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Mechanical properties of a new thermoplastic polymer orthodontic archwire

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ABSTRACT

A new thermoplastic polymer for orthodontic applications was obtained and extruded into wires with round and rectangular cross sections. We evaluated the potential of new aesthetic archwire: tensile, three point bending, friction and stress relaxation behaviour, and formability characteristics were assessed. Stresses delivered were generally slightly lower than typical beta-titanium and nickel-titanium archwires. The polymer wire has good instantaneous mechanical properties; tensile stress decayed about 2% over 2 h depending on the initial stress relaxation for up to 120 h. High formability allowed shape bending similar to that associated with stainless steel wires. The friction coefficients were lower than the metallic conventional archwires improving the slipping with the brackets. This new polymer could be a good candidate for aesthetic orthodontic archwires.

1. Introduction

The interest in aesthetic orthodontic appliances is increasing: labial placed brackets, aesthetically coated archwires, and ceramic brackets are different examples. The latest development is a polymeric orthodontic archwire, translucent, with high springback and high ductility [1]. Marroco ML et al. [2] and Goldberg et al. [3] studied a new polymer wire based on polyphenylene, a novel polymer whose rigid molecular structure leads to a high yield strength and modulus of elasticity [1]. The clinical evaluation demonstrated the efficiency of tooth movement during the first stage of levelling phase of treatment [4].

The clinical plateau of the unloading curve (deactivation curve) is the main interest in relation to the moving teeth [5]. This plateau allows the orthodontist to apply an almost continuous light force with larger activations that results in the reduction of tissue trauma and the patient discomfort, thus facilitating enhanced tooth movement. In contrast, forces that are high in magnitude encourage hyalinization of the periodontal ligament and may cause irreversible tissue damage such as root resorption.

Besides the aesthetic reasons, the oral cavity represents a harsh environment for a metallic orthodontic appliance of any kind [6]. Corrosion of orthodontic appliances has been thoroughly studied [7–12]. Two main concerns are directly related to the effects of corrosion: biocompatibility and appliance performance [13]. The most important aspect is the interaction that the appliance may have with the patient in terms of absorption of corrosion products and the systemic reactions that may arise. Attention has been focused on nickel [14–23] as being an element able to induce allergenic reactions since it is one of the most used constituents of the alloys commonly used in orthodontics like stainless steel, nickel–titanium and copper–nickel–titanium. Recently, Ni-free Ti alloys with superelastic behaviour have been studied for orthodontic applications [24–27].These alloys are beta-titanium and more specifically the family Ti–Nb with different additional elements (Ta, Hf). These alloys have superelastic features due to the presence of austenite in the microstructure at 37 °C [25–27]. The alloy shows a superelastic effect with physiological critical stress (low and continuous) and a minimal loss of the recovery around 150 mechanical cycles. The increase of the corrosion resistance improves the values obtained by different NiTi alloys avoiding the problem of the Ni adverse reactions caused by Ni ion release. Cell culture results showed that the adhered cell number in the new substrate was comparable to that obtained in a commercially pure Ti grade II or beta-titanium alloy evaluated in the same conditions. Consequently, the new alloy has an excellent in-vitro response. These new alloy Ni-free superelastic alloys are being studied for the first time in orthodontic applications. Because of the above, TiNb alloys can be a good candidates for orthodontic applications since they avoid allergic problems. They do not, however, solve aesthetic problems.

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For polymeric archwires activated, there is an instantaneous applied stress proportional to the activation. With time, the extended molecular conformations relax towards their equilibrium position causing a gradual decrease in the applied force even though the deflection is constant: stress relaxation. For metallic archwires, the stress remains constant with a constant activation.

Recently, Hadjichristidis et al. [28,29] have studied a series of multigraft polystyrene-g-polyisoprene copolymers, which are thermoplastics elastomers with high strains at break, up to about 1550% [29]. The mechanical properties can be controlled by both molecular architecture and morphology. Due to the high strains at break and low residual strains in hysteresis tests, these materials have a behaviour similar to superelastic materials. The low tensile stress is the main problem in order to apply these polymers as orthodontic archwires.

The aim of this work is to obtain and determine the mechanical properties (tensile, three-point bending, stress relaxation and friction behaviour) of a new thermoplastic polymer orthodontic archwire and to compare its properties with the metallic archwires. These new polymer archwires present the aesthetic advantages; avoid the corrosion and the ion release.

2. Materials and methods

2.1. Material

The resin was obtained by mixing a liquid phase (methylmethacrylate monomer and butyl acrylate) and a solid component (benzoyl peroxide, tricresyl phosphate and dichloromethyl silane). Once mixed, the material was initially cured at 40 °C for 2 h and afterwards at 60 °C for 14 h. The material was then subjected to a post-curing heat treatment of 1 h at 130 °C.

