Nugget mechanical properties of combination (rectangular and round) welded and soldered stainless steel wires

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ABSTRACT

Background: This study aimed to compare the mechanical properties between four groups of newly fabricated combination wires according to their method of union, according to the gauges of wires and a comparison were made between them and their originals.
Materials and method: A total of 60 stainless steel combination wires were fabricated , divided into four groups according to gauge of wires and their method of union, each of them with 15 samples, the groups were welded (0.016x0.022-0.016 and 0.016x0.022-0.018) and soldered (0.016x0.022-0.016 and 0.016x0.022-0.018), samples were made according to certain parameters which were : for the welded samples: length,weight, duration of pulsation and size of copper electrode tips used; for the soldered samples: length, weight, distaince from the heat source and duration of heat application
Results: The descriptive statistics showed that the maximum value for ultimate force and ultimate tensile strength was for the soldered 0.016x0.022+0.018 inches combination wires, while the minimum was for the welded 0.016x0.022+0.016inches wires. Elastic modulus showed higher values for the soldered 0.016x0.022+0.016 and resiliency values for the welded 0.016x0.022+0.016 were the highest. Comparison between combination wires and their originals showed a decrease in the mechanical properties after soldering and welding.
Conclusion: Higher gauge wires and soldering method of union showed better mechanical properties than the other groups and both soldering and welding method showed changes in the mechanical properties of the newly fabricated wires when comparing them with their originals.
Keywords: Archwire, stainless steel, combination wires, soldering and welding. (J Bagh Coll Dentistry 2014; 26(3):169-173).

الخلاصه

المقدمة: تهدف هذه الدراسة إلى المقارنة بين الخواص الميكانيكية بين أربع مجموعات من الأسلاك المركبه وفقا لطريقتهم في الاتحاد،وفقا لقياسات الأسلاك وتم إجراء مقارنة بينها وبين الاسلاك الاصليه.
المواد والطريقه: مجموعه من 60 سلك مصنوع من مادة الفولاذ المقاوم للصدأ ، قسمت الى أربع مجموعات وفقا لقياسات الأسلاك وطريقةاللحام، كل واحد منهم يتكون من 15 عينة، تم لحم الاسلاك ذات القياسات التاليه (0.016 +0.022x0.016 و 0.022x0.016+0.018) وفقا لبعض الضوابط والتي كانت: الطول، الوزن،ومدة النبض وحجم نحاس الاقطاب المستخدمة (بلنسبه للعينات الملحومه عن طريق التيار الكهربائي) ومدة عملية اللحام والبعد من مصدر الحراره (للعينات الملحومه عن طريق الحراره).
النتائج:أظهرت النتائج للقوه القصوى المحتمله ولقوة الشد القصوى للعينات الملحومه عن طريق الحراره (0.016 × 0.022-0.018) قيم عالية بالمقارنة مع العينات الاخرى الاقل حجما والملحومة عن طريق التيار الكهربائي, و اظهرت نتائج معامل المرونه للعينات الملحومه عن طريق الحراره(0.016 × 0.022-0.016) قيم عاليه بلمقارنه مع العينات الاخرى الاكبر حجما الملحومه عن طريق التيار الكهربائي , اما نتائج معامل الطاقه المخزونه فقد اظهرت قيم عاليه للعينات الملحومه عن طريق التيار الكهربائي (0.016 × 0.022-0.016) وقد لوحظ انخفاضا في الخواص الميكانيكيه عند مقارنة الاسلاك المركبه مع الاسلاك الاصلية قبل اللحيم.
الخلاصة
أظهرت الأسلاك ذات القياس الأعلى وأسلوب لحام عن طريق الحراره خواصاميكانيكية أفضل من المجموعات الأخرى وعلى حد سواء عند مقارنة الاسلاك الجديده مع النسخ الأصلية الخاصة بهم اظهرت النتائج انخفاضا في الخواص الميكانيكيه بلنسبه للاسلاك المركبه الجديده.
الكلمات الرئيسية: سلك تقويم، الفولاذ المقاوم للصدأ، أسلاك الجمع، لحام بطريقتين.

