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Effects of a Temperature Distribution on a Dental Crown System

Analysis, Design and Control of a Hovercraft Model

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Research Experience for Undergraduates
Institute for Systems Research

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Section 1- Effects of a Temperature Distribution on a Dental Crown System

Problem Statement

A dental crown system is a type of extracoronal restoration, or a restoration that exists around a remaining tooth structure. It is used in situations where there is not enough remaining solid tooth structure after decay or when a tooth has fractured and is missing important structural reinforcements. It typically consists of four layers, including the original tooth core, a layer of cement, a crown layer to provide the structural support, and a veneer layer that gives the look of a real tooth. All of these layers were created and assembled in order to accurately represent a crown system for the project. An enlarged view of the model is shown below.

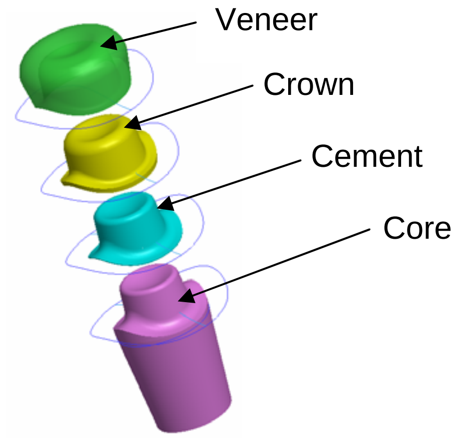

Figure 1: Assembly Parts Used for Analysis

The goal of this project is to determine the effects of a temperature change on the maximum principle stress for the crown layer of the system. This helps determine how long the crown can be used before it will break. Temperature and stress analyses will be done for four different material combinations in order to see what effect these have on the system as well as what materials are better to use for a crown system.

Approach

Pro/Engineer was the program used for all of the analyses in this project, so a preliminary learning phase was necessary to become acquainted with the program. After spending a week learning how to use the program and obtaining the necessary part and assembly files, stress analyses were run in order to recreate data that had already been collected. The analyses were run at various locations on the model, as shown in the picture below. The axis angles include 0°, 30°, 60°, and 90°. A downward vertical force of 200 N was applied along the edge of each small individual circle, each of which is 1 mm in diameter.

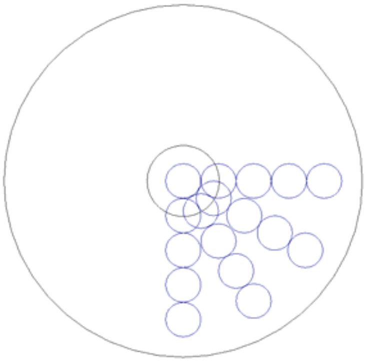

Figure 2: Top View of Analysis Locations

The analyses were done for all of the given materials: zirconia and composite resin cement. Additional crown and cement materials were tested: gold alloy and Unmodified ZOE cement. The material properties used can be found in Appendix A. Tables of this collected data can be found in Tables 1-4.

Once the stress analyses were completed for the four different material combinations, temperature analyses were run. A temperature of -16 °C was used to represent the serving temperature of ice cream, and a temperature of 60 °C was used as the serving temperature of coffee. The reference temperature used was 37 °C, the normal human body temperature. Once a temperature analysis was run, a temperature stress load was created from this in order to represent the forces created on the crown by thermal expansion or contraction. The force of 200 N was also applied to the tooth at the center to represent the force created from the chewing motion. After this, another stress analysis was run to determine the changes in the maximum principle stress for the model. This was done for each temperature using the same material combinations as the previous stress analyses.

The temperature stress analysis can be broken into two pieces, thermal stress and structural stress. Tables of these values can be found in Tables 5-8, and Figure 4 shows the relationship between each of the individual stresses and the total maximum principle stress.

Results and Discussion

The following tables show the changes in maximum principle stress on the crown layer as the location of the applied force changes.

