MEMO

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SUBJECT: ME 472 – Final FEA Project Report

Introduction

An important part of every basketball shoe is the tread pattern. The tread pattern effects the traction that is required when moving, cutting around, and stopping on a basketball court. This report will answer the question about what type of tread pattern would be best for a basketball shoe out of four preselected patterns. This will be done by looking at which tread pattern has the smallest deflection under a given load. The patterns are shown later in the report. SolidWorks, ANSYS Workbench, ANSYS Mechanical, and Shigley's Mechanical Engineering Design textbook were used to complete this analysis.

Methods

For the geometry, four different tread patterns were selected to be tested. The profiles that are shown in Figure 1 below are the SolidWorks models of those tread patterns. To reduce the time taken to prepare the geometry, and to simplify the model, only one tread of each pattern was modeled. Each of the semi-

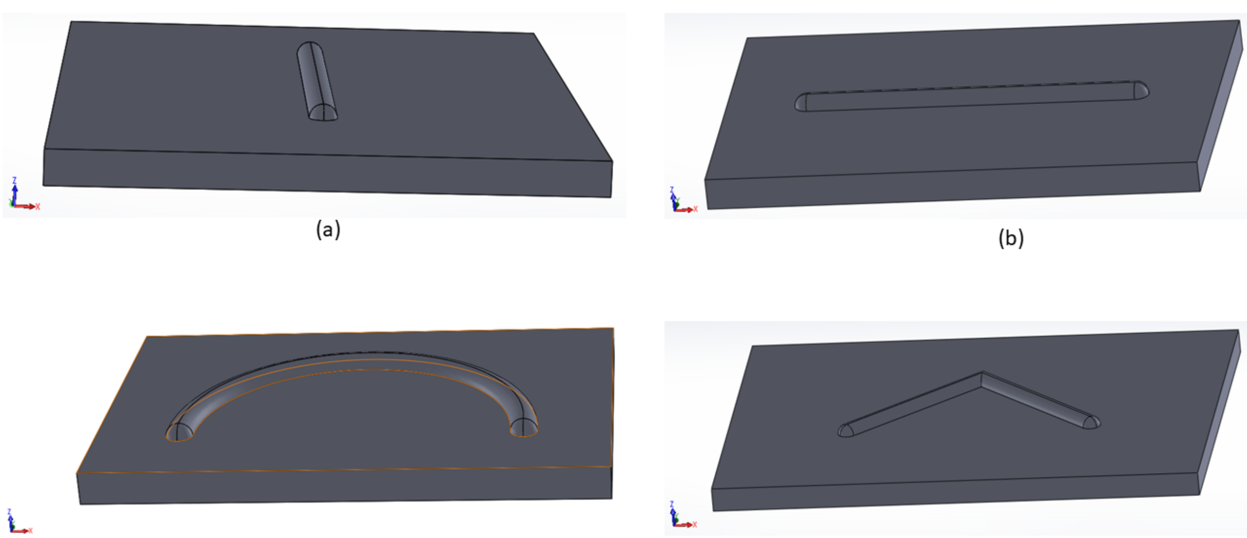
(a) (b) (c) (d)

Figure 1: Views of the different tread patterns that were tested. (a) Treads straight in the Y-direction. (b) Treads straight in the X-direction. (c) Semi-circular treads. (d) 45°angled treads.

circular tread profiles have a radius of 2 mm. The square block below the tread pattern represents the rest of the sole of the shoe that the tread is attached to.

During the conception of this project, it was realized that the force would act primarily at the apex of the tread and the area over which the force acted would increase as the top of the tread was deformed, showing that the treads were self-energizing. However, due to the difficulty of modeling the self-energizing aspect of these treads, a 27.68 N force in the Y-direction was placed at the apex of each of the tread patterns. A derivation for how I got that force is listed in the Hand Calculations section of this report. The location of this force is better shown in Figure 2 below and is noted by the red line and arrow in each of the pictures.

