ANALYSIS OF MARTENSITIC TRANSFORMATION AND BENDING DEFORMATION OF NiTi ARCH WIRE AGAINST DIFFERENT DEFLECTION AND TEMPERATURE RANGE

MOHD ZUHAIR BIN AHMAD

UNIVERSITI SAINS MALAYSIA

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ANALYSIS OF MARTENSITIC TRANSFORMATION AND BENDING DEFORMATION OF NiTi ARCH WIRE AGAINST DIFFRENT DEFLECTION AND TEMPERATURE RANGE

by

MOHD ZUHAIR BIN AHMAD

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my investigations, except where otherwise stated. Other sources are acknowledged by giving explicit reference.

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ACKNOWLEDGEMENT

This thesis titled "Analysis of martensitic transformation and bending deformation of NiTi arch wires against dimensional variability of dental bracket slots." has been successfully completed with all kinds of support and help from many individuals in my life. In this section, I would like to take this opportunity to express my sincere thanks to all of them.

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Mohd Zuhair Bin Ahmad

August 2022

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LIST OF SYMBOLS

E_A	Austenite elasticity
ν_A	Austenite Poisson’s ratio
E_M	Martensite elasticity
ν_M	Martensite Poisson’s ratio
ε_L	Transformation strain
$(\delta\sigma/\delta T)_L$	Loading
σ_{SL}	Start of transformation loading
σ_{EL}	End of transformation loading
T_0	Reference temperature
$(\delta\sigma/\delta T)_U$	Unloading
σ_{SU}	Start of transformation unloading
σ_{EL}	End of transformation unloading
σ_{SCL}	Start of transformation stress in compression
ε_{Max}	Maximum Strain
α	Alpha level parameters

LIST OF ABBREVIATIONS

NiTi	Nitinol Shape Memory Alloy
SMA	Shape Memory Alloy
SME	Shape Memory Effect
A_f	Austenitic Finish
M_f	Martensite Finish
DSC	Differential scanning calorimetry
SE	Super Elastic
AuNi	Gold Nickel Alloy
SS	Stainless Steel
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
3PB	3-Point Bending
SIMT	Stress Induced martensitic transformation
RS	Total friction or slip resistance
FR	Friction, kinetic or static
BI	Binding
NO	Notching
4WTB	4 Wing Tie Bracket

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ANALISIS TRANSFORMASI MARTENSITIK DAN UBAH BENTUK WAYAR LENGKUNG GERBANG NITI TERHADAP PESONGAN DAN JULAT SUHU YANG BERBEZA

ABSTRAK

Wayar lengkung Nitinol (NiTi) amat popular dalam dunia pergigian. Ia digunakan secara meluas dalam rawatan ortodontik kerana sifat-sifat fleksibiliti dan bio-kompatibiliti yang sesuai dengan tubuh manusia. Kekuatan wayar lengkung dalam pemasangan pendakap pengikat 4 kepak adalah dipengaruhi oleh rintangan gelinciran gigi pesakit apabila wayar lengkung dan pendakap bersentuhan. Dalam kajian ini, daya telah dikenakan ke wayar lengkung NiTi berbentuk segi empat tepat, seterusnya dianalisis sebagai perubahan suhu dan pesongan wayar dalam rongga mulut telah dilakukan.Tingkah laku daya-sesaran wayar lengkung bersifat anjal telah dikaji dengan menggunakan pemodelan unsur terhingga tiga dimensi (3D).Kandungan martensit dalam struktur mikro wayar lengkung dan keadaan fasa telah dikira menggunakan pemodelan unsur terhingga, bergantung kepada beberapa faktor seperti julat pesongan wayar dan suhu. Model berangka telah meramalkan penemuan lenturan 3-Titik yang sejajar dengan ramalan dalam teori. Penemuan dalam kajian ini telah menunjukkan beberapa perkaitan jika dibandingkan dengan kajian lain. Graf pesongan daya telah terubah suai disebabkan struktur ikatan. Ia mengubah transformasi martensit menjadi condong apabila sentuhan dikenakan antara pendakap dan wayar. Apabila wayar lengkung NiTi dilenturkan pada suhu dan pesongan yang lebih tinggi, ia menghasilkan daya pemuatan dan pemunggahan tambahan. Pada suhu yang lebih tinggi dan pesongan yang lebih besar, wayar lengkung akan terdedah kepada terikan yang lebih besar dan suhu yang tinggi. Hal ini menghasilkan daya terikan yang lebih

maksimum semasa pemuatan berbanding wayar lengkung yang dipesong ke tahap yang lebih rendah. Apabila pesongan meningkat, peralihan martensitik wayar lengkung NiTi super anjal mula berkembang. Akhirnya, transformasi martensitik kepingan NiTi adalah tidak dipengaruhi oleh turun naik suhu, berdasarkan kepada analisis unsur terhingga.

ANALYSIS OF MARTENSITIC TRANSFORMATION AND BENDING DEFORMATION OF NITI ARCH WIRE AGAINST DIFFRENT DEFLECTION AND TEMPERATURE RANGE

ABSTRACT

Nitinol (NiTi) arch wires are widely used in orthodontic treatment around the world due to their extreme flexibility and biocompatibility with human body. The arch wire strength of the 4-wing tie bracket assembly is affected by the slip resistance of the patient's teeth when the arch wire and bracket come into contact. In this study, the force applied by the rectangular NiTi arch wire was analyzed as changes in temperature and deflection in the oral cavity. Force-displacement behavior of super elastic arches was investigated using a 3D finite element model. Arch wire microstructure martensite content and phase state were calculated using finite element modelling, dependent on wire deflection range and temperature factors. The numerical model predicted 3-Point bending findings that were in excellent accord with theoretical predictions. The findings may also be compared to other recent studies that have shown a connection to these ones. Force deflection curves were modified by the bond, which changed the martensitic transformation plateau into an inclination as the contact established between the bracket and the wire. Flexing the NiTi arch wire at higher temperatures and deflection released additional loading and unloading forces. At higher temperatures and bigger deflections, an arch wire exposed to greater strain and temperature released more maximum strain during loading than a NiTi arch wire deflected to a lesser degree. As the deflection increases, the martensitic transition of super elastic NiTi arch wires develops. Finally, the martensitic transformation of NiTi

sheets was unaffected by temperature fluctuations, according to finite element analysis.