Table 1: Zirconia and Composite Resin- Max Principle Stress (MPa)

Offset (mm)	0°	30°	60°	90°
0.00	67.32	67.32	67.32	67.32
1.00	66.33	66.43	66.61	67.02
2.00	75.55	74.74	71.52	74.57
3.00	49.26	52.53	49.87	49.19
4.00	44.22	28.54	18.73	18.64

Table 2: Gold Alloy and Composite Resin- Max Principle Stress (MPa)

Offset (mm)	0°	30°	60°	90°
0.00	35.63	35.63	35.63	35.63
1.00	35.66	34.94	35.21	35.52
2.00	44.68	45.71	44.41	45.87
3.00	33.74	34.94	33.97	33.24
4.00	19.06	16.42	15.56	15.67

Table 3: Gold Alloy and Cement- Max Principle Stress (MPa)

Offset (mm)	0°	30°	60°	90°
0.00	59.45	59.45	59.45	59.45
1.00	59.80	59.47	59.94	60.43
2.00	71.49	73.69	71.67	74.50
3.00	51.45	54.41	52.51	52.21
4.00	43.89	27.48	25.96	26.27

Table 4: Zirconia and Cement- Max Principle Stress (MPa)

Offset (mm)	0°	30°	60°	90°
0.00	92.37	92.37	92.37	92.37
1.00	90.06	90.91	91.32	92.16
2.00	96.86	95.91	93.09	96.09
3.00	65.45	66.13	64.32	63.91
4.00	80.67	53.18	29.99	33.26

The maximum principle stress remains fairly constant until the applied load reaches an offset of 2 mm. At this point, the stress increases dramatically. The stress decreases rapidly as the applied force moves away from the center location, and these variations in stress values can be attributed to the geometry of the system. The following pictures show the location of the maximum principle stress as it is shifted along the tooth.

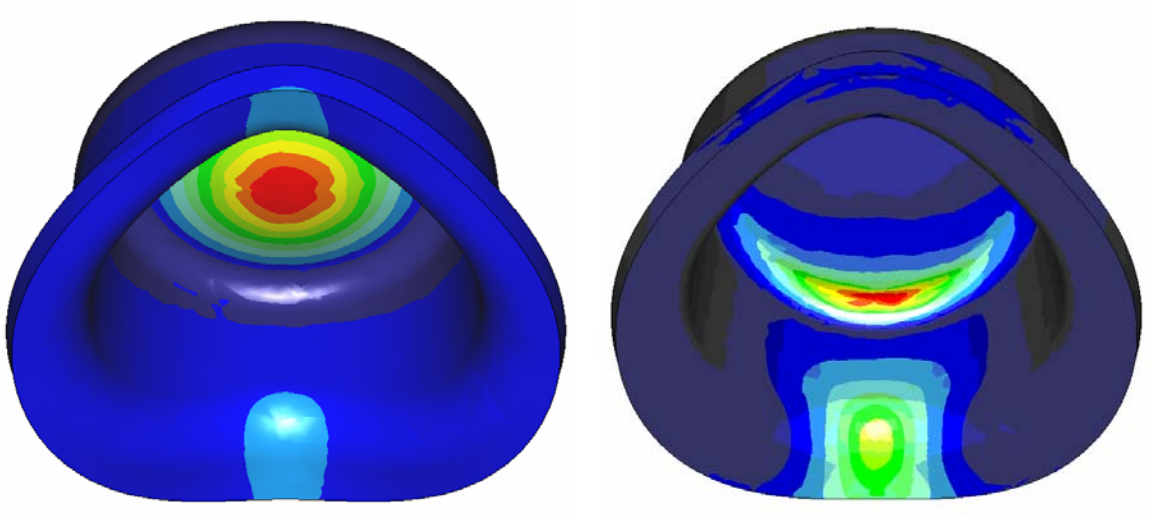

Figure 3: Location Shift of Principle Stress

The following tables show the maximum principle stress values obtained when a thermal stress is added to a structural stress that is already located at the center of the tooth. These values are for the crown layer.

