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Evaluate the Load Deflection Properties of Titanium Orthodontic Archwires Coated with Zirconium: An *In Vitro* Study

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Abstract**—***The purpose of this study was to evaluate the load deflection characteristics and analyze the compositions of two products of titanium orthodontic archwires after surface coating. Timonium titanium archwires (TIM) and beta-titanium orthodontic archwires (β-Ti III) were obtained from (3M Unitek® USA and TIM orthodontic archwires 3M and TP Orthodontics® USA). The electron beam physical vapor deposition (EB PVD) was used to coat (5, 10, 25, and 50 thick) of pouring Zr on chose archwires. The load deflection properties were assessed by the modified bending test utilizing a 3-point bend structure, the samples were held in slots with underpins 10 mm apart and displaced at the midpoint. The wires were set up as straight of lengths of 14 mm. A 3-point bending test was performed with a Hounsfield test machine. load deflection tests demonstrated significant contrasts between Zr-covered archwires coated and uncoated archwires. A high load deflection rate was shown by the coated β-Ti III archwires and a low load deflection avoidance rate was displayed by the coated TIM archwires. Load deflection test of 1 mm demonstrated comparable forces for both uncoated β-Ti III archwires and those coated with 5 nm Zr was 250g. The value for β-Ti III archwires coated with 10, 25 and 50 nm Zr, was up to 261g. In this way, the coating of 5 nm Zr on β-Ti III archwires have not shown decrease in an archwires quality while coating of 10, 25 and 50 nm Zr have displayed increments in archwires deflection force. β-Ti III archwires contain strong elements, for example, Mo and Zr and coating of 5, 10, 25, and 50 nm Zr might improve the deflection force for titanium orthodontic archwires.*

Keywords**:** load deflection - titanium orthodontic archwires – coating - 3-point bending test.

I. INTRODUCTION

Many metals utilized alternative for hard tissues as dental inserts and furthermore can be utilized as break recuperating helps (screws, bone plates, orthodontic archwires, and brackets) [1,2,3]. The most broadly utilized metallic biomaterials are unadulterated Ti and Ti alloys, stainless steel (SS), and chromium-cobalt (Cr-Co) composites [4,5]. The β-Ti III archwires have a composition of Ti, Mo, Zr, and Sn. Al, V, Mn, and Cr are four components which are normal to numerous α and α+β alloys, Timolium (TIM) is a trend setting innovation titanium archwire. It contains Ti, Al, and V, which affirms that this archwire is a blend of α and β stages [6]. Orthodontic archwires are produced using diverse combinations. It is presently conceivable to level phases of treatment with orthodontic archwires as indicated by its mechanical properties. On this basis, the (TMA) beta stage delivers an appealing blend of flexibility and strength when utilized as orthodontic archwires to apply biomechanical forces that affect tooth movement [7]. As of late, it has increased expanded ubiquity in orthodontic treatment. There are, however, still disadvantages related with the utilization of orthodontic archwires, for example, high surface roughness, which increases friction at the archwire brackets interface during the sliding procedure [8,9]. Friction influences the sliding movements of the wire and bracket [10]. Archwires characteristic, for example, great load deflection, tensile strengths, hardness, and low modulus of versatility and opposition against erosion and wear determine the area of the contact surface, along these lines affecting the friction. So as to consider the mechanical properties of orthodontic wires and to choose the best materials as per their behaviour [11,12]. One of the most dependable and clinically

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important appraisals of orthodontic wires is given by the assessment of the elastic deflection utilizing bending test. This test simulators acceptably what happens in the clinical practice when the orthodontist inserts a wire in the bracket slot [12-14]. However, two unique methods of leading the bending test have been proposed. One is performed with the utilization of a clinical simulation device (CSD)[15]. The other, which is most regularly utilized in Engineering, is the 3-point bending test. This test is much easier to assess the relationship between the defalcation and loading which was utilized in the study [12,16,17,18]. The objective of this study was to evaluate and compare the load deflection properties of titanium orthodontic archwires, and also analyses the compositions of coated and uncoated titanium orthodontic archwires.

