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ALTERNATIF KONSEP UNTUK DESAIN PRODUK *TRAMPOLINE PROTECTIVE EDGE* DENGAN MENGGUNAKAN MATERIAL BARU

TUGAS AKHIR SAXION-UII

Diajukan Sebagai Salah Satu Syarat

Untuk Memperoleh Gelar Sarjana Teknik Kimia

Konsentrasi Teknik Tekstil

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Yogyakarta, 20 Agustus 2018

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LEMBAR PENGESAHAN PEMBIMBING

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ALTERNATIF KONSEP UNTUK DESAIN PRODUK *TRAMPOLINE PROTECTIVE EDGE*
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Yogyakarta, Agustus 2018

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KATA PENGANTAR

بسم الله الرحمن الرحيم

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Yogyakarta, 20 Agustus 2018

Penulis

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List of Abbreviations

ASTM	American Society for Testing and Materials
C2C	Cradle to Cradle
DIN	*Deutsches Institut für Normung* (German Institute for Standardization)
EPE	Expanded Polyethylene
EVA	Ethylene-Vinyl Acetate
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
LDPE	Low Density Polyethylene
LLD	Low Linear Density
PBS	Product Breakdown Structure
PE	Polyethylene
PES	Polyester
PVC	Poly Vinyl Chloride
TPU	Thermoplastic Polyurethane
UTM	Universal Testing Machine
UV	Ultra Violet

List of Key Definitions

Abrasion Resistance	:	The ability of the fabric to resist the physical destruction, resulting from the rubbing of a textile surface over another surface (Abdullah, Blackburn, Russell, & Taylor, 2006).
Adhesion Strength	:	The ability of the external coating compound to adhere to the inside base fabric.
Colourfastness	:	The ability of the textile material to withstand colour reducing from the surface of the textile material during undergoing process and treatment.
Cradle to Cradle	:	Beneficial design approach integrating multiple attributes: safe materials, re-use of materials, clean water, renewable energy, and social fairness (McDonough & Braungart, 2016)
Expanded Polyethylene	:	Moulded semi-rigid, non-crosslinked, closed-cell polyethylene foam made of LDPE resins.
Fibreglass	:	Fibre-reinforced plastic using glass fibre also commonly known as glass-reinforced plastic (GRP)
Poly Vinyl Chloride	:	Synthetic thermoplastic chloro-polymers material made by polymerizing vinyl chloride is also known as 'vinyl' often divided into rigid PVC (unplasticized) and flexible PVC (Added with plasticizers).
Polyester	:	Synthetic fibre commonly made from the reaction of a Terephthalic acid and Ethylene glycol (PET) in the form of filament or staple yarn.
Polyethylene	:	Thermoplastic polymer made of ethylene monomer $(CH_2CH_2)_x$. Classified by density and branching, the polymer has significant different mechanical properties depend on molecule extent, type of branching, the crystal structure and the molecular weight.
Product Breakdown Structure	:	An effective tool that details the physical components of a product under desired consideration. At the top of the hierarchy, there is the final product that followed by sub-categorized product elements.
Protective edge/ safety pads	:	The safety pad or protective edge is the part which is used to covers both the frame and springs with an extra-wide plank thick foam for protection.
Silicone Rubber	:	A synthetic elastomer (rubber-like material) made of silicone with the polymer is built from the bonding of carbon, hydrogen, oxygen and silicon elements in which silicon comes from silica sand.
Tear Strength	:	The ability of the fabric to withstand the effects of tearing or cuts when in tension.
Tensile Strength	:	A maximum stress load that a material can support without fracture when being stretched, measured as force per unit area.
Thermal Insulant	:	The physical property of the material in which can prevent heat transferring from one place to another in the ways of convection, conduction, and radiation.
Thermoplastic Polyurethane	:	Any of a class of polyurethane plastics properties, including elasticity, transparency, and resistance to oil, grease and abrasion.

Preface

The area of textile is consistently evolving with an unlimited number of applications. Without much of us knowing, it has helped modern society with not just for apparel, but in much more technical ways, for instance, my graduation project, which studies textile application for “a trampoline protective edge”. This final thesis has been written to fulfil graduation requirements of my double-degree program in Chemical-Textile Engineering, Islamic University of Indonesia and Fashion & Textile Technologies (TEM), Saxion University of Applied Sciences the Netherland.

My graduation project was undertaken at the request of BERG Toys B.V. Ede, where I conducted it as a Trainee Development in R&D department. I was responsible for research in technical coated fabric properties and behaviours, especially for outdoor trampoline applications. It was hard at the beginning to understand this material, but learning it, really excited me to know more about materials and enriched my knowledge by discovering things that I have no such ideas before. During my internship, I gained a lot of experiences for working in a Dutch-based company. Furthermore, this internship program broadens my networking by meeting many new people.

I would like to thank my company supervisor, Mrs Charlotte van Arragon who helped me in this project with useful comments and guidance. Also for my graduation coach, dr. Pramod Agrawal for his time, valuable input and instructions in finishing the report. Moreover, to R&D colleagues, Mr Arie Snel, and all BERG employees that I cannot mention one-by-one.

My special gratitude is given to my parents and family for their endless support and prayers for me. Also my friends in Enschede and EDS, for all the encouragement and love all these times. I could not have made it this far without those who always believe in me.

Alhamdulillah, I am grateful to Allah SWT who gave all the strength, courage, preservation, and patience to finish this report. Hopefully, this research can be beneficial for the company and the advancement of technical textile material science.

Enschede, 20th June 2018

Galang Galih Gibran

Summary

The trampoline protective edge is the part used to cover both the frame and springs consist of fabric cover outside and foam inside. Nowadays, most of the safety pads fabric cover used on the trampoline is made of woven fabric that coated with PVC film plastic. However, it contains PVC and phthalates which have been restricted for environmental reasons. PVC coating also can become rigid after a certain period of using due to plasticisers migration. The study was aimed to create an alternative product design with new material option focused on complying with C2C green concepts such as recyclability and zero PVC. It is also expected to have similar or better performance than the current BERG safety protective edge.

The Lamb & Kallal framework is used as first guidance in the prototype development steps and set up the list of requirements for the new material based on functional (60%), expressive (30%), and aesthetic (10%). The investigating of new material will focus only on the fabric cover. Using the PBS method, the search of material is divided into fabric construction, fabric material, and plastic polymer coating. After literature research and searching for an available supplier, three different materials examined such as silicone rubber coated glass fabric (SIL 020 R and 025 R), LDPE coated HDPE (Tencate NICOLON C888), and TPU coated PES (Novolter 1.04 mm and 0.54 mm). These fabrics are then evaluated and compared with BERG PVC coated PES (BERG Champion & Elite). The investigation consists of laboratory testing such as tensile strength, tear strength and weather resistant (UV & artificial rain) test, also by material price, banned C2C chemical contents, recyclability, and thermal insulant consideration.

The NICOLON C888 is chosen as the final material since it complies with the previous testing standard, also has a comparable price with BERG current material. Environmental safety aspects even met which are containing no restricted substance and easy to be recycled. The NICOLON C888 then used as the material in the prototype development and further evaluated with BERG PVC Elite and Champion fabric.

The prototype development consisted of 3 phase: (Imitation, Observation, and Modification of design). The safety pads prototype part made of LDPE coated HDPE fabric cover, EPE foam and stitched by using PES thread. In the development process, NICOLON C888 shows a stiffer property compared to BERG Elite & Champion PVC which lead to cracking in the curved part of safety pads. An additional part that connects upper and bottom layer in the safety pads are given to reduce the cracking on the safety pads surface. Hot air treatment is also provided to help bend down the skirt part fabric (safety pads surrounding part).

Furthermore, the samples are evaluated by standard test methods such as adhesion, low-temperature bending, and abrasion resistance test. The tensile and tear strength also re-performed with the company supplier standard. The results indicated an average performance value for NICOLON C888 with average tensile strength, highest tear strength, and lowest adhesion strength compared to BERG Elite & Champion PVC. The low-temperature bending test indicated NICOLON C888 might better resist cracking in cold temperature while the abrasion test shows a strong endurance of NICOLON C888 against abrasion but has twice less coating weight and thickness compared to BERG Elite & Champion PVC.

Finally, this study has succeeded to design a 100% PE-based material composition for BERG safety pads and established new testing methods for testing the fabric cover material which may be beneficial for company's reference for material evaluation and new protective edge model.

Chapter I - Introduction

1.1. Background

1.1.1. Introduction words over BERG Toys BV

BERG Toys BV was established in 1985 by Henk van den Berg with its first product focusing on the go-kart. The company headquarter is located in Ede, Gelderland province, The Netherland. BERG has grown to become one of the biggest players in the outdoor toy market, and BERG has expanded its product to a wide range of outdoor toys by producing pedal go-kart, backyard trampolines, and rides along with its accessories and spare-parts. Nowadays, BERG Toys products are sold and distributed to more than 65 countries with Europe such as Germany, U.K and Scandinavian countries as the most prominent market. BERG is also trying to expand its market to the U.S shortly.

The company has the vision for creating Fun, Innovative and Quality product with core values: Quality, Safe, Fun, Sustainable, Exclusive Design, and Innovation. Thus, the company is continuously working with Research & Development-Product Management department to develop innovation within the product to stay as the market leader.

Berg Toys as one of a company that specialised in backyard trampoline product are producing various types of trampoline such as BERG Talent, BERG Favorit, BERG Champion, and BERG Elite which also available in BERG Grand and BERG flat ground trampoline type. BERG Toys are currently working for innovation of their trampoline product which is aimed to design a better quality, durable and more eco-friendly trampoline protective edge.