Table 5: Zirconia and Composite Resin- Stresses at Center Location (MPa)

Applied Temperature (° C)	Total Principle Stress	Structural Stress	Thermal Stress
-16	94.09	67.31	55.19
0	86.00	67.31	38.53
15	78.42	67.31	22.91
37	67.32	67.32	0.00
45	63.27	67.31	5.625
60	55.69	67.31	16.17

Table 6: Gold Alloy and Composite Resin- Stresses at Center Location (MPa)

Applied Temperature (° C)	Total Principle Stress	Structural Stress	Thermal Stress
-16	72.88	35.63	74.88
60	21.36	35.63	23.41

Table 7: Gold Alloy and Cement- Stresses at Center Location (MPa)

Applied Temperature (° C)	Total Principle Stress	Structural Stress	Thermal Stress
-16	86.16	59.44	85.76
60	48.03	59.44	9.145

Table 8: Zirconia and Cement- Stresses at Center Location (MPa)

Applied Temperature (° C)	Total Principle Stress	Structural Stress	Thermal Stress
-16	109.9	92.35	53.59
60	84.76	92.35	96.85

The structural stress does not change, which is expected since the applied force remains constant and the temperature is the only variable that changes with each analysis. The thermal stress, however, begins to decrease as the temperature rises. When the temperature is equal to the reference temperature, the thermal stress goes the zero, but as the temperature continues to rise, the thermal stress begins increasing. This is due to the combination of compressive and tensile stresses in the structure. Eventually, the value of the maximum principle stress drops below the original value even though the thermal stress continues to increase. The following plot shows the relationship between all of these stresses.

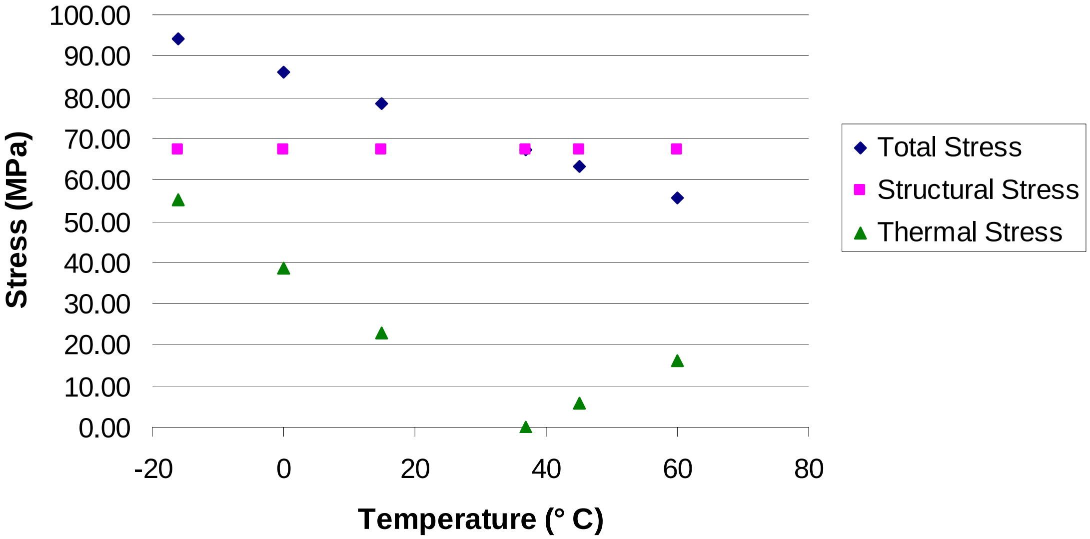

Figure 4: Zirconia and Composite Resin

Conclusion

From the data collected, it cannot be determined which material would be best for the dental crown system. Each material combination had varying changes take place, some being more affected by the change in location of the applied force than others. Some were also more affected by the change in temperature than others. These varying effects can be attributed to the materials’ different mechanical and thermal properties.

There may not be one specific material that is better than another to use simply because the people who have the dental crown systems are very different. Much of the life span of the crown can be attributed to the force applied when a person chews as well as the angle at which it is applied. Since people’s teeth have different geometries, the chewing force is different for every person. This has a major impact on the value and location of the maximum principle stress within the system. The temperature also has a large impact on the value of the stress. Cold temperatures cause a much larger change in the stress than hot temperatures. The most effective way to avoid damage to a crown system is simply to avoid very hot and very cold foods as well as chewing carefully or not at all on the crown side of the mouth.

