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FIRE ENGINEERING ASSESSMENT OF WOOL RICH CARPETS FOR COMPLIANCE TO THE BUILDING CODE OF AUSTRALIA

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EXECUTIVE SUMMARY

A statistical analysis was carried out on a body of data (198 tests) consisting of wool and wool rich carpets tested according to the fire test AS ISO 9239 Part 1 to assess the likelihood of compliance with the BCA requirements for floor coverings for Class 2 to 9 buildings (BCA Volume 1, Specification C1.10a). The statistical analysis was performed based on 198 test reports of tests to AS ISO 9239.1 from NATA or ILAC accredited test laboratories. The criterion used was that a carpet of similar construction should have an estimated probability of failure on each test of less than 0.1%. This was considered to provide a level of safety that will satisfy the Performance Requirements CP4, of the BCA 2007.

Test reports for wool/nylon blend carpets where the wool content is of 80-100%, the Nylon content is a maximum of 20% and the Total Pile Mass (TPM) is 1060g/m^2 or greater were the basis of the assessment.

Table A summarises whether, with 99.9% confidence, samples of various types of carpets, where the wool content is of 80-100%, can be expected to exceed the minimum value of Critical Radiant Flux (CRF) required by the BCA for floor covering materials. This depends on the underlay, the pile type, the installation method and the weight (TPM). Also shown in the table is an indication of whether, with 99.9% confidence, those samples can be expected to have Smoke Development Rate (SDR) values below the maximum value required by the BCA for floor covering materials. The CRF and SDR values depend on the underlay and the weight (TPM). The types of carpets shown as achieving the CRF and SDR criteria are estimated to have a probability of 0.1% or less of failing the test at these levels.

No conclusion could be made regarding PVC backed carpet, FR Rubber underlay, or carpet tiles. Where a conclusion on the expected CRF or SDR 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.

This report is valid for carpet of the above description manufactured by Brintons, Feltex Carpets, Godfrey Hirst Australia, Quest Carpets, Tascot, Tuftmaster Carpets, Victoria Carpets, Cavalier Bremworth, Chaparral Carpet Mills and Supertuft.

Table A: Summary of Critical Radiant Flux and maximum Smoke Development Rate values that 100% Wool carpets and Wool/Nylon blend carpets with a wool content not less than 80% and with a Total Pile Mass in the range 1060g/m^2 to 3000g/m^2 achieve with probability 99.9% and hence which can be considered to conform without further testing.

Installation Method	Underlay	TPM (g/m^2)	CRF (kW/m^2) by Pile Type				SDR (%.min)
			All	Loop	Cut/Loop	Cut	
Direct Stick	**Nil**	**All**	4.5				750
Conventional	**Rubber, Felt, Reconstituted Fibre, Rebond Foam**	**All**	2.2				750
Double Bond	**Reconstituted Fibre**	**<1200**		4.5	4.5	2.2	750
		≥1200	4.5				750
	SBR Latex	**<2000**	4.5				750
		≥2000	2.2				750
	Rebond Foam	**All**		4.5	4.5	2.2	750

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TABLE OF CONTENTS

GLOSSARY

AHJ – Authority Having Jurisdiction.

BCA – Building Code of Australia

CIA – The Carpet Institute of Australia

CRF – Critical Radiant Flux

CHF – Critical Heat Flux

SBR – Styrene-butadiene rubber

SDR – Smoke Development Rate

TPM – Total Pile Mass the mass of fibre not including the backing or underlay expressed as g/m^2.

1 INTRODUCTION

An assessment was undertaken by the Fire Science and Technology Laboratories - CSIRO Division of Manufacturing and Infrastructure Technology, for the Carpet Institute of Australia (CIA). The study examines the range of the fire performance of pure wool and wool rich carpet when tested in accordance with AS ISO 9239 Part 1 [7].

The carpet was assessed in the context of an Alternative Solution that will satisfy the relevant Performance Requirements of the Building Code of Australia (BCA) Australian Building Codes Board2006. The process involved a statistical analysis of a body of fire test data on a range of carpets to assess the likelihood of wool rich carpet of a specified character will comply with the BCA requirements for floor coverings. 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) over a building compliance matter.

2 SCOPE OF WORK

2.1 General Description

The BCA requires all materials and combinations of materials for use in buildings, other than single dwellings (Class 1 and 10 buildings), to be tested for fire performance compliance. A brief overview of the results of wool/nylon blend carpets where the wool content is of 80-100% and the Nylon content is a maximum of 20%, the Total Pile Mass (TPM) is1060g/m^2 indicates that all tests have passed regardless of the underlay, 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 fire test data provided.
- Examine BCA framework and approach for the assessment.
- 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.

- Prepare a report concluding the assessment outcomes and limitations.
- Identify areas where further data is needed.
- Prepare a report concluding the assessment outcomes and limitations.

Stage 2. Update based on inclusion of further data.

- Revise the assessment including the additional data gathered.
- Prepare a report concluding the assessment outcomes and limitations. 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:

- Clause 2 of Specification C 1.10a of the Building Code of Australia which includes, for different classes of buildings and areas of use:
- a Critical Radiant Flux (CRF) of not less than 4.5kW/m^2 and a maximum Smoke Development Rate of 750 percent-minutes; or
- a Critical Radiant Flux (CRF) of not less than 2.2kW/m^2 and a maximum Smoke Development Rate of 750 percent-minutes.

The *critical radiant flux* is determined by testing according to AS ISO 9239 Part 1.
Carpet Specification assessed:

- 100% wool carpets, 1060g/m^2 and above; and
- Wool/nylon blend carpets where the wool content is a minimum of 80% and the Nylon content is a maximum of 20%, 1060g/m^2 and above

Typical installation techniques and underlay types include, but are not limited to:

- Conventional installation over felt underlay, rubber sheet underlay, reconstituted fibre underlay or rebond foam sheet underlay.
- Double Bond Installation over styrene-butadiene rubber (SBR) latex sheet underlay and reconstituted foam sheet underlay.
- Direct Stick Installation without underlay.

2.2 Report Basis

This report is based on:

(i) The BCA 2006, Building Code of Australia Volume 1, 2007 Edition Australian Building Codes Board2006;

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

(iii) Meetings with CIA on 23rd February 2007, 24th April 2007 and 7th December 2007.

3 OBJECTIVES OF THE STUDY

3.1 General Objectives

In simple terms, the objective of the study is:

1. Compliance with the Building Code of Australia (See Section 3.2).

3.2 BCA Objectives

The compliance of the fire properties of materials is covered under Section C of the BCA hence the objectives of the BCA relevant to this study are:

3.2.1 Fire Resistance:

- safeguard people from illness or injury due to a fire in a building; and
- safeguard occupants from illness or injury while evacuating a building during a fire; and
- facilitate the activities of emergency services personnel.

3.3 BCA Requirements

3.3.1 Deemed-to-Satisfy Requirements

Specification C1.10a of the BCA states:

> *A floor material or floor covering must have—*
>
> *(a) a critical radiant flux not less than that listed in Table 1; and*
>
> *(b) in a building not protected by a sprinkler system complying with Specification E1.5, a maximum smoke development rate of 750 percent-minutes.*

Critical radiant flux means the critical heat flux at extinguishment as determined by AS ISO 9239.1. The data provided to CSIRO used the term CRFFlameout to describe the critical radiant flux data. The term CRFFlameout was used throughout the analysis and is synonymous with critical radiant flux. Critical radiant flux is also known as critical heat flux and has units of kW/m^2.

Maximum smoke development rate means the maximum smoke development rate during the test as determined by AS ISO 9239.1 Annex A. The data provided to CSIRO used the term SmokeFlameout to describe the maximum smoke development rate data. The term SmokeFlameout was used throughout the analysis and is there synonymous with maximum smoke development rate. Smoke development rate has unit of percent x minutes (%.minute) or (percentage-minute).

Carpet used on walls, ceilings or as other building elements must comply with other Sections of the BCA and appropriate test methods.

The critical radiant flux is a level of imposed radiant heat below which sustained burning does not continue hence a high value of CRF pertains to a more onerous requirement or a better forming material.

BCA Specification C1.10a Table 1 Critical Radiant Flux (CRF in kw/m^2) of floor materials and floor coverings.

Class of Building	**General**		**Fire-isolated exits**
	Buildings **not** fitted with a sprinkler system complying with Specification E1.5	Buildings fitted with a sprinkler system complying with Specification E1.5	
Class 2,3,5,6,7,8 or 9b Excluding accommodation for the aged	2.2	1.2	2.2
Class 3 Accommodation for the aged	4.5	2.2	4.5
Class 9a Patient care areas Areas other than patient care areas	 4.5 2.2	 2.2 1.2	 4.5 4.5
Class 9c Resident use areas Areas other than resident use areas	 - -	 2.2 1.2	 4.5 4.5

3.3.2 BCA Performance Requirements

The relevant performance requirement of the BCA is CP4, which states that:

CP4 A material and an assembly must, to the degree necessary, resist the spread of fire to limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to—

(a) the evacuation time; and

(b) the number, mobility and other characteristics of occupants; and

(c) the function or use of the building; and

(d) any active fire safety systems installed in the building.

3.4 Proposed Alternative Solution

The proposed alternative solution is to document an assessment that provides an appropriate level of confidence that carpet within certain construction parameters will satisfy the BCA requirements.

3.5 Limitations

- This report does not assess the use of carpets as a building material other than use as a floor covering. The BCA requires testing of materials in accordance with various test methods for use as wall and ceiling linings and as other elements.
- This report does not apply to those situations where a person is involved, either accidentally or intentionally, with the fire ignition or early stages of development of a fire; building fire safety systems are not generally designed to protect such persons.
- This report does not encompass situations that involve fire hazards outside the range normally encountered in buildings, such as storage of flammable liquids, processing of industrial chemicals or handling of explosive materials.
- Conventional building design can only provide limited protection against malicious attack. Large scale arson, large quantities of deliberately introduced accelerants, terrorism and multiple ignition sources has not been considered. These events can potentially overwhelm some fire safety systems.
- The scope of a Fire Safety Engineering assessment is limited to compliance with the Building Code of Australia matters such as property protection (other than protection of adjoining property), business interruption, public perception, environmental impacts and broader community issues (such as loss of a major employer, impact on tourism etc.) 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 Deemed-to-Satisfy 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. Fire and its consequent effects on people and property are both complex and variable. Thus, a fire safety system may not effectively cope with all possible scenarios. 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 checking compliance of a carpet type for the specific building under consideration and lodgement with prescribed bodies. All practitioners should treat all fire safety 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 fire 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.
- 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 BCA Section A. The International Fire Engineering Guidelines Australian Building Codes Board2005 and the Engineers Australia – Society of Fire Safety Code of Practice for Fire Safety Design, Certification and Peer Review [5] have also been consulted.

4.1 Meeting the Performance Requirements

As stipulated in BCA Clause A0.5 (b), it will be shown that compliance with the Performance Requirements will be achieved by:

a combination of:
(a)compliance with D-t-S provisions; and
(b)(ii) is shown to be at least equivalent to the Deemed-to-Satisfy Provision.

4.2 Assessment Method

According to Clause A0.9 the Assessment Methods to be used will be:

(a) Evidence to support that the use of a material, form of construction or design meets a Performance Requirement or a Deemed-to-Satisfy Provision as described in A2.2.

(b) (ii) such other Verification Methods as the appropriate authority accepts for determining compliance with the Performance Requirements.

An Evaluation Extent Level 1 as defined by the International Fire Engineering Guidelines Australian Building Codes Board2005 shall be performed to evaluate the performance of proposed alternative solutions.

4.3 Verification Methods

The verification method will be the following:

- Review the fire 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.

4.4 Acceptance Criteria

In accordance with International Fire Engineering Guidelines Australian Building Codes Board2005, the following acceptance criteria shall be used to evaluate the performance of the fire engineering design of the building:

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 wool and wool-rich carpets to be approved as complying with the Performance Requirements in the BCA, they currently need to pass both of the requirements for CRF and SDR as determined in the AS 9239.1 test.
2. In order for wool and wool-rich carpets of a particular class to be approved as

complying with the Performance Requirements in the BCA, 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 of failing either of the two test requirements.

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. For example, the description of the Test method has an Annex B which gives the precision of the test method, in terms of its repeatability and reproducibility, obtained from a round robin exercise using 13 laboratories.

Repeatability provides the standard deviation (SD) related to the test method (same carpet, same laboratory, same operator), while reproducibility is a standard deviation where the same carpet is tested in a different laboratory by a different operator.

