Title

Comparison of Deformation and Torque Expression of the Orthos and Orthos Ti Bracket Systems

Authors

Garrett W. Melenka, BSc;[a] Ryan A. Lacoursiere, DMD, MSc;[b] Jason P. Carey, PhD;[c] David S. Nobes, PhD;[d] Giseon Heo, PhD;[e] Paul W. Major, DDS, MSc, FRCD(C)[f]

[a] Garrett W. Melenka, Graduate Student, Mechanical Engineering Graduate Program, Faculty of Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2N8 (email: gmelenka@ualberta.ca)
[b] Ryan A. Lacoursiere, DMDS, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada T6G 2N8 (email: lacours@ualberta.ca)
[c] Jason P. Carey, Associate Professor, Mechanical Engineering, Faculty of Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2N8 (email: jason.carey@ualberta.ca)
[d] David S. Nobes, Assistant Professor, Mechanical Engineering, Faculty of Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2N8 (email: david.nobes@ualberta.ca)
[e]Giseon Heo, PhD; Assistant Professor, Statistics; School of Dentistry; University of Alberta Edmonton, Alberta, Canada T6G 2N8 (email: gheo@ualberta.ca)
[f]Professor, Department Chair, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada T6G 2N8

Corresponding Author:
Dr. Paul Major
Lead, School of Dentistry
Professor and Chair
Department of Dentistry
Faculty of Medicine and Dentistry
3036 Dentistry/Pharmacy Building
University of Alberta, Edmonton
Canada, T6G 2N8
Phone: 780-492-0574
Fax : 780-492-7536
Email: major@ualberta.ca

Abstract

Introduction: Orthodontic Torque expression is the result of axial rotation of rectangular archwires within a rectangular bracket slot. This study investigates the effect of bracket material on torque expression. Torque exerted by a rotating archwire on each bracket will be measured as well as the relative deformation of each bracket slot.

Methods and Materials: A total of sixty (60) tests were performed where archwires were rotated within a bracket slot in order to produce torque within a bracket. Thirty (30) Ormco OrthosTi and thirty (30) Orthos SS were compared to investigate the effect of torque on bracket material. Each bracket was mounted on a six axis load cell which measured forces and moments in all directions. The archwire was rotated from an initial angle of 0° in 3° increments to maximum angle of 51° and then returned to the initial position. An overhead camera took images at each 3° increment. The bracket images were post processed using a digital image correlation technique to measure the relative deformation of each bracket slot.

Results: The maximum torque expressed at 51° was 99.8Nmm and 93.0Nmm for OrthosTi and Orthos SS, respectively. Total plastic deformation measured at 0° post torquing of the Orthos SS was 0.038mm compared to 0.013mm for OrthosTi.

Conclusions: The OrthosTi brackets plastically deformed less than the Orthos SS brackets after torquing. The Orthos SS bracket plastic deformation was 2.8 times greater than that of OrthosTi brackets. The OrthosTi brackets expressed more torque than the stainless steel brackets but exhibited substantial variation.

Keywords: torque, deformation, bracket, digital image correlation, archwire, edgewise orthodontic treatment

Introduction

Rectangular archwires are utilized in edgewise orthodontic treatment in order to achieve buccal or lingual root movement1. A rectangular archwire rotated within a rectangular bracket slot produces a force couple which causes tooth movement; this tooth movement is defined as third order torque. Torque and torque expression are defined as the physical moment which is generated within a bracket slot. Torque expression is affected by several factors: wire, bracket material properties, wire material properties, bracket slot dimensions, wire dimensions, and the angle of twist of the archwire relative to the bracket slot 2-9.

Brackets of different material properties will exhibit different responses to an applied torque. Depending on the material properties of a particular bracket and the amount of torque applied elastic and plastic deformation of the bracket tie wings may occur. Plastic deformation is a permanent change to the bracket shape which occurs if the force applied to a bracket exceeds the yield strain of the bracket material at any point along the structure[10]. Brackets of different material properties will have different yield strains and therefore plastically deform at different levels of applied torque. Strain is defined as the ratio of total deformation to the initial dimension of an object[11]. Titanium brackets are manufactured using Ti-6-4 and have a modulus of elasticity of 114 GPa and a yield strain of 0.00789mm/mm[12]. Stainless steel brackets are manufactured using 17-4 alloy for the bracket tie wings and Type 304 AISI for the base of the bracket[13]. The stainless steel brackets have a modulus of elasticity of 190 GPa and yield strain of 0.00672 mm/mm[14]. It is probable that Titanium brackets will exhibit greater elastic deformation, but less plastic deformation than stainless steel brackets of same geometry due to the inherent material properties of these brackets.

The goal of this study is to examine torque expression in two geometrically similar conventional ligation brackets of different materials during loading and unloading. Brackets will be compared using loading and unloading curves of the measured torques and by comparing the deformation of the bracket slots measured using a digital image correlation technique.

Methods and Materials

This study consisted of sixty (60) first right maxillary incisor brackets with 0.022” x 0.028 slot dimensions. All brackets had a 15° torque and 5° tip prescription. Thirty (30) OthosSS brackets and thirty (30) OthosTi brackets (Ormco, Orange, Calif) were used. Torque was applied to each bracket using 0.019” x 0.025” stainless steel archwires (Ormco, Glendora, CA) using elastomeric ligation. The two brackets were compared to determine if a difference exists between the magnitudes of torque expressed and to compare the bracket slot deformation due to the engagement of an archwire within each bracket slot.

The torque measurement device presented by Badawi et al. [15] was modified for this experiment and the method used for this study is described by Lacoursiere et al. (2010). [16] Each bracket and archwire combination was tested by rotating the archwire from 0° to 51° and then returning the wire to the original position of 0°. The angle of the archwire was increased in 3° increments resulting in a total of 36 data points collected for each bracket/ archwire combination. At each data point, 3 components of force and moment were measured using a 6- axis load cell (ATI Industrial Automation Nano 17 Multi- Axis force/ torque transducer, Apex, NC, USA). Data was collected using a data acquisition card (DAC 16-bit E Series NI PCI-6033E, National Instruments, Austin, Tex, USA). A custom program (LabWindows/ CVI, National Instruments, Austin, Tex, USA) was utilized to control the experiment, provide real-time feedback and record the logged data.

