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Impact Reduction Factors of Energy-Absorbing Rubber Support as a Component in Elastic Flooring System

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Abstract: The popularity gained in martial arts raises the concern on the vitality to provide safety during the martial arts practice. Among numerous martial arts, Taekwondo and Karate are recorded to have the highest number of injuries; dominantly occurring in lower limbs due to repeated and prolonged impact force from landing, braking, sudden deceleration and change of direction. Physical lower limb injuries are asserted to be affected upon contact with sport surfaces with ground impact force. The aim of this paper is to design and evaluate a proposed elastic flooring system which comprises of a plywood board (as the upper member) with rubber supports (as the lower member for energy-absorbing). First, the dynamic characterization of the elastic rubber pads for different sizes were conducted using compression test set up. Then, drop test using a drop test set up comprising of 20 kg load and accelerometers were carried out. Dropped at 55mm height constantly for all the floor design based on different impact reduction factor treatments, the acceleration for all the drop tests were recorded. Manipulating on several impact force reduction variation on the lower member, identified as; number of rubber support (X), gap between rubber supports (Y), size of rubber support (Z) and thickness of rubber support (T), an experimental study utilizing sensors and instrumentation is done based on eight samples of the proposed flooring system. The results revealed a positive result on reduction of ground impact by almost 50% significantly, produced by the floor sample using 8 Nos of 0.15m² sized rubber supports with 50mm thickness arranged in 50mm gaps.

Keywords: Elastic floor system, acceleration reduction, impact-absorbing

1. Introduction

Nowadays, martial arts are practiced for various reasons, including self-defence, sports, fitness, combat skills, character development (Bu et al., 2010), and as an alternative therapy for some medical conditions (Sharpe et al., 2007). The variety in practicing purposes of martial arts raises the concern to provide adequate safety from injuries to the practitioners either professionally or non-professionally. Among various types of Martial Arts globally, the highest occurring injury is highlighted to be in Karate (Yard et al., 2007) and Taekwondo (Zetaruk et al., 2005) with similar injuries pattern. Various studies have underlined lower limbs (Peeri et al., 2001; Destombe et al., 2006; Zetou et al., 2006; Ji, 2016) to be the prominent injuries region among karate and taekwondo practitioners; a result from the repeated and prolonged impact of practices which happens from landing, sudden deceleration, or change in direction on an inadequate impact-reducing floor surface. Elliot (1999) introduced the term as "overuse injury".

Although Martial Arts may be perceived to only cause light injuries and are demonstrated as safer than any other sports due to the careful instruction and control in practice and competition (Woodward, 2009), the repetition of impact

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force exerted on the lower limbs of the practitioners especially the ones with lack of experience (i.e. school children or non-professional practitioners) is however a great concern for injuries that may appear in the later years of their life as injuries occur where the force is exceeding the tissue strength (Sterkowicz & Sterkowicz-Przybycien, 2013).

Sports surfaces, specifically for Martial Arts like Karate and Taekwondo principally have two significant functions; to provide a good condition for the practitioners to perform well and to protect practitioners from tending injuries (Yukawa et al. , 2012; Shorten et al., 2002; Farhang et al. 2015). Literature highlights that injuries commonly occur due to collisions of practitioners with hard surfaces (Orchard, 2002) which therefore underlines the floor surfaces or systems with impact-reducing properties to become a relevant approach in lowering injuries probability among practitioners.

Previous study implementing the concept of elastic flooring system have proven the positive outcomes on impact reductions. For instance, the elastic floor invention patented by Baumann (1963), consisting of floor covering supported by elastic elements arranged at suitable gaps results in impact force reduced, whereas a gymnastic floor by Harinishi (2008), with vertical elasticity provided by support members is found to provide high impact resilience against external forces. By the same token, a patented invention of a floating floor system for apartment buildings by Yoshimi (1987) has found that the floor structure with support members and air gaps in between is able to distribute heavy impact force exerted through the neighboring supporting members. This asserts that the elastic floor system with support member is feasible to be proposed for injury prevention for martial arts practitioners.

