Slip Resistance Assessment of Carpets for Compliance to National Construction Code of Australia

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	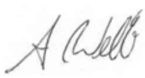	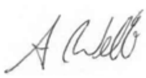
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Executive summary

A statistical analysis was carried out on a body of data consisting of the slip resistance test results, in accordance with AS 4586 Appendix A, on a range of carpets. The analysis assessed the likelihood of compliance with the NCC BCA Volume 1 Class 2 to 9 buildings and NCC BCA Volume 2 Class 1 and 10 buildings requirements for dry surfaces including stair treads, ramps and landings. The relevant clauses require a minimum Slip Resistance Classification (SRC) of Class P3. The statistical analysis was performed based on 102 test reports of tests from two test laboratories. A probability that a carpet of similar construction determined to have a probability of failure (Classification less than P3) of less than 0.1% was considered to provide a level of safety that will satisfy the Performance Requirements DP2 of the BCA Vol 1 2019 and Performance Requirements P2.5.1 of the BCA Vol 2 2019.

Table 1 summarises our statistical analysis results (Section 9) of whether, with 99.9% confidence (that is, 1 chance in 1,000 of a non-complying result), samples of various types of carpets can be expected to exceed the minimum value of SRC of Class P3 as required by the NCC for stairs, landings and ramps. This depends on the fibre type, style and the pile thickness (PT, the fibre length above the substrate). This implies that, for samples of carpets of the types identified, SRV values should have less than a 0.1% probability of not achieving the predicted performance if tested under AS 4586 Appendix A.

Table 1: Results from statistical modelling and analysis. Range of carpet which will achieve Classification not less than P3 and hence which can be considered to conform without further testing for stair treads, landings and ramps not steeper than 1:14.

<table>
<tr><th colspan="3">Fibre Type (“face fibre” or “wear surface”)</th><th></th></tr>
<tr><th>Wool and wool rich (≥80% wool)</th><th>Nylon</th><th>Other</th><th>Style</th></tr>
<tr><td rowspan="2">OK for all PT 4.1mm≤PT≤15.2mm</td><td colspan="2">OK for 3.8mm≤ PT ≤ 8.0mm</td><td>Cut Pile</td></tr>
<tr><td>OK for 3.5mm≤PT≤6.6mm</td><td>insufficient data</td><td>Loop Pile</td></tr>
</table>

Based on the test data received and the statistical analysis of that data, carpets conforming to the above description and manufactured by Beaulieu Australia, Brintons, Cavalier Bremworth, Feltex Carpets, Godfrey Hirst Carpets, Interface, Norman Ellison Carpets, Milliken-Ontera, Quest Carpets, Supertuft, Tuftmaster Carpets and Victoria Carpets are covered by this assessment.

No conclusion could be drawn for carpet outside these ranges.
No conclusion could be made regarding Cut/Loop combination pile carpets.
No conclusion could be made regarding loop pile carpets with pile fibre of other than wool or nylon (i.e. Polypropylene, polyester and triexta).
Where a conclusion on the expected SRV value for a carpet system could not be drawn, or where a tighter specification is required than shown here, the carpet must therefore be formally tested.

Ramps steeper than 1:14 of Class 2 to 9 buildings and 1:8 of Class 1 and 10 buildings are excluded from the conclusions of the assessment as these require a test P4 result.

Note that the above results were based on statistical analysis of carpet samples tested without underlay, which means these conclusions are constrained by this test condition. The test method does not require specimens to be tested with underlay.

This report refers to 102 test reports. the sponsors of the referenced tests have provided permission for CSIRO to prepare this report in the name of the assessment sponsor being the Carpet institute of Australia Limited (CIAL).

TERM OF VALIDITY: This report will expire on the 1st day of May 2025.

1 Introduction

An assessment was undertaken by the CSIRO Infrastructure Technologies for the Carpet Institute of Australia Limited (CIAL). The study examines the range of the slip resistance performance of carpet for use in dry areas when tested in accordance with Appendix A of AS 4586:2013[1].

A statistical analysis was carried out on a body of data consisting of carpets tested according to the slip resistance test AS 4586 Appendix A. The carpet was assessed in the context of a Performance Solution that will provide evidence that will satisfy the relevant Performance Requirements of the National Construction Code (NCC): Building Code of Australia (BCA) Volume 1[2] and Volume 2[3]. The process involved a statistical analysis of a body of slip test data on a range of carpets to assess the likelihood of carpet of a specified character complying with the BCA requirements for surfaces of stair treads, landings and ramps (not steeper than 1:14 Class 2 to 9 and not steeper than 1:8 for Class 1 and 10). The objective is to reduce the quantity of testing that would otherwise have to be performed by the carpet industry while maintaining an appropriate level of life safety.

Application: When completed this report may be used as part of a submission to a regulatory body or an Authority Having Jurisdiction (AHJ) as evidence of compliance over a building compliance matter.

The reissue of this report in 2020 included changes to the NCC which were:

- Volume 2 extended requirements to ramps and landings.
- Revision and restructure of Section A.

Ontera changed name and transferred ownership to the test reports to Milliken-Ontera.

2 Scope of Work

2.1 General Description

The BCA requires stair treads, ramps and landing surfaces in Class 1 to 10 buildings to be tested for slip resistance compliance. For dry areas AS 4586 Appendix A is specified. A brief overview of the results for carpets tested to AS 4856:2013 Appendix A indicates that all test results were in Class P5, P4 or P3 regardless of the pile thickness, construction type, installation technique or manufacturer.

Based on the above observation the scope of work to undertake for this project was agreed to be:

Stage 1. Original assessment

- Review the slip resistance test data provided.
- Examine BCA framework and approach for the assessment.
- Assess the test data on a statistical basis to examine the variables and influences on the test results.
- Assess the limitations of the test data and the parameters within which the assessment is valid.
- Prepare a report concluding the assessment outcomes.
- Identify areas where further data is needed.

Stage 2. Update based on inclusion of further data.

- Revise the assessment including the additional data gathered.
- Prepare a report concluding the assessment outcomes. The conclusions are to state if the test data

meets the relevant performance requirements of the BCA and the limitations of the work.

Test criteria assessed:

The *slip resistance classification (SRC)* is determined by testing according to Appendix A of AS 4586:2013. Carpet Specification assessed achieve class not less than P3:

2.2 Report Basis

This report is based on:

(i) The NCC 2019, Building Code of Australia Volume 1, 2019 Edition[2];

(ii) The NCC 2019, Building Code of Australia Volume 2, 2019 Edition[3];

(iii) Test data files provided by CIAL, as further described in this report; and

(iv) Meetings with CIAL.

3 Objectives of the Study

3.1 General Objectives

In simple terms, the objective of the study is to show compliance with the NCC 2019 including the Building Code of Australia Volume 1 (Class 2 to 9 buildings) and Volume 2 (Class 1 and 10 buildings).

This report will describe Class 1 and 10 buildings as “domestic”.

This report will describe Class 2 and 9 buildings as “non-domestic”.

The requirements for these two groups of buildings are slightly different as described below.

This report will only cover surfaces in “dry” areas. NCC Volume 2 Clause 3.9.1.4 has the following Explanatory information:

To determine the appropriate surface of a tread or the floor surface of a ramp, it is necessary to determine the likely conditions the tread or ramp will be subject to over the life of the building. This can be either dry, wet or both. A dry surface is one that is not normally wet or likely to be made wet other than by an accidental spill. A wet surface is one that is normally wet or likely to be made wet, including areas exposed to the weather.

3.2 BCA Objectives

3.2.1 DOMESTIC BUIDLINGS

The objective of the BCA Vol 2 relevant to this study drawn from section 2.5 :

O2.5 *The Objective is to provide people with safe access to and within a building.*

3.2.2 NON DOMESTIC BUIDLINGS

Objectives have been removed from NCC Volume 1 for this aspect.

3.3 BCA Performance Requirements

3.3.1 DOMESTIC BUIDLINGS

The relevant performance requirement of the BCA vol 2 is P2.5.1, which states that:

P2.5.1 Movement to and within a building

So that people can move safely to and within a building—

(b)any stairway or ramp must—

(iv)have slip-resistant walking surfaces on ramps, and on stairway treads or near the edge of the nosing.

3.3.2 NON DOMESTIC BUIDLINGS

The relevant performance requirement of the BCA Vol 1 is DP2, which states that:

So that people can move safely to and within a building, it must have—

(c) any stairways and ramps with—

(i) slip-resistant walking surfaces on—

(A) ramps; and

(B) stairway treads or near the edge of the nosing;

3.4 Deemed-to-Satisfy Requirements

3.4.1 DOMESTIC BUIDLINGS

Clause 3.9.1.4 of Volume 2 of the Building Code of Australia, states:

3.9.1.4 Slip-resistance

The requirements for slip-resistance treatment to stair treads, ramps and landings are as follows:

(a)Treads must have—

(i)a surface with a slip-resistance classification not less than that listed in Table 3.9.1.3 when tested in accordance with AS 4586; or

(ii)a nosing strip with a slip-resistance classification not less than that listed in Table 3.9.1.3 when tested in accordance with AS 4586.

(b)The floor surface of a ramp must have a slip-resistance classification not less than that listed in Table 3.9.1.3 when tested in accordance with AS 4586.

(c)Landings, where the edge leads to the flight below, must have—

(i)a surface with a slip-resistance classification not less than that listed in Table 3.9.1.3 when tested in accordance with AS 4586, for not less than 190 mm from the stair nosing; or

(ii)a nosing strip with a slip-resistance classification not less than that listed in Table 3.9.1.3 when tested in accordance with AS 4586.

Table 3.9.1.3 Slip-resistance classification

Application	*Dry surface conditions*
Ramp not steeper than 1:8	*P4 or R10*
Tread surface	*P3 or R10*
Nosing or landing edge strip	*P3*

The *slip resistance classification* is determined by testing according to AS 4586:2013.
The data columns in the table for “wet surface conditions” are not relevant to this study.

The first row of Table 3.9.1.3 requires ramps steeper than 1:8 to have at least a classification of P4. This report assesses the likelihood of a classification of not less than P3, hence ramps steeper than 1:8 in domestic buildings are excluded from the conclusions of this assessment.

3.4.2 NON DOMESTIC BUIDLINGS

Clause D2.10 (c), Clause D2.13 (a)(v) and Clause D2.14(a)(ii)(A) of Volume 1 of the Building Code of Australia, states:

a surface with a slip-resistance classification not less than that listed in Table D2.14 when tested in accordance with AS 4586;

Table D2.14 SLIP-RESISTANCE CLASSIFICATION

Application	Surface conditions	
	Dry	Wet
Ramp steeper than 1:14	P4 or R11	P5 or R12
Ramp steeper than 1:20 but not steeper than 1:14	P3 or R10	P4 or R11
Tread or landing surface	P3 or R10	P4 or R11
Nosing or landing edge strip	P3	P4

The *slip resistance classification* is determined by testing according to AS 4586:2013.
The data columns in the above tables for “wet surface conditions” are not relevant to this study.