For example, for a Wool/Polyamide carpet (80/20), the mean Critical Radiant Flux at flameout (CRFFlameout) is given as 7.8 kW/m^2, and the reproducibility SD is given as 1.5 kW/m^2. Given that this is based on 13 laboratories, we assume that the SD has 12 degrees of freedom. Based on this, we can assess the probability of a carpet in this class having a CRFFlameout of less than 4.5 kW/m^2. This is given by

$$\text{Prob}(X < 4.5) = \text{Prob}\left\{ t_{12} < \frac{4.5 - 7.8}{1.5\sqrt{1 + 1/13}} \right\} = 0.028$$

Here, the symbol t_{12} represents a t-distribution with 12 degrees of freedom and tables or computer software can be used to determine the probability that the value of t_{12} is less than the number calculated. There is a sense in which this is likely to under-estimate the probability of failure. It is based on a single wool/polyamide carpet sent to a number of laboratories for testing. The variation (SD=1.5) is solely about the variation in the test method, and does not include a component for the fact that different wool/polyamide carpets will differ from each other. If we had tested a variety of such carpets, then the mean might well be different from 4.5, in either direction, but it is likely that the SD of 1.5 is an under-estimate. A larger value for the SD would lead to a higher probability of failing the test.

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 Montgomery, D. C.2004.

For comparison purposes the operational reliability of fire protection systems such as sprinklers, smoke detection and compartmentation have been estimated as in the range of 72 to 99.5% reliability [3].

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".

4.5 Summary of Non-Compliances and Methodology.

Table 4.1 Summary of the non-compliances, Performance Requirements

Item	BCA D-t-S non-compliance	Performance Requirements	Alternative Solution	Meeting Performance Requirement as per A0.5	Assessment methods as per A0.9
3	Specification C1.10a(2) floor materials. "Some carpet systems will not be tested. Acceptance will be based on existing test data and statistical analysis".	CP4	Show that the probability of carpet failing the test is less than 0.001	a and b(ii)	a and b(ii)

5 CARPET CHARACTERISTICS

5.1 Carpet Manufacturing Methods

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

- Tufting
- Weaving - Axminster and Wilton
- Modular carpet (tiles)
- 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.

The fibres used in the carpet pile yarns are usually wool, nylon, polypropylene, polyester or acrylic or a combination of these with wool and wool rich carpets forming about 30% of the market.

5.2 Carpet Styles

Tufted carpets were originally produced in loop pile, and in coarse or wider gauge qualities. Despite the efficient production methods, and good wear performance of the tufted carpets, they had little consumer appeal compared to traditional Axminster and

Wilton carpets, which could display various degrees of patterning, and which were available in cut pile styles.

In the 1960's major moves were made in simple patterning devices and the introduction of more suitable fibres and yarns. Possibly the most attractive feature of tufted was and is the production efficiencies and speed.

Tufted carpet manufacturers have gone a considerable way towards being able to produce pattern carpet indistinguishable from woven Axminster and Wilton carpets. Today, tufted carpet has about 90% of the Australian market.The market for carpet is split approximately as show in Table 5.1.

Table 5.1: Australian carpet market by style

Tufted	90%
Woven	5%
Modular (Carpet Tiles) and Other	5%

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.

5.3.1.1 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.

5.3.1.2 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

Modern tufting machines produce carpet in excess of the traditional 366cm (12 feet) in width, so that even after shrinkage from the backcoating process, the carpet can be trimmed to produce a final width of 366cm. 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 2.5mm to 16mm above the backing depending on the quality of the carpet being produced. In the range covered by this application, the pile thickness is likely to be 5mm or more.
- The primary backing – this is normally a sheet of woven polypropylene fabric of weight approx 115 g/m^2. It can also be a layer of non-woven polyester of similar density.
- The secondary backing – this is a layer of woven jute or woven polyethylene of weight approx 75g/m^2 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 of total density of approximately 820 g/m^2.

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 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.

5.5 Carpet Installation

Carpet is 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.

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 taught 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 at a rate of about 3.5-4 m^2/l.

This type of installation is primarily used for low end installations in spec. built flats and units to cheapen the installation cost or in commercial installations where the carpet is installed for aesthetic reasons and foot comfort is of less importance. Typically there is only one type/brand of glue used in the industry.

5.5.3 Double Bond Installation

Underlay is adhered to the floor using a peelable adhesive at a rate of about 10 m^2/l (typically there is only one type/brand of glue used in the industry) and then the carpet is stuck to the underlay using a non-peelable adhesive similar to that used in direct stick applications at about 2.5-3 m^2/l (typically there is only one type/brand of glue used in the industry).

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 Types

The underlay types in common use in Australia are listed in Table 5.2. These are the combinations of Material and Installation Method which are of interest.

Table 5.2: Underlay types in use in Australia

	Domestic	Commercial
Double Bond	Rarely used	SBR Latex – 5mm & 1400 g/m^2 Reconstituted Fibre – 6-7 mm & 900-1100 g/m^2 Rebond Foam – 5mm & 170 kg/m^3
Conventional Installation	Felt – 10-14mm & 1200 g/m^2 Rebond Foam – 8mm & 69 kg/m^3 Rubber – 7-9.5mm & 1700-3200 g/m^2. SBR Latex is not used.	Felt – 12-17mm & 1400-1800g/m^2 Rebond Foam – 7mm & 120 kg/m^3 Reconstituted Fibre – 9mm & 900 g/m^2 Rubber – 7-8mm & 1700-2360 g/m^2 SBR Latex is not used.

5.7 Carpet Type Assessed

The carpet assessed in this report and covered by the conclusions in this report are:

5.7.1 Pile Weight

The pile weight or Total Pile Mass (TPM) which is the mass of fibre not including the backing or underlay:

- 100% wool carpets of TPM of between 1060g/m^2 and 2880 g/m^2; and
- Wool/nylon blend carpets where the wool content is a minimum of 80% and the Nylon content is a maximum of 20%, with TPM of between 1060g/m^2 and 2429 g/m^2;

5.7.2 Pile Type

Cut and loop carpet.

5.7.3 Underlay

The types of underlay:

- Rubber up to 9.5mm & 1700-3200 g/m^2,
- Reconstituted fibre up to 14mm & 1550 g/m^2,

- No underlay (NIL),
- SBR Latex of up to 7mm thick and 2200 g/m^2,
- Rebond foam of up to 8mm and/or 120kg/m^3 and
- Felt of up to 17mm thick.

5.7.4 Manufacture Type

Woven (Wilton and Axminster) and Tufted carpet.

5.7.5 Backing Type

Types of backing include:

- The primary backing –a sheet of woven polypropylene or non-woven polyester fabric of weight approx 115 g/m^2.
- The secondary backing –woven jute or woven polyethylene of weight approx 75g/m^2.
- Latex – glue applied between the primary and secondary backings and heat cured of total density of approximately 820 g/m^2.

5.7.6 Application Method

Carpet is installed using one of three techniques.

- Conventional Installation
- Direct Stick Installation
- Double Bond Installation

6 THE DATA

The data assessment was done in two stages which are described as the “original assessment” [8] and a subsequent “update” (this report) following CSIRO receiving some additional data to provide information in specific areas. The data sets are described in Section 6.1 and 6.2.

In what follows, the various factors and variables used in the analysis will be represented with a capital letter (e.g. Weight, Pile and Installation Method). In addition, the levels which these factors are assigned in the data file (such as SBRLatex, RebondFoam, ReconFibre) are used as abbreviations in the analysis.

6.1 Original Data Sets

The original data analysis covered two data files. These were received on 1 March 2007 and contain some additions to the earlier data files received on 25 February 2007. In order to distinguish these, we have added a "2" to their names to distinguish them from those sent earlier. The data files are:

- CSIRO Data - Wool Only2.xls
- CSIRO Data - Wool Nylon2.xls

The first of these contains 146 rows, corresponding to 146 test results for carpets which are all 100% Wool. The second file contains 50 rows, corresponding to 50 test results for carpets which are 80−95% Wool and 20−5% Nylon.

All tests were carried out in a NATA or ILAC accredited laboratory. Results have been given back to the Carpet Institute and assembled into spreadsheets which have been provided to CSIRO for analysis. In these spreadsheets, the manufacturer's identity has been protected by replacing them with a numbered code to which CSIRO does not have the key.

Subsequent to the data files of 1 March, there were a number of minor changes which were notified by email (Emails from Bob Doyle, 2 May). These were in response to a number of queries that had been made about some of the data:

- Two samples from the Wool Only data were missing the SmokeFlameout value. These are shown below. For the second of these (Ref No.50), the Smoke Flameout value of 229 was recovered.

```
TestRef ManufID FibreType FibreDetails Pile ManufMethod Weight Underlay
     34       1      WOOL     100%Wool Loop      Tufted   1627   Rubber
     50       3      WOOL     100%Wool Loop      Tufted   1060   Rubber
TestRef       Install CRFFlameout SmokeFlameout Comment
     34  Conventional         6.0           NA    <NA>
     50  Conventional         6.1           NA    <NA>
```

- In the two data sets, there were seven samples which had Pile type "Cut or Loop". These were checked and amended as follows:

```
TestRef     Pile(was)      Pile(is)
195         Cut or Loop    Cut
196         Cut or Loop    Cut
197         Cut or Loop    Cut
240         Cut or Loop    Loop
241         Cut or Loop    Cut/Loop
252         Cut or Loop    Loop
253         Cut or Loop    Cut/Loop
```

- A number of samples (4 in the Wool Only file and 11 in the Wool/Nylon file) were listed as Nil Underlay with Conventional Installation. While it is possible to undertake the test method under these conditions, it was agreed that this was not a technique that would be used in practice and it was therefore decided to remove these15 test results from the data.

Once these modifications were made to the data files, they were renamed:

- CSIRO Data - Wool Only3.xls
- CSIRO Data - Wool Nylon3.xls

All summary tables and analyses listed below refer to these revised data files. There are now 142 and 39 test results, respectively, in the two data files.

Table 6.1: Description of pile categories and manufacturing methods

ManufMethod Pile	**Wool only**				**Wool/Nylon**			
	Tile	**Tufted**	**Woven**	**Total**	**Tile**	**Tufted**	**Woven**	**Total**
Cut	0	27	0	27	1	5	14	20
Cut/Loop	0	4	1	5	0	0	2	2
Hi/LoLoop	0	9	0	9				
Loop	1	91	1	93	0	17	0	17
MultiLevelCut/Loop	0	1	0	1				
MultiLevelLoop	0	7	0	7				
Total	**1**	**139**	**2**	**142**	**1**	**22**	**16**	**39**

Table 6.2: Description of underlay categories and installation methods

Install / Underlay	Wool Only				Wool/Nylon			
	Conv	Direct Stick	Double Bond	Total	Conv	Direct Stick	Double Bond	Total
-	0	26	0	26	0	16	0	16
Felt	2	0	0	2	1	0	0	1
FRRubber	5	0	0	5				
PVCBack					0	1	0	1
RebondFoam	1	0	1	2	1	0	3	4
ReconFibre	31	0	1	32	4	0	5	9
Rubber	60	0	0	60	3	0	0	3
SBRLatex	2	0	13	15	0	0	5	5
Total	**101**	**26**	**15**	**142**	**9**	**17**	**13**	**39**

We noted earlier that we need to identify "classes" of carpets and then find the properties of those classes. Clearly, very small "classes" will have properties which are very poorly estimated and it will not then be possible to make reliable estimates of the parameters. There are several ways of dealing with this:

1. Consolidation: Knowledge of the carpet industry could be used to assert that certain categories are highly likely to be very similar to other categories. This then has the dual effect of reducing the number of combinations, while at the same time increasing the number of tests in particular classes.
2. Exclusion: There are some combinations which are not seen as being similar to other carpets and which are so poorly represented that there is no chance of reliably determining their properties. In such cases, we will indicate that these should be tested individually as they arise.
3. A fortiori: Where there is a strong argument that a small class should be "not worse than" some other larger class, and where that is substantiated from the limited data available, we might conclude that the small class can be assumed to have similar properties (or better) to the larger class and might therefore not need additional testing.
4. Further testing: Where a class of carpets is relatively poorly represented but is considered to be an important class, recommendations may be made to obtain tests on further samples so that reliable estimates can be determined.

The judgments made at this stage, arising out of Tables 6.1 and 6.2 are:

- For Pile type, (i) Loop, Hi/Lo Loop and Multilevel Loop will be consolidated to a single class, and (ii) Cut/Loop and MultiLevel Cut/Loop will also be combined. This reduces the number of Pile types to three.
- There are only two samples which have Manufacturing Method as "Tile". There is no obvious class which these could be joined with. It is recommended that "Tile" carpets be excluded from the study and tested on an individual basis as they arise.
- For Underlay, there is only one PVCBack sample. (This sample is also one of the two "Tile" samples.) It is recommended that "PVCBack" underlays be excluded from the study and tested on an individual basis as they arise.
- Having removed "PVCBack", the DirectStick method is applied only with no underlay and will be regarded as a separate class.
- The FRRubber (FR=Fire Retardant) is a small class with only 5 samples, but should have properties superior to the Rubber class.
- It was noted earlier that SBR Latex underlay is not used with Conventional installation, only with Double Bond. Yet there are two samples here which are classified as SBR Latex underlay with Conventional installation. These have been left in the data set.

