Title: A Study on the Design of Knee kicker Bumper for Reducing Knee Morbidity among Carpet Layers

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Keywords: Knee-kicker; Impact testing platform; Bumper

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Abstract: Serious knee injuries frequently result when carpet layers use a knee-kicker to install a carpet. The aim of this study is to improve the design of the knee-kicker bumper by reducing the risk factors. Because the bumper isn't a standardized test piece and thus unsuitable for the ready-made stand testing platform, an improved pendulum-type impact testing platform was designed as an evaluative apparatus. The objects was tested at four levels of impact energy, with the impetus, impulse, and coefficiency of restitution serving as evaluation criteria. The newly developed bumper end up with improved firmness from drilled blind holes, an increase of effective forward force by 25%~135% implying less operational and lighter knee burden, and positive evaluation of the newly designed sample by the subjects. Moreover, by improving the shape of the contact surface, effective force will not be affected while the pressure can be distributed over a wider area.
Dear Sir,

We would like to thank Scientific Editor Patrick G. Dempsey, Ph.D. and two anonymous reviewers for their critical comments of earlier versions of this manuscript (Ms. Ref. No.: JERG-D-08-0022. A Study on Tool Improvement for Reducing Knee Morbidity among Carpet Layers). The comments such as the following:

“I believe that a thorough re-write will be required such that the revised manuscript would essentially constitute a substantially different contribution.”

“The study may be a good work. But, the report is very difficult to read as it is. It needs some serious editing for consistency.”

“The authors have identified an interesting research topic…… until they read the Results and Discussion section of the manuscript. The authors should rethink their organization of this manuscript.”

“I hope you find them constructive as you move forward with this work.”

The new re-write version of manuscript was completed. I confirm that the manuscript has not been published or under consideration for publication elsewhere. Further, this submission has been approved by the institution where the study was conducted. I look forward to learning your response to our submission.

Your sincerely,

Wan-Fu Huang

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Dear Editor,

Thank you for your useful comments and suggestions on structure of our manuscript. We have modified the manuscript accordingly, and detailed corrections are listed below point by point:

1) Abstract should be within 100-150 words. Your abstract (200 words) is more than 150 words.
   v The abstract has been revised and its word count is now 149.

2) Do not embed figure/table in the text; provide figure captions on a separate page, and present figure caption, figures and tables, in this order at the end of the article.
   v We have revised the whole captions on a separate.

The manuscript has been resubmitted to your journal. We look forward to your positive response.

Yours sincerely,

Chih-Fu Wu
Associate Professor
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A Study on the Design of Knee kicker Bumper for Reducing Knee Morbidity among Carpet Layers

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Abstract

Serious knee injuries frequently result when carpet layers use a knee-kicker to install a carpet. The aim of this study is to improve the design of the knee-kicker bumper by reducing the risk factors. Because the bumper isn’t a standardized test piece and thus unsuitable for the ready-made stand testing platform, an improved pendulum-type impact testing platform was designed as an evaluative apparatus. The
objects was tested at four levels of impact energy, with the impetus, impulse, and
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end up with improved firmness from drilled blind holes, an increase of effective
forward force by 25%~135% implying less operational and lighter knee burden, and
positive evaluation of the newly designed sample by the subjects. Moreover, by
improving the shape of the contact surface, effective force will not be affected while
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1. **Introduction**

The knee kicker has been not only used in professional carpet-laying for over 40
years, but also widely implemented in western countries for over 7 decades. A knee
kicker is made of cast aluminum and weighs about 2 kg. Every carpet layer owns one.
During a typical installation, the carpet layer first prepares the floor by nailing tack
strips along the perimeter of the room. After the padding material is installed, the
carpet is spread and cut to the size and shape of the room. The carpet layer then uses
the knee kicker to engage an edge of the carpet onto the tack strip. To stretch the
carpet, the knee kicker is pressed onto the carpet by one hand and its padded end
(bumper) is kicked with the suprapatellar area, as shown in Fig. 1. As operators
proceed, kick by kick, they hold the secured carpet onto the strip so that it will not unhook.

