Original Article

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Comparison of slot deformation in stainless steel and ceramic brackets during torque - A finite element analysis

Harikrishnan, Pandurangan [1]***; Magesh, Varadaraju*** [2]***; Kingsly Jeba Singh, Devadhas*** [2]

1 Teeth"N"Jaws Center, Chennai - 600034, India

2 Bio-Mechanics Laboratory, Department of Mechanical Engineering, SRM University, Chennai, India

ABSTRACT

Introduction: Torque in orthodontics is vital in final positioning of the teeth during fixed appliance therapy. Torqueing of archwires is a significant factor in transferring the applied forces to the bracket which might cause deformation of the slot. Any deformation in the bracket slot can vary the torque prescription and thus can affect the tooth position.

Aim: To evaluate and compare the deformation of stainless steel (SS) and ceramic bracket slots during torque, using finite element analysis.

Materials and methods: A maxillary right central incisor bracket (0.022 x 0.028 inch) dimensions were measured using a profile projector, and a finite element (FE) model was constructed. Bracket materials considered were stainless steel (SS) and ceramic. An SS rectangular archwire (0.019 x 0.025 inch) with angles of twist ranging from 5° to 40° was theoretically converted into torque. The bracket slot deformation was obtained at the top, middle and bottom locations using FE analysis.

Results: There is a uniform increase in deformation in the bracket slot walls from torque of 9.7 to 77.62 Nmm except that there is a 100 percent increase in deformation when the torque changed from 38.81 to 48.51 Nmm. The top location in the gingival slot wall showed maximum deformation compared with middle and bottom slot positions in both the materials. The deformation of SS bracket slot was more than the ceramic bracket slot.

Conclusion: This study showed that the bracket slot walls of both SS and ceramic brackets are subjected to deformation by application of torque and the maximum deformation was in the upper part of the bracket slot.

Harikrishnan P, Magesh V, Kingsly Jeba Singh D. Comparison of slot deformation in stainless steel and ceramic brackets during torque - A finite element analysis. South Eur J Orthod Dentofac Res. 2017;4(1):5-8.

Submitted: August 25, 2016; Revised: February 24, 2017; Published: April 19, 2017

INTRODUCTION

In fixed appliance therapy, there is transfer of force from the archwire to the teeth through the bracket. In this force transfer mechanism especially during torque, there is a possibility of bracket deformation. It is necessary to study the bracket deformation, in order to understand the effective torque. Torque is the ability of force to rotate an object around an axis or pivot. In orthodontics, torque is a moment generated by the torsion of a rectangular wire in the bracket slot. The terms "moment", "torsional moment", "couple", "biomechanical torque", "third-order torque" is often used in the orthodontic literature indicating the same loading conditions. [1] The variables in the expression of torque include the stiffness of wire alloys, the play between wire and slot, the ligation modes, and the bracket design. [2] The rectangular archwire - bracket slot relationship establishes the stability of tooth root position. Incisor torque is important to get the proper interincisal angle, overjet and for optimal posterior teeth occlusion as well.

Corresponding Author:
Pandurangan Harikrishnan
Teeth"N"Jaws Center,
600034 Chennai, India
e-mail: teethnjaws@rediffmail.com

Experimental studies available for predicting the orthodontic bracket behavior for an applied torque needs extensive instrumentation. [3-6] Moreover, they do not allow a graphical display of the deformation and stress distribution for the clinicians to visualize. Prior deformation studies have been limited to tie wing displacement. [6-8]

The finite element (FE) method is an approximation technique used by numerical equations. This technique can be used to model the physics of complex structures. [9] The development of a numerical model makes it possible to quantify and evaluate the effects of torsional forces applied to achieve tooth movement.[10] Finite element method is suggested by many authors for deformation and stress studies.[11-12]

As in orthodontics, stainless steel (SS) and ceramic brackets are commonly used, these two material characteristics were used in this study. Our hypothesis in this study is that there is torque relevant deformation in the bracket slot area. Thus we compared the slot deformation of SS and ceramic bracket during torque, using finite element analysis.

MATERIALS AND METHODS

Materials

Standard Edgewise (Tweed's) maxillary right central incisor SS bracket (ORMCO, California, USA) with 0.022 x 0.028-inch slot was used.

