Review Article

# Surface Coated Nickel–titanium archwires – A Review of Literature

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## Abstract

Since its introduction in early 1960s, nickel–titanium (NiTi) has undergone evolution through various stages for a better orthodontic treatment. NiTi archwires are now the most commonly used initial aligning and leveling archwires because of their unique properties such as shape memory, superelasticity, low modulus of elasticity, low and constant forces, and high elastic range. An increase in esthetic concern among the adults undergoing orthodontic treatment has led to the development of esthetic surface coatings for NiTi archwires. In addition to improved esthetics, surface coatings also affect the various mechanical properties of NiTi wires such as load deflection rate, friction, corrosion, nickel ion release, anti-adherent, and antibacterial property. In this review article, the various properties of surface coated NiTi archwires are evaluated.

**Keywords:** Archwire, Esthetics, Nickel–titanium, Surface coating.

## Introduction

Archwires are used in fixed orthodontic appliances to exert force on teeth that bring about tooth movement. Initial archwires are the first archwires that are inserted into the fixed appliance at the beginning of treatment and are used mainly for aligning teeth by correcting crowding and minor tooth rotations.[1] The initial archwires must be biocompatible and ideally have:

- Low stiffness
- Deliver light forces on activation – light continuous forces are the most desirable to achieve controlled and predictable tooth movement with minimum root resorption and less harm to supporting tissues[2,3]
- High strength and resistance to permanent deformation
- Elastic behavior over weeks to months
- Ease of engagement within fixed appliance
- Low cost[4,5]

Historically, precious metal alloys (e.g., gold) were used for the fabrication of initial archwires, but their use was limited because of high cost. Stainless steel replaced gold, which offered comparatively good strength and springiness, corrosion resistance, and low cost. Stainless steel archwires can be bent to almost any desired shape without breaking.[1] The development of nickel–titanium (NiTi) archwires has led to a decline in popularity of stainless steel wires for initial alignment. NiTi wires are used worldwide because of their very low force delivery and wide elastic working range.[6] NiTi wire can be used in Class I, Class II, or Class III malocclusions, in both extraction and non-extraction cases. The primary criteria for case selection for the use of NiTi wire are the amount of malalignment of teeth from the ideal arch form.[7] The more the wire is deflected from the ideal arch form when ligated into the bracket, the greater benefit will be obtained from nitinol wire than stainless steel wire. NiTi is differentiated by its exceptional properties such as high ductility, high resilience, and higher tensile strength (1500 MPa) than yield strength (430 MPa) which indicates its ability to undergo substantial work hardening, very low elastic modulus (approx. 41 GPa) which results in very low force delivered by the appliance compared with similarly constructed, and activated appliances from stainless steel and Co-Cr-Ni alloys and the springback or elastic range available for tooth movement is much greater for nitinol, shape memory effect, and superelasticity.[8] These properties make NiTi attractive for biomedical applications.[9]

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In the oral environment, orthodontic archwires are affected by many factors which include saliva flow, ingested food and fluids, temperature fluctuations and masticatory, and appliance force. As a consequence of these factors, friction or biocorrosion processes may occur.[9] These conditions will affect the function of orthodontic elements, causing changes in their microstructure, surface topography, and mechanical properties. Many attempts have been made from the past to improve the mechanical properties of orthodontic wires using variable types of alloys and surface treatment of archwires. Coating the orthodontic archwires is one such attempt that is still under research. An increase in esthetic demands of patients undergoing orthodontic treatment has also lead to the progress toward esthetic coated archwires. In this literature review, evolution of NiTi archwires and the various properties of surface coated NiTi archwires are presented.

## History and Evolution of NiTi

In the early 1960s, nitinol was invented by Buehler[7], a research metallurgist at the Naval Ordnance Laboratory in Silver Springs, Maryland (later called as the Naval Surface Weapons Center). The name nitinol is an acronym of nickel (Ni), titanium (Ti), and Naval Ordnance Laboratory (nol).[7] The NiTi alloys used in orthodontic practice have nearly equiatomic compositions 50 at.% Ni and 50 at.% Ti. Because of the differing atomic weights of Ni (58.7) and Ti (47.9), these alloy compositions are approximately 55 wt.% Ni (55-Nitinol).

