

The Hardest slap-shot

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Analysis of Ice Hockey Stick performance through the lens of
FEA (*finite element analysis*) to optimize a more powerful ice hockey slap-shot.

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Introduction

In the game of Hockey, a slap-shot with a greater speed has a higher chance of a successful goal than one at a lower speed because it gives the goalie and other defenders less time to react. Players have begun to switch to hollow carbon fiber/epoxy hockey sticks due to its strength to weight ratios compared to solid wood sticks. Using carbon fiber may enable a player to be more agile around the hockey rink, but does that style of hockey stick affect the tool's main purpose of shooting a powerful slap-shot? The goal of the following analysis and report was to identify the material and length of the hockey stick that would optimize the overall speed of the shot. The process for this analysis included using ABAQUS models as well as finite element analysis to find the tip deflection of hockey sticks as well as the stress throughout the stick. The overall fastest shot was considered to correlate with the stick with the highest deflection, due to the assumptions highlighted in the following section. A general hollow carbon fiber stick and a solid maple stick at 12% moisture were the two materials compared in the analysis. The three measurements compared included stick lengths of 50, 60, and 70 inches.

Assumption(s)

Many assumptions were made throughout this analysis in order to idealize the slapshot action and ultimately put all focus on the hockey stick material/structure. A lot of different factors come into play to perform a successful slap-shot with a hockey stick. These factors vary between the abilities, traits, and technique of the player shooting, the varying friction of the ice, distance from the goal, positions of defenders around the goal, the angle of contact between the puck and the hockey stick, and more. This experiment focuses solely on the material and length of the hockey stick to see how using a different hockey stick would have different results in the same surrounding scenario. It was also assumed that the variation of length would have the same resulting trends in both materials, therefore length was only varied for the wood material, and then carbon fiber was only compared at one length, which isolated the variables and limited the number of models to four instead of six.

In order to focus on isolating the material, each ABAQUS model had the same configuration with loads and constraints. Forces such as gravity, friction between the stick and ice, and twist of the stick were considered negligible when calculating the deflection of the hockey stick in the direction of the slap-shot. The contact point of the stick with the puck was idealized so that it would be in the center of the stick that would not cause rotation of the hockey stick. With that idealization, the shape of the hockey stick was able to be modeled as a beam without the typical blade at the foot. The top hand position on the stick was modeled as a clamped constraint so that the force of the shot comes only from a centered point load on the backside midway down the stick length. Containing the top hand enabled the entire deflection of the hockey stick to be seen at the bottom of the stick where the puck would make contact.

It was assumed that the fastest slap-shot had the best chance of a successful goal without including factors such as accuracy or the various shot types. A further assumption was made that the fastest slapshot occurs from the stick that provides the strongest output force on the puck.

Continuing on that train of thought, it was assumed that the stick with the maximum deflection gives the greatest amount of potential energy to be used in the force as well as more space to accelerate into the puck for the whiplash effect. The varying snap time of the deflection returning to its original unflexed position was ignored.