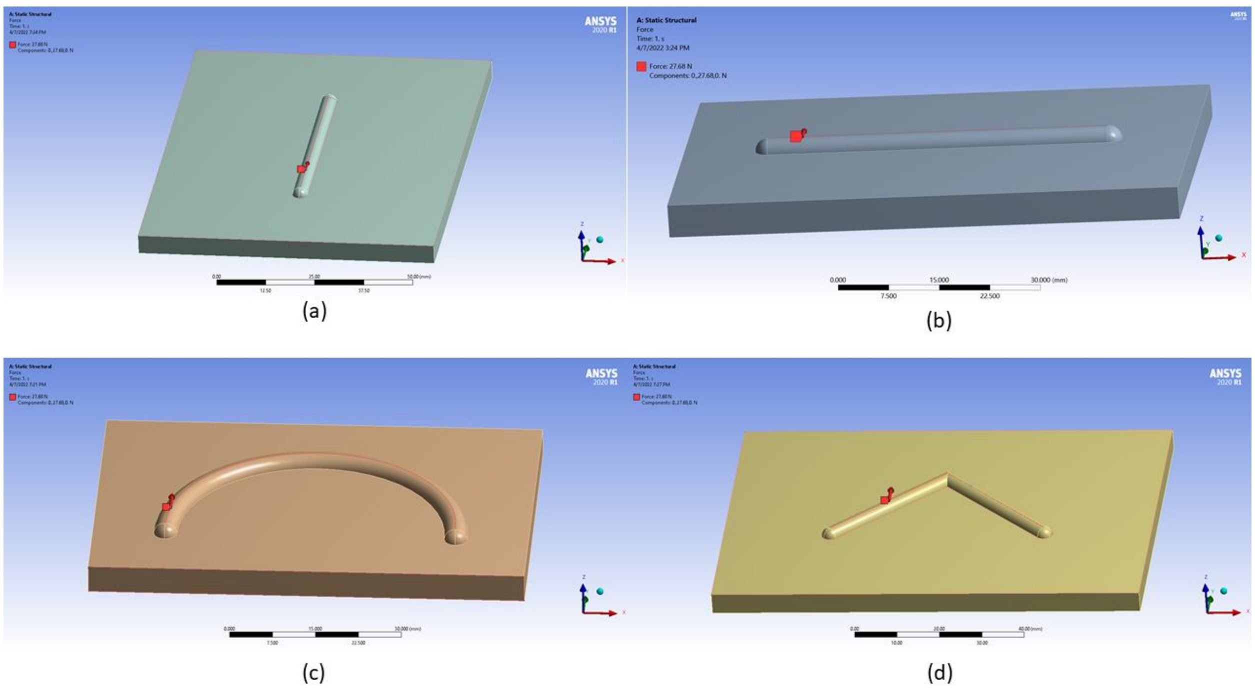

Figure 2: View of how and where the forces are acting on the different tread patterns. The force is acting along the red line. (a) Tread pattern that is straight in the Y-direction. (b) Tread pattern that is straight in the X-direction. (c) Tread pattern that is semi-circular. (d) 45° angled tread pattern.

In addition to the force that is applied to these models, a fixed support was placed on the underside of the rectangle below the tread pattern as shown in Figure 3, shown on the next page. The fixed support was placed there to better represent how an actual sole of a basketball shoe would react to forces from the court. This support was consistent in its placement over each of the four models, so only the model with the tread straight in the X-direction is shown in Figure 3 on the following page.

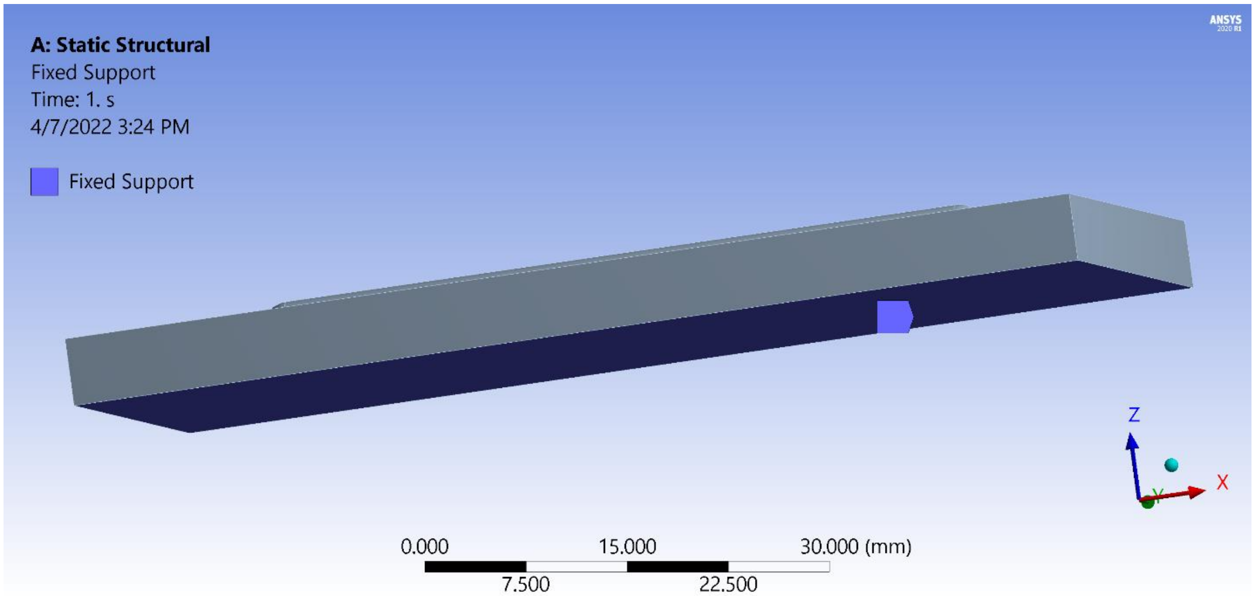

Figure 3: Picture showing the location of the fixed support on model that is shown in Figure 1b.