When carpet layers kneel down to perform their jobs, their work may involve multiple sources of acute and chronic knee trauma from kneeling, pressure from sharp objects, and the use of the knee kicker to stretch wall-to-wall carpet. In the following, a review of related literature will be given.

According to a biomechanical study, the maximum impact of such kicks exceeds 3,000 Newton—about three to five times the body weight (Garstein, 1979; Duffin, 1962). Workers spend approximately 75% of their time in the kneeling position using knee kickers to stretch and install carpets. During a typical installation, these strong knee kicks are repeated 120 to 140 times per hour (Bhattacharya et al., 1985).

Both kneeling and the use of the knee kicker are significantly related to its operator’s knee morbidity. Long hours of kneeling down on the hard ground and knee-knocking are more likely to expose carpet layers to knee ailments and work injuries than any other laborer by 108 times (Tanaka et al., 1982), and floor layers or tile setters, who also work in the same kneeling position, by twice (Green et al., 1985). Carpet layers frequently report bursitis of the knee, fluid buildup that requires knee aspiration (knee taps), skin infections of the knee, and a variety of knee symptoms
Workers who kneel down to perform their jobs may inflict chronic trauma on their knee joints. Disorders such as the “housemaid’s knee” of women who kneel to scrub floors and “beat knee” of British low seam coal miners are well recognized (Hunter, 1978).

Carpet layers should always wear protective knee pads while working directly on the hard floor. Such pads provide comfort and protection to the knee by distributing the weight of the body over a wider area. They also reduce the chance of suffering wounds and potential infection that can result from kneeling on sharp objects. Although kneeling cannot be eliminated, carpet layers should wear protective knee pads whenever kneeling on hard surfaces (NIOSH, 1990).

In the mid-1980s, another type of tool, the Power Stretcher, was introduced as the “savior of all carpet layers’ knees.” A lever toggle mechanism that requires the pushing of the arm and the body replaces the knee kicker. However, as it is limited by usage conditions and is too pricy, heavy, inconvenient to carry around, and unsuitable to all working environments, it has not been as popular as expected (Tannaka et al., 1989).

To alleviate carpeting-related occupational injuries, tool improvement is a recommended option in addition to changing work approaches and using appropriate protective devices. Although the traditional knee kicker is not a well-designed tool, it
is easy to carry around, easy to use, applicable in many kinds of construction sites, and economically affordable. As a result, even now carpet layers are still used to doing carpet laying with knee kickers. Thus, it is imperative to improve knee kickers, in particular the foamed natural-rubber bumper, which calls for further improvement to avoid injuries, in particular the harm to knees done by the rear part of a knee kicker in direct contact with the knee. For this reason, how to improve knee kicker bumpers is set as the target of this study.

From the mechanical point of view, the action of kicking during the use of knee kickers can be represented by a formula of impulse and momentum. The shorter the time of contact, the larger the impact power and the greater the forward transmitted effective impetus that causes carpet tension. Therefore, the effective forward force (impetus) is adopted as the first criterion for this study. Counterforce is produced in opposition to force. Bumpers not only pass force but also absorb partial energy and return it to the knee. The returned energy affects the safety of the knee. Therefore, counter-elasticity of fixed elasticity is set as the second criterion. In this connection, the testing platforms for other professional products similar to bumpers (such as shoe pads, packing equipment, protectors, etc.) available in the market can be used to measure the second criterion, but the measuring equipment that can meet both the first and the second criteria is very rare, considering especially the fact that the thickness
of the target is as much as 70 mm, which is in far excess of the specification of standard sample pieces (<25 mm) and thus unsuitable for the ready-made standard testing platform. Under the circumstance that the current testing platform cannot be used to verify if there is any improvement, it becomes necessary to design a proper one for this study.