1.1.2. Problem definition

Most of the protective edge used nowadays in the trampoline is made of woven fabric as the core material which is laminated with PVC film plastic and addition of phthalates plasticisers. These type of materials are also used by BERG TOYS for all their trampoline products.

Some customers have reported if, after several months, some safety pads of the trampoline product started to show de-lamination between PES fabric and PVC film. PVC coating also tends to become rigid and peel off which is thought happened due to plasticiser migration. Studies also show if PVC (vinyl) lifecycle forms large quantities of hazardous organochlorine by-products that released to the environment. Both of PVC and phthalates are also listed in chemical restricted substances for Cradle to Cradle product regulation. In most of the European nations, certain uses of PVC have been limited or eliminated for environmental reasons, while several countries have ambitious agenda to reduce PVC use overall (Thornton, 2000).

Unfortunately, there are still not many other options or alternative for the trampoline protective edge which is not only more eco-friendly but also has similar or better physical properties mainly in the weather resistance. Thus, these problems trigger Berg toys with its R&D department to do innovation for finding its alternative protective edge design and improve the product for their consumers. However, the obstacle comes with limited knowledge regarding the textile material. Hence the researcher presence to work within the company is expected to give a new perspective. The researcher duty in the company will focus on finding material besides that company currently used, and designing the alternative trampoline protective edge which expected will have at least similar or better performance.

1.2. Consumer needs analysis & FEA design criteria

BERG Toys as the client in this project has target consumers who mostly are families with children. In company perspective, since the decision of buying and choosing the product will rely much on the parent, it is essential to create an exclusive design that satisfies the children safety requirement and family standard such as protection, good quality and fit in the backyard area of the typical family house (BERG, 2017).

For BERG Trampolines product the market areas are regularly in EU countries. As mentioned in problem definition, the European nations have concerned the issues of PVC more seriously, and now working to reduce the use of this plastic. Thus, to address the market needs for less PVC product, the future safety pads should contain zero PVC material. The Scandinavian countries are one of the most rapidly growing market and now take 20 % of the total selling. Therefore, it is important for the alternative material to be able to withstand the sub-tropical climate condition especially to maintain its structural integration under a freezing temperature as the Scandinavian countries.

The FEA design criteria will focus on material physical properties analysis considering the safety pads are an outdoor used product. Furthermore, the physical stress analysis and weather resistance property analysis of the product take the highest portion of the focused of the research to find the alternative material. Another aspect such as production cost, environmental impact, and aesthetic overview of the new design also take into the analysis, with the company current protective edge model and material as the reference for the standard of the new concept.

1.3. Literature study

As shown in Figure 1, BERG Toys trampolines are made of four primary components: a) tubing, b) springs, c) jumping mat, and d) safety pads.

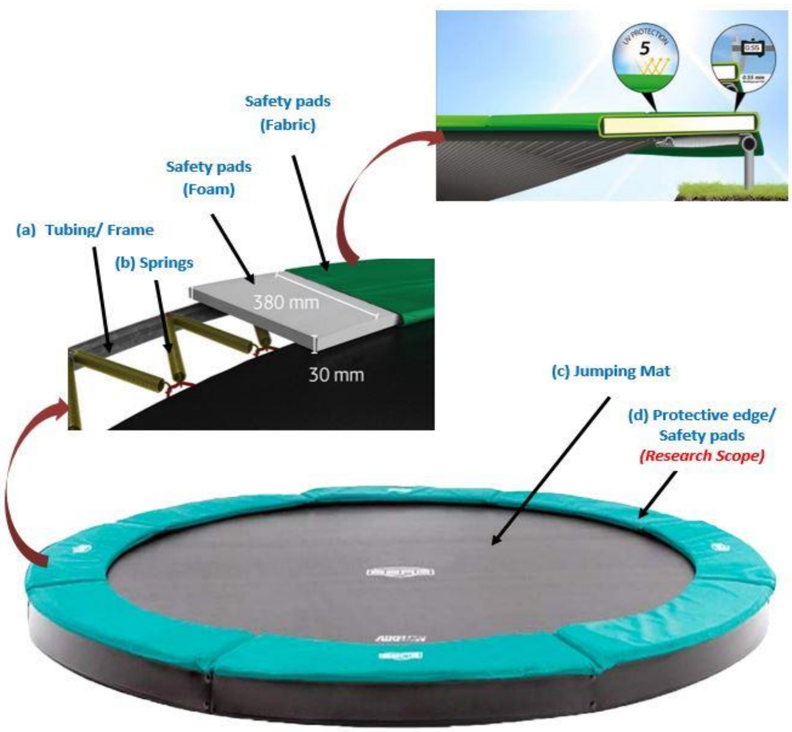


Figure 1 - BERG Toys standard trampoline with all the sub-parts.

The safety pad or protective edge is the part which is used to cover both the frame and springs with an extra-wide plank thick foam for protection. There are many shape designs presence in the market for safety pad such as a hexagon, octagon, rectangle, circle, and an ellipse. In functional requirement, the decision of material relies on numerous factors with performance and weather-proof aspects as the primary factor to be considered. At least the material should meet several standard criteria such as:

- Highly waterproof, especially for the outdoor trampolines
- Resistant to ultraviolet radiations and colour retention
- Tear resilient and capable of absorbing shock

The trampoline protective edge including that created by BERG toys is made of two basic materials which consist of the protective cover and the foam. The material illustration is described in the following:

1. Protective cover

The protective cover is made of a single layer of fabric, generally a woven fabric which is reinforced with a plastic polymer. It is combined by two methods; first, by laminating the plastic layer. Second, by using the knife coating which is applied to both sides of the fabric. The combination creates a structure shown similar to Figure 2 below:

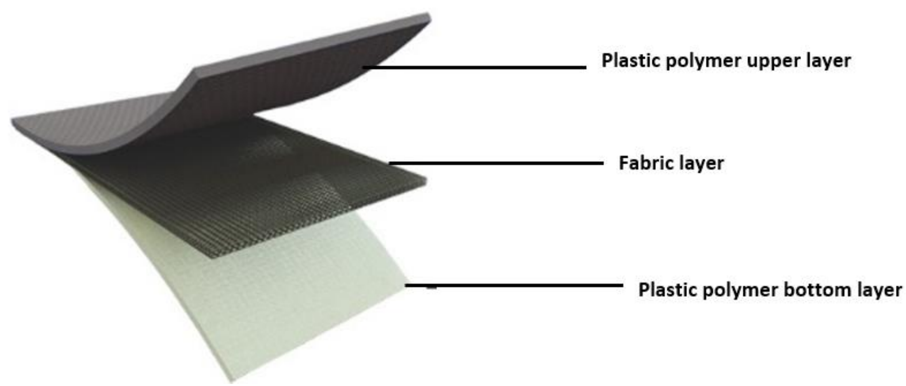


Figure 2 - Protective cover structure.

In the structure, the base or the woven fabric will determine mostly the strength properties such as tensile and tear strength while the plastic polymer material will determine more in the resistance to the environment weather such as waterproofness, UV resistant, colourfastness, biological/ chemical attack, etc. The protective cover material is often similar to the material used in tarpaulin. The materials that currently available in the market are described below:

a. Fabric layer

Majority of safety pads which are available made of Polyester (PES) although some also made of nylon. The commercial PES fibres which made nowadays are composed of Terephthalic acid and ethylene glycol (PET). Polyester fabrics and yarns made from this type of PES are durable, very elastic, have high abrasion, and wrinkle resistance. However, polyester fibres may not as strong as nylon fibres. It has an excellent tensile strength and organic resistance. It also has good resistance to UV radiation, but the fibres can burn slowly. The other benefit because PES fabric is relatively inexpensive. Compared to PES, nylon has higher impact strength, not flammable, and provide good resistance to most chemical but it tends to absorb moisture and relative to be more expensive than PES. At the application, the threads are woven into net fabrics construction in which will be coated or laminated with a plastic polymer such as PVC or PE (CROW, 2015).

b. Plastic polymer

The plastic polymer which currently used mostly is PVC. Reinforcing PVC will strengthen and create stiff property while maintaining a low density. PVC is economical in price, it is not easily burned and has excellent resistance against chemical or biological attack. PVC is quite stiff or rigid. Thus, the PVC for coating are often added with plasticizers such as phthalates to make it flexible, but since PVC has low aging resistance, this plasticizer will migrate through time and creates cracks and peels especially when exposed to cold weather. Lastly, it has good colour retention. Thus, the colour of the trampoline safety pads will not change with time. Since PVC has found to be not eco-friendly, several alternatives for coating can also be used such as Polyurethane (PU), Polyethylene (PE) or silicon, but in general, it is still hard to compete the PVC regarding price and functionality. Therefore, further research needs to be conducted to study these alternative materials.

2. Foam

The foam functions as a pad and it also used to absorb shock especially when people step on the safety pads, the foam should be able to maintain or return to its original form. Expanded polypropylene (EPP) expanded polyethylene, and Ethylene-Vinyl acetate (EVA) foam are several examples of foam material which are available in the market. EPE foam is a foam which is currently used by the company. EPE has a lightweight, non-abrasive, chemically inert and also recyclable. The closed cell structure also made EPE becomes water resistant and has good shock absorbing capability (Andrews, 2018).

1.4. Design brief

The project design is following the diagram process of Apparel Design Framework (Lamb & kallal, 1992). The reasons behind are the systematic tasks given by the company, and the result is similar in which to not only conducting a research but also to develop a prototype as the final result. This framework also helps the researcher to justify the demand of the company for the new design product. The research design stages will be performed in 5 steps as shown in the diagram in Figure 3 below.

