A COMPARATIVE STUDY OF THE SURFACE OF FACTORY AND HAND-MADE LOOPS ON TITANIUM-MOLYBDENUM ORTHODONTIC ARCHWIRE

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ABSTRACT

The most important part of the brackets, used in orthodontic treatment, is the archwire, which, when activated, generate light and long-lasting biomechanical forces that make the teeth move. Different manufacturers offer ready-made expensive solutions for orthodontists - archwire with loops along the length of the wire of different shape, which increases the cost of treatment. However, orthodontic practice is strictly individual, depending on the patient's orthodontic problems, the stages and methods of treatment.

Orthodontists often have to choose between expensive archwires with pre-made loops or using an archwire that they can manually bend in the right places depending on the patient's individual characteristics and specific needs. In this case, the orthodontist's decision depends on preserving the quality of the archwire surface.

The surface roughness of the orthodontic archwire plays an important role in the bracket-archwire complex and is an essential factor that determines the effectiveness of the guided movement of the teeth along the arch. Surface roughness not only affects the efficiency of sliding mechanics, due to frictional effects, but also corrosion behaviour and aesthetics.

A comparison of the surface characteristics of Ti-Mo archwire - with factory and hand-made loops is made. The surface of the archwire in the bending zones of the loops was investigated by SEM analysis and Surface roughness analysis.

The analysis of the results shows that manual bending practically does not change the surface of the archwire, does not introduce additional defects that increase the contact friction, as well as create conditions for faster deterioration of properties and the undesirable breakage of the archwire. Research results give orthodontists confidence that the manual bending process does not degrade the quality of the archwire surface. The hand-bent archwire preserves the possibility of trouble-free movement in the braces when tightening or loosening during the different stages of treatment.

Keywords: *Ti-Mo archwire, mushroom loops, hand-made loops, surface characteristics, SEM analysis, surface roughness analysis.*

INTRODUCTION

Improving people's quality of life and their quest for better vision has led to a serious attitude towards their dental health. Orthodontic treatment occupies an essential place in dental practice. Many people undergo various orthodontic solutions to achieve a more beautiful smile and better chewing power. One such solution is the placement of dental brackets, through which adjustment, alignment, straightening of the teeth to their correct location (positioning) in the patient's oral cavity, correction of the bite and various other deficiencies of the teeth and jaw are achieved. In this case, the good aesthetic result is combined with a healthy human result.

Traditional dental brackets are made of a metal alloy that is biocompatible and has certain properties such as biostability, formability, elasticity [1]. The bracket-archwire complex includes bracket that are attached to the front of the patient's teeth and the most important part - flexible wires or archwires that connect and hold the brackets together, Fig.1. The archwires placed in the bracket slot, by activation, generate light and continuous biomechanical forces, slowly decreasing over time and effecting the movement of the teeth until they all occupy the most correct possible position [2].

During orthodontic treatment with a fixed technique, in which brackets are worn for a long time (depending on the complexity and type of problems), a change may occur in the structure and in the structure and mechanical properties of the metal from which the wires are made, as a result of which, the used orthodontic archwire loses its original properties and effectiveness and must be replaced. When brackets get adjusted, the orthodontist makes a decision whether to modify and retain the archwire or remove it and replace it with another. Often, loss of archwire quality is the cause of sudden arc fracture and unwanted delay in treatment [5, 6].

The use of archwires of different metal alloys is a great possibility leading to quality and effective therapy, which implies the orthodontist making different decisions suitable for the specific patient. The correct choice of archwire (material, shape, dimensions, with and without different loops) in the clinical context is the responsibility of the treating orthodontist and is a guarantee of a good treatment result [5, 7, 8]. However, in practice, orthodontists often experience difficulty in choosing archwires from a given material, as they do not have information from the manufacturer about the chemical composition, the characteristics of the material (structure, physical and mechanical properties), about the method of production and processing.

Today, many manufacturers offer orthodontists ready-made expensive solutions for their practice. Orthodontists can choose between straight and curved archwires adapted to the oral anatomy. Anatomic archwires are available without loops and with factory bent loops, with different designs, formed to exacting standards - T-loop, L-loops, keyhole loop, teardrop loop and mushroom loop, opus loops, vertical closing loop and open-vertical loop [1]. The use of such archwires in some cases is a convenient, rational and quick solution for orthodontists, but in others - impractical, because orthodontic treatment is strictly individual and depends largely on the orthodontic problems of the patient, on the professional decision of the orthodontist related to the stages and the methods of treatment, of the cost of treatment, etc. Therefore, orthodontic archwires with factory loops are not always suitable for a given treatment. In these cases, orthodontists often resort to manually bending suitable loops by bending straight wire, cheaper than looped wire, using dental pliers. In this way, the orthodontist receives an archwire with an individual number of loops, with a different design and placement along the length of the wire, according to the individual characteristics and dental problems of the patient. In addition, they take advantage of the excellent