INTRODUCTION

One of the most common methods oftranslating a tooth orthodontically is by the use of sliding mechanics. Inthis technique, mesiodistal tooth movement is accomplished by guidinga tooth along a continuous archwire with the use of an orthodontic bracket. Adisadvantage of this technique is thatfriction is generated between the bracketand the archwire, which tends to resist themovement of the bracket and tooth in thedesired direction [(1)].One of the primary focuses of the ideal conditions for orthodontic tooth movement (OTM) is the reduction of friction at the bracket-wire-ligature interface in certain stages of treatment [(2)].

The friction present during orthodontic sliding mechanics represents a clinical challenge to the orthodontists because high levels of friction may reduce the effectiveness of the mechanics, decrease tooth movement efficiency and further complicate anchorage control**[(3)]**. Therefore, lower but still sufficient to promote OTM forces could be used [(3)] when the wire dimension was increased from "0.016×0.022" stainless steel to "0.017×0.025" stainless steel, friction increased. Frictional force was directly proportional to the wire size [(4)].

To solve this problem a combination archwire composed from anterior segment rectangular to prevent tipping and posterior segment round to allow anterio - posterior bodily movement & tipping in bucco-palatal dimension and facilitate the canine retraction were needed. Joining different diameter wires is used to obtain the desired moment differential rather than utilizing

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spring positioning [5]. Stainless steel can be fused together by welding but this generally required reinforcement with solder [6,7]

Soldering defined as the joining of metals by the fusion of intermediary alloys which are of a lower melting point. The lower fusing metals or solder, is fused to the parts to be joined. Welding: The welding process employed by the orthodontist is known as resistance welding or spot welding. The two pieces to be welded are held under pressure and an electric current is applied for a given period of time. The electrical resistance of the juncture of the two parts causes a rise in temperature and a localized fusion of the metal parts occurs [8].

MATERIALS AND METHODS

A total of sixty stainless steel combination wires were prepared, thirty of them united by soldering group and the other thirty united by welding method group, in each group samples were equally divided into two sub-groups according to the sizes of wires used which were: (0.016×0.022+0.016) inches,(0.016×0.022+0.018) inches, the ultimate force, ultimate tensile strength of nugget area (joints) were tested by universal testing machine, elastic modulus and resiliency were calculated by special equations.

Samples were prepared according to specific parameters which were: length, weight and for (soldered samples) the distance from heat source and time of heat application.

For the welding method fifteen samples were prepared for each gauge of straight stainless steel wires, a combination of 0.016 inch with 0.016×0.022 inch and combination of 0.018 inch with 0.016×0.022 inch, which means that the number of the welded sample were 30 (thirty),each piece of wire (4 inch in length) is bended at right angle for (0.4 inches) to increase welded surface area, joints made in this way are stronger than those made with wires laid parallel according to [9], and then fixed by hand with the other piece in the welding machine, then four electrical pulsations were made (the duration of each pulsation was 1/25 second).

For the soldering method, Fifteen samples were fabricated for each gauge of straight stainless steel wires, a combination of 0.016 inch with (0.016×0.022) inches and combination of (0.018) inches with (0.016×0.022) inches, before starting the soldering procedure each sample were welded with two electrical pulsations (the duration of each pulsation was 1/25 second) only to ensure fixation of the sample during soldering, then a plaster of pairs were mixed and applied to the combination wire around the nugget area to prevent transfer of heat to the rest of the wire, Wires were fixed on a customized cartoon board stand to grasp the wire during soldering procedure. Orthotechnology silver solder and flux were used for soldering all joints. The joint site was adequately heated with the reducing zone of the flame (Piezo gas burner2000, Japanese) and as soon as the site reached solder flow temperature, 6 mm of the solder was held in a tweezer and introduced at the joint site. The work were held 3mm beyond the tip of the blue cone in the reducing zone of the flame, soldering were observed in a shadow, against a black back ground, so that the temperature can be judged by the color of the work. The color should never exceed a dull red. Solder were added and heating were continued until metal flows around the joint. The flame was withdrawn when the solder had flown over the joint site in a feather edge configuration. All specimens were immediately quenched in cold water as recommended by [10].The flame were applied nearer to the rectangular wire than the round wire because rectangular wire tolerance to heat is greater than the round wire (to avoid unwanted annealing effect to the wire).

