Clinical and Mechanical Caracteristics for Orthodontic Nitinol Wires

CAMELIA, SZUHANEK[1], T., FLESER[2]
[1] Faculty of Dental Medicine, "Victor Babes" University of Medicine and Pharmacy Timisoara, ROMANIA
[2]Mechanical Engineering Faculty, POLITEHNICA University of Timisoara, ROMANIA
camelia_fleser@yahoo.com, trfleser@yahoo.com

Abstract: The materials such as the shape memory alloys in the medical field ensures the possibility of designing and practical achievement of certain cosmetic dentistry works with special advantages regarding the enhanced biocompatibility, superelasticity. The Ni-Ti alloys, have the characteristic of superelasticity which is around 20 times higher than that of stainless steel.The experimental program included the mechanical caracyeristics four NiTi orthodontic wires: traction test, determining the elasticity, alternating bending test, determining the hardness.

Key-Words: shape memory alloys, NiTi orthodontic wires, mechanical caracteristics.

I. Introduction

Shape memory alloys. and in particular NiTi-based materials, have enjoyed a long-standing interest with academicians and inventors. For many of its nearly forty year history, however, the allure of perpetual motion or "magic" prevented Nitinol from being seriously considered for commercial applications. These alloys are characterised by their capacity to return to their original shape after heating to their transformation temperature after having been deformed. This is known as the "shape memory effect" and is caused by a change in the crystalline structure during the transition from the martensitic phase to the austenitic phase. It gives these materials attractive actuation capabilities.

There are three different types of wires available: linear elastic, shape memory and superelastic. although the latter is used most often. The obvious advantage of supereJastic archwires is that they can provide a constant, gentle pressure to move teeth compared with stainless steel. These shape memory alloys have enjoyed commercial success in the following commercial applications: orthodontics, general medicine, temperature control, electrical connections, pipe and tube joining systems. They have a high power to weight ratio (up to ten times that of conventional actuation systems) and in the martensitic phase they can withstand large amounts of recoverable strain (up to 8%). When heated to above their transition temperature they can exert high recovery stresses of up to 700MPa which can be used to perform work. On the downside, they are relatively inefficient (less than 10%), having a slow response speed (predominantly dictated by the need for cooling) and are relatively complex to control due to inherent non-linearities and hysteresis in the shape memory effect.

Since the initial works of Buehler and colleagues at the Naval Ordnance Laboratory in the 1960s and the publications of Andreasen and colleagues in the early 1970s[1, 2, 3, 4, 5], NiTi archwires have gained wide popularity among orthodontists during the initial aligning stage of treatment. These alloys have at least two distinct crystallographic phases: a crystalline form present at high temperature and low stress, called the austenitic phase; and a low-temperature and high-stress variant, called the martensitic phase.

The most common shape memory alloy is Nitinol and alloy of nickel and titanium. The initial Nitinol was introduced by Unitek (Monrovia, CA, USA) was preferred over stainless steel because of its low stiffness and high springback. This alloy, which undergoes a severe hardening during its manufacturing process, presents a stable martensitic phase under clinical conditions.

In the 1990s, new copper NiTi alloys with austenite finishes were introduced to the market on the assumption that adding copper would stabilize the transformation temperatures and result in horizontal plateaus of reduced slope.

During the last two decades, industrial means have led to the development of materials having the defining characteristic of coming back to their initial geometrical configuration by an increase in temperature.

The NiTi materials fall within this category, have gained significant use in orthodontics. They are frequently provided in the form of wire. The respective alloys are employed in two different structural states resulted from heat processing. The structural state is correlated to the functional scope. The use of intelligent materials such as the shape memory alloys in the medical field ensures the possibility of designing and practical achievement of certain cosmetic dentistry works with special advantages regarding the enhanced biocompatibility, superelasticity, the effect of the shape memory, resistance against corrosion and wear, etc., which leads to very favourable functional and aesthetic effects. Consequently, the social impact upon the numerous patients with malfunctions of their braces is extremely high [6, 7, 8, 9].

