***Original Research Article***

# The Annealing Effects on the Modulus of Elasticity Properties of Different Varieties of Orthodontic Wires – In Vitro Study


## Abstract

**Aim and Objectives**: The main purpose of this study was to define the outcome of annealing on the modulus of elasticity of Heat-activated nitinol, Super elastic nitinol, Stainless Steel, Beta -titanium (TMA), and Cooper nitinol wires. Specific points were tested beside the wire to define how distant from the annealed ends the modulus of elasticity of the wires was affected. **Methods**: Seventy-Five orthodontic wires consisting of Five groups of Heat Activated Nitinol, Super Elastic Nitinol, and SS/TMA/Copper Nitinol were utilized for this in vitro study. The wires measurement and markings were done by 5mm, and all the wires were sectioned into 33.00 mm. The gas torch was used to heat the wires until the first 13.00mm wires were seen red hot. We contended load-deflection tests using an Instron® testing machine at 5mm distances from the end of the wire where annealing is performed and then determining variation in modulus of elasticity. **Results:** Two-way ANOVA test was done, and the results showed. Concluded that there were significant differences in the change in modulus of elasticity among the parts of the wires in the annealed segment. Stainless Steel wire had the highest primary elastic modulus, Beta Titanium (TMA) wire, Heat Activated Nitinol, Super Elastic Nitinol, and Heat-activated Nitinol had the lowest modulus of elasticity in the Annealed section of wire 8.0/13.0/18.0/23.0mm. **Conclusion:** There were significant variances in the change in modulus of elasticity among the portions of the wires in the annealed segment. The parts were 5mm and 10mm further from the annealed section. The difference in elastic modulus within the annealed area was significantly more significant at 8 mm than at 13mm. There was considerably greater than 18mm and 23mm and 5mm and 10mm past the annealed segment, separately. Stainless steel showed the biggest changes in elastic modulus throughout annealing and breakages of the wire were compared to the other orthodontic wires.



**Key Words:** Annealing, Heat-activated nitinol, Superelastic Nitinol, Stainless Steel, Beta - Titanium (TMA), Modulus of Elasticity, The Load deflection rate


## 1. Introduction

Optimum control of tooth movement entails the application of precise orthodontic force systems(Goldberg, Vanderby & Burstoane)[1]. Preformed archwires in applied Orthodontic Practice have been developed significantly since technology elaborated in producing wires by different Manufacturers worldwide. Characteristic features of the wires are substantial to the success of the treatment and selecting the wires with specific properties during the various stages of the orthodontic treatment (John D. Verhoeven,1975)[2]. The modulus of elasticity is the tendency for an object to be deformed elastically when force there is a force applied to be defined as the slope of the object's stress-strain curve in the elastic deformation region. The development of technology produces different types of metal wires such as Heat-Activated Nitinol, Super-elastic, Beta titanium (TMA), and Copper-nitinol wires with other mechanical properties. Stainless steel wire has exceptional mechanical properties, easy to form, has High stiffness, and has low prices. Nickel-titanium wire has shape memory properties, which can yield to its original shape without distorting the wire. Beta- Titanium (TMA) wire substitutes Stainless steel and Nickel-titanium wire because it does not contain nickel. The orthodontist can practice it in patients with hypersensitivity to nickel metal, Hong-Po Changab, Yu-ChuanTsengac [3] 2018. Nickel-titanium with a significant addition of copper component can produce shape memory properties, and the wire will become active at a specific temperature. Ideal Requirements of wires should be easy to mold with high elastic modulus, less stiffness, less resilience, large spring back, non-toxic, corrosion resistance, and less friction mechanical properties (Verhoeven, J.D. 1991) [4]. Light wire with a low modulus of elasticity, high spring back, and less constant force delivery should be applied in the early stages of tooth alignment. The modulus of elasticity tends an object to be deformed elastically when a significant force is applied (Burstone CJ) [5]. During several stages of treatment, it is substantial for the wire to be cinched back in the most posterior tooth to prevent the anterior teeth from flaring up the wire and sliding through the most posterior attachment of the buccal tube to deflection of the archwire. During the function, the annealing procedure occurs in stages, and it uses heat to generate a more workable material t uses heat to generate a material more workable. When heating increases, the rate of diffusion increases and issues the energy to disrupt the bonds. In the first phase of the procedure, recovery marks the softening of the metal by removing displacements beside internal stresses. In the second phase, recrystallization happens when strain-free grains develop, placing the grains where the internal stresses have deformed. In the third phase, grain growth occurs as the microstructure becomes thicker, making the metal misplace a substantial amount of its original strength [6]. In extraction cases, the essential wire is rigid enough when the bodily movement of the teeth through the extraction is spaced to avoid tipping. For minimal resistance, the wire should have a low coefficient of friction to allow the teeth to move during the treatment. To maintain a good torque during the retraction of the anterior teeth. It is necessary to have the correct dimensions of the rectangular wire. Throughout the finishing stages of treatment, the wire should be formable and receive bends to achieve the esthetic and functional effect. The diffident experimental precision of the above test plans inhibits them from being able to line the true values of the test material's modulus of elasticity. For comparison, it may be noted that the ISO standard has as a requirement that the measured modulus of elasticity for linear materials is within the range claimed by the manufacturer, using the same test, which involves three-point bending on a 10mm span, at 23 ◦C [7]. The objective of this study was to conclude the impact of annealing on the modulus elasticity of Heat Activated, Nitinol, Super Elastic nitinol, Stainless Steel, Beta-titanium (TMA), Copper-Nitinol wires. To define how distant the annealed ends are and to conclude the elastic modulus of the different types of orthodontic wires, which is affected after the annealing process.

## 2. Material and Methods

### 2.1 Procedures

Seventy-five samples of wires were divided into five groups Heat Activated Nitinol, Super-elastic Nitinol, Stainless steel, Beta –Titanium (TMA), and Copper Nitinol (Damon) wires, with each group having both annealed end and unannealed samples (Fig 1). One end of each archwire was used as a sample of annealed and one term for a sample of an unannealed. All the archwires were provided by Trueform - I - G&H Orthodontics and were 0.17 x 0.22 inches in dimension. Before any testing, distances of 3.00/8.00/13.00/18.00/23.00mm were measured from the end of the wire using a Digital calliper (Fig.3) and marked using a fine-tipped marker. These marks indicated the beginning of the annealed section (3mm), the middle of the annealed area (8mm), the end of the annealed section (13mm), 5mm past the annealed section (18mm), and 10mm past the annealed area (23mm). Load deflection tests were performed at all of these distances (8.00/13.00/18.00/23.00mm) using an Instron® machine Model no. 3366 (Fig 2) at Central Institute of Plastics Engineering and Technology CIPET Mysuru, Karnataka India. The load-deflection test done was at 3 pinpoints at these different distances along the wires. A stopwatch has been used to monitor the amount of time that the wire was exposed to the flame. A device might also have been fabricated to allow the flame to travel along with the distance of the annealed section at a constant rate, and a thermometer is used to frequently monitor the temperature while annealing the wires. The measurements were made for the duration of loading the wires. The first 13mm of the end of the wires was the annealed section of the wires.