In clinical orthodontics, Andreasen and Hilleman were attracted by the unique properties of NiTi alloys, such as high elastic limit, high resilience, and low modulus of elasticity and rigidity and they developed the first commercial NiTi alloys aimed at orthodontic purposes.[10] Subsequently, the stabilized NiTi alloy for clinical use under the trade name NITINOL was produced by Unitek Corporation. It was developed on the weight percentage of 55% Ni and 45% of Ti, and clinically used in 1972 for the 1st time. Nitinol had an excellent spring back property, but it did not have shape memory or superelasticity. Andreasen and Morrow in 1978[7] compared the cantilever bending properties and torsional properties of round and rectangular nitinol and stainless steel wires. Nitinol showed lower stiffness, lower bending moment or torsional load, greater stored energy, lower, more constant and continuous force on the teeth than the stainless steel wire of equivalent size. The study also emphasized certain limitations of nitinol which include resistance to permanent bend, breakage when bent over a sharp edge, difficulty in bending loops.

In 1978, Miura *et al*. developed a superelastic Japanese NiTi (SE NiTi)[11,12] alloy, possessing all three properties (excellent springback, shape memory, and superelasticity). The stress value remained fairly constant during deformation and rebound for the Japanese NiTi (Figure 1) – this is called as "superelastic property." They have also introduced coil springs fabricated from Japanese NiTi.[13] This wire was marketed worldwide as Sentalloy.

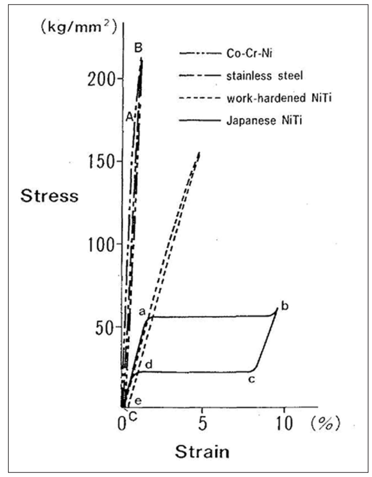


**Figure 1:** Stress–strain curves for orthodontic wires of 0.016 inch in diameter at the moment of pulling and on tensile release[11]

Concomitant to the discovery of Japanese (superelastic) NiTi, another NiTi alloy with similar characteristics was developed specially for orthodontic appliances by Tien Hua Cheng at the General Research Institute for Non-Ferrous Metals (Beijing, China) and was introduced by Burstone *et al*.[14] This alloy has unique characteristics and offers significant potential in the design of orthodontic appliances. Its history of little work hardening and a parent phase which is austenite yield mechanical properties that differ significantly from nitinol wire. In addition, Chinese NiTi wire has a much lower transition temperature than nitinol wire. Although the term superelasticity was not emphasized by Burstone *et al*.[14] for Chinese NiTi, the bending test plots for Chinese and Japanese NiTi were very similar,[15] indicating that the Chinese alloy also showed superelastic behavior. The Chinese NiTi wire was marketed by Ormco under the brand name NiTi.

The next major development was the commercial introduction in the early 90s of the first shape memory wire at the oral environment temperature (Neo Sentalloy) by GAC International.[6] Since 1963, Buehler[7] has observed the shape memory effect, asserting that, in low temperatures, the NiTi alloys were easily deformed and when heating them above their transition temperature, their original configurations were reestablished. However, the complexity of the thermic treatment of NiTi alloys made it impossible, at that time, to manufacture heat-activated wires. NiTi wires with copper (CuNiTi) emerged, commercially, in the mid-90s and were manufactured in three transition temperatures – superelastic (CuNiTi 27°C), heat-activated CuNiTi 35°C, and heat-activated CuNiTi 40°C.[6] These three clinical activation temperatures correspond to the different austenite finish temperatures for the wire products. These variants would be useful for different types of orthodontic patients. For example, the 27°C variant would be useful for mouth breathers; the 35°C variant is activated at normal body temperature; and the 40°C variant would provide activation only after consuming hot food and beverages.[16] Cu (efficient heat conductor) added to Ni and Ti, these wires present better defined transition temperatures, which not only ensures the generation of more homogeneous loadings from arch to arch and from end to end but also increases the effectiveness of tooth movement.[17]

