

A SUMMARY RESEARCH REPORT - SHOCKPAD LAYERS FOR SYNTHETIC SPORTS SURFACES



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1. Introduction

This report summarises the research findings and makes recommendations to the sports surfacing industry regarding shockpad layers used in outdoor synthetic sports pitches, and is aimed at improving the quality and consistency of shockpads constructed on-site. These recommendations are based on the findings of the PhD research project conducted at Loughborough University, which investigated the following areas:

- The effect of mix design variables on shockpad and shockpad-carpet system mechanical properties
- Shockpad behaviour and development of a theoretical mechanical model to describe this behaviour
- Development of new test methods appropriate for shockpad and constituent material mechanical testing and quality control

For the purposes of this study, the results presented in this report were obtained from the construction and testing of laboratory-constructed shockpads rather than full-scale on-site constructions, due to the high accuracy of mix design specifications required. The research methods and findings in this investigation focused on cast in-situ shockpads, however, the recommendations are considered applicable to prefabricated shockpads. Furthermore, these comments may, in general, be useful for any bound rubber crumb installation, such as playground and walkway surfaces.

This report discusses the findings in the sections below and is concluded with a list of recommendations. For full details of the methodology used, the results and a more in-depth discussion of the findings refer to the references provided at the conclusion of this report for the PhD thesis (Anderson, 2007) and two Engineering of Sport conference papers (Anderson et al, 2004 & 2006).

2. Shockpad Mix Design and Mechanical Properties

Previous knowledge relating to the effect of shockpad design on the mechanical properties was based on ad-hoc measurements and empirical relationships developed by members of the construction industry. This lack of methodical scientific investigation meant the effect of both intentional (development) and unintentional (changes in site practices during construction) mix design changes were not understood in relationship to the changes in mechanical properties. In addition, there existed a lack of suitable mechanical test methods stipulated by sports governing bodies for the purposes of quality control purposes.

These research issues were addressed by the controlled design, construction and mechanical testing of laboratory constructed shockpads. A benchmark shockpad, 'typical' of that used within the synthetic pitch constructions, was designed by characterising the design of shockpads obtained from site and advice from the industrial collaborators. The effect of mix design changes which may be

introduced to produce changes on player and ball interaction characteristics and/or durability was investigated by ranging mix design and producing a series of shockpads. The following mix design variables were investigated:

- Shockpad thickness
- Binder content
- Rubber particle size and Particle Size distribution
- Bulk density
- Binder type

The mix design variations were produced by altering each variable through a range of values while all other variables remained unchanged from the benchmark standard value. The range of values examined for each variable are outlined in Table 1.

The lack of suitable mechanical test methods to verify construction practice and mechanical performance was addressed by the trialling of new mechanical test methods alongside traditional tests stipulated by sport governing bodies. The following tests were conducted on each of the constructed shockpads.

Player interaction:

- Berlin Artificial Athlete Impact test - Industry standard test for shock absorbency of surface/pitch performance
- 2.25kg Clegg Hammer Impact test – potential alternative simpler test

Ball interaction:

- Vertical Hockey Ball Rebound Test - Industry standard test for whole pitch performance

Durability:

- Tensile Strength – Industry standard test for shockpads
- Cyclic Fatigue - Alternative test for shockpad

A change in mechanical properties was termed 'significant' if the mix design variation produced a change in value that was larger than the standard error of each test method. By applying this criteria, player interactions, as measured by the Berlin Artificial Athlete and 2.25 kg Clegg Hammer, were found to be affected by shockpad thickness, bulk density, rubber size and distribution and binder type. Shockpad thickness was shown to be a 'primary' mix design variable influencing player interaction tests, demonstrating a large (322g) reduction in peak deceleration (Clegg) and 25% increase in force reduction (Berlin Athlete) for the shockpad thickness range of 8 to 20 mm, as shown in Figures 1 and 2. Bulk density, rubber size and distribution and binder type were identified

as 'secondary' mix design variables influencing player interaction tests (to a lesser extent) by demonstrating overall changes in peak deceleration measurements of 44g, 32g and 16g respectively over the range examined for each variable. These changes were deemed 'significant' for the Clegg Hammer.

Ball interaction tests produced much lower energy impacts than the player interaction tests. As a consequence, the induced deformations are lower, and it was observed that only shockpads less than 12mm (i.e. 8mm) in thickness showed a significant effect on the recovered energy, albeit a small change of 4.4% (see Figure 3). This reduction in ball rebound for thinner shockpads was due to a greater energy loss during impact, whereby the greater strains induced produce greater hysteresis in the rubber. The changes in properties of the shockpads observed demonstrate the importance of achieving consistent shockpad mix design and placement practice, particularly for thickness, across the entire area of the surface/pitch, and in particular for shockpads with a specified thickness of 15mm or less for player interactions and 12 mm or less for ball interactions.