CHAPTER 1
INTRODUCTION

1.1 Introduction

Orthodontics is a field of dentistry related to facial growth, tooth development and occlusion, and diagnosis, prevention and treatment of malocclusion[1]. Orthodontic therapy is also acknowledged as a way for enhancing the look and arrangement of teeth by straightening or repositioning crooked teeth. Orthodontic treatment generally consists of three stages: early, intermediate, and final. Each treatment level has significantly different wiring requirements. The first phase focuses on mandibular and maxillary tooth alignment and levelling.

Orthodontic brackets are a form of long-term fix for misaligned teeth that may improve both their function and appearance. Forces are transmitted from the arch wire to the bracket and then to the tooth[2]. Depending on the moment force ratio, the teeth are more susceptible to translational, rotational and tilting movements[3].

Figure1.1 First permanent molar banding on the bottom half of the tooth. It is important to notice the gingivally positioned hook, which may be used for elastic traction.

Figure1.2 The canines, premolars, and molar teeth have been banded in this fixed appliance case. The effect of bands on the appliance's attractiveness may be easily seen.

One of the most commonly used shape memory alloys in the medical field is Nitinol (NiTi), a spectrum of nearly equiatomic nickel-titanium alloys. Nickel-titanium base wires are listed in Table 1.1 below and contain information about the trade name, composition, number of strands, and test conditions for each wire type included. Innovative tools and implants have been developed using Nitinol's shape memory, super elasticity, and superior wear resistance in a wide range of surgical fields, from orthopedics to vascular treatments[4]. At this point, NiTi arch wires are favored above other metal orthodontic wires for correcting misaligned teeth[5]. For one thing, NiTi arch wires take less time to level and cause less pain in the mouths of patients, as described by Morrom and Andreasen, and give a continual mild force for tooth movement, periodontal ligament injury, and undermining resorption[6].

Table 1.1 The nickel titanium-based wires used in this study are categorized by trade name, composition, number of strands, and test conditions.

Group	Number	Commercial Name	Composition	Number of stands	Test condition
1	20	Rematitan “Lite”	NiTi	Single-strand	As-received
2	20	-	-		Recycle

3	20	Damon Copper NiTi	Copper NiTi	Single-strand	As-received
4	20	-	-		Recycle
5	20	Supercable	NiTi	Multi-strand	As-received
6	20	-	-		Recycle

These two crystalline phases are present in all SMAs, including NiTi arch wires and are the major solid crystalline phases. The transition between the two stages of hyper elasticity and shape memory effect is combined. This transition can occur at temperatures higher than austenitic finishes (A_f) and under external stress[7]. Bradley claims that austenite-martensite transformation occurs at various temperature ranges for each kind of arch wire. Differential scanning calorimetry (DSC) is used to identify these phase transitions[8]. An analysis of the DSC curve must include temperatures such as A_s and A_f to establish exactly when the NiTi arch wire is in its super elastic phase[9].

The NiTi arch wire's force delivery capabilities in orthodontic therapy are ideal. In order to give the finest and most predictable treatment outcomes, it is necessary to know the amount of force during activation and deactivation[10]. Orthodontic therapy relies on two forces: the activation force and the deactivation force. To bend an orthodontic arch wire and secure it in a bracket, the activation force is the amount of force needed. As soon as the orthodontic wire is linked to the bracket, it exerts a deactivating force on the tooth, forcing it to move back toward its previous position and position. The deactivation force becomes the most important consideration in orthodontic therapy. The force-deflection behaviour of NiTi arch wire is determined by conducting bending tests. This test, which is employed by Krishnan and Kumar to assess the force-deflection qualities, is a key foundation for figuring out the biological origin of tooth movement, according to them[11]. NiTi arch wire’s force-deflection behaviour is evaluated by bending tests. Three-point bending (Fig.1.3) is used to analyse the force-deflection capabilities of teeth, and it is a crucial foundation for understanding the biological basis of tooth movement[10].

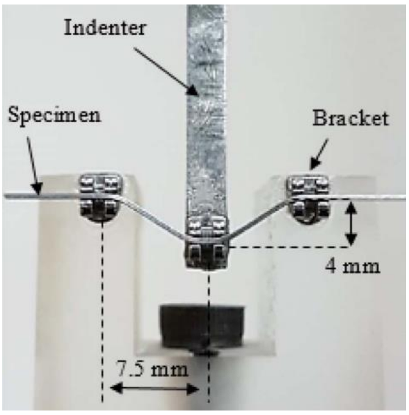

Figure1.3 NiTi arch wire bent with a modified 3-point bending setting.

1.2 Background Study

Intensely flexible SMA Arch wires made of NiTi are often utilized in the early stages of orthodontic treatment all around the globe. After being severely deflected by the uneven bracket locations, the arch wire's super elastic (SE) nature permits it to restore to its original arch form.

NiTi arch wires will be bent to various degrees of deflection and temperatures, and their phase change behaviour and stress concentration will be studied. This study paper's findings may help orthodontists better understand the mechanical behaviour of NiTi arch wires at varied deflections and temperatures, which can be utilized to improve patient care and treatment outcomes.

A NiTi wire in a 4 Wing Tie bracket system 3D finite element model is ready for usage. The existing model may be improved if required in this investigation. The simulation may be run, and the results shown when the models are ready in Abaqus FEA, which is software for 3D finite element analysis and computer-aided engineering. Once the models are ready, they can be utilized in the simulation.

1.3 Problem Statement

NiTi arch wires are often utilized in the early stages of orthodontic therapy because of their high elasticity. Due to the random bracket locations that is placed based on the location of the patient’s teeth, the wire might revert to its arch form because to the wire's (SE) nature. It is for these reasons that we are investigating the behaviour of NiTi arch wire during phase transition and the stress concentration in 4 Wing Tie Bracket (4WTB) in various temperature and deflection range. A 3D finite element model of NiTi wire in a dental bracket system has previously been done in earlier studies throughout the years. Since additional slot sizes may be added to the present model, it can be improved.