II. MATERIALS AND METHODS

Titanium orthodontic archwires supplied by two manufacturers, Rectangular β-Ti III with nominal sizes of 0.48×0.64 mm was obtained from 3M Unitek® USA, and round TIM orthodontic archwires with nominal sizes of 0.40×0.55 mm was from TP Orthodontics® US. The pour Zr was purchased from Good Fellow® of the UK. The archwires samples were cut into 14-mm long from the straight ends of the archwire. The EB-PVD technique (Pennsylvania, US) was used to deposit pure Zr with various thicknesses 5, 10, 25 and 50 nm on chose archwires. Coatings made by the EB-PVD process commonly have a uniform microstructure and a good surface finish [19]. The Zr was put into the crucible and the archwires samples substrates were mounted into the e-beam evaporator. The machine was closed and evacuated for 24hr. Thereafter, the e-beam deposition of Zr onto the archwires samples substrates was completed. This experiment was repeated under different deposition rate of 5, 10, 25 and 50 nm Zr, within the ranges from 0.6 Å/sec to 1.2 Å/sec. The vacuum pressure was approximately 2×10-6 mbar and the current 180 mA. In order to better simulate the oral cavity environment, samples were be immersed in artificial saliva (pH 5) at 37 °C for 28 days [20]. Energy-dispersive spectroscopy (EDS)/ Scanning Electronic Microscopy FEI Nova Nano SEM 230, (Eindhoven, The Netherlands) shown in “Fig. 1” was used to determine the chemical composition of uncoated and coated archwire.

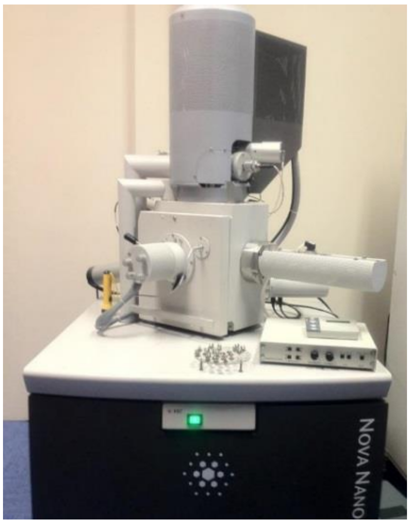

Figure 1: Scanning electronic microscopy (SEM) used for determining elemental composition of orthodontic archwires

A. *Deflection Test: Experimental Details*

A materials testing machine, Model H25KS, Hounsfield Test Equipment Ltd. (Redhill, Surrey, United Kingdom) “Fig. 2” was used to determine the force by testing archwires deflection. A selection of β-Ti III and TIM orthodontic archwires was to compare their deflection ranges. The samples comprised uncoated and coated β-Ti III/TIM orthodontic archwires with 5, 10, 25 and 50 nm thicknesses of pure Zr.

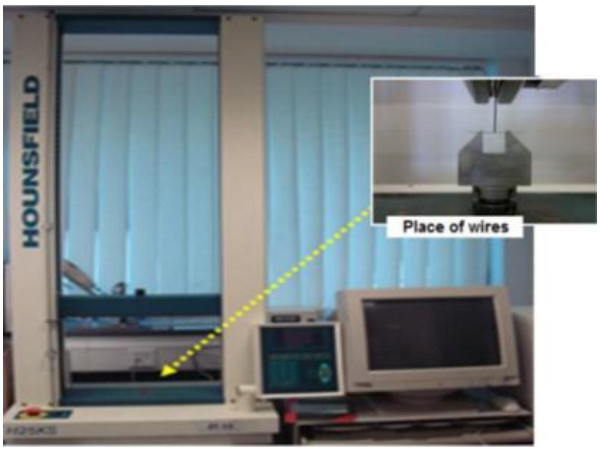

Figure 2: Hounsfield (Model H25KS) machine used for determining load deflection characteristics for orthodontic archwires

B. *Model Designs*

For the 3-point bending test, design “Fig. 3” the archwire samples were prepared as straight of lengths of 14 mm, held in slots with supports 10 mm apart and displaced at the midpoint. A modified bending test was carried out on the wires with a Hounsfield machine fitted with a 5 kg and a deflecting rod tip formed from 1.6 mm diameter polished SS.