**2.2 Wires have been divided into Five Groups** :

| | |
|---|---|
| **Group - 1** | Heat Activated Nitinol |
| **Group - 2** | Super-elastic Nitinol |
| **Group - 3** | Stainless Steel |
| **Group - 4** | Beta – Titanium (TMA) |
| **Group - 5** | Copper Nitinol (Damon) |

**Table 1**: Five different types of orthodontic wires

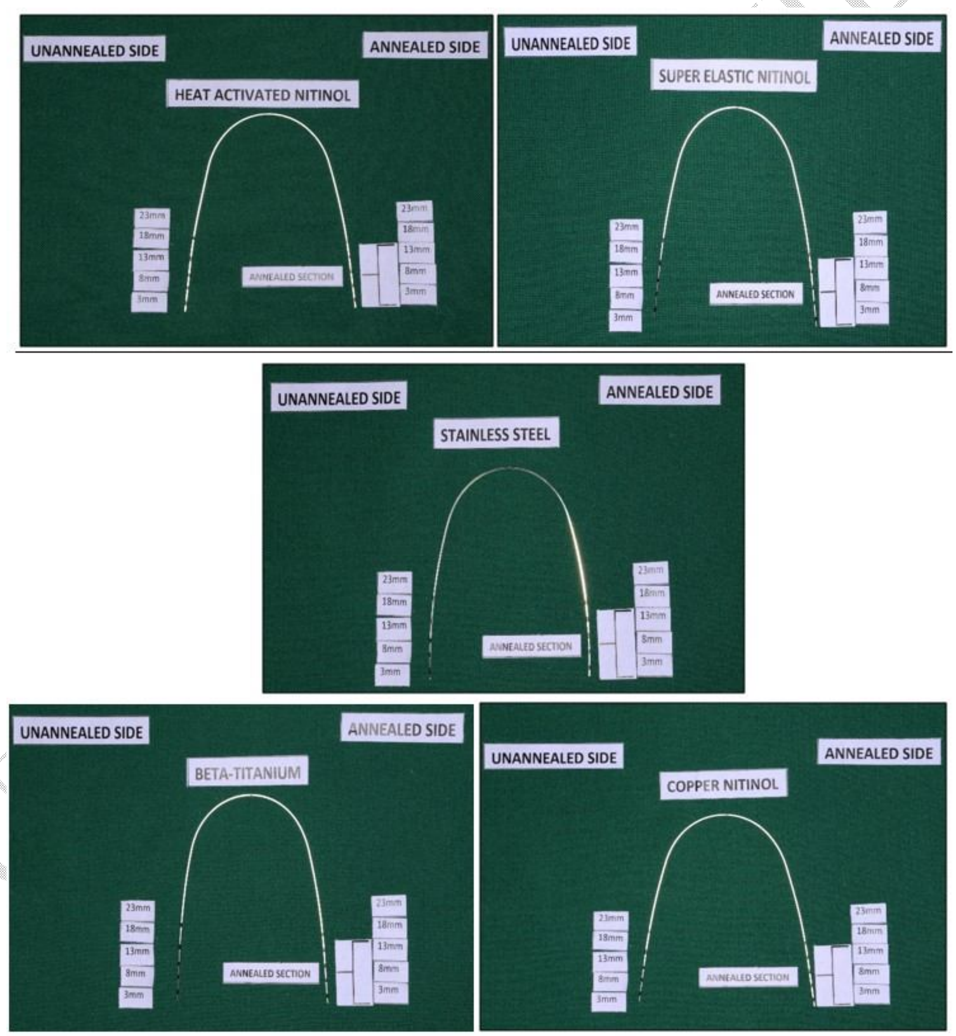



**Figure 1** – Archwires divided into 5 Groups a. Heat Activated Nitinol® b. Super-elastic Nitinol® , c. Stainless Steel, d. Beta Titanium and e. copper Nitinol® Annealed and Annealed sides with different measurements on both sides

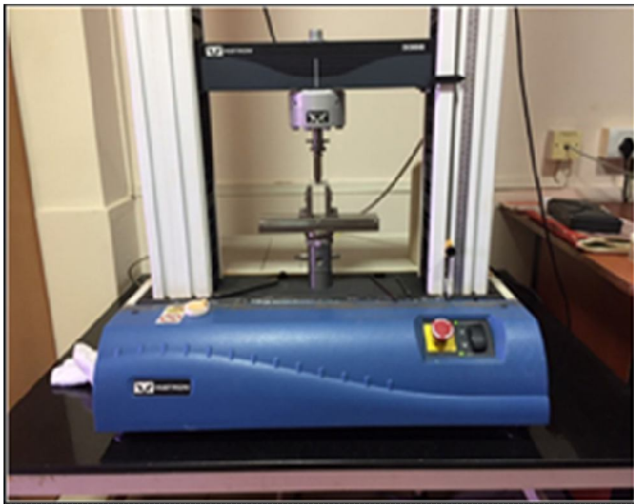


**Figure 2 –** Load deflection rate test was conducted in Instron® Machine Model no. 3366 used to test each wire with a 3-point method (CIPET) mysuru**.**

It regulated the electronic motor of the Instron machine before starting eight measurements each of all 75 samples. Before testing, it sectioned each wire to a total length of 33mm to avoid the wire from touching anything except the 3 points being tested. This allows the archwire to be divided into annealed and unannealed sections of wire. Each examination of the wire was placed 13 precisely in the middle front to back and side to side of the text block, and the crosshead was loaded to 0.1N. So that it just touches the wire. All wires were bent to 3mm with a 5mm/min +/- 0.100mm/mm crosshead speed. For the samples of annealed wire, a gas torch was used for annealing the end of the wire for a total distance of 13mm. To retain the heat source steady the temperature of the wires was held at a distance of 22mm from the end of the torch while annealing.

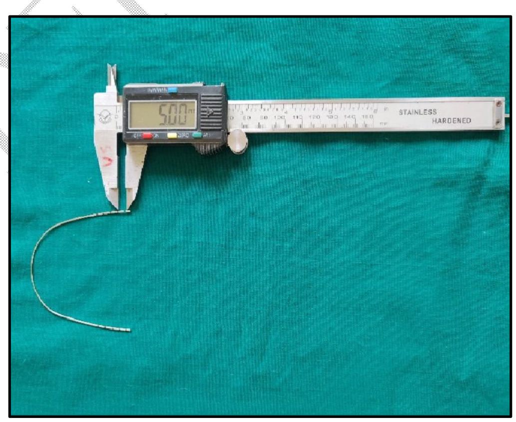



**Figure 3**: Digital Caliper is used to Measure the Annealed section of the wire (3/8/13/18/23mm).

This distance was measured at each end of the wire earlier to annealing to ensure that all wire fragments remained 22mm from the end of the torch. After each test was accomplished, the elastic modulus was calculated. It identified two points along with the graph in the flexible portion to indicate the slope of the curve. These points were used for the program to calculate the modulus of elasticity. All unannealed values were subtracted and calculated from annealed values to conclude the changes in the modulus of elasticity.

### 2.3 Statistical Analysis

A two-way ANOVA test was used to define if there were any significant changes in the modulus elasticity of the Five types of wires (Heat-activated Nitinol wire, Super-elastic Nitinol wire, Beta Titanium (TMA) wire, and Stainless steel wire. Four different distances measured values (8/13/18/23mm) Table 2. Finally, a test was concluded to examine the interaction between distance and wire types. All statistical analyses were implemented using the IBM® SPSS® 28 - 2021. A p-value of 0.05 was considered significant.

