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RESEARCH ARTICLE

FINITE ELEMENT ANALYSIS FOR STRESS-STRAIN DISTRIBUTION IN BRACKET-ARCHWIRE CONFIGURATION

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ABSTRACT

Objective: To develop an optimum bracket design, the stress-strain distribution of a particular material can be studied by means of finite element models (FEM). The purpose of this study was to design a basic structure of bracket-archwire configuration and to determine the location of stress-strain distribution.

Method: Two 3D FEM of bracket-archwire configurations were designed. The first model was constructed with a stainless steel (SS) bracket having 0.022×0.028-in slot size along with 0.019×0.025-in SS archwire. The second model was designed with the same bracket model having 0.019×0.025-in nickel- titanium (NiTi) archwire. The wire was subjected to +/-0.025N of sliding force. ANSYS software was used to determine the stress-strain patterns at each nodal point.

Results: In both the models, irrespective of the change in material properties, stress-strain with respect to bracket was seen to be concentrated at the contact boundary and in the archwire the maximum stress-strain was seen at the loading sites. The centre of the slot surface of the bracket and centre of the wire experienced the least amount of stress-strain values.

Conclusion: The principal stress-strain was much below the normal values of the material properties indicating that both the bracket and the archwire can undergo heavy forces without undergoing fracture.

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INTRODUCTION

In Orthodontics, the design of the appliance plays a crucial role in the performance, reliability, efficiency and optimization of the final treatment outcome. The orthodontic literature notes numerous variables that affect the levels of stress-strain distribution at the bracket-archwire interface (Mendes Rossouw, 2003; Wichelhaus *et al.,* 2005; Bourauel *et al.,* 1998; Kusy *et al.,* 1991; Kusy and Whitley, 2000; Drescher *et al.,* 1990; Bazakidou *et al.,* 1997). Studies of the numerous parameters, such as bracket composition, bracket width, inter bracket distance, slot size, archwire type, archwire size, second order angulation, degree of torsion and ligation, have helped our understanding by identifying trends or patterns of stress-strain distribution (Emile Rossouw, 2003; Kusy and Whitley, 1997; Articolo and Kusy, 1999; Frank and Nikolai, 1980; Proffit, 2000; Cacciafesta *et al.,* 2003; Drescher *et al.,* 1989). Friction is not likely to be eliminated from materials, thus the best remedy is to control friction by achieving two clinical objectives: maximizing both efficiency and reproducibility of the orthodontic appliances (Shivapuja and Berger, 1994; Cacciafesta *et al.,* 2003; Pizzoni *et al.,* 1998; Eberting *et al.,* 2001; Risinger and Proffit, 1996; Stannard *et al.,* 1986). To better understand this nature, it is of utmost importance that we have a thorough knowledge of the stress-strain distribution between the bracket-archwire interface. The

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purpose of this study was to design a basic structure of bracket-archwire configuration and to determine the location of stress-strain distribution using finite element method (FEM).

MATERIALS AND METHODS

The Finite Element Analysis (FEA) is a numerical method that enables the stress-strain distribution to be calculated in the internal structures. It also has the potential for equivalent mathematical modeling of a real object of complicated tri-dimensional geometry. At the same time, it permits the application of various force systems at a set point and the study of distribution of such forces between bracket and archwire. The three dimensional bracket-archwire assembly was designed using ANSYS software. The study consisted of the following three FEA models: SS bracket with 0.022×0.028-in slot, 0.019×0.025-in SS wire and 0.019×0.025-in NiTi wire. The material properties of SS and NiTi are mentioned in Table 1. The model was meshed with tetrahedral elements having 2,393 nodes (Figure 1a, 1b). Boundary conditions were applied with a tensile load of ±0.025N (Figure 2). Stress-strain distribution was evaluated for SS bracket-SS archwire assembly and SS bracket-NiTi archwire assembly.

RESULTS

The finite element models were evaluated and minimum and maximum von mises criterion was calculated. Principal stress-strain distribution for the SS bracket-SS wire assembly and SS bracket-NiTi wire assembly was determined (TABLE 2-5). In the wire, maximum stress-strain was seen at the loading sites (FIGURE 3a, 3b). In the bracket, maximum stress-strain was seen at the contact boundary (edge) where in the wire makes contact with the bracket (FIGURE 4a, 4b). The centre of slot surface of the bracket and centre of the wire experienced the least amount of stress-strain values.