To account for the test bracket offset from the load cell a transformation was utilized to convert load cell forces and moments, to forces and moments experienced by the bracket. The transformation was applied and saved using a spreadsheet (Microsoft Office Excel 2003, Microsoft Corp. Redmond, WA, USA). This transformation was detailed by Major et al (2010).[17]

Overhead images of each bracket were taken to measure the deformation of each bracket. Images were collected with a high resolution CCD (piA2400 -12gm, 2448 x 2050 pixels, 8 bit, gray scale, Basler Vision Technologies, Exton, PA, USA) camera equipped with a long working distance microscope (Edmund Optics, 55-908 MMS R4, Barrington, NJ, USA) and epi- illumination. Images were collected at each data point and digital image correlation was utilized to measure the relative deformation. Images were processed to produce displacement vector files using a digital image correlation approach that determined the relative deformation of the bracket tie-wings between data points with using commercial imaging software (LaVision GmbH, DaVis 7.2, Göttingen, Germany, 2007). Displacement vector files were further processed to determine the relative motion of each bracket. [18, 19] Displacement vectors were process using custom software (The MathWorks, Inc., Matlab, Natick, MA, USA) to determine the average relative motion and displacement of the tie wings. Details of the deformation analysis are discussed by Major et al. and Lacoursiere et al.[16, 17]

Deformation and torque measurement results at each angle increment for the two brackets were compared using a statistical software package (SPSS, SPSS 17, Chicago, Il, USA). A Kolomogrov- Smirnov test was utilized to examine the normality of the torque expression data. If the collected data violated the equal variance assumption for ANOVA analysis test statistics using a Brown- Forsythe and Welch method were planned. A P-value of greater than 0.05 was utilized as the criteria to determine if a statistically significant difference existed between the two brackets.

Results

A total of sixty (60) tests were performed using thirty (30) stainless steel Orthos and thirty (30) OrthosTi. Of the sixty (60) tests performed two (2) of the stainless steel brackets and one (1) of the titanium separated from the epoxy used to hold the brackets in place. Therefore, the final samples size for this study was twenty- eight (n_{SS} = 28) stainless steel brackets and twenty- nine (n_{Ti} = 29) titanium brackets.

Torque Expression

The mean torque expressed by the titanium and stainless steel brackets is compared in Figure 1. Both brackets show similar torque characteristics over the range of applied archwire angle. There is an initial region of applied archwire angles where there is essentially on torque expression. This is followed by a path of increasing torque to a maximum. On the unloading of the bracket a different load path is followed. Figure 2 shows the individual torque curves for each stainless steel (Figure 2a)) and titanium (Figure 2b) bracket. From Figure 2 it can be seen that the torque measured during the unloading of each bracket is less than the torque during loading for both the titanium and stainless steel brackets. Figure 2 also includes error bars for each angle which represent ± one standard deviation. The error bars in Figure 2 indicate that the titanium brackets have larger variation at each angle than stainless steel brackets.

To compare the torque expressed by the stainless steel and titanium brackets a Welch and Brown- Forsythe statistical test was utilized since the equal variance assumption is violated. Figure 3 shows the Welch and Brown- Forsythe analysis results. Points which lie below the 0.05 significance cutoff indicate that a statistically significant difference exists between the two brackets at the specified angle. Torque expression was not statistically significant during loading up to approximately 45° degrees of wire rotation. Torque expression was significantly different during unloading until the bracket engagement angle (approximately 18°) was reached. Summary statistics for the torque at each angle for the titanium and stainless steel brackets are shown in Table 1.

Bracket Slot Deformation

The average relative deformation between cross-slot tie wings of each of the brackets is compared in Figure 4. It can be seen from this figure that the deformation of the stainless steel brackets during the loading and unloading is greater than the titanium brackets. For both bracket types deformation during the unloading (decreasing angle) portion of the graph is greater than during loading (increasing angle). The final average deformation represents the plastic deformation which occurred with 51° of wire rotation. The mean plastic deformation of the stainless steel brackets is 0.038 mm compared to a deformation of 0.013 mm for the titanium brackets.

A comparison of the deformation of the stainless steel and titanium brackets was performed using a Welch and Brown- Forsythe statistical test. Figure 5 shows the results from the Welch and Brown- Forsythe analysis. Bracket deformation was significantly different during loading in the range of 12°-33° of wire rotation. Deformation was significantly different during the entire unloading phase. Summary statistics for the deformation of stainless steel and titanium brackets are displayed in Table 2.

Discussion

This study was designed to evaluate how two conventional twin brackets of similar geometric design but of different materials behave when a torque is applied. Torque expression and bracket slot deformation were evaluated. Prior investigations into bracket deformation were only able to measure plastic change and were not capable of measuring deformation as a torque is applied to a bracket[7, 8].

The majority of previous investigation report torque during loading[4-6, 8]. However, in the clinical setting, the wire is twisted to engage the bracket and it is the unloading torque expression which results in tooth movement. The loading and unloading torque curves are different for both bracket types with unloading torque dropping fairly quickly as the wire is rotated back toward the neutral position. Stainless steel brackets had significantly less torque expression during unloading down to 12°, which is approximately the engagement angle. Although clinically appropriate torque levels are not well established,[20-22] several researchers have suggested that 5 – 20 Nmm is the clinically relevant range[6,9,13]. During loading 5Nmm was reached at approximately 15° wire rotation and 20 Nmm was exceeded at approximately 20° of rotation, with no significant difference between Stainless Steel and Titanium brackets. During the unloading phase torque expression dropped quite quickly with Stainless Steel having clinically relevant torque expression between 33° and 24° of wire rotation. Titanium brackets had clinically relevant torque expression between 31° and 15°. The range of wire rotation with clinically relevant torque expression was larger for titanium brackets.

The deformation of the slot of the titanium and stainless steel brackets is compared in Figure 4 which shows how the tie wings separate when under load. It can be seen that while the angle of the archwire rotation is increasing (loading) the curves of the titanium and stainless steel brackets are similar. However, while the angle of archwire rotation is decreasing (unloading) the curves for the stainless steel and titanium brackets follow different trends. The average final titanium deformation is 0.013 mm while the average final deformation of the stainless steel bracket is 0.037 mm. The stainless steel bracket deformation is approximately 2.8 times that of the titanium brackets. Differences in torque expression during unloading may be the result of plastic bracket deformation.