With concern for the activities conducted on ground surfaces without safety flooring, this study asserts to come up with a preventive measure for the lower limb injuries by adapting cushiony or elastic floor surface to provide the best impact-reducing function (Ghani and Rased, 2014). Rubber, a natural resilient material having the capability to absorb energy upon impact as it deforms and distorts elastically and eventually releases a reduced amount of energy as it unloads, returning to the original state, normally utilized as shock absorber (Ucar & Basdogan, 2017) could become a beneficial energy-absorbing element to be applied in an elastic flooring system as the lower member support components.

The aim of this paper is to design and evaluate a proposed elastic flooring system which comprises of a plywood board (as the upper member) with rubber supports (as the lower member - for energy-absorbing). Experimental study is done by manipulating on several impact force reduction factors treated on the lower member; identified as number of rubber support (X), gap between rubber supports (Y), size of rubber support (Z) and thickness of rubber support (T). The study covers on the relationship between each factor and the contribution of each factor towards impact reduction of the floor system.

2. Methodology

Generally, the elastic floor system proposed comprises of a plywood board (1000mm x 500mm 12mm) as the upper floor member, supported by a series of rubber pads, acting as the lower support member as well as providing elasticity to the whole floor system. Four different impact reduction factors are treated on the rubber supports manipulating on X-the numbers of rubber support (8Nos and 6Nos), Y-the gap between the rubber supports (100mm and 50mm gap), Z- the size ($0.1m^2$ and $0.15m^2$), and T-the thickness (10mm-50mm). Figure 1 and Figure 2 illustrate typical arrangements and dimensional characteristics of the elastic components in a flooring system.

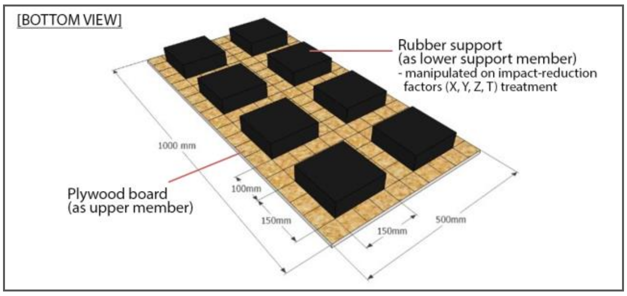


Fig. 1 - (From bottom view) Plywood board (as upper member) rubber supports (as lower members).

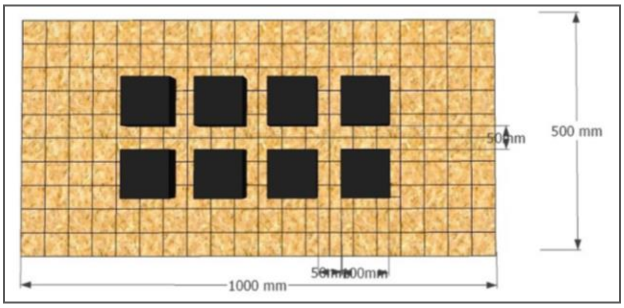


Fig. 2 - Sample of Elastic Floor System treated with impact reduction factors treatment (bottom view).

2.1 Preliminary Test (compression test)

Preliminaries tests (Fig. 3) were conducted to study on the dynamic characterization of the rubber pads (lower member support) for different sizes (0.1m² and 0.15m²) where the thickness factor is kept constant at 50mm.

Table 1 - Preliminaries test based on size factor.

Size of rubber support	**0.1m²**	**0.15m²**
Deflection test on 50mm rubber support	Test 1	Test 1
	Test 2	Test 2
	Test 3	Test 3

With the seating load of 0 kN, a load cell with 10 kN force is pressed (using a compression test machine) upon the rubber pads to see the deflection of the rubber (using LVDT sensor connected to Kyowa data logger). The test is to study on energy-absorbing capacity, and the capability for the rubber to return to its original state; proving elasticity. Data from the test was collected to generate analysis to be related with the main test.

Fig. 3 - Compression test set up (Preliminary test).

