An improved mouthguard material

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Abstract

A modified mouthguard material which reduces transmitted forces is described. Tests showed that the inclusion of air cells in a 4 mm thick polyvinyl-acetate-polyethylene (EVA) copolymer reduced the effects of impacts of less than 10 kN when compared with a material of the same EVA composition and thickness. The EVA copolymer with air-inclusions is suitable for the construction of stock, mouth-formed and vacuum-formed mouthguards. The improved elastic properties of the modified mouthguard material reduced transmitted forces by 32 per cent when compared with traditional EVA mouthguard polymers of the same thickness.

Key words: Mouthguard materials, air-inclusions, transmitted force, impact.

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Introduction

Mouthguards reduce orofacial injuries in persons participating in contact sports. They decrease injuries to teeth and lips,[1-4] and reduce the severity and prevalence of jaw fractures and concussion.[5,6]

Mouthguards have been manufactured from a variety of materials including vinyl resins, natural rubber, acrylic resins and polyurethane. However, the material most commonly used is the polyvinyl-acetate-polyethylene (EVA) copolymer. Physical properties of the EVA copolymer may be changed by altering the ratio of polyvinylacetate to polyethylene. Elastic properties are important for mouthguard material function. Elasticity of the copolymer determines the effectiveness of the mouthguard material through the absorption of impact energy as it is transmitted to underlying oral tissues. If the elastic limit of the copolymer is exceeded, permanent deformation or rupturing of the material occurs. The impact absorption properties of the EVA mouthguard material may be improved by increasing thickness.[7] However, this must be balanced against a reduction in wearer comfort due to awkwardness and speech restriction.

This paper describes an improved mouthguard material which has better energy absorption properties while having a thickness of 4 mm. This thickness is commonly used in vacuum-formed mouthguard materials. The improved material is also suitable for use in stock and mouth-formed mouthguards.

Material and methods

Samples of mouthguard materials were subject to impacts. The testing apparatus used was similar to a CHARPY or IZOD impact rig as detailed in AS1544.§ The test unit employed a blunt striker with a flat circular face of 20 mm diameter. The energy of impact was close to 4 joules. The swing arm head was fitted with a Brüel and Kjaer accelerometer, type 4335.‖ The acceleration of the pendulum was measured to calculate the peak transmitted force through the mouthguard material. The linear acceleration of the pendulum is directly related to the force through the equation:

$$\text{Force} = \text{mass} \times \text{acceleration}.$$

The striker mass was constant. The accelerometer was connected to a Brüel and Kjaer charge amplifier, type 2635.‖ The accelerations were captured on a Hewlett Packard Digitizing Oscilloscope, model 54501.¶ The data were transferred to a computer file using a Hewlett Packard Basic program. Tests were carried out on 5 samples of each of the 3 new materials which were all 4 mm thick. Five samples of 4 mm thick Stay-guard** mouthguard material were used as a standard. Fifty millimetre diameter discs of the modified and standard materials were used in testing.

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§Methods for Impact Tests on Metals, 1989.
‖Brüel and Kjaer, Australia Pty Ltd, Brisbane, Queensland.
¶Hewlett Packard Australia Ltd, Blackburn, Victoria.
**Stay-guard, Worldwide Dental Inc., Clearwater Florida, USA.

Table 1. Peak and mean transmitted forces

Material	Peak transmitted force (kN)					Mean transmitted force (kN)
	Test 1	Test 2	Test 3	Test 4	Test 5	Mean ± standard deviation
Stay-guard	7.49	7.49	7.62	7.67	7.54	7.56 ± 0.08
Sample 1	5.22	5.41	5.56	5.56	5.56	5.46 ± 0.15
Sample 2	5.97	6.35	6.35	6.04	6.04	6.15 ± 0.18
Sample 3	5.06	5.23	5.23	5.23	4.86	5.12 ± 0.16

Thermal gravimetric analysis confirmed that the modified material samples and the Stay-guard standard had the same composition of 20.4 per cent vinyl acetate copolymer.

