Welding of Attachments in Orthodontics: Technique Recommendations based on a Literature Search

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ABSTRACT

Joining of fixed appliance components has several applications in orthodontics. Joining attachments to archwires allows the clinician to transfer the point of force application to a location that is more advantageous from a biomechanical standpoint. Although several methods of joining attachments have been proposed, resistance spot welding and soldering have been the most commonly used procedures. Despite its common use, the literature regarding spot welding has been scarce and the technique improperly applied. The aim of this article is to describe the theory behind the use of electric spot welders and achieving an optimum weld joint. Recommendations have been made for the correct application of the parameters involved in electric resistance spot welding so that a clinically useful weld joint can be obtained.

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INTRODUCTION

Joining of attachments to the basic orthodontic appliance set up has several applications. The attachments may range from molar tubes to lingual sheaths and several others. Joining of hooks and extensions to the archwire provides the orthodontist with the freedom of varying the relationship of the point of force application to the center of resistance of the units to be moved and hence the type of tooth movement achieved.

In orthodontics, there are several ways by which attachments or auxiliaries can be joined. These include:
1. Brazing
2. Soldering
3. Welding:
   a. Electrical resistance welding.
   b. Laser welding.
   c. Tungsten inert gas welding, etc.

The disadvantages of Brazing and the development of more sophisticated methods have made it almost obsolete in orthodontics.

Soldering and welding are the methods commonly used in practice for joining components of orthodontic appliances. Soldering involves the use of a filler material between 2 closely approximated components and is a technique sensitive procedure. Welding on the other hand is a simpler procedure and involves the passage of current through resistant weldmates to achieve fusion.

S Sestini et al evaluated the in vitro toxicity of silver soldering, electrical resistance and laser welding of orthodontic wires. They found that:
1. Electrical resistance welding is well tolerated.
2. Traditional silver soldering is toxic for osteoblast differentiation, fibroblast viability, and keratinocyte growth.
3. Laser welding was well tolerated by all cells tested, thus showing its high biocompatibility.

Although Laser welding is well tolerated, soldering and electrical resistance welding are the common clinically used procedures for fixing attachments to the archwire, band, etc. This is because the latter are more economical, require minimal armamentarium and all orthodontists are trained in the use of these methods.

Though welding is one of the technical procedures most commonly used by orthodontists, the process is usually poorly understood and not employed efficiently. This article aims to describe the technical details and the recommendations for efficient spot welding based on a literature search.

WORKING OF ORTHODONTIC WELDERS

Brusse and Carman L introduced spot-welding to the profession at the 1933 AAO meeting in Oklahoma City with the first spot-welder.
Binder described the theory behind orthodontic spot welders to enable clinicians to use them more effectively. Orthodontic spot welders employ the electrode technique and are used instead of soldering in cases where the heating cycle must be very short, in order to prevent changes in the physical properties of the components being joined. Figure 1 (the electrical circuit of an orthodontic spot welder) shows the electrical circuit of an orthodontic spot welder.

Orthodontic welding is achieved by passing a large amount of current for a very short duration through an area of high resistance. An electroconductive contact surface is created between the workpieces by pressing them together. Heat is generated of a magnitude great enough to cause melting at the interface. Electrodes convey a pressing force to the joint and direct the welding current to the joint in the appropriate manner. After welding, the electrodes rapidly cool down the welded joint.

The copper electrodes in orthodontic spot welders have low resistance to passage of electricity and heat. The stainless steels used in most orthodontic materials have 50 times the resistance of copper. Although somewhat variable, the resistances at the electrode-stainless steel (electrode-weldmate) interface and at the stainless steel-stainless steel (weldmate-weldmate) interface are respectively two and four times that of the stainless steel alone.

Thus, in orthodontic welding, the resistance at the junction between the two pieces of stainless steel being joined is much greater than that of either the electrode or the stainless steel masses. Because of this differential resistance, essentially all of the heat generated by the current flow is contained within the weld area. As sufficient heat is generated at the weldmate-weldmate interface, the stainless steel components soften, flow and fuse together under the influence of mechanical pressure, forming a weld nugget.

**VARIABLES AFFECTING THE WELD JOINT**

A satisfactorily welded joint is one which is strong, has not undergone oxidation (blackening), and has not been over compressed during fusion. Satisfactory welding of orthodontic attachments depends on the proper use of each of the following three variables:  

1. The current flowing through the circuit.
2. The time during which the current is allowed to flow.
3. The mechanical pressure applied at the welding head.