Section 2- Analysis, Design, and Control of a Hovercraft Model

Project Statement

A hovercraft is a special type of vehicle that moves on a cushion of air. The lifting motion is controlled by a fan or fans so that an air gap can be formed beneath the vehicle. Such separation between the bottom of the hovercraft and the ground provides a motion platform, on which the friction force between the hovercraft and the ground reduces to a very small amount. Since a hovercraft does not have wheels, the forward motion is created through propulsion, which is generated by the use of a fan or set of fans located on the back end of the hovercraft. These propulsion fans send the air backward to produce a thrust force, which moves the hovercraft forward. A picture of the constructed model used is shown below.

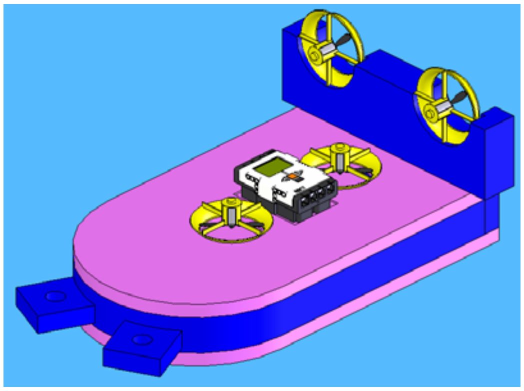

Figure 5: Hovercraft Model

The goal of this project is to analyze, create, and control a working hovercraft model. Initially, flow analysis will be performed on a hovercraft model created in SolidWorks. After a design has been found that provides the necessary lift force, the model will be constructed using materials provided by the University of Maryland. Once the model is assembled and working, programming will be done in order to control the motion of the hovercraft. This will be done using an NXT control box. The ultimate goal is to have the model follow a specified path by using feedback from light sensors to control the movement.

Approach

To begin the project, we were given a series of notes with some information and calculations that needed to be done in order to find the necessary lift force for the model. An assembly of the model was created in SolidWorks and flow analysis was performed to see if there would be a large enough pressure difference to allow the hovercraft to lift off of the ground.

An estimated mass of 1 kg was used to find the necessary lift force to get the model off of the ground. By multiplying the mass by the gravitational constant, we determined that a force of approximately 10 N was needed. After this, we calculated the input flow rate for the flow analysis to be 0.07 m^3/s. This was done using the equation below, where D is the exit diameter of the fan, P is the pitch value, and N is the rotational speed of the fan blade, which was measured using a tachometer.

$$FlowRate = 0.75 * \pi * \frac{D^2}{4} * P * N \tag{1}$$

After these calculations, the analysis was run for various gap heights, and the pressure differences between the air inlet and exit were found. Multiplying the pressure difference by the lift area gives the value for lift force. The lift area that was used was 0.20 m^2. A summary of the pressure differences and their associated lift force values can be found in Table 9.

Following the flow analysis, two models were constructed. The models have different design parameters; however, both used the same number of fans for lift and propulsion. The only difference between the two hovercrafts was the inclusion of a bottom plate on one model. Once both designs were completed and working properly, we began wiring the hovercrafts with relay devices. The devices were connected to the NXT box and provide control for the power to the propulsion fans. Light sensors were used to provide a reading for changes in color. Since the specified path was made of black electrical tape, the sensors can detect when the hovercraft deviates from its path. The program then sends a signal through the relay device and controls the power to the propulsion fans. One fan is shut off to allow the hovercraft to turn and recover its position on path.

Results and Discussion

The following table summarizes the results for the flow analysis. Adjusting the gap size allowed us to determine the lift force provided by the resultant pressure difference.

Table 9: Summary of Flow Analysis

Number of Fans	Gap Size (in)	Pressure Difference (Pa)	Lift Force (N)
1	1/4	4	0.808
	1/8	201	40.6
	1/16	222	44.9
2	1/4	60	12.1
	1/8	872	176
	1/16	960	194

As the gap size increases, the pressure difference drops causing the lift force to drop as well. This simulates the hovercraft as it lifts off of the ground. Since the lift force is much higher than the necessary 10 N for a small gap size, the model will continue to rise. For the two fan model, a height of ¼ in. provides a somewhat equal force of 12.1 N, so this is approximately the point when it stops rising and begins to hover.