1.4 Objectives of this research

1) Investigation of force-displacement behaviour of super elastic NiTi arches over various deflections and temperature ranges.
2) To investigate the martensitic transformation progression of super elastic NiTi arch wire in various deflection and temperature range.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the latest and most important research in this area. The next section provides an overview of orthodontic treatment, orthodontic wires and brackets, and the force-displacement behavior of super elastic NiTi arch wires in various tooth fracture designs. Martensite conversion process of SE NiTi arch wires in various brace designs examined in this article. The review derives dimensional variation in the tooth bracket slots of the orthodontic NiTi bracket and compares it with the data. This is a list of all the major research articles published in the last decade.

2.2 Orthodontic Treatment

Adults who may not have had easy access to orthodontic treatment as their children turned to a record number of braces as the public became more aware and embraced of the device. According to current recommendations, misaligned teeth can be corrected with different types of braces. Malocclusion is a term used in dentistry to describe the misalignment of teeth. For malocclusion, the most common cause is a mixture of genetic and environmental factors. Malocclusion is affected by a variety of factors, including: What you put in your mouth affects how bones, muscles, and ligaments work together[1]. Molars may generally be classified into one of four groups: When teeth are in perfect alignment, they're known as normal occlusion. The severity of the other three malocclusions is shown in Figures 2.1 to 2.3. Malocclusions such as these follows. A malocclusion is classified into one of three groups based on the severity of the occlusion: Neurocclusion, Distocclusion, and Mesiocclusion[1].

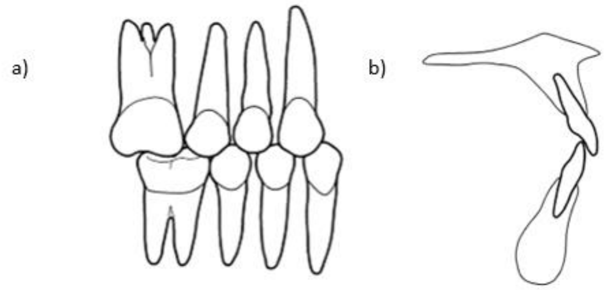

Figure 2.1 a) Angle’s classification of class I. b) Incisor classification — Class I.

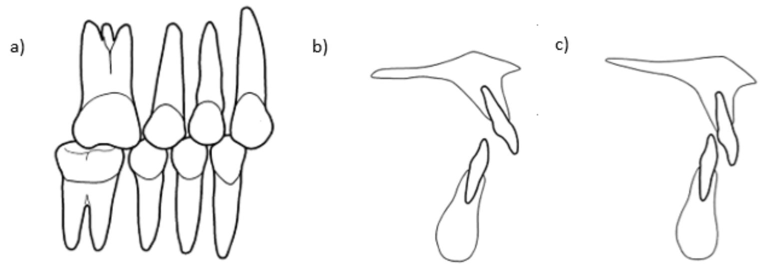

Figure 2.2 a) Angle’s classification of class II. b) Incisor classification — Class II division 1. c) Incisor classification — Class II division 2.

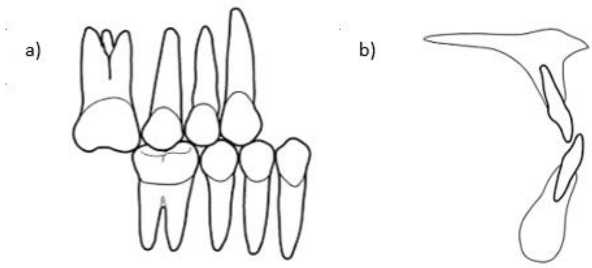

Figure 2.3 a) Angle’s classification of class II. b) Incisor classification — Class III

Class I malocclusions and normal malocclusions share the same molar relationship, although crowding and rotation are both present in class I malocclusions. There is a difference in the occlusion line's position in class II and III malocclusion from normal occlusion. Psychological well-being may be affected by a person's facial appearance, swallowing and mastication problems and speech impediments related to malocclusion, as well as an increased risk of tooth decay or periodontal disease[12].

Orthodontic treatment to correct misalignment is best done with the acquisition of a variety of teeth. There are several reasons why teeth come in different shapes and sizes during rumination. There are several human teeth as shown in this figure 2.4, including the incisions (upper), canines (lower) as well as the relative sizes of these teeth. Maximum damage and most obvious positional anomalies were observed in the canines of the mandibular teeth[13].

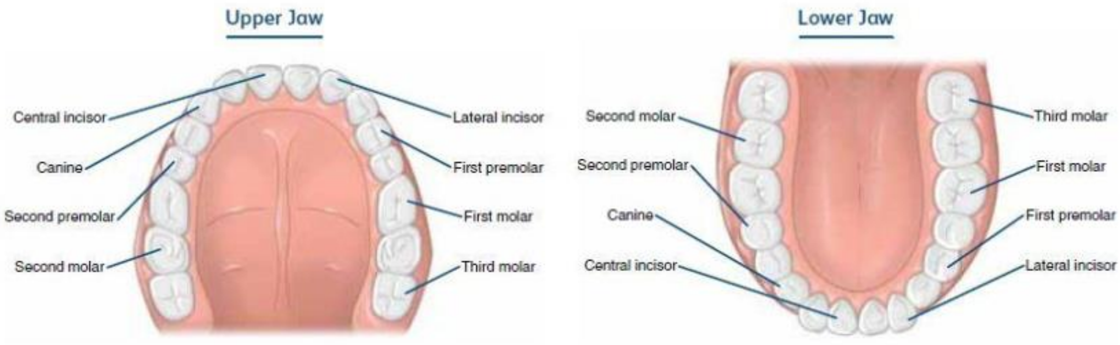

Figure 2.4 Type of human teeth on the upper and lower jaw.

The six types of tooth development are shown in Figure 2.5: I uncontrolled tipping, (ii) controlled tipping, (iii) interruption, (iv) interpretation, (v) immaculate root development, and (vi) expulsion. Tipping is more common on the canines than on other types of tooth development.