The influential factors of bumper materials are material type, foam density, density distribution, and structure (Alp, 1995; Cavanagh, 1981; Rogers, 2003; Soper, 1962; Yang et al., 2000). This study plans to alter the buffering effect by changing the density distribution from original uniform distribution to non-linear distribution, subsequently, the overall thickness. It means that the contact surface between the bumper and the knee is to be made softer (i.e., of less thickness) than it currently is. Therefore, there are three hypotheses for this study. The first one is: The ideal knee kicker bumper can transmit the most forward force but return the least kicking impact energy. The second one is: If the newly designed bumpers cannot reduce the effective force transmitted forward, the harm done to knees from the softer contact surface will be less severe. The third one is: While kicking, use knee pads or change the bumper contact surface by bringing the geometric configuration of the impact surface close to that of the receptive surface, the pressure distributed should be reduced, and so will the harm done to knees.
In contrast to the study on the best predictive indicator in the subjective evaluation of the comfort for three-hand tools by Kuijt-Evers et al. (2007), knee kickers should be similar to “offering a high task performance” (Mirka et al., 2009). In terms of knee kickers, the goal of this study is to obtain the same effect with less kicking force, so that the degree of job completion can be increased. This is also an item to be evaluated when users perform their subjective evaluation.

2. General Method

2.1. Introduction to knee kicker bumper

The cross-section measure of a current typical bumper is 120 mm*120 mm. There are two different thicknesses, 40 mm and 70 mm. The existing bumpers and the knee kickers are linked up and have to be covered by a piece of skin, which is available in only two fixed sizes. Because of the material foaming, the part in direct contact with knees is raised like a hemisphere with a radius of 500 mm, as shown in the circle in Fig. 1. Foamed natural-rubber knee kicker bumpers possess the viscoelastic property of macromolecule materials. Their buffering effect is related to their materials, hardness, thickness, and structure designs (Soper & Doven, 1962). The hardness of the current bumpers is controlled by the foam density. There are two corresponding levels of surface hardness for current bumpers, Shore A25 and Shore A40. All testing samples of the bumper in this study were provided by their manufacturer (Allied
2.2. Introduction to the self-developed platform

The actual test of this type of buffer material is usually performed with one of the two different methods adopted in the industry: free-falling and pendulum hammer hitting. The resilience feature can be defined by the rebound height and the rebound angle. The change of physics quantities can be measured by pointer scales, high-speed cameras, acceleration sensors, etc. Besides, this feature can also be defined by the change in energy. Presently, there are several ways to measure the resilience, but there is no absolutely standard measurement.

The pendulum hammer style is the closest to the operation form of knee kickers. Thus a pendulum testing system, which is easy to use, workable, and applicable for simulating the kicking action by knees, is developed to measure the impact bumper. It can not only be used to measure the two criteria previously mentioned, but also change the impact energy, the impact contact’s surface configuration, and the point of impact according to different needs to measure other types of buffer materials.

This study plans to adopt the direct impact method in dynamics. Energy change is measured by the maximum rebound angle, and the speed is calculated to obtain the coefficient of the restitution of the buffer materials as a basis for comparing the evaluation. Accordingly, COF (symbolized by e) = - speed of the pendulum hammer
2.2.1. Apparatus

Based on the improvement on the impact experiment equipment frequently seen in material labs as well as on the Lupke testing pendulum of the ISO TC/45 standard often applied in labs in Europe, the hardware for the testing system included four major parts: the support base, the sliding platform, the side frames, and the pendulum hammer. The support base and the A-shape side truss frames located on both sides of the body were welded with thick L-shape steel. A bearing set connecting the base was placed above the side frames. The pendulum hammer set included five main components: an impact pendulum hammer, a pendulum rod, a rotation axis, an angle fixing ring, and an angle dial. The distance between the center of the impact pendulum hammer and the center of the rotation axis was 1 meter. The total weight of the pendulum hammer set was around 10 kg. The turning inertia was $I_{ae}=3.55 \text{ kg-m}^2$. When the pendulum rod was lifted to the horizontal position (90 degrees) from the neutral position, the potential energy equaled 45.42 joules of impact energy. The sliding platform was connected to the base with a ball bearing track.

For this study, a measurement device was developed using the Load Cell as the
force sensor and the variable resistor as one of the angle-change sensors for the data miner. On the other side of the platform, there was a CNC-processed angle dial (with division of 5° and subdivisions of 1°) to make visual judgment easier. The pendulum rod was lifted to a certain angle before it was let go for free fall. The gravity potential was converted to rotating kinetic energy, and the impact pendulum hit the bumper and transmitted the force forward. The bumper absorbed part of the energy and generated a rebound energy that raised the pendulum rod. From the maximum rebound angle of the pendulum, the difference between the energies before and after the collision could be determined. Illustration of the testing device is shown in Fig. 2.