## 3. Results

Stainless Steel wire had the highest primary elastic modulus, followed by Beta Titanium (TMA) wire, finally, Super Elastic Nitinol, Heat-activated Nitinol, and Copper Niti had the lowest initial elastic modulus ( Table 2 and Figure 2) in the Annealed section of wire 8.0/13.0/18.0/23.0mm. The Annealed part of the Elastic Modulus of the wires ( Table 1 and Figure 1) graph showed the ordering of the wire same as the initial elastic modulus of the wire. There was a significant difference in (F=3.208 and P=0.0005) in elastic modulus of Annealed and elastic modulus of unannealed wire among all the five wires stainless steel had the change in elastic modulus Mean = 1.88mm and Standard variation of 0.614,( Table 3 and Table 6 and Figure 3), which Beta Titanium trails with a mean difference of 1.65 mm and standard deviation of 0.488mm (Figure 4) and Heat Activated Nitinol, Superelastic Nitinol there was no significant difference in this two wires but Copper Nitinol (Table 2 and Figure 1,2 and 5) with a lowest mean difference and Standard deviation. There was a significant difference in distance (F = 2.293, p = 0.0005) in the change in elastic modulus of (Elastic Modulus of annealed and Elastic Modulus of unannealed) between the four distances (See Table 3/ Figure 3). In the middle of the annealed section (8mm), the change in Elastic modulus was 1.5elastic modulus increase thanly greater increase in elastic modulus than for all other distances. At the end of the annealed section (13mm), the change in Elastic Modulus was 1.65+/-1.73mm Which means a change was significantly greater than for 5mm and 10mm past the annealed section (18mm and 23mm). There was no significant difference for change in EM between 18mm (1.49+/-1.56) and 23mm (1.23-1.58). Stainless steel showed the modulus of elasticity for ststresssteel wires which showed 23,000,000 to 29,000,000 Pounds per square inch ( Psi) (Figure 6) and 199.95 Great point Average (GPA), followed by Copper Nitinol wire compared to other wires (Figure 7). Homogeneous subsets test shows Copper Nitinol and Superelastic Nitinol shows same Mean and Heat-activated, Beta – Titanium (TMA) and Stainless Steel have different Mean. There was a significant interaction (F = 61.9288, p = 0.005) between the wire types and distance, however, this interaction negated the differences between the wires since the changes didn't occur at all distances. The mean change in elastic modulus of the four wires was different at 8mm and 13mm within the annealed section, but this is clinically immaterial since this is a non-working portion of the wire. Figure 10 shows the entire interaction between the wire types and distance. Figure 10 a shows the interaction that takes place between 18mm and 23mm. There is an interaction between the change in the modulus of elasticity for SS and TMA at those distances. At 18mm, SS had the greatest change in elastic modulus (1.84 +/- 3.58) and TMA had the smallest change (-0.43 +/- 2.62), whereas at 23mm, SS had the smallest change in elastic modulus (-1.32 +/- 3.20) and TMA had the greatest change (0.50 +/- 2.21) (See Table 4). Stainless steel showed highest Mean = 2.0400 significant-1.000, followed by Beta- Titanium (TMA) Mean = 1.6743.

1. **Initial Elastic Modulus of Different types of wires (Gpa)**

| Wire Type | Mean | SD |
|---|---|---|
| **Heat Activated** | 53.44 | 16.74 |
| **Super Elastic** | 48.53 | 9.34 |
| **SS** | 189.74 | 11.91 |

| | | |
|---|---|---|
| **TMA** | 72.52 | 9.44 |
| **Copper Niti** | 44.83 | 10.37 |

**Table 2:** Initial elastic Modulus of unannealed different wire

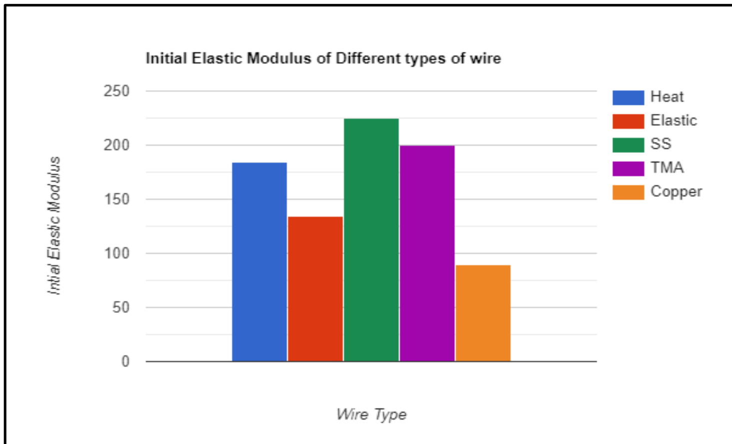



**Figure 4:** Initial Elastic Modulus of different types of wire (Gpa)

## 2. Annealed Elastic Modulus in Different Wire Types (GPa)

| Wires | Mean | SD |
|---|---|---|
| **Heat Activated** | 45.46 | 1.13 |
| **Superelastic** | 39.45 | 0.93 |
| **SS** | 176.67 | 3.89 |
| **TMA** | 64.49 | 1.91 |
| **Copper** | 26.90 | 0.59 |

**Table 3:** Annealed part of elastic modulus of different types

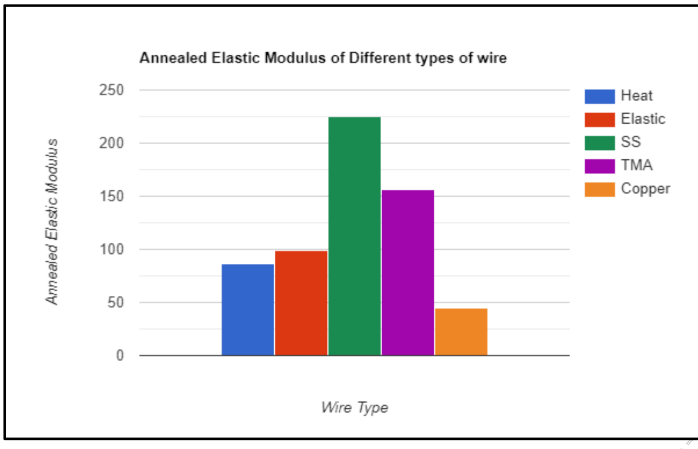



**Figure 5:** Annealed Elastic Modulus of different types of wire

**3. Two-way paring the Elastic Modulus Differences for Distance/Wire Type/and Their Interaction**

| Variable | Mean | Standard Deviation | F | P |
|---|---|---|---|---|
| **Wire Type** | | | | |
| Heat Activated | 1.28 | 0.994 | | |
| Super Elastic | 1.51 | 0.459 | | |
| SS | 1.88 | 0.614 | 3.208 | 0.0005 |
| TMA | 1.65 | 0.488 | | |
| Copper Niti | 1.46 | 0.653 | | |
| **Distance Type** | | | | |
| 3 | 1.61 | 0.647 | | |
| 8 | 1.57 | 0.528 | | |
| 13 | 1.65 | 0.569 | 2.923 | 0.0005 |
| 18 | 1.49 | 0.557 | | |
| 23 | | | | |
| **Distance x Wire Type** | | 61.9288 | 0.0005 | |

