DESTRUCTION PROPERTIES OF GRADING MATERIALS USED IN THE MARTIAL ARTS

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Common materials used for 'breaking' in martial arts were subjected to static load tests using an Instron 8501 machine. The test materials, including 'Radiata' pine boards and ceramic roofing tiles, demonstrated significant variability (≈30%) in peak yield force during static load-to-failure tests. Individual force-time histories demonstrated that each board had a linear elastic region and no plastic region prior to the yield point. Though still essentially linear, the elastic region for ceramic tiles was less regular, but still revealed a definitive yield point. Furthermore, such factors as grain structure, applied force position, orientation, and material size and age were shown to affect the destruction properties.

KEY WORDS: martial arts, taekwondo, karate, kung fu, destruction, breaking

INTRODUCTION: The term 'destruction technique' describes the act of breaking a sturdy object with hand or foot. 'Breaking' has been used in a variety of martial arts, including Taekwondo, Karate and Kung Fu for many years as a means of gauging the destructive power generated by a student. It is often utilized for grading purposes, as a successful break requires high levels of skill, speed and power. Previous scientific research in the martial arts has been concerned predominantly with the dynamics of various striking movements (Sorensen et al., 1996; Costelloe et al., 2002). To date, however, the importance of the material properties of the specimens being broken has been virtually ignored. The aim of this research was to better understand the various factors that might influence static destruction properties, and determine the variability of two materials commonly broken in a martial arts grading. The results will help to confirm some existing theories held by marital arts practitioners and yield practical information that can be used by students to achieve a successful break.

METHODS: Two materials that are commonly used for breaking – 'Radiata' pine boards ('adult size': 290 x 290 x 19 mm and 'junior size': 250 x 290 x 19 mm) and Bristile 'Marseille' ceramic roofing tiles: 450 x 280 x 25 mm), were subjected to materials testing using an Instron 8501. For the sake of consistency, all tiles were chosen from a single manufacturer's batch, and all boards (within the various categories) were cut from a single representative plank. The 'Junior' boards are slightly smaller than 'Adult' boards in order to (theoretically) reduce the impact force required for a successful break. Whilst the ceramic tiles are virtually identical, the pine boards vary markedly in grain structure. Pine boards can be generally divided into two groups – those with high grain density (narrow grain) and those with low grain density (wide grain). Categorising grain structure is highly subjective (Figure 1), and some boards may exhibit regions of both structure types, though planks with mixed grain structures were avoided in this study.

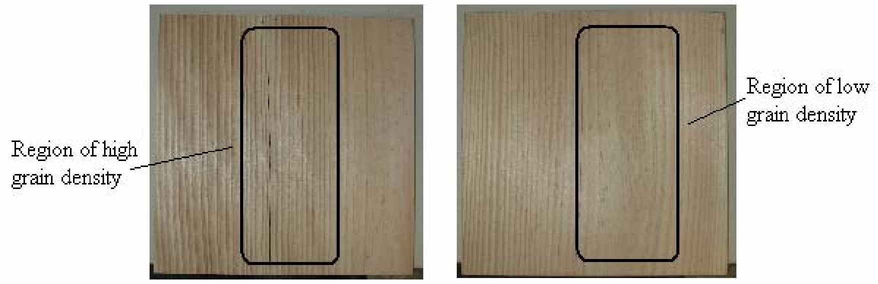

Figure 1

Figure 2

The Instron 8501 machine can test material properties under a variety of conditions, including tensile, compressive and cyclical loading (Figure 2) at variable loading rates. A load cell is incorporated within the hydraulic ram that measures the displacement of a specimen and the corresponding applied load during deformation. The specimen is supported at either end by a custom-made attachment; the purpose being to simulate the manner in which it would normally be supported during a breaking attempt. In order to accommodate each of the test materials, the supporting bars at either end of the attachment were adjustable so that each specimen was supported 15 mm in from the edges. Furthermore, in order to better simulate a strike by a clenched fist or a kick with the heel, an attachment of similar dimensions was created to apply force to the specimens. For these trials, a steel cylindrical attachment (shown in Figure 2) with a flat contact surface of 80 mm diameter was used. Specimens were deformed at a very slow rate (0.1 mm/s) using a simple ramp function. The slow deformation rate allows the assumption to be made that the specimen was being loaded statically, thereby removing any effects that loading rate may have on the response to loading. Each specimen was deformed until it ruptured, and data related to specimen loading and deformation (stress-strain) was sampled from the load cell (sampling rate = 1000 Hz) and plotted on a laptop computer. The maximum force applied was also noted. This information was then imported into Microsoft Excel for further analysis.

