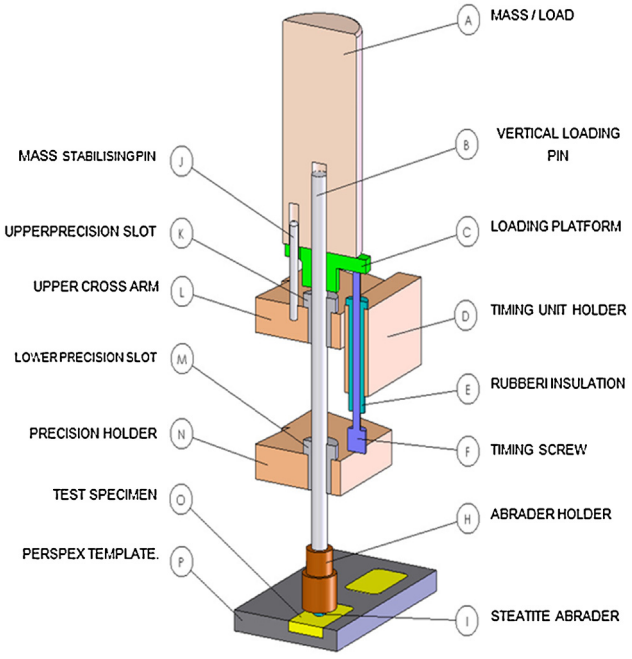

Fig. 1. Schematic illustrating a cross section cut through one of the ten wear stations where a custom made antagonist holder was devised that could be attached underneath the vertical rod.