A clinical examples where NiTi wires are used are shown in figure 1. T is a case treated with labial appliances (classical technique). in which the NiTi wires of succesive diameters have helped in aligning a crowded upper arch.

Fig. 1 The application of NiTinol archwires in clinical practice. Labial treatment - Clinical case –initial situation(a), start of treatment(b), treatment in progress(c).

Unlike the classic materials, the intelligent materials have physical and mechanical characteristics which can be modified via metallurgical factors, respectively through the design of the tensioning device, being explicitly included in the primary mathematical models which describe the materials mentioned [10, 11, 12, 13, 14, 15].

The shape memory alloys, such as the Ni-Ti alloys, have the characteristic of superelasticity which is around significant higher than that of stainless steel. Superelasticity refers to an unusual characteristic of certain metals of resisting to a high plastic deformation. The high elasticity of these alloys is a very important advantage, but for underlining the value of the Ni-Ti alloys for the medical industry, the advantages are the following: biocompatibility, torsional strength, stress constancy, physiological compatibility, shape memory, dynamic interference, and wear resistance hysteresis. A high variety of products is now available on the market, using this particular design feature.

A thermoelastic martensitic phase transformation in the material is responsible for its extraordinary properties. These properties include the shape memory effect, superelasticity, and high damping capability. The properties of Nitinol can be modified to a great extent by changes in alloy composition, mechanical working, and heat treatment. In most cases a trial and error process is required to optimize these factors for a particular application[16, 17, 18, 19, 20, 21, 22].

On the other hand, the pseudoelastic response of NiTi wires has been exploited in orthodontics in recent years to provide a constant physiological force in the correction of malocclusions . The force developed by NiTi wires remains constant on condition, however, that the oral cavity temperature is constant. Since the intraoral temperature can be modified during eating or drinking hot or cold food/liquids , modifications in the pseudoelastic reversion force acting on the teeth are expected during therapy. It seems clear that correct orthodontic therapy cannot be achieved without full knowledge of the evolution of the superelastic force during therapy.

The superelastic effect is a remarkable orthodontic feature that is characterized by the presence on a stress-strain diagram of a horizontal plateau upon unloading.

The objective of this paper was the comparative describe the defining mechanical characteristics for the use of four wires with rectangular section made of Ni-Ti based material, provided by different suppliers. This property is because an initial austenitic structure incorporates stress-induced martensite at a temperature greater than austenite finish. Superelasticity allows the archwires to exert a constant force or moment on a large range of deactivation.

In orthodontic treatment, we currently use round and rectangular section wires. Their use have been shown efficient in order to transmit the mechanical load to the teeth[23, 24, 25, 26, 27].

Based on the set it is envisaged sending requests to the elements dedicated orthodontic work, tensile, compression or bending, which requires a personalized concept of anchoring systems for treatment[28, 29, 30, 31, 32].

The evaluation of the mechanical properties may be ascertained either by cantilever testsor three-point bending. Three-point bending tests offer reproducibility, which has facilitated comparison between studies. However, none of these methods simulate the clinical situation. In spite of many attempts, the ideal test cannot be performed, since the clinical efficiency depends not only on force systems and surface related variables, but also the delivery of the force and the functional environment into which the wire is inserted. It has been suggested that the most appropriate wire test may be that which reproduces conditions encountered clinically, where the wire is constrained as part of a fixed appliance. It is demonstrated significant differences between the three-point bending test and the three-bracket bending mode, and similar findings[33, 34, 35, 36] .

The physical properties of the new thermodynamic NiTi wires have made it possible to insert larger guage rectangular wires during the initial phases of orthodontic treatment in order to gain three-dimensional control of tooth movement. Although many studies have focused on the evaluation of NiTi wires, large guage rectangular wires have not yet been submitted to any laboratory tests, leaving clinicians to rely only on the manufacturer's information.