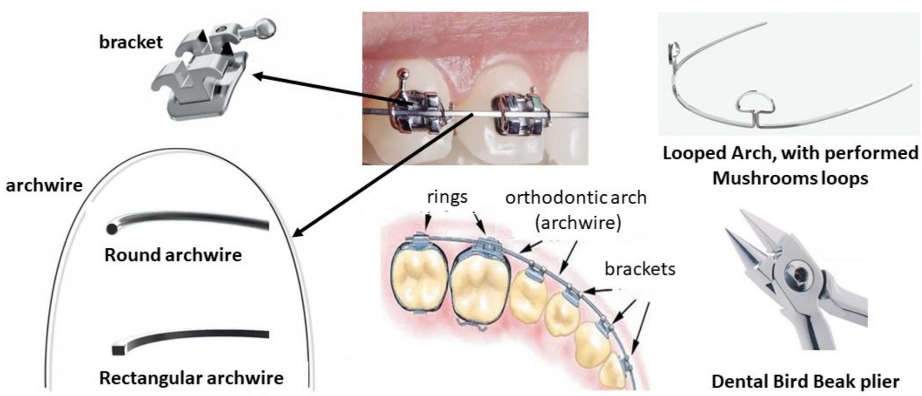

Fig. 1. Illustration of the bracket-archwire complex, archwire with mushroom loops [3] and dental Bird Beak plier [4].

properties of wires and reduce treatment costs.

Although in most cases loops of a simple design are made, the obtaining of which is reduced to manual bending of the wire at a right angle, the bending process depends both on the properties of the material from which the wire is made and on the skill of the orthodontist. When making a loop manually, the orthodontist must be sure that the surface quality of the straight archwire used is preserved, i.e. it must bend the wire without damaging its surface and without significantly increasing its roughness. Obtaining, because of manual bending, notches, cuts and other deep marks on the surface of the wire are undesirable, since they would play the role of obstacles to the sliding of the arc, which takes place in the slot of the brackets. The presence of such defects on the surface of the wire will lead to an increase in friction between the components of the brackets, and this will reduce the efficiency of the archwire during treatment. Furthermore, the degraded surface, resulting from notches, would cause the archwire to break during force application, as they appear to be stress concentrators at these locations.

Among the characteristics of the archwire that change its behavior during therapy, surface roughness plays an important role. It is an essential factor in the bracket-archwire complex, which determines the effectiveness of the guided movement of the teeth along the arch. The surface roughness of the archwires affects not only the efficiency of sliding mechanics, due to frictional effects and the size of the contact surface between brackets and archwire, but also the corrosion behavior, biocompatibility and aesthetics of orthodontic components [9 - 11].

A mushroom archwire made of titanium-molybdenum alloy was used in this study. The purpose of the work is, using modern methods of analysis, to examine and assess the condition and roughness of the archwire surface after the orthodontist has manually made a mushroom loop on it. After that, the obtained results of the studied parameters should be compared with those of the factory-made loops. The purpose of the work is dictated by the orthodontic practice, in response to the questions that orthodontists ask themselves, related to the quality of the archwires after manual fabrication of loops and their desire to make a correct and informed decision about their use in treatment for the benefit of the patient.

EXPERIMENTAL

Material

The studies were conducted on a rectangular orthodontic arch with cross-sectional dimensions of 0.017 x 0.025 inch (0.43 x 0.635 mm), with a rounded anatomical shape and factory-made mushroom loops located on both sides of the arch, Fig.1. The archwire is constructed of titanium-molybdenum alloy and manufactured by OrthoOrganizer Inc, USA. These looped arches with performed mushrooms are easy to bend, have a smooth and polished surface, have a greater range of activation, providing constant and gentle forces, gradually reducing forces during orthodontic treatment [3].

The chemical composition of Ti-Mo arch of the same manufacturer was investigated, according to which, the alloy contains 77 % Ti, 11.5 % Mo, 6.5 % Zn, 4.5 % Sn and presented in [12].

The mechanical properties of the material from which the archwire is made are essential for its application during treatment. Modulus of elasticity is an important factor in determining the clinical performance of orthodontic archwires, and hardness, as a strength indicator, is related to wire movement and strength. Results of nanoidentification tests on a similar Ti-Mo arc (TMA) are presented in [13]. The indentation hardness of 6 GPa and the indentation modulus of 117 GPa were determined, reporting that the results obtained are relatively high. The tests were performed using a Nanoindenter G200, and the test method, the subsequent calculations and approximation methods used, as well as the analysis of the results are presented in work [13].

Bourauel's work presents the results of measuring the surface roughness of beta-titanium archwires by three methods (optical roughness, AFM and profilometry), and the determined surface roughness is approximately 0.21 μm [9]. Beta-titanium archwires are reported to have the highest roughness compared to stainless steel and NiTi alloy archwires.

