Power Required to Break Boards

Fuji Mae Polar Boards vs the Equivalent Wood or Finger Boards

A thesis presented to iTKD by Richard Burr in preparation for grading to IV Dan

Summary

Experimental data has determined that simple addition of the energy required to break a single board is a poor predictor of the actual energy required for multiple board breaks. A model for predicting the energy required for multiple board breaks is presented that is accurate to within 10%.

An incremental ranking of boards from singles, to multiples and mixed coloured boards is presented. This should be of value for both gradings and competition to either incrementally increase (or decrease) the requirements, or evaluate the power generated by techniques performed on various board combinations.

Introduction

Power breaking in Taekwon Do competition and grading has traditionally used pine boards as the material of choice to destroy. The increasing cost, availability and variability of pine boards of suitable width (280-300mm) and quality has seen plastic re-breakable boards commonly used as an alternative.

When evaluating the power developed for a technique the wide variability of pine boards makes valid comparison between techniques and competitors difficult. The condensed encyclopedia of Taekwon-Do describes boards for destructions as 30 cm (12 inches) square, 1.27 cm (one inch) thick pine boards. In the New Zealand construction industry pine boards are commonly rough sawn to nominally 300mm (11 13/16“) wide and 25mm (63/64”) thick. We rarely see green (undried) rough sawn boards used. More commonly kiln dried, ‘clear’ or ‘dressing grade’ dressed timber is used. This timber is force dried to approximately 5-8% moisture content and milled to a smooth finish of 280mm (11 1/32”) wide and 18mm (45/64”) thick. The variability of power required to break these boards is much reduced compared to ungraded, green, rough sawn timber. But even still the variables of grain direction, density, defects, age, moisture content and species means that there is still large variations from board to board.

Plastic re-breakable boards that simulate traditional pine boards are manufactured to tolerances of dimensions and materials that greatly reduce this variability making them well suited for making valid comparisons between breaks. Most commonly available boards now are of the ‘polar’ (keyed) or ‘finger’ (interlocking fingers) type. The polar style of boards have been favoured for competition and training due to their closer resemblance to pine boards in the mechanism of breaking (explained further below). Of the polar type, Fuji Mae brand is readily available in New Zealand and globally.

There is a little hard data on the dynamic force required to break inividual and combinations of this type of boards. Static data (force constantly applied to the surface of the board) to determine the point of destruction is of limited use as it does not represent the dynamics of breaking with a tool (hand, foot, elbow, knee, wrist) in a fluid motion.

This article addresses some of the common questions regarding the approximate energy required to break polar boards (singles and multiples, of different colours) and the equivalents to polar boards in timber and finger boards. The data obtained from these experimants forms the basis for recommendations for power competitions and grading.

The Dynamics of Breaking

A simple method for measuring the relative 'strengths' of boards is to slowly apply an increasing force, or pressure to the board until it fails, or breaks. This method may be appropriate for the same kind (polar, timber, finger) of board, but poorly represents the real dynamics of striking a board.

With all materials (whether it is wood, concrete, glass, plastic) there is a degree of elasticity or flex that the material will withstand, returning to it's starting state after impact (no break!). If sufficient energy is applied to exceed the critical deflection the material will break.

In more scientific terms – when striking a board, a force is applied to the board over a very short time interval. The board absorbs that energy, storing it for a short period. The maximum energy that the board can store before beginning to fail, or break is defined as

$U_{max}=V*\sigma_b/2E$

Where U_{max} is the maximum stored energy

V is the board volume

σ_b is the breaking stress

And E is Youngs Modulus – the specific measure of a materials's stiffness of an eleastic material[i]

If the energy imparted to the board exceeds U_{max} then the board will deflect past it's critical point and break. If the energy is less than this, the board will store this energy momentarily, returning it back to the striking tool. This is the pain or shock of a failed break.