This reduced the number of Wool samples to 141 and the number of Wool/Nylon samples to 38. Even with these decisions, there were some combinations here with very small numbers of samples. One way to improve the numbers is to try analysing the data as a single data set, where we allow for differences related to the %Wool in the carpets, which will now range from 80% to 100%. In the earlier report, the data files were kept separate for the initial assessment, but then combined for the full analysis.

6.2 Additional Data Received in October

As a result of the initial analyses, CSIRO made recommendations for an additional (approximately) 8 samples for each of Rebond Foam underlay and FRrubber underlay, where the number of samples was insufficient to draw useful conclusions. Felt underlay similarly had too few samples to draw useful conclusions but it was recommended that no further samples be taken.

Further samples were obtained and these were supplied to CSIRO on 13 October 2007. These samples consisted of:

- 4 samples with SBR Latex underlay, with Double Bond installation,
- 10 samples for Rebond Foam underlay, with 6 Conventional and 4 Double

Bond installation, and with 6 Loop and 4 Cut pile,

- 10 samples with Felt underlay, all with Conventional installation, and with 6 Cut and four Loop pile.

Of the 24 additional samples, only 2 were Wool/Nylon mix. No additional samples were provided for FRRubber and it was agreed, in discussion with CIA, that FRRubber would be removed from the final analysis. When the three data sets were combined and FRRubber removed, there were a total of 198 samples and this is the data set analysed in this report.

7 ALL CARPETS

7.1 CRFFlameout (Critical Radiant Flux)

7.1.1 Determining the Effects of the Covariates

An analysis of the 198 values of CRFFlameout was conducted with all the covariates included. This first analysis shows that there are significant effects related to Pile, Underlay and Weight, and that there is a significant difference between Conventional and DoubleBond installation. It appears that there are no significant effects due to ManufMethod (Tufted vs Woven) or %Wool (given that all are at least 80% Wool). After deleting ManufMethod and %Wool from the list of factors considered, the full analysis (lmC4) shows the following.

- There are highly significant effects for Pile (P=0.0002), with Cut having average values 0.733 (SD=0.194) lower than Loop. Cut/Loop has values very similar to Loop.
- The largest differences are related to Underlay (P<0.0001). The largest class, Rubber, is used as the baseline. The major difference is due to the Direct Stick method which has no Underlay at all and which has CRFFlameout 1.813 (SD=0.233) higher than Rubber. None of the other Underlays have CRFFlameout significantly different from Rubber.
- Double Bond has CRFFlameout higher than Conventional installation by 1.272 (SD=0.362).
- A linear increase in CRFFlameout with Weight is evident (t=2.50, P=0.013). This effect has reduced substantially with the additional 24 data points.

The analysis was followed by production of a Normal Probability plot. The fact that this is close to a straight line is indicative that the data is behaving close to a Normal distribution, thus justifying the calculations of tail probabilities needed later on in this analysis.

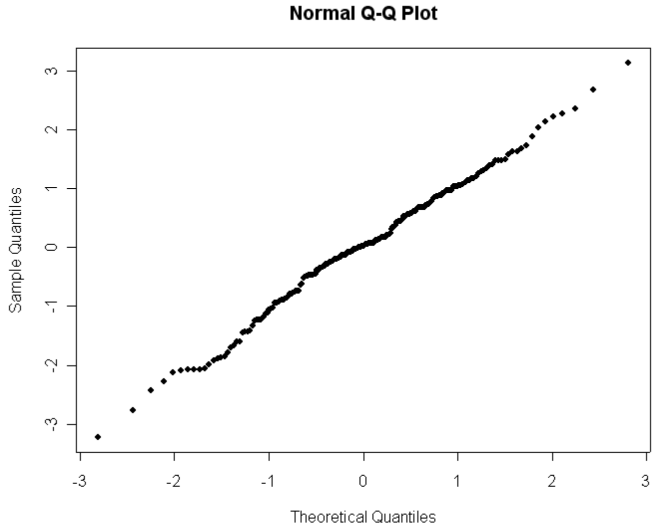


Figure 7.1: Normal probability plot for 198 residuals from analysis of CRFFlameout values

An analysis which looks at whether the linear effect of Weight depended on the Underlay class showed that these slopes did differ significantly between classes (P=0.009). However, it was apparent that this was largely due to the fact that there was an apparently negative slope relating to SBRLatex, while all other slopes were positive and effectively the same. A formal test of significance showed that there were no significant differences between the slopes of the other five underlay classes, so a common slope was used for these five classes, and a separate slope was used for SBRLatex.

The formulae thus obtained for CRFFlameout are summarised in Table 7.1. In producing this table,

- We have converted the Weight (g/m^2) to a centred variable W=(Weight-1477)/1000. The value of this is that the constants given refer to carpets with an average weight of 1477 g/m^2. The slope then shows how the CRFFlameout increases for each 1000 g/m^2 increase in the weight of the carpet.
- The formula in the left-hand column is obtained from an overall analysis of the 198 samples, using a common slope for Weight throughout. There is no evidence of significant differences between the slopes.
- The formulae in the right-hand column are obtained by fitting a model with one slope for SBRLatex and a common slope for the other 5 Underlay classes.

Table 7.1: Formulae for CRFFlameout for major classes, for Loop pile and Conventional installation. Additional terms are shown that need to be added in for a different pile and for DoubleBond installation.

Material	No.samples	Full analysis	Different slopes	Installation
Rubber (63)	Loop: 44 Cut: 17 Cut/Loop: 2	7.580+.0.767×W Cut: –0.733 Cut/Loop: -0.097	7.591+1.359×W Cut: –0.709 Cut/Loop: +0.149	All are Conv
ReconFibre (41)	Loop: 26 Cut: 13 Cut/Loop: 2	8.119+0.767×W Cut: –0.733 Cut/Loop: -0.097 DoubleBond:+1.272	8.060+1.359×W Cut: –0.709 Cut/Loop: +0.149 DoubleBond:+1.281	6 are DoubleBond
DirectStick (41)	Loop: 32 Cut: 8 Cut/Loop: 1	9.393+0.767×W Cut: –0.733 Cut/Loop: -0.097	9.417+1.359×W Cut: –0.709 Cut/Loop: 0.149	
SBRLatex (24)*	Loop: 14 Cut: 6 Cut/Loop: 4	7.958+0.767×W Cut: –0.733 Cut/Loop: -0.097 DoubleBond: +1.272	8.088-0.859×W Cut: –0.709 Cut/Loop: 0.149 DoubleBond:+1.281	22 are DoubleBond
RebondFoam (16)*	Loop: 9 Cut: 7	7.665+0.767×W Cut: –0.733 DoubleBond: +1.272	7.580+1.359×W Cut: –0.709 DoubleBond:+1.281	8 are DoubleBond
Felt (13)*	Loop: 7 Cut: 6	7.384+0.767×W Cut: -0.733	7.433+1.359×W Cut: –0.709	All Conv

* An extra 10 values for each of RebondFoam and Felt, and 4 for SBRLatex.

7.1.2 Presentation of the Data

The final model here is quite complex. We have a different line for each of the six Underlay classes, based on the Underlay and the Weight, but then we have further adjustments to those models based on the Pile and the Installation Method.

We can reduce the number considered as follows:

- For Rubber underlay, we have three lines corresponding to the Pile types. However, Cut/Loop is very similar to Loop and so the probability of failure for Cut/Loop will be very similar to Loop. Hence we only need to consider Loop and Cut. All are Conventional installation.
- For ReconFibre underlay, the same applies, but we also have two more lines corresponding to the DoubleBond.
- For Direct Stick, as for Rubber, we only need to look at Loop and Cut.
- For SBRLatex underlay, we have Loop and Cut as with the others but we will calculate these only for DoubleBond, since the earlier material suggests that Conventional installation is not applicable for SBR Latex underlay.
- For Rebond Foam underlay, we have Loop and Cut for Conventional

installation, but we will have two more lines for DoubleBond,

- For Felt underlay, we have Loop and Cut for Conventional installation only,
- The data can now be plotted, with the fitted lines in place.

To make it easier to see, we break these up into three graphs, using the same axes for each:

- The first graph shows all the data for Rubber and ReconFibre. Six lines are plotted. In each case, the upper line of a pair corresponds to the Loop pile and the lower line to the Cut pile. The Cut/Loop line is virtually identical to the Loop line and hence is not shown.
- The second graph shows the data for DirectStick and SBRLatex. Here, there are just four lines, corresponding to Loop and Cut as before, but with DoubleBond shown for SBRLatex.
- The third graph shows all the data for RebondFoam and Felt. Six lines are plotted. In each case, the upper line of a pair corresponds to the Loop pile and the lower line to the Cut pile. The Cut/Loop line is virtually identical to the Loop line and hence is not shown.
- In each case, the darker line, corresponding to Cut, is 0.709 units below the lighter line, corresponding to Loop.

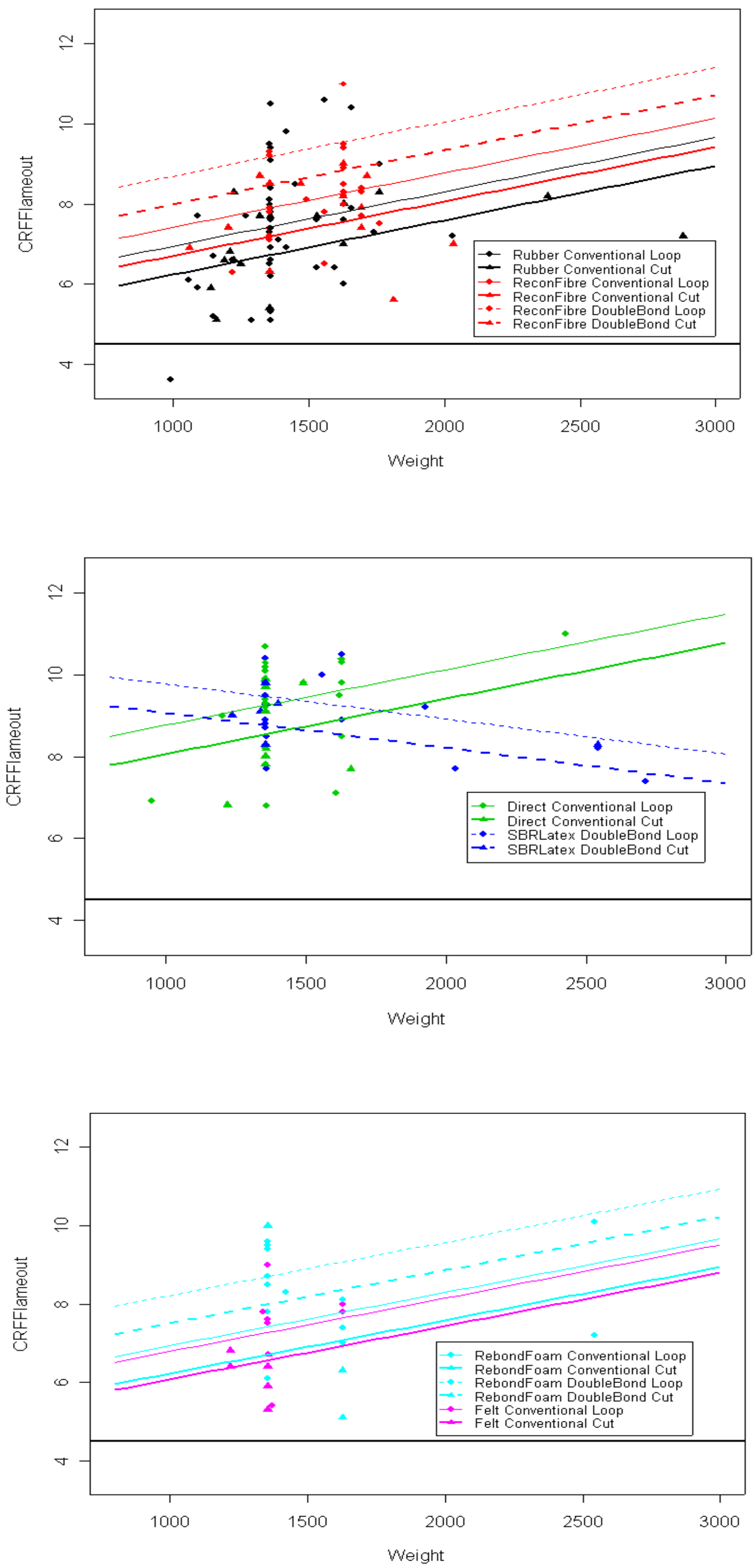


Figure 7.2: CRFFlameout vs Weight under a variety of different conditions

7.1.3 Determining Failure Rates

As we did earlier, we need to determine the probability of a sample falling below the specification limit of 4.5 kW/m^2. The calculations are now more complex, because Weight is a continuous random variable. As a result, the probability of a sample failing will vary with Weight and the levels of Underlay, Pile and Installation Method. The graphs below will show the 95% prediction intervals for the fitted lines. This means that there is a 2.5% chance that a future value will lie below the lower prediction interval line for each of the six Underlay classes. We will show six graphs, one for each of the underlay classes, with the 95% confidence limits for each of Loop and Cut. The lines for Cut/Loop in each case are 0.149 units above the lines for Loop and have not generally been drawn here.