The improper application of these variables can result in either over or underwelding of the weldmate.

An underwelded assembly does not have sufficient strength to resist the forces applied on it during use. The reasons may be:

1. Insufficient current flow.
2. The current may have been passed for an insufficient amount of time to achieve a high enough temperature for melting.
3. Pressure applied to the weldmate may have been inadequate to bring them into maximum approximation.

Overwelding, by overheating the metals, may yield as weak a joint as underwelding. The appearance of sparks during the welding procedure is indicative of localized overwelding and should be avoided. Another undesirable consequence of an overweld and an oversized joint is progressive corrosion. This occurs when chromium is precipitated at the grain boundaries of each crystal. This process is known as weld decay. Better grades of stainless steel usually contain trace rare metals which help to inhibit this process.

**Welding Current and Weld Time**

The amount of energy input in the weld depends on the welding current used and weld time. Short cycle times are usually preferred in resistance welding, which means higher welding current and as short a weld time as possible. In this case, less heat is conducted to the areas immediately surrounding the weld and therefore thermal expansion remains at a lower level, in addition to which the weld also solidifies and cools down faster. When using too low a welding current, the workpiece and electrodes conduct all heat away from the connecting surface and no weld pool is created.

Increase in weld time increases the wear of the electrodes and the size of the indentation on the workpiece. In addition, heat will have more time to conduct to a wider area around the weld. This results in a longer cooling time. Combe recommends using 2 to 10 volts, 250 to 750 amp current at 1/25 or 1/50 of a second for welding of stainless steel components.
Electrodes and Electrode Force

Electrodes convey the force and welding current to the desired location. Electrodes also cool down the weld after the welding process. Electrode force affects the contact between electrode tips and the work piece. Too little force does not create the required contact between workpieces and between the electrodes and the workpiece. In this case, sparking, splashing and rapid wear of electrodes may occur.

Sufficient electrode force keeps the weld pool inside the joint so that it cannot protrude or splash outside the area supported by contact surfaces. When welding using the correct electrode force, contact resistance in the electrode-weldmate interface remains at such a low level that no melting occurs in the interface and the electrodes can cool down the weld properly.

Too high electrode force presses the electrodes too much on the workpiece surface, which causes indentation. Large indentation lowers the strength of the weld.

In the orthodontic welders, the electrode force is not adjustable and therefore not in the orthodontist’s control.

The diameter of welding electrodes have a great impact on the welding process and weld properties in spot welding. The proportion between the diameter of the electrodes and the workpiece thickness must be correct.

In spot welding, the electrode tip diameter is usually $5\sqrt{t}$, where $t$ is workpiece thickness. The geometry and diameter of electrodes affect the localization of the force and current density in the weld interface and therefore, to an extent, also the location of the weldable area.

MICROSTRUCTURE OF A WELD JOINT

During welding, the temperature exceeds various critical temperatures at which phase transformations occur in the metals involved. The parent metal melts and then solidifies into a cast structure. The microstructure of a weld joint (Fig. 2) reveals three distinct zones:

1. Weld metal zone.
2. Heat affected zone.
3. Unaffected parent metal.

The weld metal zone is the region in the center which is formed as the weld metal solidifies from the molten state. This zone is a cast metal whose microstructure reflects the cooling rate in the weld. Depending on the chemical composition, a martensite structure indicates a very fast cooling rate; fine pearlite and coarse pearlite showing comparatively slower rates of cooling. The weld metal is less homogenous than the base metal on the microlevel and therefore cannot be expected to have the same properties as the wrought parent metal.

Adjacent to the weld metal zone is the heat-affected zone that is composed of the parent metal that did not melt but was heated to a high enough temperature for a sufficient period that grain growth occurred. This zone contains a variety of microstructures and is the weakest area in a weld. Most weld joint failures occur in this zone.

Outside the heat affected zone is the parent metal that was not heated sufficiently to cause a change in its microstructure.

In an electrical resistance welded specimen, these changes are a result of localized rapid heating by the concentrated thermal energy from the narrow electrode, followed by rapid quenching from the surrounding cold parent metal.

WELDABILITY OF ORTHODONTIC ARCHWIRE ALLOYS

The alloys used in orthodontics are many and varied. Among the archwires stainless steel, beta titanium, nickel titanium and cobalt chromium are the predominant ones.