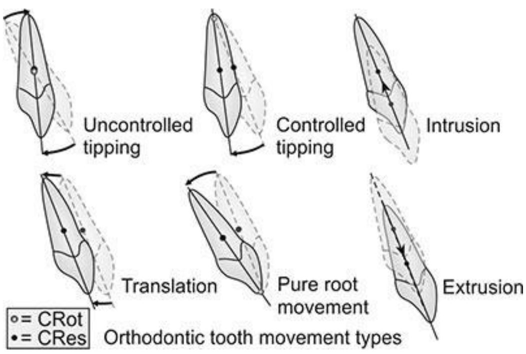

Figure 2.5 Type of tooth movements in orthodontic treatment[14].

The first step in straightening and aligning teeth is the gentle movement of crooked teeth. The main purpose of this step is to align and balance the arches and arches of the upper and lower jaws. After that, it is not possible to start orthodontic and occlusal correction therapy. This phase focuses on fixing the deep, open bite, sealing the extraction spaces, and moving the teeth parallel to each other. To conclude orthodontic treatment, minor adjustments and corrections are made to tooth positions, apex, torque, rotation and other connections[12].

2.3 Orthodontic Wire

In the early stages of orthodontic treatment, metal alloy arch wires are usually used to orthodontic teeth. Typical materials used for arch wires include beta titanium and stainless steel. The orthodontic wire is permanently attached to the tooth and begins orthodontics. Devices placed on the teeth to release the stored energy apply stress and torque[15]. Choosing the right arch wire material is very important for the transmission of optimal orthodontic force in the mouth. In terms of orthopaedics' considerations, the biocompatibility and corrosion resistance of metallic materials in the mouth environment are critical.

Au-Ni alloy was originally used for orthodontics in the early 20th century. Due to the low rigidity of alloys, orthodontic treatment with these restrictions requires frequent patient examination. In the 1920s and 1930s, Au-Ni was replaced with austenitic stainless steel, which has excellent strength and corrosion resistance. It's still too hard for orthodontists who prefer more supple materials. The stainless-steel (SS) wire has been replaced by the Ni-Ti wire reported by Burstone et al. It is shown that the stiffness is reduced, and the robustness is slightly improved. Andreasen already started selling Ni-Ti wire to the general public in 1972[16]. Their super elastic and shape-memory qualities have yet to be identified. For numerous years, they have only been used as an initial wire in very restricted circumstances. In the early 1980s, Miura et al and Andreasen et al found super elastic that was suitable for orthodontic therapy.

Arch wires come in round and rectangular types. Round wires are used to treat congestion, level arch wires, widen occlusions, and fill gaps in early and mid-term treatment. Crown and root transplants need the use of rectangular wires in the latter phases of therapy.

2.4 Orthodontic Brackets

When using orthodontic brackets, the arch wire moves the teeth. The most common size of retainer slots is 0.02 inches, with a range of 0.018 to 0.018 inches. In the early stages of treatment, the .018 "size feels less powerful and comfortable than the 0.018" size[17]. Traditional and self-ligating commercial orthodontic brackets are available. These brackets are self-ligating and do not require elastic or stainless-steel bands to hold the arch wire in place. Neither rubber nor metal bands are present. Self-ligating brackets provide a number of advantages over conventional ligatures, including greater comfort, enhanced tooth movement and sliding mechanics, faster chair time, and less bio-hostility[18],[19]. Traditional brackets and self-ligating brackets were shown to have no statistically significant differences in performance. Installing and removing self-ligating brackets is much simpler than with regular brackets. After all, it took less time to remove the wire than to replace it. Brackets with self-ligating mechanisms did not enhance orthodontic therapy or decrease the number of visits to the dentist[18].

Kinya Fujita taught undergraduate and graduate students in the orthodontics department at Kanagawa Dental University in Japan. From that year forward, the dentist started manufacturing and utilizing his three-dimensional orthodontic appliance system, which allowed each tooth to be relocated in all three dimensions. He displayed the versatility of his equipment by performing extractions on children and adults alike. Dr. Craven Kurz, on the other hand, is a pioneer in the lingual appliance area. The front teeth`s lingual surfaces were braced with plastic braces. The plastic bracket was chosen because it is easy to bend. Dr. Kurz taught occlusion and gnathology at UCLA School of Dentistry. Lingual instruments such as quad helices, oral lids and lingual arches have long been used in combination with traditional permanent labial instruments. Lip orthodontic braces that fit on the back of the teeth have become more popular in recent years after patients have expressed concerns about pain, speech problems, and delays in treatment. Dr. Kurz 's lingual bracket had some problems. In short, it involves inadequate adhesion and patient discomfort[20].

Since its introduction in 1997, Invisalign® has been a popular alternative to traditional metal braces for the mouth[21]. As a result of stereolithography CAD / CAM technology, the Invisalign system can accurately predict treatment and create thousands of unique aligners from a single impression. Each aligner can be shifted by 1-3 mm every 14 days. It will continue as long as it takes until the perfect tooth position is achieved[22].

Figure 2.6 A modal of Invisalign

Since Invisalign's introduction in the 1990s, orthodontic treatment has been revolutionized. Based on experiments and simulations published throughout the day, this type of orthodontic treatment differs from traditional methods that use brackets. The goal of both procedures is to put the teeth in the right place and make sure they are functioning properly. As a result, there are pros and cons to each treatment.

2.5 Why the Usage of NiTi Wire is favored in Orthodontic.

When the SMA is stretched beyond its elastic limit, it returns to its original shape. In addition to sensors and actuators, medical implants, mechanical and aerospace components, and civil engineering, SMA is a smart and functional metal that can be used in a variety of applications. Figure 2.8 shows the reaction of the alloy to different stresses and strains and different magnetic fields. One of the most biomedically relevant shape memory alloys is NiTi (nickel and titanium)[4]. NiTi wire has a lower modulus of elasticity than steel and titanium alloys but has better formability. It is also less biocompatible and ductile than steel and titanium alloys. Additional features include high energy storage and excellent elasticity[23]-[24]. Figure 2.7 shows the changes in SMA crystal shape leading to hyper elasticity and SME as a result of stress (caused by heating).