The biomechanical characteristics on NiTi wires are still not enough previously studied. The large variety of producers and of products existing on the market makes the clinical selection of the wires very difficult[37]. Elasticity is the most apparent of the advantages afforded by this material, but by no means the only or most important. Because of their unique physical characteristics, these materials are finding increasing application where resiliency, conformation, and actuation are needed. Nitinol, the most frequently manufactured shape memory alloy, responds to thermal and mechanical stimuli with remarkable mechanical properties such as shape memory effect, super-elasticity, and high damping capacity.

Above its transformation temperature, Nitinol displays superelastic behavior. This is due to martensite forming in areas that are stressed, even though the temperature is above where martensite normally occurs. Then, when the stress is removed this martensite returns to the undeformed austenitic state.

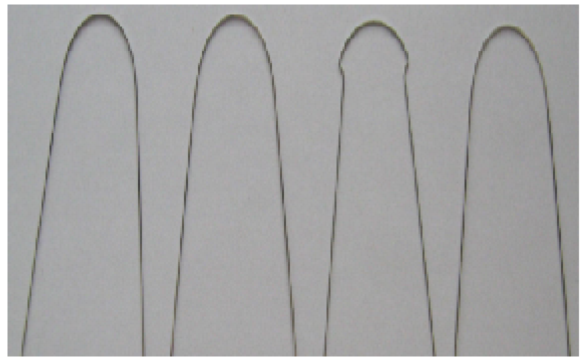
Based on the previous information, we are focusing on the Ni-Ti wires that are used in the initial alignement phase during orthodontic treatment. Most research studies of the fatigue properties of Nitinol have focussed on either stress-controlled or strain-controlled conditions.

Our experimental program conducted focused on short-and long-term behavior of the NiTi wires, noting in particular the mechanical characteristics of elasticity.

II. Material and Method

The experimental program included four similar wires with an arch configuration, provided by established manufacturers(figure 1):

1. G&H Wire Company,
2. G&H Wire Company,
3. Gestanco,
4. Leone.



1 2 3 4

Fig. 2 The aspect of the wires used as samples.

These are part of the group of orthodontic materials having shape memory function. The wire section was of 0.41 x 0.56 mm. The modulus of resistance, according to different bending stresses corresponding to the 0.56 mm side is of 0.006 mm^4, respectively for the 0.41 mm side is of 0.003 mm^4. The mentioned values shall have effects upon the behaviour of the samples to bending.

The experimental program included the following:

a. Traction test,
b. Determining the elasticity:
- The closing of the arch with wire undergoing a height stress with 0.56 mm side,
- The twisting of the arch with wire undergoing a height stress with 0.41 mm side,
- The bending of the linear section with wire undergoing a height stress with 0.56 mm side,
- The bending of the linear section with wire undergoing a height stress with 0.41 mm side,
- Long lasting bending stress,

c. Alternating bending test,
d. Determining the hardness.

The experiments had as reference the provisions in the American Dental Association specification number 32.

Regarding the traction test, the standard SR EN 10002-1/2002 was employed, respectively for the alternating bending test, the standard SR ISO 7801:1993 was used [38, 39, 40].

The equipment for the traction test had the capacity of 1000 N (figure 3)

In order to determine the elasticity, a direct load with standard weights and the electronic measurement of deformations were employed. The results of the experiments were statistically processed in order to emphasize the average values, the amplitude (R) and the mean square deviation (S).

Fig. 3 Equipment for the traction test.

III. RESULTS AND DISCUSSIONS

A. The results of the traction tests have led to the results in table 1.

Table 1. The results of the traction tests

Run no.	Sam-ple	Alternating ben-ding / no. of cycles		HV hardness 0.05		
		Late-rally	Regarding height	HV med	R	S
1	1	3.0	1.5	191.7	60.8	22.1
2	2	3.5	2.0	217.3	28.1	11.2
3	3	3.5	2.0	177.3	14.3	5.7
4	4	2.5	2.0	213.0	19.5	7.2

The group of samples 1 had a traction strength approx. 26% lower than the one of other groups of samples.

The individual values were within the range of the deviations of maximum 14.09 /N/mm^2 around the average value, while the mean square deviation was within the range 4.0 – 5.5. A low breaking strain is noticed. In exchange, the amplitude of the deformations has reached for sample 2 the level of 12.2% of the average value. The mean square deviation has presented low values. The aspect of the breaking sections is typical for the tensile stresses of the metal wires having rectangular section (figure 4).

