THE ROLE OF MECHANICAL PROPERTIES
IN THE ERGONOMIC PERFORMANCE OF
COMMERCIAL MATS

Introduction

The report which follows describes the results of mechanical tests conducted on various commercially available mats. The approach to the development of the test program was based upon the assumption that the ergonomic performance of a mat can be reflected in part by the behavior of the material under various loading configurations. Specifically, the cushion and support of a mat could be related directly to the behavior of the mat under uniaxial compression, whereas the impact resilience and impact energy absorption could be measured from an anvil impact experiment. These properties, which are often qualitatively evaluated by users, are quantified from the results of these tests.

Procedure, Approach and Analysis

Six types of mat were tested: Statfree Type i, Ergomat, typical rubber mat, vinyl top sponge mat, sponge vinyl and domed mat. The data were analyzed as described in the following paragraphs. For the cushion and support testing, mat samples of 3" in diameter were tested in uniaxial compression using a MTS hydraulic loading frame with an axial load capacity of 250,000 N (N=newton, the metric unit of force). The samples were loaded to a force of 1000 N (220 pounds) in 20 seconds after which time the load was maintained for an additional 40 seconds. The force and displacement were monitored continuously and recorded using a 16-bit digital oscilloscope. The impact resilience was evaluated using an anvil impact device instrumented with optical switches to measure the impact velocity of an aluminum hammer just prior to and following impact of a 2.5" diameter mat sample.

Cushion

The compliance of each mat sample was measured as the ratio of the displacement to load as the peak load of 1000 N was attained (i.e. at 20 seconds). A more compliant, and hence more comfortable mat would displace more under a given load than a stiffer mat. To illustrate this point, consider that concrete displays no noticeable deflection when stepped on and is therefore considered stiff and relatively uncomfortable to walk upon. On the other hand, carpeting "deforms" readily when stepped on and is considered soft or compliant and is relatively more comfortable to walk upon. In a similar test, it is clear that the more "comfortable" carpet would experience a greater displacement for a given load than the concrete. The same is true of mats.

Support

The creep relaxation of each mat was evaluated from the time variation of the displacement once the constant load of 1000 N had been obtained. A parameter reflecting the relaxation of each mat is expressed as a percentage given by the following relation

$$\frac{d_f - \Delta d}{d_f} \tag{1}$$

where Δd is the increase in displacement to maintain the constant force of 1000 N and d_f is the displacement recorded just as a force of 1000 N was attained. This parameter measures the relative amount that the mat "sinks" once it has been loaded, and hence how much "support" the mat provides. A completely supportive mat (no further displacement once the load has been reached) would have a value of this parameter of 1 or 100%. In order to demonstrate the relevance of this parameter consider the familiar example of a mattress. A mattress is considered to provide support if an individual does not, in effect, "sink-in:" the analogous concept is applied to mats herein.

Impact Energy Reflected or Resilience

The resilience quantitatively measured the spring or buoyancy of the mat in response to a rapidly changing load. Mats with high resilience have significant bounce in response to impact. Both the resilience and absorption experiments were conducted with a pendulum impact device. Mat samples of 2.5" in diameter were mounted to a rigid backing plate and impacted with the face of a cylindrical aluminum hammer attached to the end of a 3' aluminum rod which rotated freely. The hammer head was 4" in length and had a diameter of 2.5", such that the mass of the hammer was -2 pounds. The velocity of the hammer was measured using a short flag attached to the hammer which passed between the emitter and detector of an optical switch. The optical switch was positioned such that the flag passed through the emitter-detector pair just prior to impact. After impact, the hammer rebounded off the mat and the flag again passed between the emitter-detector pair. By monitoring the voltage output from the detector, the total time that the flag covered the emitter (the interrupt time) could be measured directly. Therefore, the velocity of the hammer just before and after impact was calculated by dividing the known length of the flag (-0. 18") by the interrupt time. The resilience of the mats is defined as the ratio of anvil kinetic energy following impact to the anvil kinetic energy just prior to impact. The ratio is calculated from the ratio of the output velocity to the input velocity squared, i.e. $(v_{out}/v_{in})^2$. In all the experiments an impact velocity of 2.4 meters per second.