Methods and experimental work

To investigate the influence of manual bending on the quality and surface characteristics of an orthodontic wire, a comparison was made between two loops of similar shape - factory and hand-made by the orthodontist. For this purpose, on the straight section of the studied Ti-Mo archwire with factory mushroom loops, using dental Bird Beak plier, Fig.1, combined with a square and round tip, two types of bends of the wire under 90° were made. As a result, two characteristic points can be indicated on the hand-made loop, Fig. 2: point 1 - hand-made bend at an angle of 90° with the square tip of the Bird Beak plier and point 2 - hand-made bend at an angle of 90° with the rounded tip of Bird Beak plier. Bird Beak plier tips are specially designed to prevent scratching the wire.

In Fig. 2 and 3 the points for observation, analysis and comparison of the surface are presented, respectively, for the hand-made and the factory loop. In Fig. 2 shows the places of observation (points 1 and 2), where analyses of the surface were made in two mutually perpendicular planes, namely: in the tension zone of the fold - B1 and B2 and the front of the fold of the loop - C1 and C2.

In a previous study, the arch surface characteristics were investigated by SEM, in the shown in Fig. 2 and 3 points, indicated respectively - for the hand-made loop - with points B1 and B2, and for the factory loop with the points - A0 (in the straight section of the wire) and A1, A2, ..., A6 (in the loop) [14]. The SEM images obtained by Yoradnova et al. are summarized in Fig.4 [14].

The present study is a continuation of the previous comparative analyzes presented in work [14], with additional investigations of the arch surface in the bending zones of the loops by SEM analysis and surface roughness analysis.

In the work, an Optical Metrology System based on the principle of focus variation, model Infinite Focus SL, manufactured by Bruker Alicona, Austria, was used to measure and evaluate the surface roughness. The measurement is non-contact and fully automated. Through the Optical Metrology System used, easy, fast and repeated, non-invasive measurement of surface characteristics is achieved, and the results are obtained with high resolution. According to information from the manufacturer, "Focus Variation works on the basis of moving a focal plane over a surface and collecting robust 3D data which can then be used to measure geometric form and surface finish from a single optical sensor".

To compare the results, the analyzes were performed on points A6 and its corresponding point 1 of a hand-bent mushroom loop (bend below 90°). Points A4 and point 2 (bending at an angle greater than 90°) were examined similarly.

RESULTS AND DISCUSSION

An essential factor for effective tooth movement in orthodontic treatment with brackets is the roughness of the archwire. The different roughness of materials leads to different coefficient of friction between them. The frictional force occurring between the wire and the brackets is a harmful factor that prevents the correct sliding of the bracket on the wire, due to the interlocking of the components caused by their roughness [15]. Frictional forces in brackets can significantly reduce orthodontic force (over 50 %), because of which guiding the tooth along the archwire, moving it, tilting it and rotating it can be significantly difficult [16].

Orthodontic tooth movement is a very complex process involving a number of critical factors. Many scientific studies have been conducted to evaluate the various factors affecting friction in brackets, respectively

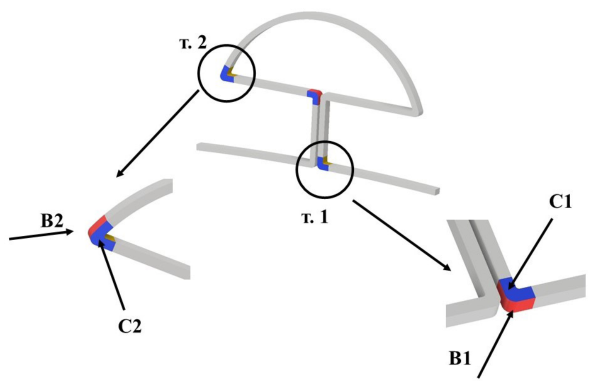

Fig. 2. Schematic representation of a hand - made mushroom loop, observation and analysis points.

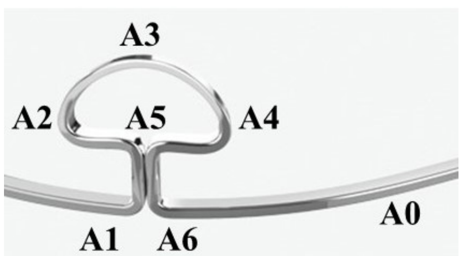

Fig. 3. Factory-made mushroom loop; observation and analysis points.

