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The Mechanical Behavior Variation of Nickel - Titanium Orthodontic Wires in Different Fluoride Mouthwash

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ABSTRACT

In this study, an orthodontic arch wire of Ni-Ti alloy made by Germany in four different mouthwashes contain fluoride was investigated in mechanical behavior. This research focused on the mechanical behavior changes in different mouthwashes. The Mouthwashes were chosen from most popular one in Iran including Oral-B, Gum, and Behsa Mouthwash. The wires after 3 month in touch with mouthwashes were studied and the result was presented. The result show that the lowest power to reshape the wire, is for the wire in Crest case (3). The maximum power assigns to wire in Behsa case (1). Also, the shortest treatment period is for wire in Behsa mouthwash case (1) with 0.087 Nm strain energy and the maximum duration of therapy is related to case (3) Crest mouthwash with 0.039 Nm. Moreover, the wires in Oral-b (0.095 Nm) has the lowest and Gum mouthwash (0.140 Nm) has the highest energy intake. The energy absorbed by the wires in Behsa and Crest is in the middle. Finally, it is proposed that patient could use all mouthwash but based on their condition, one product will be useful.

Key words: Mechanical behavior; nickel-titanium orthodontic wires; fluoride mouthwash.

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INTRODUCTION

Conventional orthodontic wires, so far were often made of stainless steel or Co-Cr alloy. But the use of NiTi orthodontic wires due to super elastic properties, allows the dentist to be able make continuous and slightly force to the patient's teeth and reduce the amount of inconvenience for the patient. In recent years, the Ni-Ti alloys, due to unique properties such as memory shape, super elastic behavior and good biocompatibility with body has been used ad bio-materials in various medical fields. These alloys are being used as orthodontic wires more than 20 years. Therefore, today the use of NiTi orthodontic wires is very popular in the field of dentistry, especially at the early stages of the treatment when malocclusion is high. It is noteworthy that Ni-Ti alloys as orthodontic wires, has a great environmental compatibility with the body. Since NiTi alloys contains about 55 percent of nickel, so it is possible that some patients suffer from sensitivity. By using super elastic Ni-Ti wires which have a reversible strain of 1-8 percent, a constant force could be applied to the teeth, and the period of the course of therapy will significantly reduce.

According to research conducted in Europe, 10 to 20 percent of women are allergic to nickel continent. That is why the corrosion behavior of the wires in artificial saliva and the speed of separation of nickel from Ni-Ti alloys and stainless steel were compared by different researchers. The results obtained by the researchers are different [1]. Some scientists believe that the speed of separation of nickel from Ni-Ti alloys and stainless steel in artificial saliva statically is the same. While some scientists have concluded that Ni-Ti orthodontic wires release lower nickel compared with the orthodontic wires made of stainless steel, some other scientists believe that NiTi orthodontic wires release more nickel. But what is clear is that in any case, the amount of released nickel is much less than allowed on the body [2]. This is because of protective layer of titanium oxide (TiO_2) in Ni-Ti alloys. The memory effect of NiTi alloys is due to the reversible thermoelastic Martensitic transformation in these alloys. The high temperature phase (austenite) with B2 crystal structure during cooling will be converted to the low temperature phase (martensite) with structure B19’ (monoclinic). During heating, the reverse transformation occurs from B19’ to B2. Initial and final temperature of Martensite formation during cooling will be presented as MS and Mf respectively. During the warm-up, initial temperature of formation of austenite is AS and the final temperature is Af. In the nickel-titanium binary alloys, the amount of Hysteresis in a sweep is approximately 20-30 °C [3]. The martensite could be obtained by stress on the memory alloy at a temperatures higher than as. This type of martensite which is made by stress is called Stress Induced Martensite or SIM.

Figure (1) shows the stress-strain diagram of a Ni-Ti shape memory alloy and a stainless steel. Both alloy elastic strain is about 0.5 percent. Whereas strain resiliency of Ni-Ti shape memory alloy is about 8 percent. In fact, memory effect strain of superplasticity in Ni-Ti alloys is ten times more than the strain of other alloys such as stainless steel [4]. When the tension of Ni-Ti alloys arrives to a certain level, considerable strain is created in the sample. This strain is caused by austenite to martensite phase transformation. If the stress is removed gradually, at lower stress value with the change in the reverse mode, which means the martensitic transformation under the influence of stress on the mother phase, the strain which the amount is beyond the elastic limit, will be completely restored. This type of behavior of shape memory alloy is called the effect of super elastic. In some of the memory shape alloys, reversible strain is 10 percent approximately [5].