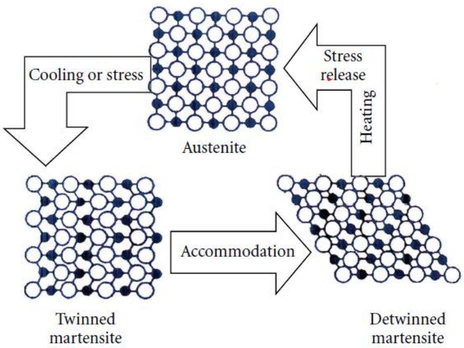

Figure 2.7 Changes in the crystal structure of SMA that result in SME and Super elasticity (induced by heating).

Medical professionals often refer to this NiTi wire as "SE" or "SME". These are two terms that reflect their excellent properties. As demonstrated in Figure 2.8, the shape memory effect ensures that the wire keeps its original form upon heating. It returns to its original shape with a constant force and is not distorted by plasticity. NiTi wire cannot generate plateau curves when using shape memory only. This is not possible. Due to its high spring back, low modulus and super elasticity, this NiTi wire was ideal for early orthodontic treatments that required large deflections[25].

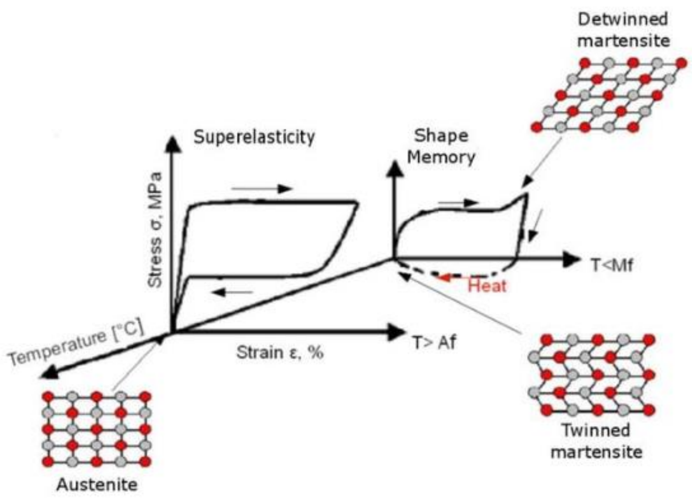

Figure 2.8 Super elasticity and shape memory effect are shown in 3D in relation to phase transition in the SMA material[26].

When referring to this NiTi wire, terms such as SME and SE are often used. Figure 2.8 shows that the wire keeps its original form after being heated because of the shape memory effect. It returns to its original shape with a constant force and is not distorted by plasticity. The plateau curve formed by super elastic NiTi wire cannot be realized by shape memory alone. Due to its excellent spring back, low modulus, and super elasticity, this NiTi wire was ideal for the early stages of orthodontic treatment, which requires a large amount of deflection[8].

As shown Austinite Finish (A_f), shape memory occurs below Martensite finish (M_f) and hyper elasticity occurs in the martensite phase above M_f (see Figure 2.8). NiTi wire can withstand the high pressure of the martensite phase, but when the force is reduced, it cannot return to its original shape after unloading[25]. During the heat treatment, the material can transition from weak martensite to strong body-heart austenite and return to its original structure. The austenite phase of NiTi wire exhibits a plateau with higher stress levels than the martensite phase known as the lobe-type hysteresis loop. Reverse-phase transformation (SIMT) causes hyper elasticity when discharging on a plateau with a higher stress level, while forward-phase transformation (SIMT) restores austenite to its original state on a plateau with a lower stress level[27]. Because of its high elastic strain limits, this NiTi is capable of recovering from massive deformations.

2.6 Factors influencing Friction during arch wire sliding in dental bracket.

Three-point bending (3PB) tests were used to examine NiTi arch wire force-displacement properties, as shown in figure 2.9. This figure illustrates that a consistent force may be transferred throughout a wide range of tooth motions during deactivation[28]. Therefore, the initial alignment performance of NiTi cannot be evaluated using this basic test. A 3-point bracket bend test (3PB), proposed as the most reliable wire test for simulating clinical situations [29]. Temperature and friction can affect the performance of NiTi wire at 3PB. Much research has been done on how arch wire materials balance stress. Some orthodontists consider the high elastic limits and low forces that remain constant over a wide range of activations to be ideal materials for orthodontists[30].

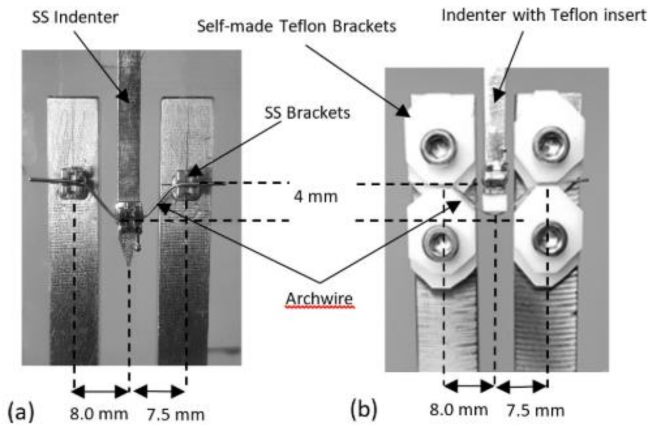

Figure 2.9 A stainless steel bracket which is on the left and a hand-made polytetrafluoroethylene bracket on the right are used in a three-point bracket bending jig[31].

Figure 2.10 shows the force required to bend the arch wire 4 mm using the force-displacement curve. It is clear that the active and deactivated stages of stress-induced martensitic transformation (SIMT) are incompatible with each other as the activated plateau rises and the deactivated plateau decreases. When applied, the initial deflection is only 1 millimeter (0.04 inch). When three-point bending is used to reach the dotted line, scholars focus on the activated plateau and the second stress plateau after elastic behavior. Effective tooth movement requires a constant power supply to the NiTi wire. For this force-displacement behavior, there is no friction between the bracket slot and the NiTi wire. As shown in the image below, the friction of the 3-point bracket bend transforms the activated and deactivated plateau into an increasing trend (solid line).