2.2.2. Data collections and processing

To measure the forward transmitted force, the Load Cell (NTS Technology Co., Ltd. NTA-5KA) capable of sustaining 5,000 N was employed to read the small voltage changes stemming from the deformation caused by the stress the front end sustained. The signal was amplified through the amplifier circuit and then transmitted to the computer via the A/D C (Analog to digital converter Advntech USB-4711 Portable Data Acquisition Module) data miner. The software WaveScan that came with the A/D C data miner could be used to monitor the change in voltage signals and convert it to floating-point arithmetic data. Whenever necessary, other software programs could be employed for data analysis. The signal process is shown in Fig.3.
For angle measurement, the linear variable resistor was employed as the angle sensor. One end of the variable resistor was fixed on the test device. Its rotation/twist bearing was fastened to the pendulum bearing of the pendulum impacting tester for synchronous rotation. The resistance of the pendulum rod was changed with the swinging of the pendulum rod. When a fixed voltage was provided, the voltage varying with angle changes could be measured and the corresponding angle at which the pendulum rod swings could be determined. In practice, after using the angle dial and the fixing ring to lift the pendulum rod to a certain angle, the component voltage was measured and recorded with GW GDM-8145 digital multimeter for every 10 degrees the pendulum rod was lifted. Because the voltage change was not significant when the rod angle was less than 20 degrees, these data were excluded from regression. The relationship between the rod angle and the resistance component voltage obtained from regression was:

\[ Y = 62.298X + 21.672 \quad R^2 = 0.994 \]

[ X: Voltage (V) \quad Y: Rod Angle (degree) ]

2.3. Calibration

In order to measure the magnitude of the forward transmitted force of the knee kicker after it sustained a kick, the load cell was connected to the signal-magnification circuit for calibration. For Load Cell and magnifier circuit calibration, a Tinus Olsen all-purpose material tester and a GW GDM-8145 digital multimeter were used.
Through primary regression analysis using Microsoft Excel, it was confirmed that when the Load Cell was under a pressure load the relationship between the voltage and the active force continued to be linear after both were magnified through the magnifier circuit as shown below:

\[
Y = 61.157X - 0.0542 \quad R^2 = 0.9998
\]  \[X: \text{Voltage (V)} \quad Y: \text{Force (Kg)} \] \[2\]

The following mechanical formulas were used for computation: the relationship of the pendulum rod angle and energy, the highest velocity at which the pendulum could reach a relationship between the pendulum rod angle and the voltage of the variable resistor measured at the angle.

\[
Y = -0.00003X^3 + 0.0084X^2 - 0.0294X + 0.136 \quad R^2 = 1
\]  \[X: \text{Rod Angle (degree)} \quad Y: \text{Energy (J)} \] \[3\]

\[
Y = -0.00003X^2 + 0.0201X - 0.0088 \quad R^2 = 1
\]  \[X: \text{Maximum Instantaneous Pendulum Velocity} \quad X: \text{Pendulum Lift Angle} \] \[4\]

2.4. Preliminary study

The purpose of the pretest was to obtain the optimized experiment conditions of this testing system as a reference for formal experiments, including issues like the appropriate sampling frequency, the best impact angle to simulate a kick, and the confirmation of evaluation criteria. In the literature review, the largest kicking force of carpet layers on knee kickers was 3000 N (306 kgf) (Bhattacharya et al., 1985), which was one of the important reference indicators. In the preliminary test, a typical
bumper was used as a testing sample. The sample thickness was 40 mm; surface hardness was Shore A40. There were 13 levels for impact energy (2.24 J~45.42 J, corresponding to 13 different angles, from 20°~90°. Under 40°, a level every 10 degrees; Over 40°, every 5 degrees). By substituting the maximum Load Cell voltage value into formula [2], a preliminary comparison was performed. The voltage-time graph generated was similar to that from other shoe pad buffer researches. And the largest rebound angle could be measured accurately. The flowchart is shown in Fig. 4.