Material Properties

After a quick internet search, we learned that elastomers, specifically polyurethane, is a common material used for the soles of shoes. Due to this, I went to our textbook*, Shigley's Mechanical Engineering Design* by Richard Budynas, to find a value for Young's Modulus to then input into ANSYS. Below in Figure 4 we can see the values that were used for this study.

Polyurethane

Structural

Isotropic Elasticity

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	3e+07 Pa
Poisson's Ratio	0.3
Bulk Modulus	2.5e+07 Pa
Shear Modulus	1.1538e+07 Pa

Figure 4: Material properties for polyurethane as used in this analysis.

Validation of the Model

To show that the results from our model are valid and correct, assumptions were made and hand calculations were performed. Below you will find the assumptions, hand calculations, and mesh convergence explained in detail.

Assumptions/Simplifications

A couple of assumptions and simplifications were made so that hand calculations could be made and time could be saved while performing the analyses. The first simplification is that all of the treads that are on a shoe can be modeled as a single tread. The first set of assumptions that were made started with all of the treads that would exist on a shoe could be simplified down to one single tread. After we decided to only use one tread, in order to perform hand calculations, we assumed that the semi-circular tread could be assumed to be a cantilever beam. From that point, we assumed that the load would only act at the end of the cantilever beam and that the force from the players body would act at an angle of 45° from the horizontal plane of the court.

To determine the forces that are applied to the shoe assumptions were made regarding the person using the shoes. It is assumed that the user weighs 90 kilograms, are moving at a speed of 2.5 m/s, and that they stop over a distance of 50.8 millimeters.

Hand Calculations

The following hand calculations were used and Table 1, below, provides a summary of the names of variables and what values are used for those variables.

$$J = \frac{1}{2} \cdot m \cdot v^2 \tag{1}$$

$$N = \frac{\frac{J}{S}}{T} \cos(\theta) \tag{2}$$

$$I = \left[\frac{\pi}{8} - \frac{8}{9 \cdot \pi}\right] \cdot r^4 \tag{3}$$

$$\delta_{max-end\ load} = \frac{NL^3}{3EI} \tag{4}$$

Table 1: Description of variables and values used for those variables in the hand calculations above. Note that some variables are calculated from other variables in equations.

Variable	What it is	Value used
J	Energy (J)	281.25
m	Mass (kg)	90
v	Velocity (m/s)	2.5
N	Force (N)	27.68
S	Stopping distance (mm)	50.8
T	Number of treads (#)	100
θ	Angle of impact into the ground	45°
I	Moment of inertia (mm^4)	1.75611
r	Radius (mm)	2
$\delta_{max-end\ load}$	Max deflection when forces act at end of the cantilever beam (mm)	1.401

Mesh Convergence

To ensure that the model in ANSYS does not have any error introduced due to an excess of nodes, a mesh convergence was performed. Table 2 below shows the mesh element sizes and the refinements that were used followed by the maximum deformation reported.

Table 2: Mesh convergence study performed on the model from Table 1b.

Mesh Element Size (mm)	Refinement	Directional Deformation Maximum (m)	Number of nodes
2.5	1	$9.7011 \cdot 10^{-5}$	7959
2.5	2	0.00010305	11509
2.5	3	0.00010733	22927
1	1	0.00010665	37563
1	2	0.00011146	48648
1	3	0.00011428	82903
0.5	1	0.00011708	$1.3243 \cdot 10^5$
0.5	2	0.00012322	$1.5732 \cdot 10^5$
0.5	3	0.00012521	$2.3392 \cdot 10^5$
0.25	1	0.00012684	$5.1006 \cdot 10^5$
0.25	2	0.00013197	$5.6218 \cdot 10^5$
0.25	3	0.00013529	$7.2347 \cdot 10^5$
0.1	1	FAILED	$3.0341 \cdot 10^6$

Based on this mesh convergence in Table 2, we see that the mesh never actually converges. The reported maximum deflection continues to increase as the number of nodes increases. If time was an infinite resource and I had access to a better computer, I would continue to refine the mesh until it converges. However, since time is a finite resource and I have access to the singular computer that I am currently using, a mesh element size of 1 millimeter with a refinement of 2 is what we have decided to use. This is because the change of deflection from a mesh element size of 1 millimeter with a refinement of 2 and a mesh element size of 0.25 millimeters with a refinement of 3 is 0.02383 millimeters (0.000938”). Due to how small that difference is, and the time that will be saved by using the larger mesh element size, we will be going with the larger mesh element size. This mesh will be applied to all of the different tread patterns for consistency.