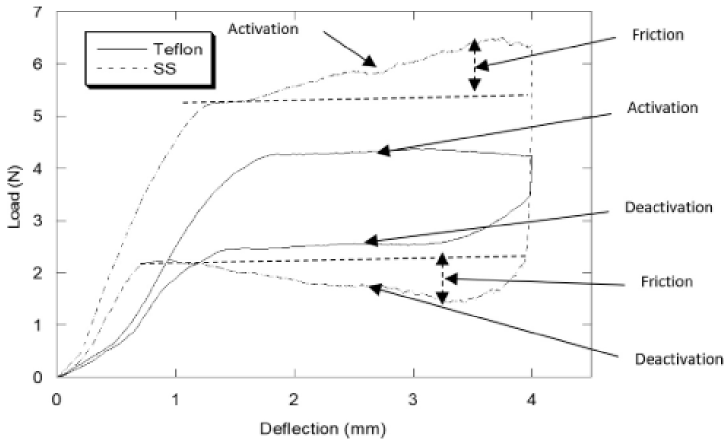

Figure 2.10 The bending curve of the NiTi round arch wire obtained in[31] as a result of the three-point bracket experiment.

2.7 Friction distribution in altering the force-deflection behavior.

Deceleration is caused by friction when two things slide against one other or move tangentially against each other[32],[33]. Bracket slot with NiTi wire friction reduces tooth movement's optimal force need in half. Generally speaking, static and sliding friction are the most common kinds of friction, respectively. Both static and dynamic friction are defined as the resistance to movement that is caused by the presence of two objects in contact. As seen in Figure 2.11, static friction is more common than sliding friction since moving an item requires more effort[32].

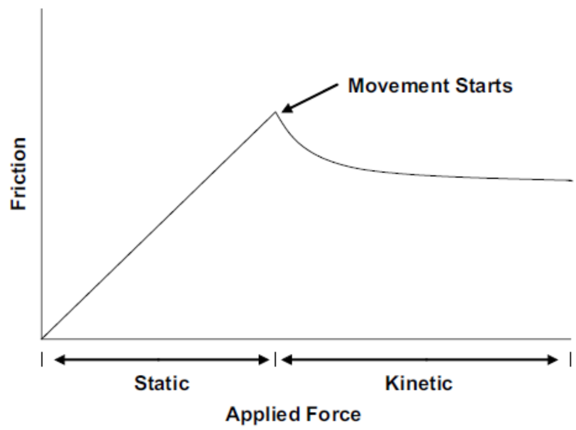

Figure 2.11 A force applied to an item result in stiction until the force overcomes the initial movement resistance. After that, sliding friction prevents further movement. Static friction exceeds sliding friction[34]

The ability of NiTi wires to slide between brackets is important in orthodontic treatment with orthodontic appliances to achieve proper leveling and alignment treatment. Friction, on the other hand, has an effect on the wire's ability to slide through the bracket. Tooth movement takes greater force than friction at the bracket-to-wire contact, hence this is a necessary consequence. Total friction or slip resistance (RS) can be explained by Kusy and Whitley's equation[35]:

$$RS = FR + BI + NO$$

Where FR is friction, kinetic or static, BI is binding, and NO is Notching.

Figure 2.12 shows the phenomenon of slip resistance after orthodontic treatment. The wire that comes in contact with the bracket is the main cause of FR. This only happened if there was enough space to move into the wire and bracket slots. When the wire bends, it comes into direct contact with the corners of the bracket, leaving no room for error[34]. At this point, FR was almost non-existent compared to BI. There is permanent distortion at the point where the wire and the bracket meet as the angle rises[36]. When this happens, NO takes the lead while FR and BI fade out. As the wire slides, the teeth are exposed to a different RS. Orthodontists should have a complete understanding of RS and the best treatment options available.

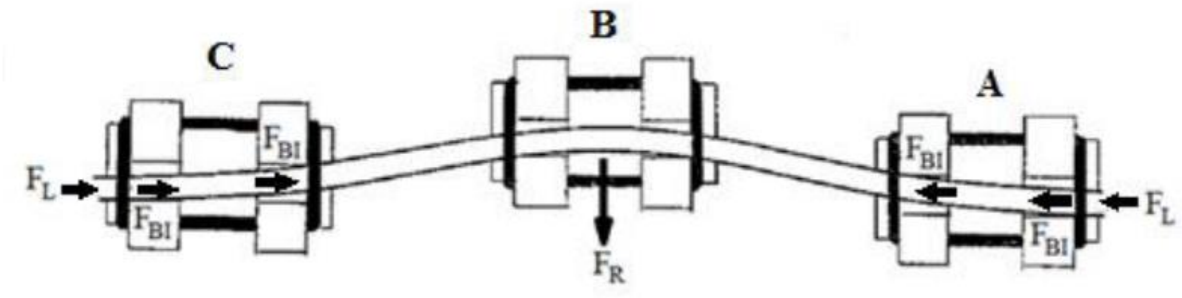

Figure 2.12 A picture to show how the brackets create frictional resistance.

2.8 Force Magnitude for Orthodontic Treatment.

Both effective tooth movement and maximum patient satisfaction during orthodontic treatment require some effort. To achieve the fastest possible tooth movement while minimizing the risk of orthodontics, the relationship between orthodontic force and tooth movement speed should be investigated. Table 2.1 shows the six tooth movement techniques and the optimal force required for each. To get the best results, varying levels of force may be needed depending on the size of the tooth surface[37]. If the force is too great, the force will be too small to move the teeth. Strong pressure can lead to tissue damage, discomfort, and root resorption[38].

Table 2.1 Varying types of tooth movement need different amounts of power[39].

Type of Movement	Force (N)
Tipping	0.35 - 0.60
Translation	0.70 - 1.20
Root Movement	0.50 - 1.00
Rotation	0.35 - 0.60
Extrusion	0.35 - 0.60
Intrusion	0.10 - 0.20

2.9 Simulation of Superplastic Behavior of NiTi Alloy Under Tensile, Three Point Bending, And Bending Test in Bracket System.