Table 1. Material properties of stainless steel and nickel-titanium MPa= MegaPascal, GPa= GigaPascal

Material/ Material properties	Yield strength (MPA)	Young's modulus (GPA)	Poisson's ratio
Stainless steel	215	193-200	0.29
Nickel-titanium	70-140	28-40	0.33

Table 2a. Minimum von-mises stress values (S) for SS bracket- SS wire assembly. Pa=Pascal

Principal stress	S1	S2	S3
Node	64	2384	52
Value (Pa)	-50.214	-509.84	-2018.6

Table 2b. Maximum von-mises stress values (S) for SS bracket-SS wire assembly. Pa=Pascal

Principal stress	S1	S2	S3
Node	2257	1754	194
Value (Pa)	2530.7	804.12	432.53

Table 3a. Minimum von-mises stress values (S) for SS bracket-NiTi wire assembly. Pa=Pascal

Principal stress	S1	S2	S3
Node	64	3	52
Value (Pa)	-64.452	-643.54	-2694.9

Table 3b. Maximum von-mises stress values (S) for SS bracket-NiTi wire assembly. Pa=Pascal

Principal stress	S1	S2	S3
Node	710	710	194
Value (Pa)	3486.0	887.81	442.54

Table 4a. Minimum von-mises strain values (S) for SS bracket-SS wire assembly. Pa=Pascal

Principal strain	S1	S2	S3
Node	571	1610	710
Value (Pa)	0.24000	0.30715	0.11906

Table 4b. Maximum von-mises strain values (S) for SS bracket-SS wire assembly. Pa=Pascal

Principal strain	S1	S2	S3
Node	1613	572	710
Value (Pa)	0.12795	0.30587	0.23090

Table 5a. Minimum von-mises strain values (S) for SS bracket-NiTi wire assembly. Pa=Pascal

Principal strain	S1	S2	S3
Node	571	194	710
Value (Pa)	0.35095	0.35027	0.19307

Table 5b. Maximum von-mises strain values (S) for SS bracket-NiTi wire assembly. Pa=Pascal

Principal strain	S1	S2	S3
Node	710	711	572
Value (Pa)	0.17912	0.24925	0.43360

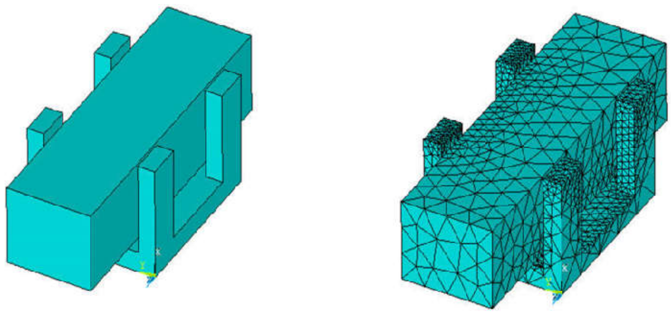

Figure 1A. Bracket-archwire assembly; 1B. Bracket-archwire assembly with nodes and elements.

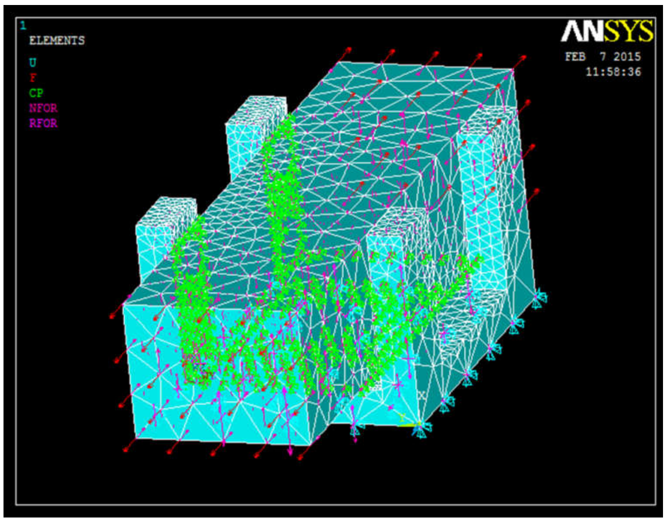

Figure 2. Bracket-archwire assembly exhibiting boundary conditions

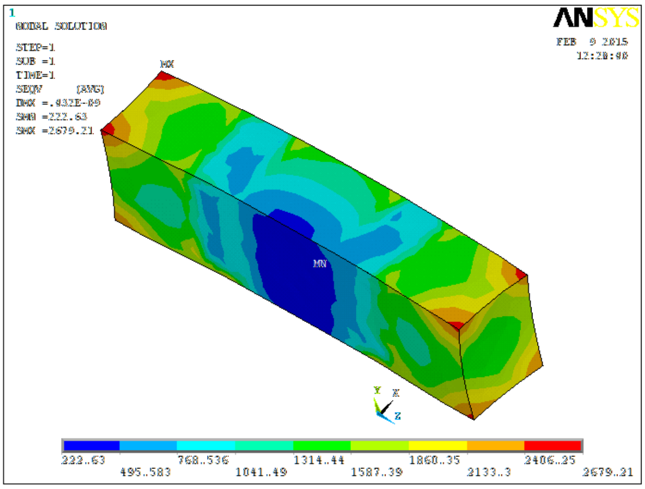

Figure 3. Maximum stree-strain distribution in stainless steel and nickel-titanium wire