Titanium has a lower modulus of elasticity (E) than stainless steel. Modulus of elasticity is a material is a material property and does not depend on material geometry. Titanium has a modulus of modulus of elasticity of 114 GPa compared to that of stainless steel which is 190 GPa. Since titanium Since titanium is a more flexible metal than stainless steel it was expected that the titanium brackets titanium brackets would not express as much torque as the stainless steel brackets at a given amount given amount of archwire rotation. However, torque expression curves are a structural representation of the behavior and thus bracket geometry is also an important parameter. In these In these tests, a point load (or line load across) is applied on the tie wing. Hypothetically this load is this load is half of the force couple applied by the wire (torque/distance between two contact points). contact points). Each tie wing can be modeled as a cantilever beam in bending. An example of the example of the deflection of a cantilevered beam is shown in Figure 6: Cantilevered Beam Example(a) Cantilevered Beam with point load (P) applied at location from fixed end (b) Orthodontic bracket with point load (P) applied at location from fixed tie wing end

. This figure compares the bracket tie wing to a cantilevered beam. Deflection measured at the top of the tie wing can be approximately solved using δ_{max} equation[11]:

$$\delta_{Max} = \frac{Pa^2}{6EI}\left(3L - a\right) \text{ (Equation 1)}$$

where the deflection is a function of elastic modulus (E), applied load (P), length of cantilevered beam (L), moment of inertia of the tie wing cross section (I), assuming a constant cross section and the position at which the load is applied (*a*). To add to the complexity of the results; as the wire is loaded/ unloaded and turns the position of the load application and its magnitude changes. As seen from Figure 7 and Figure 8, the large section of the tie wing at the top is unlikely to deform under the loads as the cross section can double that of the base. Any differences in the base dimensions could have a significant effect on the expected results of two geometrically similar brackets.

The final (plastic) deformation of the stainless steel brackets was expected as stainless steel is a more rigid metal than titanium. Also, titanium has a higher yield strain than stainless steel 0.0078 mm/mm compared to 0.0067 mm/mm. Titanium is more flexible than stainless steel and therefore will plastically deform less than stainless steel. Figure 9 compares the load against deflection of titanium and stainless steel brackets. As expected titanium brackets deform the same distance as stainless steel brackets at a considerably lower applied load.

The large variation in torques expressed by the titanium brackets may be due to the archwire engaging the bracket slot at different positions. An example of an archwire engaging a titanium bracket slot is illustrated in Figure 7. This variation could be caused by differences in the manufacturing of the titanium brackets. Slight variations in the manufacturing of the titanium brackets tie wings would result in the elastomeric ligation securing the archwire at different locations within the bracket slot. Figure 8 compares the location of bracket/ archwire engagement. Figure 8 (a) shows an archwire engaging a bracket high within the bracket slot. If this scenario were to occur less torque would be expressed due to an increased moment arm acting on the bracket tie wing. Conversely, Figure 8 (b) shows an archwire engaging a bracket at a lower location within the bracket slot. This second scenario would result in greater torque expression.

Different locations of archwire engagement within the bracket slot and variations in bracket tie wings may account for the titanium brackets not exhibiting a substantial difference in maximum deformation as the stainless steel brackets. To compare the cross-sectional areas of titanium and stainless steel brackets tie wings a calculation was performed to determine the moment of inertia (I) of each bracket using (Equation 1. The bracket slot height was assumed to be 0.7112 mm long and the point load was assumed to act a distance of 0.5334 mm above the bottom of the slot. The deformation found at 51° was utilized as the maximum deformation (δ_{max}) found for each bracket. From this calculation it was determined that the stainless steel bracket moment of inertia was 4.72 x 10^{-6} mm^4 compared to a moment of inertia of 1.25 x 10^{-5} mm^4 for titanium. This indicates that a difference in the cross sectional areas of the two bracket exists. A difference in the cross sectional area of the brackets would account for the titanium brackets deflecting less than expected. Titanium is more flexible than stainless steel and therefore should deflect more if the load and cross-sectional area of the two brackets is the same.

Conclusion

This study investigated the effect of bracket material on torque expression. The relative deformation of each bracket slot was also compared. The following conclusions were found when comparing the results of the OrthosTi and Orthos SS brackets:

- Torque expression was greater during loading than unloading. Titanium brackets demonstrated larger torque expression during unloading and a larger range of clinically relevant torque expression.
- Material properties of a bracket affects how much torque is expressed in the bracket and the amount of deformation that the bracket experiences after a torque is applied and then released
- Titanium brackets demonstrated a greater amount of variation of torque expressed than stainless steel brackets
- Stainless steel brackets plastically deformed approximately 2.8 times more than titanium brackets after applying and releasing a torque

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Tables and Figures

Figure Legend

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Table 1: Comparison of Average Torque of Stainless Steel and Titanium Orthos Brackets

