Mechanical Behavior of Orthodontic TMA Wires

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Abstract. Titanium based alloys are recently gaining increased popularity in orthodontic treatment. Unlike the classic materials, these intelligent materials have physical and mechanical characteristics which can be modified via metallurgical factors. 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. TMA materials fall into this category.
The research program is focused on four different TMA wire to highlight the characteristics of strength, elasticity and hardness.

Key-Words: TMA orthodontic wires, mechanical caracteristics, orthodontics, biomechanics.

1 Introduction

Over the past years, recent developments in mechanotherapy and biomechanics have led to important breakthroughs in orthodontic treatments.New devices and materials were introduced, in order to improve the clinical success.

Beta titanium alloys have received increased attention in aerospacial and chemical processing industry. The Beta Titanium(TMA) alloy was firstly introduced by Charles Burstone in the 1980's. TMA® is a stabilized titanium alloy in the beta phase composed of titanium (79%), molybdenum (11%), zirconium (6%), and tin (4%). This alloy presents lower modulus of elasticity, springback greater than that of steel, and a combination of adequate shape memory, medium stiffness, good formability, weldability and high attrition. It offers a good combination between stiffness and elasticity, which provide good characteristics for finishing stage in orthodontic treatment.

In orthodontics, the force developed by a deformed wire is transmitted to the teeth through fixed appliances (e.g. brackets, molar bands, and tubes) and tooth movements are achieved(Fig. 1).

Therefore, the load generated by orthodontic wires is of importance in designing an appropriate treatment plan. Ever increasing demands on performance in orthodontics have led the development of appropriate materials The TMA materials fall within this category. They are frequently provided in the form of wire.

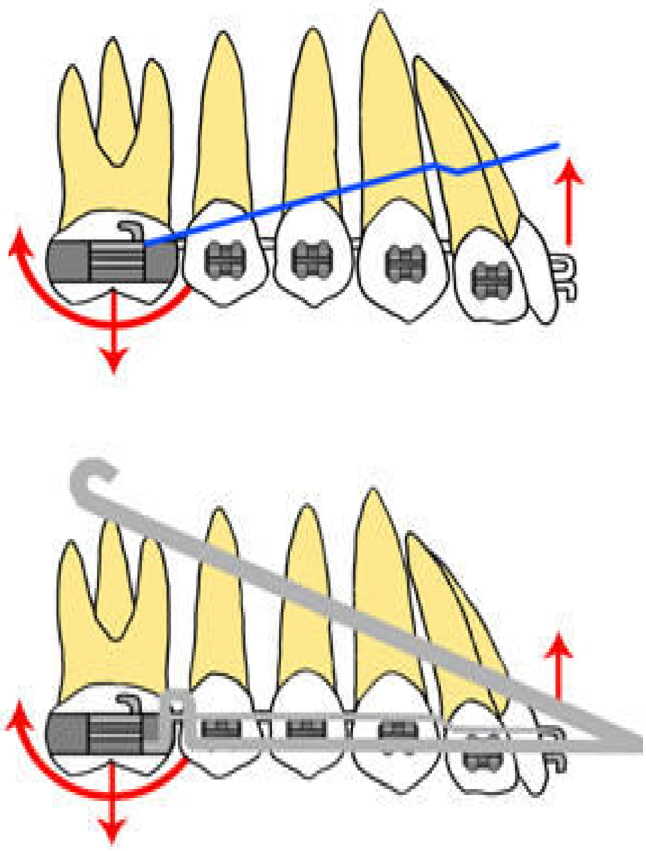


Fig. 1. The use of TMA intrusion archwires.

The respective alloys are employed in two different structural states through the contents of martensite, of austenite, respectively, resulted from heat processing. The structural state is correlated to the functional scope. The TMA alloys are recognized as "intelligent materials" because they are able to preserve certain geometric configurations, including mechanical features important for use. Special advantages regarding the enhanced biocompatibility, superelasticity, the effect of the shape memory, resistance against corrosion and wear, etc., leads to very favourable functional and aesthetic effects [1, 2].

A special feature is the ability to induce structural changes in areas suitable for use. The "smart 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 [3,4,5]. In this conditions, the TMA alloys, have the characteristic of superelasticity which is around 20 times higher than that of stainless steel, which recommends them in the design of various performance medical products.