Shockpad durability was assessed by the industry standard tensile test, and a cyclic fatigue test was assessed as an alternative. Increasing binder content (Figure 4), increasing shockpad thickness, increasing bulk density and increased rubber size (2-8mm and 2-6mm assessed) all produced an increase tensile strength. However, there is no clear relationship between tensile strength and shockpad durability and hence the magnitude of the effect of changes in mix design changes cannot readily be quantified in terms of shockpad life. Design guidance suggests shockpads should achieve greater than 0.1MPa tensile strength, although in this work that target figure was rarely achieved despite very careful sample preparation and testing. A cyclic fatigue test was developed, although only changes in binder content and shockpad thickness were tested in this programme. The cyclic test applied a controlled load (vertical and horizontal – from using angled plates) over a 100mm square sample, with repetitions estimated to simulate a period of eight years in-service use. The data measurements aimed to assess mechanical degradation in terms of the two failure modes of shockpads; excessive changes in mechanical properties (by impact testing) and loss of rubber to polyurethane bonds (i.e. damage). The results showed that for the thinner and lower binder content pads there was an increase in damage and specifically more of the bonding appeared to deteriorate. For thicker shockpads the cyclic fatigue caused little change in ball rebound (as expected from the previous findings described above) but there was an appreciable reduction in shock absorbency.

In addition to the 'element' testing of shockpads on their own, some 'composite' systems were assessed whereby a carpet surface layer was added and the effect of the changes to the shockpad was assessed in relation to the whole pitch behaviour. Two different carpets were used, one a nylon water-based carpet (with a foam backed 3mm integral shockpad) as used for elite hockey, and the other a long-pile sand/rubber infill '3G' carpet as used for football. The specification for these carpets is provided in Table 2.

In general, the effect of the carpet was to reduce the magnitude of the changes observed in the test measurements for the changes in mix design of the shockpad. These carpets were of course new, and no accelerated wear tests were done to estimate the likely effects for 'worn' carpets, but it could be assumed that as the carpet wears and flattens and/or the infill compacts, that the effects of

the shockpad properties would become more dominant in the overall system behaviour. This is the reason, of course, for some sports governing bodies insisting on a shockpad beneath a '3G' system to ensure continued performance in the longer-term life of the facility.

The addition of the two carpets, on the standard 12mm shockpad, gave a similar decrease in the ball rebound height of 4.5% and increase in artificial athlete force reduction of 18% (or a Clegg Hammer reduction in peak deceleration of 140g) showing the carpet addition causes a significantly 'softer' impact and greater energy losses under ball impact, as may be expected.

For the changes in mix design, where a significant effect had been observed for the shockpad alone, the effect of the carpet was to greatly reduce the effects of these in any test measurements, with the exception of shockpad thickness. Shockpad thickness was the only mix design variable to show a 'significant' effect on the combined shockpad-carpet system's mechanical properties (see Figure 2a), whereby a 10% increase in artificial athlete force reduction (a 45g decrease in Clegg peak deceleration, Figure 1b) was measured on both carpet systems for increasing the shockpad thickness from 8 through to 20 mm.

It is anticipated that continued research into shockpad behaviour will evaluate the effects of the shockpad properties for older worn carpet systems, where it is expected that more of an impact force will be transferred to the shockpad and the effects of shockpad thickness, bulk density, binder content/type and rubber particle size/distribution will have a greater influence on the whole system response.

A summary of the results of mechanical property testing for variations in shockpad and shockpad-carpet system mix design is provided in Table 3, showing a qualitative indicator of the effects of the mix design variables.

3. Shockpad Behaviour Model

The behaviour of shockpads was evaluated during impact tests using force plate measurements, to help analyse the mechanism of force versus deflection behaviour. This analysis demonstrated a strong non-linear relationship during both the loading and unloading periods of impact, and also displayed significant hysteresis (energy loss) in the system. The analysis resulted in the classification of three distinct phases of the loading behaviour for the shockpads: Phase 1 was termed 'air void compression'; Phase 2 termed 'transition'; and Phase 3 'rubber compression'. The following descriptions aim to explain the shockpad behaviour observed during each phase, and they are represented graphically in Figure 5.

Phase 1: Air Void Compression

Deformation of the shockpad is initially controlled by low resistance to compression of the air in the voids between the rubber particles (typically the air void content may be around 40-50%). This phase controls the initial (low) stiffness and high deflection under a compressive load, and typically occurs over the 0 to 20% strain range, leading up to the transition phase.