Modeling of orthodontic bracket

An optical profile projector (Model: ph 3515F, Mitutoya South Asia Pvt. Ltd, Japan.) was used to measure the stainless steel bracket dimensions. The points were taken along the profile of the bracket. The points were imported to drafting package (AutoCAD 2014, Autodesk, Inc, San Rafael, California, USA) to draw the profile of the bracket with the imported points. The same profile was used for ceramic bracket as well. A three-dimensional solid bracket model was constructed with the measured dimensions in modeling software (CATIA V5 R12, Dassault Systems, Villacoublay, France).

The FE model was generated using software (HyperMesh 10.0, Altair Engineering, Michigan, USA). The bracket model was meshed with 37282 isoparametric four-node tetrahedral solid elements and 17730 nodes as shown in Figure 1. The meshed model was imported to finite element software (Ansys 10, AnsysInc, Pennsylvania, USA). The material properties of the bracket were obtained from published literature [12] and assigned to the model as shown in Table 1. The ceramic brackets used in this study were considered as ceramic alone and not reinforced with stainless steel slot inserts. The materials are linear, elastic and isotropic.

Figure 1. *Finite element bracket model.*

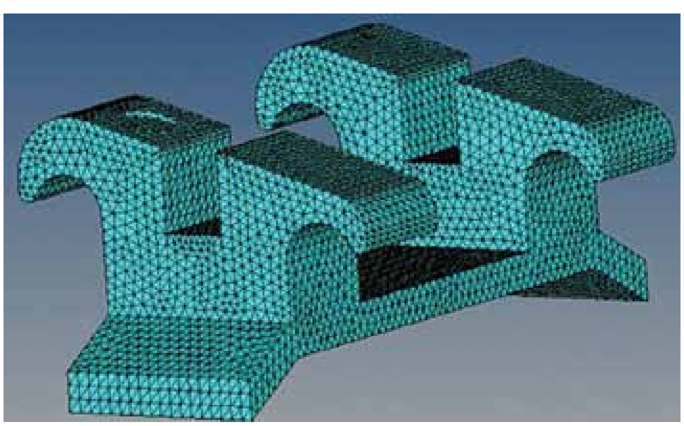


Table 1. *Material properties of stainless steel and ceramic*

Material	**Young's modulus** (MPa)	**Poisson's ratio**
SS	200000	0.30
Ceramic (Al_2O_3)	380000	0.29

MPa – Mega Pascal

Calculation of forces exerted by archwire

The equivalent torque for a stainless steel archwire with cross section 0.019 x 0.025 inch was ascertained by calculation. In this study, the twist ranges from 0° to 40° with 5° intervals was used as this are the torque limits commonly used in orthodontics. The angle of twist of rectangular archwire was converted as torque (T) using the formula.[13]

$$\emptyset = \frac{42\ T\ LJ}{G\ d^4\ b^4}$$

Where $\emptyset$ is the applied twist in radians, 'G' is the shear modulus of the stainless steel archwire material which is 86 Giga pascal, 'd' and 'b' are the cross section dimensions of the rectangular archwire, 'L' is the length of the archwire which was taken as 10 mm, and 'J' is the polar moment of inertia of rectangular cross section.

The force (F) used to create the torque (T) in the archwire was calculated using the formula T = F x d, where 'd' is the perpendicular distance between the couple applied. The calculated torque and force values are presented in Table 2.

Table 2. *Calculated torque and force values*

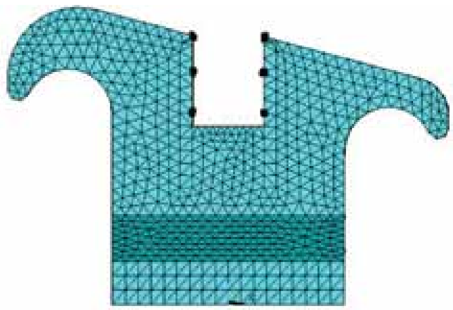
Angle of twist (degree)	**Torque** (Nmm*)	**Force** (N)
5	9.70	18.62
10	19.40	36.68
15	29.10	55.02
20	38.81	73.36
25	48.51	153.04
30	58.21	183.65
35	67.92	214.26
40	77.62	244.85

**Newton millimeter*

Finite element analysis of bracket

When a torqued archwire is inserted into the bracket slot, it is in contact with the bracket slot walls strongly at few locations during palatal root torque. In this study, the couple applied was considered in two stages. In stage-1, the angle of twist ranged from 5° to 20° and in stage-2, from 21° to 40°. All the nodes in the base of the bracket were completely arrested in all degrees of freedom. In the FE bracket model, the nodal displacements were measured at the top, middle and bottom positions in the slot walls of the bracket as shown in Figure 2.