**Table 4** - Elastic Modulus Differences for Distance/Wire Type/and Their Interaction

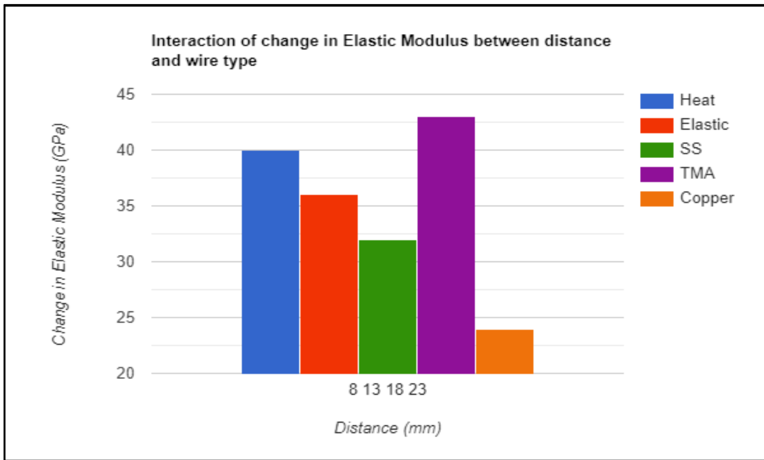



**Figure 6:** Interaction of changes in different types of wire in Elastic Modulus between a distance of the wire and type (Distance by mm)**.**

**4. Elastic Modulus between Different Wire Types at Different Distances**

| | 8mm | SD | 13mm | SD | 18mm | SD | 23mm | SD |
|---|---|---|---|---|---|---|---|---|
| **Stainless steel** | 2.10 | 0.441 | 2.14 | 0.714 | 1.90 | 0.790 | 1.88 | 0.268 |
| **TMA** | 1.76 | 0.563 | 1.76 | 0.572 | 1.80 | 0.407 | 1.65 | 0.276 |
| **Copper Nitinol** | 1.41 | 0.571 | 1.53 | 0.390 | 1.29 | 0.564 | 1.57 | 1.145 |
| **Heat-activated Nitinol** | 1.36 | 0.307 | 1.36 | 0.423 | 1.25. | 0.397 | 1.34 | 0.344 |
| **Super elastic Nitinol** | 1.52 | 0.380 | 1.64 | 0.179 | 1.46 | 0.326 | 1.44 | 0.532 |

**Table 5** - Changes in Elastic Modulus between Different Wire Types at Different Distances

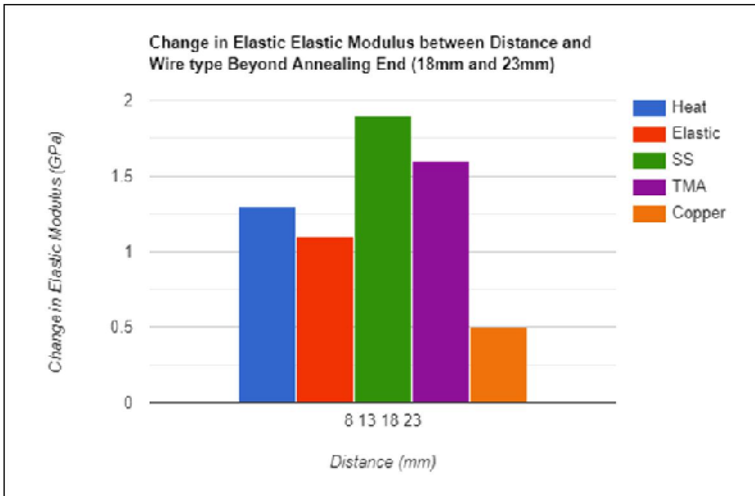



**Figure 7**: Interaction in Elastic modulus between distance and type of wire beyond annealing end 18mm and 23mm



**5. Analysis of Univariate Variance between the Subjects Factors**

| | | Value Label | N |
|---|---|---|---|
| | 1.00 | Heat activated Nitinol | 75 |
| | 2.00 | Super elastic Nitinol | 75 |
| **Groups** | 3.00 | Stainless steel | 75 |
| | 4.00 | Beta-titanium | 75 |
| | 5.00 | Copper Nitinol | 75 |
| | 1.00 | | 75 |
| | 2.00 | | 75 |
| **VAR00001** | 3.00 | | 75 |
| | 4.00 | | 75 |
| | 5.00 | | 75 |

**Table.6**: Univariate analysis variance between the groups

**6 . Unnaealed samples of Five different wires the four different distances measured values**

| Groups | Annealed Samples | Mean | Std. Deviation | N |
|---|---|---|---|---|
| **Heat-activated Nitinol** | 3.0mm | 1.27 | 0.515 | 15 |
| | 8.0mm | 1.36 | 0.307 | 15 |
| | 13.00mm | 1.19 | 0.423 | 15 |
| | 18.0mm | 1.25 | 0.379 | 15 |
| | 23.0mm | 1.34 | 0.344 | 15 |
| | Total | 1.28 | 0.394 | 75 |
| **Super elastic nitinol** | 3.0mm | 1.51 | 0.722 | 15 |
| | 8.0mm | 1.52 | 0.380 | 15 |
| | 13.00mm | 1.64 | 0.179 | 15 |
| | 18.0mm | 1.46 | 0.326 | 15 |
| | 23.0mm | 1.44 | 0.532 | 15 |
| | Total | 1.51 | 0.459 | 75 |
| **Stainless steel** | 3.0mm | 2.16 | 0.722 | 15 |
| | 8.0mm | 2.10 | 0.441 | 15 |
| | 13.00mm | 2.14 | 0.714 | 15 |
| | 18.0mm | 1.90 | 0.790 | 15 |
| | 23.0mm | 1.88 | 0.268 | 15 |
| | Total | 2.04 | 0.615 | 75 |
| **Beta-titanium** | 3.0mm | 1.64 | 0.581 | 15 |
| | 8.0mm | 1.76 | 0.563 | 15 |
| | 13.00mm | 1.76 | 0.572 | 15 |
| | 18.0mm | 1.54 | 0.401 | 15 |
| | 23.0mm | 1.65 | 0.276 | 15 |
| | Total | 1.67 | 0.488 | 75 |
| **Copper Nitinol** | 3.0mm | 1.48 | 0.305 | 15 |
| | 8.0mm | 1.41 | 0.571 | 15 |
| | 13.00mm | 1.53 | 0.390 | 15 |
| | 18.0mm | 1.29 | 0.564 | 15 |
| | 23.0mm | 1.57 | 1.145 | 15 |

| | | | | |
|---|---|---|---|---|
| | Total | 1.46 | 0.653 | 75 |
| **Total** | 3.0mm | 1.61 | 0.647 | 75 |
| | 8.0mm | 1.63 | 0.528 | 75 |
| | 13.00mm | 1.65 | 0.569 | 75 |
| | 18.0mm | 1.49 | 0.557 | 75 |
| | 23.0mm | 1.58 | 0.622 | 75 |
| | Total | 1.59 | 0.586 | 375 |

**Table. 7**: ANOVA Comparison between, Unnaealed samples of Five different wires the four different distances measured values (8/13/18/23mm)