The first row of Table D2.14 requires ramps steeper than 1:14 to have at least a classification of P4. This report assesses the likelihood of a classification of not less than P3, hence ramps steeper than 1:14 in class 2 to 9 buildings are excluded from the conclusions of this assessment.

3.5 AS-4586:2013 Requirements

Appendix A of the standard describes the pendulum test method. Characteristics are determined by pendulum swings brushing the surface of the flooring.

AS 4586:2013 defines the following terms

British Pendulum Number (BPN)

Dimensionless unit of slip resistance when measured using the pendulum friction tester.

Slip resistance value is defined by AS 4586:2013 as:

The mean BPN value for the sample that has been tested and calculated in accordance with Appendix A, regardless of whether the surface was level or on a slope.

The classification of new pedestrian surface materials shall be in accordance with Tables 2 extract from the standard show below.

TABLE 2

CLASSIFICATION OF PEDESTRIAN SURFACE MATERIALS ACCORDING TO THE AS 4586 WET PENDULUM TEST

Class	Pendulum SRV (see Note 1)	
	Slider 96	Slider 55
P5	>54	>44
P4	45–54	40–44
P3	35–44	35–39
P2	25–34	20–34
P1	12–24	<20
P0	<12	

Carpet used on wet areas, floors or as other building elements must comply with other Sections of the NCC and appropriate test methods.

3.6 Proposed Performance Solution

The proposed Performance Solution is to document an assessment that provides an appropriate level of confidence that carpet within certain construction parameters will satisfy the NCC requirements.

3.7 Limitations

- This report does not assess the use of carpets as a building material other than use as a floor covering.
- This report does not assess the use of carpets in areas where surface conditions are “wet”.
- This report does not assess the use of carpets on ramps steeper than 1:14.
- This report does not encompass situations that involve hazards outside the range normally encountered in buildings.
- The scope of the assessment is limited to compliance with the National Construction Code of Australia, matters such as property protection, business interruption, public perception and broader community issues have not been considered.
- Where a comparison with Deemed-to-Satisfy (D-t-S) assessment is carried out the most relevant D-t-S design has been identified as the benchmark for the building. Where more than one D-t-S design is considered relevant, the design that provides the highest level of safety to the community has been adopted as the benchmark.
- The methods of analyses, input data and acceptance criteria are appropriate for the application being considered in this report only.

- The goal of 'absolute' or '100%' safety is not attainable and there will always be a finite risk of injury, death or property damage. Slips and falls and consequent effects on people and property are both complex and variable. The intent of regulations and this report related to health, safety and amenity in buildings is to mitigate risks to a level accepted by the community.
- AHJ's and peer reviewers should not use information provided in this report for review for any purposes other than for determining compliance of a carpet type for the specific building under consideration and lodgement with prescribed bodies. All practitioners should treat all engineering reports, peer review reports, test data research reports and similar supporting documents as confidential, unless permission is granted for broader distribution or use.
- Test data utilised in this report has been used with the express permission of the owner of the data.
- The safety engineering assessment is based on the typical construction configuration of carpets in use at this time. The assessment does not cover the issues that may arise for manufacturing techniques and application methods that may arise in the future.
- The AS 4586 test method does not require testing with underlay, it does however require reporting if underlay is present. Weights and thicknesses of carpet underlays, backings and adhesives were not available as part of the data set provided by Carpet Institute of Australia. The CSIRO analysis and the conclusions drawn from the analysis therefore assume that the test data provided are representative of the range of values used in normal practice for these weights and thicknesses.

4 Methodology

The methodology is to be carried out within the framework provided by the NCC Volume 1 and 2 Section A.

Compliance with the NCC is achieved by complying with—

(1)the Governing Requirements of the NCC; and

(2)the Performance Requirements.

4.1 Meeting the Performance Requirements

A2.1 Compliance with the Performance Requirements

Performance Requirements are satisfied by one of the following, as shown in Figure 1.*:*

(1)A Performance Solution.

(2)A Deemed-to-Satisfy Solution.

(3)A combination of (1) and (2).

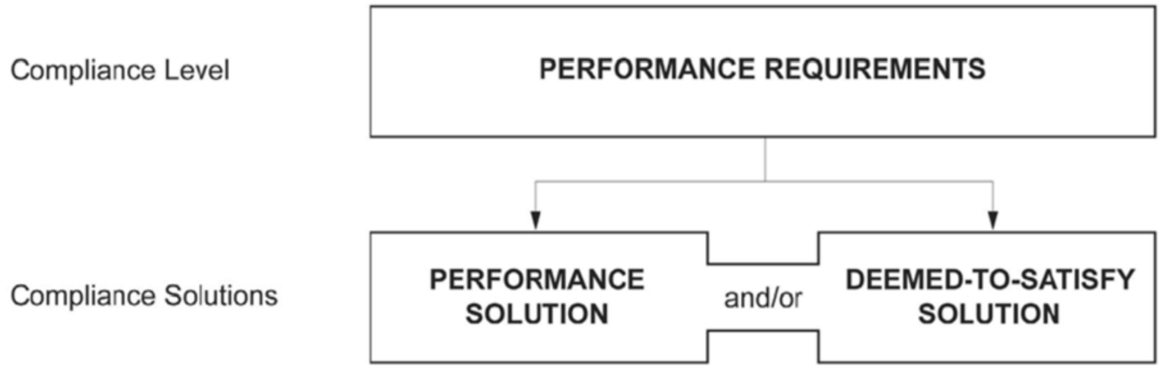

Figure 1: NCC compliance option structure.

As stipulated in BCA Clause A2.2 (1), it will be shown that a Performance Solution is achieved by demostrating:

(b) the solution is at least equivalent to the Deemed-to-Satisfy Provisions.

4.2 Assessment Method

(2)A Performance Solution will be shown to comply with the relevant Performance Requirements through a combination of the following Assessment Methods:

(a)Evidence of suitability in accordance with Part A5 that shows the use of a material, product … meets the relevant Performance Requirements.

(b)(ii)Other Verification Methods, accepted by the appropriate authority that show compliance with the relevant Performance Requirements.

(d)Comparison with the Deemed-to-Satisfy Provisions.

Section A2.4 A(3) Where a Performance Requirement is satisfied by a Performance Solution in combination with a Deemed-to-Satisfy Solution, in order to comply the following method must be used to determine the Performance Requirement or Performance Requirements relevant to the Performance Solution:

(a)Identify the relevant Deemed-to-Satisfy Provisions of each Section or Part that are to be the subject of the Performance Solution.

(b)Identify the Performance Requirements from the same Sections or Parts that are relevant to the identified Deemed-to-Satisfy Provisions.

(c)Identify Performance Requirements from other Sections or Parts that are relevant to any aspects of the Performance Solution proposed or that are affected by the application of the Deemed-to-Satisfy Provisions that are the subject of the Performance Solution.

The process outlined above has been described below and summarised in Table 4.

An Evaluation Extent Level 1 as defined by the IFEG shall be performed to evaluate the performance of proposed Performance Solutions.

4.3 Verification Methods

The verification method will be the following:

- Review the test data provided.
- Set an acceptance criteria based on statistical confidence intervals.
- Assess the test data on a statistical basis to examine the variables and influence on the test results.
- Assess the limitations of the test data and the parameters within which the assessment is valid.
- Conclude parameters of carpet construction within which the acceptable confidence limits are achieved.

The fire safety industry is the predominant user of performance based approaches hence some elements of International Fire Engineering Guidelines (IFEG)[4] and the ABCB guide[5] have also been consulted.

4.4 Acceptance Criteria

In accordance the statistical methods referenced below, the following acceptance criteria shall be used to evaluate the performance of the slip resistance of the carpet.

4.4.1 GENERAL STATISTICAL METHODOLOGY

At the outset, it is necessary to make a clear distinction between the current method by which a carpet passes (or does not pass) the test, and the proposed method.

1. In order for carpets to be approved as complying with the Performance Requirements in the NCC, they currently need to achieve not less than Class P3 (SRV>35) as determined in the AS 4586 Appendix A test.
2. In order for carpets of a particular class to be approved as complying with the Performance Requirements in the NCC, a representative set of carpets of that class need to provide test results which collectively indicate that any carpet of that class would have a chance of less than, say, 0.001 to achieve the minimum mandatory P3 slip resistance classification.

Thus, "acceptance" for an individual carpet would then come from one of two routes – that it either passes the tests itself, or that it is identified as belonging to a "class" of carpets which have been collectively demonstrated in the past to have a high probability of passing the required tests.

The implications of the second route are

1. It is necessary to define a set of "classes" of carpet, where all carpets within that "class" would be expected to have similar properties on both tests,
2. These "classes" need to be determined through a judicious combination of the knowledge of carpet experts and statistical analysis designed to detect whether carpets within a proposed class are "similar enough".
3. It is necessary to have a representative sample from each proposed class in order to determine both its mean response to each test and the degree of variability in those test results, in order to determine the likely range of values for the test in relation to the specification limit.

The statistical analysis that is undertaken here is then centred on two aspects. The first is the identification and confirmation of the distinct classes and their properties on each test. The second is the determination of the level of confidence with which we can say that a future carpet from that class will pass the test.

4.4.2 CONFIDENCE INTERVALS

Each carpet tested either passes or fails the test. However, in each case, the outcome of the test is a specific value and this value is subject to random variation arising from a number of sources.

In manufacturing, control limits for a product are generally set at 3 standard deviations either side of the average value for that product[6]. A process is said to be "in control" if the control limits sit inside the specification limits. In the carpet situation, the specification limit is one-sided, so the process of producing the carpet will be in control provided the mean of the test results is more than three times the estimated standard deviation away from the specification limit for that test. Provided the data for that class (or some suitable transformation of the data) can be shown to be close to a Normal distribution, then the probability of a test failing when it involves carpet from that class of carpets will then be less than 0.00135 or 1 in 740. To reduce this probability to 0.001 requires 3.09 standard deviations[7].

Because different classes of carpets will have different means, and possibly different standard deviations, it is necessary to undertake an analysis of the data across a large number of tests to see whether in fact different classes have different means and to decide which classes of carpets can be considered to be "in control".

4.4.3 ANALYSIS BASED ON NORMAL DISTRIBUTION

If we assume the SRV from the carpet test samples are of a Normal distribution, we can use these test data to calculate the 99.9% lower bound of a new (future) sample, based on the assumption that the new/future carpet will also come from the same population as the test samples, using the following mathematical formula:

$$99.9\% \text{ lower bound} = \text{average} - qt \times SD \times \sqrt{(1+1/N)}$$

where:

average = the average SRV of the test data

N = test sample size

SD = standard deviation of SRV from the test data

qt = is the t-distribution quantile for probability 0.999 and (N-1) degree of freedom, which equals to the sample size minus one. Table 2 gives examples of qt for various sample size with 99.9% probability. It can be seen that it starts (with a sample size of 2) very large and converges to just above 3 very quickly.

Table 2: Examples of t-distribution quantiles for various sample size.