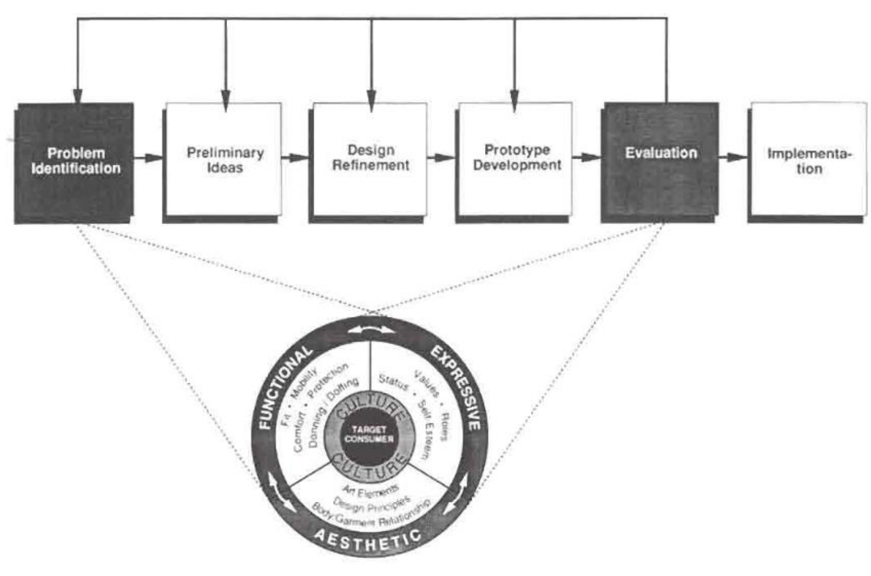


Figure 3 - Apparel Design Framework.

Categorisations based on the Lamb & Kallal functional, expressive and aesthetic aspects are important because to design a prototype, one must not only see the technical performance of the product but also need to consider product attractiveness. It also should have other additional values for the customers, offering something different from other competitors. The framework also helps the researcher to ask targeted questions to the company. For the graduation assignment, the researcher will work until the fifth stage. The results will be used by the company as the recommendation to be implemented and further developed. Moreover, it is necessary to develop trampoline protective edge concept design which has strong outdoor performance and can address the safety and environmental issues.

1.5. Research questions

1.5.1. Main research question

How can an alternative design be realised for trampoline protective edge with similar or better performance concerning functional, expressive, and aesthetic properties for BERG Toys?

1.5.2. Sub-questions

1. What are BERG Toys functional, expressive, and aesthetic list of demands and list of requirements for the alternative trampoline protective edge?
2. What are the suitable material(s) and parts required for the alternative design of the trampoline protective edge?
3. How will the chosen design concept for alternative trampoline protective edge be transformed into a prototype?
4. What tests need to be performed to evaluate and compare the newly developed prototype with the existing trampoline protective edge based on BERG Toys requirements?

1.6. Structure description (Scope of the research project)

The bachelor thesis will focus on how to make the realisation of the trampoline protective edge alternative design. Lamb & Kallal model which divides the product design criteria into functional, expressive, and aesthetic properties will be used as guidance to get the information of company demand to the alternatives design. It is also useful for standardising and check the new design to make sure if nothing is missing during the process. The researcher will conduct literature study, investigation of the current material properties, and analyse the alternative options available in the market. There still not many studies for replacing the PVC coating especially for the trampoline application but the idea to replace the PVC have been an issue, especially in this decade due to environmental disadvantages caused by the PVC. Based on literature researchers and Lamb & Kallal guidance, this research work is conducted in a way as Figure 4.

From the flow chart, Lamb & Kallal product design model will become guidance to control each step especially when making the list of demands, interview the company, and when planning or execute the testing plan. Lamb & Kallal is essential to make sure that the alternative has followed through company wish. From the Lamb & Kallal diagram shown in Figure 5, it also indicates if, in the product design, the functional aspect will be the first consideration, followed by expressive and aesthetic aspect.

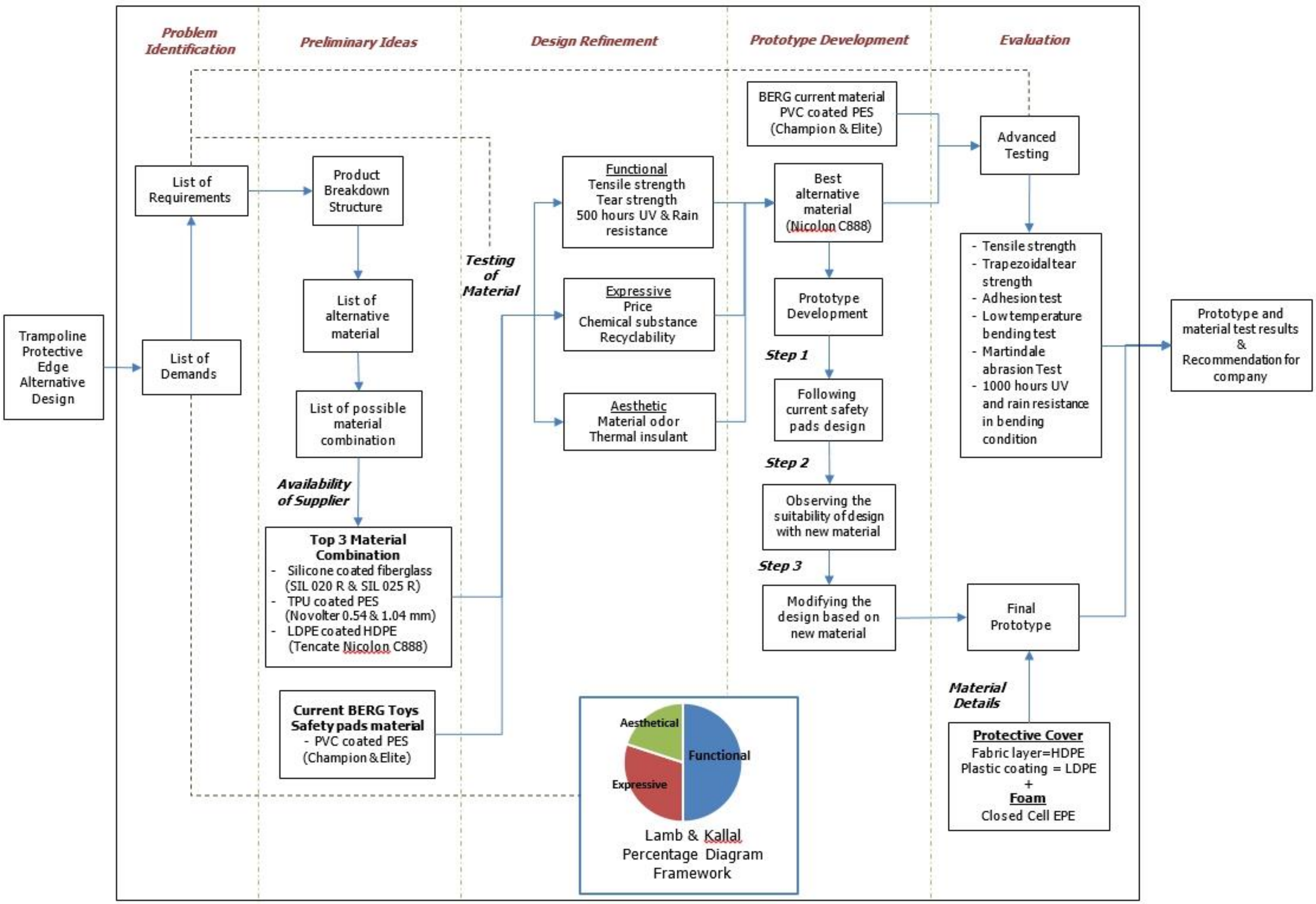


Figure 4 - Flow Chart diagram shows the research approach and detail product development planning of alternative trampoline safety pads.

Chapter 2 – Materials & Methods

The material used in the development of the prototype is searched in the market with the properties based on criteria set up in a "List of demands" which then transferred into a more specific "List of requirements." The lists become a guide for each next step, from the research of the materials until the making of the prototype and testing methods of the material. Along with categorisation based on Lamb & Kallal 3 aspects, the list of demands is also divided into two levels:

a) Requirement Properties which are "must have" or fulfilled by the alternative material
b) Wish Properties which are not obligatory, but it will be considered as "nice to have" in the new alternative material. It can be stated as additional benefits.

Appendix 1 – Lists of demands and List of requirements details information (Functional, expressive, and aesthetic aspects) describes all company's demands which are transferred into requirements that can be measured for instance laboratory testing method, price, availability of supplier, and become the comparison indicator of the alternative with the current material company used.

Product Breakdown Structure then used to categorise the product into its required components. The objective of this breakdown is to provide a visual representation of a products components and the relationship between those components. In turn, product planners are equipped with a visual representation that offers the clear understanding of what the end product required (Product Breakdown Structure, 2018). The searching and making of possible material(s) as well as combination lists will follow the PBS model. In PBS model, the protective cover will be split into three categories such as the fabric material, coating material, and fabric construction, while the overall alternative protective edges are divided into two components; the protective cover and the foam.