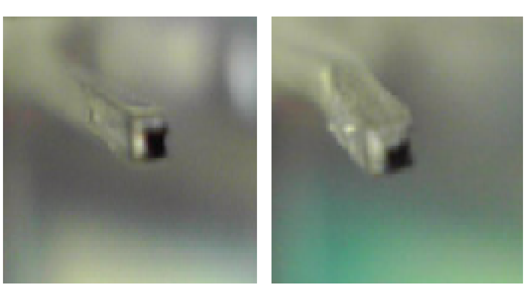


Fig. 4 The aspect of the traction breaking areas. - samples 1, 2.

Fig. 5 The aspect of the traction breaking areas-samples 3, 4.

B. Under the strain circumstances of the analyzed wires, the elasticity characteristic is extremely important. This is the reason measurements were carried out regarding the following:

a) The bending stress, in the first variant, targeted the closing of the arch which were in their delivery state. The samples were embedded on a linear wing and the load was applied on the end of the free wing together with the curved section in order to transfer the stress onto the plane with the 0.56 mm quota (figure 5).

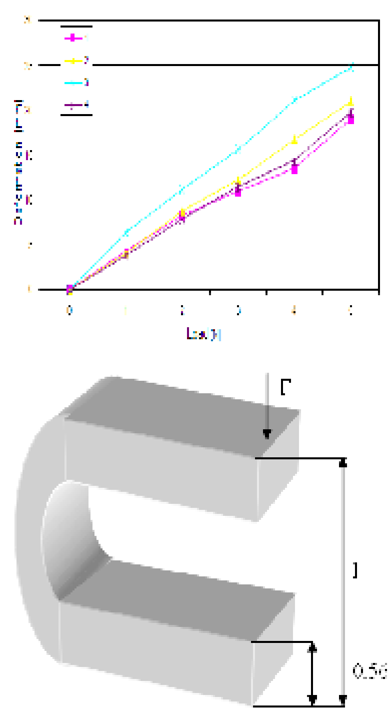


Fig. 6. The correlation with the load of the deformation upon the closing of the arch. F – load, l – deformation.

The graphical representation emphasizes for the four groups of samples almost linear dependencies between the deformation induced by the load. Regarding sample no. 3, an approx. 16% higher elasticity is noticed at the maximum stress in comparison to the behaviour of the other samples. The situation is according to the geometrical form of the arch which ensures a constructive elasticity higher than that of the other samples.

b) The torsion stress of the arches in their delivery state with the embedment of one wing and the stress applied to the free wing, together with the curved section in order to transfer the stress onto the plane with a 0.41 mm quota (figure 6).

In comparison to the previous situation, considerably higher values of the deformations can be noticed. The situation is normal, taking into account the fact that the bending reaches around the axis a quota of 0.41 mm. It is noticed that samples no. 1 have a significantly higher deformation capacity, especially for loads exceeding 0.02 N. For the other samples, a similar behaviour can be noticed. The samples undergoing testing did not experience any registrable plastic deformations after removing the stress.

c) Bending stress of the straight wires with the embedment and the stress on the vertical side of 0.56 mm (figure 7).