Sample size	qt value
N = 2	318.3
N = 3	22.3
N = 4	10.2
N = 5	7.2

N = 6	5.9
N = 7	5.2
N = 8	4.8
N = 9	4.5
N = 10	4.3
...	...
N = 100	3.2
...	...
N = 200	3.1
...	...
N = 2,000	3.09

From the above formula, it can be seen that the 99.9% lower bound depends on many factors including the sample average (i.e. the starting point), the sample standard deviation (i.e. the spread of sample), and the sample size which determines qt and the mathematical term √(1+1/N), which works on a reverse sense (i.e. larger the sample size, smaller the √(1+1/N) term).

It should be pointed out that if there is no spread in the sample (i.e. all samples have the same value), then its 99.9% lower bound will be equal to its average value.

Table 3 provides eight hypothetical examples to show the effects of sample spreading/ variance and the sample size, and the numbers marked *red italic* on the right column indicate that they are below the criterion of 35.

Table 3: Examples of 99.9% lower bound values for various hypothetical samples.

Example No.	hypothetical SRV	99.9% lower bound of SRV
1	36 36	36
2	36 37	*-239.2*
3	36 36.01	33.2
4	36 36.001	35.7
5	87 88	*-188.2*
6	87 87.1	59.5
7	87 87.2	*32.0*
8	87 87 88	72.4

The explanation of the above table is as follows:

Eg 1. The first row of this table shows the argument above that, if there are only two samples even though their SRV are as low as 36 (just above the limit), their 99.9% lower bound will also be 36, hence satisfying the criterion.

Eg 2. If the only two samples now have their SRV values changed to one unit apart, i.e. 36 and 37, then their 99.9% lower bound is -239.2!

Eg 3. Following on with Eg.2, even if we artificially make the two SRV only 0.01 unit apart (although we are aware that the current SRV measurement contains no decimal points), they still will fail to meet the criterion.

Eg 4. Following on with Eg.2 and Eg.3, mathematically it can only take a 0.001 unit difference (this depends on the average value) in order to make their 99.9% lower bound to be above 35.

Eg 5. Now let us check the other end of SRV value, i.e. 88 (the largest value represented in the current test data) and it still cannot accommodate the spread of 1 unit.

Eg 6. However, a 0.1 unit spread at this level is OK, which is quite different from the case of SRV = 36 (see Eg.2 to Eg.4).

Eg 7. But it cannot take a difference of 0.2 unit.

Eg 8. Now, what about three samples instead of two? It can take a whole unit spread at the high end of SRV.

These examples show that with a small sample size, any small variance or inaccuracy will lead to a vastly different result. For accurate and stable analysis, a large sample size is usually desired.

Coming back to our test dataset, just as a matter of interest, if we treat all test samples as though they came from the same distribution (this assumption almost certainly untrue), and we calculated the 99.9% lower bound using all 102 SRV values together, the result we get is 31.2. Using this overly simple method does not satisfy the criterion.

4.5 Summary of Non-Compliances and Methodology

The following table summarises the assessment in accordance with the NCC. Each row identifies which D-t-S clause of the NCC is not complied with and then the various performance based clauses.

Table 4: Summary of the non-compliances, Performance Requirements

Item	BCA D-t-S non-compliance	Performance Requirements	Performance Solution	Meeting Performance Requirement as per A	Assessment methods as per A2.2
	Class 1 and 10				
1	Clause 3.9.1.4 Slip Resistance - (a) treads and (c) landings "Some carpet systems will not be tested. Acceptance will be based on existing test data and statistical analysis".	P2.5.1	Show that the probability of carpet failing the test is less than 0.001	A2.2(1)(b)	2(a), (b)ii and (d)
	Class 2 to 9				
2	Clause D2.10 (c).- ramps not steeper than 1:14 "Some carpet systems will not be tested. Acceptance will be based on existing test data and statistical analysis".	DP2(c)(i)	Show that the probability of carpet failing the test is less than 0.001	A2.2(1)(b)	2(a), (b)ii and (d)
2	Clause D2.13 (a)(v) stair treads "Some carpet systems will not be tested. Acceptance will be based on existing test data and statistical analysis".	DP2(c)(i)	Show that the probability of carpet failing the test is less than 0.001	A2.2(1)(b)	2(a), (b)ii and (d)
2	Clause D2.14(a)(ii)(A) stairway landing "Some carpet systems will not be tested. Acceptance will be based on existing test data and statistical analysis".	DP2(c)(i)	Show that the probability of carpet failing the test is less than 0.001	A2.2(1)(b)	2(a), (b)ii and (d)

5 Carpet Characteristics

5.1 Carpet Manufacturing Methods

Carpet is manufactured in a number of ways. The most commonly used methods are:

- Tufted
- Woven - Axminster and Wilton
- Other: e.g. bonded, flocked, etc.

Tufted and woven carpets are sold for both domestic and commercial installations. Woven carpets traditionally form the high end of the market, while tufted carpets span the market from economy styles to high end. Modular carpets are used mainly in commercial installations.

Today, tufted carpet (both broadloom and modular tile) has over 90% of the Australian market.

The fibres used in the carpet pile yarns are usually wool, nylon, polypropylene, polyester and triexta or a combination of these with wool and wool rich carpets (≥80% wool) forming about 15% of the market.

5.2 Carpet Styles

Cut pile and loop pile are the standard carpet constructions. Their combination creates a cut and loop pile combination structure.

5.3 Types of Carpet Manufacture

5.3.1 WEAVING

The pile yarns are held between warp (lengthwise) yarns of Jute, cotton and/or synthetic fibres and weft (crosswise) yarns of jute and/or synthetic. The production looms use complex versions of the standard over and under weaving technique.

The backing produced by the weaving process is sufficient to stabilise the carpet and no additional backing is applied although on occasions a latex size is applied to stiffen the carpet.

Wilton

Wilton carpet manufacture consists of many painstaking and laborious processes. Several loom types are used to manufacture a variety of carpet constructions where single frame Wilton and Jacquard and multi frame Wilton produce the woven carpet. Wilton carpet is typically 100% wool or 80% wool/20% nylon.

Axminster

Axminster carpets are woven in two distinctly different types of looms; these are the spool Axminster and the gripper Axminster. Axminster is typically 100% wool or 80% wool/20% nylon.

5.3.2 TUFTING

A great variety of needle gauges, pile heights and pile styles are created by modifying the tufting process. Needles are fitted into the needle bar, which is driven by the eccentric shaft in a reciprocating fashion. The needles extend across the width of the tufter, the number depending on the gauge and width of the machine. A tufted carpet consists of a number of layers:

- The wear layer – the pile surface of the carpet. This can vary from say 2.5mm to 16mm above the backing depending on the quality of the carpet being produced.
- The primary backing – this is normally a sheet of woven polypropylene fabric. It can also be a layer of non-woven polyester.
- The secondary backing – this is a layer of woven jute or woven polyethylene and provides dimensional stability to the carpet.
- Latex – this is the “glue” that holds the layers together. It is applied between the primary and secondary backings and heat cured. It consists of filled (Calcium Carbonate, $CaCO_3$ or similar) latex.

5.4 Pile Types

Carpet pile can be either left as the loop that is formed during the weaving/tufting operation or the loops can be cut to provide a softer feel to the surface.

Loop pile is used primarily in commercial installations and low end residential installations where appearance retention is more important than underfoot feel. Cut pile tends to be more applicable in residential installations and high end commercial installations where underfoot feel has greater importance.

There are also a number of combinations of cut and loop combination pile, provided mainly for aesthetic reasons. Hi/Lo Loop and Multi-Level Loop are essentially the same, differing only in the number of levels of loops in the blend. Similarly Cut/Loop and Multi-Level Cut/Loop differ only in degree and position of the Cut and Loop piles in the design.

Axminster carpet is always cut pile while Wilton carpet and Tufted carpet can be either cut or loop pile.

The Pile Thickness (PT) is defined as the height of fibre above the substrate backing when measured in accordance with AS/NZS 2111.5.

Cut pile and loop pile carpet have been assessed in this report. Carpet with of cut and loop combinations pile have been excluded from this report as there was insufficient data available for the statistical analysis.

5.5 Carpet Installation

Carpet is mainly installed using one of three techniques.

- Conventional Installation
- Direct Stick Installation
- Double Bond Installation

These three techniques are used in a number of different circumstances which can be described as set out below.

AS 4586 does not require carpet to be tested in combination with the underlay, therefore the influence of underlay has been excluded from this report.

5.5.1 CONVENTIONAL INSTALLATION

Carpet is laid loose over an underlay and secured to the floor at the edges of the room using wooden strips with nail points protruding upwards to grip the carpet. The carpet is stretched into place to provide a taut surface on which to walk. Conventionally installed carpet is generally installed over an underlay of some description. See the attached table for details.

Conventionally installed carpets are used in most installation situations, both domestic and commercial. It is used across the whole range of carpet qualities from inexpensive to luxury. Woven carpets are usually a conventional installation.

5.5.2 DIRECT STICK INSTALLATION

Carpet is stuck directly to the floor without underlay using a water based adhesive applied in accordance with the adhesive manufacturers installation instructions.

5.5.3 DOUBLE BOND INSTALLATION

Underlay is adhered to the floor using a peelable adhesive and then the carpet is stuck to the underlay using a non-peelable adhesive similar to that used in direct stick applications.

Double Bond installation is primarily used in commercial installations where foot comfort is important and the substrate is in good condition (e.g. over concrete floors).

5.6 Underlay and Backing Types

The underlay types in common use in Australia are SBR latex, reconstituted fibre, rebond foam, rubber and hairfelt. Types of backing include:

- The primary backing –a sheet of woven polypropylene or non-woven polyester fabric.
- The secondary backing –woven jute or woven polyethylene.
- Latex – glue applied between the primary and secondary backings and heat cured.

The influence of underlay and backing has been excluded from this report.

6 The Data

The latest data file, received on 24 April 2015.

- Slip Resistance Test Results 24 04 2015.xlsx

There are a total of 122 lines of data, including four Brintons samples without SRV (slip resistance value) and three oil ramp test results, which were not included in our analysis.

Three lines of data have been removed from Grassman (1), Karndean (1) and Northstate (1) due to insufficient sample size.

Three samples have been removed all from GHA (Report Nos: 6973.1s, 6973.2s and 6973.3s), due to the fact that their test results were from an old method.

For consistency reasons, data from a further 6 tests were removed because these tests were performed with underlay, while all others were not.

This leaves us a total of 102 data points.

6.1 Data summary

Table 5 provides a summary of each of the variables (attributes) describing the carpets tested.

