Mechanical behavior of TMA orthodontic wires

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Abstract. Unlike the classic materials, the 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. Elasticity was analyzed for short durations, ie long wires request.

Key-words: TMA orthodontic wires, mechanical characteristics.

1 Introduction

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. 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. Are recognized as “smart 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. 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. The survey carried out had as its goal the collection, 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.

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. 1): 3M (1), Gi&M (2), Lancer Ormco (3), A Company (4).

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. 2).

![Fig. 2. Equipment for the traction test.](image)

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).

### 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>
<thead>
<tr>
<th>Running no.</th>
<th>Sample number</th>
<th>Breaking strength in traction* (Rm)</th>
<th>Breaking elongation* (Am)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1036.01 /N/mm$^2$</td>
<td>9.11 /N/mm$^2$</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1224.84 /N/mm$^2$</td>
<td>10.01 /N/mm$^2$</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1293.01 /N/mm$^2$</td>
<td>11.19 /N/mm$^2$</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1230.03 /N/mm$^2$</td>
<td>10.09 /N/mm$^2$</td>
</tr>
</tbody>
</table>

*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. 3).

![Fig. 3. The aspect of the traction breaking areas. a, b, c, d – samples 1, 2, 3, 4.](image)
with the curved section in order to transfer the stress onto the plane with the 0.56 mm quota (Fig. 4). 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 (Fig. 5).

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 difference significantly deformation capacity between samples. The samples undergoing testing did not experience any registrable plastic deformations after removing the stress.

d) Bending stress of the straight wires with the embedment and the stress on the vertical side of 0.56 mm show Fig. 6. The results show 21% differences between 1 and 2 the analyzed samples.

Fig. 4. The correlation with the load of the deformation upon the closing of the arch. F – load, l – deformation.

Fig. 5. The correlation with the load of the deformation upon the twisting of the arch. F – load, l – deformation.

Fig. 6. 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) Bending stress of the straight wires with the embedment and the stress on the vertical side of 0.41 mm show in figure 7.

![Fig. 7. The correlation with the load of the bending deformation of the wire with a vertical side of 0.41 mm. F – load, l – deformation.](image)

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.
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 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° (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.

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

<table>
<thead>
<tr>
<th>Running no.</th>
<th>Sample</th>
<th>Alternating bending / no. of cycles</th>
<th>HV hardness 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lateral Regarding height</td>
<td>HV med R S</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>3.5 2.5</td>
<td>217.7 20.2 9.1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4.0 3.5</td>
<td>227.3 18.1 10.1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4.0 3.0</td>
<td>212.3 16.2 6.7</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3.5 2.5</td>
<td>228.0 19.0 6.1</td>
</tr>
</tbody>
</table>

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.

**4. Conclusions**

1. 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.
2. The experimental program targeted the comparative analysis between mechanical tests, between wires configured by manufacturers for specific orthodontic purposes.
3. Experiments have shown small differences in the tensile breaking strength, alternating bending, hardness.
4. At the request of bending of short and long term elastic behavior was highlighted particularly favorable airmelor analyzed.
5. 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.
6. Uniformity of mechanical properties proved to be high, provided by mechano-thermal processing optimized and severely monitored.

References