The figure below shows the flow trajectories of the air as it escapes beneath the skirt of the hovercraft; which is represented by the green stripe. This simulates the air flow under the model as it is being lifted from the ground.

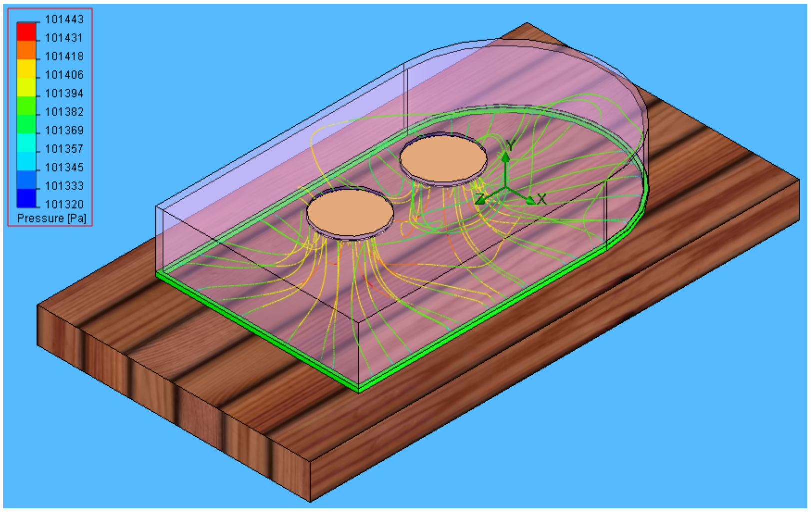

Figure 6: Flow Trajectories

Conclusion

From the collected data and constructed models, the flow analysis in SolidWorks accurately portrayed the lifting motion of the hovercraft. It provided an estimate for the lift height as well as information about the number of lift fans that would be needed for the actual model. The constructed models lifted and propelled as expected, however, the movement of the hovercrafts was not controlled. Given more time, the hovercraft could be finished and programmed so that it would be able to follow a specified path.

Throughout this project, various things could have been accounted for in order to change the outcome. Several weeks were spent working on the flow analysis because we did not realize that the air gap must be included. This would have significantly decreased the time spent on the analysis. More time could have also been spent on the programming of the controls if we would have had fewer side projects to work on. Overall, the allotted amount of time for this project was insufficient for us to accomplish all of the project goals.

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Appendix A

Properties for Materials Used in Dental Crown System Analyses

	Dentin	Porcelain	Zirconia
Density	2.14e-09 tonne/mm^3	2.4e-09 tonne/mm^3	2.4e-09 tonne/mm^3
Young's Modulus	16000 N/mm^2	70000 N/mm^2	205000 N/mm^2
Poisson's Ratio	0.31	0.19	0.19
Conductivity	0.569 N/s/degC	1.00 N/s/degC	2.2 N/s/degC
Specific Heat	1.59e+09 mm^2/s^2/degC	1.09e+09 mm^2/s^2/degC	4e+08 mm^2/s^2/degC
Thermal Expansion	10.59e-06 /degC	6.9e-06 /degC	10.3e-06 /degC

	Gold Alloy	Cement (Unmodified ZOE)	Composite Resin
Density	12.3 g/cm^3	2.05 g/cm^3	2.19e-09 tonne/mm^3
Young's Modulus	78 GPa	0.28 GPa	8000 N/mm^2
Poisson's Ratio	0.33	0.33	0.33
Conductivity	125.60 N/s/degC	0.293 N/s/degC	1.09 N/s/degC
Specific Heat	1.26e+09 mm^2/s^2/degC	1.76e+09 mm^2/s^2/degC	8.25e+08 mm^2/s^2/degC
Thermal Expansion	14.1e-06 /degC	35e-06 /degC	39.4e-06 /degC