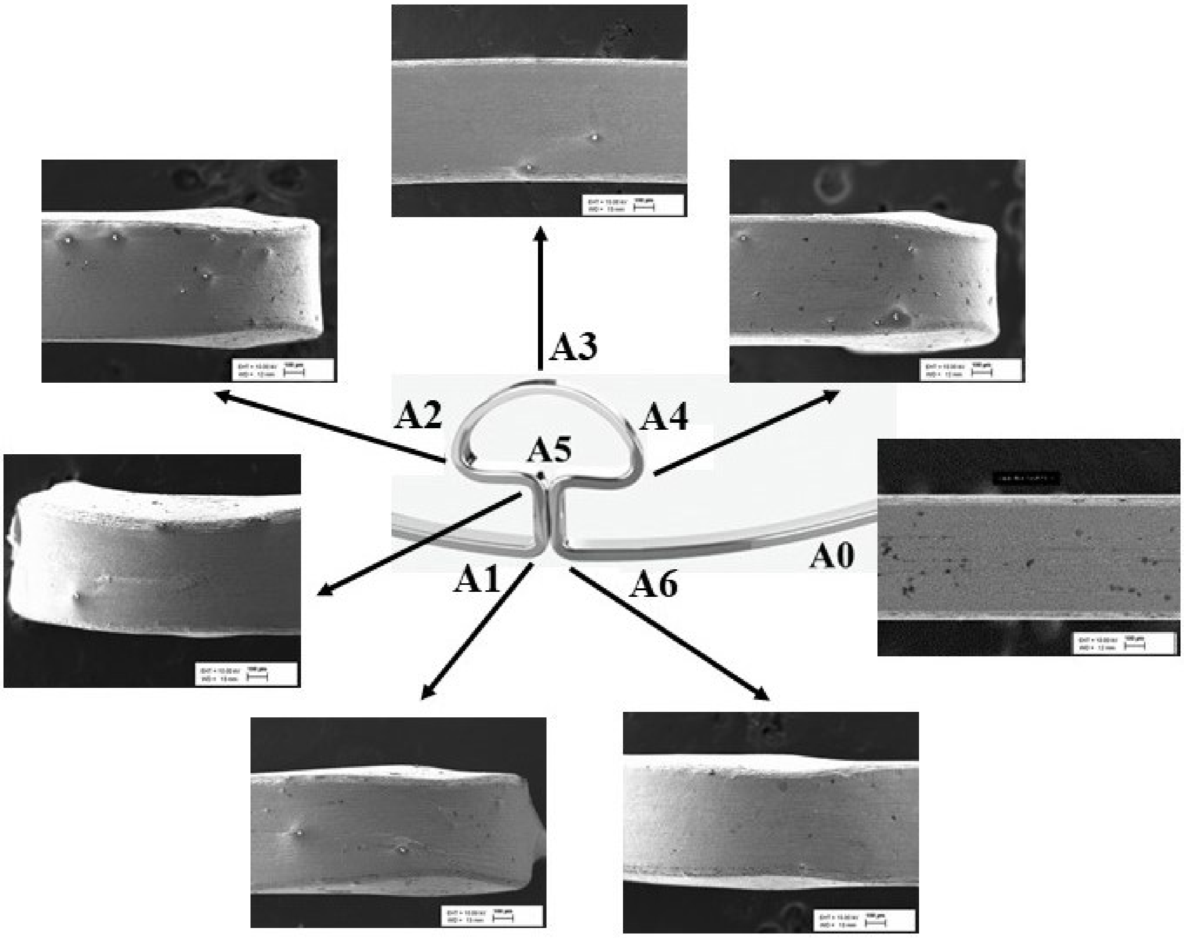

Fig.4. SEM micrographs of the observed surfaces of the factory made Mushroom Looped Archwire; magnification 200x, measurement line - 100 µm [14].

slowing down the speed of tooth movement. It is considered that the characteristics of the material are of dominant importance for the loss of orthodontic force due to friction [16 - 19]. Studies in recent years have shown that the roughness of the arch surface, the bonding method and the notches along the archwire are some of the main factors that slow down tooth movement [20].

Different archwires have different surface roughness, determined to the greatest extent by the characteristics of the material from which they are made [8, 9, 16, 21], by the design and shape of their cross section [17], by the method of production [22] and surface treatment of the wire by applying coatings [9, 11, 18]. An increase in archwire surface roughness also creates favourable conditions for unwanted plaque build-up, which also affects arc properties and performance [11].

The present study is a continuation of previous SEM comparative analyses in the bending locations of factory and hand-made mushroom loops along the length of a Ti-Mo archwire [14]. The archwire is smooth and polished (approximately 0.21 µm, according to [9]), however, SEM analysis of the straight section of the arc (item A0, Fig. 4) shows striations (slide streaks) obtained because of the technological process of receiving the wire. The SEM analysis of the factory-made loop shows that the characteristic compressive and tensile zones are observed when the wire is bent, with different degrees of metal deformation in different parts of the loop [14]. Comparative studies of the surfaces of the two types of loops (factory and hand-made) in different places of the loop have shown that the grooves on the surface in the pressure and tension zones of the loop are of different sizes, while the hand-made loops are of almost same or less changes in surface condition compared to factory made loops [14].

This comparative study focuses on: - determination of a change in the surface roughness of the examined orthodontic archwire, because of manual creation of a loop; - the evaluation of the roughness of the surface of the wire in the places of the factory and manually bent loops.