2.2 Main test (drop test)

Referring to a standard setup test used to measure shock absorption of sporting surfaces and other uses for years back – i.e. Berlin Artificial Athlete (ASTM, 2007; DIN, 2001; EN Standard, 2009), in this study, a drop test setup using accelerometer sensor and National Instrumentation data logger is developed to study on the impact reduction factors treated on the rubber support.

The experimental apparatus for the drop test (see Fig. 4) consists of 2 accelerometers, 20kg load, National Instrument data logger, a computer, and the floor system to be tested. Dropped at 55mm height constantly for all the floor design based on different impact reduction factor treatments, the acceleration for all the drop tests are recorded. Accelerometer is used to detect acceleration; one of the major contributing factor for impact. The floor system design based on impact reduction factors are categorized as in Table 2.

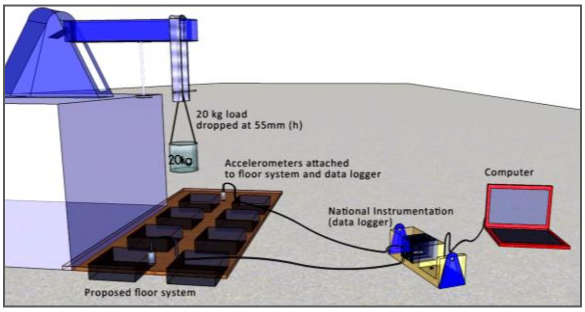


Fig. 4 - Drop test set up (main test).

Table 2 - Floor system design based on impact reduction factors.

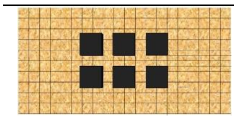
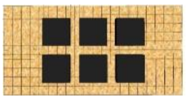
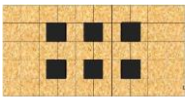
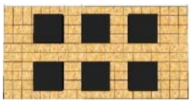
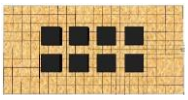
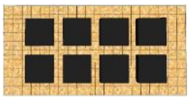
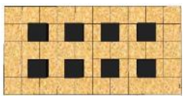
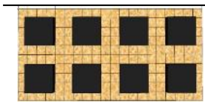
Floor System Design	(X) Nos of support	(Y) Gap between support (mm)	(Z) Size of support (m²)	(T) Thickness of rubber support (mm)
	6	50	0.1	10 20 30 40 50
	6	50	0.15	10 20 30 40 50
	6	100	0.1	10 20 30 40 50
	6	100	0.15	10 20 30 40 50
	8	50	0.1	10 20 30 40 50
	8	50	0.15	10 20 30 40 50
	8	100	0.1	10 20 30 40 50

Table 2 - Floor system design based on impact reduction factors (Cont.).

Floor System Design	(X) Nos of support	(Y) Gap between support (mm)	(Z) Size of support (m^2)	(T) Thickness of rubber support (mm)
	8	100	0.15	10 20 30 40 50

3. Results and Discussion for Preliminary Test (compression test)

Table 3 shows the result for deflection of the rubber support tested to provide the dynamic characterization on the energy-absorbing capacity and elasticity between different sizes. Result shows that the rubber support with smaller size ($0.1m^2$) has higher deflection value upon compression, compared to the bigger rubber support ($0.15m^2$) which means the smaller sized rubber support is more elastic. However, from the Fig. 5 and 6 below, observing at the behaviour of the rubbers support throughout the compression from 0kN to 10kN and back to 0kN, it is found that the bigger rubber support ($0.15m^2$) deflects at a quicker rate if compared to the smaller size ($0.1m^2$). The quicker rate of deflection by the $0.15m^2$ rubber support is asserted to contribute to higher energy-absorbing capacity of the bigger sized rubber support. Dynamic characterization on size manipulation concludes that smaller sized rubber support is more elastic but has lower energy-absorbing capacity compared to bigger sized rubber support.

Table 3 - Deflection of rubber at kN of compression.

