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# THE CLINICAL RELEVANCE OF ORTHODONTIC ARCHWIRE PROPERTIES: A REVIEW.

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**ABSTRACT**

Archwires are the active components of a fixed appliance through which forces are generated and consequently tooth movement is achieved. Recent advances in orthodontic wire alloys have resulted in a varied array of wires that exhibit a wide spectrum of properties. Presently the orthodontist may select from all the available arch wires one that best meets the demands of a particular clinical situation and the efficiency of the operator. The selection of appropriate wire in turn would provide the benefit of optimum and predictable treatment results. The clinician must therefore be conversant with the difference in the mechanical properties and clinical application of this various types of wires

***KEY WORDS*: Orthodontic wires, Arch wires, mechanical properties, Clinical application**

## INTRODUCTION

Assessment of orthodontic archwire properties is based on a few, but well recognised ex - vivo bench tests. Although this bench tests are essential for assessment of material properties, it does not necessarily follow that these properties are mirrored in vivo. In an attempt to provide clinical meaning to much of the recent in-vitro testing, Andreason and Morrow (1998)[1]and Gold berg and Burstone (1979)[2] Burstone and Gold berg (1980)[3] and Kapila and Sachadeva (1989)[4] have described a number of characteristics of archwire which are desirable for optimum performance during treatment.

The mechanical properties of an archwire are an important consideration in the construction of an orthodontic appliance. Incorporated into the archform are certain characteristic bends which, as the wire is pinned to the teeth becomes activated i.e., stresses are produced in within the wire and these generate force which act on the teeth. The magnitude and continued application of the resolved sum of these forces are vital for effective functioning of the appliance. For maximum control of the anchorage and efficient tooth movement, it is necessary for the arch wire to remain active for many months. The appliance is continuously subjected to masticatory forces, so the wire must be sufficiently resilient to resist permanent deformation and maintain its activation.

The three basic properties of wire which describe load deflection characteristics are[5],

a) Strength
b) Stiffness
c) Spring back

The other properties are formability, frictional resistance, Resilency corrosion resistance, joinability etc..,

Strength, stiffness and range are the properties based on only the linear portion of the stress- strain curve. They are inter related as shown in the following formula.[6]

**Strength = Stiffness X Range.**

**Strength:** Strength is a force value that is a measure of the maximum possible load, the greatest force that the wire or the arch arrangement can sustain/ deliver if it is loaded to the limit of the material.[7]

Three different parts on the stress / strain diagram can be taken as representative of the strength of a material, each represents in a some what different way i.e. the yield strength, proportional limit and ultimate tensile strength ***( Fig. 1)***. Whenever a wire is loaded along its long axis deflection in produced. when this load - deflection ratios are converted to stress - strain which are independent of the geometry of the wire, stress - strain curves are obtained.[4,7]

In the region where stress is proportional to the strain, the material behaves elastically. If the applied load is removed at any point during elastic deformation the strain would return to zero. The ratio of stress to strain in the linear portion of the curve is elastic modulus[6,7].

The value of stress where direct proportionality between stress and strain ceases is known as proportional limit. Deformation of the wire beyond the proportional limit involves both elastic and plastic strain. On release of the load, the elastic strain is recovered, but the sample will exhibit permanent deformation. Orthodontic wires in the as - received condition is heavily deformed so that the transition from elastic to plastic deformation is not accompanied by a marked change of the slope in the stress - strain curve[7].

Yield strength is that value of stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Thus yield strength of material is the ability to resist plastic deformation. In materials where the proportional limit or the elastic limit is less obvious it is common to define the yield strength as that force required to give 0.2 % plastic offset. In other words yield strength is defined in the stress required to produce an arbitrary permanent deformation. The deformation most used is 0.2 % and the strain corresponding to the yield strength is called as yield strain.[7]

Three different criteria can be used to characterise the resistance of a wire to permanent deformation.[5]

a) The maximum elastic stress.
b) The maximum elastic strain.
c) The maximum stored energy.