The modified materials consisted of two laminations of EVA copolymer separated by a layer with air-inclusions. The air-inclusions in Sample 1 were 2 mm x 2 mm x 2 mm, and the walls separating them were 2 mm thick. Sample 2 had air inclusions 2 mm x 2 mm x 2 mm; However, the walls separating the air inclusions were 1 mm thick. The third sample had 3 mm x 3 mm x 2 mm inclusions with 1 mm wall separations.

Figure 1 illustrates the construction of the modified material.

Results

The results of the test impacts are shown in Table 1. The measures of transmitted forces ranged from a maximum of 7.67 kN for the Stay-guard material to a minimum of 4.86 kN for sample 3 of the air-inclusion material. All three test materials transmitted less force than the Stay-guard standard. Samples 1 and 3 transmitted less force than Sample 2. The mean peak impacts or transmitted forces are summarized in Table 1. The mean transmitted force for the Stay-guard standard was 7.56 kN with a standard deviation of 0.08. Samples 1, 2 and 3 presented means of 5.46, 6.15 and 5.12 kN respectively. Standard deviations from these test materials were 0.15, 0.18 and 0.16.

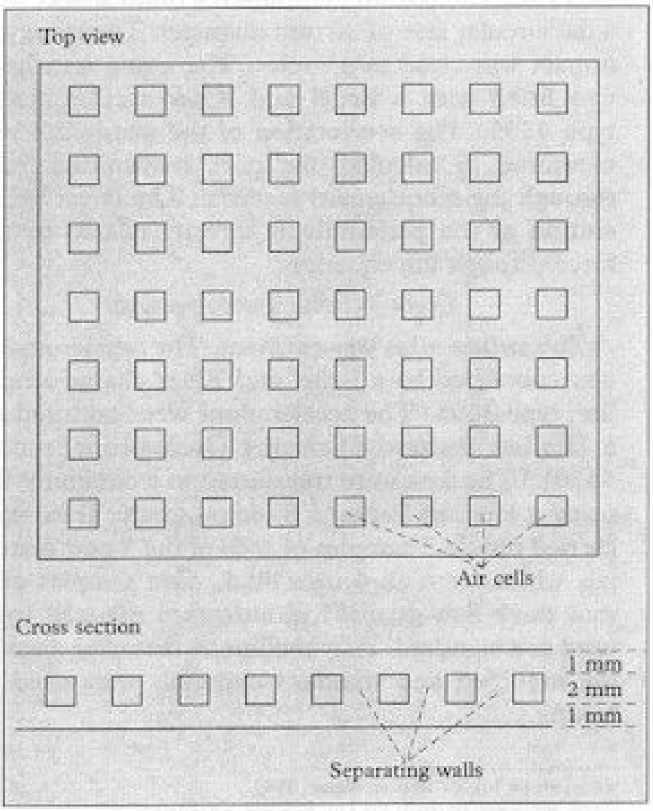

Fig. 1. – Material construction.

The Table shows that when the mouthguard materials were impacted, the inclusion of air in the EVA copolymer reduced the transmitted force. There was a reduction of 31.9 per cent in the transmitted force through Sample 3 when compared with the Stay-guard standard.

Figure 2 shows the reductions in peak transmitted forces in the standard Stay-guard compared with the air-inclusion materials. At the same time, there was an increase in the impact duration in the modified materials.

A two-way analysis of variance was performed on the data in Table 1. The analysis showed that the differences between materials were highly significant, p-value <0.001. The mean force for each material, shown in Table 1, indicates that the Stay-guard material transmitted the highest force. Pairwise comparisons between the Stay-guard and each of the Samples 1, 2 and 3, revealed significant differences with the test samples transmitting lower forces.

Discussion

Going *et al.*[8] analysed a comprehensive set of physical and mechanical properties of different mouthguard materials. Tests included tensile strength, elongation, tear strength, hardness, impact energy absorption, resistance to impact penetration and water sorption. No recommendations concerning the most desirable material were provided.