Figure 2. Nodal displacement measured positions in the slot (Marked cubes).



RESULTS

The torque applied exhibit different locations of archwire contacts in the bracket slot as shown in Figure 3. As the torque increases the contact points change in the slot. There is a gradual uniform increase in deformation in both SS and ceramic bracket slots at torque of 5° to 20° (stage-1). There is sudden 100 percent increase in deformation, when the torque angle changed from 20° to 25° and returning to uniform deformation at torque of 25° to 40° (stage-2). The deformation also varied in the top, middle and bottom locations of the slot as shown in Tables 3 and 4. The brackets deformation for 40° twist is visually displayed in Figure 4 and 5 for SS and ceramic materials respectively. The comparative graphical representation of the deformation of both materials is shown in Figure 6.

Figure 3. Contact areas of torqued wire in the slot.

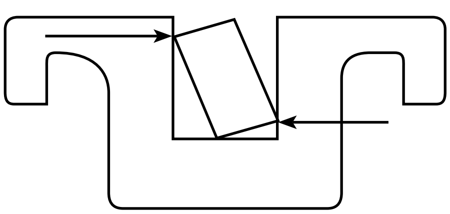


Table 3. Bracket slot wall deformation of SS bracket

Angle of twist (degree)	Slot deformation (µm)		
	Top	Middle	Bottom
5	1	0.6	0.3
10	2.1	1.3	0.7
15	3.3	2	1.1
20	4.4	2.7	1.5
25	8.6	6	2.7
30	9.3	7.3	3.3
35	12	8.5	3.9
40	13.7	9	4.4

Figure 4. Deformed SS bracket (40° angle of twist).

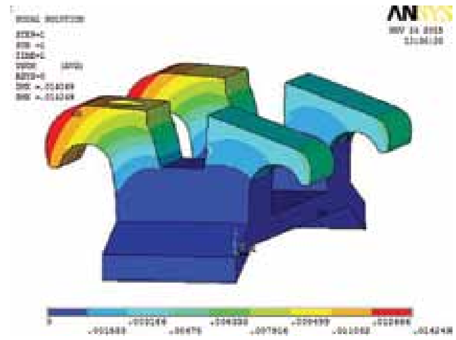


Table 4. Bracket slot wall deformation of ceramic bracket

Angle of twist (degree)	Slot deformation (µm)		
	Top	Middle	Bottom
5	0.5	0.2	0.2
10	1.1	0.7	0.3
15	1.7	1	0.5
20	2.2	1.4	0.7
25	4.4	3.1	1.4
30	5.3	3.7	1.7
35	6.3	4.5	1.9
40	7.1	5.1	2.3

Figure 5. Deformed ceramic bracket (40° angle of twist).

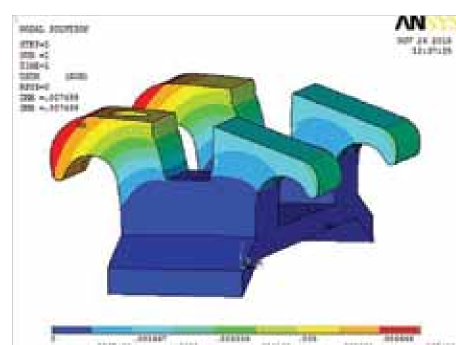
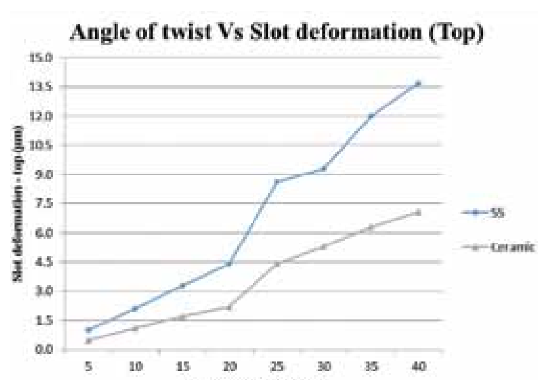


Figure 6. Comparison of slot (top) deformation in SS and ceramic brackets.



