OVERVIEW

Bending Properties of Superelastic Nickel Titanium Archwires

FRANZ MARTIN SANDER, DMD, PD
CHRISTIAN SANDER, DMD, PD
W. EUGENE ROBERTS, DDS, PHD
FRANZ GÜNTER SANDER, DMD

(Editor's Note: In this quarterly column, JCO provides an overview of a clinical topic of interest to orthodontists. Contributions and suggestions for future subjects are welcome.)

Nickel titanium alloys were originally developed for orthodontic use in the early 1960s and have continued to evolve since then.[1-16] Nickel titanium archwires, usually composed of about 55% nickel and 45% titanium, are commonly marketed as "memory" or "superelastic" wires. Because they cannot be adjusted by traditional wire-bending, superelastic archwires are primarily used in the straightwire technique, and then only for leveling in the initial phase of treatment. To place the 1st-, 2nd-, and 3rd-order bends needed for detailing and finishing, most clinicians use titanium molybdenum alloy (beta titanium) or stainless steel archwires.[5,12] This is unfortunate, because the low force levels of nickel titanium wires make them particularly well suited to finishing treatment with optimal efficiency and patient comfort.[14,16]

This article describes the bending characteristics of superelastic nickel titanium wires and their clinical implications.

Properties of Nickel Titanium Wires

We tested standard and low-force Titanol* nickel titanium wires from Forestadent, as well as Forestadent stainless steel and Ormco TMA**

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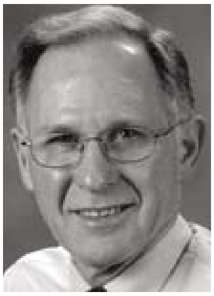
Drs. F.M. Sander and C. Sander are Assistant Professors and Dr. F.G. Sander is Professor and Head, Department of Orthodontics, University of Ulm, Ulm, Germany. Dr. F.G. Sander has a financial interest in the Memory-Maker. Dr. Roberts is Jarabak Professor of Orthodontics, School of Dentistry, Indiana University, 1121 W. Michigan St., Indianapolis, IN 46236; e-mail: werobert@iupui.edu.


Dr. F.M. Sander


Dr. C. Sander


Dr. Roberts


Dr. F.G. Sander

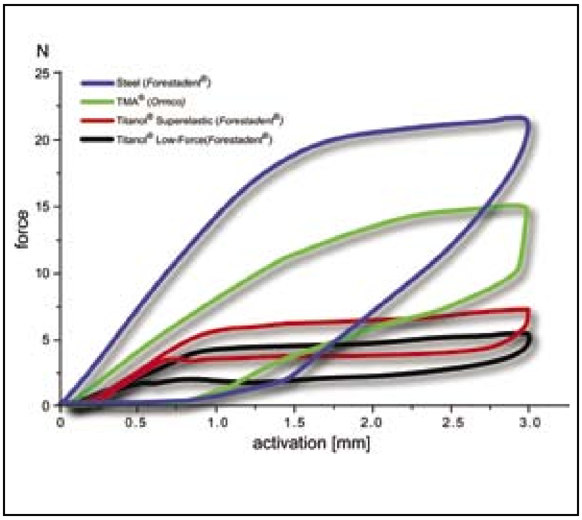


Fig. 1 Performance of various .016" × .022" wires in three-point bending test.

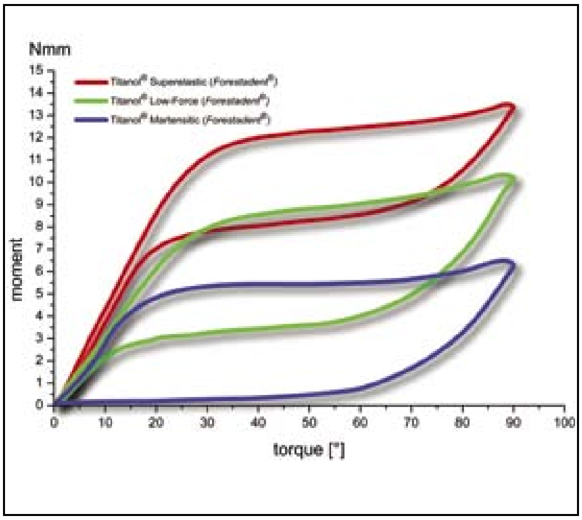


Fig. 2 Torsion test of three different .016" × .022" nickel titanium (Titanol*) wires from same manufacturer.