These 95% two-sided prediction intervals are defined as

$$(a_i+bW) \pm\ 1.973\ \sqrt{(s^2+V)},$$

where a_i is the intercept for each of the six levels of Underlay and b is the slope for that particular Underlay, as given in the formulae above. W is the weight at which the calculation is being done and V=Var(a_i+bW) is the variance of the predicted CRFFlameout at weight W. The multiplier 1.973 is $t_{(.975,187)}$, the upper 97.5% point of a t-distribution with 187 degrees of freedom and s^2 is the residual variance from the model, given by 1.268. This formula provides the prediction intervals plotted in the graphs.

These can be turned around to give the probability of being below the specification limit of 4.5 kW/m^2 by finding the value of α for which

$$(a_i+bW) \pm\ t_{(\alpha,187)}\ \sqrt{(s^2+V)} = 4.5.$$

When this is solved for α, it provides the (left) tail probability in a t-distribution with 187 degrees of freedom when the t-value is given by

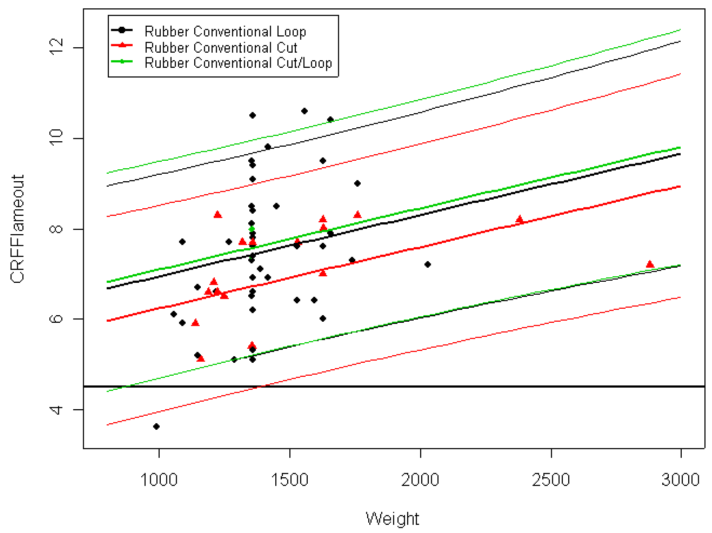
$$\{4.5 - (a_i+bW)\}\ /\ \sqrt{(s^2+V)}.$$

This then provides the second in each pair of graphs, in which we plot the probability of failing the test, as a function of Underlay, Pile, Weight and, where appropriate, Installation Method. In some cases, a further graph is given, showing the probability of being below the weaker specification limit of 2.2 kW/m^2. We now describe each of these in turn.

Rubber Underlay

The dark lines in the top graph represent the prediction lines for Loop, Cut and Cut/Loop, while the lighter lines represent the 95% prediction intervals for future values. We see, for example, that for Cut pile, the lower red line crosses the specification of 4.5 kW/m^2 at around 1400 g/m^2. This implies that, at 1400 g/m^{2,}

there is about a 2.5% chance that a future test with Rubber underlay and Cut pile will fail the test. The bottom graph reverses the calculation and shows the probability of failing the test for each Weight. For example, we see that the red line corresponding to Cut pile has a 1% probability of failing the test at a weight about 1750 g/m^2 but increases as the weight decreases.



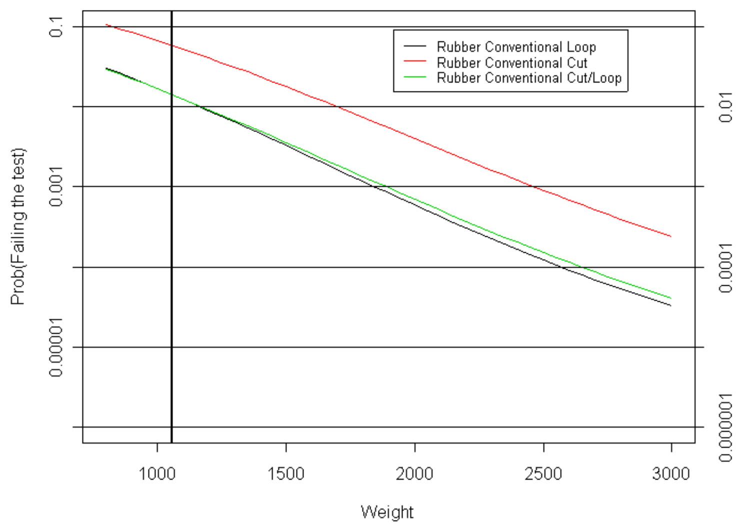


Figure 7.3: CRFFlameout vs Weight for Rubber wih 95% prediction intervals; and probability of failing the CRFFlameout test at 4.5kW/m^2.

The graph on probability of failure was repeated here with a revised specification limit of 2.2 kW/m^2. The following graph shows that this underlay now fails the test for all piles with a probability of much less than 0.1%.

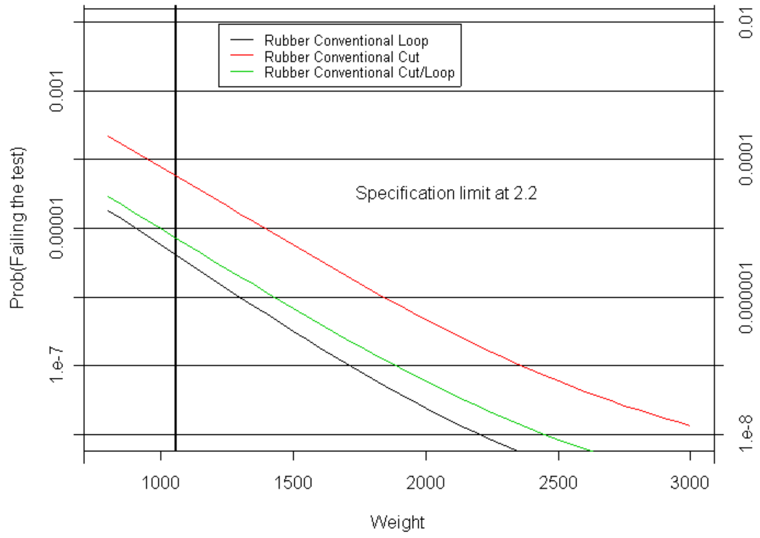


Figure 7.4: Probability of failing the CRFFlameout test at 2.2 kW/m^2; Rubber

The graphs and associated calculations show that for Rubber underlay with conventional installation:

- For Loop and Loop/Cut, the probability of failing the test at 4.5 kW/m^2 drops to 1% at 1200 g/m^2, and to 0.1% at 1800 g/m^2,
- For Cut pile, the probability of failing the test is higher, dropping to 1% only at 1750 g/m^2.
- If the specification limit is moved to 2.2 kW/m^2, then the probability of samples with Rubber underlay failing the test drops below 0.1% for all piles.

Summary: Rubber underlay is only installed by the Conventional method. For Rubber underlay, samples from all types of piles have a probability of less than 0.1% of failing the test with the specification limit at 2.2 kW/m^2. However, with the specification limit raised to 4.5 kW/m^2, we can only reliably assert that the probability of failing the test is less than 10% for Rubber underlay, and so cannot make any general statement.

Reconstituted Fibre Underlay

For ReconFibre underlay, we show two pairs of graphs. The first is for the Conventional installation, while the second is for the DoubleBond. We note that there are only 6 samples for DoubleBond – only five appear in the graph because the Cut/Loop sample (green) is actually two samples with identical values of CRFFlameout (both were ">11", the maximum value that can be obtained). There are in fact no Loop pile samples for DoubleBond here, so the lines drawn are obtained from estimates implied by the full analysis.

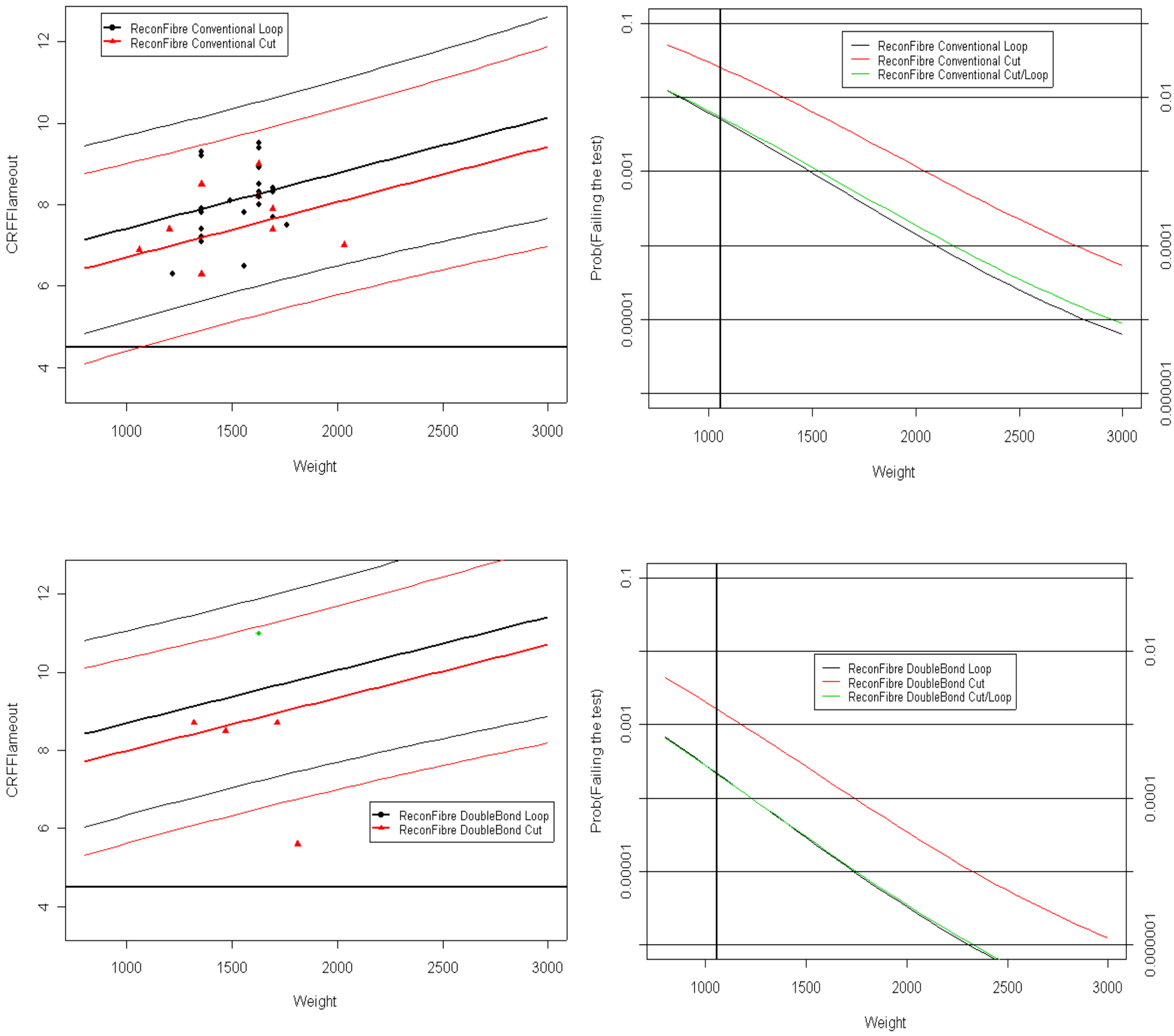


Figure 7.5: CRFFlameout vs Weight for Reconstituted Fibre with 95% prediction intervals, and probability of failing the CRFFlameout test at 4.5 kW/m^2.

The graph on probability of failure for Conventional installation was repeated here with a revised specification limit of 2.2 kW/m^2. The following graph shows that this underlay now fails the test for all piles with a probability of much less than 0.1% at all weights. By the "a fortiori" argument, the probability of failure at this specification limit would be even less for Double Bond installation.

