Skateboard deck materials selection

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Abstract. The goal of this project was to identify the ideal material for a skateboard deck under $200 in price, minimizing the weight. The material must have a fracture toughness of 5 MPa/m², have a minimum lifetime of 10,000 cycles and must not experience brittle fracture. Both single material and hybrid solutions were explored. When further selecting to minimize weight, woods were found to be the best material. Titanium alloy-wood composites were explored to determine the optimal percentage composition of each material. A sandwich panel hybrid of 50% titanium alloy and 50% wood (Ti-Wood) was found to be the optimum material, performing better than the currently used plywood.

1. Introduction

This report looks at materials selection for a skateboard, focusing specifically on the skateboard deck. Skateboards are sporting equipment used for transportation and fun. Every complete skateboard contains three parts which are the deck (the actual board), the truck (a component usually made of metal that holds the wheels to the deck), and the wheels. The main body of the skateboard is the deck. Most skateboards share similar dimensional and strength characteristics. The general categories for skateboards are longboards and cruisers. Longboards are more for street riding (commuting) whereas the cruises are intended for performing tricks. The function of the deck is to support user standing on the skateboard safely. When user moving is moving on the deck, the deck should be able to support the user without breaking. While skateboarding can serve as a fun sport and practical method of transportation, it comes with many risks. Over 78,000 people get injured while skateboarding per year [5]. Reducing the number of these injuries would be ideal. An alternative skateboard deck material could possibly provide a safer experience, or fail in a less catastrophic and injury inducing manner.

2. Objectives

Two separate scenarios were chosen, to establish appropriate material selection. The first scenario is an average use case for general skateboarding. The second scenario is a less common case for general usage, but incredibly common when doing tricks. The objective for the first scenario is to minimize weight and the second scenario is to minimize bending deflection.

3. Mechanical Loading

The free body diagram of a skateboard being ridden in the forwards direction is shown in Fig. 1. During this process, the deck withstands weight of the skateboarder due to gravity and the weight of the board itself. The deck also provides friction to keep the skateboarder stable and attached to the board. A maximum average mass of 160kg (350lbs), extrapolated from the population data in [14]. Most common skateboard decks are 32” long x 8” wide x 1/2” thick. The maximum moment occurs at the middle part of the deck and is equal to 706N * 40.64 cm = 28691.84 N*cm. The moment of inertia can
be calculated by \( I = \frac{bh^3}{12} \), so \( I = 3.47 \text{ cm}^4 \). By using \( \sigma = \frac{MY}{I} \), the stress can be calculated as 52.53 Pa. Therefore, the estimated stress in the deck is about 52.53 MPa. Moment, \( \sigma \): Tensile stress, \( I \): Moment of inertia, \( Y \): Perpendicular distance, \( b \): Width, \( h \): Height from neutral axis. Skateboarding tricks provide additional, more complex loadings to the board. The Ollie is a fundamental skateboarding trick and we can analysis first two stages. In stage one of the Ollie, the skateboarder is crouched down and is preparing to jump off the board (Fig. 2 left). The three forces (red, black, and blue arrows) all balance out to zero in this stage since the board is stationary. In stage two, the tail strikes the ground (Fig. 2 right). This generates a large vertical impulse force from the ground. This propels the board upward and also causes the board to rotate clockwise. The force exerted on the board by his left foot is broken down into two components. (One of the forces is perpendicular to the board, the other one is parallel to the board) The magnitude of the force depends on how the skateboarder executes the trick.

**Figure 1:** Free body diagram of skateboard deck.

**Figure 2:** Free body diagram of Ollie.

### 4. Design Constraints

On a very broad level, optimal deck width for a generic skateboard is based mostly on the shoe size of the user, with some variation based on personal preferences and desired aesthetic. As you can see in both Fig. 3 and Fig. 4, the skateboard deck width doesn’t vary too much (approximately 6 1/2” to 8 1/2”) even when the customer’s foot length differs massively (approximately 3’ to 6 1/2’). Most generic skateboard decks are 32” long x 7 1/2” - 8 1/2” wide x 1/2” thick [9]. Cost for a usual skateboard deck is around $70 [11]. Weight is a hard constraint because users must be able to pick up and carry their skateboard with relative ease, using only one arm. We will assume that our potential user isn’t relatively strong and set our maximum weight at 5 kg. Stiffness is a hard constraint of skateboard deck, because safety is incredibly important and non-negotiable engineering design. According to Stiffness Equation:

\[
\text{stiffness} = \frac{\text{load}}{\text{deflection}}
\]

The load is fixed. If the stiffness is too low, it will have high deflection which can make riding on skateboard is unstable. Designers must additionally take into account the added stresses when a user does tricks with the skateboard. The stiffness of the current average skateboard deck is 482.15 kg/cm [13].