Table 5: Summary information for "Slip Resistance Test Results 01 05 2015.xlsx"

Attribute	Number of levels	Frequency
Report No.	N/A	All individual but there may be repetitions such as 6973.1Bs & 6973.2Bs, or were there for the same carpet but run tests from different labs.
Company	14	Beaulieu(10), Brintons (2), Cavalier Bremworth(Cav Brem)(11), Feltex(11), GHA(19), Interface(6), Norman Ellison(1), Ontera*(6), Quest(8), Supertuft(5), Tuftmaster(11), Victoria Carpets(VC)(12) *Note Ontera changed name and ownership of reports to Milliken-Ontera in 2015.
Name	Mostly unique but a few repeats	Angelia(2), Antiquity(1), Augusta Lane(1), Avatar(1), AX 928A(1), Ax1178FA(1), Ballad(1), Beauvais(1), Bellagio Twist(1), Canadian Bay(1), Carramar(2), Castilla Tile(1), Celine(1), Champs Elysees(1), City by City(1), Classic City(1), Colourbase(1), Consequence(1), Contexture 111(1), Contours(1), Coronet Peak(1), Critics Choice(1), Crossley Grey(1), Darebin 2827(1), Degree(1), Denim(1), Devon Place(1), Dyestart(1), Eclipse(1), Elaborate(1), Enchant(1), Evision(1), Escape Twist(1), Escape Valour(1), Essington(1), Galet (3030)(1), Groove(1), Hillendale(1), Hip Hop(1), Horden(1), In Home(1), Infinity 231 Tile(1), Izmit(1), Kingsgate Town(4), Knights Point(1), Landscape(2), Liberation Palazzo(1), Mantra Roebuck(1), Marquetry 529(1), Medallion(1), Mirimar(1), Mystic Charm(1), Net Effect B703(1), Nevada Sands(1), New Sensations(1), Ninth Island(1), Noble Plush(1), none(3), Pacific Cedar Plank(1), Pacific View(1), Paritea(1), Phoenician 48(1), Pineer Grecian(1), Pique 11(1), Plain Sailing(1), Pluto Desert Echo(1), Polygon 1(1), Queens Twist(1), Ravine(1), Ricarda(1), Riccarton(1), Rochford Street Vanilla(1), Royale Luxury(1), Rushcutter(1), Savior Faire(1), Scenic Walk(1), Soft Delight(1), St. Tropez(1), St. Helier(1), Stitched up(1), Straightforward Flatweave(1), Suits U(1), Sunrise(1), Tactics Mountain

		Lake(1), Tanzania(1), Terabyte(1), Tornado(1), Torridon 2541(1), Toulon 30(1), Tudor Twist Supreme(1), Twyne(1), Valley Charm(1), Verve 6528(2), Whenever(1), Willow Grove(1), Zion(1)
Attribute	**Number of levels**	**Frequency**
Carpet Code	Mostly unique but a few repeats	A-BL(2), A1-BL(1), … But basically two types: broadloom (BL)(85) and tile (T)(16) including tile with integrated backing (TIB)(1)
Type	3	Tufted (94), Woven (8)
Fibre	12	80W/10N/10PYR(1), 80W/20N(8), 80W/20S(1), 80W10N/10Poly(1), 80W20PP(2), 90W/10N(1), nylon(48), polyester(6), pp(3), triexta(4), wool(27)
Style	3	Cut pile(55), loop pile(47)
TPM	N/A	410 -2588 g/m^2
SPM	N/A	128 - 2349 g/m^2 and 1 with missing value
PT	N/A	0.8 - 15.2 mm
SRV	N/A	45 - 88
Class	2	P4(18), P5(84)

7 Data preparation

In order to examine the statistical significance of different types of carpet with respect to SRV, it is necessary to reduce the level of factors for some attributes based on their similarity effects. In particular, two attributes were examined and grouped: Carpet Code (i.e. the types of carpet) and Fibre (material).

7.1 Carpet Code

Though the values of Carpet Code appear to be all different, they all essentially belong to one of two types of carpet: (1) BL (broadloom) and T (tile) including TIB (tile with integrated backing). Hence, the values in Carpet Code column have been simplified to either BL (85) or T (17). Figure 2 shows the distribution of broadloom and tile carpet with respect to their pile thickness and SRV.

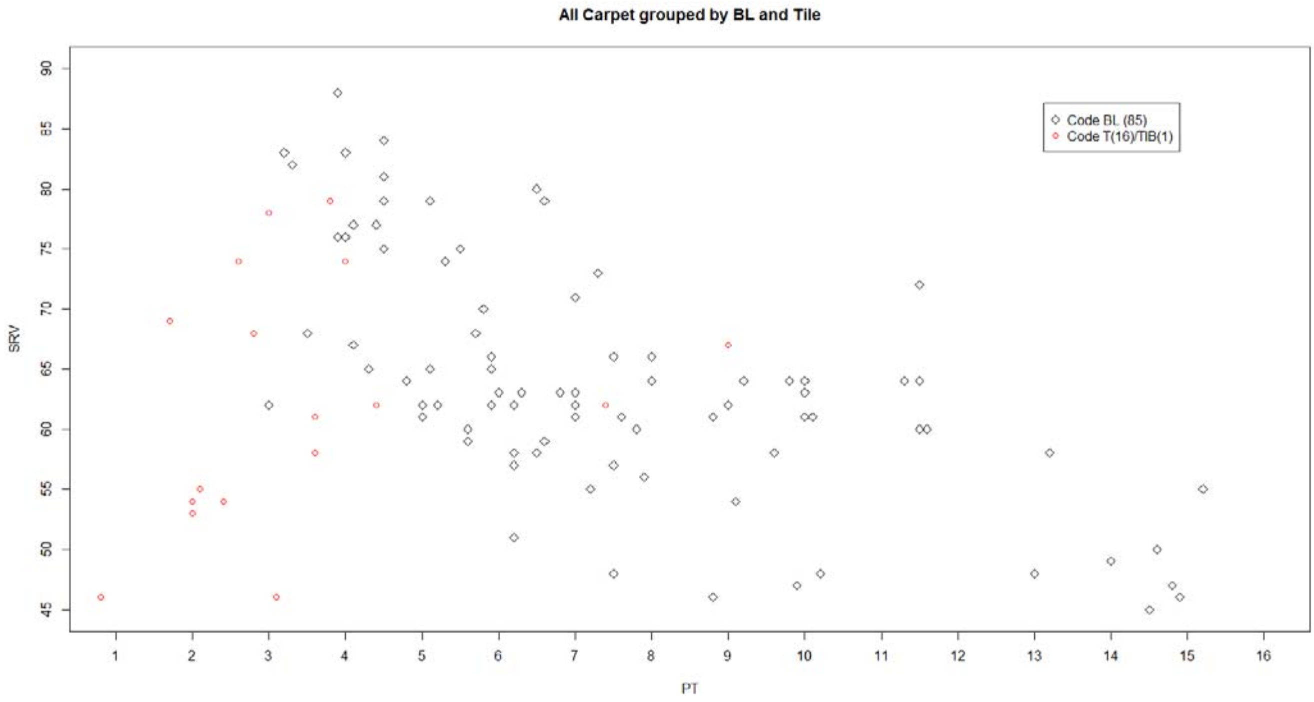

Figure 2: Distribution of broadloom (BL) and tile (T) carpet.

7.2 Fibre

Many kinds of materials have been used to produce carpet, but we may group them into three basic groups:

1. Wool rich (80% or more of wool, while the smaller proportion is synthetic fibre),
2. Nylon, and
3. "Poly" short for "*other polymer*" including non-nylon polymer fibre -polyester, polypropylene and triexta.

Table 6 lists the results of regrouping the Fibre attribute and Figure 3 displays their distribution on pile thickness vs SRV. It can be seen that Wool carpets in general fall into a middle range of SRV, while Nylon has shorter average pile thickness and covers a wider range of SRV. This plot provides evidence that each type of fibre (Wool, Nylon and Poly) has a distinctive relationship between pile thickness and SRV, hence our analysis and modelling have been based on each type of Fibre; for details see Section 9.

Table 6: Regrouping of Fibre values.

New group of Fibre name	Original Fibre name (sample size)
Nylon (48)	nylon (48)
Wool (41)	wool(27), 80W/10N/10PYR(1), 80W/20N(8), 80W/20S(1), 80W10N/10Poly(1), 80W20PP(2), 90W/10N(1)
Poly (13)	polyester(6), pp(3), triexta(4)

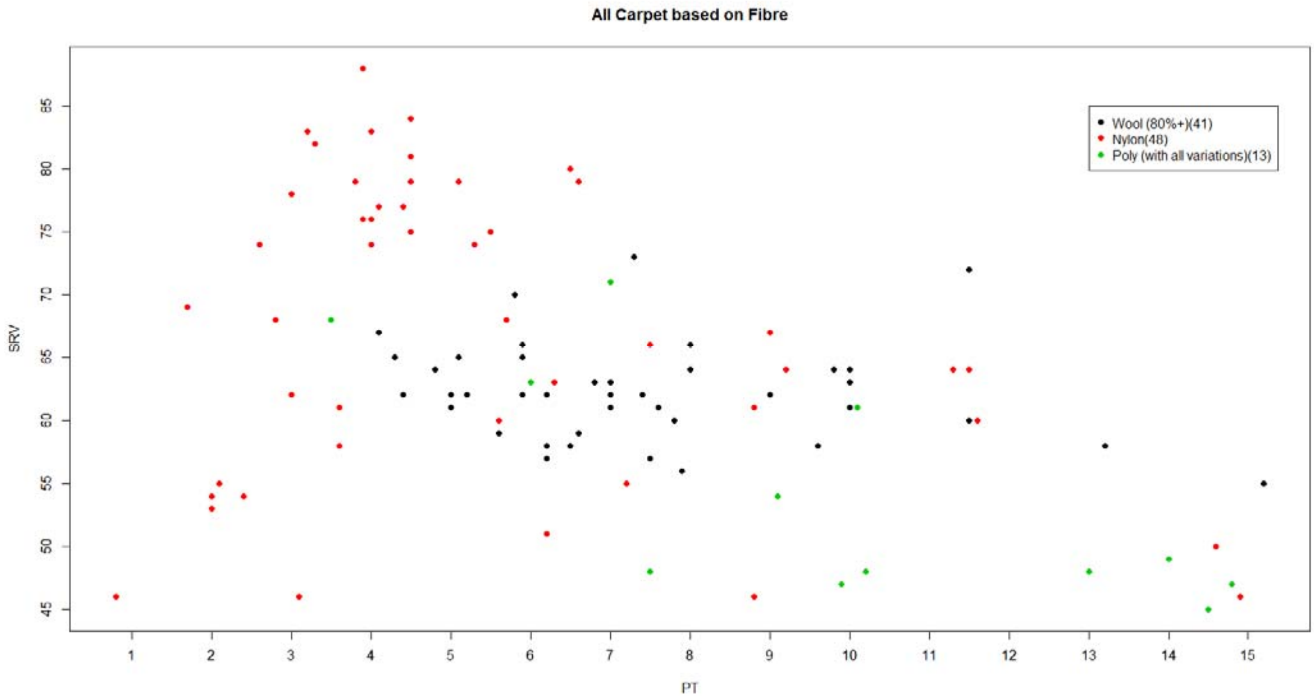

Figure 3: Distribution of Fibre types after regrouping.