Phase 2: Transition

This phase is characterised by the transition from a low to a higher stiffness response, i.e. an increase in the steepness of the curve in Figure 5. There is some further compression of the reduced volume of air voids, and initial rubber particle compression and distortion. The number and interface area of the rubber particles in contact increases, and there is an increased resistance to deformation at this intermediate range of shockpad strain (e.g. 20 to 40% of shockpad thickness). The individual rubber particles are subject to relatively small strains in this phase (similar to a series of springs in series) but resistance increases rapidly with increasing strain.

Phase 3: Rubber Compression

Deformation in this phase is characterised by a high stiffness response from the significant compression and high strains within the rubber particles. This phase dictates the final stiffness, peak impact forces and peak deflections for the impact tests carried out, and typically occurs at vertical shockpad strains greater than 40%. In the past this high stiffness response has been termed 'bottoming out' for shockpads and surfaces comprising cellular foam or voided elastomeric materials.

The factors that influenced the range of each phase, and the detail of the force deflection curves included the shockpad mix design, the device used to impact the shockpad (its shape, impact mass and velocity), the carpet and the foundation layer beneath. Shockpad thickness was again shown to be a key mix design variable. The shockpad behaves more linearly as it gets thicker (i.e. the strains are reduced for the same impact energy) and the stiffness response reduces. The increase in average stiffness between Phase 1 and 3 was a factor of nearly 5 for the thinner shockpads, and a factor of around 2 for the thicker shockpads. The non-linear nature of the shockpad and shockpad/carpet system response demonstrates that if one expresses the 'stiffness' of a sport surface as a single number, e.g. 1500kN/m, then it must be made clear over what range of deflection this was measured. The average stiffness can be expressed to permit a simple estimate of deflection under load, or for simple comparison between systems – but ideally under the same peak displacement or strain.

The addition of the carpet above the (standard 12mm) shockpad reduced the 'average' stiffness from 1600 kN/m to 267 kN/m for the water based system and 400 kN/m for long pile 3rd generation carpet system. The slightly stiffer response of the rubber infill 3rd generation carpet system, compared to the water based carpet, was unexpected but explained by movement of the rubber particulate during repeat testing and a reduced effective thickness of infill.

The foundation layer *beneath* the shockpad was shown to have some influence on the measured properties and behaviour for the relatively thin (8-12 mm) shockpads. Thicker shockpads (15 and 20 mm) followed a similar load and unload stress-strain behaviour, for the impacts carried out in this programme. The thinner (8 and 12 mm) shockpads showed very high non-linearity in the stiffness response as the rubber particles themselves clearly became highly compressed. This demonstrates, to some extent, that where the foundation is very rigid, i.e. concrete or asphalt, thinner shockpads

will not provide high shock absorbency under high energy loads. Where the base is unbound (often termed 'dynamic') then the shockpad does not need to be as thick as for a rigid base. However, where a shockpad is omitted because a thin integral shockpad is used such as in hockey, or where an unbound base is used for football or rugby clearly the infill has to be kept to greater than a critical level to avoid very high reaction forces under the athlete whilst running or falling. These findings show the importance of the proper engineering understanding of the different layers of a sport surface/ pitch system and how they can interact to provide the desired properties.

It was interesting to observe that whilst the potential energy input by the Clegg Hammer test was slightly more than 4 times that of the hockey ball (9.9Joules compared with 2.3Joules), both impactors produced an energy return of approximately 40% (for the benchmark shockpad). This warrants further investigation, but suggested in this case that energy return is dependent on the properties of the shockpad, not the input energy of the impact test or subject. However, it is expected that players of varying mass, and performing various sport movements, will produce varying shockpad behaviour response – such as peak impact forces, stiffness response and hence deformations in the surface. These aspects of shockpad and whole pitch behaviour potentially influence player fatigue and possibly injury – though neither aspect of player performance are as yet well documented in the literature with regard to sport surface properties. A summary of the factors observed to influence affecting shockpad behaviour and mechanical properties by this investigation are summarised in Figure 6.

A mechanical model was developed to describe shockpad behaviour. Of several models developed, with increasing complexity, a non-linear damped model was favoured. This model comprises a spring-mass-dashpot system whereby the response of the shockpad mass is predicted by a parallel combination of a non-linear spring (stiffness K and non-linear coefficient n) and a damper (c) that absorbs energy (acts to oppose motion of velocity v). The mathematical equation used to describe the model is given in Equation 1. However, the coefficients (k , n , and c) of the model were found to be dependent on shockpad mix design, the impact test type and the stiffness of the base or carpet layers.

$$F = kx^n + cv \quad \text{----- Equation 1}$$

Where:

F	=	Vertical reaction Force	[N]
x	=	Surface displacement of shockpad	[m]
v	=	Velocity of shockpad	[m.sec ⁻¹]
k	=	Spring Stiffness Coefficient	[N.m ⁻¹]
c	=	Damping Coefficient	[N.sec.m ⁻¹]
n	=	Coefficient of non-linearity	dimensionless

4. Quality Control and Test Methods

Synthetic sports pitch performance specifications issued by sporting governing bodies often only require tensile strength measurements to be conducted on constructed shockpads (either made by

hand or laid on site into special trays) and for the result to pass a minimum criterion. The tensile test is intended, it appears, to indicate sufficient binder content has been incorporated and to provide some assurance of durability in-service. However the results of this investigation has highlighted the influence of many factors on tensile strength and an issue with the repeatability of the test. It is argued that what is required is consistency in the shockpad produced, and this is not specified. In addition, the lack of current stipulation of a performance related test to ensure the shockpad layer meets some form of player or ball interaction requirement can mean that inconsistencies in the shockpad layer are not identified until after installation of the carpet layer. Thickness and density of the shockpad were highlighted as key performance related mix design variables, and they can be affected by the planarity of the base layer the shockpad is laid on or the workmanship of the operatives constructing the shockpad. Construction and performance specifications also lack suitable tests to ensure consistency of the raw materials being used in shockpad construction.

The Berlin Artificial Athlete is the current standard test but is not a practical test for assessing the shockpad layer. However, in this study the 2.25 kg Clegg Hammer (peak deceleration) showed good correlation with the Berlin Artificial Athlete (force reduction) and was concluded to be a non-destructive, rapid and simple portable test – several hundred tests can be done in half a day. The Clegg test was sensitive to variations in shockpad thickness, bulk density, binder type and rubber particle size and distribution. However, the test was not sensitive to the binder content of shockpads. The results of mechanical property testing show the primary factor influencing the Clegg values was shockpad thickness. In general the range of peak deceleration values was from 450gravities to 125 gravities (one gravity = 9.81ms^{-2}) for the range tested in this programme. However, the development of a database of field readings would assist in the development of specific target Clegg Hammer impact values, or from pre-contract test samples as is currently required now. The research data here has shown, however, that the acceptable limits for the Clegg test could be reasonably wide without unduly affecting ball bounce or player comfort once the carpet is applied.

The tensile test is recognised as a simple pass/fail test used by the industry. However, repeatability was poor, largely due to sample size versus rubber particle size issues and inconsistent coverage of binder it was thought. It is of course only an indirect test, relying on an empirical relationship with likely shockpad life. An accelerated cyclic fatigue test was developed as part of this research to simulate the mechanical degradation mechanisms of shockpads, and directly measure the response, to measure the response after many millions of cycles of load. The preliminary test results showed potential for this test to be implemented as perhaps a research and development test or laboratory based accreditation test for mechanical durability. No accelerated ageing of the samples was carried out however, thus no ageing of the binder was investigated.

In addition, several methods of extracting the binder from a constructed shockpad were experimented with, aimed at providing a needed solution to many reported site disputes. However, to date no accurate and repeatable method has been established. The tensile test is likely to remain in place until a binder content verification test is established.

There are currently few specification requirements placed on raw materials used in shockpad

construction. The current onus relies on binder manufacturers to recommend binders which are suitable for shockpad construction and for shockpad constructors to conduct trials prior to using a new product. However, there are issues with the quality and consistency of recycled rubber particulate which may vary in terms of size range and distribution, shape, rubber and additive composition and cleanliness (i.e. dust, fibre and steel content). The prospect of the rubber particulate being procured from many different sources in the future (as prices and demand rise) or an increasing array of new infill materials suggests standards may need to be introduced.

Several test methods were trialled in this research programme to identify and measure changes in the mechanical properties of the source rubber particulate. These included compaction and compression tests, looking at the effects of particle size, particle packing and resistance to compression of loose particles in a mould – all adapted from standard civil engineering soil tests. The force-deflection behaviour of initially loose particles under high compressive loads and from several cycles of load-unload showed promise in measuring an intrinsic stiffness of the rubber sample. However, further work is required to develop this into a useful test to describe the mechanical compression properties of the raw materials used in shockpads.