Size of rubber support	**$0.1m^2$**	**$0.15m^2$**
Deflection test on 50mm rubber support	4.2mm	3.8mm
	4.4mm	3.9mm
	4.8mm	3.5mm

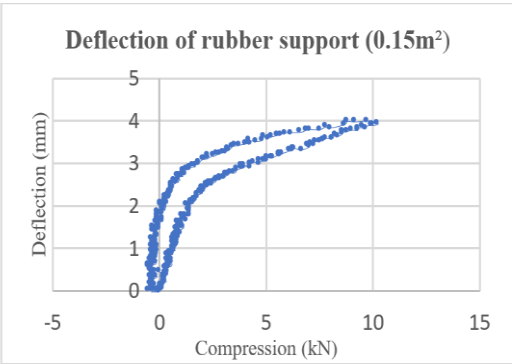


Fig. 5 - Deflection for $0.15m^2$ rubber support

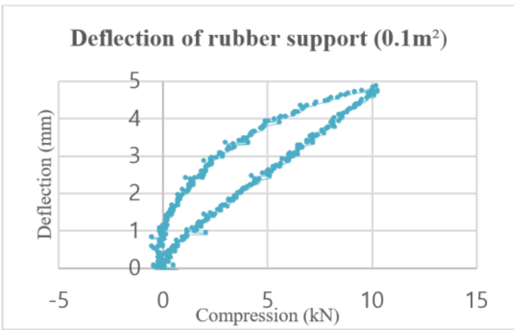


Fig. 6 - Deflection for $0.1m^2$ rubber support.

3.2 Results and Discussion for Main test (drop test)

Table 4 below shows the result collected for the drop test done, referring to the Berlin Artificial Athlete test setup [20, 21, 22]. The manipulations on impact reduction factors treated for every floor sample design (number of support factor (X), followed by gap (Y), size (Z) and (T) thickness)) are tested and translated in the percentage of reduction in acceleration from the impact directly onto hard concrete surface.

Percentage of Acceleration Reduction is calculated based on the Force Reduction equation of Berlin Artificial Athlete Test. The Acceleration Reduction (AR) is asserted as follows:

$$\textit{Acceleration Reduction (\%)} = ((Ac-Ai)/Ac)) \times 100 \qquad (1)$$

Ai is the maximum acceleration recorded onto the floor system and Ac is the acceleration of impact onto concrete surface.

Table 4 - Reduction in acceleration (%).

(X) Nos of support	**(Y) Gap between support (mm)**	**(Z) Size of support (m^2)**	**(T) Thickness of rubber support**	**Reduction in acceleration (%)**
6	50	0.1	10mm	0
			20mm	10.12
			30mm	24.40
			40mm	27.01
			50mm	36.21
6	50	0.15	10mm	19.05
			20mm	33.93
			30mm	38.39
			40mm	43.45
			50mm	45.24
6	100	0.1	10mm	25
			20mm	25.60
			30mm	33.63
			40mm	39.29
			50mm	41.67
6	100	0.15	10mm	13.22
			20mm	22.41
			30mm	20.83
			40mm	32.14
			50mm	46.73
8	50	0.1	10mm	18.39
			20mm	23.56
			30mm	31.61
			40mm	35.63
			50mm	41.38
8	50	0.15	10mm	33.33
			20mm	39.29
			30mm	46.43
			40mm	44.05
			50mm	43.15
8	100	0.1	10mm	14.94
			20mm	16.67
			30mm	25.86
			40mm	20.12
			50mm	13.79
8	100	0.15	10mm	14.29
			20mm	0
			30mm	17.26
			40mm	26.79

Result shows the highest percentage of reduction in acceleration through factor-by-factor method is indicated by the floor system designed with 6 Nos of 0.15m² rubber supports with 50mm thickness arranged in 100mm gaps with 46.7% of reduction, which is observed to be quite significant.

The results on reduction in acceleration collected are then sorted according to their range of reduction in percentage (0-10%, 10-20%, 20-30%, 30-40% and 40-50%). Table 5 shows the floor samples design with most optimum range of percentage with 40-50% reduction according to the impact reduction factors treated.

Relating to the preliminary test on the dynamic characterization of the rubber supports for different sizes, the floor samples design with most optimum range of percentage of impact reduction (as observed in Table 5) shows 6 out of 8 samples are using a bigger sized rubber support (0.15m²). This deduces that the bigger sized rubber support (0.15m²), although less elastic than the smaller sized (0.1m²), it has however a higher energy-absorbing capacity which enables the bigger rubber support to reduce more impact compared to the smaller size.