Table 7 lists the counts for each combination of the two carpet pile styles and three carpet materials. Due to Poly Loop carpets only having an insufficient sample size of two, they are not included in this statistical analysis at this stage.

Table 7: Carpet counts based on pile Style and Fibre.

	Fibre			*total*
Style	Nylon	Poly	Wool	
Cut pile	22	11	22	55
Loop pile	26	2*	19	47
total	48	13	41	102

*insufficient sample size

8 Data visualisation

The purpose of data visualisation is to examine the data visually in order to identify any inherent linear or otherwise non-linear relationships between the independent variable(s) and dependent variable (i.e. SRV in our case), before detailed analysis takes place.

8.1 Histogram of SRV

First, let us look at the distribution of SRV using a histogram, see Figure 4. Note that the criterion requires the SRV to be at least 35, while the current test data minimum is 45 and average is 63.7.

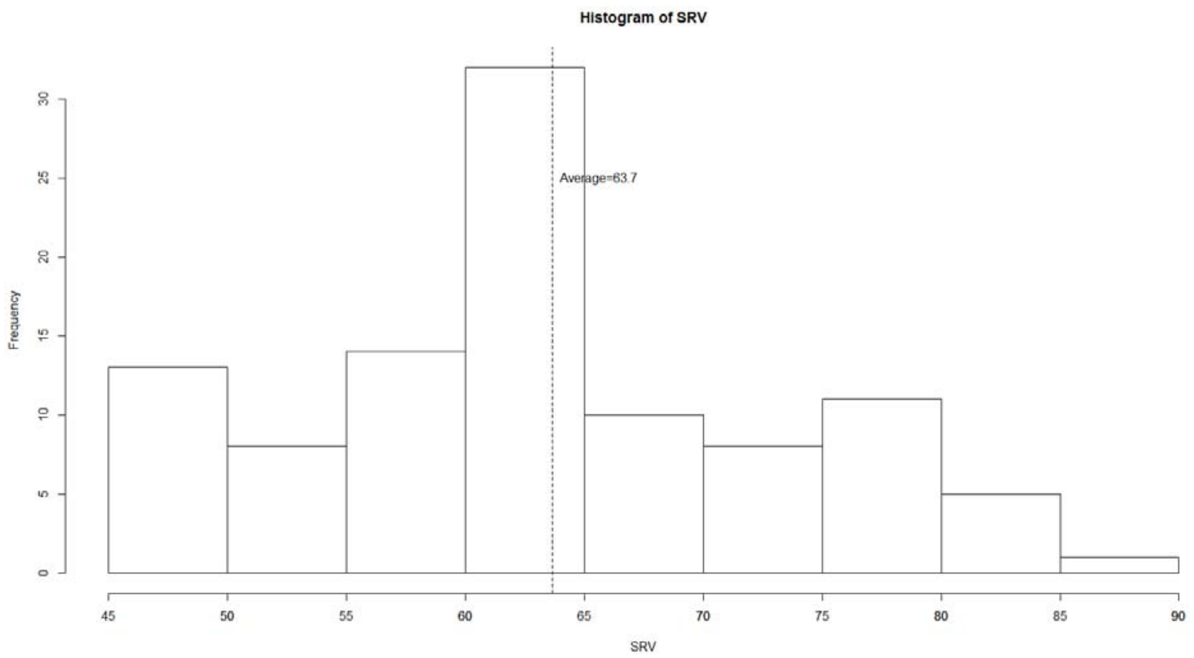

Figure 4: Histogram of SRV.

8.2 Cut and Loop Pile Styles

Another way of categorising the carpets is the cut pile and loop pile styles; see Figure 5. A general observation from the plot is that loop pile carpets have low and mid pile thickness but covers the entire spectrum of SRV values, while cut pile carpets do not have very short pile and exhibits an inverse relationship between pile thickness and SRV value.

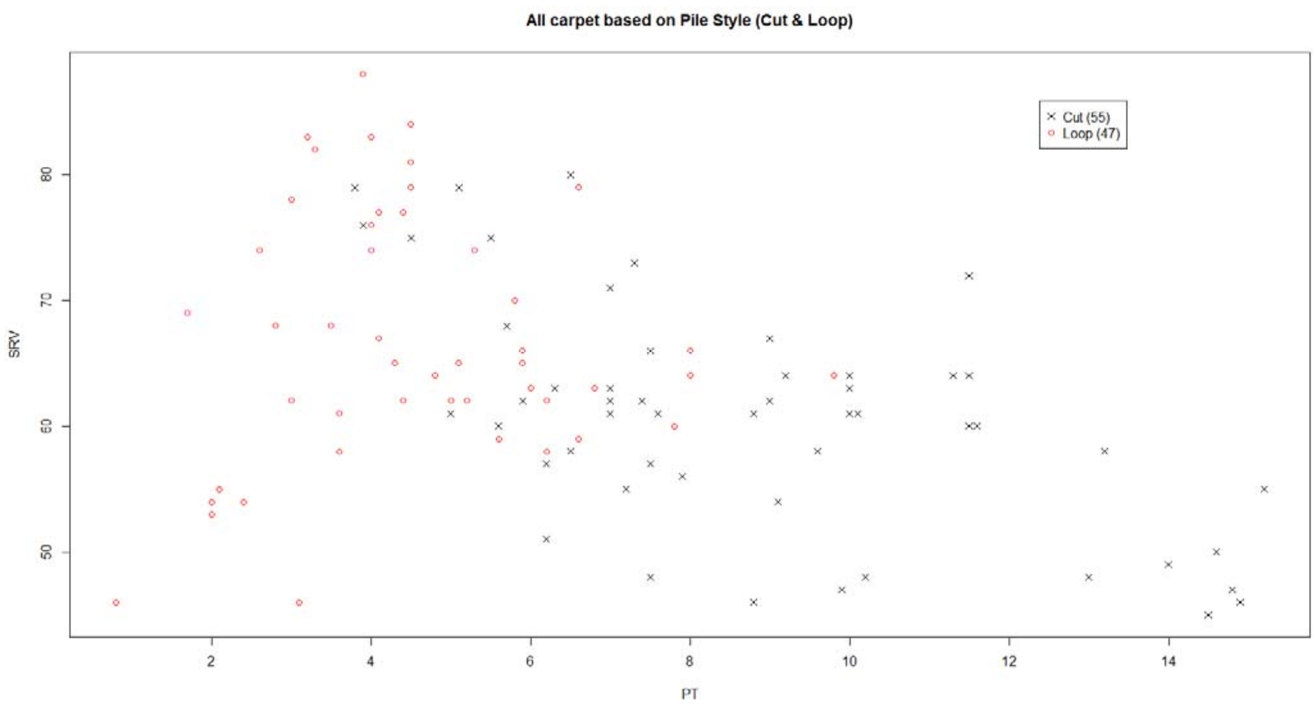

Figure 5: Distribution of Cut pile and Loop pile styles of carpet.

In Section 7, we have regrouped fibre into three main types of materials: Wool, Nylon and Poly, see Figure 3. Now let us examine Wool carpet alone, see Figure 6, which suggests a horizontal linear model, while Figure 7 does not support a separate modelling of the cut pile and loop pile carpet, respectively.

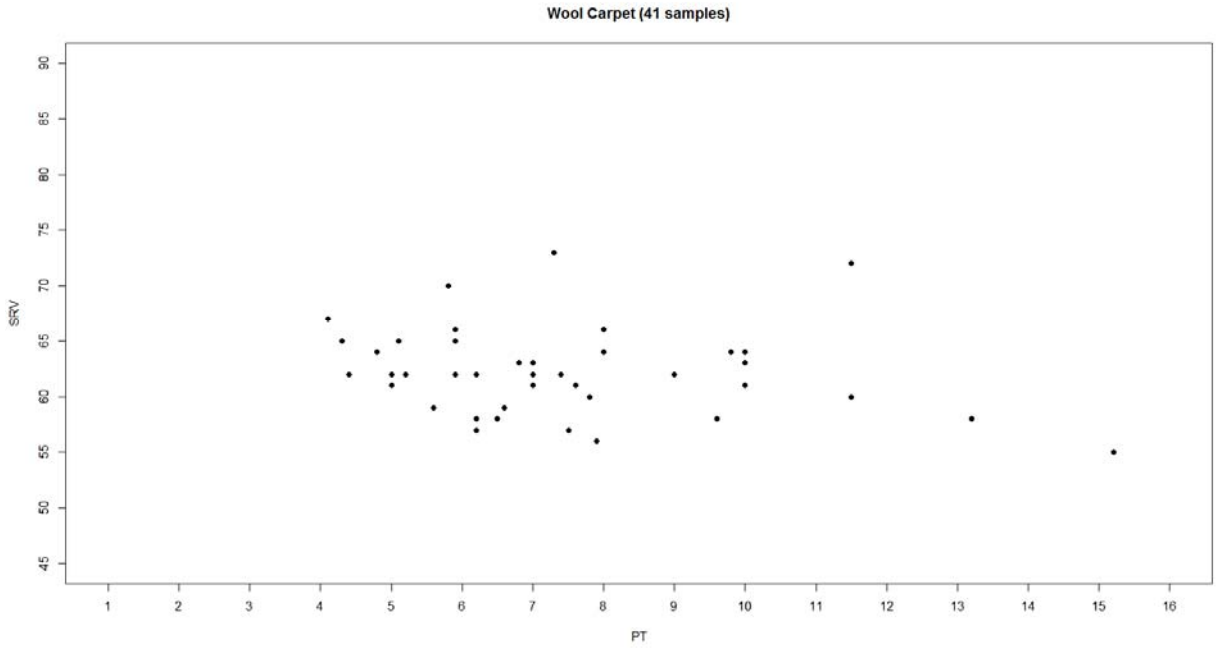

Figure 6: Distribution of Wool carpet.