After a week, another test was performed under the same condition. The data collected from this test was compared with those obtained from the test done in the previous week. The difference was under 2%, meaning that the system is stable. This testing platform was proved to be workable.

More sample tests might lead to a better understanding of characteristic in this testing platform and the knee kicker bumper. The manufacturer also provided three other samples. There were four test samples in total (There were two levels each for thickness and surface hardness), including the original one. To reduce the number of tests, the number of levels for impact energy was reduced to 4 (11.35 J, 13.3 J, 22.7 J, and 33.67 J, which were correspondent to 37°, 45°, 60°, and 75°, respectively). During the preliminary test, it was found that if the impact angle was over 80° the testing hardware would shake. But if the platform was nailed to the ground near the
pillar, the shaking problem could be resolved. Therefore, the upper limit was set at 75°. When the angle was under 30°, the voltage-time graphic performance was not significant. The impact energy of 37° was half that of 60°.

The voltage-time relationship curve obtained in the pretest revealed: (1) The collision action time was very short (7.5–16 ms), and the sampling frequency needed to be over 2,000 Hz. The sampling frequency of this study was 5,000 Hz. That the voltage-time relationship chart displayed significant characteristics made reading simple. (2) The thinner and the harder the test piece (in terms of firmness), the shorter the action time of the forward-transmitted force, the quicker it reached the extreme, and the greater the maximum impact obtained. (3) The maximum impact of the effectively transmitted force measured at this moment was 280 kgf (2744 N), which was already very close to the indicator value. The effectively transmitted force of 370 kgf (3626 N) obtained from the 65° impact experiment was not adequate. It was learned that 60° (22.7 J) was a better pendulum impact angle for the test. (4) This system could measure two criteria at the same time. The typical curve for the voltage-time (force-time) relationship is shown in Fig. 5.

3. Tool Improvement and Experimental Variable Design

3.1. Bumper improvement

The literature review reveals that the buffering effect of the bumper is significantly
correlated with its firmnesses (Rogers, 2003). There are several ways to measure material stiffness, including the stress-strain ($\sigma$-$\varepsilon$) of pressure and notch hardness comparison. It is generally believed that the rebound is in direct proportion to the firmnesses and transmitted impact but in inverse proportion to the buffering time.

Because the manufacturer has no plans to change the materials, foaming density (hardness control), and the thickness of the bumper, therefore, this study begins with the structure design factor, using the method of adjusting density distribution to improve the buffering effect. The side of the bumper in direct contact with knees is softer while the other side is harder.

Originally, we planned to slice up bumpers of different hardness (firmness) and combine them to change the overall hardness. Yet in consideration of the time constraint, soft material cutting technology, and the possibility of mass production in the future, we employed the perforation approach to attain the same result. As shown in Fig. 6, the blind borehole method is adopted for adjustment. Factors such as the borehole diameter, depth, number of boreholes, and density distribution could control the overall hardness of bumpers. The manufacturer provided nine samples with different borehole handlings. Since the manufacturer was unable to provide detailed information of the test samples, we had to conduct the tests with Red Star Instrument’s HT-2402 computer-server-controlled material tester and make a
comparison for design improvement. The tests were carried out on these nine newly
designed bumpers at only one impact energy level (22.7 J). Evaluated by the two
criteria, the bumper with the best performance was chosen for the extensive test in the
next phase.

3.2. The influences of the contact surface geometric configuration

It can be observed from the live video of carpet layers working at construction sites
that the geometric shape of their knee areas can differ from a sphere to a plane,
depending on whether they wear professional protective gear, kick directly with their
knees, and work in staircases. The surface of bumpers is made into a bulged sphere
because of the foaming process. Would it be better if the diameter of the sphere is
increased so that the sphere will approximate to a plane, or if the radian of the
professional protective gear is increased?