Regarding citotoxicity, histopathological analysis of the positive control and the used Nitinol® and TMA® wires showed necrosis and apoptosis. The multiple end-point analysis with comparison between the different used wires revealed that stainless steel induced less toxicity/loss of viability compared with Nitinol® and TMA®[9-14].

Superelasticity refers to an unusual characteristic of certain metals of resisting to a high plastic deformation. The value of the TMA 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.

During orthodontic treatment, archwires play an important role because they provide the force systems necessary for tooth movement. Once a wire is engaged into the bracket/band, it exerts forces on the tooth. The forces transmitted to a tooth by an arch wire depend on several parameters of the arch wire used and the relationship between the brackets in which the wire is engaged [25-35].

During fixed orthodontic treatment, TMA wires are used in order to achieve final settling of the dental occlusion. It can be used in rectangular or round section, depending on the desired clinical result.

The mechanical force system produced depends on the appliance design and the mechanical and physical properties of the wire used. A variety of factors should be considered in the selection of a wire during a particular phase of the treatment, including the amount of force desired, the elastic range, formability, and ease of soldering or welding.The load due to buckling depends on material composition, wire length, the amount of activation, temperature, and deformation rate. The results can be considered as the lower bound for the loads experienced by teeth as far as a buckled wire is concerned[35-42].

At a temperature higher than the austenite finish transition temperature, superelastic wires were strongly dependent on temperature and deformation rate. The effect due to an increase of deformation rate was similar to that of a decrease of temperature. Load variations due to temperature of a superelastic wire with a length of 20 mm were estimated to be approximately 4 g/°C. The high performance of an applied superelastic wire may be related to the high dynamics of the load in relation to temperature. In order to exemplify the use of TMA o orthodontic wires, a clinical situation is shown in figure 2.

TMA develops a higher force than NiTi and CuNiTi wires but this force drops to zero during unloading following a steep slope[9].

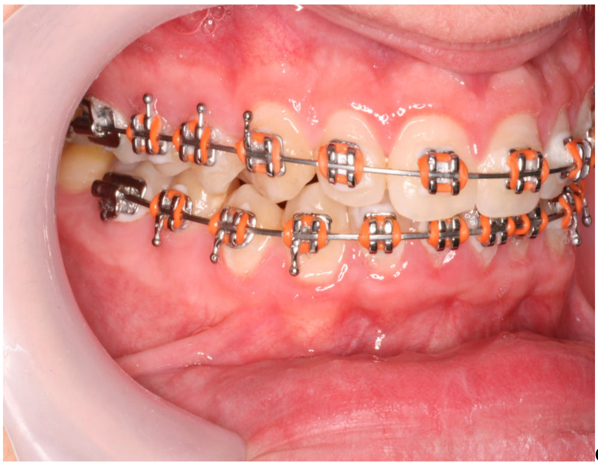
At 37°C and upon unloading, the superelastic feature of NiTi and CuNiTi is manifested through a fairly constant value of the load over a wide range of deformation. For superelastic wires, the load due to buckling decreases as the wire length or the amount of activation is increased.

The mechanical characteristics of orthodontic archwires are very important in achieving clinical succes. The forces developed by orhodontic archwires should be kept at minimal levels in oder to preserve the periodontal health and to avoid the unwanted secondary effects. The forces developed by TMA archwires are depended on many factors, including size, diameter and shape. In adult patients, the size of TMA wires are always chosen in smaller diameters, especially in those with periodontal problems and alveolar loss.

The objective of this study was the comparative description of defining mechanical characteristics for the use of four wires with rectangular section (0,41x0,56 mm) made of TMA based material, provided by different suppliers[42-46].

a)

b)


c)

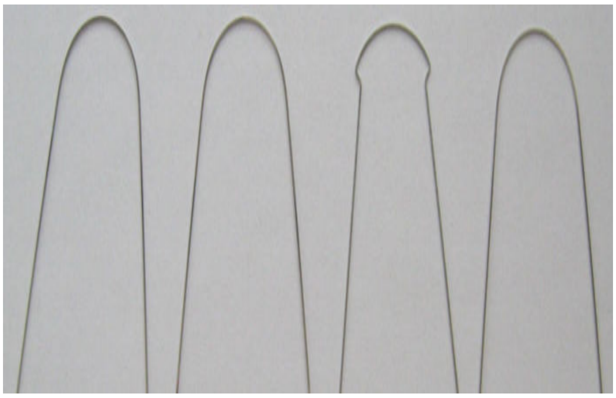

d)


e)

Fig.2. A 19 years old young man with a clasII/1 malocclusion(a). After aligning the teeth with NiTi wires(b), TMA wires were used(c) in order to achieve final settling. d-final result.