Results/Conclusions

Below is Table 3, which shows the deflections for each of the tread patterns when a force of 27.68 N is applied. Based on these results, the Semi-circular tread pattern deflects the least and therefore is the tread pattern that would be recommended to be used on future basketball shoes.

Table 3: Table showing the results of the various analyses.

Type of Tread Pattern	Maximum Deflection (mm)
Straight in the Y-direction	0.11295
Straight in the X-direction	0.11146
Angled at 45°	0.079998
Semi-circular	0.071529

Figure 5, on the next page, contains the plot for the results for each of the tread patterns.

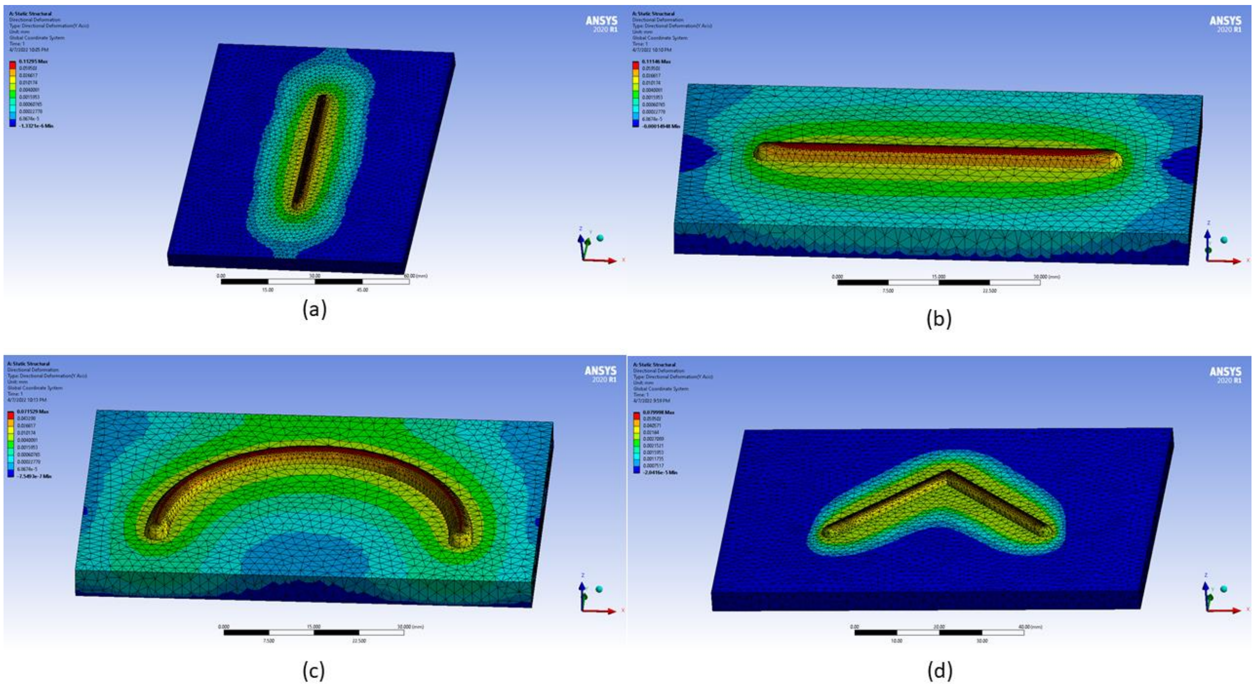

Figure 5: Plot of the results for the various different tread patterns. (a) Tread pattern that is straight in the Y-direction. (b) Tread pattern that is straight in the X-direction. (c) Tread pattern that is semi-circular. (d) $45°$ angled tread pattern.

Commentary on Analysis

As can be readily seen, the maximum deflection that was obtained for the four tread patterns is off by a factor of about 10 from the hand calculations that were performed. This could be due to the assumption that was made that the semi-circular tread pattern could be simplified to be a cantilever beam, when in reality this could not be a valid assumption. If that is the case, equations would need to either be developed or found that provide the deflection of a semi-circle when a force is applied at its apex.

Another possible location for error in this analysis would be due to the lack of convergence in the model. If the model had converged on a deflection, then we would be able to rule out that this is a potential place for error in this analysis.

Also, since basketball players rarely only need to stop in a single direction, and are usually moving such that there would be forces in both the X and Y directions, further analysis should be done to make sure that the semi-circular tread would be best in those types of instances as well.