For the experiment discussed in this section, a specially made pendulum hammer
was employed, based on the size of the knee area according to the ergonomic
measurement data (Tilley, 1993). One end of the pendulum hammer was a 60mm-R
sphere whiles the other a 60mm-R cylinder. Despite the change made, both the
original leveled pendulum hammer and the newly devised one should have the same
mass and rotation inertia; in addition, for both the distance between the collision
contact surface and the neutral position should be the same. The raw material was
profiled after the required configuration and perforated for material reduction and weight adjustment. Based on the precision calculation by Dassault Systems SolidWorks 2003, the newly devised device had the same weight and rotation inertia moment as those of the leveled pendulum hammer. Its appearance is shown in Fig. 7.

Fuji prescale pressure measuring film LLW two-sheet type was employed both to explore the pressure distribution of the 3 hammers of different geometric configurations when they hit the bumper and to optimize the geometric configuration of the bumper contact surface and the hammer. When the impact energy is the same, from the pressure formula \( P = \frac{F}{A} \), one can learn that the larger the contact area is, the smaller the average pressure will be. As the pressure can be dispersed, for those using the knee kicker bumper, their chance of knee injuries is reduced.

3.3. The Independent variables and dependent variables in the experiment

The experiment includes two major parts: (1) Comparison of the 5 Typical Test Pieces through ANOVA; (2) Testing and study of the influence of the geometric configuration of the pendulum contact surface on the valid thrust. The independent variables and dependent variables are listed in the table 1 as below:

4. Experiment results and discussion

4.1. Part 1 - Comparison of the 5 typical test pieces & ANOVA

This section consisted of 4 typical existing bumpers (2 thick and 2 thin ones, 2
kinds of hardness—Shore A25/A40) with a newly designed bumper test piece for characteristic comparison, using the statistical method of ANOVA. Four different impact energies were applied. Comparative analysis was conducted in terms of the maximum impact, impulse, and resilience restitution coefficient. The initial numeral of material property of test bumper (see Table 1) represents test piece thickness; the second character indicates test piece hardness: H stands for 40_ShoreA; S stands for 25_ShoreA. For instance, 70H represents test piece thickness 70 mm_40_ShoreA and surface notch. The hardness of the surface notch of the newly designed bumper was not significant as a result of the perforation. The last numeral (see Fig. 8) indicates the number of drilled holes. Experiment outcomes are listed in Tables 2, 3 and Fig. 8.

A review of the P-Value of ANOVA tables (with the level of significance set at a p-value of 0.05) indicates that collision energy significantly affects the three performance indexes: Material property exerts a significant influence on the maximum impact but not on the other two performance indexes, possibly because of the fact that there are only two kinds of material thickness and that the bumper is made of natural rubber via the foamed-profiling process, which causes its internal density distribution to be non-uniform.

4.2. Part 2- Testing and study of the influence of the geometric configuration of the pendulum contact surface on the valid thrust

One set of the pressure films was cut to the size slightly larger than the hammer contact surface and pasted to the impact sustaining face of the bumper with permeable
tapes. The same energy was used to exert one impact; the distribution as well as the level of the pink color block displayed on the pressure film was examined after the bumper sustained the collision. Its appearance is shown in Fig. 9. The voltage-time relationship curve is shown in Fig. 10.

When observing the color distribution and level of the 3 pink pressure films at the bottom, the pressure distribution of the leveled hammer was found to be more uniform. The pressure at the center of the cylindrical hammer was greater and was gradually reduced toward the left and right sides. The pressure at the center the spherical hammer was the greatest in case the pressure film was not taken into consideration; other portions were like concentric spheres in that the further away the measure was from the center, the smaller it was.

The more the geometric configurations of the impacting (hammer) and impacted (bumper) surfaces were closer to each other, the more the pressure was uniformly distributed under the same impact. Thus it can be reasonably argued that if the slightly protruding big arch contact surface of the bumper is changed to an indented surface corresponding to the configuration of the knee area, the impact pressure distribution will be more uniform. However, in view of the fact that the geometric configuration and the size of the knee differ from person to person and there are technical issues in foam production of the bumper, it is recommended that the slightly protruding
small-radius spherical surface of current bumpers be changed into a slightly
protruding large-radius spherical surface or even into a leveled surface. Besides, the
level-surface knee pad can be used. Ideally, the bumper contact surface should be
indentated.