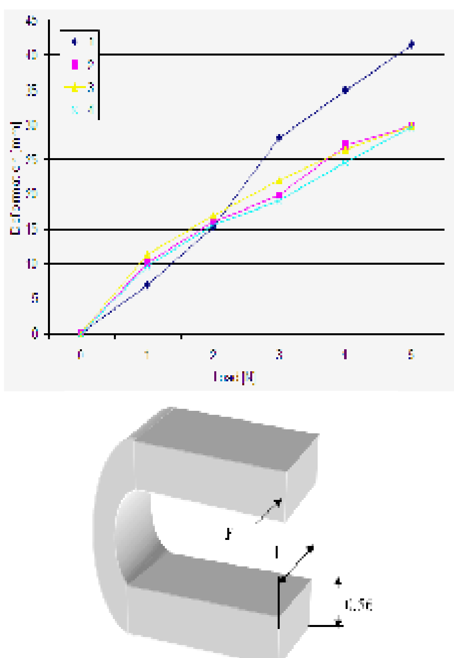


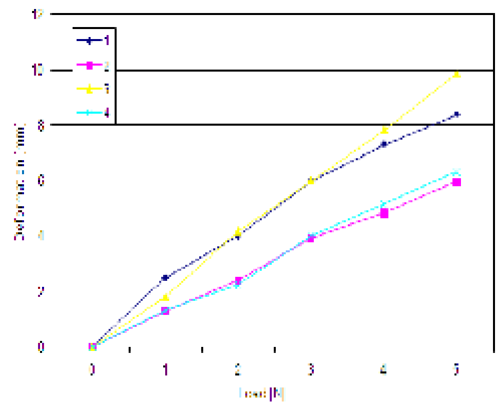
Fig. 7. The correlation with the load of the deformation upon the twisting of the arch. F – load, l – deformation.

The results emphasize the noticeable differences between the analyzed samples. The 3rd sample under the 0.05 load presented an approx. 33% higher elasticity in comparison to sample 1, respectively a double elasticity in comparison to the deformation of sample 2.

d) Bending stress of the straight wires with the embedment and the stress on the vertical side of 0.41 mm (figure 8).

The order of the deformation values remains similar to the previous stress case. The 3rd sample under the 0.05 N load presented approx. 25% higher deformations in comparison to the 1st sample which proved to be the closest regarding its behaviour. Samples no. 1, 2, 4 had a behaviour within limitations under 2 mm, within the loading range.

At induced stresses, what should be taken into account is the close linearity dependency between the deformation and the load, fact which emphasizes the high elasticity of the samples.



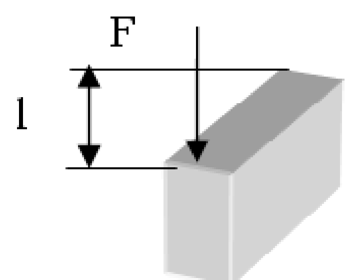


Figure 8. The correlation with the load of the bending deformation of the wire with a vertical side of 0.56 mm. F – load, l – deformation.

e) The long term bending stress took place by embedding the wires at one end and the application on the free end of the acknowledging stress of 0.075 N during a 240 hour period. The stress was carried out on the vertical side of 0.56 mm. The bending moment reached 4.125 Nmm.

For sample 2, during the first 4 hours of strain a deformation speed of 0.015 mm/hour was registered, which gradually decreased by balancing the tensioning state. At the end of the 240 hour period, an additional deformation of 0.83 mm was recorded in comparison the initial one.

For sample 1, values of the initial deformation speed were recorded, respectively of the final deformation under load which were higher than the previous ones by approx. 15%.

The results of the samples 3 and 4 were between the values of the samples 2 and 1.

C. The alternating bending test was carried out in order to determine the deformation capacity around the tap with a radius of 1.5 mm. A stress cycle was considered for 360^0 (Table 2). The deformation was carried out by supporting the 0.56 mm side (laterally), respectively of the 0.41 mm side (along its height). In this way, a ratio of 3.66, respectively 2.67 has been established between the thickness of the material and the diameter of the supporting tap.

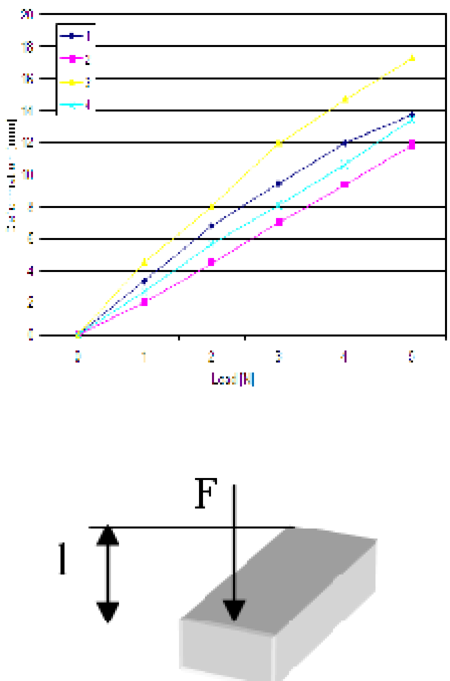


Figure 9. The correlation with the load of the bending deformation of the wire with a vertical side of 0.41 mm. F – load, l – deformation.