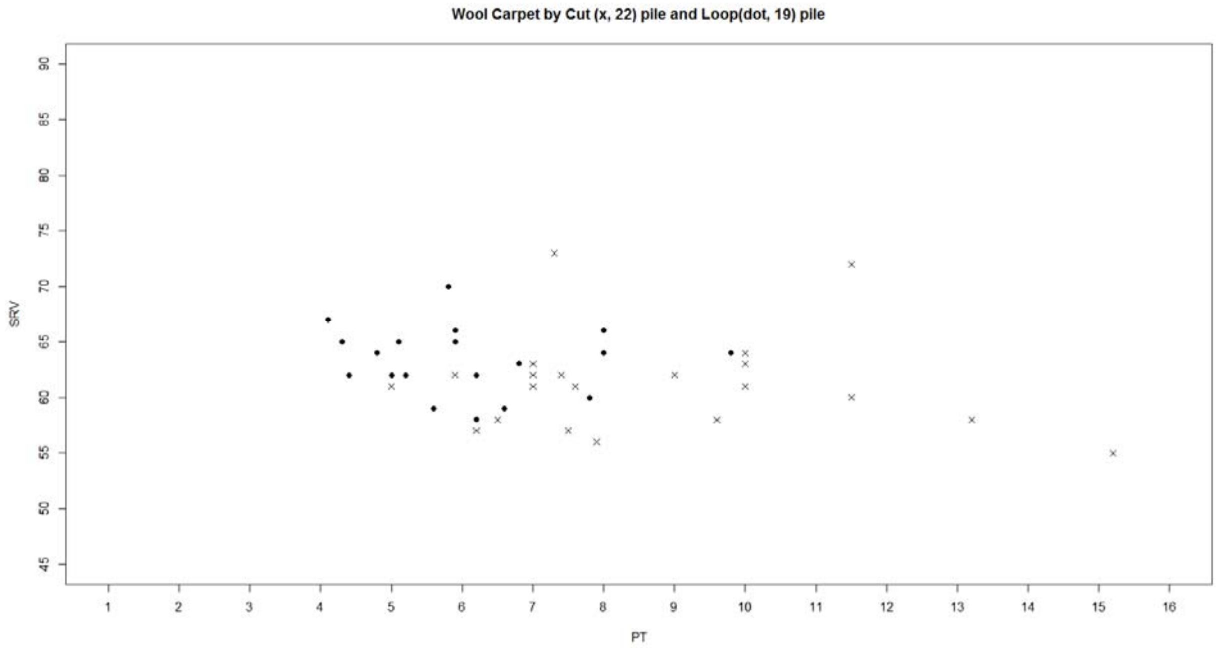

Figure 7: Distribution of Wool carpet based on Cut pile and Loop pile styles.

9 Analysis and modelling

9.1 Analysis of the Wool carpet

Statistical analysis on the Wool carpet resulted a horizontal line model (i.e. a line of average), see Figure 8. It shows that the average SRV for Wool carpet is 62.2 and its 99.9% lower bound is 49.1, well above the required SRV value of 35 shown as a red solid line. Therefore, we can conclude that all wool carpet with both Cut pile and Loop pile styles satisfy the criterion.

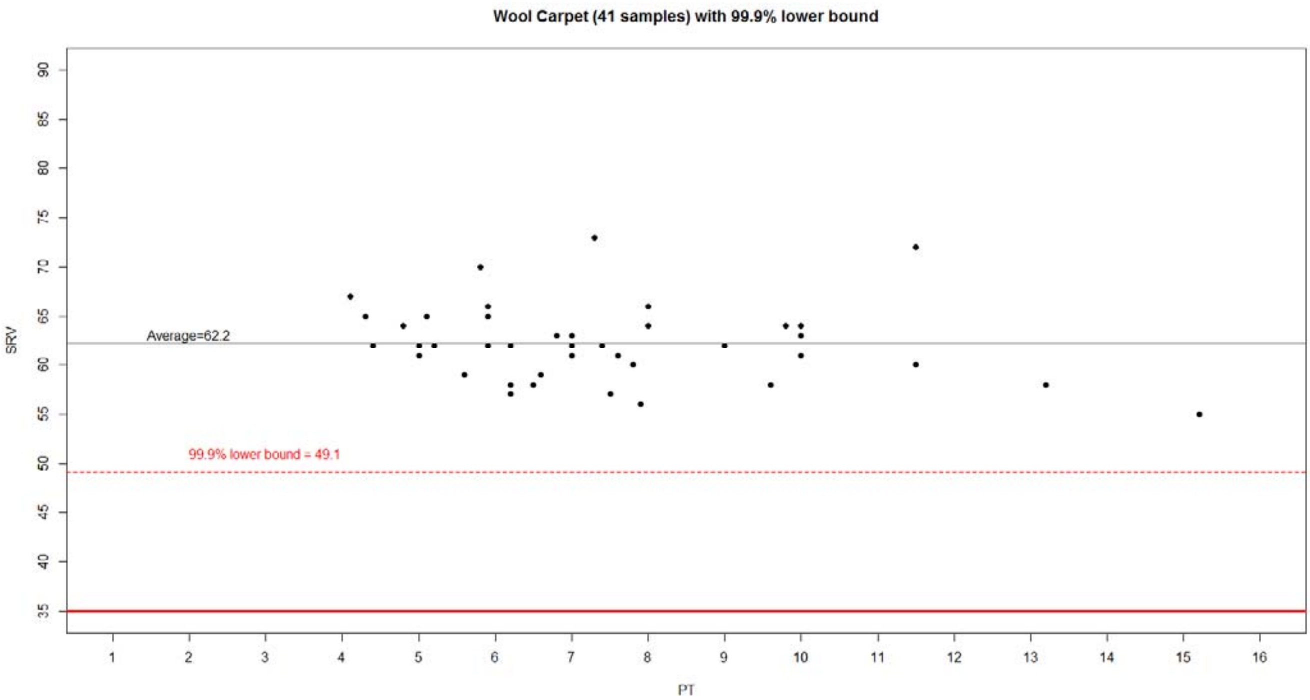

Figure 8: Modelling of Wool carpet.

9.2 Analysis of Nylon Loop pile carpet

Because there are distinct patterns between Nylon loop pile and cut pile carpets (see Figure 9 and Figure 13), it makes sense to model them separately. First, let us look at the Nylon Loop pile carpet shown in Figure 9 which displays a positive linear relationship between the pile thickness and SRV. Further examining their manufacturing types of broadloom and tile (see Figure 10), however, shows no evidence of requiring separate models, that is, the general positive trends (models) from these two types of carpets appear to be consistent though they seem to be located in two different regions.

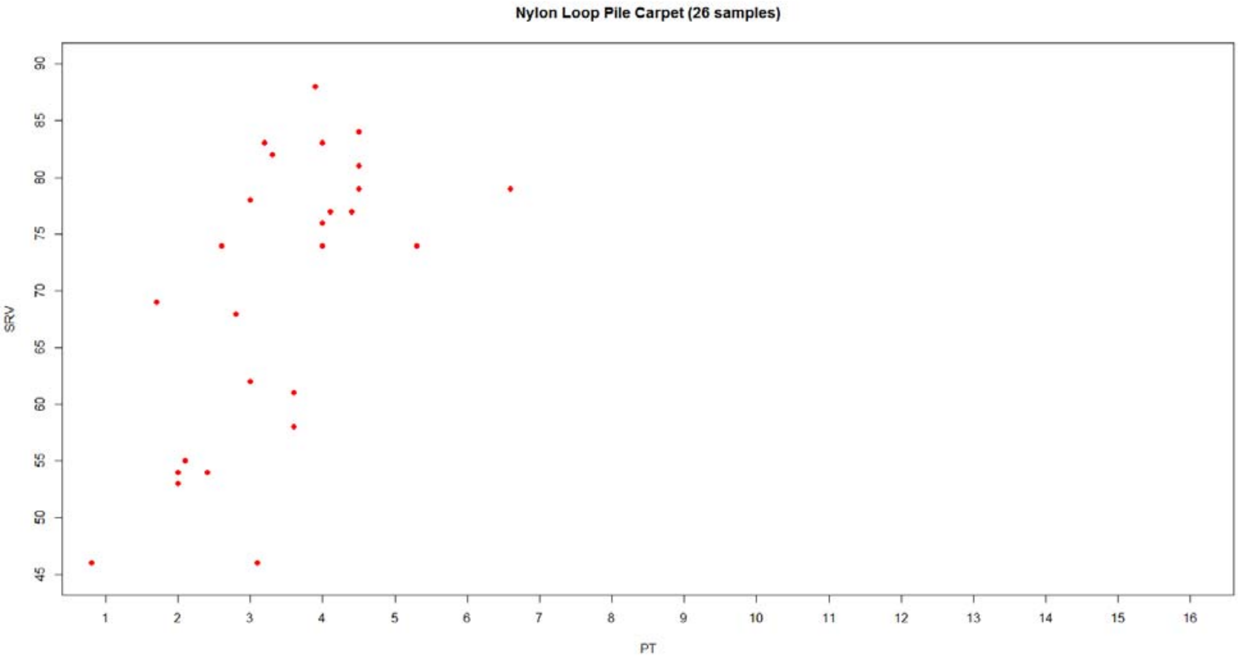

Figure 9: Distribution of Nylon Loop carpet.

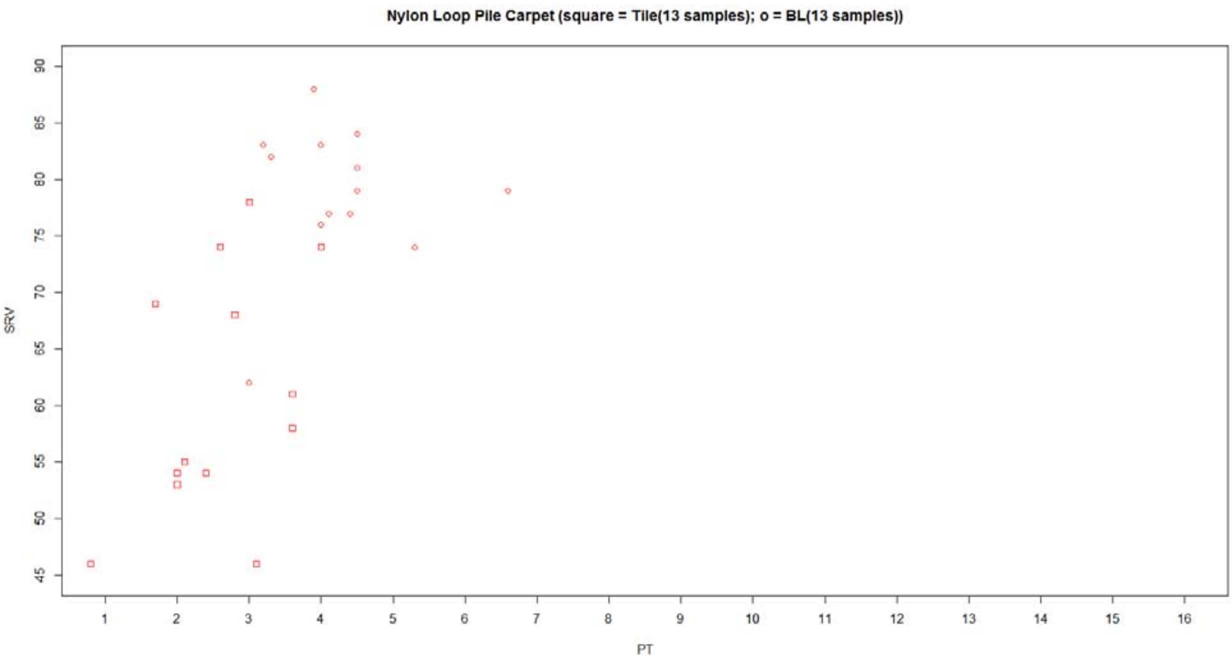

Figure 10: Distribution of Nylon Loop carpet with broadloom and tile separated.