RESULTS: An example force-displacement plot for ‘adult’ pine boards with narrow and wide grain structures is shown in Figure 3. The plot demonstrates that each tested board has a linear elastic region and no plastic region prior to the yield point. This is useful because it shows that, no matter how hard or how frequently each board is struck, provided it doesn’t break and that external wood fibres are not damaged during the trial, it will behave the same way for subsequent impacts. This figure also indicates a degree of variation between trials in the maximum force that each board can withstand before rupture (destruction force).

Pine Boards Initially, multiple tests of both wide and narrow grain boards were conducted in order to investigate the variability between similar specimens. From Table 1 it is clear that there exists significant variation (26% and 31% respectively) between similar boards from both categories. Furthermore, boards with a narrow grain structure are inherently stronger than those with a wide grain, with the former requiring greater force to deform and reaching a higher value before yielding. Table 1 also shows that less force was required to break the specimen when the load was applied on the edge, rather than at the centre. Pine boards display greater flexibility when the load is applied at the edge (less support material), so that smaller forces are required to deform the edge and propagate a stress-induced crack. Prior to testing, it was expected that 'junior' boards would exhibit lower resistance to breaking than 'adult' boards. However, the results in Table 1 show that the narrow grain 'junior' board we tested required a similar magnitude of destructive force to the 'adult' boards. Finally, the orientation of the board was also investigated, since it is the task of the instructor to hold or position the board correctly during grading. The results demonstrated that an incorrectly orientated board required five times the magnitude of force needed to break a similar board with the correct orientation.

Figure 3. Comparison of Static Behaviour when Force is Applied to the Edge of Wide and Narrow Grain Boards

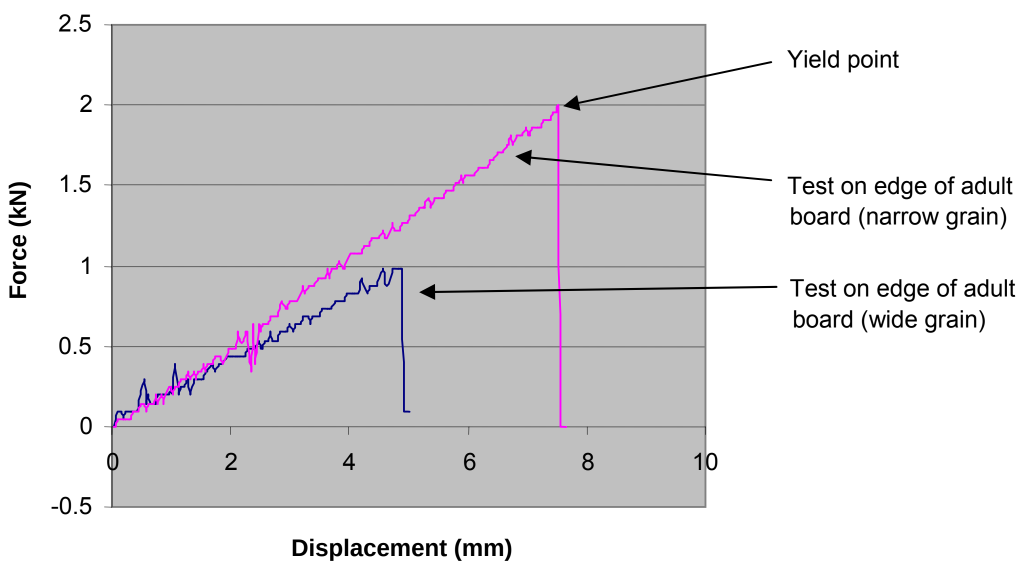

Table 1: Average and range of destruction forces for pine boards and ceramic tiles under multiple conditions