2 Material and method

General scheme of the experimental program has been used by authors to investigate and other orthodontic materials. In this experimental program were included four similar wires with an arch configuration, provided by established manufacturers(Fig. 3): 3M (1), G&M (2), Lancer Ormco (3), A Company (4).



1 2 3 4

Fig. 3. 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[8]. 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 [6, 7]. The equipment for the traction test had the capacity of 1000 N (Fig. 4)[6, 7, 8].

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. 4. Equipment for the traction test.

3 Results and discussions

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

The group of samples 1 had a traction strength approx. 18% lower than the one of other groups of samples.

The individual values were within the range of the deviations of maximum 11,19 /N/mm^2 (0,94%) around the average value. The mean square deviation was within the range 3,8 – 5.3. From this perspective, the results within each marker, can be considered homogeneous.

Table 1. The results of the traction tests.

Run. no.	Sample	Breaking strength in traction*			Breaking elongation*		
		Rm /N/mm^2/	R /N/mm^2/	S	Am /%/	R /%/	S
1	1	1036.01	9.11	4.1	2.1	0.3	0.12
2	2	1224.84	10.01	3.8	3.7	0.4	0.14
3	3	1293.01	11.19	3.9	2.8	0.2	0.11
4	4	1230.03	10.09	5.3	2.0	0.2	0.11

* Rm – breaking strength in traction, Am – average breaking elongation, R - amplitude, S – mean square deviation

A low breaking strain is noticed. In exchange, the amplitude of the deformations has reached for sample 2 the level of 10,8% 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 (Fig. 5).

B.Under the strain circumstances of orthodontic wires analyzed, the elasticity of wires 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 (Fig. 6).

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

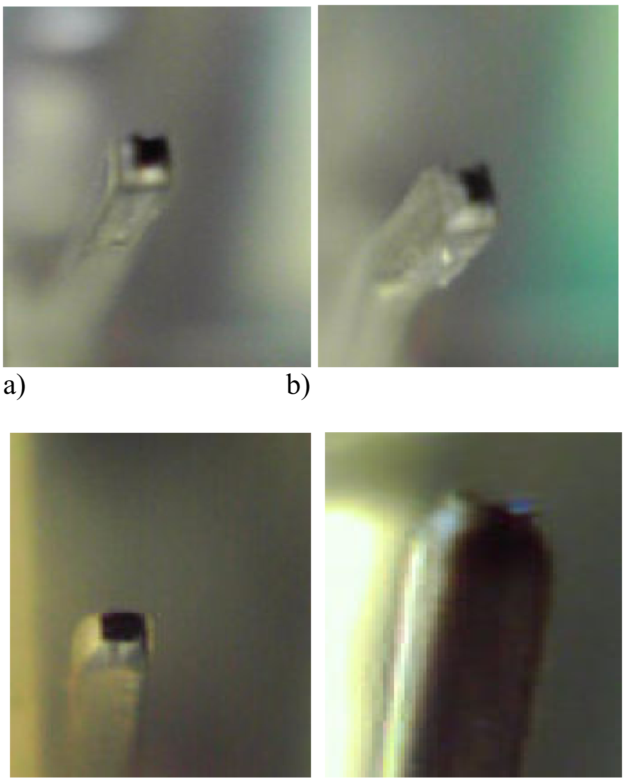


Fig. 5. The aspect of the traction breaking areas. a, b, c, d – samples 1, 2, 3, 4.

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 (Fig. 7).

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.

c) In comparison to the previous situation, 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 no diference significantly deformation capacity between samples. The samples undergoing testing did not experience any registrable plastic deformations after removing the stress.