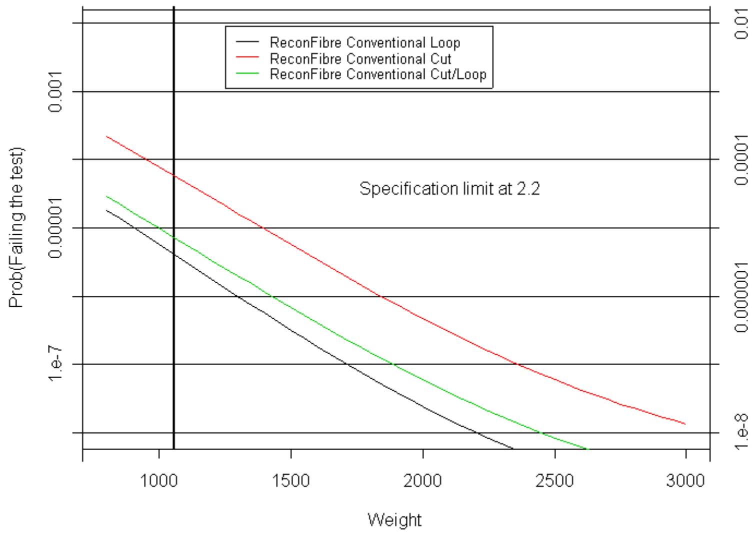


Figure 7.6: Probability of failing the CRFFlameout test at 2.2 kW/m^2; ReconFibre

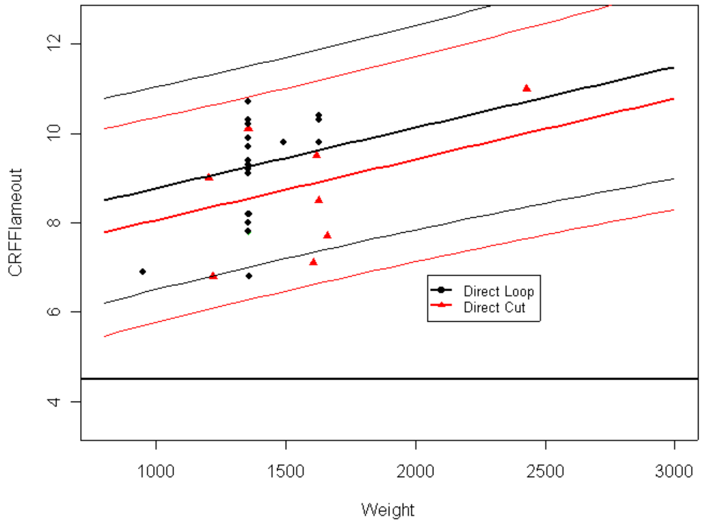
The results for Reconstituted Fibre underlay show that:

- In the right hand graph for Conventional installation, we see that the probability of failure is less than 1% for Loop and Cut/Loop at 1060 g/m^2, but at that point it is about 3% for the Cut pile. The two graphs drop below 0.1% probability of failure only when we get up to 1500 g/m^2 for Loop and Cut/Loop and at 2100 g/m^2 for Cut.
- For DoubleBond installation, the estimated lines in the left-hand graph are higher, indicating that the probability of failure is lower. The probability of failure for Loop and Cut/Loop are estimated to be well less than 0.1% whenever weight is greater than 1060 g/m^2 but such a conclusion must rely on estimates from the overall analysis, rather than the very small amount of data available for these categories. Even for Cut pile, the probability of failure is less than 0.2% at 1060 g/m^2, and drops below 0.1% at a weight of 1200 g/m^2.
- With a revised specification limit of 2.2 kW/m^2, both Conventional and Double Bond installation fail the test with probability much less than 0.1% for all piles.

Summary: For Reconstituted Fibre underlay, samples from all types of piles have a probability of much less than 0.1% of failing the test with the specification limit at 2.2 kW/m^2. With the specification limit raised to 4.5 kW/m^2, the probability of failing the test for Double Bond installation is less than 0.1% for Loop and Cut/Loop piles, but for Cut pile it only drops below 0.1% for Weights greater than 1200 g/m^2. For Conventional installation we cannot make any general statement at 4.5kW/m^2.

Direct Stick

For Direct Stick, the lower prediction limits for both Loop and Cut are well above the specification limit. This is confirmed in the bottom graph, where all piles have probabilities of failure below 0.1% when weight is above 1060 g/m^2.



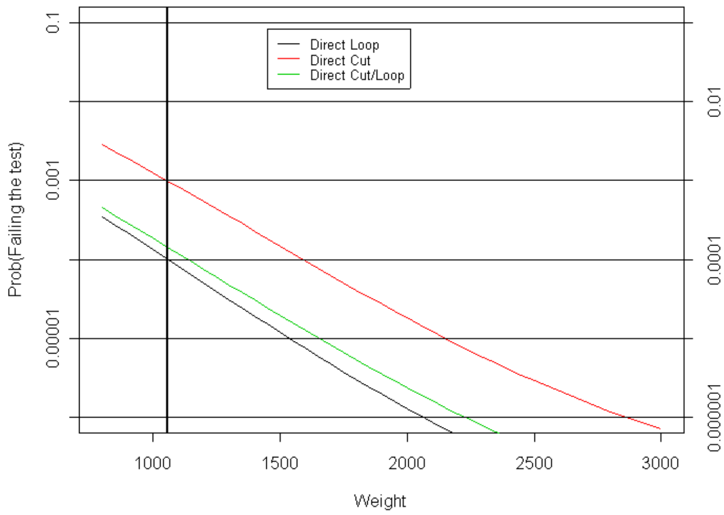
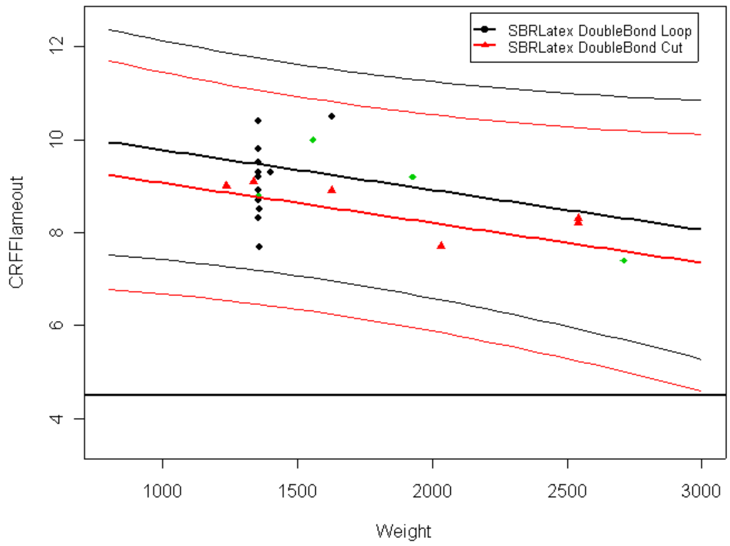


Figure 7.7: CRFFlameout vs Weight for Direct Stick and probability of failing the CRFFlameout test at 4.5 kW/m^2.

Summary: For Direct Stick carpets, there is less than a 0.1% chance of failing the test at the specification limit of 4.5 kW/m^2, when the weight is greater than 1060 g/m^2, for all piles.

SBR Latex Underlay

For SBR Latex underlay, with Double Bond installation, the lower prediction limits for both Loop and Cut are above the specification limit. This is confirmed in the bottom graph, where Loop and Cut/Loop pile have probabilities of failure below 0.1% for weights up to 2500 g/m^2. For Cut pile, the probability is below 0.1% at 1060g/m^2, but rises to go above 0.1% by the time the weight gets to 2000 g/m^2.



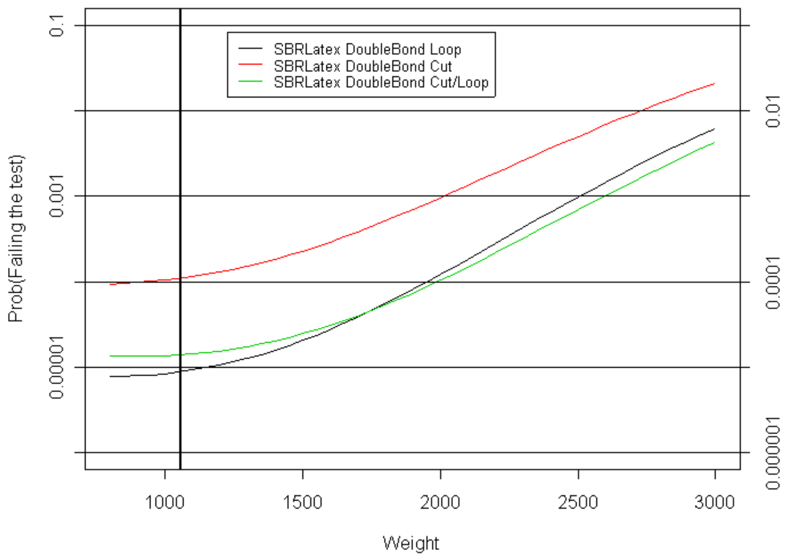


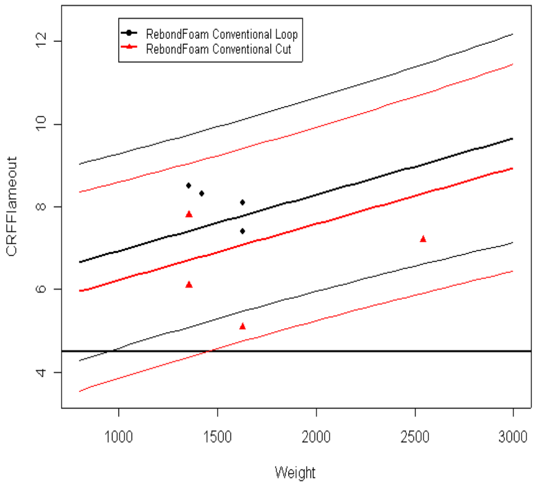
Figure 7.8: CRFFlameout vs Weight for SBRLatex and probability of failing the CRFFlameout test at 4.5 kW/m^2.

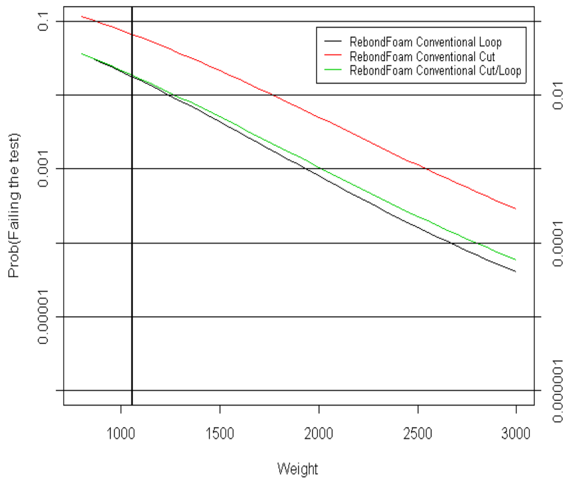
The calculations were repeated with the specification limit lowered to 2.2 kW/m^2, and this shows that the probability of failing the test at this level is below 0.01% for all weights up to 3000 g/m^2.

Summary: For SBR Latex underlay as a Double Bond installation, there is only a 0.1% chance (or less) of failing the test at the specification limit of 2.2 kW/m², regardless of the pile type. When the specification limit is raised to 4.5 kW/m², the probability of failing the test is less than 0.1% for Loop and Cut/Loop pile up to weights of 2500 g/m², but for Cut pile, this is only achieved with Weights less than 2000 g/m². We draw no conclusion about SBR Latex underlay with Conventional installation (for which there are just two samples in the data).

Rebond Foam Underlay

There are now 16 samples with Rebond Foam as the underlay. The following graphs show that for Conventional underlay, Rebond Foam fails the test at 4.5kW/m² at well above the 0.1% requirements. However, at 2.2kW/m², it fails the test with Conventional underlay less than 0.1% of the time. For DoubleBond, the RebondFoam underlay achieves the requirements at 4.5kW/m² for Loop and Cut/Loop pile, but not for Cut pile where it only achieves the required performance at weights above 1500 g/m².