Impact Energy Absorbed

The energy absorbed by a mat during impact was measured using a technique similar to that used in the resilience experiment described above. However, in these experiments, the 2.5" diameter mat sample was mounted to a hammer identical to the impacting anvil. Again, both hammers were mounted at the end of a 3' aluminum rod and allowed to swing with a pendulum motion. The velocity of each anvil after impact pact was measured in a manner similar to that described above. The energy absorbed by the mat was taken as the loss in kinetic energy of the system, which assumes that the energy absorbed by the rest of the system is small in comparison to that absorbed by the mat. Specifically, the absorbed energy was calculated from the following relation from the impact velocity, v_{imp}, the velocity of the hammers following impact, v_{1out} and v_{2out} for the impacting and sample hammers, respectively:

$$E_a = 1 - \frac{v_{1out}^2 + v_{2out}^2}{v_{imp}^2} \qquad (2)$$

Taken together, the resilience and absorption quantify the total amount of energy stored and released by the mat during impact and represents the effectiveness of the mat in resisting impact loads and will be referred to as the effective dynamic response.

Results

The results from the evaluation of the cushion, support and impact resilience and absorption of the mats are presented as bar charts which are included on the following pages.

The cushion is shown as the compliance calculated as outlined above for the six mats. The most compliant mat, the Ergomat was assigned a value of 100% and the compliances for the other mats are reported as the relative percentages of that for Ergomat. Thus, for example, domed mat, is approximately 50% as compliant as Ergomat. The mats rank as follows: (1) Ergomat - 100%, *(2)* Statfree Type i - 87%, (3) sponge vinyl - 71%, (4) vinyl top sponge mat - 60%, (5) domed mat - 51%, (6) typical rubber mat 45%.

The support is shown in two successive bar charts in terms of the parameter defined by equation (1), above evaluated 40 seconds after the load of 1000 N was attained. The first is shown plotted against a scale from 0 to *120%* in order to include the poorest performing mat, the typical rubber mat which had a support value of 40%. All other mats scored above 80%, as shown on the scale of the second support bar chart which better illustrates the differences observed between the other five mats. The mats rank as follows in terms of support: (1) Statfree Type i - 97%, (2) Ergomat - 96%, (3) vinyl top sponge mat - 94%, (4) domed mat - 92%, (5) sponge vinyl - 8 1 %, and (6) typical rubber mat - 40%.

The resilience of the mats is shown in the next bar chart. Typically, the velocity of the hammer after impact (which was initially 2.4 meters per second) dropped to below 1.3 meters per second such that the kinetic energy returned to the hammer represented less than 25% of the impact energy. Several tests were run on each individual mat, and the data shown in the chart represents the resilience calculated using the maximum output velocity (vout) from the series of tests. The mats rank as follows: (1) Statfree Type i - 28.0%, (2) vinyl top sponge mat - 25.6%, (3) typical rubber mat - 20.3%, (4) Ergomat - 18.9%, (5) domed mat -2.3%, (6) sponge vinyl - 1.6%.

The energy absorbed by the mats is shown in the following bar chart. Several tests were run on each individual mat, and the data shown in the chart represents the values calculated from the average of all tests. The mats rank as follows: (1) Ergomat - 39.5%, (2) sponge vinyl - 28.7%, (3) domed mat - 27.7%, (4) Statfree Type i - 27.5%, (5) typical rubber mat -24.9%, (6) vinyl top sponge mat - 11. 1 %. It should be noted that the differences between the second and fourth ranked mats are less than 1.5% which is on the order of the error in these measurements. As a result, not much significance can be attributed to the differences observed in this test between the sponge vinyl, the domed mat and Statfree Type i.

The final bar chart sums the values for each mat from the resilience and absorption experiments and, as noted earlier this represents the effective resistance of the individual mats to impact, termed the effective dynamic response. The rankings of the six mats are as follows: (1) Ergomat - 58.4%, (2) Statfree Type i - 55.5%, (3) typical rubber mat - 45.1%, (4) vinyl top sponge mat - 36.7%, (5) sponge vinyl - 30.4%, (6) domed mat - 30.0%.

Summary

Uniaxial compression tests were conducted to evaluate the cushion and support provide by six different commercially available mats. The cushion and support were determined from the compliance and relaxation characteristics, respectively that each mat exhibited during testing. The resilience of the mat was calculated from the input and output velocities of an impacting hammer. In the cushion and support tests, Statfree Type i and Ergomat ranked first and second, with Statfree Type i first in support and Ergomat first in cushion. The typical rubber mat ranked last in these tests and, in terms of support, performed significantly below the other five mats.

The impact characteristics of the mat were evaluated using the changes in kinetic energy occurring during pendulum impact experiments. Both the energy absorbed and the energy returned to the hammer (the mat resilience or buoyancy) were measured. The sum of these two quantities represents the effectiveness of the mat against impact, or its dynamic response. Again Statfree Type i and Ergomat ranked significantly above the other 4 mats, whereas sponge vinyl and the domed mat demonstrated the worst impact characteristics.

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April, 1997