(titanium molybdenum) wires, all .016" × .022". The Titanol wires displayed significant force-deflection advantages in the three-point bending test (Fig. 1). The stainless steel wire showed permanent deformation at about 1mm of deflection and a high load-to-deflection ratio, reflecting a relatively high modulus of elasticity. The TMA wire had a lower load-to-deflection ratio, but underwent permanent deformation at about 1.5mm of activation. After demonstrating elastic behavior over the first .75-1mm of activation, the nickel titanium wires entered a pseudoelastic range between 1mm and 3mm of deflection. This rubber-like behavior is commonly referred to as "superelasticity".

In the superelastic range, the force does not increase in proportion to the deflection. This is the principal advantage of nickel titanium archwires: they can be deformed over long distances without permanent deformation, while continuing to deliver clinically acceptable force levels. The low force remains essentially constant up to about 3mm of deflection.

The physical properties of nickel titanium wires can be affected by minor variations in chemical composition, heat treatment, and mechanical function.[2] For example, in three-point bend testing, a Titanol low-force nickel titanium archwire showed an unloading force about half that of the standard nickel titanium (Titanol superelastic) wire offered by the same company (Fig. 1). On the other hand, in torsion testing, we found a progressive decline in unloading force for Titanol superelastic, Titanol low-force, and Titanol martensitic .016" × .022" nickel titanium wires (Fig. 2). Clinicians should not assume that all nickel titanium archwires have similar mechanical properties. Wires vary considerably among different manufacturers, and even wires from the same company can be inconsistent.[3,13]

Temperature Effects

Activation and deactivation temperatures are important variables affecting the performance of a superelastic nickel titanium archwire. In cold storage (<10°C), the wire is in the martensitic phase. Warming the wire to body temperature begins the austenitic phase, which induces a transformation in the crystal lattice structure. This leads to the stress-induced martensitic (SIM) phase, where superelastic properties are noted (Fig. 3).

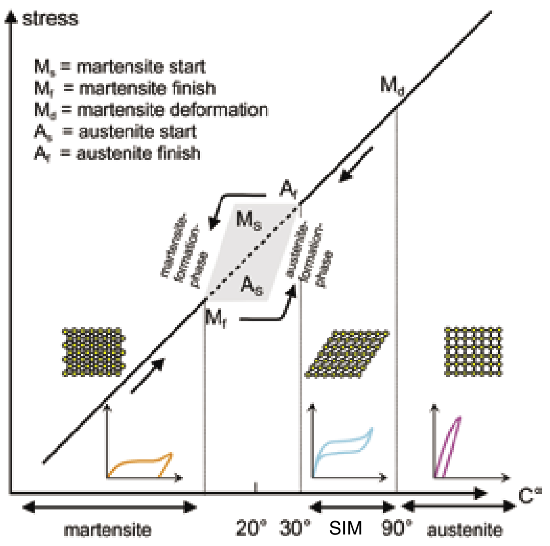


Fig. 3 Nickel titanium alloys display different behaviors under applied stress, depending on wire temperature. Phase-shift transformation occurs at about 10-30°C, stress-induced martensitic (SIM) phase at 30-90°C.

At around 90°C, martensite deformation (M_d) occurs.

The exact onset of the SIM phase depends on the material properties of the wire, but superelastic properties are generally noted in the temperature range of 30-40°C, which is characteristic of the oral environment. Clinically, however, the forces delivered by nickel titanium archwires will vary with the temperature of food and beverages consumed by the patient.[8] Heating and cooling phase shifts can be exploited during orthodontic treatment by using the one-way, two-way, and all-around effects.[14,15]

One-Way Effect

The one-way effect can be seen by placing a tipback bend in a nickel titanium archwire while it is in the cold martensitic phase (Fig. 4). During subsequent heating of the material beyond the austenite start (A_s) temperature, the wire is transformed into the SIM phase, and the tipback bend disappears completely. Cooling the archwire does not recover the tipback bend. Thus, in contrast to routine bends in stainless steel or beta titanium wires, one-way-effect bends in nickel titanium wires are not permanent conformational changes.

Any practitioner may have experienced the one-way effect by placing a routine bend in a nickel titanium wire, only to discover that it has disappeared by the next appointment. This behavior is referred to as “shape memory”: after heating, the archwire material returns to the condition that was programmed into it during the manufacturing process. To program a change in shape memory (“burning in”) requires temperatures of 300-520°C, depending on the material property desired.[14]

Two-Way Effect

The two-way effect is achieved by exposing a nickel titanium wire to a sharp deformation (severe tipback bend) while the wire is in its cold martensitic condition[14] (Fig. 5). This sharp bend produces an irreversible deformation in the lattice structure of the material. The martensite deformation is partially reversed when the wire is warmed enough to enter the SIM or austenitic phase; the remaining portion of the tipback bend is defined as the residual deformation. When the wire is cooled back into its martensitic phase, it partially recovers its original deformation.