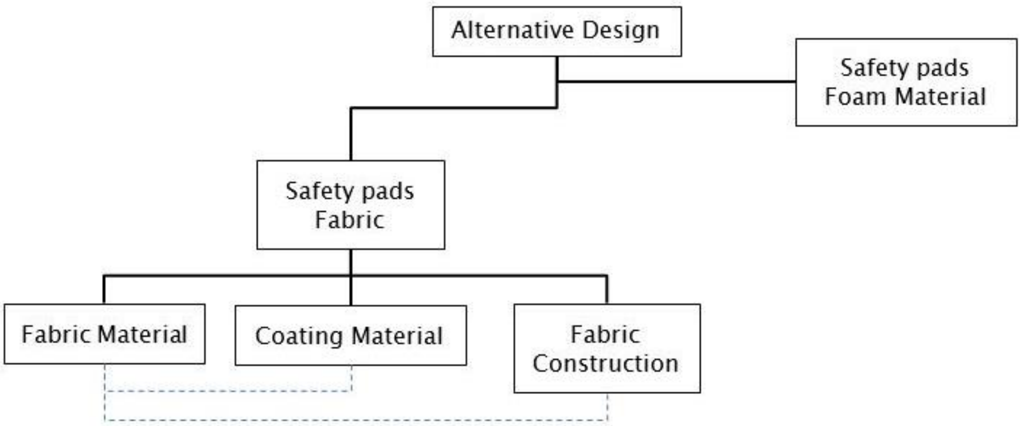


Figure 5 - Product Breakdown Structure (PBS) diagram of the trampoline protective edge.

2.1. Materials

For this assignment, the protective cover will become the primary focus since the foam has no vital issues. Thus, it will not be changed or modified unless it is necessary to compact with the new fabric cover material. After literature study, possible material combinations are chosen and put together in Table 1 below.

Table 1 - Possible combinations of fabric composition and construction.

Construction		Fabric Material		Coating
Woven Fabrics		PES		PVC
Microfibers		Nylon (Polyamide)		Silicone
Densely Woven Fabrics		Fibreglass		Polyurethane (PU)
Non-woven		Ultra-High Molecule Weight Polyethylene		PTFE Finishing
Composite				Neoprene
Ripstop grid		HDPE		LDPE

In a selection of the fabric, the researcher tries to seek for the available fabric sample based on PBS. The result is some fabrics appeared to be easily found in the market, some fabrics are specially produced by only a particular company, and the rest are rarely found. Following the observation of the fabrics, based on the appearance such as thickness some samples appear to have a very low thickness. In addition, the feasibility of application and possibility to mass produced the fabric. From all options on Appendix 2 – Overall fabric material ordered samples information the researcher comes up to continue working with five samples shown in Table 2 which is expected to have the best prospect to become the alternatives to current company material.

Table 2 - Fabric material samples chosen.

Fabric Sample order list	Supplier	Weight	Thickness (mm)
Silicone rubber coated glass fabric SIL 020 R	Fiberflon	340 g/m2	0.23
Silicone rubber coated glass fabric SIL 025 R	Fiberflon	400 g/m2	0.28
NICOLON C888	Tencate	340 g/m2	0.5
TPU coated fabric (1)	Novolter	895 g/m2	1.04
TPU coated fabric (2)	Novolter	447 g/m2	0.54

2.2. Methods

2.2.1. Selection test planning

Preparation of fabrics

The fabric samples are conditioned under room temperature for 24 hours. The specimen conditioned test samples are then laid on a flat surface. The samples are actually should not be taken from neared the selvedge especially for less than 150 mm, from wrinkled places, and folding traces. However, since the limited numbers of these samples material become the obstacles faced in the project, these requirements cannot be implemented in the first test experiment.

Cutting planning of samples

The prior laboratory tests conducted are the tensile strength, the UV test, and the tear strength. The researcher tries to perform the test in both warp and weft direction of the fabric. Unfortunately, the limitation of the samples makes this rather impossible thus an appropriate cutting planning of specimens for testing from the samples is required.

Table 3 - Size requirement for each testing.

No	Testing name	Sample size need for each specimen	Qty.
1	Tensile Strength	5 cm x 15 cm	2 (warp & weft)
2	Tear Strength	5 cm x 20 cm	2 (warp & weft)
3	UV test	5 cm x 12 cm	2 (warp & weft)

Figures in Appendix 3 – Samples cutting planning display the cutting model where it is impossible to conduct all the tests in both warp and weft directions with the available samples, thus for some tests, the researcher made the decision by using the information that could be obtained from one fabric direction only. Table 4 describes which fabric may possible to be tested in both warp and weft.

Table 4 - List of cutting samples.

Testing Name	Tensile Strength	Tear Strength	UV test
Sample size Width x Length	5 cm x 15 cm	5 cm x 20 cm	5 cm x 12 cm
SIL 020 R	warp and weft	Only warp	warp and weft
SIL 025 R	warp and weft	Only warp	warp and weft
TPU 0.54 mm	warp and weft	warp and weft	warp and weft
TPU 1.04 mm	warp and weft	warp and weft	warp and weft
Tencate NICOLON C888	warp and weft	Only warp	warp and weft

2.2.2. Selection and evaluation test explanation

All the alternative materials are first tested with basic laboratory testing such as Tensile strength, Tear strength and Weather resistance to choose the best option. The selected material is then re-evaluated with BERG current PVC coated PES and performed by following the more compatible testing standard tests from the company and the supplier. These include the re-perform of previous tests with different methods than conducted for the selection of materials. Further evaluations such as Adhesion test, Low-Temperature bending test, and Martindale abrasion test are aimed to observe if the chosen material will able to have similar or better performance than the current material used by the company. It is also necessary to know the compatibility of the material with the product design and to find out what improvement will be needed for the implementation purposes.

A) Tensile strength

The tensile strength test is conducted by ASTM D751-06 (Standard Test Method for Coated Fabrics) for the selection and DIN 53354 (Testing of Artificial Leather; Tensile test) for the evaluation.

- Motivation
  The safety pads fabric uses to cover the padding will be mostly being trampled when it is being used and also withdrawn when it is being assembled in the manufacturing process of safety pads. Thus. It should be able to resist mechanical force comes from tensile stress.
- Objective: Determine the force that breaks the fabric to know how durable the fabric is in the warp and weft direction. Additionally, this test method is similarly used by the supplier of the material thus we can clarify the legitimacy of the data provided by the supplier.
- ASTM D751-06 Specimen :
  Width 5 cm & length 15 cm (*note: modify from original standard to compact with available samples*)

- DIN 53354 Specimen :
  (Width 5 cm & length 30 cm)
- ASTM D751-06 Procedure:
  Pulling speed: (12 ± 0.5 in./min) or 100 mm/ min.
  The distance between clamps: 75mm (3 in.) Test conducted in warp and weft direction (ASTM, 2011)
- DIN 53354 Procedure:
  Pulling speed: 100 mm/ min
  The distance between clamps: 200 mm
  Test conducted in warp and weft direction
  (Lu & Yang, 2006).

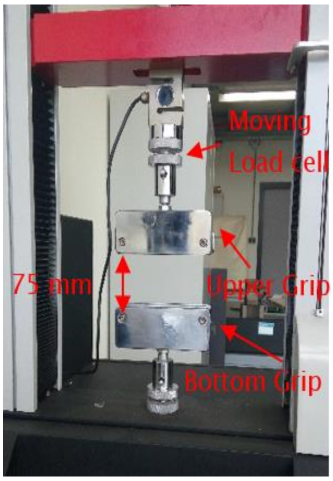


Figure 6 - Fabric tensile test ASTM D751-06.

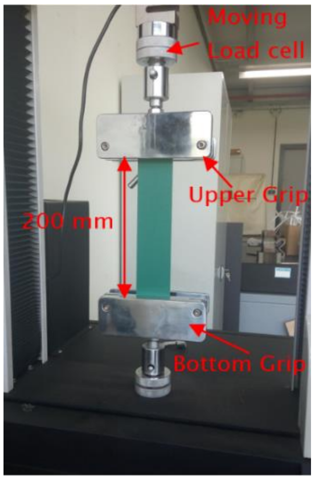


Figure 7 - Fabric tensile test DIN 53354.

B) *Tear strength*

The tear strength is conducted by ISO 13937(2) – 2000 (Tear Properties of Fabrics-Part 2: Determination of Tear Force of Trouser-Shaped Test Specimens (Single-Tear Method)) for the selection and DIN 53363 (Testing of Plastic Films-Tear Propagation Test on Trapezoidal Specimens with a slit) for the evaluation.

- Motivation
  This test should be performed due to similar reasons as previously mentioned in a tensile strength test. Moreover, in assembling process of making safety pads, the stitching process might trigger a shred. This test will make sure if this case happened, the tearing section will not easily be extended, and the fabric can maintain its shape.
- Objective: Measure of how well a material can withstand the effects of tearing or more specifically to resist the growth of any cuts under tension condition.
- ISO 13937(2) Specimen:
  Width 5 cm and length 20 cm for warp and weft direction
- DIN 53363 Specimen:
  Width 75 mm and length 150 mm (Both warp & weft direction) with the cutting method specified as illustrated in Figure 8.

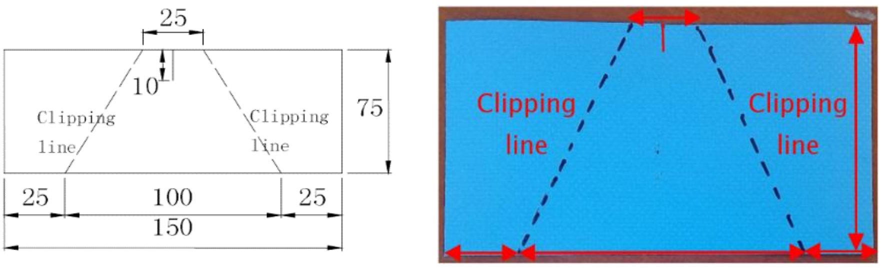


Figure 8 - Specimen model of the trapezoidal tearing test method.