	Stainless Steel (n=28)		Titanium (n=29)		Mean Difference (Ti-SS) (Nmm)	P Value
Angle	Torque Average (Nmm)	Torque Standard Deviation (Nmm)	Torque Average (Nmm)	Torque Standard Deviation (Nmm)		
0L	-0.10	0.35	1.97	6.20	-2.08	0.08
3L	1.00	1.05	2.90	6.20	-1.91	0.11
6L	2.12	1.45	3.89	6.18	-1.77	0.14
9L	3.26	2.01	4.88	6.25	-1.62	0.19
12L	4.09	3.08	5.66	6.47	-1.58	0.24
15L	6.63	4.42	9.10	6.89	-2.48	0.11
18L	12.91	5.68	14.96	7.97	-2.05	0.27
21L	21.33	6.73	22.69	9.04	-1.36	0.52
24L	30.09	7.48	31.27	9.61	-1.17	0.61
27L	39.43	7.73	40.47	10.11	-1.03	0.67
30L	48.46	7.89	49.57	10.42	-1.11	0.65
33L	56.96	7.81	58.51	10.51	-1.55	0.53
36L	65.22	7.44	67.31	10.33	-2.09	0.38
39L	72.75	6.58	75.59	10.14	-2.85	0.21
42L	79.37	5.53	83.09	9.93	-3.71	0.09
45L	85.00	4.65	89.68	9.83	-4.68	0.03
48L	89.53	4.45	94.85	9.29	-5.32	0.01
51L	93.05	5.02	99.88	10.05	-6.83	0.00
51U	92.06	5.06	98.99	10.09	-6.94	0.00
48U	77.37	4.93	84.34	9.93	-6.96	0.00
45U	64.23	4.92	71.77	10.64	-7.55	0.00
42U	51.69	4.78	58.38	9.63	-6.69	0.00
39U	40.33	4.57	46.60	9.32	-6.27	0.00
36U	30.05	4.32	35.79	8.87	-5.74	0.00
33U	21.11	3.82	26.16	8.50	-5.05	0.01
30U	13.91	3.14	18.35	8.03	-4.44	0.01
27U	9.01	2.70	13.27	7.64	-4.27	0.01
24U	5.51	2.35	10.48	7.54	-4.96	0.00
21U	3.77	2.00	8.16	7.29	-4.39	0.00
18U	3.27	1.68	5.99	7.05	-2.72	0.05
15U	2.96	1.49	5.03	6.69	-2.07	0.11
12U	2.24	1.41	4.28	6.57	-2.04	0.11
9U	1.67	1.35	3.69	6.53	-2.01	0.11
6U	0.96	1.15	2.80	6.54	-1.83	0.15
3U	0.64	1.21	2.41	6.54	-1.77	0.16
0U	-0.19	1.21	1.54	6.49	-1.73	0.17

Table 2: Comparison of Average Deformation of Stainless Steel and Titanium Orthos Brackets

	Stainless Steel (n=28)		Titanium (n=29)		Mean Difference (Ti-SS)	P Value
Angle	Average Deformation (mm)	Standard Deviation (mm)	Average Deformation (mm)	Standard Deviation (mm)		
0L	0.00	0.00	0.00	0.00	0.00	0.81
3L	0.00	0.00	0.00	0.00	0.00	0.90
6L	0.00	0.00	0.00	0.00	0.00	0.76
9L	0.00	0.00	0.00	0.00	0.00	0.54
12L	0.00	0.00	0.00	0.00	0.00	0.02
15L	0.00	0.00	0.01	0.00	0.00	0.00
18L	0.01	0.00	0.01	0.00	0.00	0.00
21L	0.01	0.00	0.02	0.00	0.00	0.00
24L	0.02	0.00	0.02	0.00	0.01	0.00
27L	0.02	0.00	0.03	0.01	0.01	0.00
30L	0.03	0.01	0.03	0.01	0.01	0.00
33L	0.03	0.01	0.04	0.01	0.00	0.04
36L	0.04	0.01	0.04	0.01	0.00	0.27
39L	0.05	0.01	0.05	0.02	0.00	0.79
42L	0.06	0.01	0.06	0.02	0.00	0.65
45L	0.07	0.01	0.06	0.02	-0.01	0.27
48L	0.08	0.01	0.07	0.02	-0.01	0.08
51L	0.08	0.01	0.07	0.02	-0.01	0.08
51U	0.08	0.01	0.07	0.02	-0.01	0.06
48U	0.07	0.01	0.06	0.02	-0.01	0.05
45U	0.07	0.01	0.06	0.02	-0.01	0.05
42U	0.07	0.01	0.06	0.03	-0.01	0.06
39U	0.07	0.01	0.06	0.02	-0.01	0.06
36U	0.06	0.01	0.05	0.02	-0.01	0.05
33U	0.06	0.01	0.05	0.02	-0.01	0.03
30U	0.05	0.01	0.04	0.02	-0.01	0.01
27U	0.04	0.01	0.03	0.02	-0.01	0.00
24U	0.04	0.01	0.02	0.02	-0.02	0.00
21U	0.04	0.01	0.01	0.01	-0.02	0.00
18U	0.04	0.02	0.01	0.01	-0.03	0.00
15U	0.04	0.02	0.01	0.01	-0.03	0.00
12U	0.04	0.02	0.01	0.01	-0.03	0.00
9U	0.04	0.02	0.01	0.01	-0.03	0.00
6U	0.04	0.02	0.01	0.01	-0.03	0.00
3U	0.04	0.02	0.01	0.01	-0.03	0.00
0U	0.00	0.00	0.00	0.00	0.00	0.00