Opinions are divided on the joinability of Stainless steel. Stainless steel can be joined by soldering, but the technique may be demanding as high heat reduces the tensile strength, hardness and proportional limit of the wire. Also the soldered joint is subject to galvanic corrosion due to the presence of silver solder. Stainless steel wires can also be fused together by welding, but this generally requires reinforcement with solder.

Cobalt-Chromium-Nickel wires can also be soldered. But like stainless steel, welded joints must be reinforced with solder.

Beta titanium wires, Titanium Molybdenum Alloy (TMA) in particular, has been proven to be the only truly weldable archwire alloy available to the orthodontist. TMA was introduced to the orthodontic profession by Burstone.
and Goldberg. It allows direct welding of auxiliaries to an archwire without reinforcement by soldering. Welded joints of TMA wires have been shown to be able to sustain high torsional loads yet not fail in the mouth under clinical loading conditions. Unlike steel, where too much heat will produce softness in the wire, overheating of titanium could lead to brittleness of an energy-imparting spring or other component.

Conventional methods for dental soldering have not been used for titanium-based orthodontic wires such as NiTi, because of their high melting points and extremely high reactivity with oxygen at elevated temperatures. For joining titanium-based orthodontic wires, recent research has introduced the application of infrared soldering and laser welding under argon atmosphere. However, these techniques require expensive equipment. In contrast, electrical resistance welding is common in orthodontics, although the application is limited to thin sections of material, such as wires and molar bands.

Krishnan and Kumar conducted a study aimed at evaluating the two most commonly used orthodontic archwire alloys, stainless steel and beta titanium, and the newly introduced, Timolium, for their weld characteristics in terms of tensile strength, surface characteristics and microstructural changes. Beta titanium was the only one to show clinically useful weld joint strength values. The scanning electron micrographs of the welded area showed that the weld surface of beta titanium exhibited smooth flow of the melted alloy with an almost intact weld interface. Microstructurally, beta titanium wire exhibited a small weld area with characteristic nugget formation and no observable porosities at the joint surface. The study concluded that, beta titanium with superior strength, better surface characteristics, and metallographic features was ranked superior to the other two archwire alloys.

Donovan et al in their study have shown that beta titanium joints of adequate strength and ductility can be produced with the standard commercial welders available to the orthodontist. Based on a comparison of four popular welders they proposed optimum settings for welding beta titanium wires with each one of them. It was shown that only TMA can be welded to TMA; it is not possible to weld stainless steel to TMA.

**RECOMMENDATIONS FOR OPTIMAL WELDING**

1. Cleanliness of the wire and electrode surfaces is of primary importance. Transfer resistance increases when electrodes get dirty or alloyed with the welded material. Increased transfer resistance between electrodes and workpiece increases heat generation at their interface, which leads to more rapid wear and deposit build-up on the electrodes, decreased heat balance at the joint and smaller weld diameter.

2. The surface of each electrode must be smooth, flat and perpendicular to its long axis. When the electrodes are together, they should be in total contact. If not, they should be filed until total contact is achieved. Sparking and localized overwelding will result if interface contact is not uniform.

3. Select the proper electrode for the thickness or shape of the material to be welded. A broad electrode should be used for thin material and a narrow one for thick material. This will allow sufficient heat to reach the weld area, but not overweld or oxidize the weldmates. If too narrow an electrode is used in welding a bracket (thick) to a band (thin), localized overwelding will occur in the thin material and underwelding in the thick material.

4. Proper electrode selection—a broad electrode for thin material (band) in conjunction with a narrow electrode for the thicker material (bracket/molar tube) (Fig. 3)—will result in an even distribution of the weld nugget.

5. The flat-to-flat electrode configuration generally produces joints with considerably less distortion than is found with the point-to-point arrangement.

6. Higher energy settings are recommended for the flat-to-flat electrode configuration, as compared to the point-to-point arrangement, which follows from the relative differences in electrode contact area.

At the optimal settings the weld joints can sustain high torsional loads and maximum angular deflection without failure in the mouth. Use of very high voltage leads to premature or brittle failure adjacent to the weld joint. Below this rather narrow voltage range, specimens fail by delamination.

**CONCLUSION**

Weldability of orthodontic archwires is an important desirable characteristic. Although electronic spot welding is a commonly used procedure, the process is poorly
understood by many. This review brings into light the working of orthodontic welders, the variables affecting the weld joint and the weldability of different orthodontic archwire materials. Based on these factors suggestions are made for achieving an optimal weld joint for orthodontic purposes. Although orthodontic spot welders allow only partial control of the variables, application of the above basic principles will ensure a good weld joint.

REFERENCES