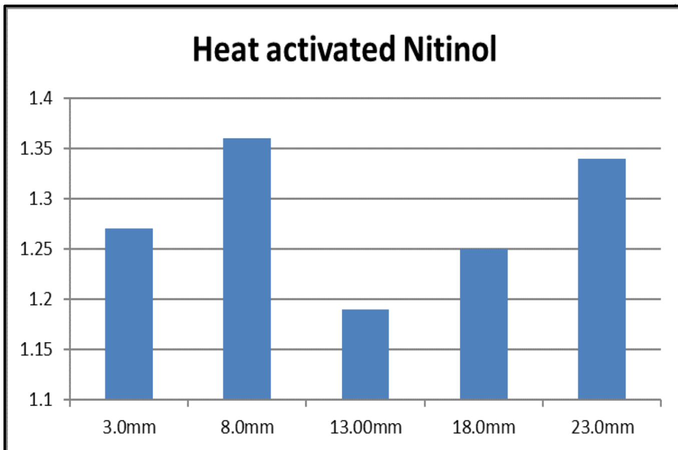



**Figure 8**: Graphs show samples of activated Nitinol wire shows higher distance measured values 8.00mm by 1.35mm

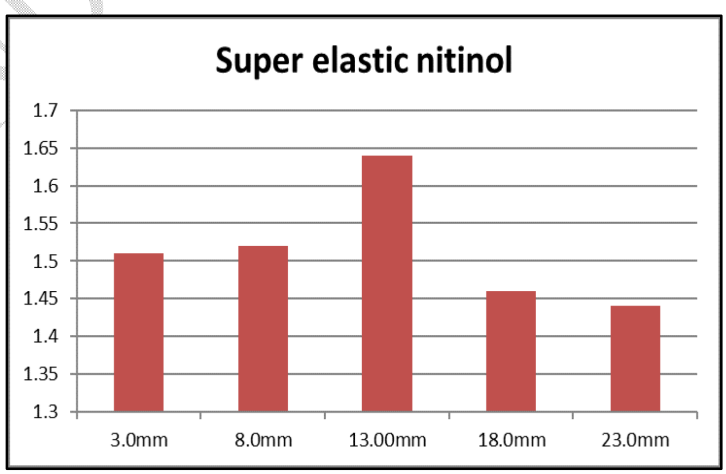
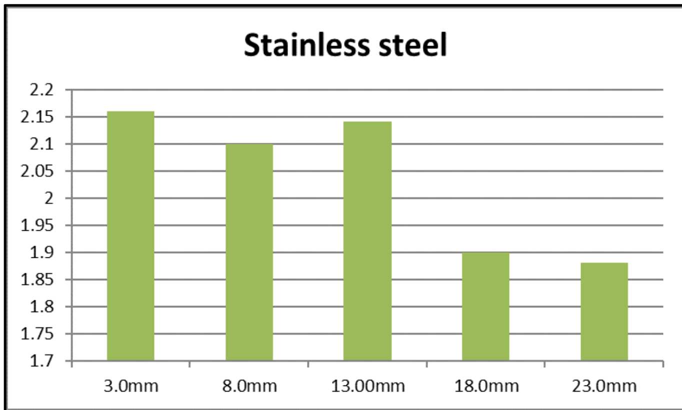


**Figure 9**: Graphs show samples of elastic Nitinol wire show higher distant measured values of 8.00mm by




1.60mm

**Figure 10**: Graphs show samples of Stainless steel wire shows the highest distance measured values of 3.0mm by 2.15mm, 8.0mm by 2.10mm, and 13mm by 2.10mm compared to other types of wires

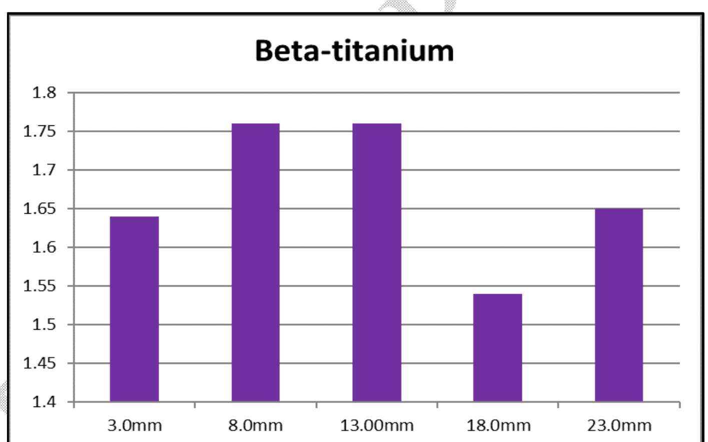



**Figure 11:** Graph shows a sample of Beta titanium (TMA) wire shows the highest distance measured values of 8.00mm by 1.75mm and 13.00mm by1.75mm but lowest to SS wire.

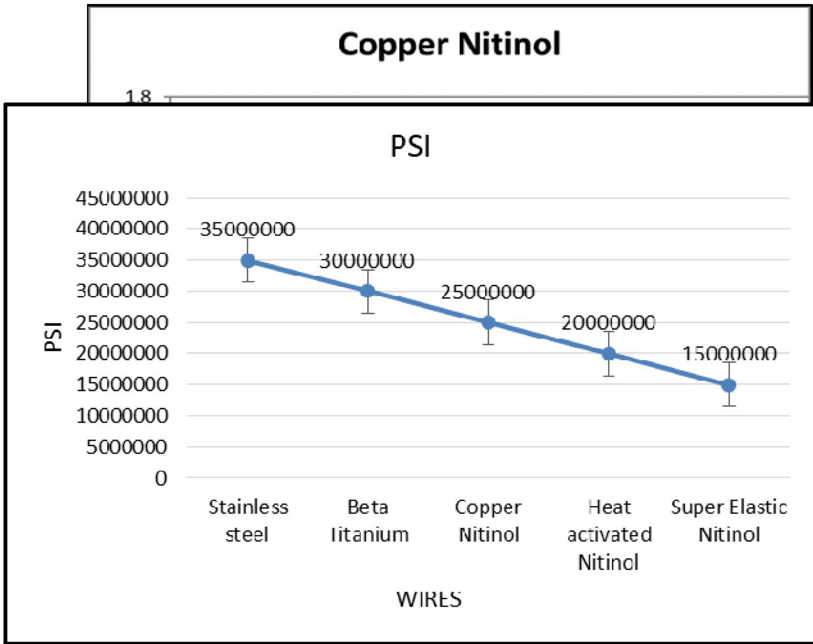



**Figure 12:** Graph shows samples of Copper Nitinol wire show the highest distance but lower than Stainless steel and Beta titanium (TMA) wire measured values of 3.0mm by 1.40mm, 13.00mm by 1.54mm, and 23.0mm by 1.58mm.

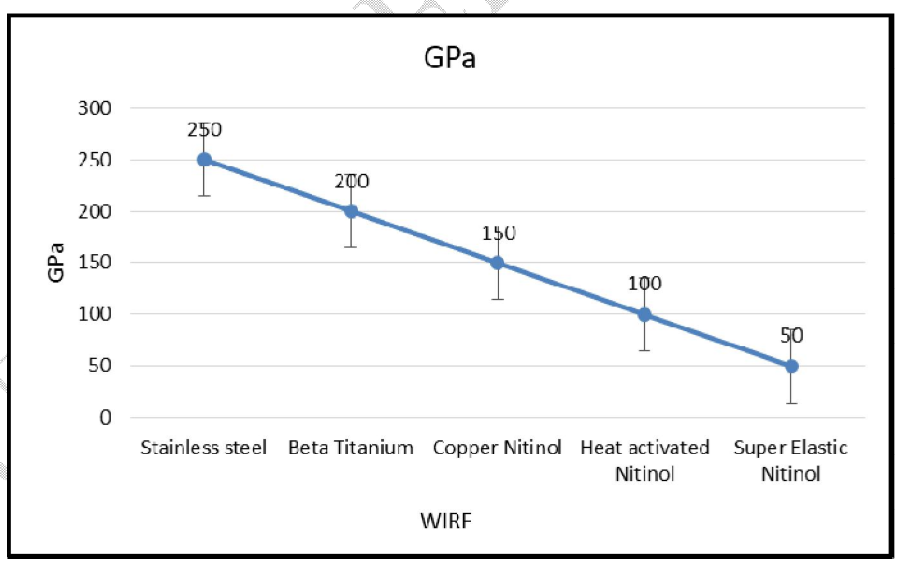



**Figure 13:** Graphs show that Stainless steel wire had Highest PSI in pressure Pounds per square inch (PSI) when pressure was reinforced on different wires with different measurements.