4.3. Subjective assessments

Because of the climate, wall-to-wall carpets are not popular in Taiwan. Carpet
layers belong to the minority of the craftsmen. Therefore, the five testing samples in
part 1 of the experiment were sent back to the original manufacturer in the United
States by Allied Arrows Associates Co., Ltd. for testing. Because the bumpers were all
covered with the skin, subjects cannot tell the difference among the bumpers. The
only way to evaluate their properties is by the actual feeling from kicking. The
company appointed seven carpet layers to take part in the experiments and complete
the questionnaires. They ranked the five samples from 1 (like very much) to 5 (dislike
very much) according to their personal preference. The newly designed bumper got
five 1’s and two 2’s. The overall evaluation was positive.

5. Concluding remarks

First, the blind boreholes of the new bumper reduce the firmnesses of the contact
surface and cause a nonlinear distribution of the hardness in order to alleviate
knee-injury factors. Under the condition that the thickness remains the same, the
experiment confirms that in terms of the maximum impact force of the newly
designed bumper outperforms the four existing types (25%~135%). But no significant
difference between the old and the new is noted in terms of impulse and resilience
restitution coefficients. In other words, less kicking energy can be used to attain the
same work efficiency. This way the damage to the knee is alleviated. Samples of the
improved product are tested by the US manufacturer, and the outcome from users’
subjective evaluation is promising. In addition, the newly designed platform proves to
be workable. These findings lead us to believe that if modify this testing platform
partially, this testing platform can be applied to the appraisal of the buffering
characteristics of hand tools, packaging equipment, cushions, shoe pads, handles, etc.
as well as new product design and development.

Second, it is recommended that for the new design the curvature of the contact
surface (to the degree that it becomes leveled or indented) of the bumper be reduced.
The difference among three voltage-time relation curves of 22.7 J collision energy is
not significant in Fig. 10; namely, the difference between the impulse and maximum
impacts is not significant. Yet observation the outcome from pressure film testing
indicates that the pressure distribution is more uniform. For the knee, the reduced
peak force is better.

Third, further studies on the subject of the knee kicker bumper may include: (a) If
the manufacturer can provide more choices of bumpers with different materials and foam densities, it is possible that an even better combination can be found, especially in the aspect of the counter-elasticity property. (b) Drilling the blind holes is one of the methods that changes whole strength (firmness), but belongs to a process of try and error, finite element analysis will probably produce a better solution. Shorten (1993) believes that the influences of these parameters should be discussed from the energy point of view and simulated with CAE, the viscoelastic model should be developed, and the energy feedback phenomenon should be analyzed with methods from numerical analysis. (c) To reduce knee morbidity among carpet layers, the same problem could be attacked from a very different angle, for example, by means of engineering approaches, tools, and continuously improved protection equipment.

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knee kicker bumper as a result of this study.

References


Rogers Corporation High Performance Foams Division. 2003 . Shock Control Design Guide. CT USA.


ADVANTECH eAutomation, Taiwn.


Fig. 1. Application of knee kicker & knee kicker bumper.

Fig. 2. Pendulum impact testing platform.

Fig. 3. Electronic signal process on pendulum impact testing platform.

Fig. 4. Test process of knee kicker bumper.

Fig. 5. Forward transmitted criteria, voltage-timing chart.

Fig. 6. Improvements made on newly designed bumpers.

Fig. 7. Three types of pendulum hammers (leveled, spherical, and cylindrical surfaces).

Fig. 8. Comparison of 5 Typical Test Pieces (△:Newly Designed Bumper).

Fig. 9. Color Distribution on the Pressure Film as a Result of the Impact of the 3 Hammers with Different Configurations (From Left to Right: Leveled, Spherical, and Cylindrical Hammers).