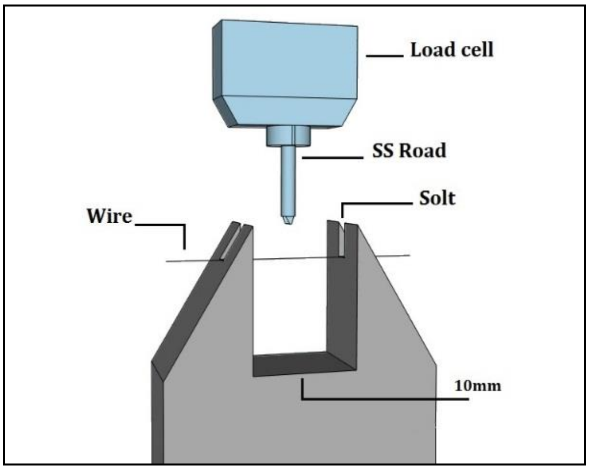

Figure 3: Schematic diagram showing 3-point bending apparatus for deflection test

The archwire samples were subjected to 3-point bending tests. A 5N load cell and the machine was run at a crosshead speed of 2.0 mm per. The wires were positioned on the supports of the 3-point bending apparatus with a fixed span width of 10 mm. A mechanical load was applied on the center of each wire at 90° to the wire axis, through a SS rod. By movement of the crosshead, at a speed of 0.2 mm/min, using a loading cell of 5 Kg, the load was increased in the curving until 2.0 mm of the wire of achieved. TexMAT® computer software was used to measure the value deflection curve. Load deflection measurements phase were measured digitally by selecting a deflection point as a plot on the computer screen. This point was picked to represent a standardized percentage of the unloading phase level in the load deflection curve. The deflection points chosen were 1.0 mm less than the maximum deflection of each bend up to 2.0 mm. The force/activation curves were measured from the passive position to an activation of 2 mm. The load was applied from 0 to 2.0 mm, during stacking, to get agent load deflection qualities for each wire.

III. RESULTS AND DISCUSSION

A. Deflection Test Results

Deviations of deactivation forces of the wires measured at a deflection of 1mm and 2 mm are shown “Fig. 4, 5”. Analysis of variance of activation forces showed significant differences between β-Ti III and TIM archwires with the same amount of activation 1 mm, TIM wires exhibited the lowest range of values, with forces of 164-176g. Uncoated β-Ti III archwires and those coated with 5 nm Zr had similar forces of 250g.

TABLE I: Results of deflection tests of uncoated and coated (β-Ti III and TIM archwires)

Titanium archwires	Deflection, (force ×g)	Deflection, (force ×g)
	1 mm	2 mm
Uncoated β-Ti III	250	404
β-Ti III with 5 nm Zr	250	407
β-Ti III with 10 nm Zr	254	409
β-Ti III with 25 nm Zr	257	412
β-Ti III with 50 nm Zr	261	413
Uncoated TIM	164	291
TIM with 5 nm Zr	170	293
TIM with 10 nm Zr	172	295
TIM with 25 nm Zr	173	298
TIM with 50 nm Zr	176	301

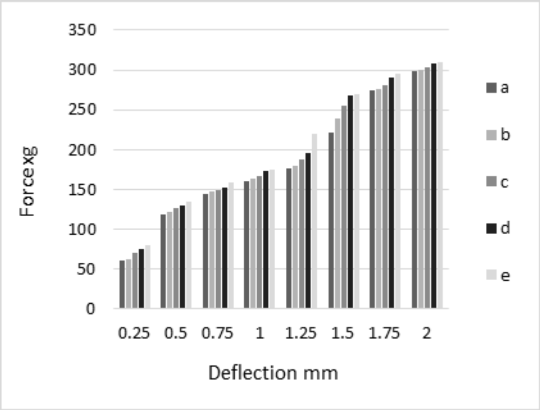

Figure 4: Load deflection graph for (a) Uncoated TIM (b) Coated TIM with 5 nm of Zr (c) Coated TIM with10 nm of Zr (d) Coated TIM with 25 nm of Zr (e) Coated TIM with 50 nm of Zr