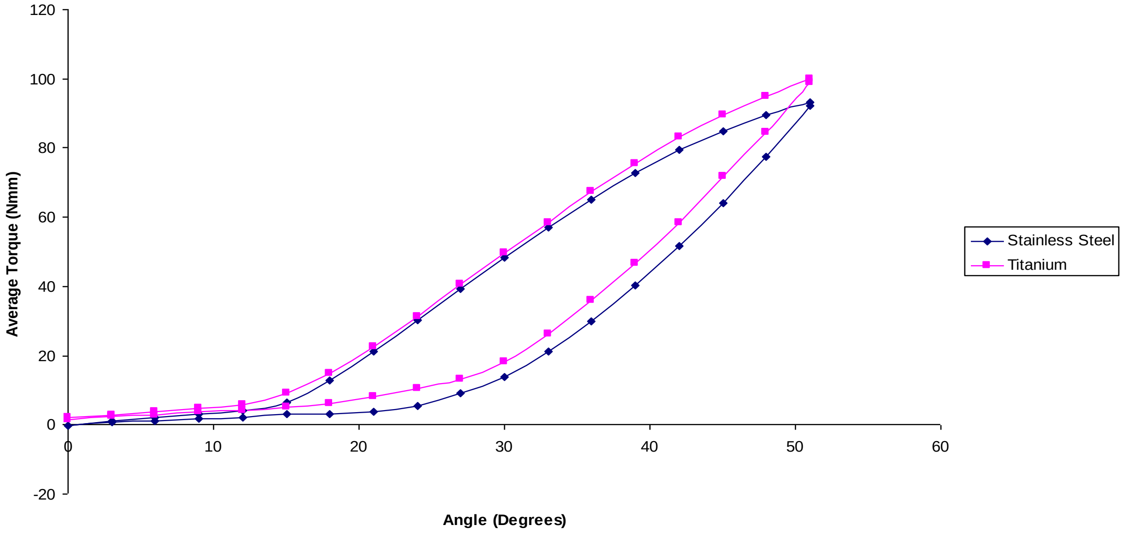
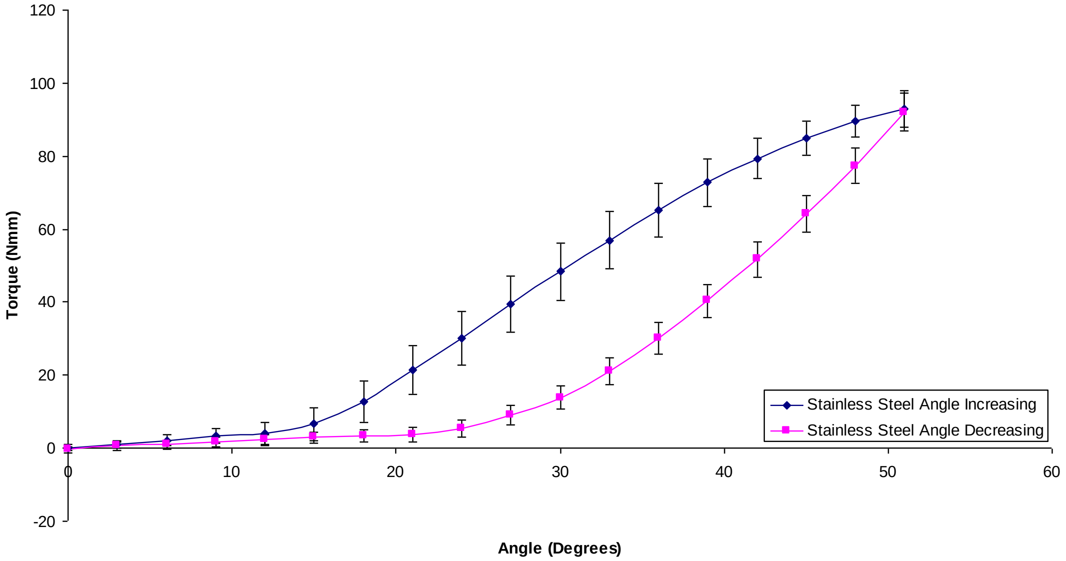
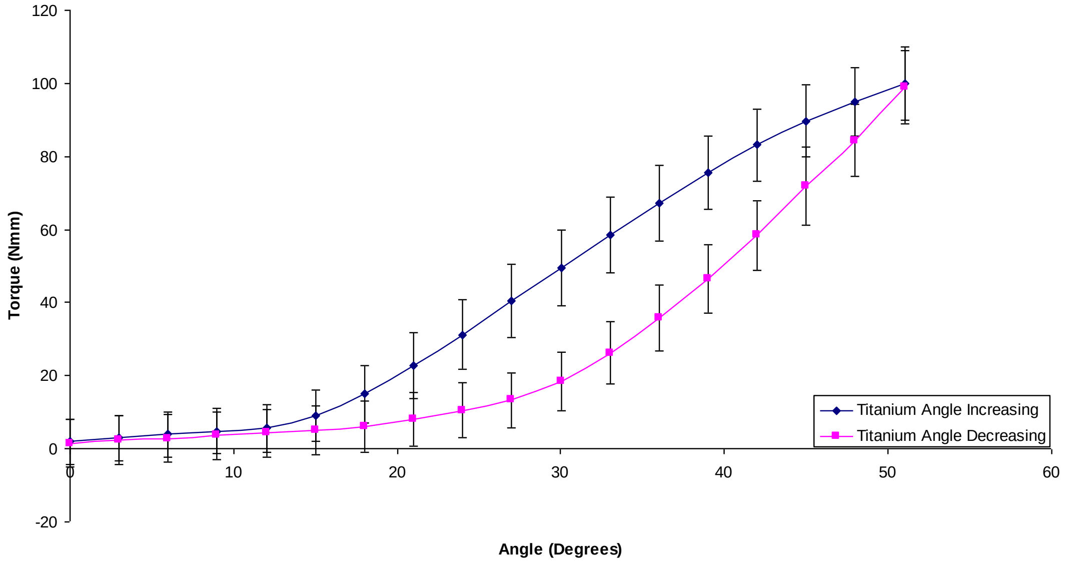


Figure 1: Comparison of torque vs. angle of wire twist for titanium and stainless steel Orthos brackets



(a)



(b)

Figure 2: Torque vs. angle of wire twist with one standard deviation error bars (a) Stainless Steel Orthos Brackets (b) Titanium Orthos Brackets