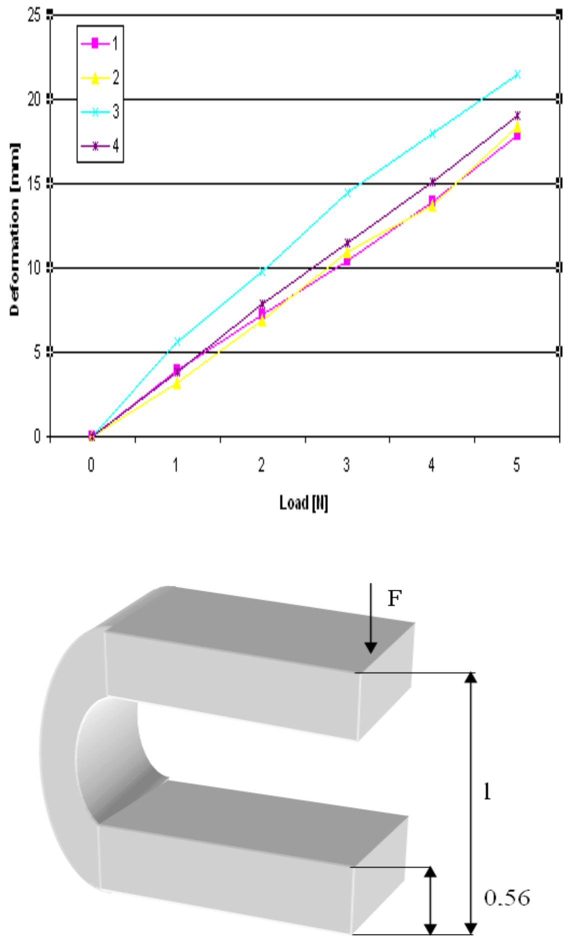


Fig. 6. The correlation with the load of the deformation upon the closing of the arch. F – load, l – deformation.

d) Bending stress of the straight wires with the embedment and the stress on the vertical side of 0.56 mm show Fig. 8. The results show 21% differences between 1 and 2 the analyzed samples.

e) Bending stress of the straight wires with the embedment and the stress on the vertical side of 0.41 mm show in figure 9.

The order of the deformation values remains similar to the previous stress case. The 3rd sample under the 0.05 N load presented approx. 52% higher deformations in comparison to the 2nd sample which proved to be the closest regarding its behaviour. Samples no. 1 and 4 had a behaviour similar 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 1 and 2.

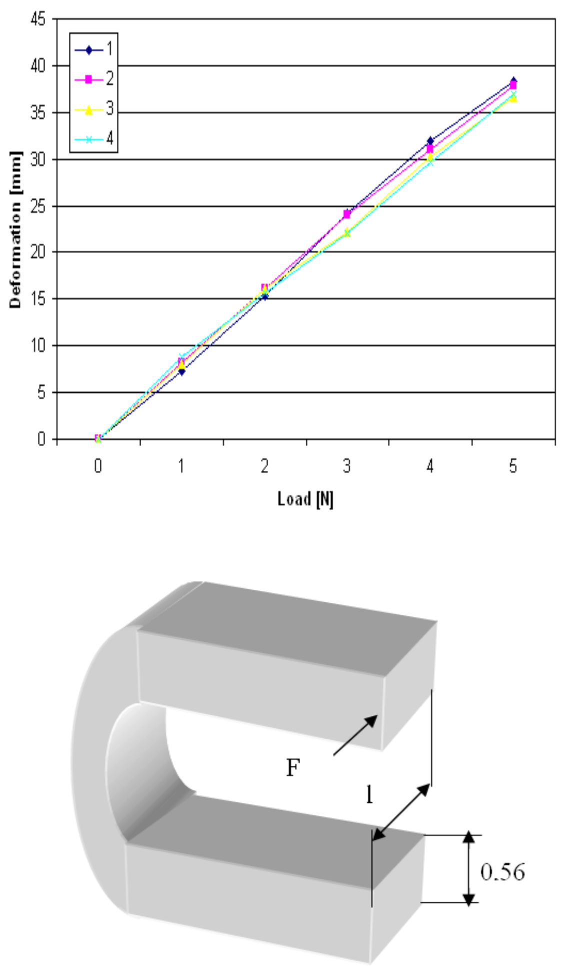


Fig. 7. The correlation with the load of the deformation upon the twisting of the arch. F – load, l – deformation.

f) 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 3, during the first 8 hours of strain a deformation speed of 0.026 mm/hour was registered, which gradually decreased by balancing the tensioning state. At the end of the 240 hour period, an additional deformation of 0.95 mm was recorded in comparison the initial one.