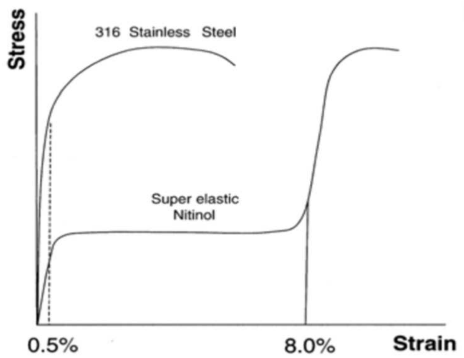

Figure 1: The comparison of elastic and super elastic behavior, or stress-strain diagram for a Ni-Ti shape memory alloy and a stainless steel

MATERIAL AND METHODS

In this study, an orthodontic arch wire of Ni-Ti alloy made by Trueform (Germany) in four different mouthwashes contain fluoride was investigated in mechanical behavior. The Trueform (Germany) orthodontic arch wire contained 50.7 percent Ni. But, this research focused on the behavior changes in different mouthwashes. The Mouthwashes were chosen from most popular one in Iran including: Case (1) Behsa Chlorhexidine Mouthwash; Case (2) Gum Sensitive Fluorinated Mouthwash; Case (3) Crest Pro-Health Complete Mouthwash; and Case (4) Oral-B Pro-Expert Professional Protection Mouthwash. Wires were in touch with mouthwashes for 3 month and after that the mechanical estimation were performed on it. Wire, at the temperature 850°C were under annealed solution for 30 minutes and quenching in water. To study the elastic behavior of wires in dental applications, tensile test was performed for each wire. Tensile testing was performed by an elasticity machine at room temperature (27°C). The length of samples is 70 mm and strain speed is 3×10^{-3} $mm.s^{-1}$. To determine the temperatures during heating and cooling in and the heat of transformation, the DSC colorimetric measurement has been used. For preparing the DSC samples, several 4mm examples have been taken from each wire. They have been put in a pan to perform DSC experiment. At first, the samples have been heated at temperatures up to 100°C. They are also kept for 3 minutes in this temperature to reach the equilibrium. By cooling the samples, measurement is performed up to temperatures of 100°C. Cooled sample is kept up to -100°C for 3 minutes to be reheated up to 100°C. Rapidly of heating the sample is 10°C min^{-1}.

Mechanical Test

In Figures (2) and (3) the stress-strain curves obtained from orthodontic arch wire without heat treatment and after thermal solution annealing have been presented. According to the curves in Figure (2), it is clear that despite the differences observed in the form of curves, all curves follow the same trend. So that all wires in a same step go into the upper Plateau Stress. At this stage, the stress on the wire does not increase with increasing the strain. While removing the stress, a sudden drop in stress can be seen at all wires and then it goes to lower Plateau Stress. Again at the end of unloading, stress-strain relationship is substantially linear. So that the stress close to zero and residual strain was not found in the samples. Therefore, all the 4 cases showed a super elastic treatment.

In the study of stress-strain curves of wires after solution annealing at 850°C for 30 min as Figure (3), it is observed that the said wire after annealed solution, do not show lower plateau stress and significant residual strain is observed in the samples. Considering that the goal of Ni-Ti orthodontic wires use is applying uniformed and permanent force to the teeth during treatment, this requires a plateau in stress-strain curve of the wires. The super elastic properties decreased during annealing solution. This is because of removal of cold performance on the wires after annealing solution operation. Mechanical behaviors of orthodontic wires in cases despite the similarities in the general trend are different with each other. Precise knowledge of the mechanical behavior of various cases of orthodontic wires, the analysis of this behavior and linking it with different application conditions is very important in planning to use super-elastic wire to shorten treatment duration and increase the efficiency of operation.

According to the curve of Figure (2), it can be seen that stress value of wire in upper and lower plateau region is different for orthodontic wires in different condition, and these values are shown in Table (1). As the amount of stress in upper plateau is less, needed stress to convert the austenite phase to the martensite phase under the effects of stress decreases. Thus, the required force to deform the wire will reduce. According to the data presented in Table (1) for stress of upper plateau in different cases, it is observed that the lowest power to reshape the wire, is for the wire of case (3) means Crest. The maximum power assigns to wire of case (1) Behsa. These values for wire case (2) and (4) are in the middle.