The archwire roughness study and comparative analysis is in relation to previous studies presented in work of Yordanova et al., complementing and elucidating the condition of the arch surface after manual fabrication of a mushroom loop by the orthodontist using standard dental plier [14].

In order to compare the results, tests were performed at points A6 and its corresponding point 1 of the hand-made mushroom loop (bend below 90°) shown in Fig. 2 and 3. Points A4 and 2 (bending at an angle greater than 90°) were examined similarly.

The SEM analysis performed on both types of loops shows the presence of streaked surfaces and slip lines obtained in the process of drawing the metal in the production of the wire. Significant deformations are observed in the bending zones of the loops. A slight difference was found in the surface characteristics of the hand-made and the factory loops, Fig. 5, which confirms the results presented in [14].

Additional investigations were carried out on the surface of the arc in the bending zones of the loops to determine and evaluate the surface roughness.

There are various non-destructive methods for analysis and determination of surface roughness - when using CEM, atomic force microscopy; laser specular reflectance (optical roughness), surface profilometry [9]. In the present study, the surface characteristics of the investigated orthodontic archwire were evaluated using an Optical Metrology System based on the focus variation principle. The measurement of roughness parameters is non-contact, and the measured surface is scanned. For the purposes of the study, two types of measurements were made - Profile roughness and Surface roughness measurements. Measurements were taken at the most bulging part of the fold of the loop (in

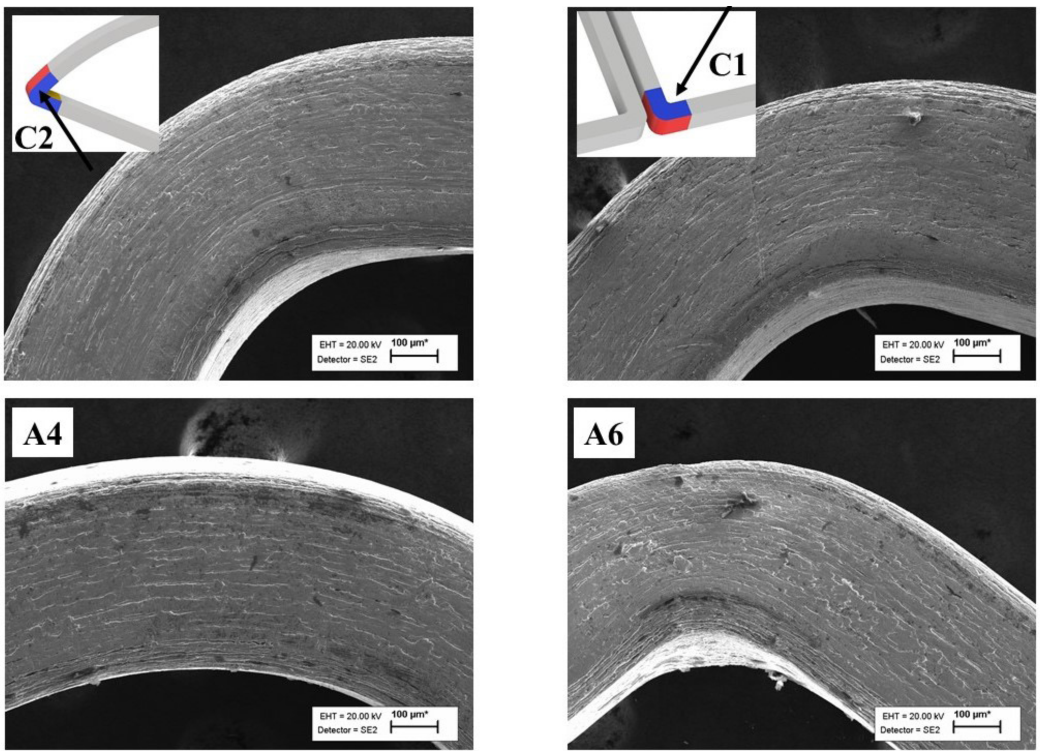

Fig. 5. SEM analysis of the loop surface, where points C1 and C2 are on the hand-made loop, and points A4 and A6 are their corresponding points on the factory-made loop; points are according to Fig.2 and 3.

the tension zone of the archwire).

With Profile roughness measurements, a profile line is extracted in which the roughness parameters are determined. The measurement line can be seen in the microscopic image obtained by the Optical Metrology System, Fig.6. The obtained results of the measurements are presented in Table 1 and Fig. 6a, b, respectively, when investigating the two types of loops in the bending zones - at a right angle and at an angle greater than 90°.

In Surface roughness measurement, the roughness parameters are determined in a selected field of the observed surface. The obtained results of the

Table 1. Profile roughness parameters of the archwires at characteristic points of the factory and hand-made mushroom loops, according to Fig. 2 and Fig.3.