For sample 2, 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 1 and 4 were between the values of the samples 2 and 3. Be kept high

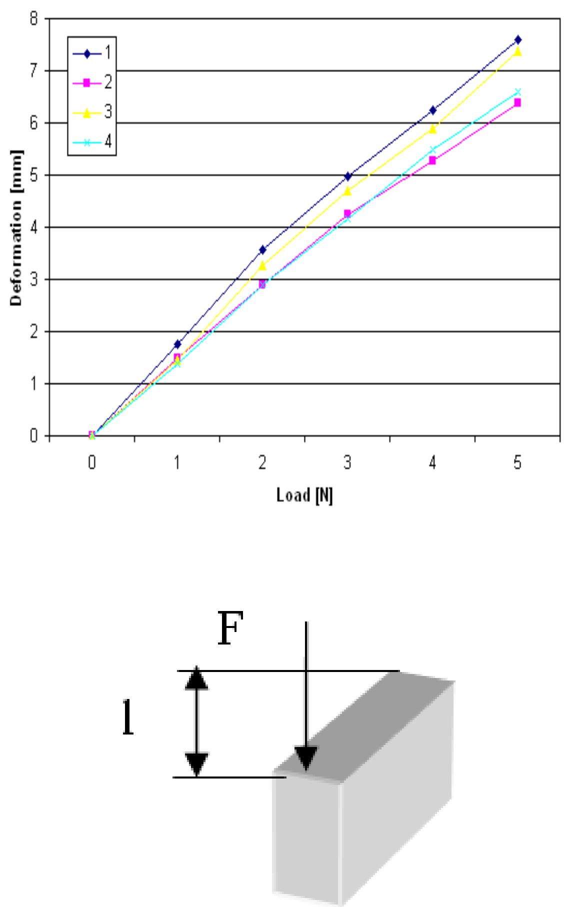
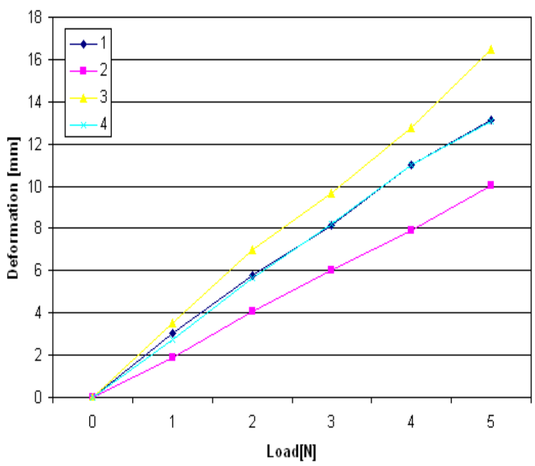


Fig. 8. The correlation with the load of the bending deformation of the wire with a vertical side of 0.56 mm. F – load, l – deformation.

linearity required bending wires. Orthodontic work is vital for this addiction.

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.



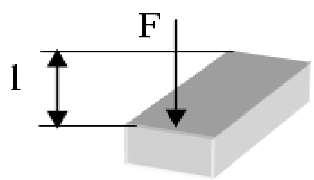


Fig. 9. The correlation with the load of the bending deformation of the wire with a vertical side of 0.41 mm. F – load, l – deformation.

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

Run. no.	Sam-ple	Alternating bending / no. of cycles		HV hardness 0.05		
		Late-rally	Regar-ding height	HV med	R	S
1	1	3.5	2.5	217.7	20.2	9.1
2	2	4.0	3.5	227.3	18.1	10.1
3	3	4.0	3.0	212.3	16.2	6.7
4	4	3.5	2.5	228.0	19.0	6.1

The lowest sensitivity to deformation upon the sides of the sample profile was emphasized by samples 1 and 4. Even if samples 2 and 3 broke after 4,0 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 - 1.5 cycles.