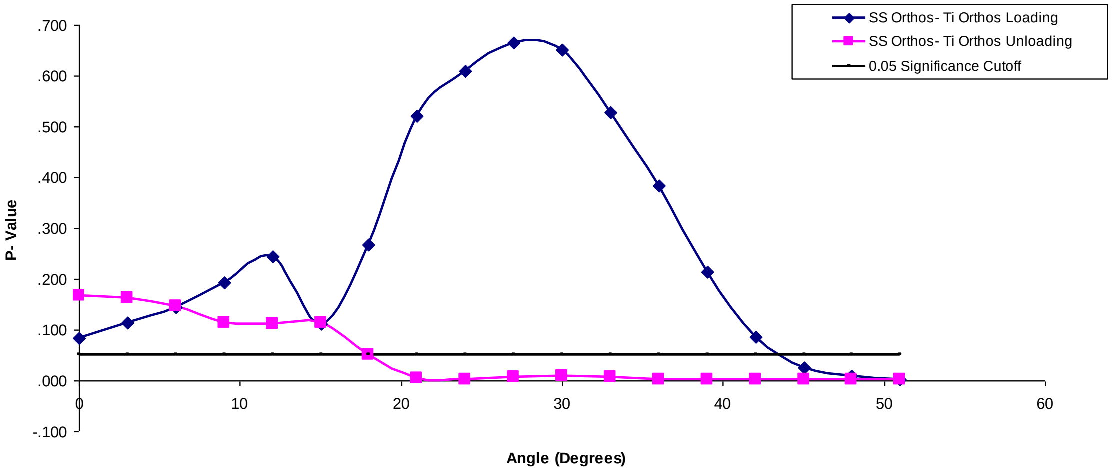


Figure 3: Welch & Brown- Forsythe significance of torque expression

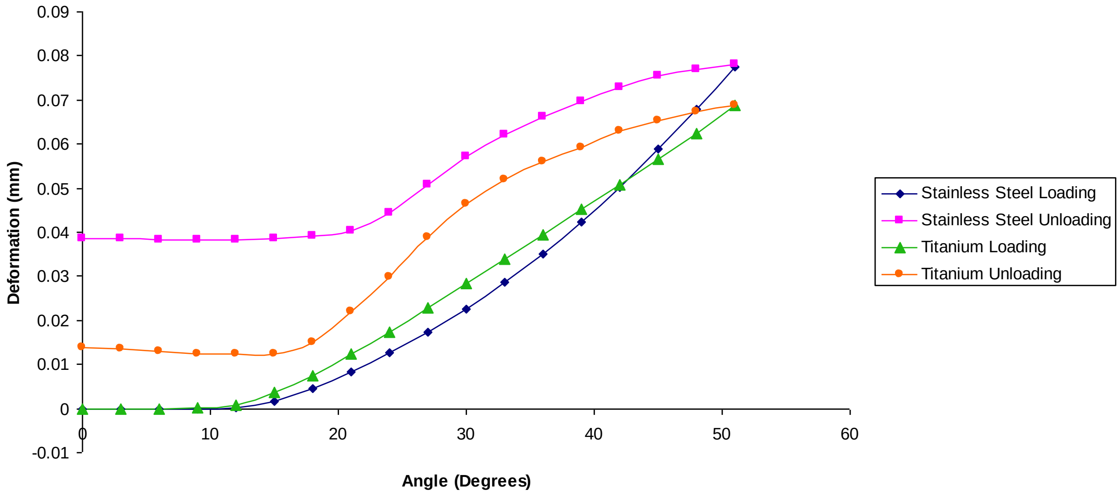


Figure 4: Comparison of relative deformation vs. angle of wire twist for titanium and stainless steel Orthos brackets

