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A5_8 A Great Punch Line

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Abstract
Leicester University has a prodigious history with its Karate Club, and this paper investigates the total force transferred in a Karate punch and the mass limit needed for a person to be able to break wood with such a technique. A punch is found to be the best technique to break through a block of wood when compared to a kick stepping forward. The average maximum thickness to punch through for a man and a woman is 8 cm and 7 cm respectively.

Introduction

The paper focusses on the kinetics of a person of mass, m, stepping forward from rest and hitting another person. We investigate the kinematics of the arm and body in the motion of the punch, and compare the resultant force to that of a kick from a person of the same mass. It is assumed that one stride is roughly equal to a metre, and that all of the force from both the punch and the kick is transferred to the wooden block. The Ultimate Tensile Strength (UTS) can then be used to determine the minimum mass of the Karateka (Karate student) necessary to break blocks of wood, as commonly depicted in media, to determine the effectiveness of the technique. It is then possible to determine whether a punch or a kick is better suited to breaking a block of wood.

It should be noted that this investigation only concentrates on the force generated by a Karate punch as taught by Leicester Karate Club, since style variations can produce different results.

Theory

The total force incident upon the block of wood can be determined by investigating the change in momentum as the motion is stopped by the material:

$$\bar{F} = \frac{\Delta p}{\Delta t} = \frac{2m_{bod}v_{tot}}{t_{stop}}, \qquad (1)$$

where $\bar{F}$ is the force incident upon the wood, p is the momentum, m_{bod} is the mass of the body, v_{tot} is the total velocity of the technique and t_{stop} is the time taken for the technique to stop on impact. This time can be calculated by determining the time taken for a wave propagating from the impact through the thickness of the block and back at the speed of sound in wood [1].

$$t_{stop} = \frac{2L}{C_s}\ , \qquad (2)$$

where L is the thickness of the wood and c_s is the speed of sound in the wood. Substituting this into Equation (1):

$$\bar{F} = \frac{m_{bod}v_{tot}c_s}{L}. \qquad (3)$$

The equation for the ultimate tensile strength of a material can then be used to determine the mass of the Karateka necessary to break through the wood:

$$UTS = \frac{\bar{F}}{A} = \frac{m_{bod}v_{tot}c_s}{L\,A}\ , \qquad (4)$$

where A is the area of the ball of the foot or the first two knuckles, given that these are the points of impact for the kick ($2.4\text{x}10^{-3}$ m^2) and punch ($6.0\text{x}10^{-4}$ m^2) respectively [2].

The total velocity of the hand at the end of the motion depends on the velocity of the body, since the hand moves with respect to the body, such that

$$v_{tot,hand} = v_{bod} + v_{hand}, \qquad (5)$$

where $v_{tot,hand}$ is the total velocity of the hand from an inertial reference frame, v_{bod} is the velocity of the body and v_{hand} is the velocity of the hand in the body's reference frame.

To calculate the velocity of the hand, we must assume that the punch and the body stop simultaneously, which is accurate to this style of Karate. The time for the body to make the stride can be calculated through the use of equations of motion assuming constant acceleration:

$$t = \sqrt{\frac{2s_{bod}}{a_{bod}}}, \tag{6}$$

where t is the time taken for a single step, a_{bod} is the acceleration of the body and s_{bod} is the length of one stride. We assume that the Karateka accelerates at the rate of that of a sprinter during the step, around 8.8ms^{-2} [3]. From this we can calculate the final velocity of the arm:

$$v_{hand} = \frac{s_{arm}}{t}, \tag{7}$$

where s_{arm} is the average length of an arm[4] [5]. A similar equation can be used to calculate the velocity of the body.

Now considering the leg, the final velocity of the foot is independent of the motion of the body, since the kick occurs after the step, and assuming the leg undergoes the same acceleration as the body, the velocity of the leg can be calculated:

$$v_{leg} = \sqrt{2a_{bod}s_{leg}}, \tag{8}$$

where s_{leg} is the average length of a leg.

Results

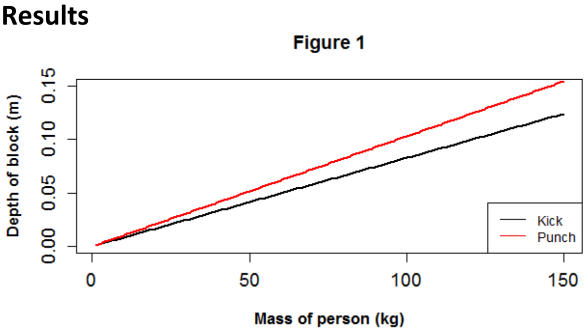

Figure 1. Depth of wooden block against the mass of the person, indicating the maximum thickness of wood each technique can break.

The figure above shows the maximum thickness of wood that each technique may break for varying Karateka mass. It is assumed that the wood is oak, which has a UTS of 1.4x10^{7} Pa when force is exerted perpendicular to the grain [6], and a sound speed of 3300 ms^{-1}. From Equation (8), the final velocity of the foot before impact was found to be 4.0 ms^{-1}, and from Equation (7) and (5) the final velocity of the hand before impact was found to be 3.7 ms^{-1}.

Discussion and Conclusions

The results show that the best technique to break through a block of oak, for a given Karateka mass, is a punch. The unintuitive results for the thickness that either a punch or kick could penetrate through possibly arise due to the small area used in the punching technique, which compensates for the larger mass of the leg.

Using the average mass of a man (80.3 kg) and a woman (70.2 kg) in the UK [7], it is found that the maximum thickness that the average man can punch and kick through is 8.1 cm and 6.9 cm respectively. For a woman, the calculated values are 7.3 cm and 5.9 cm respectively.

Further research could provide a more accurate value for the acceleration of the leg to determine the absolute maximum speed that can be attained in a kick. This may change the maximum thickness of a block of oak that it can be broken for a given Karateka mass. The author would like to note that the values calculated are only specific to the style of Karate taught at Leicester University. The assumptions made for the placement and motion of the fist and leg are explicit only for this style. Stylistic variations will alter the results and require different assumptions.

References

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