## Surface Modification and Coatings for NiTi Archwires

The major evolution for NiTi orthodontic archwires over the past two decades has involved coatings and surface modifications to improve the esthetics and frictional properties of NiTi. Coatings were intended to improve the following properties:

- Esthetics
- Mechanical properties
  - Load and deflection
  - Surface roughness and mechanical sliding mechanism (friction)
  - Decrease Ni release
  - Corrosion resistance
  - Antiadherent and antibacterial effects

## Some Commercial Coated NiTi Archwires[6]

- Polyethylene coated (Forestadent)[18]
- Teflon coated (Forestadent, GAC)[18]
- Esthetic epoxy-coated NiTi offered by G and H Wire company[19]
- NiTi wires with full tooth-colored coatings offered by TOC (UK), Hawley Russell, and Forestadent[20]
- NiTi wires with labial tooth-colored coatings offered by DB (UK) and TP Orthodontics (Westville)[20]
- IonGuard by GAC International – which uses surface modification involving nitrogen implantation – nitrogen ions create a Ti nitride surface region that reduces both friction and Ni leaching – available for both Neo Sentalloy and Bioforce plus archwires
- High esthetic Sentalloy and BioForce archwires with a low reflectivity rhodium coating that has a white appearance – offered by Dentsply GAC[21]
- Rhodium-coated NiTi offered by Tomy, Hawley Russell, and TOC and Dentalline[19]
- Esthetic coating for Woowa NiTi archwires has a double-layered structure, in which the inner layer is a silver and platinum coating and outer layer is a special polymer coating[21]
- Non-esthetic diamond-like carbon coatings on NiTi archwires

## Esthetics

There is an increasing demand for esthetic orthodontic appliances in present circumstance. Increased dental and orthodontic awareness has made fixed appliance orthodontic therapy more socially acceptable for patients, especially among adults.[22] Even though more adults patients are demanding orthodontic treatment, a study[23] highlighted that nearly a third of them would not be willing to undergo treatment with visible labial appliances. Brackets and wires have traditionally been made of stainless steel, cobalt-chromium, or Ti alloy materials. Increase in esthetic demand has led to the availability of a variety of esthetic appliances such as ceramic brackets and lingual appliances. Although the invention of ceramic brackets has satisfactorily addressed the issue both clinically and esthetically, archwires remained unchanged which have been an esthetic concern. Then, metallic archwires coated with polymer materials, such as polytetrafluoroethylene (PTFE), epoxy resin, and rhodium have been developed. However, the durability of the esthetic coatings is not clinically evident as they tear over a period of time. Coated archwires had a low esthetic value as they presented a nondurable coating. The remaining coating showed a severe deterioration and a greater surface roughness.[24]

Bradley *et al*. (2013)[25] compared esthetic properties of two types of esthetic coated NiTi wires (EverWhite American Orthodontics and via Wires Pearl Esthetic Superelastic NiTi Opal) compared with comparable regular NiTi wires in the as-received state and after clinical use. Both wire types lost a significant amount of coating after use in the areas of archwire engagement, but the Opal via Pearl wires showed better retention of the coating with a 26.44% loss versus 44.31% for American Orthodontics EverWhite. From visual observation of the wires after retrieval from the mouth, the resin is primarily lost where it was engaged in the bracket and the resin was less damaged in the interbracket span. This suggests the engagement of the wire in the bracket, where friction and force systems on the wire are high caused the resin to be peeled off.