- ISO 13937(2) Procedure:
  Pulling speed 50.8 mm/min or 100 mm/min
  The distance between clamps: 100 mm (ISO, Textiles - Tear properties of fabrics - Part 2: Determination of tear force of trouser-shaped test specimens (Single tear method), 2000)
- DIN 53363 Procedure:
  Pulling speed 100 mm/min. The distance between clamps: 25 mm

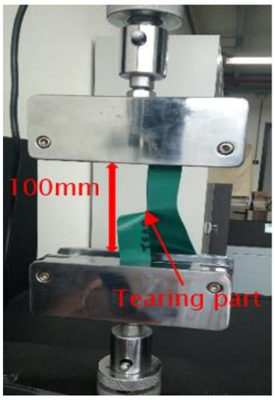


Figure 9 - Tear strength test ISO 13937(2).

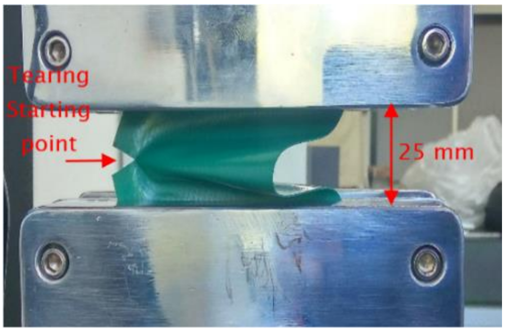


Figure 10 - Trapezoidal tear strength test DIN 53363.

C) *Weather resistant test*

The procedure reference used was ISO 11507 (Test Methods for Exposure of Coatings to Fluorescent UV Lamps and Water) and ISO 105A (Textile Test for Colourfastness).

- Motivation
  The fabric will need to stay outside and will be exposed to extreme weather conditions for more than a year. During the time, the fabric must able to maintain its aesthetic property. The discolouration must meet BERG Toys standard after this test.
- Objective: Observe the colour resistant to the fabric after exposure to artificial sun UV and spray rating (rain simulation).
- Specimen: Width 5 cm and length 12 cm (warp and weft direction)
- Procedure
  The test will expose the fabric specimen with UV and water for 500 h duration performed by Atlas UV machine, later the samples will be visually observed to see the discolouration of the material and must have discolouration grade $\geq$ 4 from scale 1 to 5 (ISO, 2001).

Figure 11 - Atlas UV testing machine.

In Figure below: The fabric samples from left to right are: (a) NICOLON C888, (b) SIL 020R, (c)SIL 025R, (d) PVC Elite, (e) PVC Champion, (f) TPU 0.54 mm, (g) TPU 1.04 mm.

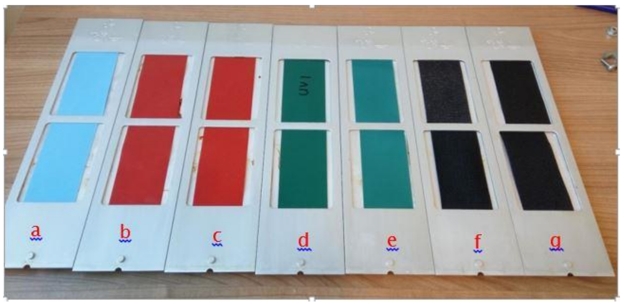


Figure 12 - Fabric samples preparations before exposure.

Besides the regular test, the same method is also used in the evaluation phase for the chosen fabric, but the samples are set in the folding conditions as shown in Figure 13. The exposure takes until 1000 hours in the machine. The observation then conducted to see the sign of cracking in the folding spot with a purpose to understand the influence of UV and rain on the appearance of cracking on the surface of the fabric material.

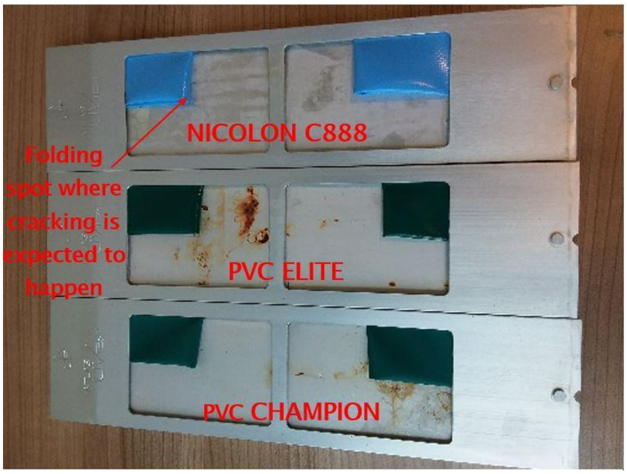


Figure 13 - Fabric samples preparations in folding condition before exposure.

D) Adhesion test

The adhesion strength is conducted by ASTM D 751-06 (Adhesion of the Coating to Fabric). Adhesion testing determines the bond strength between the outside layer (E.g., PVC, and LDPE) and the inside layer (woven yarn) of a composite fabric.

- Motivation
  Material bonds between netting and the coating are essential because the material will be flexed and folded during the period of usage. Since it will also be used outside it will be highly exposed to force for instance wind that can cause the de-lamination when its adhesion strength is not strong.
- Objective: Determine the maximum force needed to de-attach the coating of fabric from the inside netting.
- Specimen: Width 25 mm & length 300 mm

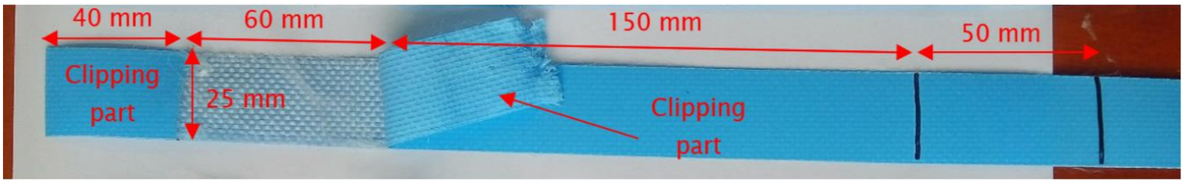


Figure 14 - Adhesion test specimen model.

- Procedure
  Pulling speed: 50 mm/ min.
  The distance between clamps: 25 mm.
  The test will be repeated three times on the specimen with the width 25 mm. The results will be multiplied by two since the company current PVC adhesion data provided by the supplier stated the adhesion strength per 50 mm. To ensure the accuracy of the results after it multiplies by 2, the researcher conducted one more test for the specimen with 50 mm width (ASTM, Adhesion of coating to fabric, 2011).

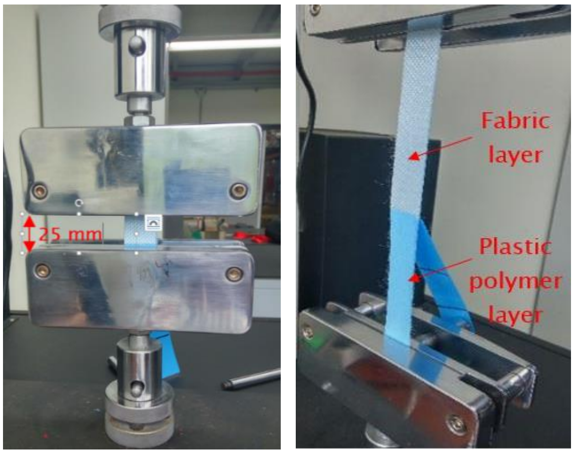


Figure 15 - Adhesion test with UTM.

E) Low-temperature Bending test

The low-temperature Bending test is performed by ASTM D 2136-02 (Standard Test Method for Coated Fabrics-Low-Temperature Bend Test). Fabrics coated with the plastic material will tend to display increased stiffening especially when exposed to decreasing ambient temperature.

- Motivation
  Trampoline products made by BERG Toys are mostly sold to the Scandinavian countries which tend to have a temperature below -15^{0}C, especially during winter. Since the trampoline will be put outside for years, the safety pads fabric should be able to maintain its flexibility under freezing temperature.
- Objective: Determine the material flexibility under specified low and describe with a pass or fail in case there is cracking appeared after the test procedure.
- Specimen: Width 25 mm & length 100 mm
- Procedure
  Put material specimens inside the chamber under temperature below -20^{0}C and then take the specimens after for 4 hours by using a glove. Lastly, fold all specimens using a metal plate to create bending. The test will be repeated three times for both warp and weft directions. After the samples are taken out, examine for fractures or coating cracks under approximately 5 times magnification (ASTM, 2012).

F) Martindale abrasion test

The abrasion resistance test is conducted by using the Martindale abrasion testing machine, the method and instruction used similarly to ASTM D 4966-98 (Standard Test Method for Abrasion Resistance of Textile Fabrics) but it will be slightly modified due to there is no specific test made found yet for testing the plastic coated fabric for safety pads application. This test determines the durability of the coating by observing the abrasion resistance of the plastic polymer.

- Motivation
  Trampoline safety pads will be exposed to numerous abrasions condition such as stepping, rough material, e.g., cloth or other things used by people who play the trampoline. Thus, it is crucial for the safety pads cover to have excellent resistance to abrasion.
- Objective: Determine and compare the abrasion resistance between samples and observe the behaviour of the fabric before and after the abrasion test conduct.
- Specimen: Samples are cut using Martindale cutting tools (Diameter = 14 cm)
- Procedure: (Figures illustrate the process and tools used can be found in Appendix 4 – Martindale abrasion resistance test tools)
  a) Measure the weight and the thickness of the samples before the test conducted.
  b) Prepare the test by cutting fine sandpaper to replace the abrasion fabric and put the abrasion fabric in the tools.
  c) Put the samples in the machine and give a weight of 12kPa after everything are ready, programmed the machine to run a batch of 500 movements.
  d) Observe the samples every batch of 500 movements until it reached 5000 movements.
  e) Measure the weight and the thickness of the samples once more after the test finished.