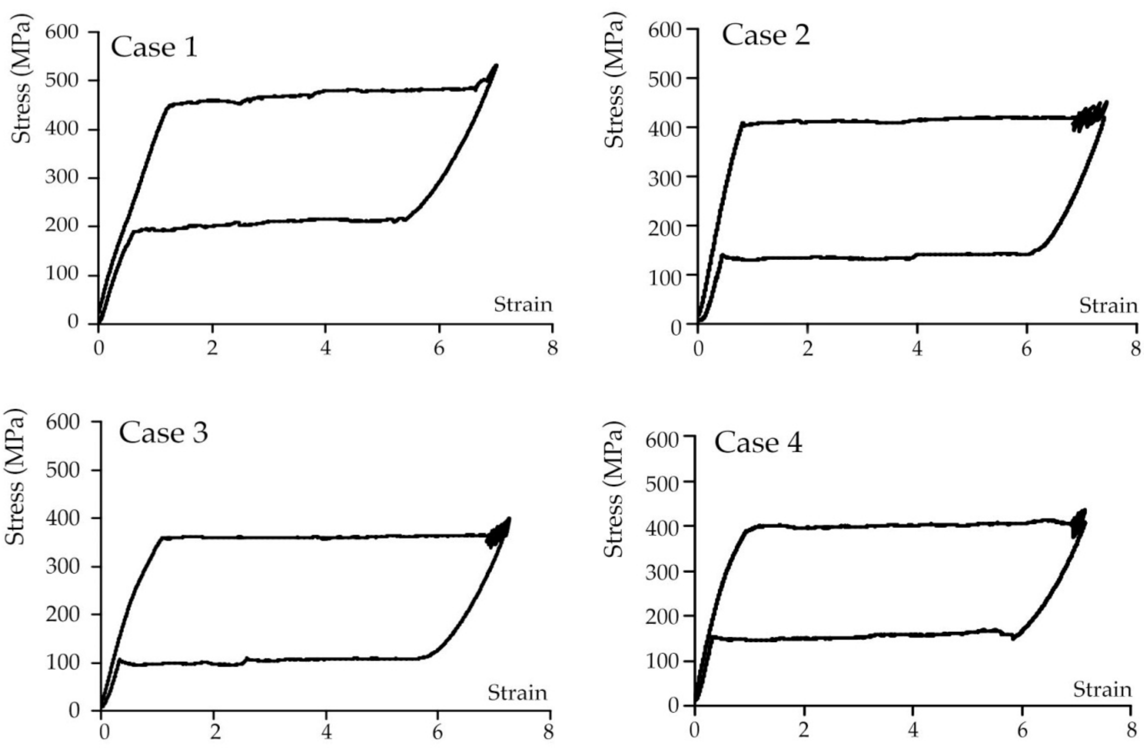

Figure 2: The stress-strain curves of orthodontic arch wire in four mouthwashes without heat treatment

