Framing Report

Aadesh Chahal, Hamza Moh’d, Ivan Pun, Muhammad Zain
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1.

The chosen item for the Materials Selection project is a hockey stick. Specifically, we will focus on the shaft of the stick. A hockey stick is a piece of sports equipment used by players to move a ball or a puck. It is approximately 150 to 200 cm in length, with a long, thin shaft and a flat extension at one end called the blade. The shaft on the stick is used to provide leverage and control when handling, passing, or shooting the puck. The shaft is typically made of composite materials or wood [6]. Which can be customized with different flex ratings, lengths, and grips to suit the player's preferences and playing style. Stick flex ratings are indicated by a number on the shaft, typically ranging from 50 to 110 [7]. The higher the number, the stiffer the stick, and vice versa. However, different manufacturers may have slight variations in their flex rating systems [7]. The flex of a hockey stick is determined during the manufacturing process and cannot be adjusted later [6]. It is essential to select the right flex when purchasing a stick, as it cannot be altered to meet individual preferences afterwards [7]. Many professional players have chosen to use sticks with a lower flex rating to maximize their shot potential, but this comes with a higher risk of the stick breaking. A lower stick flex allows players to generate more power with less effort and allows players to maximize the load in a shorter amount of time. As hockey was traditionally a sport dominated by physical players that would use their size to overpower players, they preferred a stiffer stick. In recent years more and more players are not as physically imposing and rely on technique to overcome challenges [1].

Hockey was invented in the 1800s and the sticks were made from Hornbeam and Birch trees [5]. Hornbeam was particularly prized for its strength and was often called "ironwood." A deficit of Hornbeam in the 1900s led manufacturers to seek alternative materials [5]. Yellow birch and ash (See Figure 1) were used as replacements [4],[3],[5]. Another reason for a shift to yellow birch and ash was due to the evolving industry. Companies like Canadien and Sherwood began experimenting with fiberglass-wrapped blades in the 1950s [4],[5], and manufacturers began using fiberglass to reinforce the shaft of sticks, making them lighter, stronger, and cheaper to produce [6]. Sherwood and Canadien dominated the hockey stick market with lighter sticks made of aspen wood that were reinforced with fiberglass in the 70s [2],[4],[5]. In the 1990s, Aluminum shafts were developed and tested by NHL players [3],[5] and by the mid-90s, the first composite blade was produced [1],[5]. Just recently in 2021, companies started researching on the use of Boron Fiber for hockey sticks [14],[5]. Boron has twice the stiffness when compared to Carbon, and twice the compression rating than the highest end carbon fiber in the world [14].

Modern sticks suffer from one fatal flaw that set it apart from previous designs. In the current era of hockey sticks are made from multiple composites [1]. Sticks are more prone to breaking compared to sticks of the past made from aluminum or wood.

Figure 1: Wooden hockey stick with a shaft made from solid white ash wood.

Source: Adapted from [2]

2.

Table 1: Green = Yes Red = No

	Professional and Semi-Pro Hockey players	Coaches and trainers	Families of high-level junior players	NHL, IIHF, Hockey Canada
User				
Customer				
Benefactor				

Table 2:

	Professional and Semi-Pro Hockey players	Coaches and trainers	Families of high-level junior players	NHL, IIHF, Hockey Canada
Needs	Durability, performance (e.g., flex, weight, balance), comfort in grip, and compatibility with their playing style	Equipment that enhances player performance, durability (to withstand frequent use), and suitability for a range of player sizes and skill levels.	Safety, size-appropriate for youth players, durability.	Safe equipment for players, regulate use of unfair equipment that gives advantage.
Wants	Stylish design, brand reputation, endorsements by other professional players.	Easy to store and transport, possibly with coaching/training specific features (e.g., markings for hand placement).	Affordable price, appealing design for children.	Professional leagues have a strong influence on the market so they want a stick that can be promoted well, this way they can expand their brand and tap into new players.
Requirements	Safety standards, league regulations for size and material	Compliance with league and training regulations, affordability for bulk purchases.	Compliance with youth league regulations, non-toxic materials, warranty or return policy	Equipment used must adhere to existing rules and regulations

Need Statement: A design that minimizes the density in the shaft portion of a hockey stick.

After careful consideration and analysis of various stakeholders with differing needs and wants. We have compiled all our observations into two different tables. Table 1 being color coded and categories users, customers, and benefactors from our stakeholder groups. Whereas, Table 2 is a brief description of each group's needs, wants and requirements. Where information has been collected from teammate Aadesh (a former high level youth hockey player) and teammate Hamza.

Our team has selected to design a hockey stick for high performance usage and have identified that density is our most important factor to minimize. Since our primary user base will be professional players, the equipment they use will be purchased by their organizations. So, cost is something we are not deterred by, because we know that these individuals and clubs will pay for performance.

3.

In the realm of Materials Engineering, the selection of appropriate materials for specific applications necessitates a comprehensive understanding of the mechanical stresses involved [1]. In the context of an ice hockey stick, identifying and quantifying the primary modes of mechanical loading are crucial steps to designing and selecting the materials [6]. In fact, players use a mechanical aspect of the stick to their advantage. When shooting players flex the stick between their top hand and the ice with their bottom hand to load energy into the shaft, when the stick unflexes it transfers energy to the puck creating a sling shot effect [10]-[12].