For maximum elastic stress, the superior wire is the one which will resist the greater applied load without becoming permanently deformed. This property is susceptible to minor variations in wire diameter and can be improved by even a small increase in the guage of the wire[5].

In the case of maximum elastic stress the superior wire in the one which can be deflected further before becoming permanently deformed. In this case a small reduction will improve the performance of the wire.[5] The problem with this criteria is that while the orthodontist is interested in a wire which will perform well in both respects each is susceptible to minor changes in wire diametre.[5]

Ultimate Tensile strength refer to the force needed to fracture the material. Tensile strength or ultimate strength is the maximum point shown on the stress - strain curve. It is the ratio of maximum load to the original cross sectional area of the wire. The ultimate tensile strength of the orthodontic wires may be equated with the braking strength.[8]

**Stiffness or load deflection rate:** This is the force magnitude delivered by an appliance and is proportional to the modulus of elasticity and cross section of a given archwire. Elastic modulus is the ratio of stress to strain with in elastic limit also called as young's modulus of elasticity(E).[4] It represents the magnitude of force delivered by an archwire at a given deflection. This relates to the slope of force / deflection curve[1]. For any curve the more for horizontal the slope the springier the wire and conversely the more vertical the slope, the stiffer the wire.[3]

A wire of low elastic modulus will deform elastically to a greater extent under a given load than will a wire of the same dimensions and elastic limit but with a higher elastic modulus. It is clear that wire exhibiting a high modulus of elasticity should be avoided in the initial alignment phase, since they deliver high force at very small deflection and over a short span during deactivation.[5]

A low stiffness is desirable as its provides [9]

1) the ability to apply lower forces.
2) more constant force over time as the appliance experiences during deactivation.
3) greater case and accuracy in applying a given force. However a wire with high stiffness is advantages in resisting deformation caused by extra and intra oral fractional forces.

The elastic modulus (E) depends on the anatomic structure and appears to be only marginally effected by cold working and heat treatment. Further more the elastic properties of a wire will altered to a variable extent by cold working (at the expense of ductility) and heat treatment [5].

For a given appliance component where the design, length and cross section of wire are constant, the lower the value of 'E', the lower the load required for a given deflection.[5]

However although the value of 'E' does vary by a small amount between different orthodontic stainless steel wires, small differences in cross sectional area may have a large effect on stiffness. Thus the load deflection characteristics of a component are controlled either by using a wire of different guage or by altering the design of the component.[5]

***Spring back*** *:* This is also referred to as maximum elastic deflection, maximum flexibility range of activation , range of deflection , working range or maximum elastic strain.[4]

If a wire can be deflected over long distances without permanent deformation, it has a high spring back value. This is related to the ratio of yield strength to elastic modulus [S/E]. Higher spring back values provide the ability to apply large activations with a resultant increase in working time of the appliance. This in turn implies that fewer arch wire changes or adjustments will be required. Spring back is also a measure of how far a wire can be deflected without causing permanent deformation. This property also depends upon the maximum elastic strain. Higher the values of elastic strain, the wire can be deflected further before becoming permanently deformed. The wire should be sufficiently flexible to apply light forces over a wide range of deflection[5].

Working range is defined by Thurow [6] as a measurement how a far a wire can be bent without exceeding the limits of a material or how far a wire can potentially move a tooth by single adjustment. It is a measure of distance without regard to the force that is required to accomplish the deflection.