Ulhaq *et al*. (2017)[26] evaluated the esthetic performance of four coated NiTi archwires (BioCosmetic-Forestadent, 0.017 inch; Titanol [Forestadent], 0.016 inch; TP Esthetic [TP Orthodontics], 0.014 inch; and (4) Tooth Tone [Ortho Organizers]) over an 8-week period. Coating loss and color change after clinical use was significant for all wires tested with BioCosmetic wire performing the best of all four wires.

Modifications in method of coating such as coblasting[27] and coating at lower temperature (200°C)[28] might increase the wear resistance of the coatings.

## Mechanical Properties

### Load and deflection

An ideal aligning archwire should have low load deflection rate, but the unloading force should be sufficient enough to cause tooth movement. Various studies have evaluated the effect of surface coatings on the mechanical properties of NiTi.

With conventional ligation, retrieved coated archwires generated lower unloading forces (15–29 g) than as-received coated archwires (46–59 g) when deflected for 2 mm and both groups showed zero force at 4 mm deflection. This is due to excessive friction between the archwire and the bracket and is most likely due to damage to the coating "jamming" the wire in place. When used with self ligating bracket system, retrieved and as-received coated archwires generated similar unloading force with 2 mm deflection (40-65 g) and 4 mm deflection (30-53 g).[29] Lower loading and unloading forces were shown by coated and self-ligating bracket combination. This effect might again be because of greater frictional forces in the conventional bracket system than the self-ligating bracket system.[30]

These findings demonstrate the benefits of using passive self-ligating brackets with coated archwires.

Full surface coated NiTi wires showed lower unloading forces while partial coated NiTi wires showed similar unloading force as that of uncoated NiTi depending on the dimensions of the inner metal core. Thus, the loading and unloading forces of coated NiTi archwires depend mainly on the dimension of the inner metal core and not on the type of coating.[21,31-34] Increase in coating thickness will decrease the dimension of inner metal core which, in turn, decreases the unloading forces of the coated wire. Hence, appropriate size of coated wire should be selected to obtain the force similar to that of uncoated wires.

## Surface roughness and mechanical sliding mechanism (Friction)

Friction, or resistance to sliding (RS), can be defined as the resistance to motion when a solid object moves tangentially against another [Farronato *et al*. (2012)].[35] Friction and surface roughness are important properties of the orthodontic archwire, since they determine the effectiveness of archwire-guided tooth movement.[36] There are several ways to reduce RS by improvement of the material surface of the archwire such as Teflon/Epoxy/Rhodium coating, ion implantation, diamond-like carbon coating, and fiber-reinforced polymer composite coated with poly-chloro-p-xylene. Various studies have evaluated the effect of such coatings on surface roughness and frictional properties of the archwire.

Studies of Husmann *et al*. (2002)[37] and Farronato *et al*. (2012)[35] showed improved frictional behavior or lower RS with Teflon coated NiTi wires, whereas, other studies Rongo *et al*. (2014),[38] Rudge *et al*. (2015),[20] de Albuquerque *et al*. (2017),[39] and Jejurikar *et al*. (2020)[40] showed increase in friction and surface roughness of coated archwires when compared with uncoated archwires. This difference in results is due to difference in bracket materials used in their studies. Self-ligating brackets generally showed lower friction than conventional brackets.

Studies on diamond-like carbon (DLC) coatings[41] showed increased hardness which, in turn, lead to less corrosion and lower frictional behavior. DLC coating did not affect the surface roughness of the archwire.[42] DLC coating was also stable in fluoride environment.[43] Hence, DLC coating may improve frictional behavior of the archwires but there are only limited studies regarding frictional behavior of DLC coated NiTi archwires and are all *in vitro* studies. Further *in vivo* studies are required and the biocompatibility of such coated wires need to be evaluated.

In the search for material technologies that may lead to a significant reduction of FR coefficient in orthodontic devices, self-lubricating coatings – inorganic fullerene (IF) – such as nanoparticles and inorganic nanotubes of tungsten disulfide (WS2) and subsequently of molybdenum disulfide have been contemplated. As the IF nanoparticles were known to have superior solid lubrication behavior, in addition to very hard coating, attempts are made to incorporate them in metallic coatings. Friction evaluation using Instron system presented up to 66% reduction of the friction coefficient of (IF-$WS_2$) nanoparticle coated NiTi.[44] However, further *in vivo* human studies are required to validate the efficacy of the IF-coated orthodontic materials.