The dynamic description of the break in terms of physics becomes more complex then. In real terms a striking tool is applied to the surface of the board with an instantaneous velocity and mass. The board absorbs this energy over a period of time as the striking tool attempts to deflect the board past it's critical point. During this time the attacking tool is rapidly decelerated to close to zero velocity if the break was 'just achieved'. The energy being applied to the board over the time it takes to deflect it to the point of destruction is more correctly termed impulse or change in linear momentum.

$J = F_{average}(t_2-t_1)$

Where J is the implse of force

$F_{average}$ is the average force applied

And t_2-t_1 defines the time interval.

The term impulse is often used to describe a fast acting force or *impact*. This type of impulse is frequently idealised so that the change in momentum produced by the force happens instantaneously. This is not physically possible, but serves as a useful model for computing the effects of an ideal collision.

The impulse may also be thought of as a change in momentum of an object to which a force has been applied. If the mass remains constant (in the context of this experiment it does), then impulse may also be expressed as

$J = mv_2 - mv_1$

Where m is the mass of the striking object

v_2 is the final velocity of the object at the end of the time interval

and v_1 is the initial velocity of the object when the time interval begins.

Generalisations and assumptions

In the following experiments a number of assumptions have been made. For the purposes of comparing the relative energy required to break different boards of different materials it is acknowledged that the figures obtained will be somewhat inaccurate due to errors of measurement, and simplifying the analysis of the data obtained.

Within the limits of the equipment and materials readily available, a concerted effort was made to minimise errors with attention to applying the same conditions and measurements to each experiment, and repeating to ensure the data was consistent.

For the following experiments it is assumed that:

- Frictional losses are neglible
- The energy applied to the boards is just sufficient to break them
- The velocity of the attacking tool is zero at the moment of the boards breaking
- The time interval between impact and destruction is negligible

Given the assumptions made, the figures obtained are not intended as being a definitive quantity. For the purposes of this report they are only intended to be used for comparison between the different boards and combinations examined.

Experimental design

Attacking Tool

To simulate as closely as possible a ‘real’ break, an anatomical fist made of lead was cast as an approximation of a real fist. The author’s clenched fist was first set in cloth reinforced plaster of paris. After drying the cast was cut off in two pieces, then re-assembled and glued together with further plaster of paris. After further drying a quantity of molten lead was poured into the cast from the open wrist. After cooling the cast was once again removed. The suspension point was found which allowed the fist to contact a surface with the front two knuckles only. At this point a strong hook was threaded into the fist. See figure 1.

The lead fist and hook had a mass of 5.1kg, similar to the mass of a human arm and hand.

Figure 1 - Lead fist tool and comparison to the modelled fist

Board Holder

A simple board holder was constructed of melamine MDF, with guides to allow consistent placement of boards. The holder itself was dyna bolted to a concrete floor to ensure consistent placement. The design of the holder allowed support at the two edges of 10mm each side – similar to most mechanical board holders in use.

The edge supports were progressively built up to determine the amount of deflection required to achieve a complete break, both with single boards and multiples.

The fist was suspended from a 3mm stainless wire, running to a low friction stainless/brass Ronstan pulley fixed to a point approximately 2 meters from the ground, and terminating in a small clip used as a handle. A short zip tie was fixed securely to the fist as a point to measure from. See Figure 2, 3, 4.

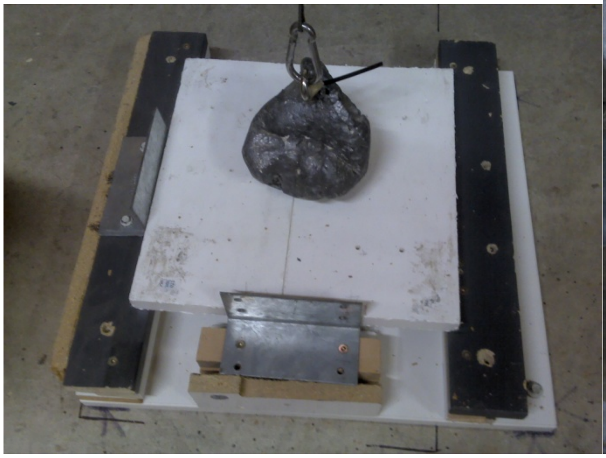

Figure 2 Board holder and guides

Figure 3 Ronstan low friction pulley

Figure 4 Successful board break

Experimental Design

Materials

Kiln dried 'clear' graded, dressed Pine (*Pinus* radiata) boards, 280mm square x 18mm thick