Elastic compliance [C] is the reciprocal of modulus of elasticity and is related to the flexibility of the archwire.[10]

Two groups of factors determine the effective range of the wire in clinical situation. The first group consists of wire's cross sectional shape, size - both cross sectional and overall arch form, the archwire design and the physical properties of the alloy constituting the wire. The other group consists of bracket geometry frictional resistance, mode of securing the arch wire to the bracket and effective inter bracket span. Deformation from the occlusal load is sometimes a significant factor to consider.[10,11]

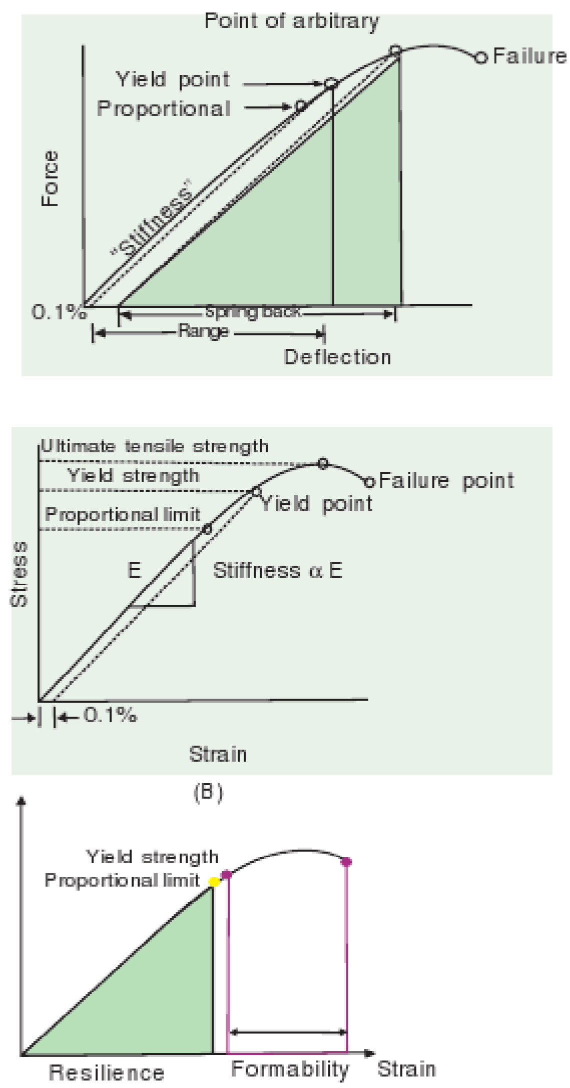


**Fig.1** Properties of orthodontics wire – Load deflectio

**Resilence [ Maximum energy or Spring energy ]** This represents the work available to move teeth. This represents the area under stress strain curve at the given maximum. The ability to provide energy for work during deactivation depends on the ability of the wire to perform perfect elastically, with no permanent set. If a material exceeds its yield point during bracket engagement, recovery is unlikely. Amount of elastic energy stored in a body when one unit volume of the material is stressed to its proportional limit is given by modulus of resilency [inch - pounds / inch$^3$].[10]

If two wires have similar elastic modulus (E), then there is a proportionality between the tensile strength and maximum stored energies.The wire which will more resistant to deformation in the mouth will be the one which has high values for maximum stored energy.[11]

**Stress relaxation:** In order to move teeth an orthodontic appliance needs to exert force over a period of time. The archwire is one component of the orthodontic appliance which provides stored energy for tooth movement. In the clinical situation forces exerted with the arch wire may vary with time because of tooth movement and stress relaxation. Stress relaxation occurs when stress decreases over time at a constant amount of total strain. This is conversion of elastic strain into plastic strain which can be measured as an increase in permanent deformation over time. Stress relaxation also results in a decrease in stored energy (resilency) in the wire. Clinically, a decrease in force and stored energy may lead to a decrease in the amount of tooth movement.[12]

Stress relaxation behaviour of orthodontic wire can be studied either by measuring the decrease in stress or increase in permanent deformation over time (creep deformation). In the clinical situation, if the wire used for tooth movement has under gone creep deformation, more frequent activation and arch wire changes may be required.[11,12]

**Friction:** Friction is defined a force tangential to the common boundary of two bodies in contact that resists the motion or tendency to motion of one relative to other. Sliding mechanics in orthodontic treatment involves the relative movement of brackets over an archwire. This type of movement generates frictional forces that must be overcome to elicit periodontal response for tooth movement. Therefore understanding frictional forces between the brackets and the wire is essential for adequate tooth movements and optimum biological response[12].