## Corrosion resistance and Ni release

The corrosion of NiTi archwires may cause serious consequences due to their high Ni concentration (47–50% Ni) and related biocompatibility challenges. Manufacturers try to comply with these requests by the development of coated wires or differing surface treatments of conventional orthodontic wires. Surface coatings tend to reduce the corrosion and Ni ion release from NiTi wires.

Surface nitrification showed increase in corrosion resistance under static conditions.[45,46] However, when subjected to dynamic loading similar to intraoral forces, nitride layer did not improve the corrosion resistance of the NiTi wire.[47] DLC-coated NiTi effectively reduced Ni ion release and the DLC coating was also stable in fluoride environment.[43] They also showed improved frictional characteristics. However, *in vivo* studies regarding the efficiency of DLC-coated wires are lacking. Rhodium-coated NiTi showed increased corrosion due to galvanic coupling between the noble coating and the base alloy.[45] Teflon and epoxy-coated wires showed improved corrosion resistance than uncoated NiTi.[48,49]

## Antiadherent and antimicrobial properties of coated NiTi wires

The appearance and adhesion of microorganisms on orthodontic appliances surfaces result in significant complications, such as enamel demineralization or white spot lesions around them. Therefore, applying antimicrobial coatings, which protect or obstruct the development of harmful microorganisms, have become popular in recent years. Several approaches have been applied to achieve this antibacterial behavior.

The treatment with nanoparticles of silver could be a good candidate as antiadherent and antibacterial orthodontic archwire.[19,50-52] However, the use of silver must be undertaken with caution, since the concentration-dependent toxicity has been demonstrated. It is critical to assess the durability and sustainability of silver coatings under clinical situations in the oral environment. Furthermore, it would be necessary to determine whether the thin coating of silver would alter its mechanical properties.

Titanium dioxide (TiO2) coating may provide an additional layer of protection and may help in augmenting the passivating effect of orthodontic wires.[53,54] However, studies may have to be undertaken to analyze and assess the effects of TiO2 coating on the corrosion resistance and friction of the orthodontic wires.

Zinc oxide (ZnO) nanocoating exhibits excellent antibacterial, esthetic, and biological properties together with superior frictional performance and corrosion property.[55,56] This may lead to the widespread use of ZnO nanoparticle in future orthodontic and medical practice for safer treatment. However, clinical studies are required to confirm these findings *in vivo*.

## Conclusion

To improve esthetics, NiTi archwires are coated with various materials such as PTFE, epoxy resin, rhodium, DLC, nitride, and recently nanoparticles such as silver, TiO2, and ZnO. The coating improves the esthetics but creates a modified surface that can adversely affect friction, corrosion behavior, mechanical durability, biocompatibility, and plaque accumulation.

Review on mechanical and biological properties of coated NiTi wires showed that surface coating with Teflon, epoxy resin, and rhodium decreases the surface roughness and friction of NiTi wires. Teflon coatings applied in thin layers and as partial coatings provided similar unloading force as that of uncoated NiTi, *in vitro,* as well as *in vivo*.[33,34] Surface coating technique with DLC using plasma-based ion implantation/deposition offered excellent properties such as extreme hardness, high wear resistance, decrease in corrosion, and Ni release, *in vitro*.[41,42] DLC coating was also stable in fluoride environment. Nanoparticle coatings, such as nanosilver, $TiO_2$, and ZnO, provide incredible antibacterial and antiadherent properties. In addition to antiadherent property, ZnO coating exhibited superior frictional performance and corrosion resistance than nanosilver and $TiO_2$, *in vitro*.[55,56] Thus, esthetic coating of NiTi archwires with different materials and methods improves their mechanical properties. Appropriate implementation of specific feature of each coated NiTi wire according to the clinical situation would allow for the most optimal and efficient treatment results.

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