5. Recommendations

The following recommendations are made based on the research programme's findings:

- Shockpad thickness was identified to be a 'primary' mix design variable - with the greatest effect on the compression, rebound and strength properties. This should be carefully controlled during construction and verified for consistent properties across a sport surface.
- Bulk density, rubber size and distribution, binder type and binder content were identified to be 'secondary' mix design variables, showing some effect on the properties measured but to a much lesser extent than thickness. These variables should also be controlled during design and construction.
- The contribution of a shockpad to the system behaviour of a sport surface during play was observed to be dependent on the shockpad mix design, the properties of the carpet system and base condition, and the nature of the loading applied (such as player or ball related). Shockpads should therefore be designed to accommodate all of these factors, some of which may require a compromise (e.g. low bounce versus underfoot comfort).
- As the surface ages and wears it is likely that the shockpad properties will have a greater influence on the 'system' behaviour.
- The Clegg Hammer impact test could be introduced to ensure consistent performance of the shockpad prior to carpet installation (time for curing aside). It is a simple portable test and

affordable to contractors and consultants alike.

- A test more directly related to durability should be developed to replace the currently specified tensile test. A simple binder content test is required for constructed shockpads to resolve disputes on design and workmanship.
- Tighter specifications should be implemented to ensure high standards for the raw materials used in shockpads, to ensure their consistency and suitability and maintain high quality shockpad systems for sport surfaces.

6. Acknowledgements

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7. References

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8. Tables and Figures

Table 1: Range of Mix design variables examined. Bold values represent the mix design of the ‘benchmark’ shockpad against which other mix design were assessed.

Mix Design Variable	Range Investigated
Rubber Size [mm]	2-6 2-8
Rubber Size Distribution	Small Well-Graded Large
Binder Type	1 2 3
Binder Content [%]	5 9 12 15
Layer Thickness [mm]	8 12 15 20
Bulk Density [kg/m ³]	500 550 600

Table 2: Specifications for the carpets used. The water-based carpet system was tested dry.

Carpet Type	Generic Water Based	Generic 3 rd Generation
Pile Height	12mm	65mm
Pile Weight	3.95 kg/m ³	1015g/m ²
Polymer Type	Nylon	Polyethylene
In-fill Materials	-	Rubber, Sand
In-fill Height	-	Sand: 15mm Rubber: 25mm
In-fill Weight	-	Sand: 16.5 kg/m ² Rubber: 16.5 kg/m ²
Integral Shockpad	3mm foam	-
Suitable Sports	Hockey	Football, Rugby

Table 3. Summary of the effect of each mix design variable on player interactions, ball interactions and durability for shockpads and shockpad-carpet systems

	Player Interactions		Ball Interactions		Durability
	Shockpad	Shockpad & Carpet	Shockpad	Shockpad	Tensile strength
Thickness	High	Med	Low	Low	High
Binder Content	None	None	None	None	High
Bulk Density	Low	None	None	None	Med
Rubber Size and Distribution	Low	None	None	None	Low
Binder Type	Low	None	None	None	Low

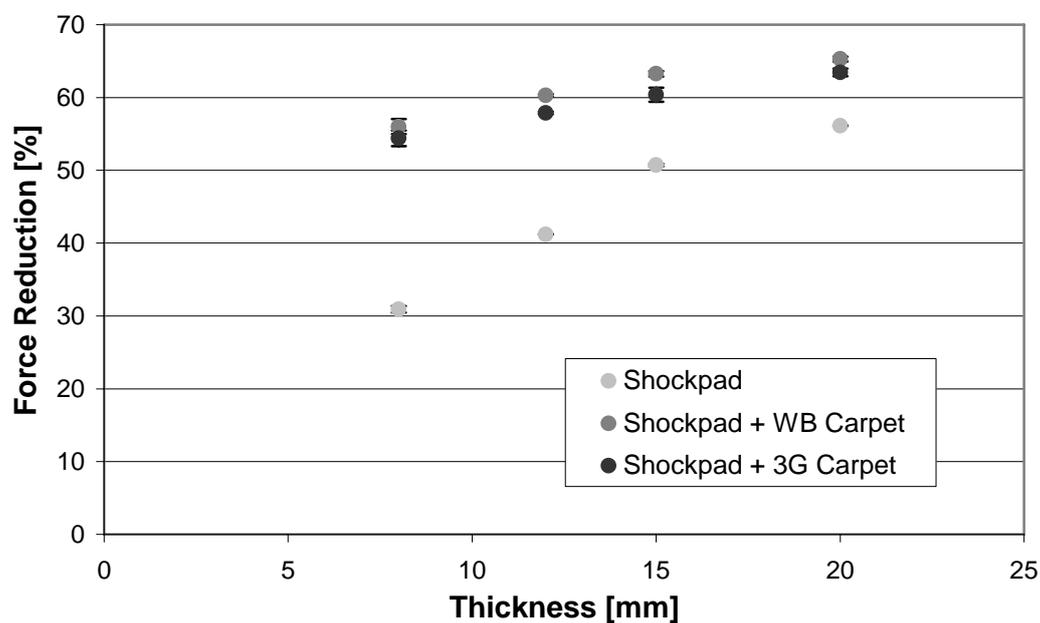


Figure 1: Effect of shockpad thickness on Force Reduction for shockpad layer and shockpad-carpet systems.