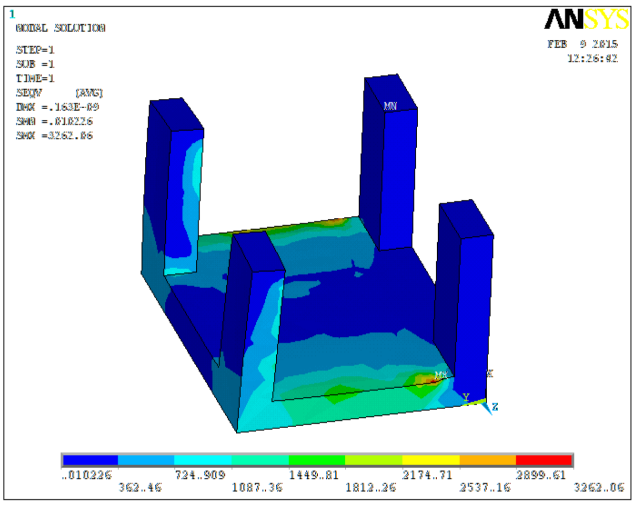

Figure 4. Maximum stree-strain distribution in stainless steel bracket wire assembly and stainless steel bracket and nickel titanium wire assembly

DISCUSSION

When designing a structure, the functionality and the structural integrity must be maintained so that each part of the system must have efficient strength to carry out its designated function. FEM helps us to ensure that each element of the system will meet the structural requirements during the course of its application. It has been demonstrated that the highest stress-strain distribution was seen with the SS bracket-NiTi wire assembly than when compared to the SS bracket-SS wire assembly. These findings are due to the difference in the material properties of each structure. Similar findings were reported in other studies were friction was more when NiTi wires were used with SS brackets (Frank and Nikolai, 1980). In a study conducted by Gosh *et al.,* 1995 the stress distribution patterns of the ceramic brackets showed that stresses tended to concentrate at or near points of application of force, and stress fields were generally not uniform in these areas. Stresses were concentrated at corners, edges, and other areas of abrupt change in the shape of the bracket. In the bracket models, this non-uniform stress pattern was mainly seen at the junction of the wings and the isthmus, the junction of the wall of the wire slot and the facial bracket surface, the junction of the walls of the wire slot with its base, and at the junction of the wings as well as the bracket base to the tying slot.

In another study conducted by Shaik and Prasad, (Shaik and Prasad, 2013) the stress distribution pattern of the ceramic bracket showed that the stresses tended to concentrate at or near points of application of force. Stresses were concentrated at corners, edges, and other areas of abrupt change in the shape of the bracket. The deformation of the ceramic bracket was less compared to stainless steel bracket and titanium bracket. The precision, with which the FEM is done, depends on modelling the structure as closely as possible to the original structure. Certain amount of approximation with respect to type, number, and arrangements of elements, is inevitable with complex designs. Factors such as formulations, material properties, nature of boundary conditions, and representation of loads can affect the validity of the results (Gosh *et al.,* 1995). A limitation of the finite element method in the analysis of solid mechanics is that a few complex phenomena, including cracking and fracture behaviour, are not accurately recorded (Desai *et al.,* 1972). It would be advantageous in the future to include the presence of micro-cracks into the bracket models and perform the study, so as to more closely simulate the real life situation.

Conclusion

- The principal stress-strain was much below the normal values of the material properties indicating that both bracket and archwire can undergo heavy forces without undergoing fracture.

- The stress-strain levels were more in the SS bracket-NiTi wire assembly compared to the SS Bracket-SS Wire assembly.
- In the archwire, maximum stress-strain was seen at the loading sites.
- In the bracket, maximum stress-strain was seen at the contact boundary (edge) where in the wire makes contact with the bracket.
- The center of slot surface of the bracket and the center of the wire experienced the least amount of stress-strain values as this may be attributed to the uniform distribution of forces because of the large surface area contact between the Bracket and the Wire creating a Neutral zone.

Combining the ideal features of design could aid in developing an optimum bracket that would provide a quality product to the field. The FEM reduces the need for prototypes and laboratory experimentation and allows more design options to be tested in a given amount of time.

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