Chapter 3 – Results & Discussion

The design refinement informs about the process of decision making to choose one material over five available material samples. These five materials (SIL 020 R, SIL 025 R, NICOLON C888, Novolter TPU coated PES 1.04 mm, and Novolter TPU coated PES 0.54 mm) are the samples which have met the important requirement such as the availability of supplier or the convenience to find the material supplier in the market. Since all the materials come from the different supplier, each of them may have different standard specification mainly in terms of functional aspects. Thus, the laboratory evaluation performed in the design refinement is used to equate all the material samples specification with the chosen tests. That way, it will be easier to compare the alternative material with the PVC material that currently used by the company.

The method analysis to come up with the final decision will first use the quantitative method in the form of a laboratory test to study the functionality aspect and second the qualitative method by material literature review and supplier interviews to examine the expressive and aesthetic aspects of the samples.

3.1. Functional tests result for material selection

3.1.1. Tensile test results of the chosen samples

The results of the tensile tests by ASTM D751-06 are also used to determine the warp and weft direction of the fabric samples and shown in the figures in Appendix 5, the overall results of all the fabrics are also shown in Table 5 below.

Table 5 - Results of tensile test and elongation for seven fabric samples.

Fabric material samples	Tensile (N/5 cm)		Elongation (mm)	
	Warp	Weft	Warp	Weft
BERG Champion PVC coated Polyester ©	1352	1205	19.75	21.8
BERG Elite PVC coated Polyester ©	2306	1617	17.75	18.79
Silicone rubber coated glass fabric SIL 020 R	1342	938	5.05	3.09
Silicone rubber coated glass fabric SIL 025 R	2103	1565	5.07	5.26
NICOLON C888	1675	1617	16.2	13.63
TPU coated PES 1.04	2982	1714	34.88	19.5
TPU coated PES 0.54	1490	1311	20.76	21.52

From the tensile test result, it is found if the TPU coated PES 1.04 mm has the highest strength in both warp and weft direction. The second is Elite PVC and SIL 025 R with an almost similar result. The third is NICOLON C888 with same strength in both warp and weft, followed by Champion PVC, and TPU coated PES 0.54. Lastly is SIL 020 R with the weft strength below 1000 N/5 cm.

As for the elongation, the TPU coated shows a high elongation, especially for the 1.04 mm thickness, can extend more than 30 mm in the warp direction, followed by BERG current Elite and Champion fabric with approximately 19.5 mm elongation length in both warp and weft, next is NICOLON C888, and the last is both silicone coated with the lowest elongation in 5 mm range.

Some of the fabrics have significant differences in strength between warp and weft direction. It is due to different yarns number per square or the fabric density since the fabric supplier data shown if the warp and weft are made with same yarn. Only the TPU coated PES 1.04 mm that shows a different yarn density in which the warp yarn can be seen to be more prominent in density compared to the weft yarn which makes a significant difference between its tensile strength and elongation in a different direction. The low elongation of the Silicone coated glass fabric is thought to be happened due to low elongation of fabric glass compared to the Polyethylene yarn. Besides, during the test, the fabric part which is clamped to the machine needs to be pasted with other fabric which can be seen in Appendix 5 – Overall tensile and tear strength results of seven chosen fabrics samples since it tends to slip during the test.

Aside from the tensile strength, the elongation of the fabric is also supposed to be taken into account since it can describe the stretching ability of the fabric. The stretching ability is important because the fabric will be trampled when it is used as the safety pads.

3.1.2. Tearing test results of the chosen samples

The complete tearing test are conducted only in warp direction by using the rest of fabric samples. Table 6 below shows the warp and weft test results but for silicone coated and NICOLON C888 fabric it is only possible to do in the warp direction.

Table 6 – Tearing test result of seven fabric samples.

Fabric material samples	Tear (N)	
	Warp	Weft
BERG Champion PVC coated Polyester	252.03	215.75
BERG Elite PVC coated Polyester	140.23	158.87
Silicone rubber coated glass fabric SIL 020 R	0	X
Silicone rubber coated glass fabric SIL 025 R	45.1	X
NICOLON C888	201.04	X
TPU coated PES 1.04	199.07	321.66
TPU coated PES 0.54	122.58	131.41

Table 6 shows the tearing strength in warp direction in the following order: Champion PVC > TPU coated PES 1.04 & NICOLON C888 > BERG Elite PVC > TPU coated PES 0.54 > SIL 025 R > SIL 020 R. However, in the weft direction, TPU coated PES 1.04 shows a significantly higher strength which exceeds 300 N.

For tearing test results, among all the fabric except the silicone coated fabric can accomplish the standard requirements for more than 100 N of the tear strength. The silicone coated fabric appears to have deficient tear strength especially the SIL 020 R which cannot maintain its netting from tearing.

Figure 16 - Seven fabric samples after the tear test.

During the tear test, the fabric samples also show different appearance in the tearing part, particularly with the champion fabric. The netting of champion fabric tends to be drawn out of the coating as seen in Figure 16. Therefore, there are long yarns visible in the tearing part of the champion fabric. This could be an indication about low adhesion between coating and fabric netting since the champion fabric is made with laminated proses between PES fabric and PVC sheet. In conclusion, the adhesion strength of PVC Champion might not be as strong as the other coated fabric which makes the yarns are pulled out in the tearing process.

3.1.3. Atlas UV testing results

After the specimen exposed with UV and water for 500 h in Atlas UV machine, a visual observation is conducted to all the material samples with the result as shown in Figure 17.

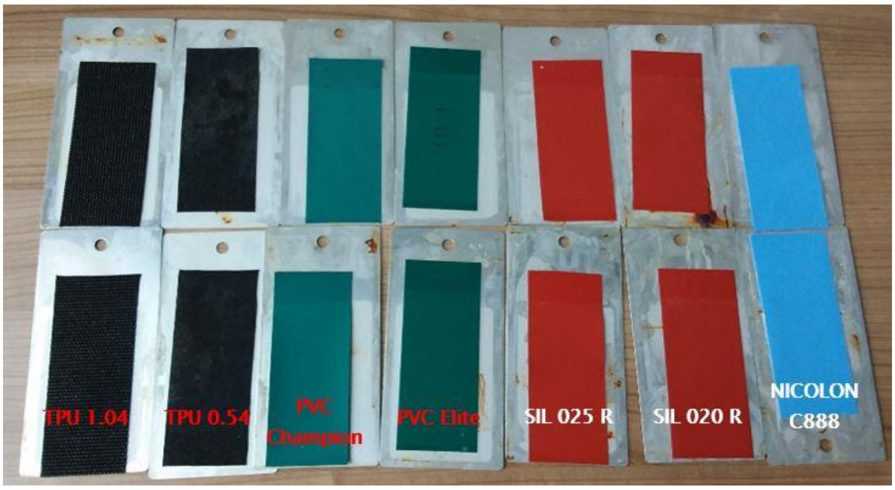


Figure 17 - Seven fabric samples after 500 hours UV test.

From the discolouration test with the scale 1 to 5, Novolter TPU with 1.04 mm thickness and Tencate NICOLON C888 shows the best results with 5 score (no discolouration after exposure), followed by BERG Champion PVC, BERG Elite PVC, SIL 020 R and SIL 025 R with score 4 (the colour a bit faded after exposure but still comply with the minimum requirement >4). The last is Novolter TPU with 0.54 mm thickness with score 3 (average to high discolouration after exposure). For the TPU 0.54 mm thickness there are white randomly spots appeared on the surface of the fabric after the exposure such as shown in Figure 18 below

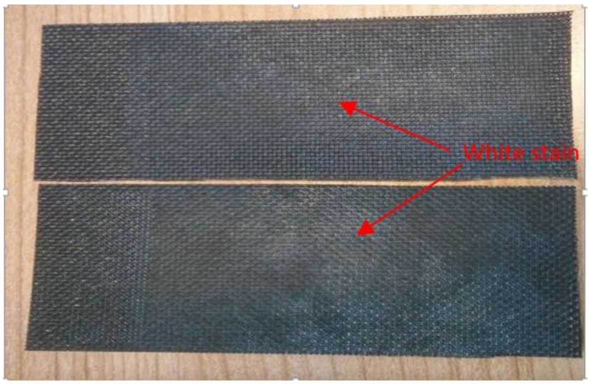


Figure 18 - Novolter TPU 0.54 mm after 500 hours UV test.

In conclusion, all the fabric samples except the TPU 0.54 mm pass the requirement for the discolouration after UV and water exposure. It means if all the fabric samples besides TPU 0.54 mm can withstand the colour when it is being put outside and being exposed to sun and rain even if there will be other factors which also can cause the discolouration of the coated fabric.

3.2. Expressive and aesthetic information

3.2.1 Expressive

- Price and restricted contents of material

The price in Table 7 is set in Dollar to follow data sheet of the company for their current materials also since most of the supplier provided the price in Dollar instead of Euro. Thus, it will make more convenience for the company to compare each price.

Table 7 - Price and banned chemical substance information of seven fabric samples.