For example, a severe permanent deformation of about 60° during the initial martensitic phase will result in a residual tipback bend of about 20° when the wire is warmed (SIM or austenitic phase), which increases to about 30° when the wire is cooled back to the martensitic phase. After the partial recovery from the initial bend, the tipback will subsequently vary from 20° to 30°, depending on the temperature of the wire. The magnitude of the two-way effect is determined by the material properties of the particular archwire.

The clinician can thus achieve a residual tipback effect by severely activating a nickel titanium wire in the martensitic phase. No practical consequence will be seen from the relatively small variation in tipback force associated with alternat-

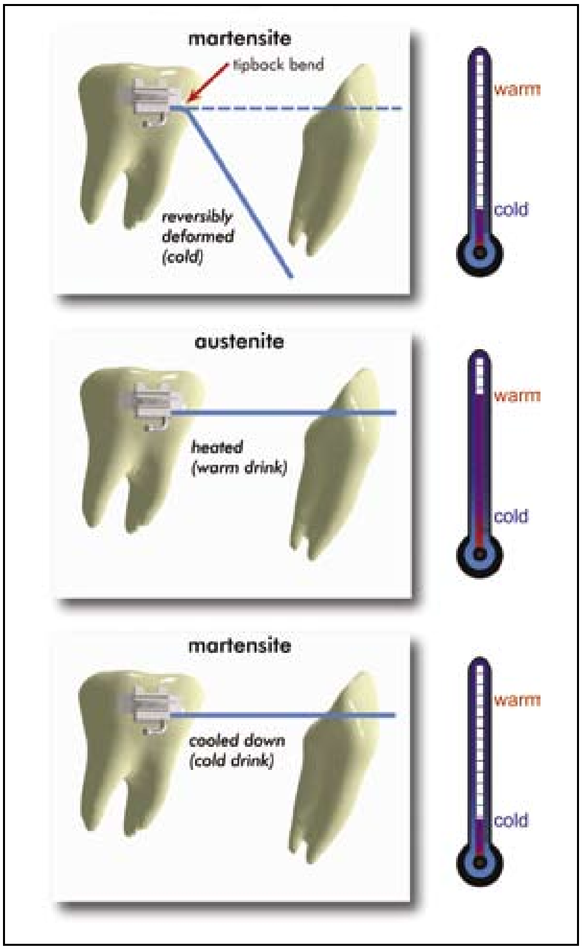


Fig. 4 One-way effect: tipback bend placed in cold nickel titanium wire is completely reversed when wire is warmed.

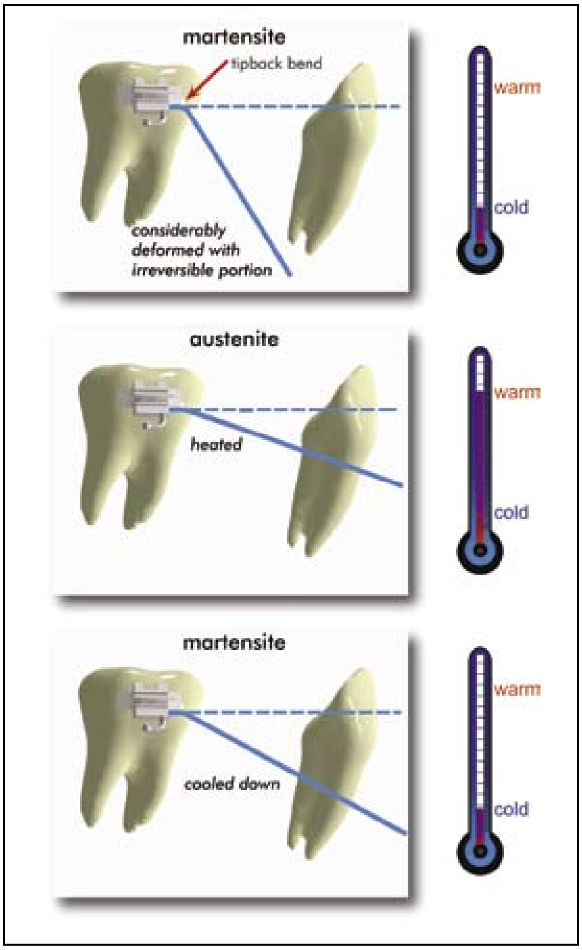


Fig. 5 Two-way effect: sharp bend placed in nickel titanium wire with special plier produces residual permanent set.

ing between the martensitic and austenitic/SIM phases. This is because the A_s temperature is usually adjusted to 30-40°C, a range in which the superelastic wire is martensitic. A detectable change in the tipback force would require a broader (unphysiological) temperature change to reach the austenitic phase.