"The Ultimate Martial Arts Board" and "Novel Industries" brands of green and black finger boards. These boards were in a well used state.

Fuji Mae polar type boards – white, red and black. These boards varied from averagely used to very new. Note was made of the condition of each board before the attempted break.

Design

For each attempted break the tool was raised to a measured point above the board. It was then released to fall under gravity to impact on the board. The height from which the board was just broken was determined by a series of attempts, gradually increasing the height until the impact completely broke the board(s). Often with multiple boards, in finding this point one or more boards were incompletely broken with either some boards not being broken at all, or some boards 'bent' (as per the ITF competition rules description). These attempts were not recorded as a successful break. The height at which the board(s) just broke was repeated a minimum of 3 times to ensure consistency.

From the corrected heights (allowing for the height of the measuring point above the board face), the time taken to fall

$$t = \sqrt{(2d/g)}$$

where t = time in seconds

d is the distance from the board face

g is the gravitational constant 9.8 m/s^2

and the velocity (v)of the tool at impact

$v = gt$ or $v = \sqrt{2gd}$

were determined. Even at relatively low impact velocities the time taken to displace the board(s) from impact to critical point was minimal. Thus a simplified measure of kinetic energy at impact

$$E_k = 1/2\ mv^2$$

Where E_k is the kinetic energy

m is the mass of the tool

and v is the velocity of the tool at impact

was used for comparisons to determine the relative amount of energy required to achieve destruction.

Results

Deflection required to break

The height of the edge supports of the board holder were incrementally increased to determine the amount of delection required to effect a complete break.

Board	Deflection required to break (mm)
18mm pine	10
White Polar	13
Red Polar	13
Black Polar	13
Green Finger	45
Black Finger	50
Multiple Polar	45

Table 1 Deflection required for destruction

Conclusions

Pine and polar boards, singly, require a similar amount of deflection to effect a break. In practical terms a single pine or polar board may be broken with a minimal amount of penetration through the target. With multiple boards it was expected that the amount of deflection applied to the first board would be transferred to subsequent boards – i.e. a deflection of 13mm of the first board (and a successful break) would also deflect the second and subsequent boards by the same amount, breaking them as well. The amount of deflection to effect a complete break on multiple boards was approximately 3 times greater than expected. The reason for this is unclear. It is suspected that the nature of transferring the impact from one board to another is not as straight forwards as initailly thought.

Finger boards, singly, required vastly more penetration to effect a break. It can be clearly observed that the process of the fingers separating occurs gradually as displacement increases, as opposed to wood and polar boards.

Location of Impact

It has been long known that finger type boards can be induced to 'unzip', separating from one edge to the other progressively by applying an along the joint line, but close to one edge. It is suspected that the propogation of a critical fracture in most materials may take less energy to initiate if started closer to one edge compared to striking in the diagonal center of the board. If the impact is applied to the diagonal center, a tension fracture line will be initiated from a point on the opposite face of the board, and spread from the impact point in either direction to the edges. This is in contrast to starting from on edge only and progressing to the opposite edge. This phenomenon can be observed with slow motion photography http://www.youtube.com/watch?v=ONotvKTqpEU

The effect of impact location on a single polar board was investigated by varying the location of the board holder and measuring the displacement from the diagonal center of the board. Displacements were made in both vertical (moving away from the joint line) and horizontal (along the joint line) directions.