Method of bending the archwire to obtain a mushroom loop		Observation points	Ra, μm	Rq, μm	Rt, μm	Rz, μm	Rt/ Rz	Rp, μm	Rv, μm	Rc, μm
bending the wire at an angle of 90°	factory made	A6	0.243	0.307	1.495	1.035	1.444	0.634	0.861	0.929
	hand-made	B1	0.210	0.295	1.732	1.119	1.548	0.429	1.303	0.886
		C1	0.221	0.277	1.370	0.892	1.535	0.663	0.707	0.921
bending the wire at an angle greater than 90°	factory made	A4	0.347	0.443	2.058	1.692	1.216	1.206	0.852	1.164
	hand-made	B2	0.382	0.491	3.091	1.862	1.660	1.434	1.657	1.530
		C2	0.159	0.199	1.082	0.648	1.670	0.445	0.637	0.661

Ra - Average roughness of profile; Rq - Root-Mean-Square roughness of profile; Rt - Maximum peak to valley height of roughness profile; Rz - Mean peak to valley height of roughness profile; Rt/Rz - Extreme Scratch/Peak value of roughness profile; Rp - Maximum peak height of roughness profile; Rv - Maximum valley height of roughness profile; Rc - Mean height of profile irregularities of roughness profile.

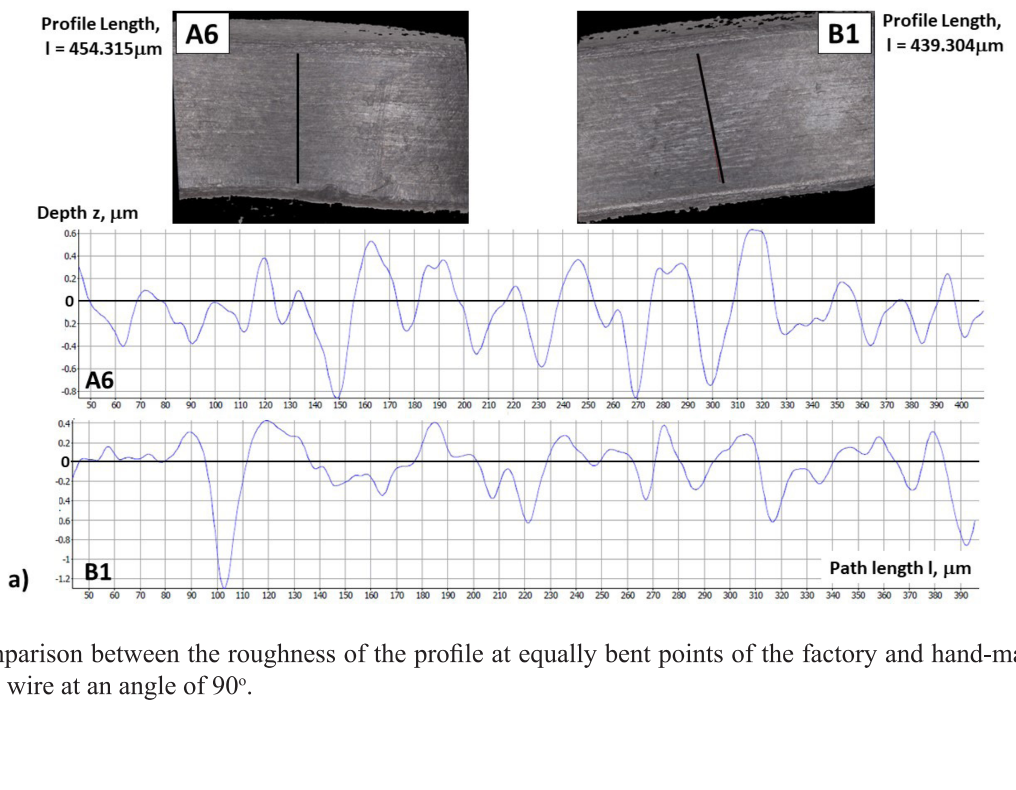

Fig. 6. Comparison between the roughness of the profile at equally bent points of the factory and hand-made loops: (a) bending the wire at an angle of 90°.