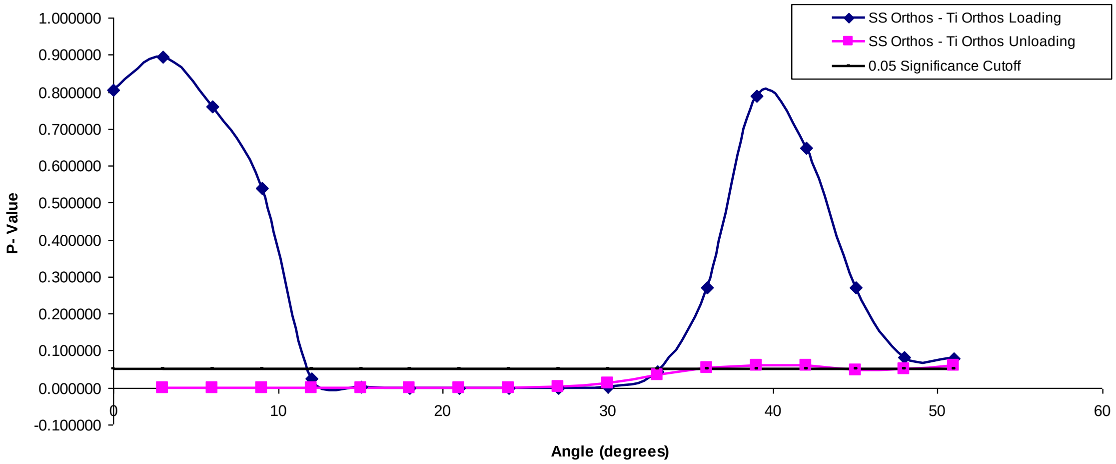


Figure 5: Welch and Brown- Forsythe significance of bracket deformation

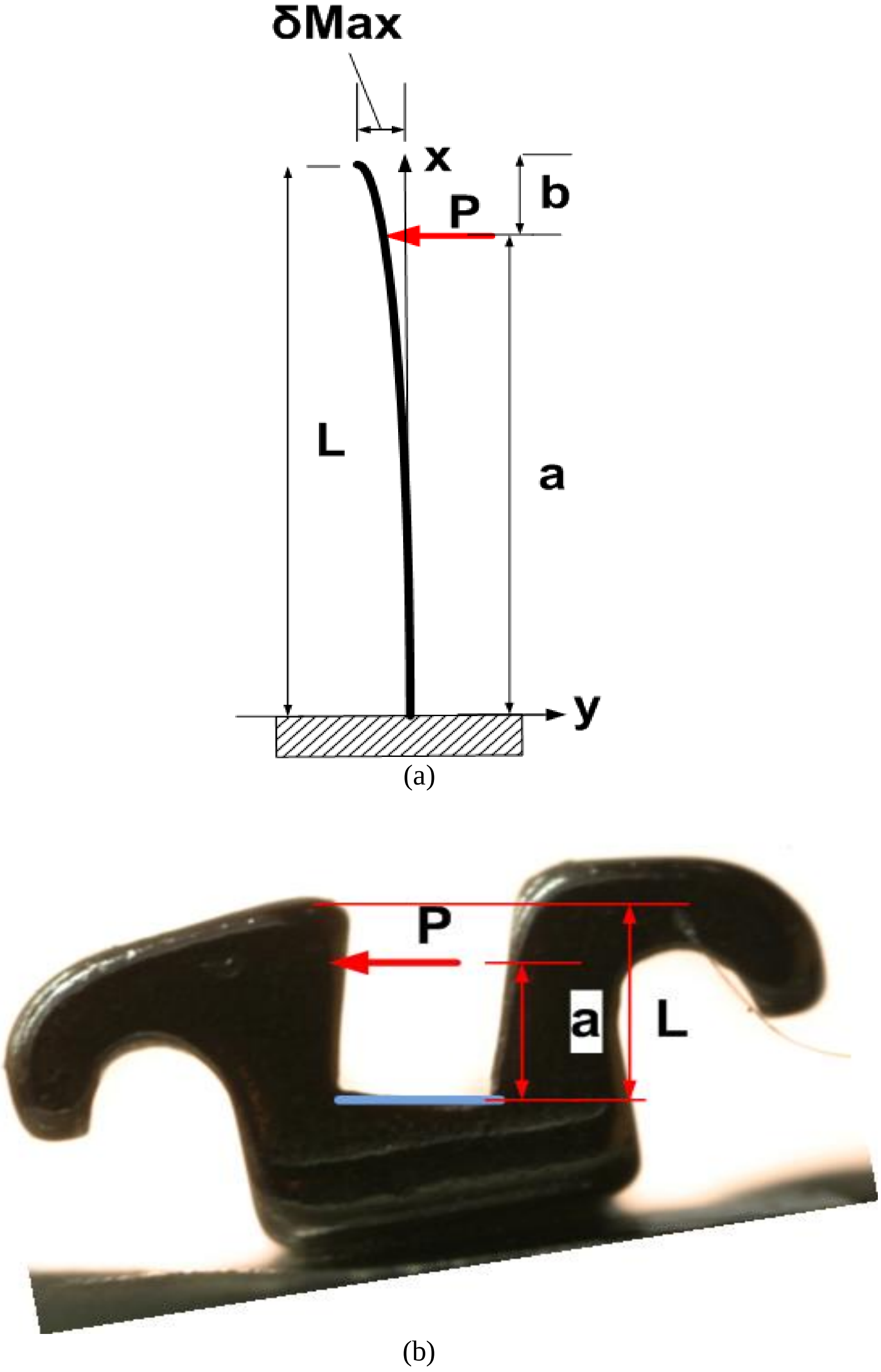


Figure 6: Cantilevered Beam Example(a) Cantilevered Beam with point load (P) applied at location from fixed end (b) Orthodontic bracket with point load (P) applied at location from fixed tie wing end

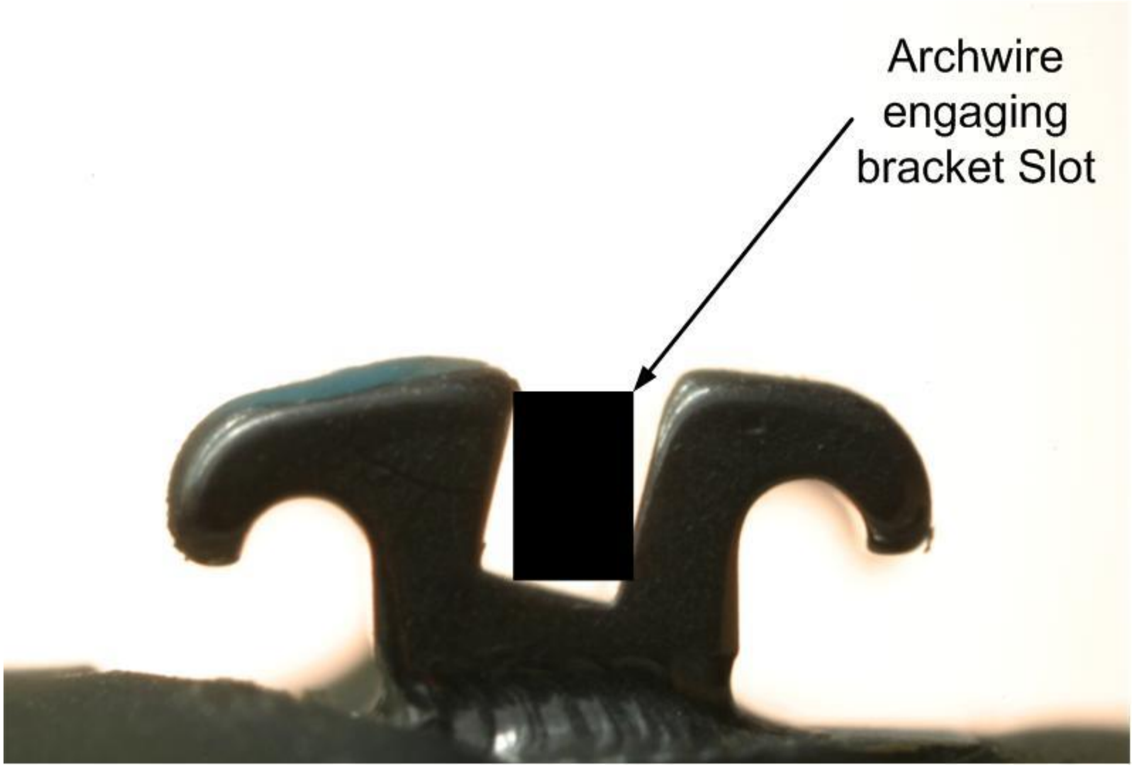
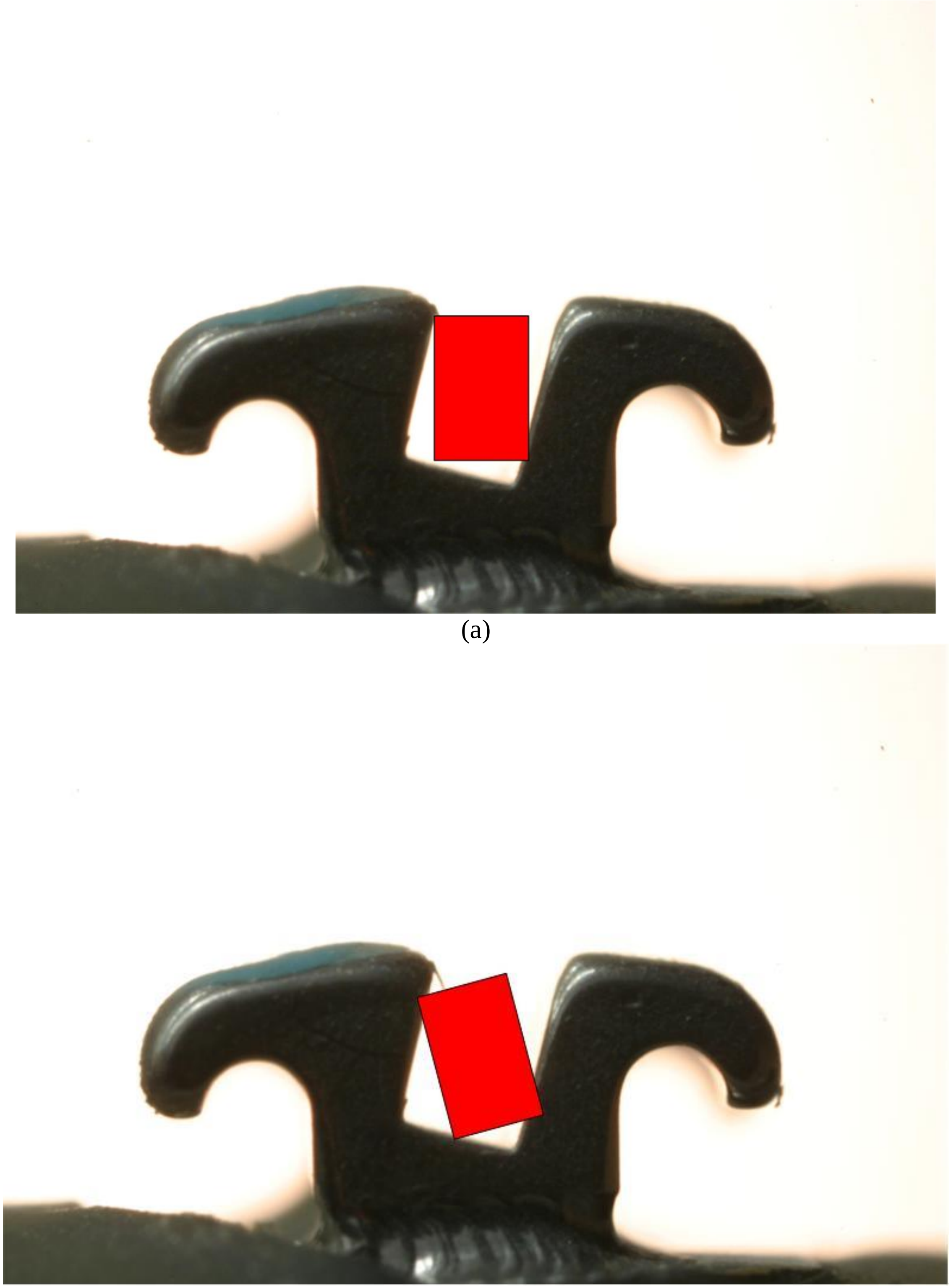