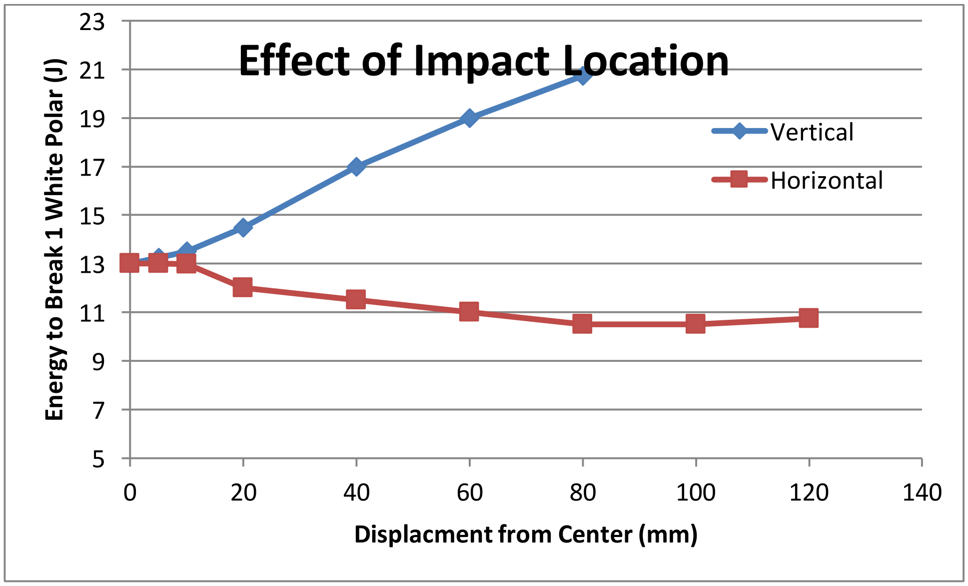

Figure 5 Effect of varying impact location

Conclusion

Varying the impact location vertically from the joint line had a negative effect. At 80 mm away from the joint line the energy required to break was approaching 1.6 times that required when striking at the center. Conversely, striking the board closer to the edge horizontally (along the joint line), the energy required to break diminished by approximately 20% at about 1/3 of the board width.

This demonstrates the importance of striking on the line. A better chance of a successful break will be achieved if striking the board at approximately 1/3 of the width of the board, rather than in the middle.

Comparison of Board Types and Combinations

Three different colours of polar boards, 18mm (senior) and 15mm (junior) pine boards and two different coloured finger boards were initially examined to determine relative breaking energy required. Then multiples and combination of polar board colours were examined.

Results obtained for green (3.25kJ) and black (2.70kJ) finger boards were considerably less than a single 18mm pine board (4.25kJ), contrasting with their advertised relative strengths – green = 1 board, black = 2.25 boards. This is probably a reflection of their extremely well used state, with some fingers broken. As a result of this the results of the finger boards was not considered to be an accurate reflection of what could be expected from boards in good condition.

Five white, four red and five black polar boards were tested, ranging from relatively new, to moderately used. The results from these and wooden boards are presented in Figure 6.

