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to: Delano Romero, Albuquerque Delicate Dentistry
Jennifer DeGreef, 01933

from: Jim McElhanon, 01821

subject: NMSBA Program with Albuquerque Delicate Dentistry

Executive Summary:

Albuquerque Delicate Dentistry entered in to an NMSBA program with Sandia National Laboratories to evaluate four polymeric materials used as mouthguard materials for sports activities. Albuquerque Delicate Dentistry was interested in identifying the "best" energy absorbing material for fabrication into mouthguards and if a nominal thickness for the material could be determined. Sandia agreed to conduct a literature search on the materials and perform fundamental material property characterization on the four materials of interest. The four materials provided by Albuquerque Delicate Dentistry were 1) polyethyl vinyl acetate (EVA), 2) Black EVA, 3) PolyShok, an EVA containing polyurethane, and 4) polytetrafluoroethylene (PTFE). Dynamic mechanical analysis (DMA) was performed on the four materials. The data revealed that PolyShok was the best energy absorption material of the four materials under evaluation. A literature search revealed studies that concluded that PolyShok provided superior impact resistance compared to pure EVA commercial products.

Literature Study

There are some significant reports in the literature on the subject of mouthguard materials, processing, and mechanical properties. A report by Gould[i] et. al. concluded that PolyShok provided superior impact resistance when tested at 37 °C (body temperature) compared to ProForm (EVA) and other EVA commercial materials. An 8 mm thickness of material was required to ascertain the material's true ability to dissipate energy. The thickness selected was not chosen as a function of the material, but rather as a requirement to conduct the impact test experiments. An excellent report by Lunt[ii] evaluated impact energy absorption of three mouthguard materials, EVA, ProForm (EVA), and PolyShok. The thesis concluded that PolyShok was the most energy absorbant material for three environments when impacted at 20 mph. The materials were conditioned at 37 °C in dry, deionized water, and artificial saliva environments and then tested at 37 °C. The thickness of each material was 4 mm. A study by Westerman[iii] et. al. described an improved mouthguard material and compared Stay-Guard (EVA) with an EVA material fabricated with air cells, each with a thickness of 4 mm. The modified mouthguard material reduced the effects of impacts of less than 10 kN by 32% compared to the traditional EVA mouthguard. Another study by Westerman[iv] et. al., compared impact data for EVA mouthguards (with a Shore Hardness of 80) with material thicknesses of 1, 2, 3, 4, 5, and 6 mm. The data showed that a thickness of 4 mm was substantially better in reducing the amount of transmitted forces compared to 1, 2, or 3 mm thicknesses. Increasing the material thickness to 5 and 6 mm only showed marginal improvement in reducing transmitted forces and that any improvement was statistically insignificant compared to a 4 mm thickness.

Dynamic Mechanical Analysis of Albuquerque Delicate Dentistry Materials

Albuquerque Delicate Dentistry provided four mouthguard materials for mechanical testing. They were 1) polyethyl vinyl acetate (EVA), 2) Black EVA, 3) PolyShok, an EVA containing polyurethane, and 4) polytetrafluoroethylene (PTFE). The materials were tested using dynamic mechanical analysis (DMA). DMA is a technique used for the characterization of the viscoelastic properties of materials. DMA measures modulus (stiffness) and damping (energy dissipation) properties of materials as they are deformed under periodic stress. Each material was subjected to DMA at frequencies between 1, 2, and 5, Hz. Figure 1 shows the storage modulus data for each polymeric sample at the tested frequencies. From this data the glass transition temperature (T_g) was measured and is listed in Figure 1. The T_g is a quantititave measurement of the reversible transition in amorphous materials from a hard and relatively brittle state into a molten or rubber-like state. All EVA based materials had a T_g below room temperature, while PTFE had a Tg of 88 °C. What this reveals is what is qualitatively observed from each material; The EVA based materials are rubbery above their glass transition temperature (which includes room temperature and body temperature) while the PTFE sample is a rigid sample and only becomes rubbery at temperatures > 88 °C (Data not shown).

Figure 1. Storage modulus and glass transition temperature data for 4 mouthguard materials using DMA.

Figure 2 shows a plot of the tan delta data for each material at 37 °C (body temperature). The tan delta value is representative of the damping ability of the material. Damping is the dissipation of energy in the material under cyclic load. It is a measure of how well a material will be at absorbing energy, a critical property for mouthguard materials. Figure 2 shows that PTFE has the lowest tan delta relative to the other materials, therefore being the poorest material capable of absorbing energy. The two EVA materials (black and clear) show about 5 times improvement in tan delta and all measurements are quite similar for each material since they are chemically identical except in color. PolyShok, the EVA containing polyurethane (EVAPU) shows the largest tan delta value at frequencies of 1 and 2 Hz. This data suggests that PolyShok would be a comparatively better energy absorbing material than EVA at low frequency.

Figure 2. DMA data of tan delta (damping ability) values for 4 mouthguard materials.

Summary and Recommendations

Our preliminary data and literature search suggests that PolyShok is a superior energy absorbing material compared to commercial EVA products. The better energy absorbing behavior must be due to the polyurethane (PU) component in this particular EVA composite material. We have not conclusively determined what an optimal mouthguard thickness should be. Our literature search revealed that for EVA, the optimal energy absorbing thickness is 4 mm. Any increase in thickness beyond 4 mm provides little additional energy absorbing enhancement.

Albuquerque Delicate Dentistry has indicated that working with PolyShok is messy and fabrication into a mouthguard material is difficult compared to pure EVA. Albuquerque Delicate Dentistry indicated that PolyShok sticks to the forming equipment and is difficult to remove. We recommend that Albuquerque Delicate Dentistry consider using a mold release compound, such as PTM & W's PA0801 mold release to mitigate these release issues.

[i] Gould, T. E., Piland, S. G., Shin, J., Hoyle, C. E., Nazarenko, S. *Dental Materials,* **2009**, *25*, 771.
[ii] Lunt, D. R., "Impact Enerty Absorption of Three Mouthguard Materials for Three Environmnets," MS Thesis, The Ohio State University, (2009).
[iii] Westerman, B., Stringfellow, P. M., Eccleston, J. A., Australian Dental Journal, **1997**, *42*, 189.
[iv] Westerman, B., Stringfellow, P. M., Eccleston, J. A., Unknown Source, Department of Mathematics, The University of Queensland.