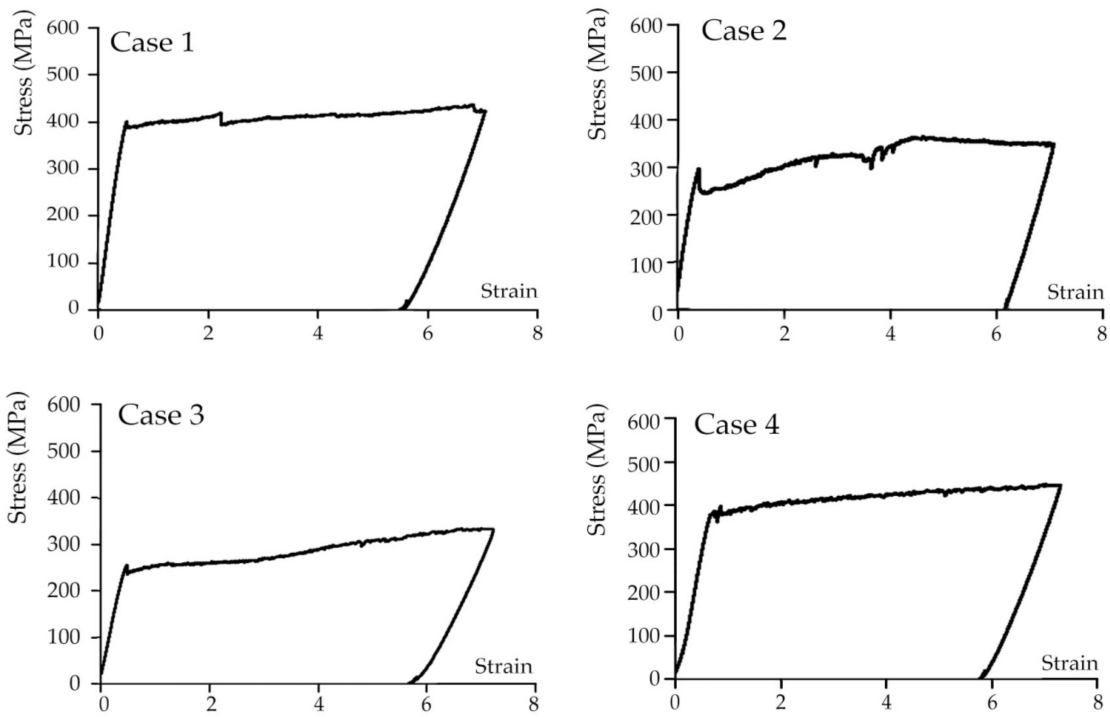

Figure 3: The stress-strain curves of orthodontic arch wire in four mouthwashes after heat treatment in 850 °C for 30 min

Table 1: The mount of mechanical parameters for orthodontic wires before and after thermal conditioning

Case No.	Mouthwash	Conditioning	Upper plateau	Lower plateau	Strain (Nm)	Energy (Nm)	Ms (°C)	AF (°C)
Case 1	Behsa Chlorhexidine	Before	468	210	0.087	0.105	31.8	30.9
Case 2	Gum Sensitive Fluorinated		409	133	0.046	0.140	63.1	23.1
Case 3	Crest Pro-Health Complete		360	104	0.039	0.115	59.2	33.5
Case 4	Oral-B Pro-Expert		401	152	0.067	0.095	63.4	19.1
Case 1	Behsa Chlorhexidine	After	412	-	-	0.190	27.5	1.44
Case 2	Gum Sensitive Fluorinated		327	-	-	0.150	15.3	13.4
Case 3	Crest Pro-Health Complete		280	-	-	0.180	15.3	21.2
Case 4	Oral-B Pro-Expert		417	-	-	0.190	23.8	3.7

Another difference in the stress-strain curves of different orthodontic wires cases can be the difference in the amount of elastic strain energy and the amount of energy stored in the wires. Elastic strain energy acts as a potential energy and encourages a reverse transformation (martensite to austenite). In other words, this energy is recovery agent of the strain that has been created. Therefore, as the amount of energy, that is equal to the area under the unloading curve, increases, the strain recovery is faster and length of the treatment period will decrease. The values for each four cases elastic strain energy is given in Table (1). According to the provided data, it is clear that the shortest treatment period is for wire in Behsa mouthwash case (1) with 0.087 Nm strain energy and the maximum duration of therapy is related to case (3) Crest mouthwash with 0.039 Nm. The wires in Gum and Oral-b are in the middle.

One of the properties of shape memory Ni-Ti alloy is high energy absorption. This feature is very important in applications that need high Damping Capacity. Amount of energy absorbed in theses alloys equal to inside the hysteresis in stress-strain curves. This feature of shape memory alloys does not have orthodontic applications and, if possible, the amount of energy absorbed by the wire should be the lowest amount. In Table (1), the amount of energy absorbed by all of mouthwashes is provided through the method of calculating inside the hysteresis of curves of stress-strain. According to the provided data, the wires in Oral-b (0.095 Nm) has the lowest and Gum mouthwash (0.140 Nm) has the highest energy intake. The energy absorbed by the wires in Behsa and Crest is in the middle.

Measuring DSC

DSC curves of orthodontic wires are shown in Figure (4). To investigate the effects of heat treatment of solution anneal on transition temperatures in orthodontic wires, DSC measurements were carried out on the same sample after annealing solution as Figure (5). According to DSC curves presented in Figure (4), it can be seen that orthodontic wires in both cooling and heating step, due to the advent of the R intermediate phase has shown the two-stage transformation. The happened transformation in the wire in Behsa case (1) has occurred in a single-stage during cooling. Wires that are under solution annealed during cooling and heating stages show single-stage transformation, as Figure (5).

The two-stage transformation in orthodontic wires is due to these wires that have been placed under thermo-mechanical treatment. After thermo-mechanical treatment, the rich deposits of Ni4Ti3 and NiT will be formed and they facilitate R intermediate phase that cause two-stage transformations [6].