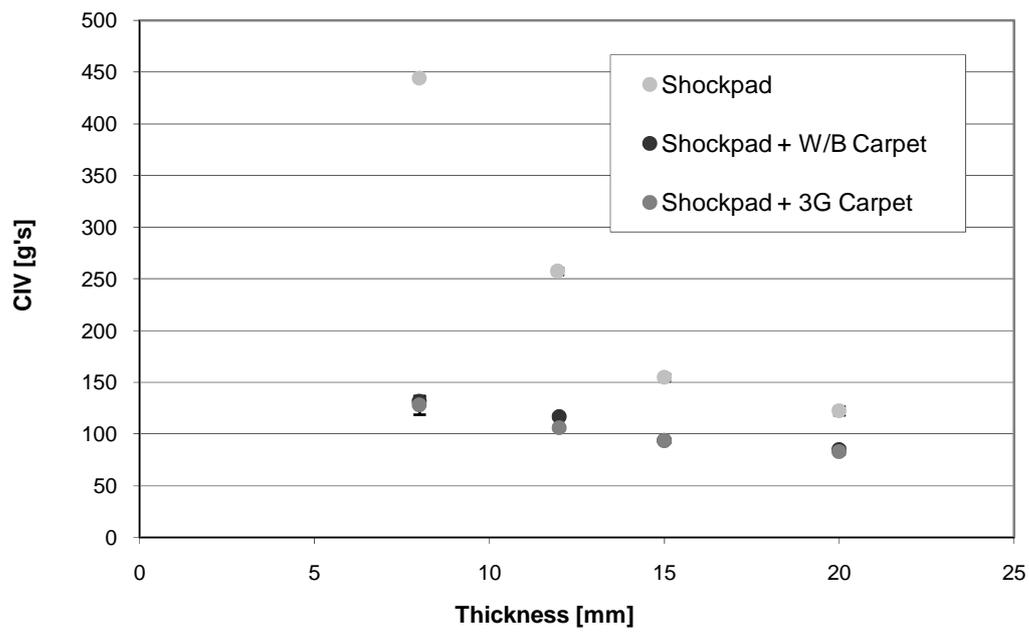


Figure 2: Effect of shockpad thickness on Clegg Impact Value for shockpad layer and shockpad-carpet systems.

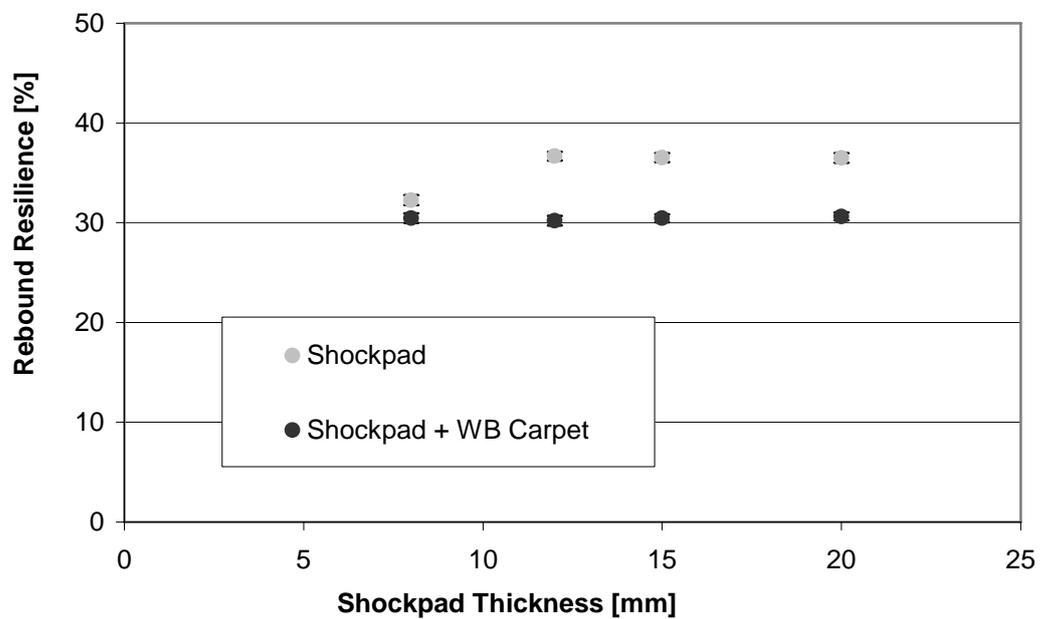


Figure 3: Effect of shockpad thickness on vertical hockey ball rebound resilience for the shockpad layer and shockpad-water based carpet system.