Table 5 - Optimum range of Reduction in Acceleration (40-50%) floor system design.

Optimum Range of Reduction (%)	Floor System Design				Acceleration Reduction (%)
40-50%	8Nos	0.1m²	50mm gap	50mm thick	41.38
	8Nos	0.15m²	50mm gap	50mm thick	43.15
	8Nos	0.15m²	50mm gap	40mm thick	44.05
	8Nos	0.15m²	50mm gap	30mm thick	46.43
	6Nos	0.1m²	100mm gap	50mm thick	41.67
	6Nos	0.15m²	100mm gap	50mm thick	46.73
	6Nos	0.15m²	50mm gap	50mm thick	45.24
	6Nos	0.15m²	50mm gap	40mm thick	43.45

From the list of optimum range of impact reduction based on the floor system design with details on the factors treated, Table 5 shortlisted the ones most significance to provide a list of solutions for people who requires certain alternate factors to either be smaller or lower number of supports possibly due to personal constraints and still be able to provide optimum impact reduction at 40-50% of reduction range.

A statistical Factorial design analysis conducted using Minitab - Design of Experiment (DoE) software is used to produce a full factorial method analysis of all the results collected from the drop test. Through the full factorial regression, interaction plot showing the connection between the four impact reduction factors (X, Y, Z, and T) is generated. From Fig. 7 below, the factorial regression model has asserted that the significant interaction between the factors are (i) XY-Gaps with Numbers, (ii), XT-Thickness with Numbers, and (iii) YZ-Size with Gap.

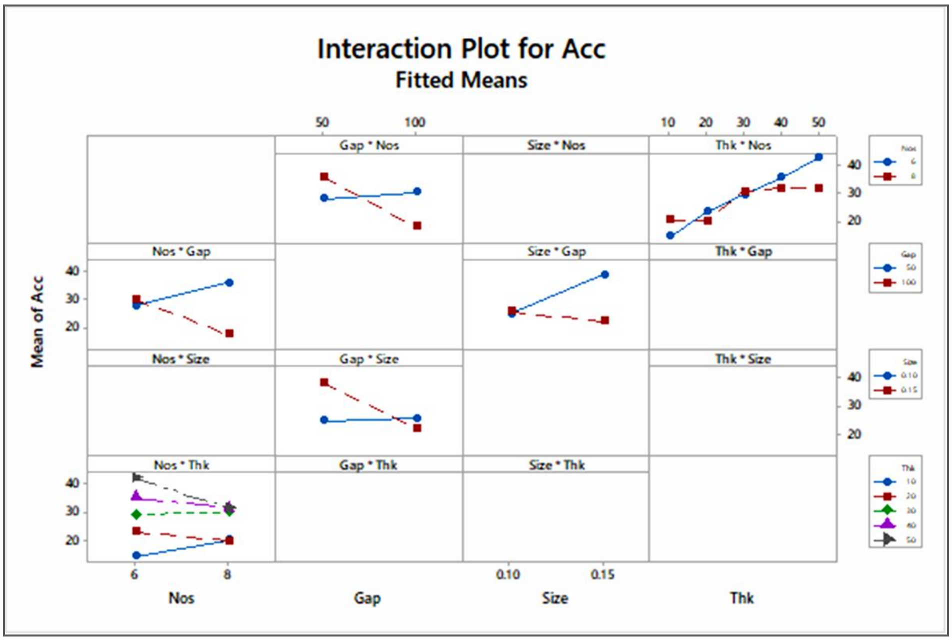


Fig. 7 - Interaction Plot between the 4 Impact Reduction Factors.

Further analysis using multi-level factorial method, analysing on the interactions between the factors and the contribution of every factor towards the total impact reduction, has produced the Response Optimization plot. The result in Fig. 8 shows that the Y factor (Gap) is the highest contributing factor towards the overall percentage of impact reduction, followed by Z factor (Size) and T factor (Thickness). X factor (Nos) is found to be a minimal contributing factor.