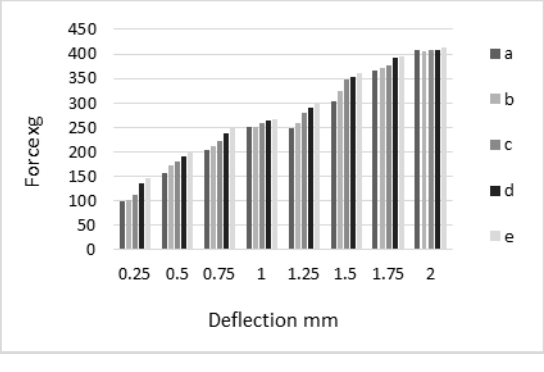

Figure 5: Load deflection graph for (a) Uncoated β-Ti (b) Coated β-Ti III with 5 nm of Zr (c) Coated β-Ti with 10 nm of Zr (d) Coated β-Ti with 25 nm of Zr (e) Coated β-Ti with 50 nm of Zr

B. Elemental Analysis

The β-Ti III archwires have a composition of 76.80% Ti, 11.84% Mo, 6.0% Zr and 4.5% Sn, and also have Al, V, Mn and Cr. Timolium (TIM) contains 89.9% Ti 6.1% Al, and 3.2% V, composition analysis results of β-Ti III and TIM archwires as received shown in (Table II).

TABLE II: Composition analysis of uncoated β-Ti III / TIM archwires, determined by EDS/SEM

Composition (wt.%)	Titanium archwires	
	β-Ti III 3M Unitek, Monrovia, US	TIM TP Orthodontics, Lodi, US
Ti	76.80	91.17
Mo	11.84	<0.05
Zr	6.55	<0.05
Sn	4.81	<0.05
Al	<0.05	5.73
V	<0.05	3.10
Mn	<0.05	<0.05
Cr	<0.05	<0.05

The results of the elemental analysis by EDS/SEM of uncoated β-Ti III archwire and coated β-Ti III archwires with 5, 10, 25 and 50 nm of Zr are given in “Fig. 6”. Coated β-Ti III archwires showed significant differences in height of rate of the Zr, also showed significant differences in declining of rate of Mo, Sn and Ti.

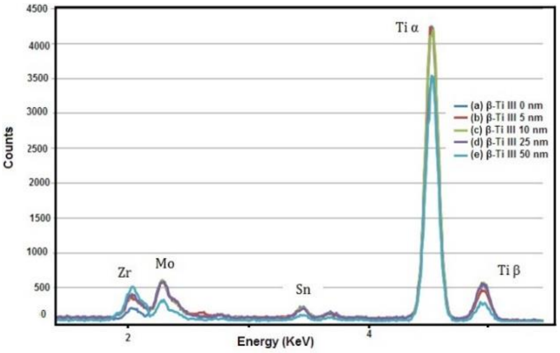

Figure 6: Elemental analysis by EDS/SEM of (a) uncoated β-Ti III (b) coated β-Ti III with 5 nm of Zr (c) coated β-Ti III with 10 nm of Zr (d) coated β-Ti III with 25 nm of Zr (e) coated β-Ti III with 50 nm of Zr

The results of the elemental analysis by EDS/SEM of uncoated TIM archwire and coated TIM archwires with 5, 10, 25 and 50 nm of Zr are given in “Fig. 7”. Coated TIM archwires showed significant differences in height of rate of the Zr and significant differences in declining of rate of Al, V and Ti. The coated and uncoated β-Ti III archwires had more Ti than TIM archwires and in addition Ti is contented Zr and Sn. Uncoated TIM archwire is contented TI, Al and V but did not content Zr.

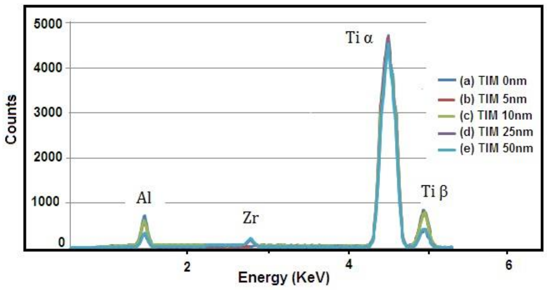

Figure 7: Elemental analysis by EDS/SEM of (a) uncoated TIM (b) coated TIM with 5 nm of Zr (c) coated TIM with 10 nm of Zr (d) coated TIM with 25 nm of Zr (e) coated TIM with 50 nm of Zr