There are several modes of mechanical loading within the shaft of the stick during play. However, the main form of loading is bending and can be modeled by a beam in 3-point bending. The standardized equation manufacturers use is provided below.

$$\delta_{max} = \frac{FL^3}{48EI}$$

$\delta_{max} = Deflection\ max$

$F = Force$

$L = Length$

$E = Young's\ Modulus$

$I = Second\ area\ moment\ of\ cross\ section$

The free body diagram of an ice hockey stick is shown below. A represents the top hand and B represents the bottom hand.

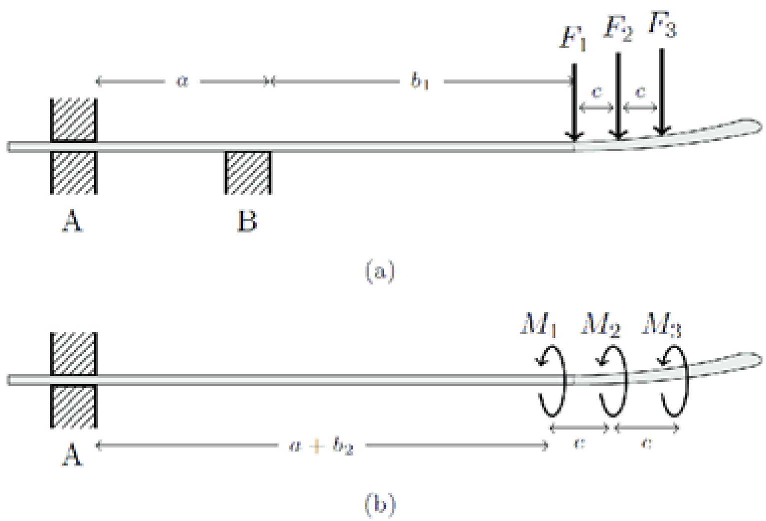

Figure 2: Free body diagram for rotation and three-point bending.

Source: Adapted from [10]

With bending, there will always be two more associated forces: tension, and compression. These forces act on the walls of the shaft and are designed to stay within the elastic region of deformation. Torsion is also an associated mode of loading with the shaft of a hockey stick and is mainly seen when receiving pucks on the blade. The free body diagram is shown above.

An ice hockey stick is a tool which deforms, and stores energy which can be modeled as a spring mass system. Hooke's Law is given below [11].

$$F = k\delta$$

$F = Force\ (N)$

$k = Spring\ Constant\ (\frac{N}{m})$

$\delta = Static\ deflection\ (m)$

Hockey stick stiffness values (effective spring constants) for several composite, wood, and aluminum hockey sticks.

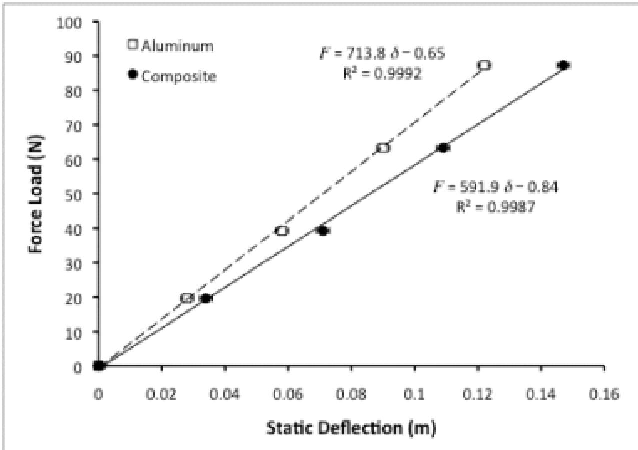

Figure 3: Graph of Static deflection in meters vs Force Load in newtons

Source: Adapted from [11]

The max load that a composite ice hockey stick is accustomed to is fully dependent on the player using it. For example, an unskilled 135-pound player will not be able to fully utilize the mechanical flex while shooting and may only be able to put in 20 pounds of force on his 60-flex stick. However, a professional 215-pound player may be putting upwards of 150 pounds of force on his 90-flex stick, causing a deflection of several inches. To ensure players can utilize their stick to the maximum potential, every stick should be able to support 2.5 to 3 times the flex rating on the stick. Force versus displacement curves for aluminum and composite hockey sticks clamped at the butt end and loaded at the blade.

Stick	Stick Material	Flex Rating	Stiffness (N/m)	Young's Modulus (GPa)
S1	1″ × 2″ pine		3686	8.88
S2	Wood	52	7026	11.71
S3	Composite	85	6740	31.97
S4	Composite	85	8913	41.77
S5	Wood		9214	11.81
S6	Composite	85	9470	31.65
S7	Composite	85	9481	
S8	Composite	90	9237	
S9	Composite	100	8644	
S10	Composite	100	9077	
S11	Wood	85	10052	11.77
S12	Wood		10286	15.82
S13	Composite	100	10419	
S14	Composite	100	10868	
S15	Wood		10475	16.25
S16	Aluminum/wood		11420	54.62
S17	Graphite/wood	100	11939	
S18	Composite	110	11384	38.05
S19	Composite	110	13064	42.16

Figure 4: Chart of different materials and their flex and stiffness ratings.

Source: Adapted from [11]

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