DISCUSSION

Torqueing is commonly done for anterior teeth root positioning. The twisted archwire ligated tightly in the slot, exerts forces on the bracket slot walls. Such forces might have a tendency to deform the slot. The largest archwire normally used is 0.019 x 0.025 inch SS wire in the 0.022-inch slot.

In this study, we evaluated torque angles from 5° to 40°, as this covers the clinical torque range commonly used. SS and ceramic materials have different mechanical properties (Young's modulus); thus the response for torque applied is expected to be varied. Our study shows the bracket slot deformation directly at different positions in the slot for various angles of twist as it happens in clinical situations. Lacoursiere et al., reported experimentally that the bracket tie wings are deformed elastically and plastically during the torque expression and showed the relative distance changes between the tie wings. [6] We consider that the slot dimensional changes are directly relevant to the torque expression, rather than the tie wings.

Ceramic brackets are being used more often on account of their esthetics, greater hardness and resistance to stains. Our results show ceramic bracket have lesser deformation than SS bracket on all torque angles. Ghosh et al., studied the stress distribution of ceramic bracket design by FE analysis and concluded that several design features demonstrated good and poor stress distribution.[14]

In our present study, the deformation for all torque angles at the top, middle and bottom positions for SS and ceramic brackets were recorded. There were gradual deformation changes in both SS and ceramic brackets to varying degrees of torque, but there is the uniform increase in the deformation from 5° to 20°. There was almost 100 percent increase in deformation when the torque angle changed from 20° to 25° which is due to the decrease in the couple arm. Thus, while clinically torquing is done, at certain stages, there might be increased deformation on the slot walls due to the changes in the couple arm. The maximum deformation at the angle of twist of 40° in SS and ceramic brackets at the top position of the slot are 13.7 µm and 7.1 µm respectively.

Our results show that as the angle of twist increases, there was more contact force on the slot walls and thus there is increased deformation of slot. Clinically, a deformation in slot wall might lead to either temporary or permanent changes in slot dimensions, leading to changes in the torque applied to the bracket slot. In both the bracket materials, the top position of slot wall shows more deformation than middle and bottom positions. The bottom position of slot wall had the least amount of deformation as that position of the slot is closer to the base of the bracket which is fixed, and thus might resist the contact force significantly. Both the bracket materials show maximum deformation at both mesial and distal gingival outer edges of the tie wings and slot walls as seen in Figure 4 and 5. This is expected as the forces applied for palatal root torque usually are translated to the gingival wings through the gingival wall of the bracket slot at the top location in the slot. Our results showed that deformations of ceramic bracket slots were lesser than SS bracket in all slot positions. A study by Holt et al., showed the ceramic brackets to be capable of withstanding torque values between 3706 and 6177 g/mm.[15] Our results also prove that ceramic brackets have higher rigidity than stainless steel brackets. Similarly, Nishio et al. reported that ceramic brackets showed significantly higher deformation resistance than plastic brackets.[16] Contrary to our results, Matsui et al., showed that ceramic brackets have similar resistance against moment loads to stainless steel brackets. [17] The elastic deformation of the material depends on their Young's modulus. SS has lesser Young's modulus than ceramic. Thus, SS bracket slot deformation was more than that of the ceramic bracket as shown in our study.

Thus, we summarize that there is deformation in the bracket slot due to torquing force and the deformation varies according to the bracket material.

CONCLUSION

As torque is commonly used in orthodontics, we evaluated the torque relevant deformation. We conclude that the bracket slots of both SS and ceramic material are subjected to deformation by application of torque. There is more deformation in the upper slot location and there is gradual reduction in the middle and bottom slot locations. The SS bracket slot deformation is greater than the ceramic bracket slot. Thus our hypothesis that there is torque relevant deformation in the bracket slot area is proved. Accordingly, such slot deformations can have significant clinical implications during application of torque in orthodontics.

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