**Figure 14**: The graph shows that Stainless steel wire had the highest GPA (Grade Point Average), followed by Copper Nitinol wire compared to other wires.

**7 . Tests of Between-Subjects Effects**

| Sources | Type III Sum of Squares | f | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 27.165[a] | 24 | 1.132 | 3.908 | .000 |
| Intercept | 955.845 | 1 | 955.845 | 3299.952 | .000 |
| group | 24.217 | 4 | 6.054 | 20.902 | .000 |
| VAR00001 | 1.214 | 4 | .303 | 1.047 | .383 |
| group * VAR00001 | 1.735 | 16 | .108 | .374 | .987 |
| Error | 101.379 | 350 | .290 | | |
| Total | 1084.389 | 375 | | | |
| Corrected Total | 128.544 | 374 | | | |

Analysis of Variance table (R Squared = .211 (Adjusted R Squared = .157)

**Table 8**: ANOVA comparison between groups

**8 . Post Hoc Test - Dependent Variable, Scheffe test (mm)**

| Group(I) | Group(J) | Mean Differences (I-J) | Standard Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Heat-activated** | Super elastic nitinol | -.2332 | .08789 | .136 | -.5054 | .0390 |
| | Stainless steel | -.7540* | .08789 | .000 | -1.0262 | -.4818 |
| | Beta-titanium | -.3883* | .08789 | .001 | -.6604 | -.1161 |
| | Copper Nitinol | -.1772 | .08789 | .399 | -.4494 | .0950 |
| **Super elastic nitinol** | Heat activated Nitinol | .2332 | Heat-activated | .136 | -.0390 | .5054 |
| | Stainless steel | -.5208* | .08789 | .000 | -.7930 | -.2486 |
| | Beta-titanium | -.1551 | .08789 | .540 | -.4272 | .1171 |
| | Copper Nitinol | .0560 | .08789 | .982 | -.2162 | .3282 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heat-activated Nitinol | .7540* | .08789 | .000 | .4818 | 1.0262 |
| **Stainless steel** | Super elastic nitinol | .5208* | .08789 | .000 | .2486 | .7930 |
| | Beta-titanium | .3657* | .08789 | .002 | .0936 | .6379 |
| | Copper Nitinol | .5768* | .08789 | .000 | .3046 | .8490 |
| | Heat activated Nitinol | .3883* | .08789 | .001 | .1161 | .6604 |
| **Beta-titanium** | Super elastic nitinol | .1551 | .08789 | .540 | -.1171 | .4272 |
| | Stainless steel | -.3657* | .08789 | .002 | -.6379 | -.0936 |
| | Copper Nitinol | .2111 | .08789 | .220 | -.0611 | .4832 |
| | Heat activated Nitinol | .1772 | .08789 | .399 | -.0950 | .4494 |
| **Copper Nitinol** | Super elastic nitinol | -.0560 | .08789 | .982 | -.3282 | .2162 |
| | Beta-titanium | -.2111 | .08789 | .220 | -.4832 | .0611 |

**Based on observation of Mean**.

The error in terms of Mean Square Error is 0.290. The mean difference is significant at the 0.05 level.

**Table 9**: Post Hoc test to determine Different types of wires for Mean square and Mean differences significance

.

**9. Homogeneous Subsets- Scheffe test ( mm )**

| Group | N | Subset | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Heat-activated | 75 | 1.2860 | | |
| Copper Nitinol | 75 | 1.4632 | 1.4632 | |
| Super elastic nitinol | 75 | 1.5192 | 1.5192 | |
| Beta-titanium | 75 | | 1.6743 | |
| Stainless steel | 75 | | | 2.0400 |
| Sig. | | .136 | .220 | 1.000 |

Alpha = 0.05

**Table 10**: Homogeneous subsets test shows Copper Nitinol and Superelastic Nitinol shows same Mean and Heat-activated, Beta – Titanium (TMA) and Stainless Steel Have different Mean

## 4. SWOT ANALYSIS

### 4.1. STRENGTHS

- **Stainless steel** produces strength to modulus of elasticity ratio indicating a lower spring back properties of stainless steel as related to the novel titanium-based alloys and yields higher forces that disintegrate over shorter stages. Consequently, involves repeated activations. Heat treatment of the wire causes decreases in residual stress and increases in resilience.
- **Nickel-Titanium alloy wire** has remarkable springiness. Shape memory is one of the significant properties of NiTi alloy wires.
- **TMA wires** have noble formability and it has good biocompatibility due to the lack of nickel and corrosion resistance are supplementary advantages of TMA wire
- **Copper Niti** depresses the loading stress while still providing that moderately high unloading stress subsequent to more active orthodontic tooth movement of teeth.

### 4.2. WEAKNESSES

- **Stainless steel** wires heat treatment at above 650 $^0$C must be evaded because rapid recrystallization of the shaped structure which takes place, results in harmful effects on the properties of the wire. Heating stainless steel to a temperature between 400 to 900$^0$ C affects the response of the Chromium and carbon to produce chromium carbide rapid and the loss of chromium from the iron solid solution matrix affects the exhaustion of chromium contented causing the stainless steel alloy to become inclined to inter-granular Corrosion (Kapila and Sachdeva) [8] 1989.
- **Nickel-titanium wire**. Employing the bends in the wire undesirably affects the spring back property of the wire. The scientific disadvantage of these alloys is that permanent bends cannot gladly be placed in the wires and soldering cannot be performed on the wires.
- **TMA** has the possibility of breakage if bent too intensely and exposure to fluoride agents breaks down the protecting passive oxide layer and the following corrosion
- **Copper NiTi wire** has a lower elasticity module and would undergo distortions

### 4.3. OPPORTUNITIES

- New advanced orthodontic archwire introduced by different manufacturers:
  **The Smart-Arch multi-force archwire:** Marc, Olsen et al [9] presented a new technology that can both accelerate treatment and multiple memory material technologies. As many as 10 levels of stiffness can be integrated into a Copper NiTi archwire which increases the modulus of elasticity.
- **Titanium niobium wire;** According to Dalstra, M et al [10]. The stiffness of the TMA wires is 80%. These wires are soft and flexible yet possess a resiliency after bending which becomes equivalent to stainless steel wires.
- **Timonium wire;** Krishnan and Kumar et al [11] conducted a study about an alpha-beta alloy with titanium, and aluminium as its components and the alloy has a smooth surface, texture, less friction, better strength than existing titanium-based alloys, high yield strength, and fewer surface defects
- **Bioforce;** Iijima et al [12] wire variable transition temperature within the same archwire leads to a form of categorized force delivery within the same archwire providing a light force of 80gms in the anterior region and a heavier force of 300gms in the posterior region.

### 4.4. THREATS

- The amount of time that the wire was visible to the flame could have been better monitored.
- A digital stopwatch might have been used to monitor the amount of time that all the wire was exposed to the flame.