D. Determining the HV hardness 0.05 pointed out different values between the samples analyzed within a range 16,2 – 20,2HV0,05 (7 – 8 %). It can be considered as materials analyzed had high hardness homogeneous, which correlates with the state homogeneous structure. By reviewing the traction behaviour, lower values of the breaking strength and of the elongation in comparison to the hardness samples analyzed are noticed. The correlation of the results may point out certain structural heterogeneous aspects of the material, but are within normal limits.

At body temperature, the start force level on deactivation of NiTi wires is slightly higher than that of CuNiTi wires, thus suggesting that copper softens the alloy structure. The load due to buckling of superelastic wires is temperature and time dependent (i.e. strain rate dependent). The effect on the load due to an increase of deformation rate is similar to the effect due to a decrease of temperature. Load variation of superelastic wires due to temperature change in the oral environment may support the hypothesis that the high performance of superelastic wires is related to the high dynamics of these wires.

Loads measured through the simply supported condition and those measured through the fixed-end condition can be considered as a lower and upper bound for the load developed by a wire in a clinical setting.

Mechanical characteristics of orthodontic wires are important in order to achieve the desired treatment result.

Beta titanium alloys have great potential in orthodontic appliances design. Proper thermal treatment can modify strenght/elasticity ratio and can improve clinical therapeutical properties. Further investigation are required in order to evaluate the metallurgical, citotoxical and clinical aspects of these medical alloys.

4 Conclusions

a. Recent developments in orthodontics have presented newer archwire materials as well as improvements in the mechanical properties of existing ones. The selection and understanding of the biomechanical requirement of each case requires proper characterization studies on archwire alloys.

b.The shape memory materials TMA, adopted as intelligent materials, have physical and mechanical characteristics which can be modified though metallurgical factors, respectively through the design of the tensioning device.

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

d. Experiments have shown small differences in the tensile breaking strength, alternating bending, hardness.

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

f. It is important to obtain the first configuration of the elements prescribed orthodontic appliances, the radii of curvature, because due to low strain capacity may cause premature rupture of the wire.

g. Uniformity of mechanical properties proved to be high, provided by mechano-thermal processing optimized and severely monitorised.

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References:

[1] Pelton, A., R,.: Medical uses of nitinol. *Materials Science Forum, Stöckel D & Duerig TW*, 2000, P.327-328: 63-70.

[2] O'Leary, J., P., et al.: The Use of TMA in the Homer Mammalok, in Engineering Aspects of Shape Memory Alloys, *Duerig TW, et al. (eds), Boston, Butterworth-Heinemann,* 2005, p 477.

[3] Szuhanek, Camelia, Faur, N., Glavan, Florica, Cernescu, A., Fleser, T.: Numerical analysis of stress and strain distribution during orthodontic treatment with space closure. *Proc. Ninth International Conference New Trends in fatigue and fracture, Journal of the Society for Structural Integrity and Life,* Beograd, 2009, ISSN1451-3749.

[4] Szuhanek, Camelia, Faur, N., Glavan, Florica, Cernescu, A., Fleser, T.: Finite element analysis of stress and strain in orthodontic miniimplants. *Proc. Ninth International Conference New Trends in fatigue and fracture, Journal of the Society for Structural Integrity and Life, Beograd*, 2009, ISSN1451-3749.

[5] Szuhanek, Camelia, Faur, N., Florica, Glavan, Cicala, E., Fleser, T.: Numerical analysis of mechanical stress induced by orthodontic forces in root apex. In *UPT Scientific Bullettin, Mechanical Serie, fasc. 1, 2009*, p.63–67, ISSN 1224-6077.

[6] x x x SR EN 10002-1/2002 *Metal materials. Traction test. Part 1: Test method at air temperature*.

[7] x x x SR ISO 7801:1993 *Metal materials. Wire. Alternating bending test.*

[8] x x x ANSI/ADA No.32 – Orthodontic Wires.

[9] De Santis, R., Dolci, F., Laino, A., Martina, R. Ambrosio, L., Nicolais, L.: The Eulerian buckling test for orthodontic wires. *The European Journal of Orthodontics 2008 30(2):190-198.*

[10] Raboud, D., W., Faulkner, M., G., Lipsett, A., W.: Superelastic response of NiTi shape memory alloy wires for orthodontic applications. In. *Smart Materials and Structures* (2000) 9:684–692

[11] Rucker, B., K., Kusy, R., P.: Elastic properties of alternative versus single-stranded leveling archwires. In *American Journal of Orthodontics* and Dentofacial Orthopedics (2002) 122:528–541.