**Figure 3:** Skateboard deck size compared to height, age and shoe size [7].

**Figure 4:** Different size for same deck shape (1 in = 2.54 cm) [8]

### 5. Screening Materials

We first consider to use fracture toughness and fatigue strength to screen the materials that fits to skateboard deck, since these are hard constraints for the deck. [15]. We made a chart by using CES software to find out those material can met our constraints, seen below as Figure 6. To make a CES chart is easy step, we just enter the range value of fracture toughness and fatigue strength into the
software. Then, the CES software will find materials that meet our requirements. The customers want skateboard deck to have a long lifetime usage, so we just chose the materials that have longer fatigue cycles. We have decided the minimum fatigue strength for this is 30 Mpa [16]. From these two charts (Fig.5 and Fig.6), we could find many materials appear in both charts. The active materials are titanium alloys, stainless steel, nickel alloys, cast iron, CFRP, GFRP, Magnesium alloys, Silicon carbide, Polyamides, Silver, Copper alloys, Zinc alloys, Aluminum alloys, Wood and Bamboo.

6. Problem Identification
Two separate scenarios were then examined. In the first scenario, the skateboarder is standing stationary with both feet on the board, while the board moves forward. In the second scenario, the skateboarder jumps up off a stationary board and lands back on the board with two feet. The objective for the first scenario is to minimize weight and the second scenario is to maximize bending deflection. For both scenarios share similar hard and soft constraints, and free variables. The hard constraints are the fracture toughness, the number of cycles before fatigue failure and force applied on the deck. These three constraints were chosen to ensure the deck does not break easily. The soft constraints are the cost per unit mass and little or no plastic deformation. Free variables are the material choice, the thickness and width. Justification for constraints and free variable choices came from the mechanical loading. The constraints were used to screen out some materials in the screening section. From above, the maximum force on the deck for a human standing stationary is $2160 \times 9.81 \frac{m}{s^2} = 1570N$. 10,000 cycles was chosen as a rough estimate for cycles before failure. If the skateboarder uses their board every day of the year and assumed the board is loaded 10 unique times, the board should last 2.74 years before failure. As skateboards get quite banged up and would look quite rough after 2 years, this is deemed an acceptable number for an average user. Note that the board may be loaded several times in one trip.

7. Optimization Case 1: Material index for standing on board while moving forward

The objective of this scenario is to minimize the weight of the board, without compromising the function. The free variables for this scenario are material choice, density and yield strength. As seen in Fig.7, this can be represented by a beam in bending with two supports at each end and a load at the center of the length. Constraint equation: $\sigma = \frac{MY}{I}, Y = \frac{b}{2}, I = \frac{bh^3}{12}$
Objective equation: $\sigma = \text{Failure tensile stress}$, $M = \text{Bending moment}$, $F = \text{Maximum weight of a person}$, $b = \text{Thickness of deck}$, $L = \text{Length of deck}$, $Y = \text{Distance from neutral axis}$, $I = \text{Moment of Inertia}$, $h = \text{width of deck}$, $m = \text{weight}$, $\rho = \text{density of skateboard material}$, $A = \text{cross-sectional area of skateboard deck} = bh$, $L = \text{length of skateboard deck}$

$$\sigma = \frac{MY}{I} = \frac{6Mb}{Ah^2}, \text{so} \quad A = \frac{6Mb}{\sigma h^2}, \text{The performance index should be} \quad M = \frac{\sigma}{\rho}$$

Thus we have $\log(\rho) = \log(\sigma) - \log(M)$ which gives us a line with slope of 1. As can be seen by looking at a material property chart (Fig.8) where the purple line intersects a materials group, there aren’t many options with a density of less than $1000 \, \text{kg/m}^3$. Best material options lie on the line at the right up corner. They are steels, titanium alloys, aluminum alloy, CFRP, Wood, ceramics and nickel alloys. Ceramics are ruled out due to their brittle failure.