To confirm that a wire is established within the range of its metallurgical properties, a deflection of no greater than 5% of span length is recommended. For the present study, this would suggest a maximum deflection of 2 mm. However, in the mouth wire, deflections of between 2 and 4 mm are the norm and these values were therefore used in the present study. The performance of an archwire in sliding depends on the archwire material, cross-sectional geometry and surface roughness. The coating of Zr on titanium archwires makes it possible to use larger archwires. Therefore, with β-Ti III and TIM, there would be less variation with the expected force delivery, thereby ensuring greater predictability of tooth movement. Although β-Ti III and TIM were expected to appear quite similar, the α-β alloy (TIM) was distinct from the β-Ti III archwires because there were layers or sheets of drawn-out material with visible steps or fissures. The SEM analyses confirmed the compositions of coated β-Ti III archwires: Ti (78.24%-78.03%), Mo (11.89%-11.09%), Zr (5.28%-5.57%) and Sn (4.56%-43.0%). This favorably compares with the β-III alloy having a composition of 78% Ti, 11.5% Mo, 6.0% Zr and 4.5% Sn, but without substantial amounts of α-formers (for example, Al) or β-eutectoid formers (for example, Cr). According to the Material Safety Data Sheet from one of the suppliers (Ultimate Archwire forms) these ranges of composition: Ti (70%-80%), Mo (10%-20%), Zr (5%-10%) and Sn (4%-8%). In contrast, the TIM archwire, contained Ti (91.87%-90.65%), Al (5.68%-5.41%), V (3.45%-2.91%) and Zr (0.64%-1.03%). This confirms that this product was a mixture of α and β phases. Absent was Mo, which is essential to stabilise a β phase. Also absent were sufficient quantities of the strengthening elements, Zr and Sn, which are present in the β-Ti III alloys. The space closure mechanics in orthodontic treatment can be carried out either as frictional or sliding mechanics. The archwires used in frictional mechanics should be able to slide through the brackets easily and should exhibit low load deflection properties for optimal force application. The coating process of Zr crossed the melting range of the beta titanium alloy and was found to affect the mechanical properties of the archwires, in order to be clinically applicable. These orthodontic archwires were consistently showing lower load deflection characteristics than its uncoated forms, which was statistically significant. This might be the result of change in its load deflection properties while coating is performed over archwire blanks. Both coated archwires withstood the load deflection rates exhibited were also comparable with each other. The load deflection rate evaluation with coated archwires showed high force application. Both β-Ti III and TIM coated archwires exhibited low load deflection characteristics in comparison with uncoated forms, making them ideal for space closure during frictionless mechanics. A low load/deflection ratio of both β-Ti III and TIM orthodontic coated archwires provide desirable force and good control of force magnitude. The fact that β-Ti III archwires possess those characteristics, among others, has made their use almost general. Deposition of Zr on β-Ti orthodontic archwires should lead to a decrease in the surface roughness of the archwires and improve the sliding between orthodontic archwires and brackets with no effect on the archwires strength. load deflection tests of 1 mm showed similar forces for both uncoated β-Ti III archwires and those coated with 5 nm Zr was 250g. The value for β-Ti III archwires coated with 10, 25 and 50 nm Zr, was up to 261g. Therefore the deposition of 5 nm Zr on β-Ti III archwires have not exhibited reduction in a archwires strength while deposit of 10, 25 and 50 nm Zr have exhibited increases in archwires deflection force. β-Ti III archwires contain strong elements such as Mo and Zr and deposition of 5, 10, 25 and 50 nm Zr contributed to improve the deflection force for these archwires.

IV. CONCLUSION

It can be concluded that the coating of Zr on β-Ti and TIM archwires improves the archwire deflection force. The β-Ti archwires do not contain elements such as Mo and Zr and contain insufficient elements of V. These elements are considered strengthening the archwires. Deposition of Zr on TIM archwires improved their deflection force. The newly developed Zr PVD coated β-Ti orthodontic archwires might be useful during the space closure stage of orthodontic mechanics, be it sliding or frictionless mechanics. β-Ti III archwires can be considered superior to TIM archwires but inferior to TIM archwires coated with 5, 10, 25 and 50 nm Zr. Clinically, this means that the net force required for transfer of movement will be lower for β-Ti III archwires and higher for TIM archwires. Surface evaluation of an archwire alloy is important because of its influence on the working characteristics.

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