A linear statistical modelling has been carried out on Nylon Loop pile carpet of 26 samples and resulted a statistically significant (p-value = 0.0003799) linear model:

$$SRV = 47.193 + 6.606 \times PT$$

and its 99.9% lower bound has also been estimated, see Figure 11. In order to satisfy the criterion, the feasible range of pile thickness is from 3.5mm to 6.6mm (which is the largest pile thickness from the test data) inclusive.

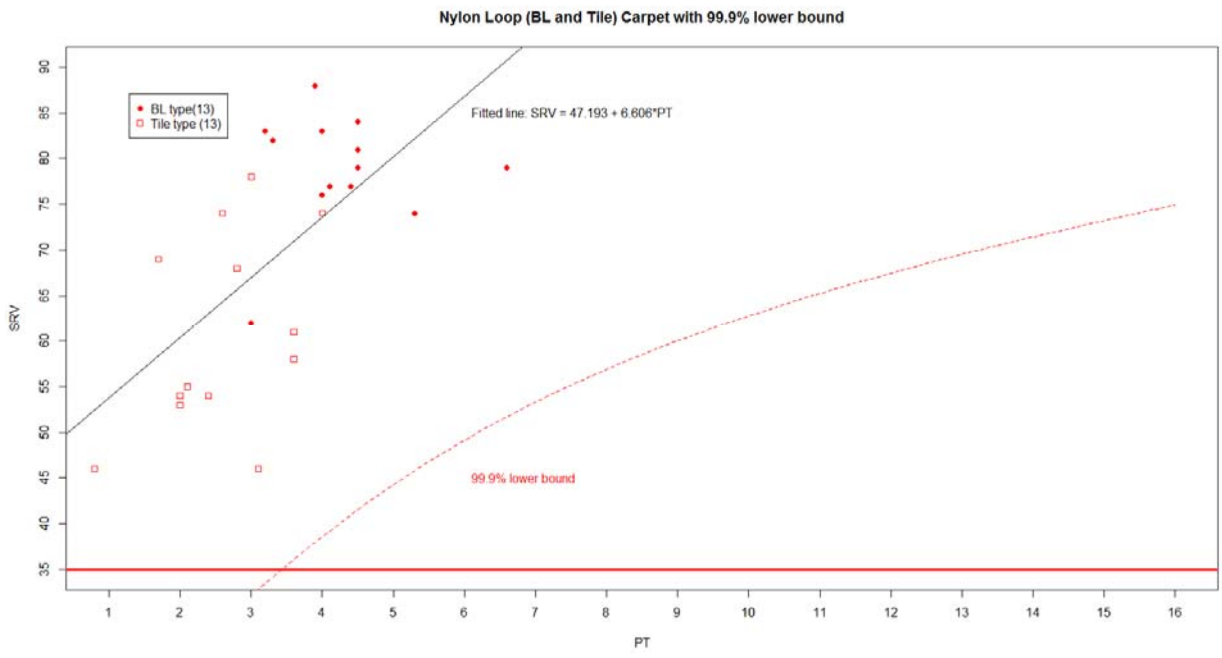

Figure 11: Modelling of Nylon Loop carpet.

A visual quality checking method is to plot the quantiles of the residual of fitted linear model against the quantiles from a Normal distribution. Such quantile plot for our Nylon Loop carpet model is shown in Figure 12, which appears a general straight line fashion, which suggests our fitted linear model is reasonable.

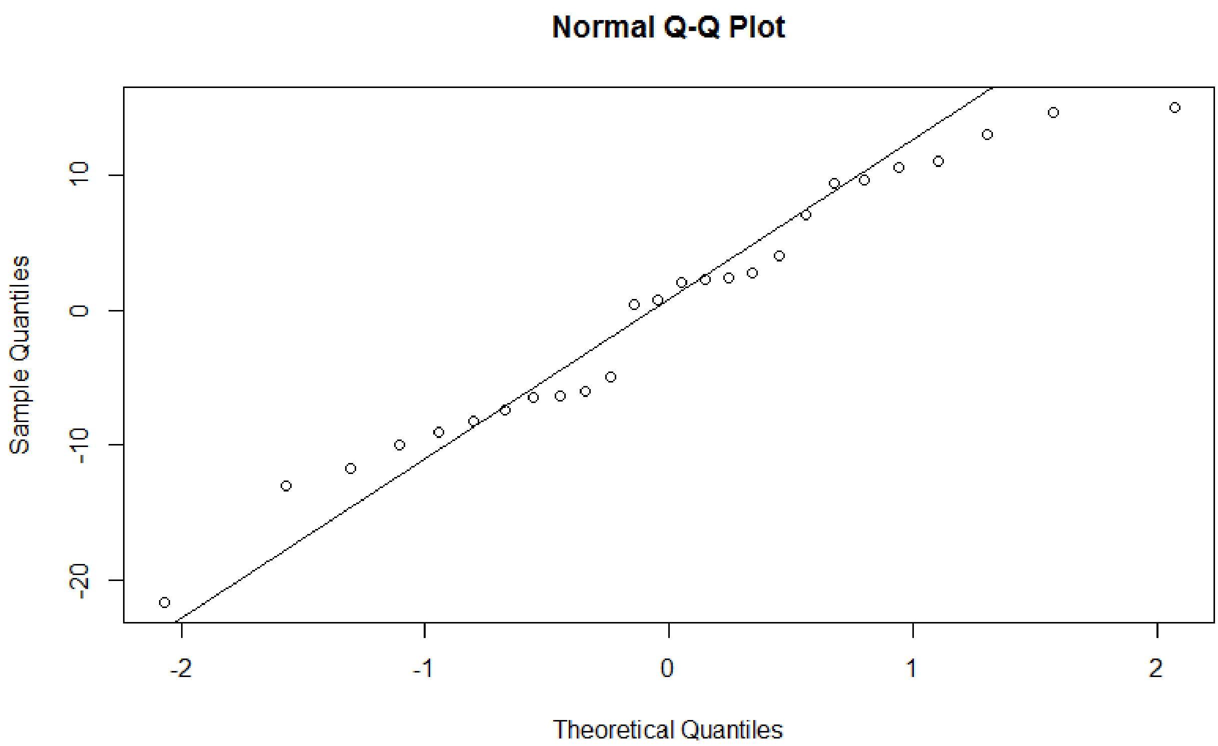

Figure 12: Quantile plot of the residual of linear model for Nylon Loop pile carpet.

Due to an insufficient sample size of only two samples, no statistical analysis was undertaken for Poly Loop pile carpets.

9.3 Analysis of Nylon Cut Pile and other Polymer Cut Pile Carpet

All the cut pile carpet samples from both Nylon (22) and Poly (11) have been plotted in Figure 13 and it has shown no evidence of supporting a separated modelling for each material, and most of them were the broadloom carpet.

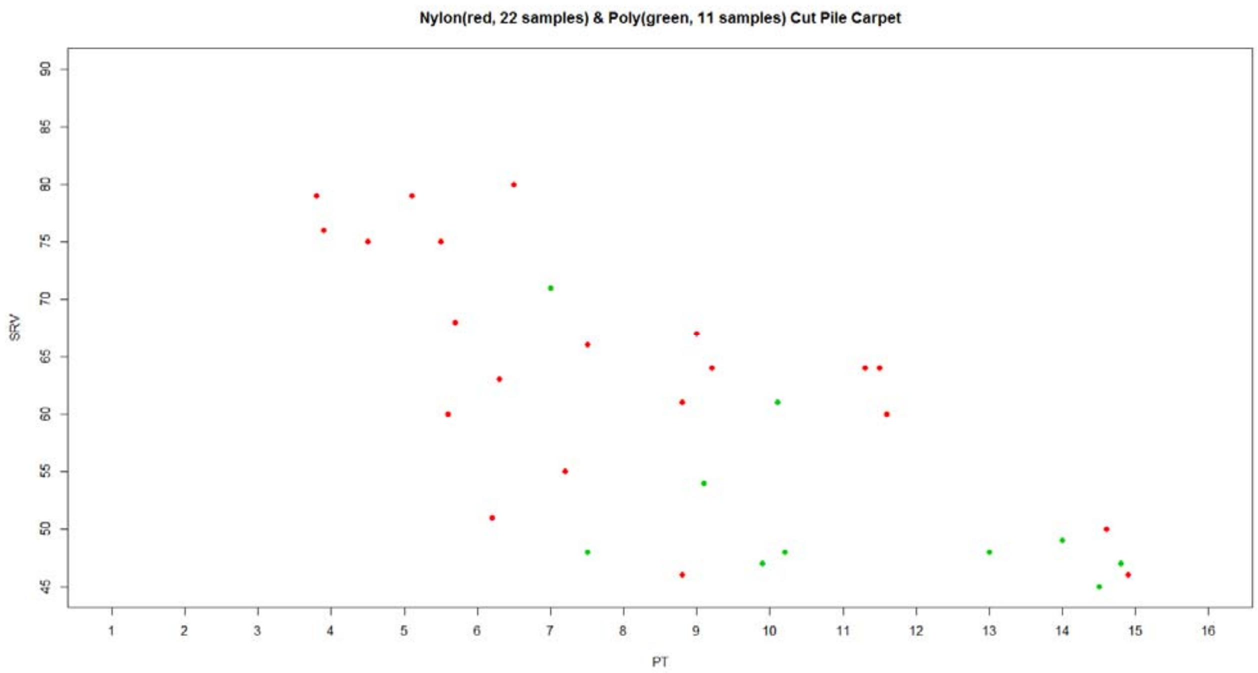

Figure 13: Distribution of Nylon Cut pile and Poly Cut pile carpet.

A linear statistical modelling of combined Nylon Cut pile and Poly Cut pile carpet has been carried out and resulted a statistically significant (p-value = 1.476e-06) linear model:

$$SRV = 82.94 - 2.486 \times PT$$

and its 99.9% lower bound has also been estimated, see Figure 14. The pile thickness for satisfying the criterion is from 3.8mm to 8.0mm, while the starting range was defined by the test sample.