Fabric material samples	Price in Dollar ($) per ($m^2$)	Chemicals Banned (C2C)
BERG Champion PVC coated Polyester	2	PVC, phthalates
BERG Elite PVC coated Polyester	4	PVC, phthalates
Silicone rubber coated glass fabric SIL 020 R	22.37	-
Silicone rubber coated glass fabric SIL 025 R	20.46	-
NICOLON C888	3.02	-
Novolter TPU coated PES 1.04	8.5	-
Novolter TPU coated PES 0.54	12	-

As shown in Table 7, BERG Champion and Elite PVC also NICOLON C888 has the lowest price which is below 5 USD per square meter, followed by Novolter TPU coated PES with cost around 10 USD per square meter and SIL 020 R & 025 R which have the highest price for more than 20 USD per square meter. Hence, the silicone coated glass fabric may have highest production cost compared to other material and can cost a lot to be mass produced. The TPU coated will still be possible but need to find a new way to reduce the cost of the material, and the NICOLON C888 will be the most affordable to be used in mass production of safety pads as like as BERG current PVC material. However, it is also important to keep in mind that the price of the materials above except BERG fabric may still be an estimation since the material may come not from a direct supplier or the production factory. Thus, the price is not an exact number and even possible to be lower than price as mentioned above.

From all the fabric samples, according to Cradle to Cradle (C2C) Banned List of Chemicals for Technical Nutrients, the PVC is restricted in the category of halogenated polymers (Braungart, 2016) along with the phthalates such as Dibutyl phthalate contained in PVC plasticisers are also restricted. In the end, besides of company current fabric material, the researcher did not find any substances contained in the fabric that restricted in C2C lists.

- Recyclability information

Since most of the promising material is a coated fabric, most of them are hard to be recycled. Among the materials, the NICOLON C888 can be the most accessible product to be recycled since it is made of 100% PE which is HDPE and LDPE. Besides, unlike other polymers, HDPE and LDPE are miscible. They can be recycled together. However, to maintain their specific properties, it is better to separate them (Anonim, Plastics recovery manual 2, 2012). The silicone coated fabric is not only difficult to be recycled but also required a high cost to separate the silicone coating from the base fabric for recycling purposes (Toyobo, 2010). The recycling of TPU and PVC coated fabric has currently developed in Germany, it is now possible to be done on an industrial scale, but the number of industry which is capable is still developed and limited (Dräger, 2000).

3.2.2. Aesthetic

- Thermal insulant

The fabric used for the padding should be a high thermal insulant fabric. To understand the thermal insulant properties of the material can be identified from a thermal conductivity value of the material in units of watts per meter-kelvin (W/K.m). Among the fabric samples, the thermal insulant values from the most thermal insulant to the lowest thermal insulant are as follows: Silicone= 0.14 W/K.m > PVC plastic= 0.19 W/K.m > TPU Plastic= 025 W/K.m > LDPE = 0.33 W/K.m. It means if the SIL 020 & SIL 025 R are the least conducive to heat and the most conducive is the NICOLON C888. However, all these materials are still considered to be a very high thermal insulant material because as an example, normal water at 200C has a thermal conductivity value of 0.6 W/K.m.

3.3. Analysis behinds final decision on chosen material

The overview of the samples can be seen in Table 8 below with evaluations and considerations in all functional, aesthetic and expressive requirements. The first selection is conducted in the functional requirement of several laboratory testing. From the functional test such as in tensile strength, tear strength, and colourfastness to UV and rain. The result is all five alternative samples can pass the requirement, except for the silicone coated fibreglass fabric. It shows a deficient tear strength which is 0 N for SIL 020 R and 45.1 N for SIL 025 R. This means that both SIL 020 R and SIL 025 R would be hard to resist the tearing especially when it is stitched, being pulled or stamped when it is used. Thus, the SIL 020 R and SIL 025 R are eliminated for the alternatives. In the artificial UV and rain tests, all the material except the TPU 0.54 mm thickness passed the minimum requirement with minimum 4 in discolouration after exposure. Furthermore, the Novolter TPU coated fabric with 1.04 mm thickness shows the overall best results in functional properties, followed by Tencate NICOLON C888, TPU coated with 0.54 mm thickness, and silicone coated fabric (SIL 025 R and SIL 020 R) at the last position.

After the functional requirements, the next selection is conducted according to expressive requirements by reviewing the price and chemical contents of the material. Based on the chemical contents, all the alternative material does not contain any restricted substance according to Cradle to Cradle (C2C) regulations. By the price, TPU coated fabric with 0.54 mm has twice higher price, and TPU with 1.04 mm has three times higher price compared to company's BERG Elite PVC product. Likewise, the Tencate NICOLON C888 has a price slightly lower than BERG Elite PVC and slightly higher than BERG Champion PVC. Thus, under the price consideration, the Tencate NICOLON C888 will be the most suitable alternative for the mass production.

Regardless the TPU coated fabric shows the best functional results. This material is preferably not the best option since it will increase the production costs to produce the safety pads massively. Thus, it is necessary to find a way to produce the TPU coated polyester fabric with a lower price. From the recyclability of the material, the Tencate NICOLON C888 also appeared to be the easiest to be recycled since it made of 100% Polyester. Thus, from the technical perspective of the convenience to recycle the material after use the NICOLON C888 will be the best option.

Lastly, in the aesthetic requirement, all the material shows a very low thermal insulation which means that all these materials would not highly absorb the heat from the sun. Therefore, after all, considerations based on Lamb & Kallal requirements and discussion with the company stakeholder. The researcher comes up with the decision to go with Tencate NICOLON C888 as the final chosen alternative material. Together with company current PVC Champion and PVC Elite fabric, the Tencate NICOLON C888 will be further evaluated especially in the functional performance to see what can be improved within the material and to compare the alternative with the company current material.

Table 8 - Overall fabric sample properties comparison.

Specific Requirement	BERG Champion	BERG Elite	SIL 020 R	SIL 025 R	NICOLON C888	Novolter TPU 1.04	Novolter TPU 0.54
Tensile Strength (N/5 cm)	Warp: 1352 Weft: 1205	Warp: 2306 Weft: 1617	Warp: 1342 Weft: 938	Warp: 2103 Weft: 1565	Warp: 1675 Weft: 1617	Warp: 2982 Weft: 1714	Warp: 1490 Weft: 1311
Tear Strength Warp (N)	252.03	140.23	0	45.1	201.04	199.07	122.58
Elongation (mm)	Warp: 19.75 Weft: 21.8	Warp: 17.75 Weft: 18.79	Warp: 5.05 Weft: 3.09	Warp: 5.07 Weft: 5.26	Warp: 16.2 Weft: 13.63	Warp: 34,88 Weft: 20.76	Warp: 19.5 Weft: 21.52
Colourfastness to 500 hours UV and rain	4	4	4	4	5	5	3
Price ($/m^2)	2	4	22.37	20.46	3.02	12	8.5
C2C Restricted Substance List	PVC, phthalates	PVC, phthalates	x	X	x	x	X
Recyclability	Hard but possible	Hard but possible	Possible but highly expensive	Possible but highly expensive	Easy and Highly possible	Hard but possible	Hard but possible
Odourless	No odour	No odour	Has a bit distinctive odour of silicone rubber	Has a bit distinctive odour of silicone rubber	No odour	No odour	No odour
Thermal insulant (W/K.m)	0.19	0.19	0.14	0.14	0.33	0.25	0.25
Overall Results Rating	★★★	★★★	★★	★★	★★★★	★★★★	★★★

Note: *For convenience purpose in reading the table and comparison of each material, the researcher categorise each property with four different colour that indicates the material quality*

Category	Colour
++ (Very Good)	
+ (Good)	
+/- (Moderate)	
- (Poor)	

3.4. Prototype development

3.4.1. List of materials used in prototype development

A prototype is made from the chosen alternative coated fabric material which is Tencate NICOLON C888 (LDPE coated HDPE) with the foam inside using the current company foam which is EPE foam (made of LDPE resins) and PES thread with the material information shown in Table 9.

Table 9 - List of materials used in prototype development.

Item	Part	Material	Colour	Dimension
1	Fabric: Tencate NICOLON C888	HDPE densely fabric + LDPE coated	Blue	2 m x 1.5 m = 3 m^2
2	Inside Foam: Non- cross-linked Closed-cell foam	EPE (Expanded Poly Ethylene)	White	(L x W x H) = 92 cm x 36 cm x 3 cm = 9936 cm^3 = 9.9 dm^3
3	Trims: Sewing thread	Polyester 420D per string (consist of 3 strings twisted per yarn)	Green	Spool

3.4.2. The development process

a. First phase

The development of the final prototype is executed in several steps as illustrated in Figure 19, the cutting model of EPE foam and the fabric cover embroidery will also follow the company model at first and will be modified if necessary. The intention is so the final prototype can have a similar model with the current company product and will be easier to be compared and evaluated.