Figure 7: Titanium Bracket with Archwire engaging bracket slot



(a)

(b)

Figure 8: Comparison of Bracket Slot Archwire Engagement
(a) Archwire engaging bracket slot close to opening of slot (b) Archwire engaging bracket slot close to bottom of slot

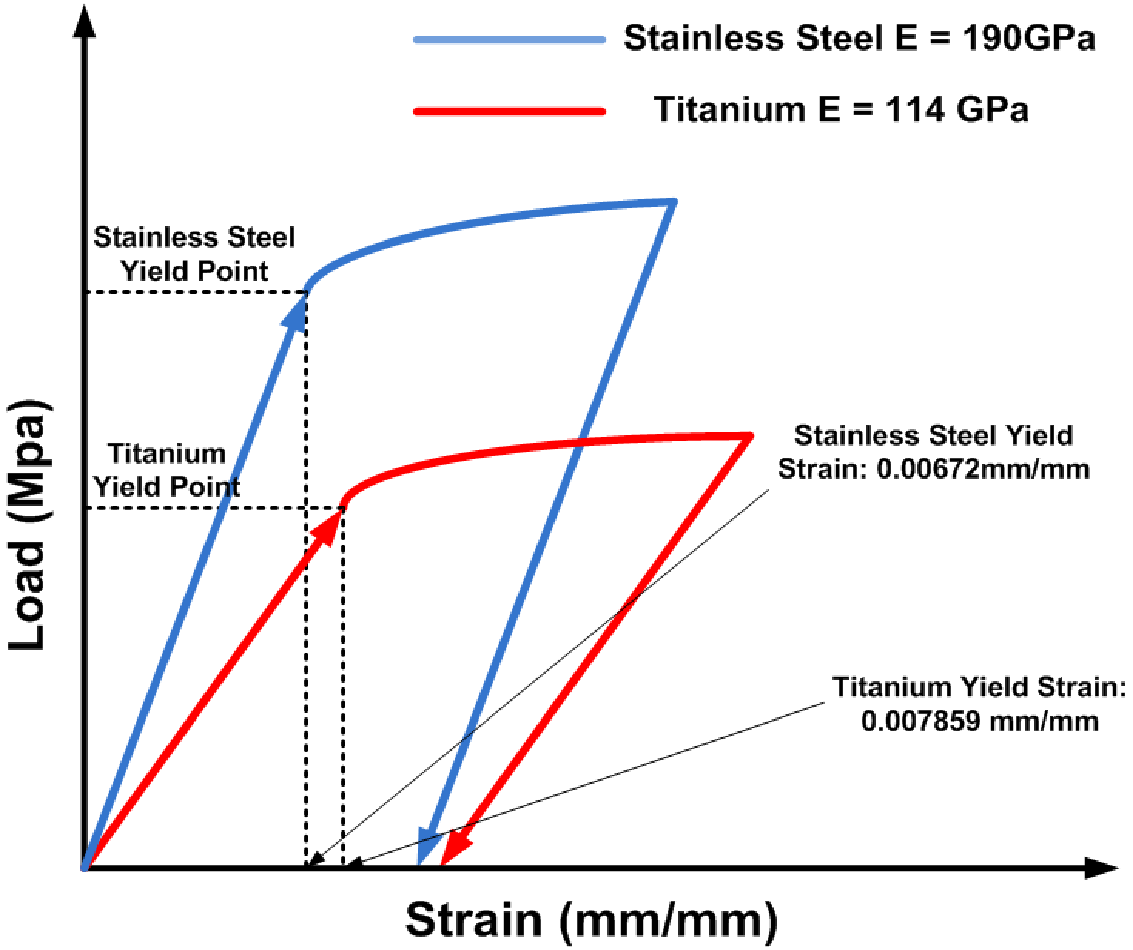


Figure 9: Comparison of Titanium and Stainless Steel Brackets Stress Strain Curves. A load is applied to each metal (load is below failure limit of each material), the yield strength of both metals is exceeded and the load is released