The universal testing machine (Tinius Olsen/ Model 50KM with a capacity of 50KN) was standardized to grasp the combination wire firmly in a vertical way by mounting wires into capstan grips with a nip-to-nip distance of 4 inches for fixation of the samples.

The test include: ultimate force and ultimate tensile strength, both of these values were calculated by testing machine, special software which calculate the ultimate force first, then by entering the diameter of the round wire it would calculate the ultimate tensile strength of the wires, during the test of welded wires the cutting were made in the nugget area (area of contact), for the soldered wires sample the cutting were made in the round wire part. Elastic Modulus values were obtained by dividing a stress value equal to or less than the proportional limit by its corresponding strain value.

E modulus =stress/strain. [11]

Units of elastic modulus is gigapascal (Gpa)

Modulus of resilience was obtained from the following equation:

$R=P^2/2E$ [12].

Statistical analysis

Descriptive statistics, including the mean, standard deviation, minimum and maximum values were calculated for each group of combination wires. Inferential statistics include independent sample t-test to compare the mechanical properties (ultimate force, ultimate tensile strength, elastic modulus, resiliency) between the wires in each method of union and between the methods of union for each wire, one sample t-test to compare the mechanical properties of the combination wires with their originals, Paired sample t-test for intra and inter-examiner calibration.

The statistical analyses were carried out using Pentium IV computer and the Statistical Package of Social Science SPSS program version 19, running under Microsoft Windows.

Data were analyzed by using, version 19). The following levels of significance were used:

Non-significant NS $P > 0.05$
Significant * $0.05 \geq P > 0.01$
Highly significant ** $0.01 \geq P > 0.001$
P= probability value.

RESULTS

The descriptive statistics showed that soldered (0.016×0.022+0.018) wires gave rise to highest values of force and ultimate tensile strength when compared with welded (0.016×0.022+0.016) inches wires which gave rise to the lowest values, while for the elastic modulus descriptive statistics showed highest values for soldered (0.016×0.022+0.016) inches, resiliency showed highest values for the welded (0.016×0.022+0.016) inches.

Comparison of significance by using independent sample t-test between sizes of wires and methods of union for the ultimate force measure showed a highly significant difference $p<0.01$ for (0.016×0.022-0.018) inches wires when compared with (0.016×0.022+0.016) inches,non- significant difference for the ultimate tensile strength, highly significant for the elastic modulus and highly significant for the resiliency.

Comparison was done using independent sample t-test between methods of union showed highly significant between soldering and welding methods of union for all mechanical properties. Comparison of significance between combination wires and their originals by using one sample t-test showed highly significant difference between them for all mechanical properties.

Table 1: Descriptive Statistics demonstrate ultimate force values of different orthodontic wires combinations

Method of union	Wires	Descriptive Statistics					Wires Comparison df=28	
		Mean	S.D.	S.E.	Min.	Max.	t-test	p-value
Soldering	16×22-16	138.70	27.01	6.97	106.70	186.50	-3.31	0.003 (HS)
	16×22-18	181.49	42.13	10.88	126.50	276.50		
Welding	16×22-16	94.91	17.41	4.49	53.30	118.50	-2.52	0.018 (S)
	16×22-18	110.78	17.08	4.41	80	135		

Table 2: Descriptive statistics demonstrate ultimate tensile strength values of different orthodontic wires combinations

Method of union	Wires	Descriptive Statistics					Wires Comparison df=28	
		Mean	S.D.	S.E.	Min.	Max.	t-test	p-value
Soldering	16×22-16	1104.08	215.30	55.59	849	1484	-0.42	0.677(NS)
	16×22-18	1141.20	265.00	68.42	795	1739		
Welding	16×22-16	755.33	138.51	35.76	424	943	1.29	0.205(NS)
	16×22-18	696.60	107.47	27.75	503	849		

Table 3: Descriptive Statistics Demonstrate elastic modulus values of Different Orthodontic Wires combinations (Gpa)