The thermoplastic was extruded by using specially designed profile dies to achieve wires with clinically relevant cross sections of either 0.508×0.762 mm^2 rectangular or 0.508 mm round. A total of approximately 60 m of wire were extruded. The wire was visually examined, and cross-sectional dimensions were inspected continuously along the length. At several locations, samples were cut and examined with optical and scanning electron microscopy to evaluate the outer surface and cross-sectional shape.

2.2. Calorimetry

The transformation temperature (T_g) was measured by means of a calorimeter. The calorimetric system used has already been described in previous papers [9] and it is based on a flow calorimeter which measures differential signals (ΔT) by means of thermobatteries. Temperature was measured by means of a standard Pt-100 probe. All signals were digitized through a multichannel recorder and linked to a microcomputer. The transformation temperatures occur when there is a sudden increment in calorimetric signal. In the same way, the final temperatures are determined when the calorimetric signal returns to the base line.

2.3. Thermal cycling effects

Five orthodontic archwires were thermally cycled ($n = 100$). The samples were treated at 100 °C to 0 °C both for 10 min followed by cooling in water at 37 °C. Transformation temperatures were determined at different numbers of thermal cycles.

2.4. Tensile properties

Tensile tests were carried out in an electromechanical universal testing machine working (MTS-Adamel) at a cross-bar speed of 10 mm/min. Laser extensometer was used in these tests. The specimens tested were of 150 mm of height in the rectangular section (0.508×0.762 mm^2) and the same height in round archwires (0.508 mm) and the gauge length of the specimens or the distance between the grips was 77 mm. The tests were carried out in an artificial saliva medium at 37 °C. The chemical composition of the artificial saliva is shown in Table 1. Elastic modulus, ultimate strength, and elongation at yield at break were determined for each orthodontic archwire ($n = 40$) at different temperatures.

2.5. Three-point bending

Three-point bending tests were conducted using the universal testing machine (MTS-Adamel). The load frame was equipped with a 1 kN static cell The measurements were taken at 35 °, 37 ° (body temperature) and 39 °C. The bending tests were investigated using a laser extensometer. Ten measurements were recorded for each specimen. The dimensions of the specimens were the same used in tensile tests. The mid portion of the wire segment was deflected at the speed of 1 mm/min under the pressure from a metal pole of 5 mm in diameter. Each sample was loaded until a deflection of 4 mm was located. The samples were unloaded at the same cross-head speed until the force became zero [5].

2.6. Friction coefficients

Friction coefficients were performed in a CSM pin-on-disk tribometer, in accordance to the ASTM G99 standard. The underlying principle on this test could be called wire-on-disk because of its analogy with the pin-on-disk test. The samples studied were 10 archwires for each material: polymer, stainless steel, TiMo, cp Ti, NiTi and NiTiCu. The chemical composition of the alloys is shown in Table 2.

The orthodontic archwires were carefully affixed with cyanoacrylate adhesive in a bakelite holder, without adhesive residues, on the wire surface to be tested. The contact wire plane and the disc were in the longitudinal direction to simulate full-arc contact bracket.

An angular velocity of the disks and the normal load of 0.5236 rad/s and 10 N were used respectively. Ideally, the normal load on the wire should have been around 1 N to simulate the load in service (in which typical values range from 20 to 100 g force). However, 10 N was employed to ensure that there was a full contact between both surfaces that could influence the determination of the coefficients of friction.

The static and dynamic friction coefficients μ (the proportionality constant between the friction force and the normal force) were determined for the orthodontic archwires against the materials commonly used for the brackets (manufactured in 316 stainless steel and Ti–6Al–4V). These coefficients were measured in an environmental chamber which contained artificial saliva at 37 °C.

The dynamic friction coefficients μ (the proportionality constant between the friction force and the normal force) were determined and the wear rates (volume loss) for the orthodontic archwires against the materials commonly used for the brackets (manufactured in 316 stainless steel and Ti–6Al–4V) were also measured.

As the wear test was being performed, gravimetric measures were controlled in a Sartorius Micro Balance CPA26P, in order to determine the weight loss over time by means of a high-precision set of scales.

Table 1
Chemical composition of the artificial saliva.

Chemical product	Composition (g/dm^3)
K_2HPO_4	0.20
KCl	1.20
KSCN	0.33
Na_2HPO_4	0.26
NaCl	0.70
$NaHCO_3$	1.50
Urea	1.50
Lactic acid	up to pH = 6.7