Experimental Models

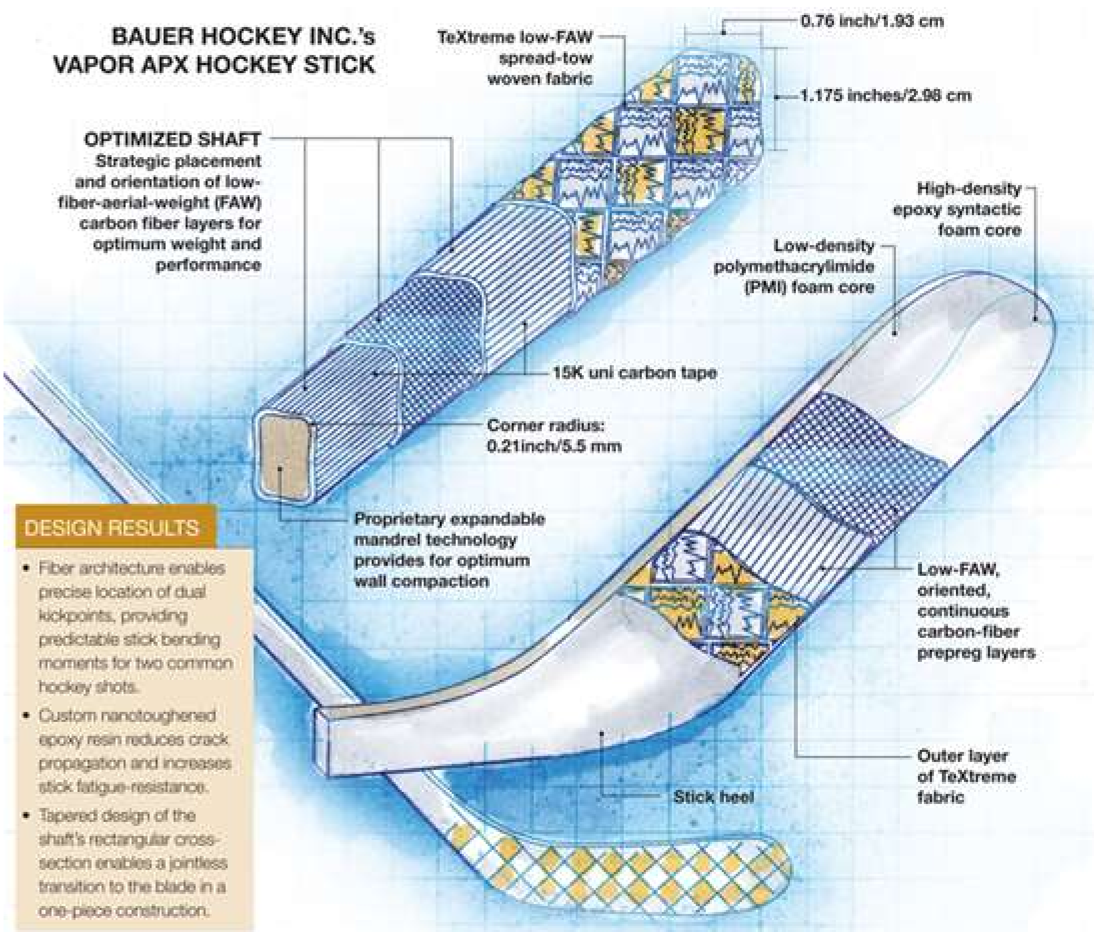

Figure 1: Dimensions used for modeling

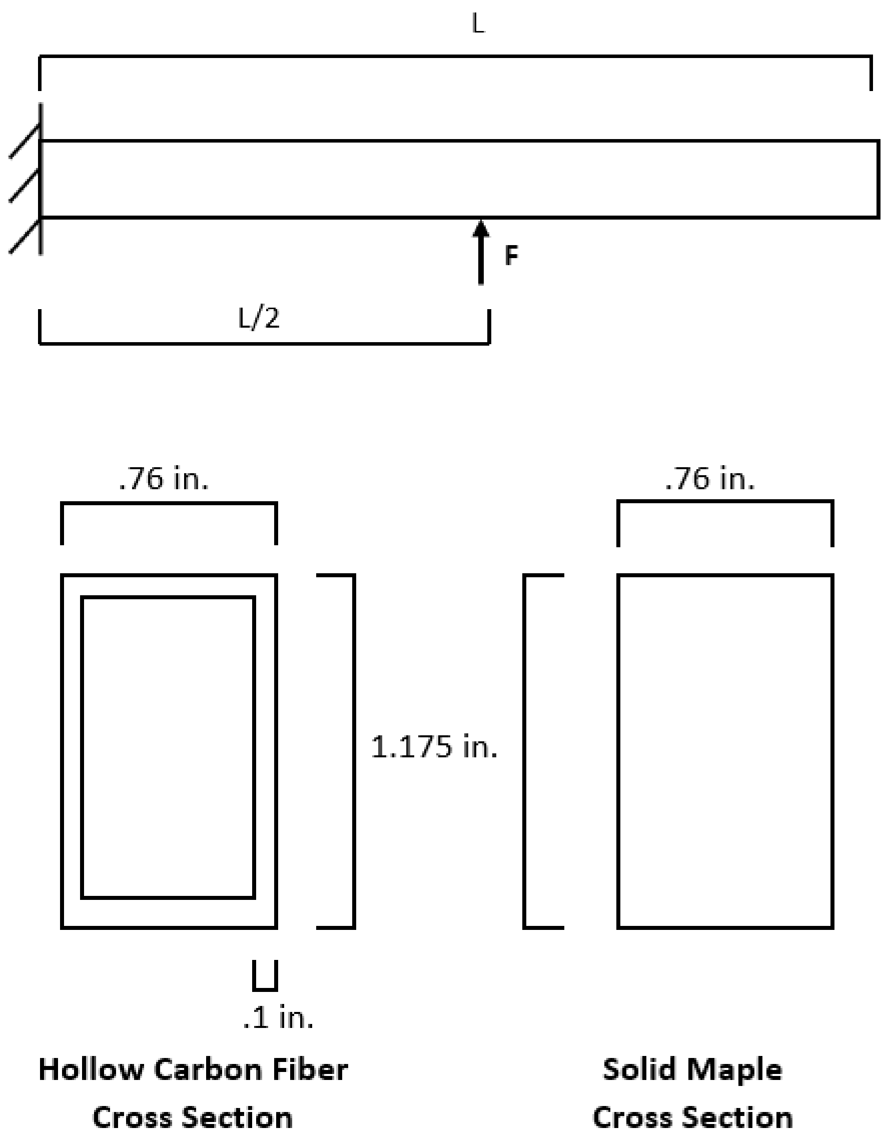

Figure 2: Simple Model Schematics

Overview

In order to understand which material would be best for shooting a hockey puck, one must first understand how the force on the puck is generated. When a hockey player shoots a puck, the top hand holds the stick still while the middle hand pushes the stick forward and creates a bend in this central region, as if the top is clamped by their hand and the bottom by the ground it is being pressed upon. This bend creates a high amount of tension in the stick and is an elastic deformation, therefore as the pressure is released, the stick snaps back to its undeformed shape and slaps the puck forward. Taking this into consideration, we can then look at the different materials we talked of previously and their effect on the performance of the hockey stick as they formerly were made from wood and have since transferred over to lighter and hollow carbon fiber sticks. Using ABAQUS we can test different factors that could affect the performance such as the material used and the length of the stick itself, while leaving all other parameters the same between the tests. From our knowledge of forces, stresses, and deflections, we can assume that the stick that creates the largest force on the bottom end and the overall highest stress will likely be the stick that results in the hardest slap-shot.

Experimental Results

The Abaqus results of deformations and stresses of the Hockey sticks are shown in Figures 3-10 below.