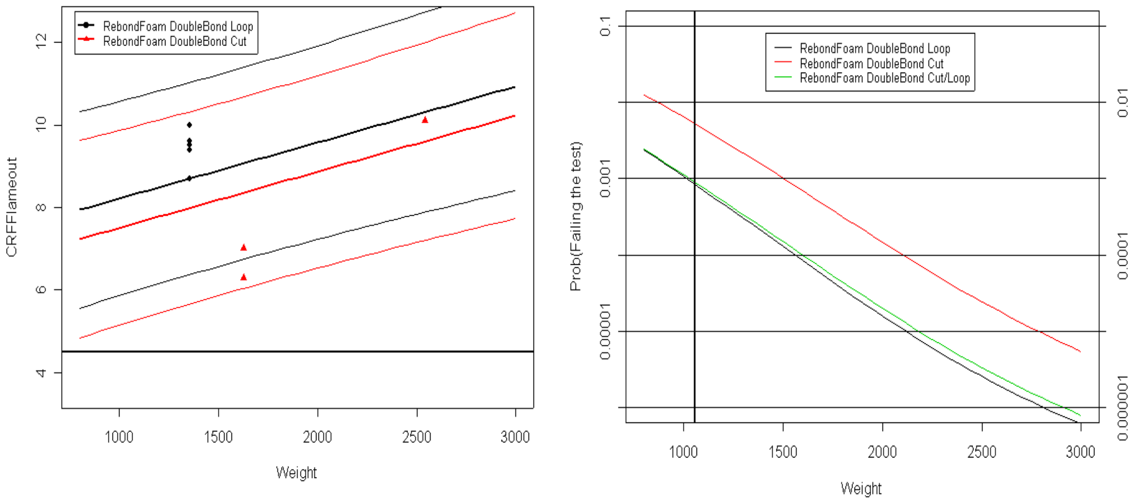


Figure 7.9: CRFFlameout vs Weight for Rebond Foam and implied probability of failing the CRFFlameout test at 4.5 kW/m^2.

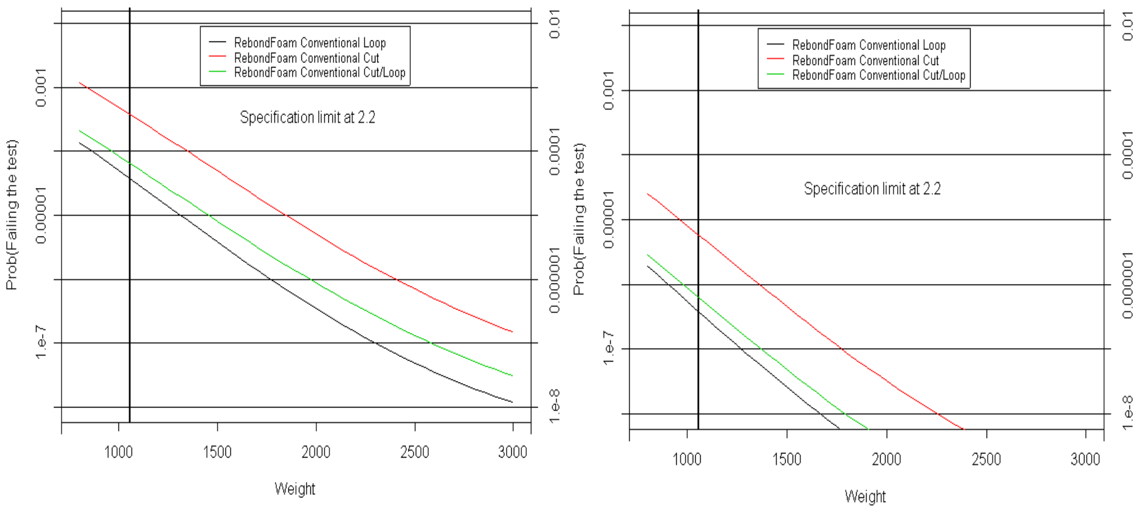


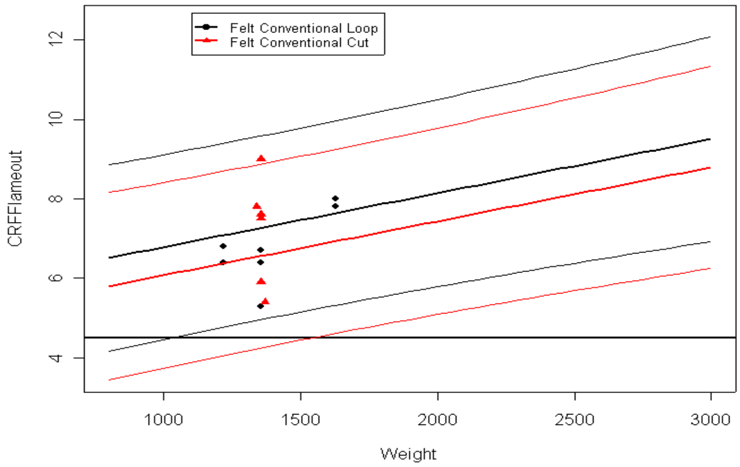
Figure 7.10: Implied probability of failing the CRFFlameout test at 2.2 kW/m^2 for Rebond Foam, Conv and DoubleBond.

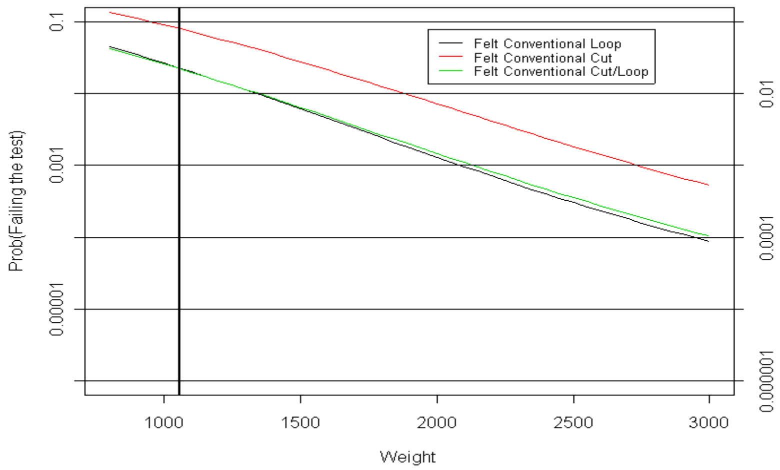
Summary: For Rebond Foam underlay and Conventional installation, the carpets meet the test requirements at the specification limit of 2.2 kW/m^2, but do not meet them at 4.5 kW/m^2. For Double Bond installation, the requirements are easily met at 2.2 kW/m^2, while at 4.5 kW/m^2., they are met by Loop and Cut/Loop, but not by Cut pile.

We note that this confirms the comment in the earlier report that "if the results are in close agreement with the average of the current samples, then Rebond Foam underlay would be satisfactory against the specification limit of 2.2 kW/m^2 but not against the specification limit of 4.5 kW/m^2."

Felt Underlay

There are now 13 samples for Felt and all have Conventional installation method. The additional samples mean that there are now 7 with Loop pile and 6 with Cut pile. The graph of CRFFlameout against Weight below shows, however, that the range of Weights is extremely narrow. This explains why the slope of CRFFlameout against Weight is so poorly estimated when we try to estimate a slope just from the Felt data. Instead, the calculations below rely on the common estimate of slope for all samples except SBRLatex.





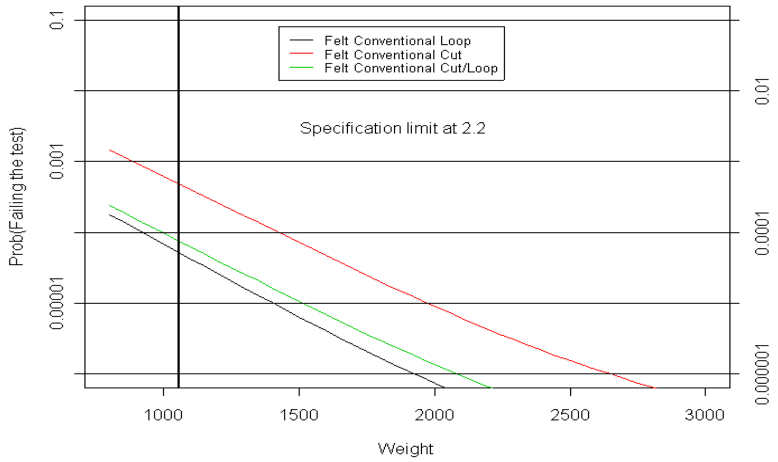


Figure 7.11: CRFFlameout vs Weight for Felt and implied probability of failing the CRFFlameout test at 4.5 and 2.2 kW/m^2.

Summary: For Felt underlay, there are 13 samples and they are all for Conventional installation. Felt meets the requirements for the specification limit of 2.2 kW/m^2. but fails to achieve the required performance against the specification limit of 4.5 kW/m^2.

7.2 SmokeFlameout (Smoke Development Rate)

7.2.1 Determining the Effects of the Covariates

An analysis of the 197 values of SmokeFlameout was conducted with all the covariates included. We note that in this analysis, the log (base e) of SmokeFlameout is used. The analysis shows that there are significant effects related to Underlay and Weight, but Pile, Manufacturing Method, Installation Method, and %Wool do not contribute to the regression. An initial assessment of the effects suggests the following:

- Installation Method should be dropped from the model since it adds nothing.
- As before, the standard errors of the coefficients for Pile gradually increase as we go down the list, reflective of the fact that we have ordered the levels of Pile by decreasing numbers of samples. The same applies to the standard errors for the levels of Underlay.
- Among Underlay, "Direct", which represents the no underlay case, has a strong negative effect ($t=-7.90$, $P<0.0001$) relative to Rubber, while ReconFibre and RebondFoam have strong positive effects ($t=2.23$, $P=0.027$

and t=3.23, P=0.0015, respectively). Other effects are quite large though not statistically different from Rubber.

- The linear effect of Weight is evident (t=3.29, P=0.0012).

Accordingly, the model was refitted with a reduced number of parameters, where we have a linear effect of Weight and a distinction among underlays. Three possible modifications were considered for this model:

- Is it reasonable to assume the same slopes for these six underlays? A formal test for whether the slopes were equal was conducted and was not significant ($F_{5,188}$=1.78, P=0.120). This is a different result from the original analysis and is due to the fact that the additional data for RebondFoam leads to a more precise, and less significant, slope for this underlay. It was decided to use the model with a common slope.
- Do the underlays have similar standard deviations? The standard deviation of the residuals was calculated for each of the categories. They were not significantly different, generally being around 0.50 and reaching a high of 0.77 for Rubber.
- Are there additional differences between manufacturers that are not captured by the categories identified? Substantial differences were identified ($F_{8,181}$=4.996, P<0.0001). Manufacturer #8, in particular, tends to have Smoke Flameout values for Rubber underlay that are much lower than the main supplier of Rubber underlay samples, and this in turn contributes to a higher apparent standard deviation for Rubber underlay. In order to provide conclusions which apply generally across manufacturers, manufacturers were left out of the model.

Outliers

There is one outlier amongst the residuals. The Normal probability plot which follows shows one value with a residual of about −2.5, highly unusual.

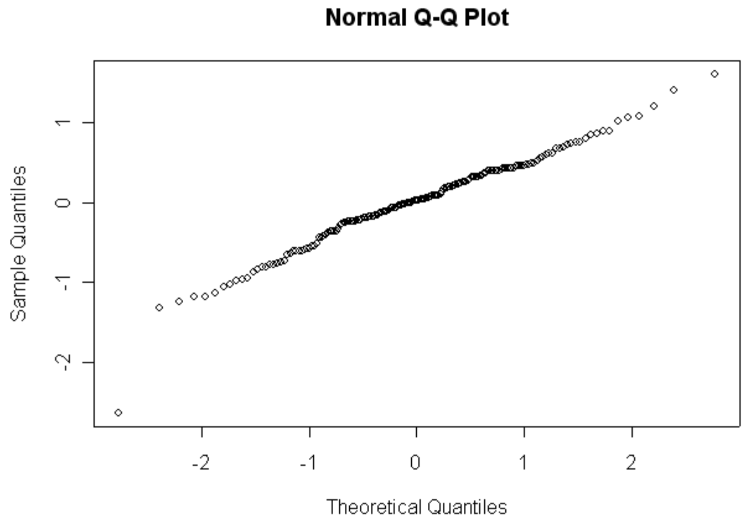


Figure 7.12: : Normal probability plot for 197 residuals from analysis of log SmokeFlameout values

This is revealed as one of 15 samples which are Rubber underlay, Weight=1360, from two different manufacturers, and with SmokeFlameout readings ranging from a low of 4 (the outlier) to a high of 227; the logged values go from 1.38 to 5.42:

	TestRef	ManufID	FibreDetails	Pile	ManufM	Weight	Underlay	Install	SmFout	lSmF
17	56	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	54	3.988
18	57	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	17	2.833
20	59	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	36	3.583
21	60	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	102	4.624
26	65	3	100%Wool	Hi/LoLoop	Tufted	1360	Rubber	Conv	116	4.753
27	66	3	100%Wool	Hi/LoLoop	Tufted	1360	Rubber	Conv	4	1.386
29	68	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	86	4.454
31	72	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	21	3.044
35	76	3	100%Wool	Hi/LoLoop	Tufted	1360	Rubber	Conv	227	5.424
36	78	3	100%Wool	Loop	Tufted	1360	Rubber	Conv	83	4.418
94	316	8	100%Wool	Cut	Tufted	1360	Rubber	Conv	29	3.367
98	320	8	100%Wool	Loop	Tufted	1360	Rubber	Conv	16	2.772
99	321	8	100%Wool	Loop	Tufted	1360	Rubber	Conv	20	2.995
100	322	8	100%Wool	Loop	Tufted	1360	Rubber	Conv	18	2.890
143	69	3	90%W/10%N	Loop	Tufted	1360	Rubber	Conv	119	4.779

Together they have a standard deviation of 1.07, considerably higher than the SD of 0.593 used overall. This higher degree of variation cannot be explained by the %Wool (all but one are 100% Wool) or the Pile (all but one are Loop).