Table 2. The results of the alternating bending and hardness tests.

Run. no.	Sample	Alternating bending / no. of cycles		HV0,05 hardness		
		Laterally	Regar-ding height	HV med	R	S
1	1	3.0	1.5	191.7	60.8	22.1
2	2	3.5	2.0	217.3	28.1	11.2
3	3	3.5	2.0	177.3	14.3	5.7
4	4	2.5	2.0	213.0	19.5	7.2

The lowest sensitivity to deformation upon the sides of the sample profile was emphasized by sample 4. Even if sample 1 broke after 3 double cycles of bending along the 0.56 mm side, increasing the deformation degree upon bending along the 0.41 mm side, the duration was reduced to 1.5 cycles.

D. Determining the HV hardness 0.05 pointed out different values between the samples analyzed within a range of approx. 22%. For sample 1, what should be taken into account is the high amplitude of the results, supported also by the mean square deviation reaching 22.1. By reviewing the traction behaviour, lower values of the breaking strength and of the elongation in comparison to the other samples analyzed are noticed. The correlation of the results may point out certain structural heterogeneous aspects of the material.

Sample 3 stands out through the lowest values of hardness, and the values of the amplitude and the mean square deviation are the lowest.

IV. Conclusions

a. The NiTi wires, adopted as intelligent materials, have physical and mechanical characteristics which can be modified though metallurgical factors, respectively through the design of the tensioning device.

b. The experimental program targeted the comparative analysis between mechanical tests, between wires configured by manufacturers for specific orthodontic purposes.

c. The experiments have pointed out differences concerning the breaking strength in traction, alternating bending, and hardness.

d. Restrictions regarding the shaping and the reconfiguration of wires regarding the radiuses of curvature are emphasized, because the early breaking of wire can take place under the circumstances of a reduced deformation capacity.

e. At the request of bending of short and long term elastic behavior was highlighted particularly favorable for wires analyzed.

f. The homogeneity of the mechanical characteristics should be high; it can be ensured via the improved and strictly monitored mechanical and heat processing.

g. The best use it is when to obtain the final configuration of the elements prescribed orthodontic appliances, the radii of curvature, because due to small radii may cause premature rupture of the wire.

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Dr.Camelia Szuhanek was born in Timisoara, Romania, on 25th of November 1975. She is a specialist in Orthodontics and Dentofacial Orthopedics and received her DDS, MSc and PhD degrees at the Faculty of Dental Medicine, University of Medicine and Pharmacy "Victor Babes" Timisoara. She is currently an Assistant Professor at the Department of Orthodontics and the director of a research project on orthodontic biomechanics at the University of Medicine and Pharmacy "Victor Babes" Timisoara. She published over 140 articles in the field of orthodontics. Dr.Szuhanek maintains a private practice limited to orthodontics in Timisoara, Romania. Her main research interests are biomechanics, numerical analysis, lingual orthodontics, multidisciplinary treatment and skeletal anchorage.

e-mail: camelia_fleser@yahoo.com

Prof.Dr. Eng. Traian Fleser is a Professor at the Politechnica University of Timisoara, Faculty of Mechanics. He graduated the Faculty of Mechanics, Politechnica University of Timisoara, Romania, in 1970. He received his PhD in Mechanical Engineering in 1981. Prof Fleser has published 28 books and more than 170 articles in the field of mechanical engineering and has directed more than 20 national and international research projects. He is a law technical expert and consultant in the field of mechanical systems.

e-mail : trfleser @ mec.upt.ro, trfleser@yahoo.com