- A device setup could have been fabricated to allow the flame to travel along with the distance of the annealed section at a constant rate.
- The temperature of the flame wasn't scrutinized, which could also have led to the breakage of wires and inconsistent results.
- A digital Microthermia with a microprocessor thermometer might have been used to measure the part of the flame that the wire passed through to ensure a constant temperature.
- Even though the distance was kept the same by the stop from the wire to the flame there still may have been some slight variation in the temperature of the flame.
- Inconsistent temperatures were found, a thermometer would need to continually monitor the temperature while annealing the wires
- One potential area of future research would be to investigate different wire types other advanced than those included in this study.



**5. Discussion**

The study aimed at a total number of 75 samples. They were divided into 15 Samples, each of five-wire groups. Archwires were split into two sides; on the left side, the Unannealed portion and Annealed portion, marking was done on both sides of the wire 3mm/8mm/13mm/18mm and 23mm. On the Annealed part of the wire, the annealed section was marked 3mm/8mm/13mm. The load-deflection rate test was conducted in Instron®Machine to test each wire with a 3-point method after the annealing process**.** Stainless steel showed the highest modulus of elasticity after annealed section of wire 18mm and 23mm distance of the wire showed beyond the annealing end by 1.90mm from 18mm and 1.88mm from 23mm, followed by Beta – Titanium (TMA) wire by 1.80mm from 18mm and 1.65mm from 23mm. Stainless steel had the highest PSi showed the modulus of elasticity of stainless steel wires which ranges from 29,000,000from Pounds per square inch ( Psi) (Figure 6) and 199.95 Great point Average (GPA), followed by Copper Nitinol wire GPa was higher by 168.5 GPa compared to other wires. A Two- way Anova test was done. The Post HOC test (Table 5) showed 95% for all the analyses of distance, type of wire, and interaction of the wire. The Homogeneous subsets test (Table 9) shows Copper Nitinol and Superelastic Nitinol show same Mean and Heat-activated, Beta – Titanium (TMA) and Stainless Steel Have different Mean The Mean Square Error showed 0.290, and the Mean Difference was significant by 0.5 level. A similar study was conducted, and there were changes in substantial variances (Table 7)in modulus of elasticity between the parts of the wires within the annealed segment and area 5areasnd 10mm away from the annealed team. The changes in modulus of elasticity within the annealed section were more significant at 8 mm than at 13mm. It was substantially larger than 18mm and 23mm, 5mm and 10mm past the annealed segment. There was no statistical difference in the variation in modulus of elasticity between and 10mm away from the annealing area 18mm and 23mm, individually. Another study was conducted on the unannealed area compared Load-deflection rate and Limit in elasticity. According to the methodology. Testing has been done on the properties of nickel-titanium wires at a temperature of $5^o$ C and $37^o$ C using the three-point bending test with 3 mm bend and 14.5 mm length of the span. According to Asadi et al [13] a study conducted about, heat treatment after the welding technique was used to improve the mechanical properties of dissimilar joints of NiTi orthodontic alloys to austenitic stainless steel. In this way, after joining the wires by laser weld method, the joints were annealed for 1 hr at 100, 200, and $300^o$C, and the joints' microstructure, phase structure, and mechanical properties the joints were investigated. A study conducted by Insabralde et al 14] to evaluate the force-deflection beta-titanium alloy wires between two leveling bracket alignment scenarios using a three-point bending test showed some significant differences in forces generated during activation and deactivation among the five types of beta-titanium wires tested. In comparing brackets during activation, only Orthometric Beta Flexy and Ormco Beta-titanium were different between them.The model in which the wire was tied to the orthodontic braces on an incisive medial tooth and a canine tooth, and successively, it was bent as an incisive side tooth. Michał et al [15] Concluded by comparing the mechanical properties of the unused nickel-titanium wires. It was determined the differences in the values of the bending and bending back forces released by them. This suggests that they have different mechanical properties. A new simulated annealing method, phase annealing, is presented which makes it possible to avoid poor embedding of observations. PA is based on the Fourier representation of the spatial field. A study conducted by Lee et al [16] is to investigate the heat treatment conditions to minimize the change of mechanical properties before and after the heat treatment of orthodontic stainless steel round wire with a length of 250 mm diameter of 0.9 mm. and the tensile test fracture displacement was higher when the heat treatment is performed at 300°C than that of the A company-specific heat treatment, B, C for the company but the specific heat treatment was higher than 300°C from 500°C heating temperature goes up higher rupture displacement. Schmeidl et al [17] introduced Gummetal as a unique multifunctional alloy that retains distinctive properties with the possibility to refine and improve the efficiency of orthodontic treatment studies stating different features achieved by various methods; thus, it was difficult to compare the results. It has low bending strength, low fatigue, and high resilience. It provides lower force than Nitinol and TMA but higher than Supercable wire. The friction of Gummetal wire is equivalent to SS and CoCr wires. Because of its non-toxic chemical composition, it might be useful in the preliminary phase of orthodontic treatment for patients with nickel allergy. A study conducted by Wei Bi et al [18] investigated low-doping concentrations using molybdenum silicides have high-temperature essential materials because their exceptional thermal stability and oxidation resistance at high temperatures. First-principles calculations were employed to investigate the effect of alloying elements, Niobium, Vanadium , Tungstin, aluminium, Gallium and Germanium on the mechanical properties of Germanium (Mo3Si). The calculated elastic constants have also evaluated some essential mechanical properties of doped Mo3Si. Chromium Cr- and Vanadium V-doping decreased the elastic modulus, while Al- and Nb-doping slightly increased the shear and Young's modulus of Mo3Si  The test was conducted on the mechanical properties of the nickel-titanium wires of many diameters. Grabowska et al [19] conducted a study on alloy elements on elastic properties of Al have been examined using first-principles calculations within the generalized gradient approximation. A supercell consisting of 31 Al atoms and one solute atom is used. A good pact is obtained between calculated and experimental data. Lattice parameters of the calculated and Al alloys originate to be dependent on the atomic radii of solute atoms. The elastic properties of polycrystalline totals including bulk modulus, shear modulus, Young's modulus, and the Bulk modulus/shear modulus ratio are based on the calculated elastic measurements. The bulk modulus of Al alloys decreases with increasing volume due to the addition of alloying elements and the bulk modulus is also correlated to the total molar volume (Vm) and electron mass.The round segment of wires unleashes forces that drop within the range of the superior force. Our study concludes there was a big difference in the change in modulus of elasticity in the annealed area, more significant and away from the annealed end of the wire. The shift in modulus of elasticity will have a minimal effect beyond the annealed part of the wire. The interaction took place between 18mm and 23mm, which is 5mm to 10mm further from the annealed area of the wire. Heat-activated nitinol, Superelastic nitinol, and Copper Nitinol wires had a drip in the change in modulus of elasticity were deceased. And the distance after the annealed portion of the wire increased from 18mm to 23mm. TMA wire had increased elastic modulus, and the length from the annealed section increased from 18mm to 23mm. Finally, Stainless steel behaved the same as the other wire distance, it had produced greater elastic modulus properties, which was more significant in Annealed section of the wire. stainless steel wires favorafavourablybetter torque control, greater stability, and subsequent smaller movement events. On the other hand, studies also showed that beta-titanium wires should be used for larger corrections. This had been attributed to the ability of these modalities to intervene against enduring excessive forces on the teeth because of their greater range of activation. SWOT analysis was done on basis of four criteria of the SWOT (Strength, Weakness, opportunities, and Threats) study (Table 7). Based on this analysis there are advantages and disadvantages the orthodontic wires. In the future orthodontic wires need to be investigated to improve the metheirnical properties by the accession of alloys on existing orthodontic wires.