Bishop *et al.*[9] reviewed the physical properties of a range of EVA copolymers in an attempt to select a suitable material and establish clinically relevant mechanical tests. These authors suggested that mouthguard materials should have low water sorption, high tear strength, good elasticity and compression behaviour, and high energy absorption characteristics. EVA copolymers met most of these requirements. Of the materials tested, an EVA copolymer in the 18 to 24 per cent vinylacetate (VA) range was thought to be most appropriate, with 18 per cent VA appearing to be the most suitable.

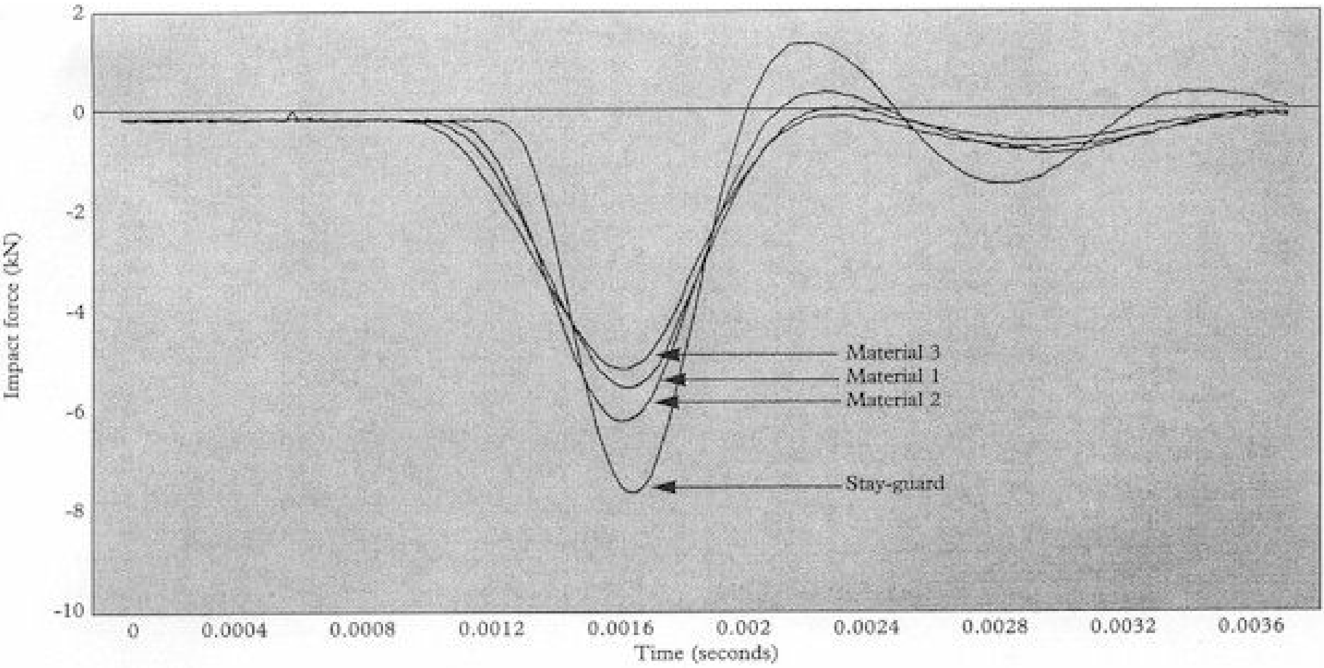

Fig. 2. – Comparison of impact forces.

The vinylacetate composition in currently available EVA copolymers include Stay-guard with 20.4 per cent and Vangard[††] with 21.5 per cent. The samples of the modified materials with air-inclusions were made from Stay-guard copolymer.

An explanation for the improved impact performance of the new materials is that the kinetic energy of the impact is better converted to heat through the elastic deformation of the test copolymers. The inclusion of air in the material enhances the energy absorption process, the sample with the largest air-inclusions showing the best energy absorption properties.

Conclusion

The incorporation of air-cells in an EVA copolymer mouthguard material produced a reduction in transmitted forces when impacted by forces less than 10 kN. Reductions of transmitted forces of 32 per cent were observed. This material improvement could be utilized in stock, mouth-formed and vacuum-formed mouthguards.

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