Method of union	Wires	Descriptive Statistics					Wires Comparison df=28	
		Mean	S.D.	S.E.	Min.	Max.	t-test	p-value
Soldering	16×22-16	143.54	19.48	5.03	110.50	182.60	2.87	0.008 (HS)
	16×22-18	117.32	29.55	7.63	66.70	173		
Welding	16×22-16	122.47	17.04	4.40	90	149	0.39	0.694 (NS)
	16×22-18	119.27	26.04	6.72	88.30	193		

Table 4: Descriptive statistics demonstrate resilience values of different orthodontic wires combinations

Method of union	Wires	Descriptive Statistics					Wires Comparison df=28	
		Mean	S.D.	S.E.	Min.	Max.	t-test	p-value
Soldering	16×22-16	1	0.38	0.10	0.44	1.79	0.45	0.66 (NS)
	16×22-18	0.94	0.33	0.09	0.51	1.58		
Welding	16×22-16	1.31	0.28	0.07	0.69	2	3.83	0.001 (HS)
	16×22-18	0.89	0.32	0.08	0.47	1.65		

DISCUSSION

In this current study which involved heat application (soldering) and electrical current (welding), involved melting of the parts to be welded, it is unfortunate that a stainless steel orthodontic wire can become annealed, in different percentages, resulting in a recrystallized microstructure in a few seconds at temperatures from 700 C° to 800°C, which lie within the soldering and welding temperature range. This disadvantage can be minimized by using low-fusing solders, and by confining the time for soldering and welding procedures to a minimum. It is important that the stainless steel wire not be heated to too high a temperature, in order to minimize carbide precipitation, and to prevent an excessive softening of the wire so that its usefulness is lost.

Wires of same thickness present no problem in soldering but if one wire is much thinner than the other, care must be taken not to overheat the finer wire. Thinner wire may be wound round a thicker wire before soldering as this makes a very strong joint [13].

The higher and more prolonged the welding temperatures, the greater will be the carbide precipitation, even though there was no carbide precipitation, a tendency to tarnish and corrode would be present because of the differences in grain structure brought about by the welding[8]. Independent sample t test showd highly significant difference between the two gauges of combination wires for the ultimate force with highest values for the large gauge because heat treatment is a quantitative factor, wires of smaller diameter will absorb heat more quickly than will a larger wire**,** non-significant for the ultimate tensile strength measure because ultimate tensile strength gave rise to higher values when the force divided on the less surface area and less value when force divided on higher surface area this may cause a non-significance between the two gauges. Elastic modulus and resiliency were higher for the smaller gauge wiresthis could be explained by the fact that the lower gauge wires could be elastically deformed more than the higher gauge wires, the smaller the wire, the more it can be deflected without permanent deformation [14], and the area under the stress- strain curve for the elastic modulus was greater for the lower gauge wires.

Comparison of significance between methods of union showed highly significant difference between soldering and welding with better properties for the soldering method because electrical resistance or spot welding of stainless steel causes melting and solidification of the alloy with localized loss of the wrought microstructure and increased stress in the surrounding heat-affected zone where joint failure is most likely to occur. [15], spot welding is carried out without the aid of flux or any other protecting material so that as the temperature of the work pieces is raised, oxidization and breakdown of the composition of materials which are alloys can occur, which will produce weakness in the weld**.** [9].

When comparing the significance between combination wires and their originals by using one sample t-test showed highly significant difference between them because when the solder is overheated to a temperature of 815 C°. (1500 F°). The diffusion of the solder into the grain boundaries becomes evident from the wire to the solder and from the solder to the wire, the composition of both the solder and the alloy has been changed with the result that mechanical properties of the joint are no longer under the control of the operator, in addition to the changes which accompanied the welding procedure which were mentioned previously.

As conclusions:

1. Higher gauge wires produced better mechanical properties than lower gauge.
2. Soldering method produced fewer changes in the mechanical properties than welding (produce stronger joints than welded nugget).
3. There is a significant difference in mechanical properties between original wires before soldering and welding and the combination wires after soldering and welding.
4. Both soldering and welding method of union produce changes in the microstructure of wires in different way (the welding produce more changes and weaken the joints), which will

give rise into changes in their mechanical properties.

5. Combination wires produced by soldering method could be employed clinically for retraction cases because of their better mechanical properties than those produced by welding method.

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