8. Optimization Case 2: Materials Index for jumping on stationary board

The objective for this scenario is to minimize the bending of the board, when loaded. The constraints are a fixed length ($L = 32 \, \text{in} = ~81.3 \, \text{mm}$) and that plastic deformation isn’t permissible. An additional constraint is the force applied to the board will not exceed the maximum force a human can exert by jumping under Earth’s gravity. A human male’s maximum jump is $1.62 \, \text{m}$ [17]. This force is found using the work-energy principle. Objective equation: $\delta = \frac{FL^2}{CEI}$

$C = \text{constant}$, $F = \text{force}$, $L = \text{length}$, $E = \text{Young’s Modulus}$, $I = \text{second moment of inertia}$, $\delta = \text{deflection of beam}$

Constraint equation: $F_j = C(\frac{I}{Y_m}) \frac{\sigma^*_y}{L} = C(\frac{I}{Y_m}) \frac{\sigma_y}{L}$

$Y_m = \text{The normal distance from the neutral axis of bending to the outer surface of the beam.}$

$$\frac{I}{Y_m} = \text{Section modulus, } \sigma^* = \sigma_y = \text{yield strength}, \text{Assume the cross-section of the board is rectangular.}$$

$$I = \frac{bh^3}{12}, Y_m = \frac{h}{2}, b = \text{width}, h = \text{thickness}$$

Figure 8: Material index line on strength-density chart [15]

Figure 9: Young’s modulus-strength chart with two material index lines [15]
\[ \delta = C_2 \frac{l^2 \sigma^3}{y_m F_j E} \]  
(C_2 \text{ is a constant other than } C \text{ in the objective equation}) \]

\[ \frac{\sigma^3}{E} = \text{ material } \]

\[ \text{Index, In Young’s Modulus vs. Strength chart,} \]

\[ \log(E) = 3 \log(\sigma_f) - \log(M) \]

is a straight line of slope 3 (material index line). The location of the two red lines on the graph (Fig.9) is because the different material indices they have. Both two lines have higher material indices. Where the lines intersect with the materials that shown on the right up corner of the graph are the materials can meet the objectives. The materials selected from the material index for jumping on a stationary board are epoxies, nickel(Ni) alloys, carbon fibre reinforced polymer (CFRP), titanium (Ti) alloys, magnesium (Mg) alloys, aluminum(Al) alloys, copper alloys, oak, pine, woods and brick. The material that were screened out are Mg Alloys, epoxies, nickel alloys, and brick. The final materials are listed below: Ti Alloys, Woods (including oak and pine), CFRP, Mg alloys, Al alloys, Copper alloys.

9. Hybrid Materials & Structure Selection

Hybrid material is a combination of two or more materials. People use hybrid material to fill the needs of a product. It has four types: composites, sandwiches, lattices, and segmented structures [18]. First, we can find general and mechanical properties of materials from CES software. Fig.10. The left column is the minimum value and the right column is the maximum value. We can see the minimum value of fracture toughness is 5 MPa and the range of fatigue strength at 10^7 cycles is 20-35 MPa which can meet our constraints. Also, the density of wood is about 600-800 kg/m^3. This tells us we can make a deck lighter weight. The reason they are making sandwich panel decks is because the additional layer makes the deck more stable, harder and more rigid [19]. From Fig.11, the minimum value of fracture toughness of aluminum is 22 MPa/m^2, but the minimum fracture toughness of wood is 5 MPa/m^2 (from Fig.10). Aluminum has such higher fracture toughness than wood. Also, from CES, we can compare the density between aluminum and other metals, aluminum has smaller density, which means it will add less weight as hybrid material. Therefore, using aluminum alloy can make a stronger skateboard deck without adding much weight. This makes the skateboard deck have a better performance for customers.

Figure 10: Properties for wood from CES software.

Figure 11: Properties for Aluminum from CES software.

10. Summary and Conclusion

The current plywood options available seem to be accomplishing their job fairly well. After performing a materials selection using materials indices, it was found that the most commonly used current material, plywood, remains the best choice for a non-hybrid material. As mentioned plywood is the most commonly used material for skateboard decks and it just different types of wood laminated together with glue. Plywood is lightweight and has a good resistance to impact [21]. A comparison between plywood and Al-Wood hybrid shows that both Young’s Modulus and Strength for Al-Wood
hybrid is higher than that for plywood. Consequently, the material indices for Al-Wood hybrid is bigger than plywood, which implies the Al-Wood could be a better choice depending on the mechanic loading examined in the previous section. As was explored decks come in many shapes. For example, Radial Concave, Progressive, W-Concave, Tub, and Flat are all common shapes [22]. Each has their own benefits when executing various tricks. Al-Wood may prove tricky to manufacture into all deck shapes. If the deck is not properly made, the stress that the deck can take before failure will decrease. Flatter shapes would prove easier to manufacture, as the aluminum and wood sheets can be tightly clamped down when glued together. Flat shapes are also easy to visually inspect for defects in the gluing process, such as lumps in the wood or bends in the metal. Curved shapes would prove far harder to manufacture and to maintain quality for. Bending the wood and the aluminum would be required, increasing the possibility of cracks or defects during the bending process and stressing the materials. Flat decks and Tub decks would be preferable shapes due to their relative flatness. Further research can also be conducted to design a new shape for the Al-Wood hybrid deck instead of just using the existing deck shapes.

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