[12] Rudolph, D., J., Willes, P., M., G., Sameshima, G., T.: A finite element model of apical force distribution from orthodontic tooth movement. In *Angle Orthodontist (2001) 71:127–131.*

[13] Sakima, M., T., Dalstra, M., Melsen, B.: How does temperature influence the properties of rectangular nickel-titanium wires?In *European Journal of Orthodontics* (2006) 28:282–291.

[14] Thompson, S., A.: An overview of nickel-titanium alloys used in dentistry. In *International Endodontic Journal* (2000) 33:297–310.

[15] Krishnan, V., Kumar, K.,J.: Mechanical properties and surface characteristics of three archwire alloys. In: *Angle Orthodontist,* 2004, 74-825-831.

[16] Claro, C.,A., Abrão, J., Reis, S., A.: Forces in stainless steel, TiMolium and TMA intrusion arches, with different bending magnitudes. In *Braz Oral Res.* 2007Apr-Jun;21(2):140-5.

[17] Vande ,V., B., Mohebbian, N., Wehrbein, H.: Toxicity of used orthodontic archwires assessed by three-dimensional cell culture.In *Eur J Orthod.* 2006 Oct;28(5):426-32.

[18] Vijayalakshmi, R., D., Nagachandran, K., S., Kummi, P., Jayakumar, P.: A comparative evaluation of metallurgical properties of stainless steel and TMA archwires with

timolium and titanium niobium archwires--an in vitro study. In *Indian J Dent Res.* 2009 Oct-Dec;20(4):448-52.

[19]Tecco ,S., Di Iorio, D., Cordasco, G., Verrocchi, I., Festa, F.: An in vitro investigation of the influence of self-ligating brackets, low friction ligatures, and archwire on frictional resistance. In *Eur J. Orthod.* 2007 Aug;29(4):390-7.

[20] Camelia, Szuhanek, Florica, Glavan, Rodica, Jianu: Biomecanica ortodontica.(Orthodontic biomechanics), *Educational Horizons House Publishing ,* 2009, ISBN 978-973-638- 435-6.

[21] Goldberg, J., Burstone, G., J.: An Evaluation of Beta Titanium Alloys for Use in Orthodontic Appliances. In *J. DENT RES.* 1979, p. 58: 593

[22] Ong, E., McCallum, H., Griffin, M., P., Ho, C.: Efficiency of self-ligating vs conventionally ligated brackets during initial alignment. In *J Orthod Dentofacial Orthop.* 2010 Aug;138(2):138.e1-138.e7.

[23] Bolender, Y., Vernière, A., Rapin, C., Filleul, M., P.: Torsional superelasticity of NiTi archwires. In. *Angle Orthod.* 2010 Nov;80(6):1100-9.

[24] Lyotard, N., Hans, M., Nelson, S., Valiathan, M.: Short-term postorthodontic changes in the absence of retention. In. *Angle Orthod.* 2010 Nov;80(6):1045-50.

[25] Luppanapornlarp, S., Kajii, T., S., Surarit, R., Iida, J.: Interleukin-1{beta} levels, pain intensity, and tooth movement using two different magnitudes of continuous orthodontic force. *Eur J Orthod. 2010, Jun 9.*

[26] Fragou, S., Eliades, T.: Effect of topical fluoride application on titanium alloys: a review of effects and clinical implications. In. *Pediat. Dent.* 2010 Mar-Apr;32(2):99-105.

[27] Sung, S., J., Jang, G., W., Chun, Y., S., Moon, Y., S. : Effective en-masse retraction design with orthodontic mini-implant anchorage: a finite element analysis. In *Am. J Orthod Dentofacial Orthop.* 2010 May;137(5):648-57.

[28] Oda, S., Arai, K., Nakahara, R.: Commercially available archwire forms compared with normal dental arch forms in a Japanese population. In *Am. J Orthod Dentofacial Orthop*. 2010 Apr;137(4):520-7.

[29] Elayyan, F., Silikas, N., Bearn, D.: Mechanical properties of coated superelastic archwires in conventional and self-ligating orthodontic brackets. In *Am. J Orthod Dentofacial Orthop.* 2010 Feb;137(2):213-7.