The classical laws of friction state that a frictional force is (1) proportional to the force normally acting at the contact (2) independent of area of contact (3) independent of the sliding velocity . Whenever a bracket is sliding along an archwire these laws imply that any friction arises from the force normally acting on the points of contact possible components of this force (1) engagement of the archwire in brackets that are out of alignment (2) ligatures pressing the archwire against the base of the slot (3) active torque in rectangular wire (4) bodily movement in which the tipping tendency is resisted by two point contact between the bracket and archwire. The relative magnitude of these components of the frictional force may vary according to the clinical situation. Clinical decision at each stage, such as choice of an archwire and method of ligation, also influence the frictional force.[12]

The maximum value of static frictional force (before motion) and kinetic frictional force ( during motion) is the product of its respective coefficient and resultant normal force [$F = \mu N$}.[14]

F = frictional force
$\mu$ = coefficient of friction
N = normal force

The value of coefficient of static and kinetic friction ranges from zero to one and dependent upon the relative roughness of the contacting surfaces. The kinetic coefficient of friction is lesser than static coefficient of friction[14].

This frictional force is always parallel to the surface in contact and its magnitude is dependent upon the amount of normal (perpendicular) force pushing the two surfaces together[14]. Since this frictional force is operating in opposite direction to that of intended motion, it is important that such force should be eliminated or minimised during orthodontic tooth movement is being planned.[14,15]

The coefficient of friction is a constant or any given two materials. The relative roughness of two surfaces in contact is an important consideration in friction and is largely dependent upon the absolute roughness of the individual surfaces.[11,13]

Surface roughness is characteristic of [13] :

(1) The material itself
(2) The manufacturing process (polishing, heat treatment etc.)
(3) Shelf and/or use time if the surface has imperfect resistance to deterioration, corrosion, creep and relaxation etc.

Another important factor to be considered in bracket wire sliding friction resistance is the stiffness of archwire because of its influence on the resultant normal force. Friction increases as the stiffness of wire increases. Friction as a result of two point contact is largely independent of wire stiffness (or) cross section. However, with brackets out of alignment strongly influences the forces normal to the points of contact and hence friction. In a well aligned arch forces that result from archwire deflection are not important and friction is largely independent of archwire stiffness. Ligation of archwires to the brackets also influences the friction.[14]

Tooth movement relative to an arch wire requires minimum friction. This friction is proportional to the force of contact and nature of the surface at the bracket / wire interface. Excessive amounts of bracket / wire friction may result in the loss of anchorage or binding accompanied by little and no tooth movement. The preferred wire material for moving a tooth relative to the wire would be one that produces the least amount of friction at the bracket / wire interface.[3]

**Formability:** This is the ability to change the shape of a material into a required configuration such as loops, coils and stops without the fracture of the wire. "This property again depends upon the elastic strain. Lower the values of elastic strain for a given wire means the wire will be easiest to form to a given shape. Thus a wire which has low resistance to permanent deformation is the easiest one to form.[5]

**Bio compatibility and enivornmental stability:** Since arch wires are in close proximity to the oral mucosa for lengthy periods they should be resistant to corrosion and should not elicit an allergic response. Environmental stability ensures the maintenance of desirable properties of the arch wire for the extents periods of time after manufacture. This, in turn ensures a predictable behaviour of the wire then in use[4].

**Joinability:** This represents the case of auxillary attachment either by soldering or welding.[3]

**CONCLUSION**

From the ongoing conclusion it is clear that an orthodontist should be well versed with the clinical application of the physical properties of different orthodontic wires and the selection should be made on the type of malocclusion and the clinical situation. wires should always be selected for their combined properties not just one single characteristic. Though a wire might have a tremendous working deflection range, the force it is capable of delivering must also be considered in selection of an archwire.

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