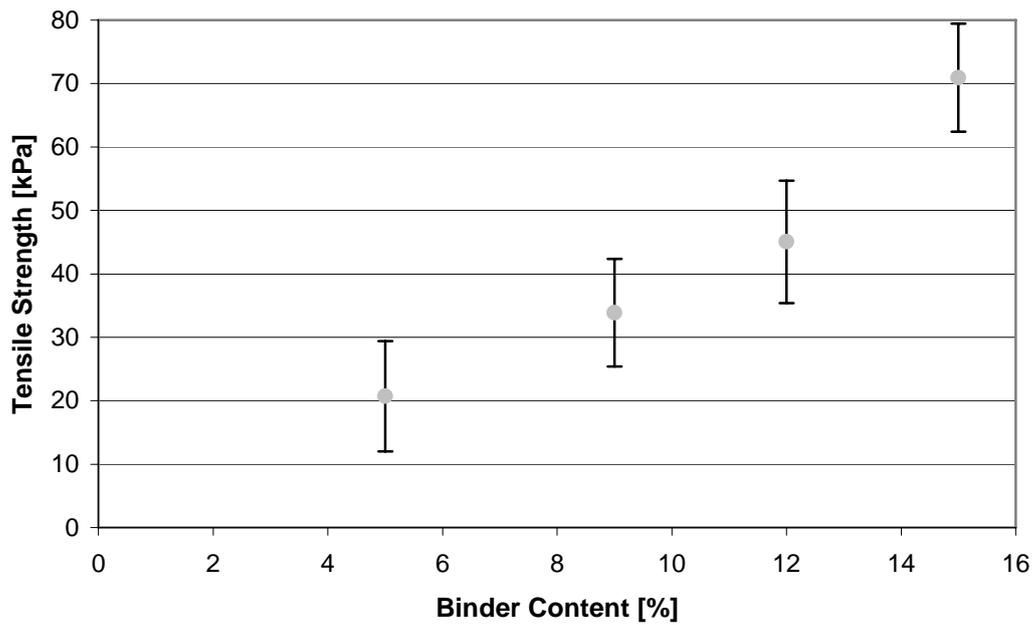


Figure 4: Effect of binder content on tensile strength of shockpads.

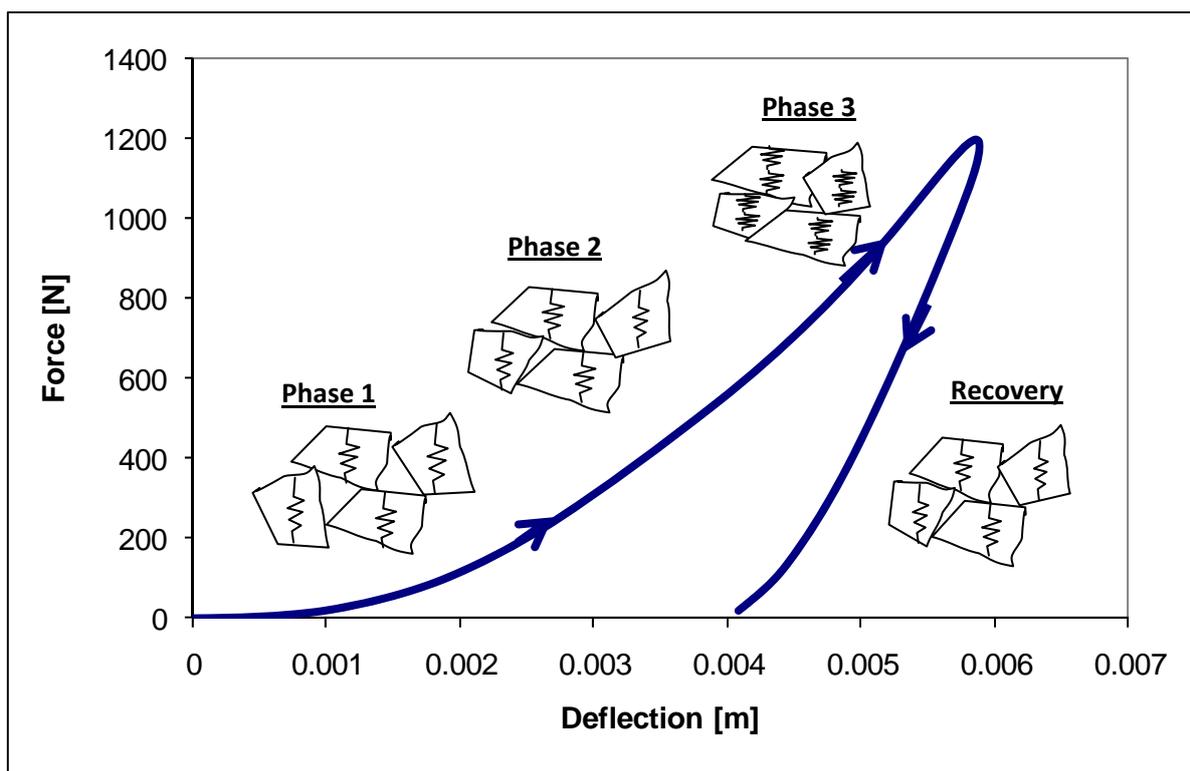


Figure 5: Compression behaviour of a shockpad under a hockey ball impact showing three phases of force-deflection behaviour