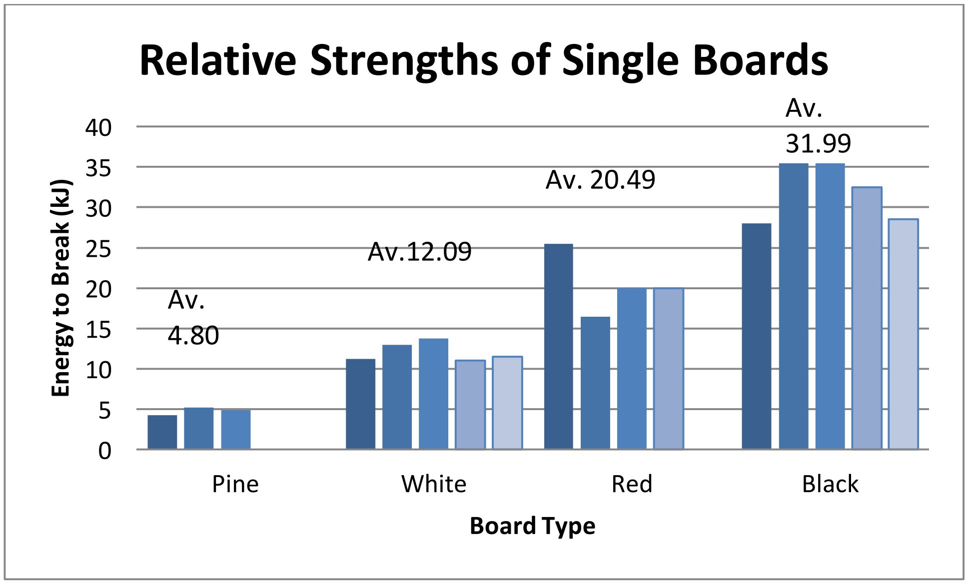

Figure 6 Energy required to break tested boards

Taking into account the variability within each board colour (reflecting it's state of use), the results could be generally stated as:

- 1 white polar board requires approximately twice the enrergy to break compared to an 18mm dressed pine board.
- 1 red polar board is requires aproximately 4 times the energy of a wooden board
- 1 black polar board requires approximately 6 times the energy of a wooden board

What is not valid is to generalise that 1 black polar board is equivalent to breaking 6 wooden boards.

It has been felt by many experienced power breakers that multiple boards are considerably harder to break than what has been considered the equivalent in a different colour. For example, Fuji Mae describes the 3 types of boards as white (easy) = 1 wooden board, red (medium) = 2 wooden boards and black (hard) = 3 wooden boards. From this you would be forgiven for assuming that breaking 1 black board would be like breaking 3 white ones.

Multiples of each board colour were tested to challenge this notion.

