THE PHYSICS OF KARATE STRIKES

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1   Introduction

In recent years, the ancient eastern art of Karate-Do (a Japanese word, literally translated as "the way of the empty hand") has become popular in the western world. Karateka—practitioners of Karate—often break boards, cinderblocks, and other solid materials in order to demonstrate the strength that their training develops. Much can be said of the history and culture associated with the expansion of martial training, but this essay—it is, after all, a physics paper—will examine the collision mechanics of a hand strike to a solid target like a board.

2   Force, Momentum, and Deformation Energy

That large objects moving at high speeds hit harder than smaller objects moving more slowly goes without saying. In attempting to break a board, a karateka seeks to hit the board as hard as possible. It therefore follows that the karateka should move his or her weapon (for the purpose of this paper, the hand) as quickly as possible in order to hit as hard as possible. But what makes for a "hard" strike? Two ways exist to answer this question, both equally accurate. The first looks at the collision in terms of **force** and **momentum**; the second looks at the collision in terms of **energy**.

Force (F) is **acceleration** (a) times mass (m): $F = m \cdot a$. Momentum (p) is mass times **velocity** (v): $p = m \cdot v$. Since acceleration measures change in velocity over time (t) (put another way, acceleration is the derivative of velocity with respect to time), force is the derivative of momentum with respect to time. Equivalently, force times time equals change in momentum, or **impulse** (Δp): $\Delta p = F \cdot t$. This is significant because momentum is a conserved quantity. It can be neither created nor destroyed, but is passed from one object (the hand) to another (the board). The reason for this conservation is Newton's third law of motion, which states that if an object exerts a force on another object for a given time, the second object exerts a force equal in magnitude but opposite in direction (force being a vector quantity) on the first object for the same amount of time so the second object gains exactly the amount of momentum the first object loses. Momentum is thus transferred. With Δp a fixed quantity, F and t are necessarily inversely proportional. One can deliver a given amount of momentum by transferring a large force for a short time or by transferring small amounts of force continuously for a longer time.

Why, then, move should the karateka swing his or her hand with as much velocity as possible? Because if the hand is moving quickly, it is likely to decelerate (strictly speaking, accelerate in the direction opposite to its direction of travel) more quickly in response to the force the board exerts on it upon collision, as per Newton's third law. If the amount of time involved in the transfer of momentum is therefore small, the amount of force that will be transferred to the target all at once will be large. This sudden transfer of a lot of force causes the part of the board that is struck and which therefore experiences that force to accelerate. If that part of the board accelerates

enough relative to other parts of the board (which are generally held still by the cinderblocks on which the boards are placed), breakage occurs.

This same phenomenon can be analyzed in terms of **energy transfer** and resulting **deformation damage**. Given and object with mass m_1 at rest (the board) and another object of mass m_2 (the karateka's hand) moving at velocity v upon impact and ignoring the negligible amount of energy lost as thermal energy (heat), the amount of energy in the system lost to deformation damage (ΔE) is given by the following:

$$\Delta E = \frac{(1-e^2)}{2} \cdot \frac{m_1 \cdot m_2}{(m_1 + m_2)} \cdot v^2$$

where e is the coefficient of restitution, which measures how elastic the collision is. It is a function of the hardness or softness of the colliding objects, which along with velocity determines impulse. If hard objects collide (for a perfectly inelastic collision, $e=0$), they will accelerate one another quickly, transferring a large amount of force in a small amount of time while soft objects colliding (for a perfectly elastic collision, $e=1$) transfer smaller amounts of energy to one another for longer periods of time. Difference in how long momentum takes to transfer and therefore in force at a given instant is why hitting a pillow with the fleshy part of the hand hurts much less than hitting a brick with the knuckles.

As ΔE is proportional to the square of velocity, the more velocity the hand has, the more energy will be transferred into the board. In the simplest possible terms, if the board is infused with more energy than its structure can handle, it breaks. More rigorously analyzed, energy transfer causes the board to dent. This process of transferring energy is **work** (W). Work is force times distance (d): $W=F \cdot d$. If the area of the board that is struck dents a sufficient distance, it will break. Since the distance it dents depends on the energy transferred to it and the amount of energy transferred depends on the velocity of the karateka's hand, a high-speed strike is most likely to break the board.

3   Striking Surface

Any martial artist who has ever struck a board with improper hand technique can attest to the physical pain associated with such impact. The human had is a complex system of bones connected by tissue, and much can be said about the importance of proper hand alignment in breaking. From the standpoint of physical science, however, what is crucial about hand position upon impact is that all formulae for force, momentum, and deformation energy are for a given unit of **area**. By minimizing the amount of striking surface on the hand involved in collision with the board, a karateka minimizes the area of the target to which force and energy are transferred and therefore maximizes the amount of force and energy transferred per unit area. Consider a martial artist capable of striking with 190 joules (J) of energy. A typical human hand is about 6 inches long including the fingers and 4 inches across, which means that a strike with the entire hand disperses those 190 J over 24 square inches, about 7.92 J per square inch. If, however, the karateka strikes with only the fleshy part of the palm, about 2 inches across and 1.5 inches long, the 190 J will be dispersed over only 3 square inches. That strike will deliver about 63.3 J per square inch, inflicting many times the amount of damage the whole hand could—the same amount of energy dispersed over a smaller area delivers more energy per unit area. This is

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