Test Conditions	Average Destruction Force (kN)	Range (kN)	Trials
Pine Boards:			
Adult wide grain boards	1.319	0.342	3
Adult narrow grain boards	2.018	0.635	3
Loading at edge (wide grain)	1.319	0.342	3
Loading at centre (wide grain)	0.977	---	1
Adult boards (narrow grain)	2.018	0.635	3
Junior board (narrow grain)	2.002	---	1
Correct orientation (narrow grain)	2.108	0.635	3
Incorrect orientation (narrow grain)	10.403	---	1
Ceramic Tiles:			
Loading at edge	0.855	0.147	2
Loading at centre	1.133	0.341	5
New tiles (load at centre)	1.133	0.341	5
Old tiles (load at centre)	0.830	0.196	2

Ceramic Tiles In contrast to pine boards, ceramic tiles do not display a smooth, linear force-displacement relationship. Though essentially linear, the plots tended to be quite irregular (perhaps as a result of small fractures occurring where the uneven edges settled onto the support rods), however each did have a clearly defined yield point. The ceramic tiles are similar to pine boards in that they are a brittle material with no demonstrable plastic region. Multiple tests were also conducted on similar ceramic tiles with the load applied at the centre. The data in Table 1 demonstrate that, like the boards, there exists significant variation (30%) between ceramic tile specimens from the same manufacturer's batch. New tiles require less force to yield when the load is applied at the edge, rather than in the centre. This is probably due to the shape of the tiles. A groove runs down the centre of the tile, resulting in an area of increased strength, whereas the edge of the tile is relatively flat, and consequently, represents a weaker point. Furthermore, regardless of where force is applied, new tiles require a greater destructive force than that of old, weathered tiles. After many years of exposure to the elements, old tiles would absorb moisture and suffer from biological decay due to mould. Both factors contribute to reducing the strength of a roofing tile.

DISCUSSION: For many years martial arts practitioners have known that it is possible to select a grading specimen that is easier to break than others, provided that the student knows what to look for (Byrne, 1984). This predictable variability of specimens was investigated under controlled, static testing conditions using two common materials – roofing tiles and pine boards. Whilst manufacturers provide data for transverse yield strength of their products, these values do not simulate a point strike, and are merely an average that conforms with the relevant Australian Standards. Substantial variation was observed between pine board specimens, despite the fact that they were alike in appearance. Similarly, the new ceramic tiles demonstrated variation in their load-to-failure. As a result, any future testing should allow for multiple trials of the material to account for this variability, or alternatively, the selection of a more uniform matter.

Pine Boards

Importance of grain structure – Grain structure clearly affects the yield strength of the material. In regions of high grain density, there exists a greater concentration of irregularities within the grain structure. These irregularities strengthen the material by hindering the propagation of cracks, which is the primary mechanism for rupture in wood. Wide grain specimens have large regions of uniform material that propagate cracks more readily.

Importance of applied force position – A decision to strike the board at the edge or in the centre can be critical in determining the outcome, with the latter requiring a greater destructive force when the board is supported at the edges.

Adult versus junior boards – Contrary to our expectation, the yield point for the junior board we tested was not lower than the average values for adult boards. Perhaps the 40 mm difference in board length was not sufficient to affect the required destructive force, or maybe this is simply a result of the wide variability in the material itself.

Importance of orientation – The primary failure mechanism of timber is via crack propagation in the direction of the grain. As force is applied the wood cracks along the grain, splintering the specimen into many long, thin pieces. These pieces are then weak enough individually to yield in the secondary failure mode, by tearing across the grain. When the board is incorrectly aligned, this crack propagation mechanism is hindered, resulting in a five-fold increase in the required destructive force.

Ceramic Tiles

Importance of applied force position – As with the boards, striking the tile at the centre will require the student to apply a greater destructive force than if it is struck at the edge.

Old versus new tiles – Though less of a challenge, the older and more weathered tiles will shatter more readily than new tiles. Consideration of the tile profile will also be important.

CONCLUSION: Common martial arts grading materials demonstrate significant variability in static load-to-failure tests, and such factors as grain structure, applied force position, orientation, and material size and age affect the destruction properties. However, it must be remembered that these tests were completed under static loading and therefore, do not account for dynamic loading at different impact velocities. Davis et al. (1964) pointed out that some materials display ‘velocity sensitivity’ to a greater extent than others.

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