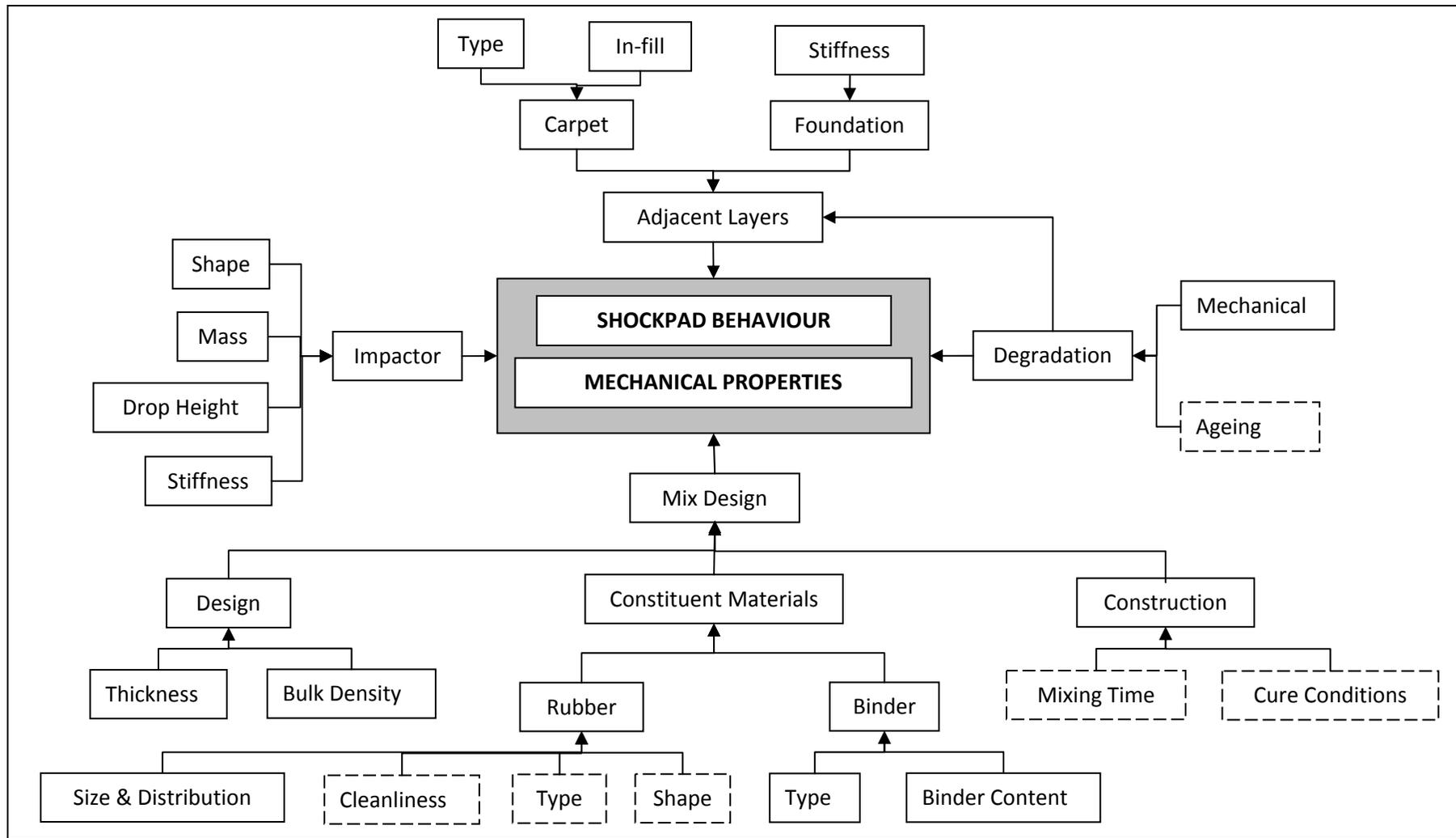


Figure 6: Factors which affect shockpad behaviour and mechanical properties