Fig. 10. Voltage-time chart of 3 different punches sustaining impact of pendulum rod lifted to 60°, 70 mm bumper.
A. Pendulum angle positioning / Pendulum rod relief

B. Hit bumper

C. Rebound

Load Cell  Bumper  Support Base  Sliding Platform  Pendulum Rod  Angle Sensor(1)  Angle Sensor(2)  Pendulum Hammer
Test piece mounting & warm up → Setting pendulum angle → The test begun after 6 trial impacts → Collecting conversion & test dates → Data analysis
Figure

Voltage (V)

Force (N)

Time unit: 0.5 ms

Peak value (Maximum impact force)

Area (Impulse)

Action time
Figure

(A) Prototype

(B) Firmness adjusted by laminated method

(C) Firmness adjusted by blind borehole method
60 Degrees Impact on 70mm No.3 Test Piece (3 Types of Punches)

- Levelled Surface
- Cylindrical Surface
- Spherical Surface

Figure
<table>
<thead>
<tr>
<th>Experiments#</th>
<th>Independent variables</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part 1</strong></td>
<td>IMPACT ENERGY</td>
<td>Voltage-time relationship curve</td>
</tr>
<tr>
<td></td>
<td>(four levels)</td>
<td>➔ Maximum forward transmitted force (Impact)</td>
</tr>
<tr>
<td></td>
<td>22.7 J, 13.3 J, 11.35 J, and 7.2 J</td>
<td>➔ Area (Impulse)</td>
</tr>
<tr>
<td></td>
<td>BUMPER</td>
<td>Maximum rebound angle of pendulum</td>
</tr>
<tr>
<td></td>
<td>(five levels)</td>
<td>➔ Resilience</td>
</tr>
<tr>
<td></td>
<td>40mm 25 Shore-A</td>
<td>➔ Resilience Restitution Coefficient</td>
</tr>
<tr>
<td></td>
<td>70mm 25 Shore-A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40mm 40 Shore-A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70mm 40 Shore-A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70mm New_Design</td>
<td></td>
</tr>
<tr>
<td><strong>Part 2</strong></td>
<td>IMPACT ENERGY</td>
<td>Voltage-time relationship curve</td>
</tr>
<tr>
<td></td>
<td>(two levels)</td>
<td>➔ Maximum forward transmitted force</td>
</tr>
<tr>
<td></td>
<td>22.7 J, and 11.35 J</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PENDULUM CONTACT FURFACE (three levels)</td>
<td>Pink color block displayed by the pressure film</td>
</tr>
<tr>
<td></td>
<td>Leveled</td>
<td>➔ Pressure distribution</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cylindrical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BUMPER (one level)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75mm 25 Shore-A</td>
<td></td>
</tr>
</tbody>
</table>
Table 2
Maximum Impact Force, Impulse, and Resilience Restitution Coefficients (R.R.C) of 5 Bumper Types

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Max. Impact Force (N)</td>
<td>Impulse (N-sec)</td>
</tr>
<tr>
<td>70H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another Style(I) Another Style(II)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>60° 45° 37° 30°</td>
<td>60° 45° 37° 30°</td>
</tr>
<tr>
<td>70H</td>
<td>103% 113% 109% 115%</td>
<td>43% 78% 74% 77%</td>
</tr>
<tr>
<td>70S</td>
<td>100% 100% 100% 100%</td>
<td>42% 69% 68% 67%</td>
</tr>
<tr>
<td>40H</td>
<td>170% 135% 122% 100%</td>
<td>71% 71% 83% 67%</td>
</tr>
<tr>
<td>40S</td>
<td>186% 127% 128% 119%</td>
<td>78% 88% 87% 80%</td>
</tr>
<tr>
<td>New</td>
<td>238% 145% 147% 149%</td>
<td>100% 100% 100% 100%</td>
</tr>
</tbody>
</table>

%
Table 3
Two-Way ANOVA Repeated Test (Maximum Impact Force & Impulse)

<table>
<thead>
<tr>
<th>Material Property</th>
<th>DOF</th>
<th>Maximum Impact Force</th>
<th>Impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>P-Value</td>
</tr>
<tr>
<td>Impact Energy</td>
<td>1</td>
<td>81.96</td>
<td>*1.77E-05</td>
</tr>
<tr>
<td>Interaction</td>
<td>3</td>
<td>159.4</td>
<td>*1.79E-07</td>
</tr>
<tr>
<td>Within Unit</td>
<td>3</td>
<td>32.30</td>
<td>*8.06E-05</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>