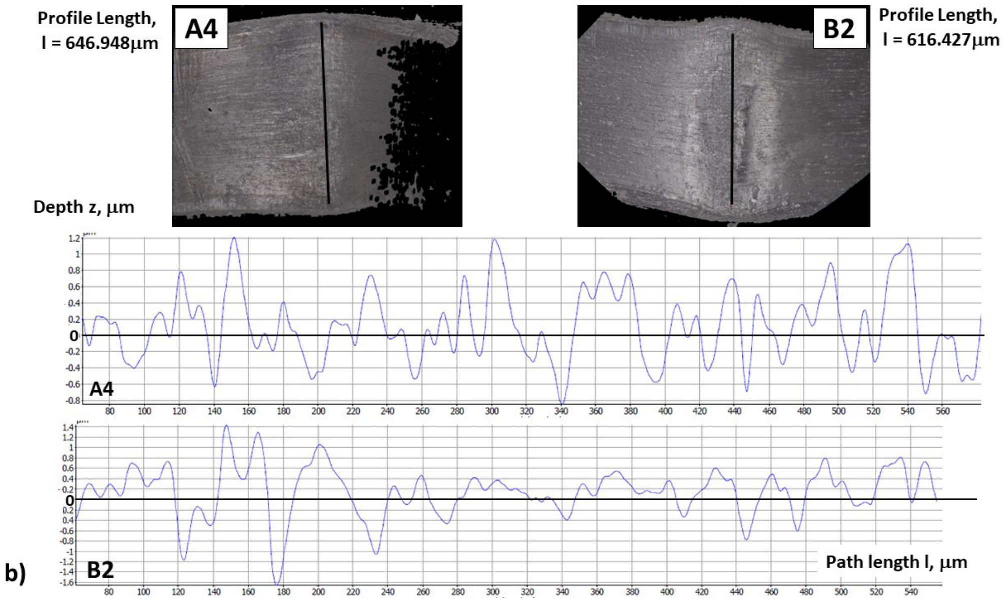

Fig. 6. Comparison between the roughness of the profile at equally bent points of the factory and hand-made loops: (b) bending at an angle greater than 90^o.

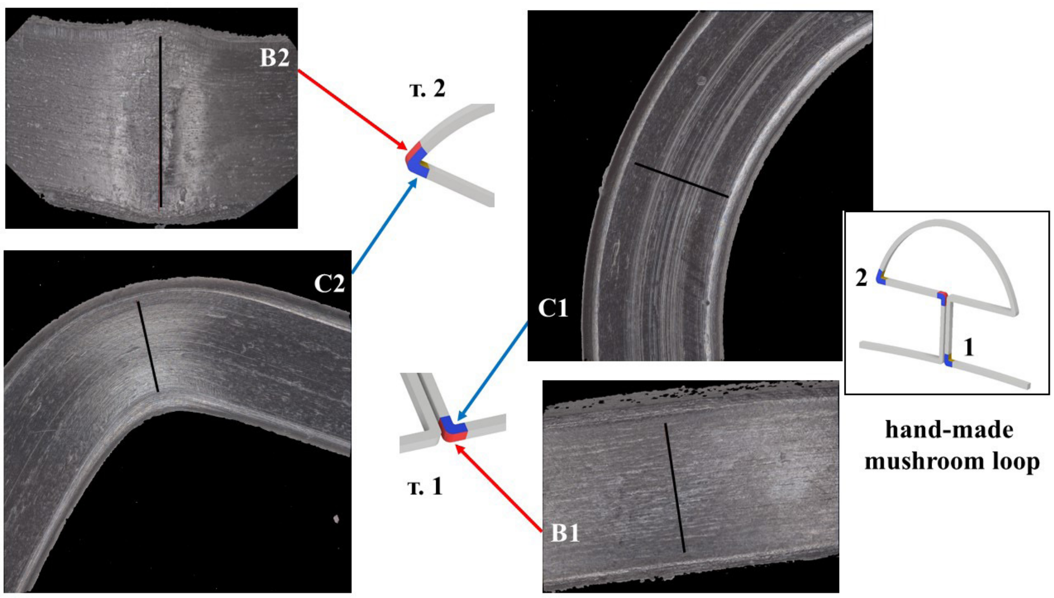

Fig. 7. Profile roughness in characteristic points of the hand-made loop in the front surfaces - C1 and C2 and the tension zones of the fold - B1 and B2.

measurements are presented in Table. 2, respectively, when examining the loops in the bending zones at a right angle and at an angle greater than 90^o.

Additionally, an analysis of the parameters of the roughness of the front surfaces of the hand-made loop at the two characteristic points (point 1 and 2 of Fig. 2), namely C1 and C2, was made. The results are presented in Tables 1 and 2 and are visualized in Fig.7. It was found that the roughness of the front surfaces of the hand-made loop in both methods of bending with the Bird Beak plier is comparable. The surface of the archwire in C1 and C2 is smoother compared to the surface of the wire that was in contact with the tips of the pliers and underwent greater deformations - surfaces B1 and B2.

Table 2. Surface roughness parameters of archwire at characteristic points of factory and hand-made mushroom loops, according to Fig. 2 and Fig. 3.

Method of bending the archwire to obtain a mushroom loop		Observation points	Sp, µm	Sv, µm	Sz, µm	Sa, µm	Sq, µm
bending the wire at an angle of 90°	factory made	A6	1.418	2.492	3,910	0.281	0,357
	hand-made	B1	1.550	1.938	3.488	0.232	0.306
		C1	1.516	1.049	2.565	0.175	0.225
bending the wire at an angle greater than 90°	factory made	A4	32.940	14.236	47.176	0.840	1.325
	hand-made	B2	6.421	5.216	11.636	0.757	0.990
		C2	1.261	1.038	2.299	0.168	0.219

Sp - Maximum peak height of selected area; Sv - Maximum valley depth of selected area; Sz - Maximum height of selected area; Sa - Average height of selected area; Sq - Root-Mean-Square height of selected area

Through SEM and surface roughness analyses, Fig. 5 - 7, the presence of clearly defined sliding lines and mechanical traces in the direction of the deformation during the wire drawing process is established. The technology of obtaining and processing the wire turns out to be the dominant factor determining the surface texture of the wire.