[30] McNamara, C., Drage, K., J., Sandy, J., R., Ireland, A., J.: An evaluation of clinicians' choices when selecting archwires.In *Eur. J Orthod.* 2010 Feb;32(1):54-9. Epub 2009 Aug 14.

[31] Pandis, N., Polychronopoulou, A., Eliades, T.: Alleviation of mandibular anterior crowding with copper-nickel-titanium vs nickel-titanium wires: a double-blind randomized control trial. In *Am. J Orthod Dentofacial Orthop.* 2009 Aug;136(2):152.e1-7;discussion 152-3.

[32] Fourie, Z., Ozcan, M., Sandham, A.: Effect of dental arch convexity and type of archwire on frictional forces. In *Am. J Orthod Dentofacial Orthop.* 2009 Jul;136(1):14.e1-7; discussion 14-5.

[33] Keim, R.,G. : The intelligence of archwires. In *J Clin Orthod.* 2009 Mar;43(3):137-8.

[34] Riley M, Bearn D., R. : A systematic review of clinical trials of aligning archwires. In *J Orthod.* 2009 Mar;36(1):42-51; discussion 15.

[35] Sander, C., Roberts, W., E., Sander, F., G, Sander, F., M.: Reprogramming the memory of superelastic nickel titanium archwires. In *J Clin Orthod.* 2009 Feb;43(2):90-7

[36] Daems, J, Celis, J., P., Willems, G.: Morphological characterization of as-received and in vivo orthodontic stainless steel archwires.In *Eur. J Orthod.* 2009 Jun; 31(3):260-5. Epub 2009 Feb 2.

[37] Petoumeno, E., Kislyuk, M., Hoederath, H., Keilig, L., Bourauel, C., Jäger, A.: Corrosion susceptibility and nickel release of nickel titanium wires during clinical application.In *J Orofac Orthop.* 2008 Nov;69(6):411-23. Epub 2008 Nov 11.

[38] Berger, J., Waram, T.: Force levels of nickel titanium initial archwires. In *J Clin Orthod.* 2007 May;41(5):286-92.

[39] Pun, D., K., Berzins, D., W.: Corrosion behavior of shape memory, superelastic, and nonsuperelastic nickel-titanium-based orthodontic wires at various temperatures. In *Dent Mater.* 2008 Feb;24(2):221-7.

[40] Kobayashi, S., Ohgoe, Y., Ozeki, K., Hirakuri, K., Aoki, H.: Dissolution effect and cytotoxicity of diamond-like carbon coatings on orthodontic archwires. In *J Mater Sci Mater Med.* 2007 Dec;18(12):2263-8. Epub. 2007 Jun 12.

[41] Yeh, C., L., Kusnoto, B., Viana, G, Evans, C., A., Drummond, J., L.: In-vitro evaluation of frictional resistance between brackets with passive-ligation designs. In *Am. J Orthod Dentofacial Orthop.* 2007 Jun;131(6):704.e11-22.

[42] Knel, M., Attin, R., Kubein-Meesenburg, D., Sadat-Khonsari, R.: Cephalometric assessment of the axial inclination of upper and lower

incisors in relation to the third-order angle.In *J Orofac Orthop.* 2007 May;68(3):199-209.

[43] Kubo, A., Suzuki,T.: A mathematical ap proach to Othemer-Stevensmodel. In *WSEAS Transactionson Biology and Biomedicine,*Issue 1, 2,2005,45-50.

[44] Ciurescu, R., Barabas, S., Sangeorzan, L., Neica, L: Digital radiography using high dynamics range technique. Mathematical methods and applied computers.In *WSEAS Press,* Vol. II, PP 599-603, ISSN 1790-2769, ISBN 978-960-474-124-3.

[45] Galvanauskas, V., Simutis, R., Levišauskas, D.: Application of evolutionary computing for hybrid model based optimization of biochemical processes, In *WSEAS Transactions on Information Science and Applications*, Issue 5, Vol. 2, May 2005, p.p. 507- 511.

[46] Bill Taher, Said Abboudi: Analysis of the Thermal Damage on Homogenized Multi-Materials under Thermo-Mechanical Behavior. In *WSEAS Transactions on applied and theoretical mechanics,* Issue 1, Vol. 5, January 2010, p.p. 11-22.