From the Response Optimization Plot, inculcating on the interactions between the factors and the effects of every factor, a more comprehensive method compared to factor-by-factor method, the final deduction of the study is the floor system designed with 8 Nos of 0.15m² rubber supports with 50mm thickness arranged in 50mm gaps provides the most optimum impact reduction which can reach up to 49.5% of impact reduction.

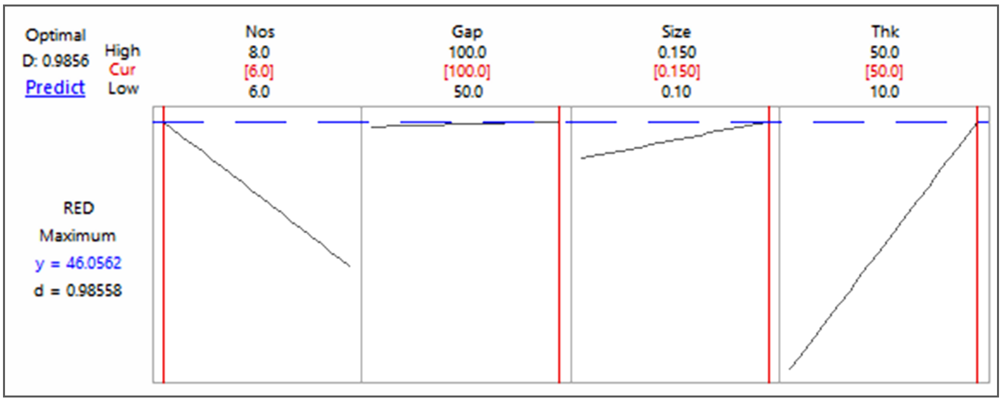


Fig. 8 - Response optimization.

Deducing from the overall results of preliminary tests, the main tests results and the analysis done both visually and through model regression, the final outcome of this study is summed up with the formulation of a reduced model of Impact Reduction Equation, believed to be significant for future research or other applications regarding impact reduction calculation. The equation is asserted as equation (2):

$$\text{Impact Reduction Equation (in coded units)} = -80.0 + 38.31(X) + 48.32\,(Y) + 31.06\,(Z) + 10.29(T) - 20.16(XY) - 3.42(XT) \quad (2)$$

In applying the Impact Reduction Equation above, it is important to use the values for the Impact Reduction Factors in coded units. Coded units in DoE applied is using 1- for low value and 2-for high value, i.e. 50mm Gap is 0 while 100mm gap is 1. This Impact Reduction Equation is possible to be further explored in future researches by applying other impact-reduction factors or for other application in impact assessments to further validate on the efficiency of the formulated equation.

4. Conclusion

From the results obtained and analysis done, the following conclusions can be drawn:

- Elasticity properties of the bigger size ($0.15m^2$) of rubber support, even though has lower deflection value, yet, the quicker time rate for it to deflect enables the rubber support to reduce more impact, compared to the higher deflection yet slower action to deflect for the $0.1m^2$ size.
- The significant interaction between the factors are (i) XY-Gaps with Numbers, (ii), XT-Thickness with Numbers, and (iii) YZ-Size with Gap.

- Floor system designed with 6 Nos of 0.15m2 rubber supports with 50mm thickness arranged in 100mm gaps provides optimum impact reduction with 46.7% of reduction when analysed through factor-by-factor method, but through a full (multi-level) factorial method, the optimum floor design with 8 Nos of 0.15m2 rubber supports with 50mm thickness arranged in 50mm gaps provides optimum impact reduction which can reach up to 49.5% of impact reduction.
- The highest contributing factor towards the overall percentage of impact reduction is Y factor (Gap), followed by Z factor (Size), T factor (Thickness) and then X factor (Nos) which is found to be a minimal contributing factor.
- The formulation of a reduced model of Impact Reduction Equation can be formulated in coded units as in equation (2).
- The elastic floor system design is considerably a significant solution for impact reduction in lower limbs for Karate and Taekwondo practitioners by almost 50% of reduction

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