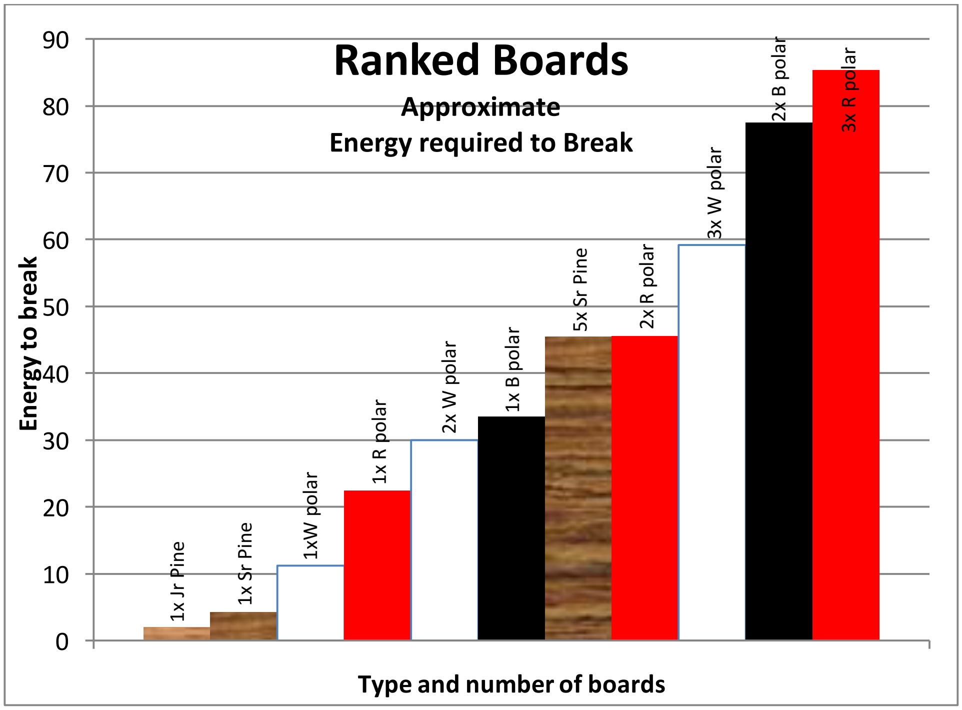

Figure 7 Relative strengths of multiple boards

The observed data shows some interesting comparisons

- A senior (18mm) pine board takes about twice the energy to break than a junior (15mm) board, even though it is only 3mm or 20% thicker
- A single red polar board required about *twice the energy* as a white polar board
- A single black polar board required about *three times the energy* as a single white polar board
- Approximately the same energy is required to break 2 white polar boards as a single black polar board
- Approximately the same energy is required to break 5x senior wooden boards as 2x red polar boards
- Two black and three red polar boards were similar in energy required to break

What is evident is that the energy required to break multiple boards is more than the sum of the energy required to break a single board.

An algorithm was developed to predict the required energy to break multiple boards.

The model best fitting the observed data is:

Predicted kinetic energy required to break multiple boards = sum of individual boards x a multiplier factor raised to the power of the number of junctions between boards

$E_k = \sum \textit{individual boards} * X^j$

Where E_k is the kinetic energy required for destruction

$\sum$ *individual boards* is the sum of the energy of each board alone

X is a multiplier factor

J is the number of interfaces between the number of boards – i.e. a stack of 3 boards has 2 interfaces, a stack of 5 boards has 4 interfaces.

Varying the multiplier factor, the predicted and observed results were compared. The multiplier achieving the minimal error between predicted and observed results across all board combinations was determined to be 1.20

Multiplier	% variation from observed data
1.25	0.27 – 21.76%
1.20	3.15 - 8.25%
1.22	1.64 - 13.20%

Table 2 Accuracy of multipliers

Conclusion

The energy required to break a number of polar boards, and possibly wooden boards too, can be predicted using the equation below with an accuracy of aproximately 10%

$E_k = \sum \textit{individual boards} * 1.20^{(\textit{number of board interfaces})}$

Assuming the above predictive model holds for combinations of different coloured polar boards, the energies to break the following combinations of boards were determined based on the above average values for individual boards (Figure 6 above). With combinations of just 2 boards of each colour, a range of breaking energies can be specified from 12kJ to 180kJ – a 15 fold range.

Combination	Sum individual	Board junctions	Board multiplier	Predicted
1W	12.09			12.09
1R	20.49			20.49
2W	24.18	1	1.2	29.016
1B	31.99			31.99
1W+1R	32.58	1	1.2	39.096
2R	40.98	1	1.2	49.176
3W	36.27	2	1.2	52.2288
1W+1B	44.08	1	1.2	52.896
1R+1B	52.48	1	1.2	62.976
2W+1R	44.67	2	1.2	64.3248
1W+2R	53.07	2	1.2	76.4208
2B	63.98	1	1.2	76.776
2W+1B	56.17	2	1.2	80.8848
4W	48.36	3	1.2	83.56608
3R	61.47	2	1.2	88.5168
1W+1R+1B	64.57	2	1.2	92.9808
2R+1B	72.97	2	1.2	105.0768
1W+2B	76.07	2	1.2	109.5408
2W+2R	65.16	3	1.2	112.5965
1R+2B	84.47	2	1.2	121.6368
3B	95.97	2	1.2	138.1968
2W+2B	88.16	3	1.2	152.3405
2R+2B	104.96	3	1.2	181.3709