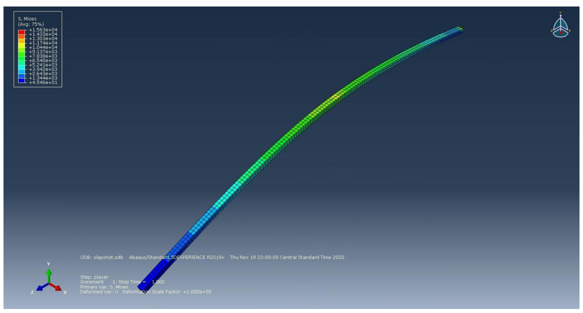

Figure 3: 70 in. Maple Stick Stress

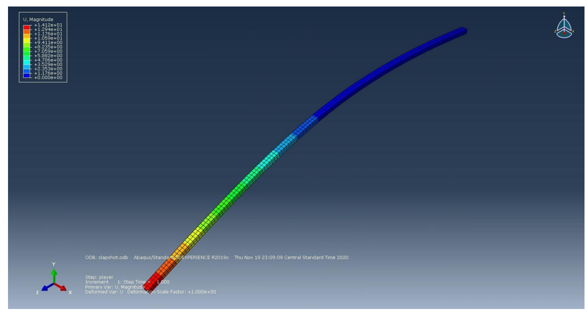

Figure 6: 70 in. Maple Stick Deformation

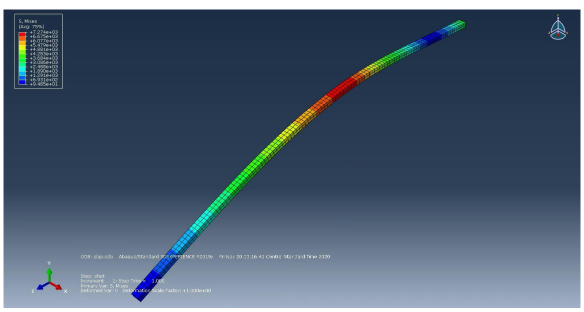

Figure 5: 60 in. Maple Stick stress

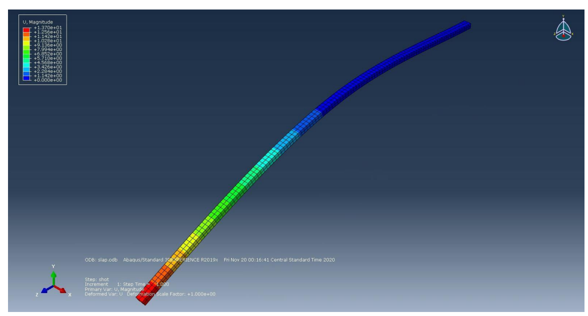

Figure 7: 60 in. Maple Stick Deformation

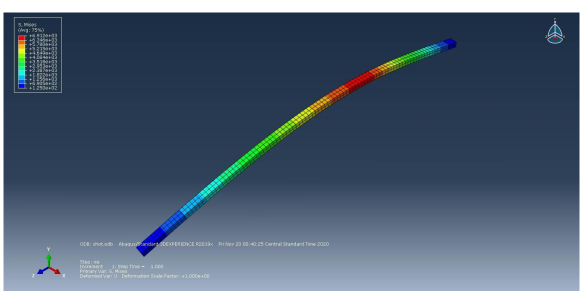

Figure 4: 50 in. Maple Stick stress

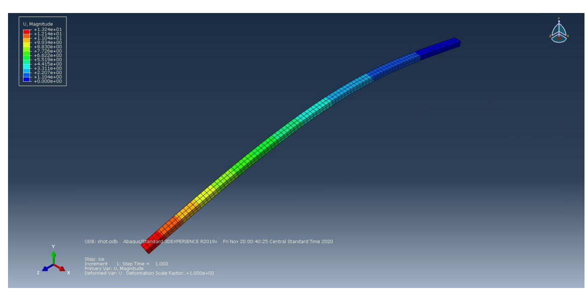

Figure 8: 50 in. Maple Stick Deformation

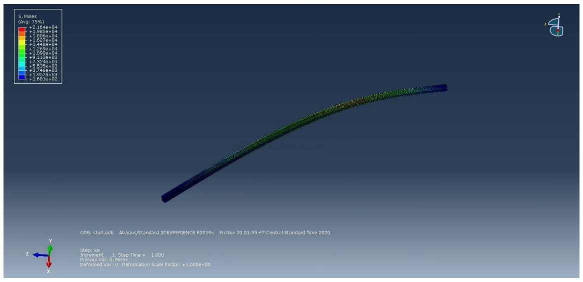

Figure 9: 60 in. Carbon Fiber Stick Stress

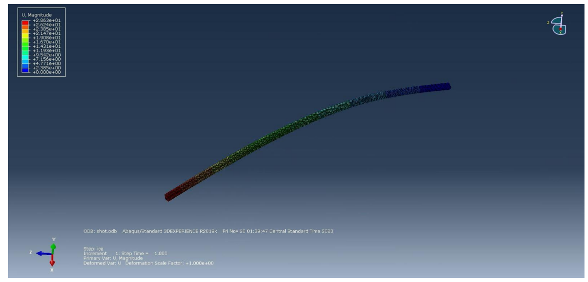

Figure 10: Carbon Fiber Stick Deformation

Table 1: Summary of Stress and Deflection

Model	Tip Deflection (in.)	Max Stress (Pa)
60 in. Carbon Fiber	28.63	21640
50 in. Maple	13.24	6912
60 in. Maple	13.7	7274
70 in. Maple	14.12	15630