A comparison of the results of the two surface analysis shows that the differences between the factory and hand-made loops are minimal within the tolerances in roughness, Tables 1 and 2.

The average roughness of profile, Ra when bending the wire below 90° is 0.243 µm for the factory loop and 0.210 µm for the hand-made loop. This indicates that the original archwire surface roughness of approximately 0.21 µm is retained to a significant extent. The average roughness of profile, Ra when bending the wire at an angle greater than 90° is 0.347 µm for the factory loop and 0.382 µm for the hand-made loop. The roughness is comparable between the two loops.

The ratio Rt/Rz (≥ 1) is determined, which gives information about the presence of extreme scratches/peaks on the surface. Higher values of the Rt/Rz ratio represent larger scratches/peaks on the surface. For factory loops, Rt/Rz is from 1.21 to 1.44, and for hand-made loops - from 1.55 to 1.66, respectively. The observed increase in the Rt/Rz ratio does not mean that the roughness has increased significantly, since the values obtained are close to 1, and must also be considered in the light of the other roughness parameters.

The surface roughness can be determined by the average height of selected area, Sa. For the factory loop in the two ways of bending, Sa is 0.281 µm and 0.84 µm, and for the hand-made ones - 0.232 µm and 0.76 µm, respectively. The values of the roughness parameters are comparable when comparing the surface of the factory and hand-made loops in both types of bending.

Therefore, no significant defects - stress concentrators, which would lead to faster deterioration of the properties and the undesirable arch breakage - were observed on the examined hand-bent loop. Therefore, it can be considered that the manual bending of the wire by the orthodontist, using dental pliers, does not significantly deteriorate the surface of the wire, proven by the experimental data presented in Tables 1 and 2.

It can be considered that the surface roughness remains relatively the same, the irregularities are of approximately the same size and the archwire should retain its efficiency as well as its good appearance ie. manual bending does not lead to significant changes in the archwire surface. This result is explained by the fact that the arch has a certain factory roughness and texture, which is difficult to change because of the manual bending performed with low force and low speed, controlled by the orthodontist.

CONCLUSIONS

The surface characteristics of a Ti-Mo archwire with factory mushroom loops, which has excellent properties suitable for treatment, were investigated. However, their high cost, stops orthodontists from using them more widely. To reduce the cost of orthodontic treatment on the one hand and to take advantage of the excellent properties of Ti-Mo arches on the other hand, orthodontists in their practice often resort to the use of cheaper straight wires, on which they manually, by bending with dental pliers, make loops suitable and tailored to the individual characteristics and needs of the patient.

The present study is a comparative analysis of the effect and impact on archwire quality of the commonly used approach in orthodontic practice of manually making loops along the length of the archwires by bending them around the quartered and rounded tip of a Bird Beak plier.

As a result of the applied two methods for research and analysis of the surface of the archwire - SEM analysis and Surface roughness analysis, results were obtained regarding the characteristics and parameters of the surface roughness of the factory and hand-made loops. The SEM analysis established a surface texture characteristic of the technological process of obtaining the wire by drawing. After subsequent manual bending of the archwire below 90^o, with the different tips of the Bird Beak plier, the surface characteristics of the wire in the loops were found to be comparable and preserved. The wire drawing process is the dominant factor in forming the surface texture of the archwire, which does not change significantly with manual loop bending due to the slower deformation of the metal with less force. An expected thickening of the slip bands in the compressive zones (on the inside of the loop folds) and widening in the tensile zones (on the outside of the loop folds) is observed.

Examination of the surface of both types of loops by means of an Optical metrology system made it possible to determine the parameters of the profile roughness and surface roughness. The comparative analysis shows that there is no significant difference in the surface characteristics of the wire in the places of bending between the hand-made and the factory bends.

The change in surface roughness of the hand-made loop is minor and will not significantly change the sliding mechanics of the bracket-archwire system, while maintaining the possibility of smooth movement in the brackets when tightening or loosening during the various stages of treatment. The finding is in favor of orthodontists, as the manually made curves do not deteriorate the qualities of the arch and do not significantly increase the roughness. Manual bending with a Bird Beak plier practically does not change the surface of the archwire, does not introduce additional defects that increase contact friction, as well as create conditions for faster deterioration of properties and the undesirable breakage of the archwire. Therefore, the results obtained give orthodontists reason to be confident in successfully applying this approach during the treatment of patients, thus reducing its cost while maintaining its effectiveness.

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