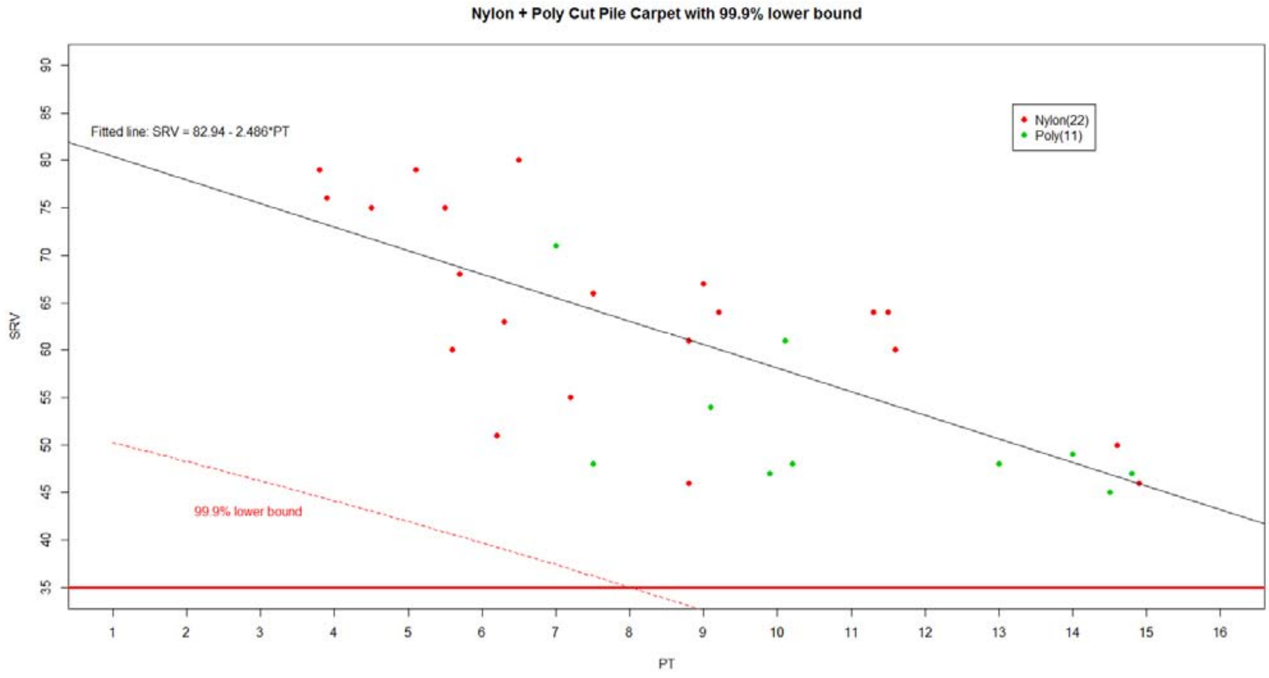

Figure 14: Modelling of Nylon cut pile and Poly Cut pile carpet.

Again, we have checked the quantile plot of the fitted residual of Nylon cut pile and Poly Cut pile carpet (see Figure 15) and it shows a general straight line pattern which supports our fitted linear model.

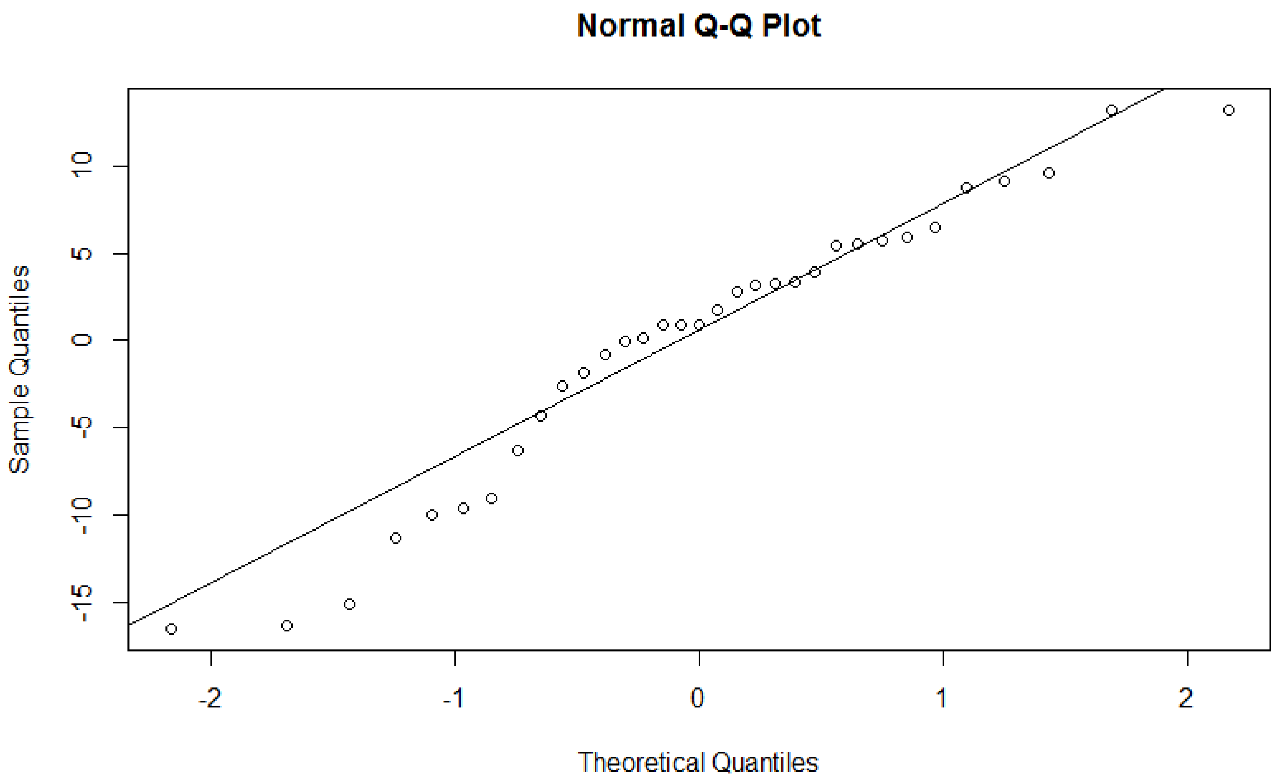

Figure 15: Quantile plot of fitted residual of Nylon and Poly Cut pile carpet.

9.4 Discussion and limitations

There are large variations presented in the current test data (see Figure 3 and Figure 5 in particular) which have not been totally captured/accounted for in our modelling and analysis exercise, this is due to the lack of data attributes/factors and the limitation of the current project scope. CSIRO is aware that there may be other factors which have not been captured in the current test data including carpet backing, underlay used and maybe others. From this point of view, adding extra test data may or may not improve the analysis results depending on where the extra data sit on the PT vs SRV plot and their spread. The adding of extra data will most likely result in the fitted models becoming better or worse, again, depending on where they sit.

10 Recommendations for future work

CSIRO would like to make the following recommendations:

1. Currently there were only two test reports for Poly (polypropylene, polyester and triexta) loop pile carpets, hence no analysis has been performed in this study. It is recommended that more test data should be supplied for future study.
2. This study was carried out only for cut pile and loop pile carpets because of constraints on supplied test data. Other pile styles such as Cut and Loop combination pile should also be analysed in a future study if such test data became available.
3. The role of underlay in the influence of slip resistance is not clear currently due to lack of relevant data. It is recommended that the relationship between underlay and slip resistance should be properly examined in a future study since most carpet is used with an underlay.
4. The role of carpet backing in the influence of slip resistance is not clear currently because backing detail was not included in the current test data. It is recommended that backing details should be recorded in all future carpet slip tests so that its relationship to slip resistance can be assessed in future.

11 Conclusions

11.1Overall Summary of Results

A statistical analysis was carried out on a body of data consisting of the slip resistance test results, in accordance with AS 4586 Appendix A, on a range of carpets. The analysis assessed the likelihood of compliance with the NCC BCA Volume 1 Class 2 to 9 buildings and NCC BCA Volume 2 Class 1 and 10 buildings requirements for dry surfaces including stair treads, ramps and landings. The relevant clauses require a minimum Slip Resistance Classification (SRC) of Class P3. The statistical analysis was performed based on 102 test reports of tests from two test laboratories. A probability that a carpet of similar construction determined to have a probability of failure (Classification less than P3) of less than 0.1% was considered to provide a level of safety that will satisfy the Performance Requirements DP2 of the BCA Vol 1 2019 and Performance Requirements P2.5.1 of the BCA Vol 2 2019.

Table 8 summarises our statistical analysis results (Section 9) of whether, with 99.9% confidence (that is, 1 chance in 1,000 of a non-complying result), samples of various types of carpets can be expected to exceed the minimum value of SRC of Class P3 as required by the NCC for stairs, landings and ramps. This depends on the fibre type, style and the pile thickness (PT). This implies that, for samples of carpets of the types identified, SRV values should have less than a 0.1% probability of not achieving the predicted performance if tested under AS 4586 Appendix A.

Table 8: Results from statistical modelling and analysis. Range of carpet which will achieve Classification not less than P3 and hence which can be considered to conform without further testing for stair treads, landings and ramps not steeper than 1:14.

Fibre Type			
Wool and wool rich (≥80% wool)	**Nylon**	**Other**	**Style**
OK for all PT 4.1mm≤PT≤15.2mm	OK for 3.8mm≤ PT ≤ 8.0mm		**Cut Pile**
	OK for 3.5mm≤PT≤6.6mm	*insufficient data*	**Loop Pile**

Based on the test data received and the statistical analysis of that data, carpets conforming to the above description and manufactured by Beaulieu, Brintons, Cavalier Bremworth, Feltex Carpets, Godfrey Hirst Australia, Interface, Norman Ellison Carpets, Milliken-Ontera, Quest Carpets, Supertuft, Tuftmaster Carpets and Victoria Carpets are covered by this assessment.

The interpretation of the above table is as follows.

This assessment provides evidence that at the 99.9% confidence interval (that is, 1 chance in 1,000 of a non-complying result), the following carpets will comply with the NCC requirements for slip rating on in Class 1 to 10 buildings without further testing for stair treads, landings and ramps not steeper than 1:14.

- Wool and wool/nylon blend carpets where the wool content is of 80-100% and the synthetic polymer content is a maximum of 20%, concluded that all carpets achieved Class P4 or better regardless of the fibre style (loop or cut) and pile thickness (within the range assessed).
- Nylon carpet in the following ranges:

a) Loop pile carpets, the pile thickness is between 3.5mm and 6.6mm;

b) Cut pile carpets, the pile thickness is between 3.8mm and 8.0mm;

- Other synthetic polymer carpets (polypropylene, polyester and triexta) cut pile style with pile thickness between 3.8mm and 8.0mm.

Note that the above results were based on statistical analysis of carpet samples tested without underlay, which means these conclusions are constrained by this test condition.

No conclusion could be made regarding Cut/Loop combination pile carpets.

No conclusion could be made regarding Loop pile carpets with fibre of other than wool or nylon (Polypropylene, polyester and triexta).

Where a conclusion on the expected SRV value for a carpet system could not be drawn, or where a tighter specification is required than shown here, the carpet must therefore be formally tested.

Ramps steeper than 1:14 are excluded from the conclusions of this assessment.

The Pile Thickness (PT) is defined as the height of fibre above the substrate backing when measured in accordance with AS/NZS 2111.5.

This report refers to 102 test reports. the sponsors of the referenced tests have provided permission for CSIRO to prepare this report in the name of the assessment sponsor being the Carpet institute of Australia Limited (CIAL).

11.2Proposed Testing Regime

Ongoing Quality Assurance of any system typically requires some testing even if it is a major reduction in the testing program for QA control, duty of care and risk mitigation. In consideration of these issues CSIRO recommend that CIA consider provide some level of testing of the carpet. The existing ACCS regime would provide a framework under which the testing can be performed.

11.3Term of Validity

This report will expire on the 1st day of May 2025.

12 References

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