The outlier here is on the low side, whereas we are concerned with estimating the tail of the distribution on the high side. It was felt that the distribution on the high side would be best estimated by removing the outlier on the low side. In some sense, removing the lowest value would seem to be a conservative approach since removing a low value will tend to produce results which are on average higher and hence closer to the specification limit. In this case, the outlier tends to inflate the standard deviation and produce a standard deviation which is not truly representative of the upper tail of the distribution. The calculations were repeated with the outlier excluded and this is the formula that is used in the subsequent analysis.

The resulting prediction equations are shown in the following Table 7.2. It can be seen that the removal of the outlier leaves the equations almost unchanged. However the standard deviation decreases from 0.593 to 0.564.

Table 7.2: Formulae for SmokeFlameout for major classes, for all piles and installation methods.

Material	Constant slope	Outlier removed	Remarks
Rubber(62)*	3.913−0.593×W	3.955−0.605×W	All are Conventional installation
ReconFibre(41)	4.191−0.593×W	4.192−0.605×W	6 are DoubleBond
DirectStick(41)	2.988−0.593×W	2.987−0.605×W	
SBRLatex(24)	4.255−0.593×W	4.257−0.605×W	Only 2 are Conventional installation
RebondFoam(16)	4.495−0.593×W	4.496-0.605×W	4 are DoubleBond
Felt(13)	4.543−0.593×W	4.542−0.605×W	All Conventional installation

7.2.2 Presentation of the Data

The standard deviation is now SD= 0.544, estimated on 189 degrees of freedom. Note that the SmokeFlameout data are plotted on a log scale, so the specification limit is at log(750)=6.62. We plot the data here for the six classes, and the fitted lines (with common slope). The vertical axis log of the graph = $\log_e$(SmokeflameOut). No lines are drawn for FRRubber, for which not enough data is available to make a reliable estimate.

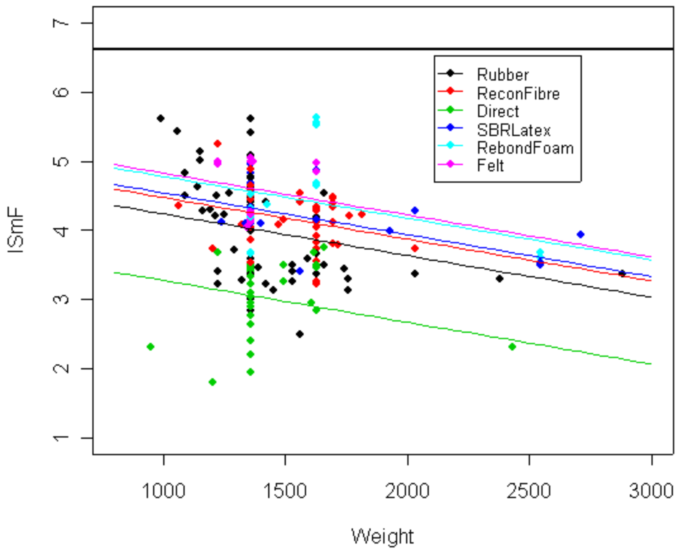


Figure 7.13: logSmokeFlameout vs Weight, with fitted lines for major classes

7.2.3 Determining Failure Rates

As we did earlier, we need to determine the probability of a sample falling above the specification limit of 750 %.minutes. This corresponds to 6.62 on the log scale. The probability of a sample failing will vary with Weight and also with the level of Underlay.

Rubber, ReconFibre and DirectStick Underlay

The graph below (Figure 7.14) shows the fitted lines (solid lines) and the 95% prediction intervals (dashed lines) for the first three classes. This means that there is a 2.5% chance that a future value will lie above the upper dashed line for each of the four Underlay classes.

These 95% two-sided prediction intervals are defined as in the previous section, but with a different slope for each class. These can be turned around to give the probability of being below the specification limit of 6.62 by finding the value of α for which

$$(a_i+b_iW) \pm t_{(\alpha,190)} \sqrt{(s^2+V)} = \log(750)=6.62.$$

When this is solved for α, it provides the (right) tail probability in a *t*-distribution with 190 degrees of freedom when the *t*-value is given by

$$\{6.62 - (a_i+b_iW)\} / \sqrt{(s^2+V)}.$$

This provides the curves in the graph Figure 7.15.

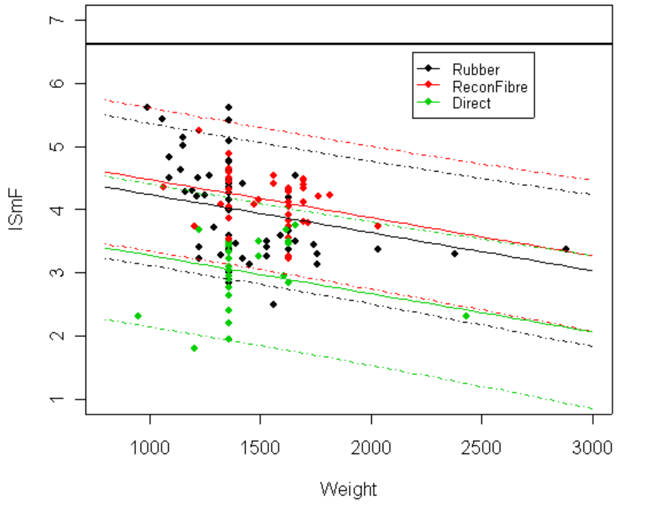


Figure 7.14: logSmokeFlameout vs Weight, with fitted curves and 95% prediction intervals for first three classes

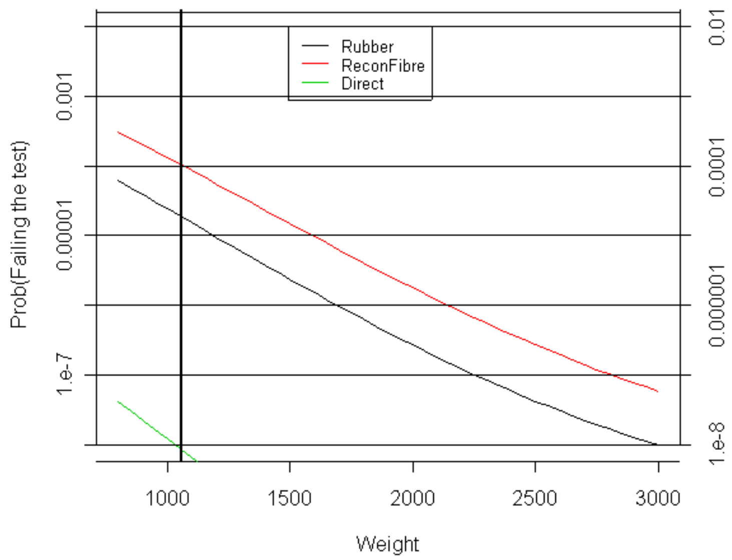


Figure 7.15: Probability of failing the SmokeFlameout test, for first three classes

The graphs show that:

- For carpets with Rubber underlay (——), the probability of failing the test at 1060 g/m^2 is estimated at less than 0.0001, and it is lower than this at all Weights above 1060 g/m^2.
- For carpets with ReconFibre underlay (——),the probability of failing the test is 0.0001 when the Weight is 1060g/m^2 and lower at higher Weights.
- For carpets with no underlay (e.g. Direct Stick)(——), the probability of failing a test is much less than 0. 0001 for all Weights.

SBR Latex, Rebond Foam and Felt Underlays

The following graph shows the data and the fitted lines for the SBRLatex, Rebond Foam and Felt underlay.

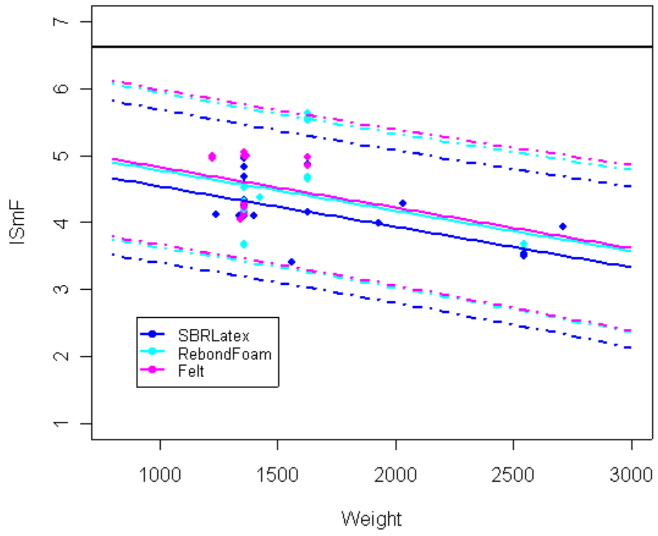


Figure 7.16: logSmokeFlameout vs Weight, with fitted curves and 95% prediction intervals for another three classes

The following graph shows the plots of probability of failure.

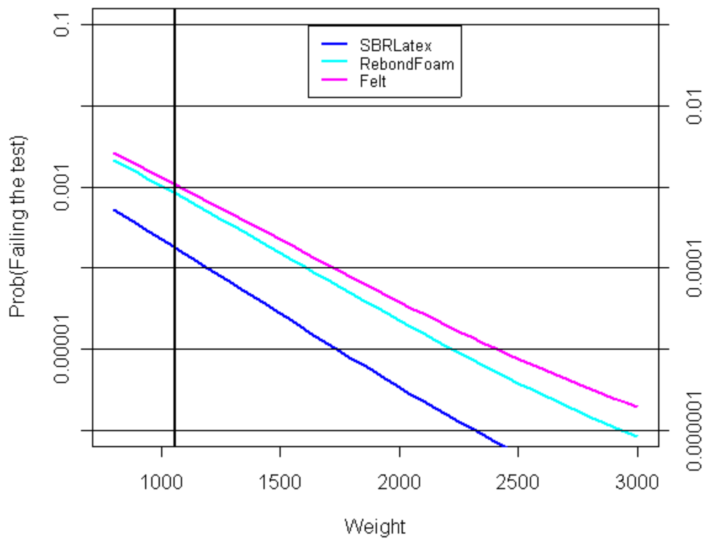


Figure 7.17: Probability of failing the SmokeFlameout test, for the other three classes

- For carpets with SBRLatex (——), the probability of failing the test is well below 0.001 whenever Weight is greater than 1060g/m^2. At 1060 g/m^2, it is 0.0002.
- For carpets with RebondFoam (——), the probability of failing the test is just below 0.001 when the Weight is 1060 g/m^2, and is lower at higher Weights.
- For carpets with Felt (——), the probability of failing the test is estimated to be 0.0011 when the Weight is 1060 g/m^2. In our view, within the accuracy of the method, this is sufficient to consider that Felt passes the test.

8 SUMMARY OF STATISTICAL ANALYSIS

8.1 The Data

- A total of 196 sample test were initially made available. These were a combination of 146 tests on Wool Only carpets, and another 50 which were Wool/Nylon mix carpets with up to 20% Nylon.
- Fifteen of the samples which were NIL underlay but not Direct Stick were excluded as not being representative of how carpets are laid in practice. A further two samples which were the only carpets in Tile format were also excluded on the grounds that they would provide insufficient data to make any useful statements. One of these two Tile carpets was also the only PVCBack sample in the study. This left a total of 179 samples on which the original analysis was based.
- Preliminary analysis had suggested that there was little difference in outcomes relation to the %Nylon and for this reason the original analysis proceeded with all 179 samples in the one data file.
- Following the original analysis, recommendations were made for additional testing to fill some of the gaps in the data. As a result, a further 24 samples were received, although no extra data was provided for FRRubber. Accordingly, the 5 samples for FRRubber were excluded from the final analysis, leaving a data set of 198 samples.