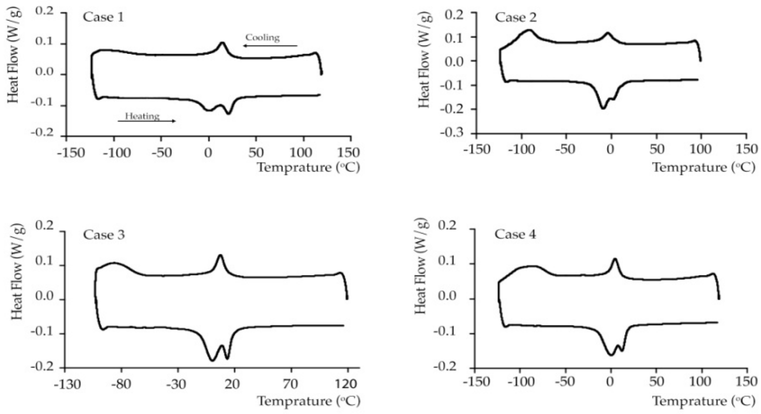

Figure 4: The DSC curves of orthodontic arch wire in four mouthwashes before heat treatment

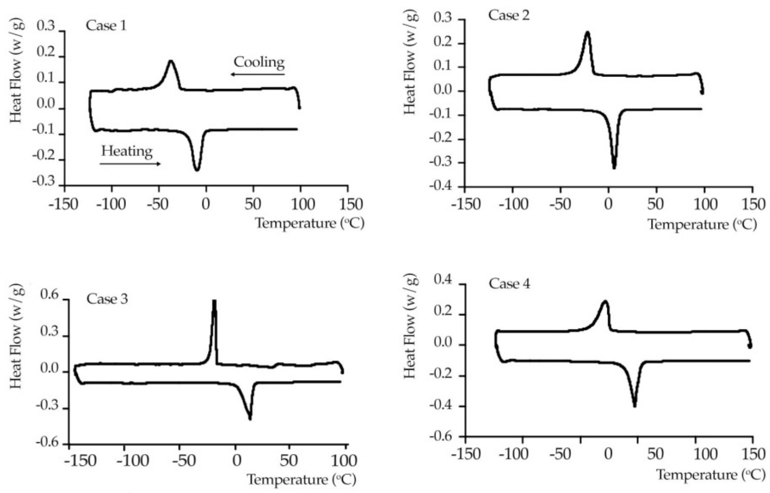

Figure 5: The DSC curves of orthodontic arch wire in four mouthwashes after heat treatment in 850 °C for 30 min

But in the wires that have been under annealed solution heating operation, rich deposits of Ni will dissolve and has no effect on the behavior of transformations. Thus, in this wire, two-stage transformation is not observed. Thermo-mechanical treatment carried out on the wires will cause rich deposits of Ni. This factor reduces the amount of Ni and increase temperatures of transformation [7]. As seen in Table (1), M_S, initial temperature of martensite formation and A_F temperature of completion of austenite, in orthodontic wires is higher due to the rich deposits of Ni, compared with the wires under the operation of annealed solution. In order to use the super-elastic properties of shape memory alloys efficiently, it is better that A_F of alloy be slightly lower than at the mouth.

If A_F of alloy is much lower than oral temperature, due to the more stability of high-temperature of austenite phase, martensite formation resulting from stress will require a lot of energy. By comparing the A_F temperatures in orthodontic wires before and after annealing in Table (1), it is observed that A_F of orthodontic wires without annealing heat operation is closer to oral temperature. The A_F temperatures of the annealed solution wires are different from the oral temperature. Thus, the lack of efficiency of annealed solution operation in terms of temperature of transformation is also justified.

While using Ni-Ti orthodontic wires, considering the differences between oral temperature and the temperature of the A_F of wire during the treatment is of great importance. That means, if the patient's teeth were too sloppy and it needs to apply great forces, the wires must be used that its A_F temperature is very different from the oral temperature. For example, wires in Oral-b mouthwash case (4). If the teeth need less force the wires should be used that their A_F is closer to oral temperature, for example wires in Behsa mouthwash case(1) or Crest mouthwash case(3) [8].

CONCLUSION

Solution annealing operation, because of eliminating the impact of cold work performed on wires, will reduce the super elastic properties. To improve performance of orthodontic wires, it is better to reduce the stress of upper plateau, and to increase the stress of lower plateau. It is also better that the inner surface of hysteresis be small. If the patient's teeth were too sloppy and it needs to apply great forces, the wires must be used that its A_F temperature is very different from the oral temperature. If the teeth need less force the wires should be used that their A_F is closer to oral temperature.

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