Table 3 Predicted values for board combinations

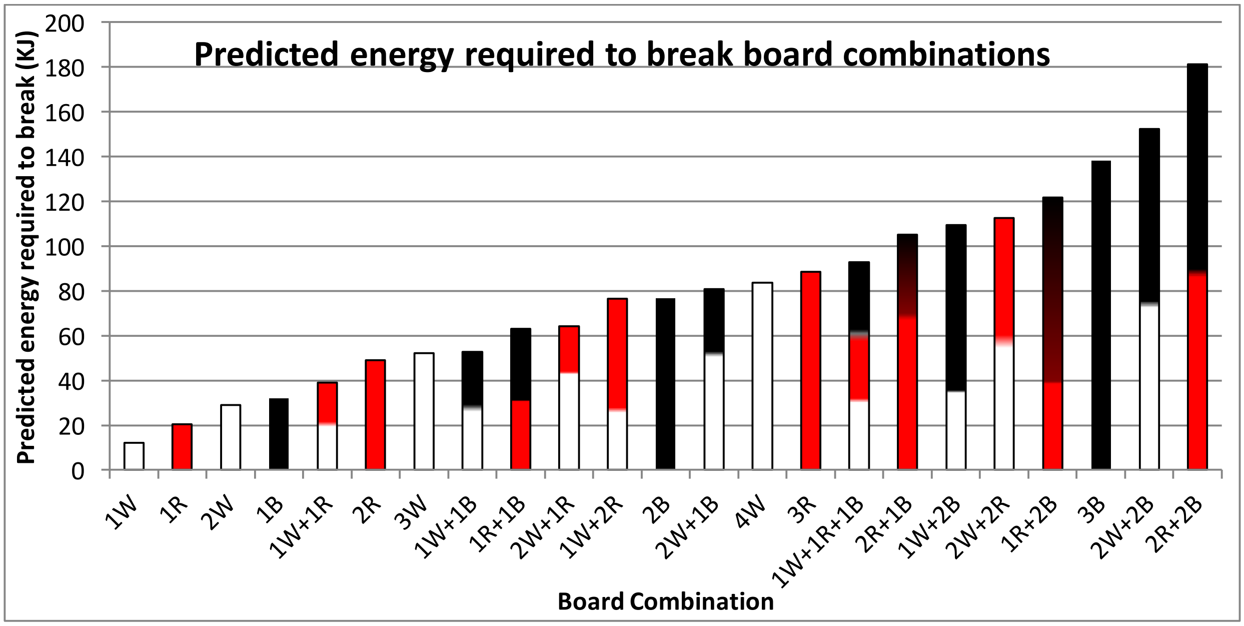

Figure 8 Predicted energy for board combinations

Recommendations

In competition and in gradings the requirements for destructions are frequently based on guesswork and assumption that simple additive energy to break single boards can be utilised to predict energy required to break multiple boards. A far more acurate method for predicting the energy for multiple breaks is outlined above.

In competition it is important that competitors train appropriately for the requirements of the event. There is little point training to break 1 black polar board for an event requiring 3 white polar boards. As seen above the energy required is approximately double that of a single black polar board!

For officials running the event – it is useful to have an accurate measure of incrementally increasing the requirement for breaking in the case of a tie, or break off being required. With various coloured boards available the range may be steped up appropriately, rather than large steps which may prolong the event trying to determine a winner, or unneccisarily expose the competitors to injury if they have not conditioned themselves sufficiently for a target requiring vastly more energy to break.

A list of ranked board combinations would be useful in preparing standards for both grading and competition.

References:

John Rennie, September 2, 2010. Busted Explanations for Karate Breaking
http://blogs.plos.org/retort/2010/09/02/busted-explanations-for-karate-breaking/

Feld, M. S. et. al. "The Physics of Karate," Scientific American, pp. 150-158, April 1979

Jasek Wasilk "Power breaking in taekwon-do – physical anaylsis", Archives of Budo, 2007; Vol 3:68-71

Brainiac: Brick Break, YouTube

www.youtube.com/watch?v=ONotvKTqpEU

Master Bill Pottle, "Pine Board Breaking in the Martial Arts"

www.kattaekwondo.com (personal communication)

[i] Approximate Youngs Modulus (Gpa) pine – 9, polypropylene 1.5-2.0, high strength concrete 30, glass 50-90