8.2 CRFFlameout

- CRFFlameout depends on Pile, Underlay and Weight, and there is a significant difference between Conventional and DoubleBond installation. It appears that there are no significant effects due to ManufMethod (Tufted vs Woven) or %Wool (given that all are at least 80% Wool). In the earlier report, a common slope was found to provide a suitable description for the way in which CRFFlameout depended on Weight of carpet. However, the additional samples, particularly for SBRLatex suggested that this underlay has a slope different from the slopes obtained for the other carpets.

- The numbers of samples are sufficient to obtain a reliable estimate of the effects of Pile and Installation Method and the effect of Weight. With the additional data, there is sufficient data to estimate the effects of different underlays, particularly if it is assumed that there is a common slope of all underlays other than SBRLatex.
- The distribution of CRFFlameout provides close to Normally distributed residuals in the model. This implies that we can use the tail probability calculations based on the assumption of Normally distributed data.

The following results are summarised in Table 8.1 below.

- Rubber underlay is only used with conventional installation. For Rubber underlay, samples from all types of piles have a probability of less than 0.1% of failing the test with the specification limit at 2.2 kW/m^2. However, with the specification limit raised to 4.5 kW/m^2, we can only reliably assert that the probability of failing the test is less than 10% for Rubber underlay, and so cannot make any general statement.
- For Reconstituted Fibre underlay, samples from all types of piles have a probability of much less than 0.1% of failing the test with the specification limit at 2.2 kW/m^2. With the specification limit raised to 4.5 kW/m^2, the probability of failing the test for Double Bond installation is less than 0.1% for Loop and Cut/Loop piles, but for Cut pile it only drops below 0.1% for Weights greater than 1200 g/m^2. For Conventional installation we cannot make any general statement at 4.5kW/m^2.
- For Direct Stick carpets, there is less than a 0.1% chance of failing the test at the specification limit of 4.5 kW/m^2, when the weight is greater than 1060 g/m^2, for all piles.
- For SBR Latex underlay as a Double Bond installation, there is a 0.1% chance (or less) of failing the test at the specification limit of 2.2 kW/m^2, regardless of the pile type. When the specification limit is raised to 4.5 kW/m^2, the probability of failing the test is less than 0.1% for Loop and Cut/Loop pile up to 2500 g/m^2, but for Cut pile, this is only achieved with Weights less than 2000 g/m^2. We draw no conclusion about SBR Latex underlay with Conventional installation (for which there are just two samples in the data).
- For Rebond Foam underlay and Conventional installation, the carpets meet the test requirements at the specification limit of 2.2 kW/m^2, but do not meet them at 4.5 kW/m^2. For Double Bond installation, the requirements are easily met at 2.2 kW/m^2, while at 4.5 kW/m^2., they are met by Loop and Cut/Loop, but not by Cut pile.

- For FRRubber underlay, there are only five samples and they are all for Conventional installation. No conclusions are drawn.
- For Felt underlay, there are 13 samples and they are all for Conventional installation. Felt meets the requirements for the specification limit of 2.2 kW/m^2. but fails to achieve the required performance against the specification limit of 4.5 kW/m^2.
- In Table 8.1 “2.2:P” indicates a pass at this level – there is only a 0.1% chance (or less) of failing the test at the specification limit of 2.2 kW/m^2.
- In Table 8.1 “4.5:P” indicates a pass at this level – there is only a 0.1% chance (or less) of failing the test at the specification limit of 4.5 kW/m^2.
- Where a percentage is given, it indicates the highest probability of failure across the weight range considered.

Table 8.1: Summary of results for CRFFlameout, for seven classes of underlay.

	Conventional			**DoubleBond**		
Underlay	**Loop**	**Cut/Loop**	**Cut**	**Loop**	**Cut/Loop**	**Cut**
Rubber	**2.2:P 4.5:<2%**	**2.2:P 4.5:<2%**	**2.2:P 4.5:<10%**	**NA**	**NA**	**NA**
Recon Fibre	**2.2:P 4.5:<0.5%**	**2.2:P 4.5:<0.5%**	**2.2:P 4.5:<3%**	**2.2:P 4.5:P**	**2.2:P 4.5:P**	**2.2:P 4.5:P***
Direct Stick	**2.2:P 4.5:P**	**2.2:P 4.5:P**	**2.2:P 4.5:P**	**NA**	**NA**	**NA**
SBR Latex	**NA**	**NA**	**NA**	**2.2:P 4.5:P***	**2.2:P 4.5:P***	**2.2:P 4.5:P***
Rebond Foam	**2.2:P 4.5:<2%**	**2.2:P 4.5:<2%**	**2.2:P 4.5:<8%**	**2.2:P 4.5:P**	**2.2:P 4.5:P**	**2.2:P 4.5:<0.5%**
Felt	**2.2:P 4.5:<2%**	**2.2:P 4.5:<2%**	**2.2:P 4.5:<10%**	**NA**	**NA**	**NA**

* Weight range for which this applies is limited to above 1200 g/m^2 (for ReconFibre) and below 2000 g/m^2 (for SBRLatex).

8.3 Smoke Flameout

- SmokeFlameout has one value missing, so that there are only 197 samples available for analysis. The distribution of SmokeFlameout is highly skewed and it is shown that the logarithm (here we use log, base e) of the values provides close to Normally distributed residuals in the model. This implies that we can use the tail probability calculations based on the assumption of

Normally distributed data.

- SmokeFlameout depends on Underlay (where Direct Stick is regarded as a NIL underlay) and Weight, but Pile, Manufacturing Method, Installation Method, and %Wool do not otherwise contribute to the regression.
- There were no significant differences between the slopes attributable to different types of Underlay. This implies that the regression line of SmokeFlameout against Weight had constant slope but a different intercept for each of the types of Underlay.
- Differences exist between manufacturers ($F_{8,181}$=4.996, P<0.001). Manufacturer #8, in particular, tends to have Smoke Flameout values for Rubber underlay that are much lower than the main supplier of Rubber underlay samples, and this in turn contributes to a higher apparent standard deviation for Rubber underlay. In order to provide conclusions which apply generally across manufacturers, manufacturer effects have been left out of the model used.
- One large outlier was detected – this corresponded to an unusually low Smoke Flameout value of 4 %.minutes for one of 15 samples undertaken with Rubber underlay at a Weight of 1360 g/m^2. These come from only two manufacturers; the four samples from Manufacturer #8 have SmokeFlameout varying from 16–29, while the 11 samples from Manufacturer #3 include a 4 (the outlier) and the remaining ten values range from 17–227. In order to more accurately capture the upper tail of the distribution, which is needed to estimate the probability of failing the test, it was decided to omit this outlier from the final analysis.
- For carpets with rubber underlay (——), the probability of failing the test at 1060 g/m^2 is estimated at less than 0.0001, and it is lower than this at all Weights above 1060 g/m^2.
- For carpets with reconstituted fibre underlay (–––),the probability of failing the test is 0.0001 when the Weight is 1060g/m2 and lower at higher Weights.
- For carpets with no underlay (i.e. Direct Stick)(–––), the probability of failing a test is much less than 0. 0001 for all Weights.
- For carpets with SBR Latex underlay (–––), the probability of failing the test is well below 0.001 whenever Weight is greater than 1060g/m^2. At 1060 g/m^2, it is 0.0002.
- For carpets with rebond foam underlay (——), the probability of failing the test is just below 0.001 when the Weight is 1060 g/m^2, and is lower at higher Weights.
- For carpets with felt underlay (–––), the probability of failing the test is

estimated to be 0.0011 when the Weight is 1060 g/m^2. In our view, within the accuracy of the method, this is sufficient to consider that Felt passes the test.

- There is insufficient data for FR Rubber to declare a result. However, if we assume that future data produces mean levels of SmokeFlameout similar to those obtained in this data, then it is likely that FR Rubber would achieve the specification.

Table 8.2: Summary of results for SmokeFlameout, for seven classes of underlay.

Underlay	SmokeFlameout (SDR)
Rubber	Pass
Reconstituted Fibre	Pass
Direct Stick	Pass
SBR Latex	Pass
Rebond Foam	Pass
Felt	Pass

9 CONCLUSIONS

9.1 Overall Summary of Results

A statistical analysis was carried out on a body of wool and wool rich carpets tested according to the fire test AS ISO 9239 Part 1 to assess the likelihood of compliance with the BCA requirements for floor coverings for Class 2 to 9 buildings (BCA Volume 1, Specification C1.10a). The statistical analysis was performed based on 203 test reports of tests to AS ISO 9239.1 from NATA or ILAC accredited test laboratories. A probability that a carpet of similar construction determined to have a probability of failure of less than 0.1% was considered to provide a level of safety that will satisfy the Performance Requirements CP4, of the BCA 2007.

The test reports for wool/nylon blend carpets where the wool content is of 80-100% and the Nylon content is a maximum of 20%, the Total Pile Mass (TPM) is 1060g/m^2 or more concluded that all carpets passed both the CRF and SDR tests regardless of the underlay, construction type, installation technique or manufacturer. One carpet with a TPM of less than 1060g/m^2 did fail the CRF.The statistical analysis however concluded that not all carpets have a probability of less than 0.1% of failing the individual tests.

- Table 9.1 summarises whether, with 99.9% confidence, samples of various types of carpets, where the wool content is of 80-100%, can be expected to exceed the minimum value of Critical Radiant Flux (CRF) required by the BCA for floor covering materials. This depends on the underlay, the pile type, the installation method and the weight (TPM).
- Also shown in the table is an indication of whether, with 99.9% confidence, those samples can be expected to have Smoke Development Rate (SDR) values below the maximum value allowable by the BCA.
- The two points above imply that, for samples of carpets of the types identified, CRF and SDR values should have less than a 0.1% probability of not achieving the predicted performance if tested under AS ISO 9239.1.

No conclusion could be made regarding PVC backed carpet, FR rubber underlay or carpet tiles. Where a conclusion on the expected CRF or SDR 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.

Table 9.1: Summary of Critical Radiant Flux and maximum Smoke Development Rate values that 100% Wool carpets and Wool/Nylon blend carpets with a wool content not less than 80% and with a Total Pile Mass in the range 1060g/m^2 to 3000g/m^2 achieve with probability 99.9% and hence which can be considered to conform without further testing.

Installation Method	Underlay	TPM (g/m^2)	CRF (kW/m^2) by Pile Type				SDR (%.min)
			All	Loop	Cut/Loop	Cut	
Direct Stick	Nil	All	4.5				750
Conventional	Rubber, Felt, Reconstituted Fibre, Rebond Foam	All	2.2				750
Double Bond	Reconstituted Fibre	<1200		4.5	4.5	2.2	750
		≥1200	4.5				750
	SBR Latex	<2000	4.5				750
		≥2000	2.2				750
	Rebond Foam	All		4.5	4.5	2.2	750

Based on the test data received and the statistical analysis of that data, carpets conforming to the above description and manufactured by Brintons, Feltex Carpets, Godfrey Hirst Australia, Quest Carpets, Tascot, Tuftmaster Carpets, Victoria Carpets, Cavalier Bremworth, Chaparral Carpet Mills and Supertuft provide a level of safety that will satisfy the Performance Requirements CP4, of the BCA 2007.

9.2 Proposed 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 /backing combinations. The existing ACCS regime would provide a framework under which the testing can be performed.

9.3 Term of Validity

This report will expire on the 21st day of October 2013.

10 REFERENCES

Reference List

1. Australian Building Codes Board (2005) *International Fire Engineering Guidelines*, Canberra: Australian Building Codes Board.

2. Australian Building Codes Board (2006) *BCA 2006, Building Code of Australia, Class 2 to 9 Buildings*, Canberra: CanPrint Communications Pty Ltd.

3. Bukowski, R.W., Budnick, E.K., & Schemel, C.F. (2002), 'Estimates of the Operational Reliability of Fire Protection Systems', *Fire Protection Strategies for 21st Century Building and Fire Codes Symposium*, Baltimore, MD, 111-124 pp, Society of Fire Protection Engineers and American Institute of Architects, Quincy, Mass.

4. Montgomery, D.C. (2004) *Introduction to Statistical Quality Control*, 5th edn. New York: Wiley and Sons.

5. Society of Fire Safety (2003), *Code of practice for fire safety design, certification and peer review*, Society of fire safety, Institution of engineers Australia

6. Standards Australia (1990), *Australian Standard 3940 - Quality control - Guide to the use of control chart methods including Cusum techniques.*, AS 3940:1990, Standards Australia

7. Standards Australia (2003), *Australian Standard 9239.1-2003 Reaction to fire test for flooring - determination of the burning behaviour using a radiant heat source*, AS/ISO 9239.1, Sydney, Standards Association of Australia

8. Webb, A. and Jarrett, R. (2007), *Fire engineering assessment of wool rich carpet floor covering*, Confidential Doc CMMT-(C)-2007-120 Revision Q, Melbourne , CSIRO

END OF REPORT