The early simulation of the NiTi alloys can be observed based on the research that was done by S. Govindjee[40] and F. Auricchio et al.[41] which can be dated back as early in the late 90' which their simulations involves a lot in the aspect of macromodelling, numerical simulation, and computational simulation. The solid-solid phase transition model of martensite solid-solid transition is published by S. Govindjee in his study. Form memory alloys are being studied and analyzed to correctly capture both shape memory and pseudoelastic properties in one dimension. Appropriate numerical approximations of the configuration have been developed to support one-dimensional thermomechanical loads. These models have two ambiguity issues that are addressed by heuristics.

Developed by F. Auricchio and his colleagues, the generalized plasticity is a novel family of inelastic models based on internal variable forms. Shape memory materials may be modelled using a generalized plastic framework here. SMA that match the suggested constitutive model exhibit a variety of material characteristics under hyperelasticity, tension, and compression, as well as the single-variant martensite reorientation process. Using a finite element approach, we investigate the model's implementation and the tangent algorithm's consistency in isothermal circumstances.

In the recent years, for the aspect of bending simulation that was done on NiTi alloy, H. Mohammed Ibrahim Al-Zuhairi[42] and Ben Naceur and Elleuch [43] published their work on doing an almost similar numerical simulation that involves in bending of NiTi SMA. Both researchers, however, have a different goal in mind and a distinct approach in use for their respective studies. The goal of Mohammed Ibrahim Al-case Zuhairi's research is to use commercial ANSYS 15.0 software and the Finite Element Method to construct a numerical model of the super elastic behaviour in a shape memory alloy wire. NiTi wire's stress–strain behaviour is affected by the material response parameter Alpha (α) when it is loaded and unloaded. However, the tribology of NiTi alloys was explored by Ben Naceur and Elleuch, who focused on the stress-induced martensitic transition. The modal that was used in [42], where the diameter of the NiTi wire is 2 mm and the length is 50 mm (Fig. 2.12). This wire was used as a cantilever, loaded until the displacement reached 15 mm (Fig. 13), and then unloaded for 2 sec. The maximum movement (15 mm) and simulation time (2 sec) were kept constants for all α levels parameter which is describe as the tension–compression asymmetry.

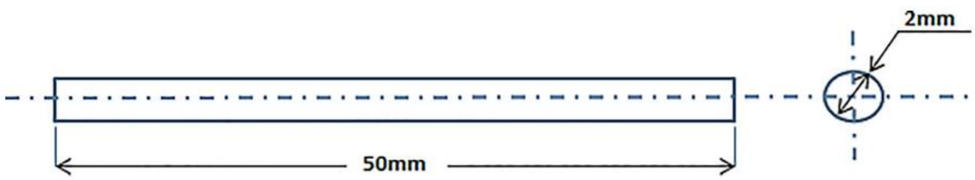

Figure 2.13 NiTi wire were used to create a 3D model.

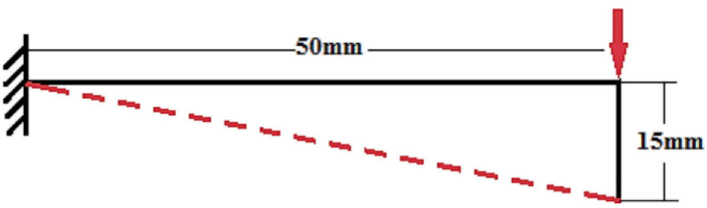

Figure 2.14 Applying a displacement of 15 mm to the free end.

While the model that was created by [42] using ABAQUS, an element analysis software, to evaluate normal forces caused by wire curvatures (Fig. 2.14, Bennaceur et al.). Table 2.2 shows the normal force unloaded from a deflected orthodontic arch wire at 37°C. An elastic ligature typically exerts 2 N of force while forcing wire into a bracket slot, according to several studies. The scholar and his team used planar 316 stainless steel pieces instead of brackets since the normal load given by these pieces normalises the suggested arrangement without the need of elastic or metallic ligature to secure the wire in bracket-slots. Their chemical composition is presented in Table 2.3.

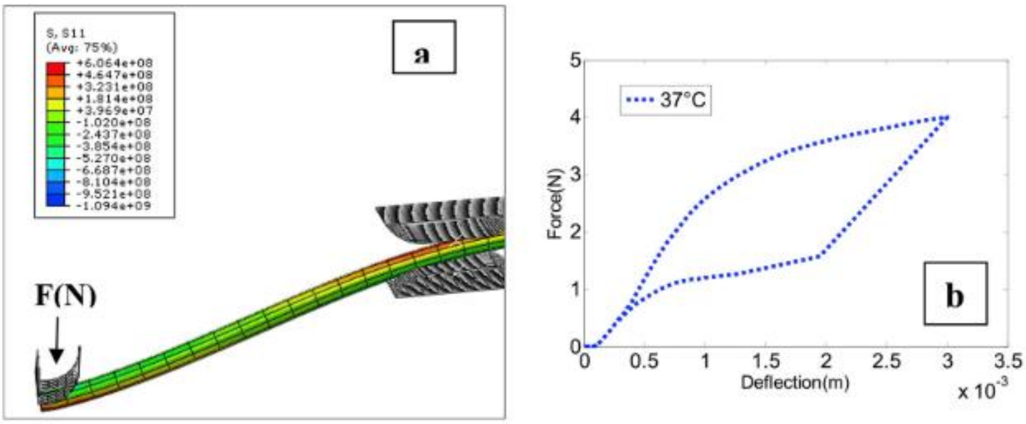

Figure 2.15 Deflection of a circular NiTi wire in 3D finite element analysis reveals the stress distribution in the tensile system. (b) A force/deflection curve that matches.

Table 2.2 Deflected orthodontic arch wire unloading at 37°C.