**6. Conclusion**

Our study aimed to conclude that the changes in elastic modulus are due to the effects of the annealing of various wires. The results were based on this study. We concluded that there were significant variances in the change in modulus of elasticity among the portions of the wires in the annealed segment. The parts were 5mm and 10mm further from the annealed section. The difference in elastic modulus within the annealed area was significantly more significant at 8 mm than at 13mm. There was considerably greater than 18mm and 23mm and 5mm and 10mm past the annealed segment. There was undoubtedly no statistical variation in modulus of elasticity amid 5 between 10mm further from the annealed part of the wire, 18mm and 23mm, separately. Nevertheless, no clinically significant effects were appreciated further than the annealed portion at the wire type is 10mm. Stainless steel showed the greatest changes in elastic modulus throughout annealing among the other orthodontic wires.

**7. Research Statements**

The amount of time that the wire was exposed to the flame could have been better monitored. A digital stopwatch might have been used to monitor the amount of time that all the wire was exposed to the flame. A device setup could have been fabricated to allow the flame to travel along with the distance of the annealed section at a constant rate. The temperature of the flame wasn't scrutinized, which could also have led to the breakage of wires and inconsistent results. A digital Microthermia 1 with a microprocessor thermometer might have been used to measure the part of the flame that the wire passed through to ensure a constant temperature. Even though the distance was kept the same by the stop from the wire to the flame there still may have been some slight variation in the temperature of the flame (Table.7). Inconsistent temperatures were found, and a thermometer would need to continually monitor the temperature while annealing the wires  One potential area of future research would be to investigate different wire types other advanced than those included in this study.

**10. Regulatory Statement**

This study was conducted following all the provisions of the local human subjects committee guidelines and policies of JSS Dental College and Hospital Institutional  Ethics Committee, JSS Academy of Higher Education and Research. The approval code for this study is: 459764

**REFERENCES**


[1] Goldberg, A.J., Vanderby, R., Jr., and Burstone, C.J, “Reduction in the modulus of elasticity in orthodontic wires”, Journal of Dental Research, vol 56., no10., pp. 1227-1231., Oct 1977. DOI.org/10.1177/00220345770560102101

[2] Kusy RP, Greenberg AR, “Effects of composition and cross-section on the elastic properties of orthodontic archwires”, Angle Orthod, vol 51., no.1., pp 325-341.,1981. DOI: 10.1043/00033219(1981)051<0325:

[3] Hong-Po Changab, Yu-ChuanTsengac, “A novel β-titanium alloy orthodontic wire”, The Kaohsiung Journal of Medical Sciences, Vol 34., no.4., pp. 202-206., April 2018. https://doi.org/10.1016/j.kjms.2018.01.010

[4] Verhoeven, J.D. “Some Applications of Physical Metallurgy. “Fundamentals of Physical Metallurgy”, 1st ed. Wiley, 1975., pp.1-567.

[5] Gerson Luiz Ulema Ribeiro and Helder B. Jacob, “Understanding the basis of space closure in Orthodontics for a more efficient orthodontic treatment”, Dental Press J Orthod, vol 21., no2., pp. 115–125., 2016. DOI: 10.1590/2177-6709.21.2.115-125.

[6] William A. Brantley, “Evolution, clinical applications, and prospects of nickel-titanium alloys for orthodontic purposes”, J World Fed Orthod., vol 9., no.3., pp.19-26., 2020. DOI:10.1016/j.ejwf.2020.08.005

[7] Kun Tiana, Brian W. Darvell, “Determination of the flexural modulus of elasticity of orthodontic archwires”, Dental materials., vol 26., no.8., pp. 821-9., 2010. DOI : 10.1016/j.dental.2010.04.007.

[8] S Kapila, R Sachdeva, “Mechanical properties and clinical applications of orthodontic wires”, Am J Orthod., vol 96., no 2., pp. 100-109., 1989. DOI: 10.1016/0889-5406(89)90251-5

[9] Marc E. Olsen, “SmartArch Multi-Force Superelastic - Archwires A New Paradigm in Orthodontic Treatment Efficiency”., J Clin Orthod., vol 54., no.2., pp. 70-81. 2020. https://pubmed.ncbi.nlm.nih.gov/32554909/

[10] Dalstra, M., Denes, G., & Melsen, B, “Titanium□niobium, a new finishing wire alloy”, Clin Orthod Res., vol 3., no 1., pp.6-14., 2000. DOI: 10.1034/j.1600-0544.2000.030103.x.

[11] Krishnan, V., & Kumar, K. J. “Mechanical properties and surface characteristics of three archwire alloys”, Angle Orthod; vol 74., no 6., pp. 825-31., 2004. DOI: 10.1043/0003-3219(2004)074<0825:MPASCO>2.0.CO;2.

[12] Natalia Martins Insabralde, Thaís Poletti, Ana Cláudia Conti, Paula Vanessa Oltr, “Comparison of mechanical properties of beta-titanium wires between leveled and unleveled brackets: an in vitro study”, Progress in Orthodontics., vol 15., no 42., pp. 1-7., 2014. DOI: 10.1186/s40510-014-0042.

[13] Iijima, M., Muguruma, T., Brantley, W., Choe, H. C., Nakagaki, S., Alapati, S. B., & Mizoguchi, I, “Effect of coating on properties of esthetic orthodontic nickel-titanium wires”, The Angle Orthodontist., vol 82., no 2., pp. 319-325. DOI: org/10.4012/dmj.2019-085

[14] Saeed Asadia, Tohid Saeida, Alireza Valanezhadb, Ikuya Watanabeb, Jafar Khalil-Allafic, “The effect of annealing temperature on microstructure and mechanical properties of dissimilar laser welded superelastic NiTi to austenitic stainless steels orthodontic archwires”, Journal of the Mechanical Behavior of Biomedical Materials., Vol 109., no 6., 2020. DOI :org/10.1016/j.jmbbm.2020.103818

[15] Michał Saul, Beata Kawala, Joanna Antoszewska, “Comparison of Elastic Properties of Nickel-Titanium Orthodontic Archwires”, Advances in Clinical and Experimental Medicine., vol 22., no 2., pp 253–26, 2013. https://pubmed.ncbi.nlm.nih.gov/23709382/

[16] Gyu-Sun Lee, “Effects of Heat Treatment on Mechanical Properties of Stainless steel wire”, Int J Clin Prev Dent., vol 13., no 4., pp. 197-202, 2017. DOI: org/10.15236/ijcpd.2017.13.4.197

[17] Krzysztof Schmeidl, Joanna Janiszewska-Olszowska, and Katarzyna Grocholewicz, “Clinical Features and Physical Properties of Gummetal Orthodontic Wire in Comparison with Dissimilar Archwires: A Critical Review”, Hindawi BioMed Research International., Volume 2021., pp.1-9., 2021. DOI : org/10.1155/2021/6611979

[18] Wei Bi, Shunping Sun, Shaoyi Bei, Yong Jiang, “Effect of Alloying Elements on the Mechanical Properties of Mo3Si”, Metals., vol 11.,no 1., pp. 129., 2021. DOI: org/10.3390/met11010129

**[19]** Zofia Kielan-Grabowska, Justyna B ˛acela, Anna Zi ˛ety, Wioletta Seremak, Marta Gawlik-Maj, Beata Kawala, Beata Borak, Jerzy Detyna and Michał Sarul, “Improvement of Properties of Stainless Steel Orthodontic Archwire Using TiO2:Ag Coating”, Symmetry., vol 13., no 9., pp. 1734, 2021. DOI : org/10.3390/sym13091734