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Optimizing bouldering pad choices: Analysis from a specific case study

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1. Introduction

Bouldering is a climbing discipline where climbers ascend walls (up to 4.5 m high) without the use of rope or harnesses. The fall, whether intentional or not, is part of the practice and is protected with foam pads. Bouldering is the climbing discipline that causes the greatest number of injuries (*Kletterhallen-Unfallstatistik 2022*, n.d.). Furthermore, these injuries are often more severe than those sustained in other climbing disciplines, falls being the primary cause, with the lower limbs mostly affected (Müller et al., 2022).

To protect participants from falls, thick sport pads are used to cushion impacts due to their good energy absorption capacity. These pads, which must comply with the norm EN 12503-2, are usually made of one or more layers of polymeric foam, covered by a polyvinyl chloride (PVC) shell.

The mechanical properties of these pads can be determined through experimental testing, including impact tests. Currently, selecting the appropriate pad characteristics based on the type of impact remains a complex task. Indeed, knowledge on the influence of the pad cover material overall mechanical properties remains limited. This study presents a methodology to optimize pads selection for a real fall scenario by: (i) estimating the impact conditions through video analysis, (ii) characterizing the mechanical properties of various foam pads, with or without cover, and (iii) selecting the ideal pad configuration to minimize the injury risks in the identified realistic fall conditions.

2. Methods

2.1 Video analysis

A video capturing a voluntary fall of a woman (27 years old, 50 kg, shoe size 37) in an indoor bouldering gym was investigated. The impact speed was determined to be 4.9 m.s⁻¹ using Kinovea software.

2.2 Mechanical properties of pads at impact

Two types of polyurethane (PU) foam cubes (length of 0.15m) were tested: an open-cell foam and a closed-cell foam (densities of 28 kg/m³ and 24 kg/m³ respectively). Each foam included one sample covered with a smooth PVC fabric (density of 680 g/m²) and one uncovered sample. Prior to the tests, the 4 samples sustained three compressions at a constant strain rate of 6.67 s⁻¹ and up to an 80% strain level, aiming at reducing the stress softening effects due to the Mullins effect.

Impacts tests were conducted with a custom-built drop rig. The samples were placed on a flat surface and subjected to uniaxial pure compression impacts using a 0.18*0.18*0.025 m square plate weighing 7.5 kg. The system was equipped with a 70 kN load cell, recording data at 50 kHz. 10 drop heights ranging from 0.25 m to 2.5 m with 0.25 m increments were tested for a total of 40 impacts. The tests were filmed with a Phantom Miro C211 (1000 fps) that was used to obtain the impactor displacements.

The transmitted force and impactor displacement were converted to engineering stress (ratio of force to initial sample area) and strain (ratio of displacement to initial

sample height), respectively. The absorbed energy was calculated by integrating the stress as a function of strain.

2.3 Pad selection

The performance of pads is determined by its capability to reduce the force experienced by the human body under impact. Therefore, selecting a suitable material for pads to cushion a given impact involves knowing the energy the pads should absorb (W) and the related stress that will be transmitted (Maiti et al., 1984). This energy W was estimated using the following equation (Gibson & Ashby, 1997):

$$W = \frac{\frac{1}{2}mv^2}{At}$$

Where m represents the climber's mass, v the impact velocity, A the contact area between the climber and the pad, and t the thickness of the landing pad. The contact area A was approximated by a rectangle having an area equal to the area of the two feet (length: 0.231 m, width: 0.1 m) (Mills, 2007).

The stress transmitted by the pad can be determined by plotting the energy W on an energy absorption diagram from the impact test. The pad that transmits the lower stress for a given energy W is considered as the optimal solution.

3. Results and discussion

Figure 1 displays the energy absorption diagram for an impact speed of 4.89 m/s (to closely match the 4.69 m/s impact speed of video analysis). The energy absorption W per unit volume to be dissipated by the pad is $2.98 \times 10^4 \text{ J/m}^3$ (red dot-dashed line). The line intersects the sample curves at critical points, from which vertical lines (grey dot-dashed line) extend to indicate the stress transmitted to the climber when impacting the pad.

The open-cell foam with a cover demonstrated the optimal performance in our study, transmitting the lowest stress among the samples at $1.1 \times 10^5 \text{ Pa}$. Furthermore, samples with covers, including the closed-cell foam with a cover at $1.2 \times 10^5 \text{ Pa}$, exhibited lower resultant stresses compared to their uncovered counterparts. This highlighted the crucial role of the cover in enhancing the energy absorption capabilities of the foams.

The study has several limitations, including the approximation made in computing the energy to be absorbed

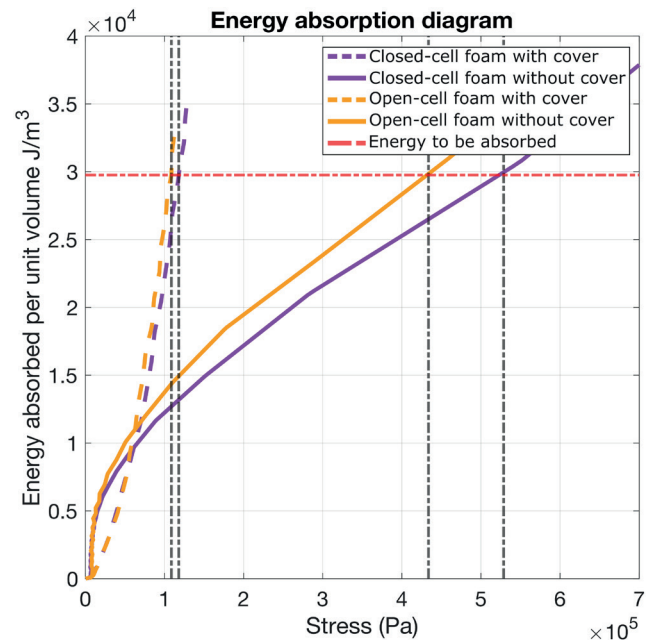


Figure 1. Energy absorbed as function of the stress
Horizontal line corresponds to the energy to be absorbed W .

by the pad, treating the contact area as rectangular, and assuming that the full pad thickness is compressed rather than the actual volume of the pad which would have been deformed under the impact. Dynamic finite element analysis (FEA) and full-size pad impact tests could further improve the estimation of the energy to be absorbed and the absorption brought by the pad. This will better reflect the real impacts of boulder climbing (Mills, 2007).

4. Conclusions

This study presented a methodology to identify the most suitable foam or pad for a specific impact scenario. The methodology was tested through a case study that involved the video analysis of a climber fall and impact testing on foam samples with and without a cover. The study highlighted the importance of the cover around the foam as enhancing the energy absorption capabilities of safety sport pads. These conclusions, based on a low-speed fall impacting the feet, should be extended to higher speeds and other body impact areas, potentially influencing protective equipment design in bouldering and other sports.

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Conflict of Interest Statement

The study received partial funding from Tyyny, a company specializing in the design, manufacture, and sale of climbing pads. Moreover, one of the authors was employed by Tyyny during the course of the study.

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