Analysis of variations

The highest deformations of each stick takes place at the free end as expected. Inspecting the deformations at the tip of varying lengths of Maple sticks, it is shown that the deformation is directly proportional to the length. The same trend is seen on the Carbon Fiber sticks. If we compare the same length of sticks made out of different materials, we can see that the 60-inch Maple stick deforms less than the 60-inch Carbon Fiber stick. Comparing the most deformed Maple stick, which is 70-inch-long, the 60-inch Carbon Fiber stick, we can see that it deforms less.

As expected, the highest stress occurs at the top hand position, which is essentially a clamped constraint in this experiment. This is consistent in all lengths and materials of sticks modeled. For the material of Maple, the highest stress is seen on the 70-inch stick and the lowest on the 50-inch stick, where the highest stress is again lower than that on the 60-inch Carbon Fiber stick.

The maximum deflection of a cantilever beam with an intermediate load is given as, where the beam length is L and a load F acts at x=a.

$$\delta_{max} = \frac{Fa^2}{6EI}(3L - a)$$

In the analysis of 60-inch Maple stick and 60-inch Carbon Fiber stick, a, F and L are kept constant, making the product of E and I, EI, the only variable. Whichever stick has the higher inverse of EI would yield a larger deformation at the tip (x=L).

The second moments of inertia (I) depend on the geometry of the sticks, in other words, the cross-sectional area. For solid rectangular cross-sections, the second moment of inertia is given as, where b refers to the width and h is the height.

$$I = \frac{bh^3}{12}$$

For hollow rectangular cross-sections, the second moment of inertia is given as, where b is the width, h is the height, b1 is the inner rectangle width and h1 is the inner rectangle height.

$$I = \frac{bh^3 - b_1 h_1^3}{12}$$

The elastic modulus (E) is a material property. The elastic modulus of the Carbon Fiber Transverse, 10 GPa, is larger than that of Maple 12% Radial Grain, which is 1663.2 MPa.

In this experiment, Maple sticks have solid rectangular cross-sections with a width of 1.18 in and height of 0.76 in. Carbon Fiber sticks have hollow rectangular cross-sections with a width of 1.18 in, height of 0.76 in and thickness of 0.1 in. The EI of Maple sticks is calculated to be 19.954 Nm^2 and the EI of Carbon Fiber sticks is 11.997 Nm^2.

The inverse of EI of Carbon Fiber sticks is higher than that of Maple sticks, causing a larger deformation at the free end of the Carbon Fiber stick. This is validated by the results shown in Table 1.

Conclusion

As seen in the section above, under the same experiment setup, the largest deformation would take place on the 60 in. Carbon Fiber stick. However, from the trend that is evident from the wood simulations, we can see that the longer the stick, the higher the deformation and we can assume that a 70 in. Carbon Fiber stick would therefore have the highest deformation if we ran that experiment. Based on the results of the lab, it is evident that carbon fiber is the best material to use when creating hockey sticks as it outperforms the wooden sticks. The carbon fiber stick is hollow which makes it much lighter and easier to use and also has a much higher strength, from these conclusions we can see that the carbon fiber stick generates higher forces, deflections, and stresses which theoretically allows it to snap from its deformed shape back to its undeformed shape with much more force and therefore shooting the puck harder than when using wood. However, this may not always be what you are looking for. For the purposes of this lab we were looking at which would result in the hardest shot, however players such as defensemen and goalies may be looking for something different such as a stick that will not break as easily and can receive more of an impact which would likely be the solid material but would need further and a different kind of testing. The results from using ABAQUS were as we expected in this scenario, with the much higher modulus of elasticity we knew from the beginning that the carbon fiber material would deform in such a way to produce a harder shot than its wooden counterpart thus proving our hypothesis correct and ultimately showing that the carbon fiber hockey stick is superior to the outdated wooden hockey stick.