Deflection (mm)	0.5	1.5	2.5
Normal force (N)	0.8	1.6	3

Table 2.3 AISI 316 has a chemical composition

C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Ni (%)	Mo (%)	N (%)
0.084	0.54	1.8	0.018	0.0038	17.28	10.51	2.02	-

In the recent years, simulation of NiTi alloy wire on 3PB can be seen carried out by scholars such as M.F. Razali [39] [44], and M.N. Ahmad[31]. Mouth temperature and deflection may be affected by forces created by the rectangular NiTi arch wire, according to M.F. Razali. A 3D finite element model was used to investigate the deflection behavior of super elastic arch wires. Based on the amount of wire deformation, a finite element model was used to calculate the martensite percentage and phase of the arch wire ultrastructure. Figure 2.15 shows that the numerical model's tensile and bending predictions are in excellent agreement with the experimental results. The link between the wire and bracket changed the plateau of martensitic transformation into a slope. The arch wire's capacity to recuperate energy was diminished as a consequence of the considerable deflection.

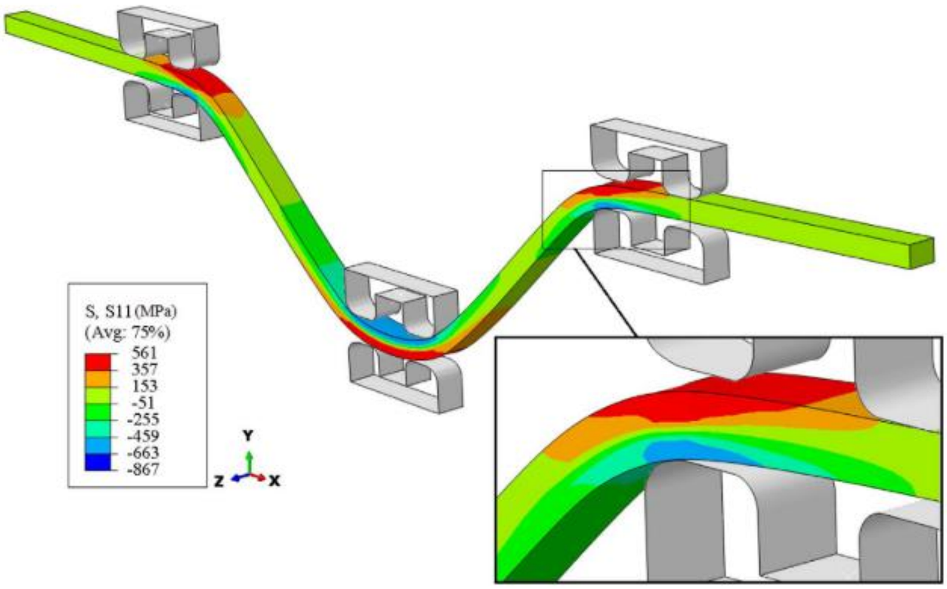

Figure 2.16 When bending the arch wire, the normal stress distribution (S11) shows up in the 3D model of the arch wire.

2.10 Summary of Literature Review.

Base on the vast literature review that was done. A lot of information and knowledge was obtained in order to further understand and grasp the concept to perform the simulation. Most of the study that was done in the past a lot involved in hands on experiment with specific set up and environment. However, there is also some simulation of bending, and 3PB that were done and the most closes on all of it to this research can referred in from M.F. Razali simulation. By replicating the set up and do some adjustment based on the current technology and software updates that are available. The objectives of the research can be achieved, and conceivably new discovery can be found fill in the research gap.

CHAPTER 3
METHODOLOGY

3.1 Introduction

The information regarding the simulation processes, the utilization of the equipment, and the samples that were obtained for each simulation model is presented in Chapter 3. To begin, there is the necessary preparation of getting the samples of orthodontic brackets and deciding how to measure those samples using the many types of measuring instruments that are accessible. Figure 3.1 provides a visual representation of the process for the whole project, which may be seen in the following diagram below.

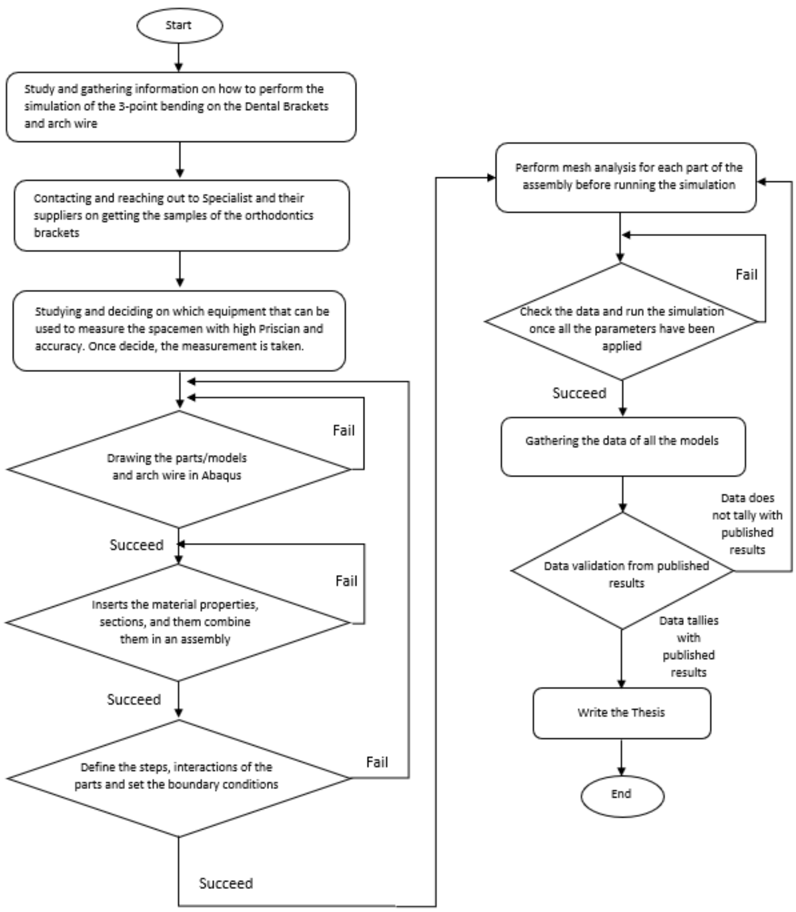

Figure 3.1 Project workflow of the Project.