The nickel titanium wire is permanently damaged by the two-way effect. Although a permanent cinch-back bend can be placed with special pliers, the deformed portion of the wire may be brittle. An accentuated posterior cinch-back or tipback bend is therefore an unreliable element of a clinical force system, because the deformed segment may fracture.

All-Around Effect

The all-around effect makes optimal use of the properties of superelastic nickel titanium wires. By heating an archwire in the martensitic phase to 300-520°C, a new shape can be programmed into it (Fig. 6). This conformational change is a permanent set that does not damage the superelastic or fracture-resistant properties of the wire. In effect, the burning-in process establishes a new memory

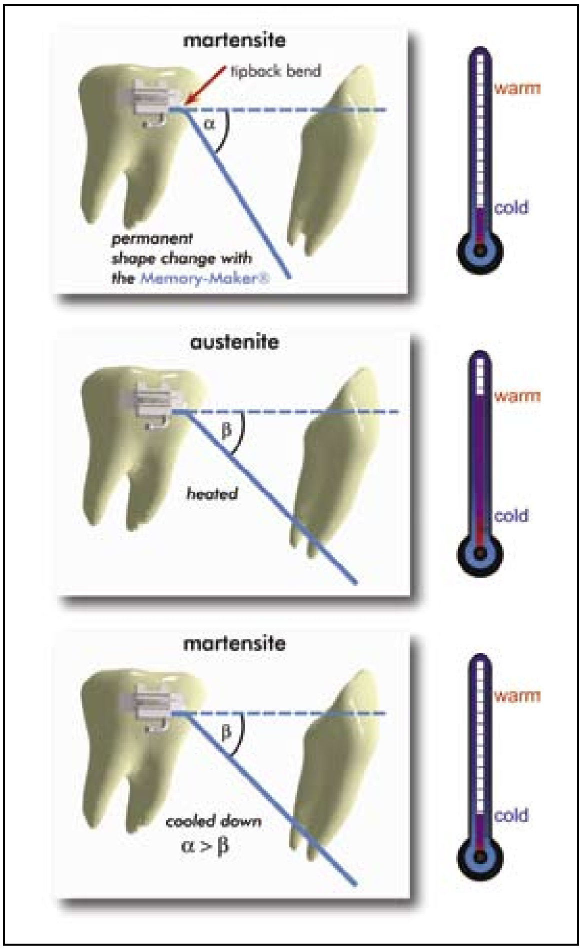


Fig. 6 All-around effect: tipback bend made with Memory-Maker* heat-induction device produces permanent set in wire without damaging its superelastic or fracture-resistant properties.

in the archwire that can be used therapeutically.

If a 60° tipback bend is placed in an archwire with the all-around effect, depending on the specific material properties of the wire, the bend will decrease slightly to about 55° when the wire is warmed up. Subsequent cooling and warming of the wire will have no effect on the residual 55° tipback bend.

In the manufacturing process, archwires are mechanically restrained in the desired shape, placed in a furnace that uniformly heats them to a specific reprogramming temperature, and then cooled. Each producer has a proprietary process for manufacturing wires with specific properties. To use nickel titanium wires most effectively, clinicians should choose manufacturers that produce consistent archwires with the most desirable characteristics.

The all-around effect is generally not possible to achieve in a typical clinical setting, because it requires the application of extreme heat. Until now, the only alternative has been to use expensive commercial services to custom-bend nickel titanium archwires.[17] The Memory-Maker* heat-induction device, which will be described in a subsequent article, was developed to allow the clinician to make permanent bends in a nickel titanium archwire at the chair.

Clinical Implications of Superelasticity

Nickel titanium wires do not show superelastic behavior at deflections of less than about 1mm, because such deflections do not adequately exceed the elastic limit of the wire. In this low range, Hooke's law applies: stress is proportional to strain. Therefore, nickel titanium wires may not be indicated for the final stages of leveling and alignment if the heat-induced deflection is too small to generate adequate force.[6] They are still desirable, however, for many low-deflection, three-dimensional detailing and finishing procedures because of their inherently low load-to-deflection ratio and favorable hysteresis characteristics compared with stainless steel and TMA (Figs. 1,2).

It should be noted that in vitro measurements of light nickel titanium forces may not be applicable in vivo, because physiological function and tooth mobility reduce the effective force of the wire. Clinically, flat nickel titanium wires may not completely correct the curve of Spee. After leveling and correction of rotation, it is best to either program a reverse curve of Spee into the nickel titanium wire or use a stainless steel archwire to complete the arch flattening.

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