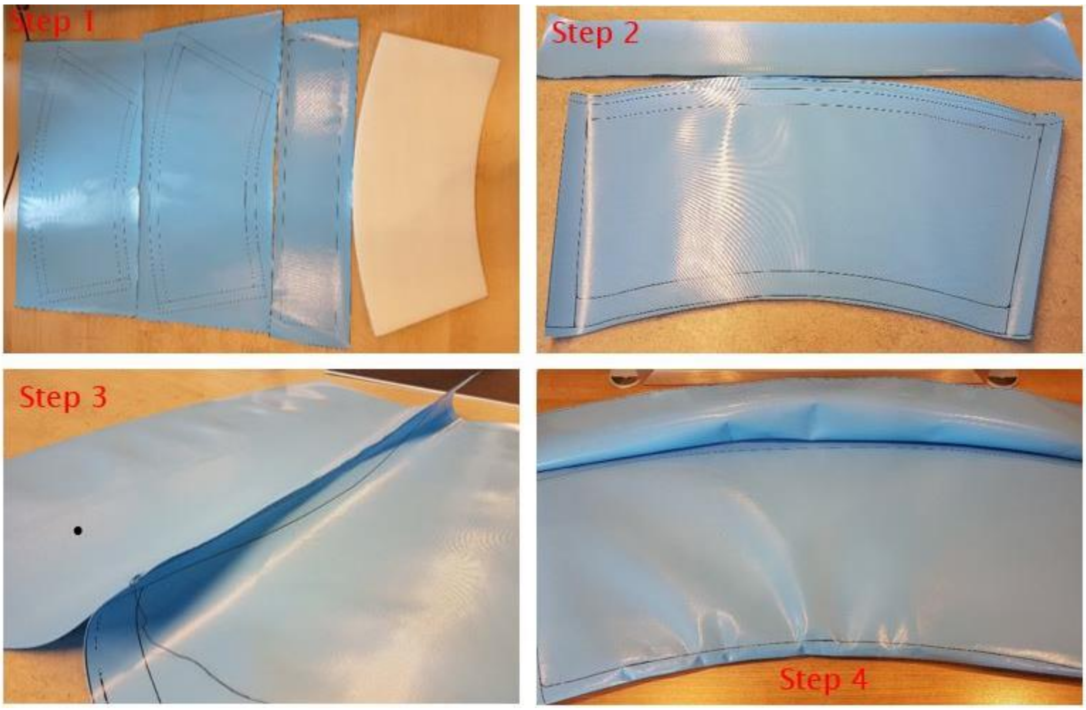


Figure 19 - First prototype development steps.

The first step is to make the cutting model of the prototype part and the sewing pattern. The trampoline cover consists of top and bottom layer of fabric which function to cover the spring also an additional part that surrounds the trampoline to cover the metal frame. The size details of all the part of the prototype can be seen in Appendix 7 – Prototype development process. The second step is to cut the fabric based on the sketch by using cutter since cutting by scissors will cause to a not smooth result. The third step is to stitch all the part which begins by stitching the upper and bottom layer of the safety pads cover and then add the surrounding part (the skirt) in the last step.

b. Second phase (Observing of the prototype)

After the first prototype is made, there are two problems occurred due to the stiffness of the material. As can be seen in Figure 20 especially in the curved area, the fabric is not able much to stretch and be flexible in the curved part in which triggered many cracking appeared in the curved area. Besides, the skirt part is also hardly bend down like PVC Elite and Champion made safety pads. Thus, the new material needs modification in the design.

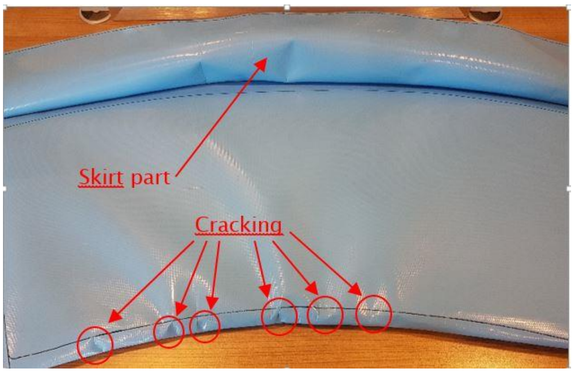


Figure 20 - Observation result of the problem that occurred in the first prototype.

Limitations in the prototype development process also come from the stitching machine used in the Saxion laboratory. The machine used in the stitching process cannot handle the yarn since the yarn has high thickness also easily untwisted. After several trials, the yarn keeps broken and tangled inside the machine. Thus, in the first prototype making process, the yarn is replaced with the ordinary yarn which has lower thickness and density.

c. Third phase (Design modification)

To decrease the cracking of the material. The new design is made with more 3D part structure by giving an additional part in the area where most cracking happened. The additional part is a piece of fabric with 50 mm width used for connecting the upper and bottom fabric which is applied as like shown in Figure 20.

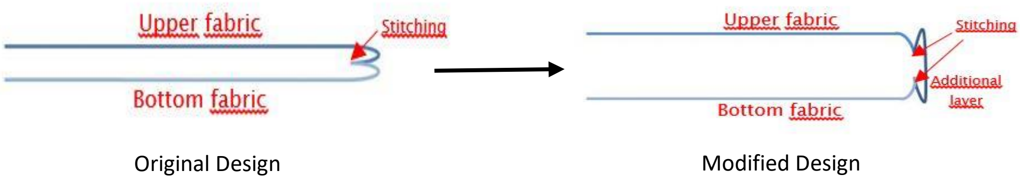
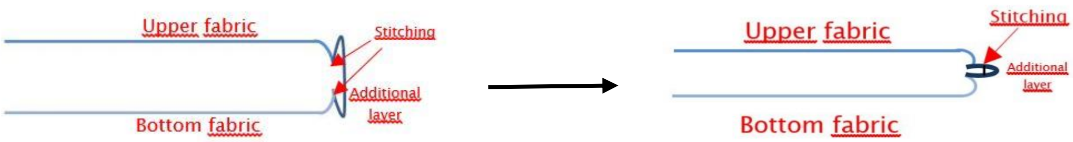


Figure 21 - Modification of original design (1).

The function of the additional part between fabrics' upper and bottom part is to reduce the folding that happened especially on the surface of the fabric cover. After the additional layer is put between the fabrics, it shows a few cracking. Thus, it needs to be modified somehow as shown in Figure 21.



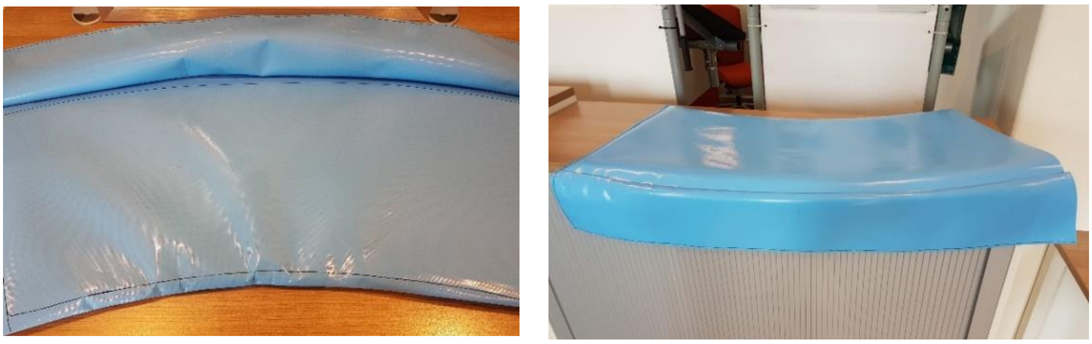
Modified Design Modified Additional Layer

Figure 22 - Modification of original design (2).

Besides solving the cracking problem in the curved part of the safety pads, the researcher is also dealing with the problem of the skirt part which is shown to bend down hard. Thus, to solve this problem, the solution is by folding the skirt and exposing it with the hot air using the hand-dryer tool. Finally, after exposing the skirt fabric part to the hot air, it can bend down just like BERG Champion and Elite PVC material. After all the modification to the original design, the final prototype with the new material can be completed. Figure 22 to 24 below display the prototype improvement before and after the design modification.

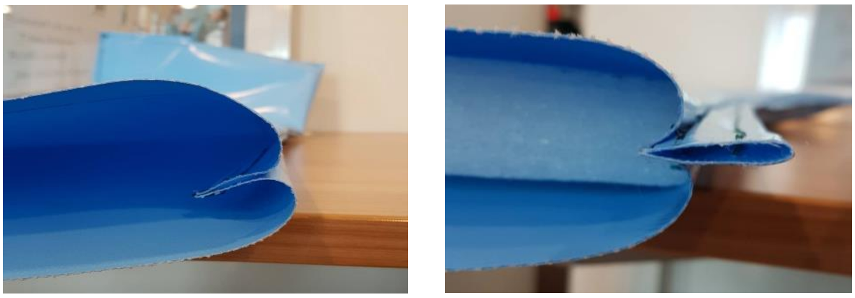
Original Design First Modification Second Modification

Figure 23 - Decreasing of cracking on the fabric cover surface after design modification.



Original Design After Modification

Figure 24 - The safety pads skirt folding property before and after design modification.



Original Design After Modification

Figure 25 - Inner view of the curved edge of the safety pads before and after design modification.

3.4.3. The prototype final result

The Figures below show the final prototype after several developmental processes. The final prototype is made of 100 % PE including the fabric cover and the foam. The fabric cover itself consists of fabric netting made of HDPE, the plastic coating is made of LDPE, and lastly, the foam is Expanded Polyethylene made of LDPE resins. By using 100 % similar material, the safety pads can be easily recycled without a need to separate the fabric cover and the foam, even the fabric inside and the coating for the fabric cover. Still and all, this final product has some disadvantages especially in the flexibility property, and the fabric cover material is still rigid thus need a special treatment mainly when it is made into a safety pad. Overall the fundamental physical properties such as tensile strength, tear strength, UV, and rain resistance shows a good result especially when it is compared with PVC Elite and Champion. Except for the abrasion and adhesion strength which still shows a lower number compared to PVC Elite and Champion. These problems can be solved by increasing the weight, and the thickness of the coating since the NICOLON C888 has half number of weight compared to PVC Elite and Champion. Moreover, the durability test may still be needed to evaluate the prototype and to observe the performance of the safety pads product prototype.

Figure 26 - Top view of the final prototype.

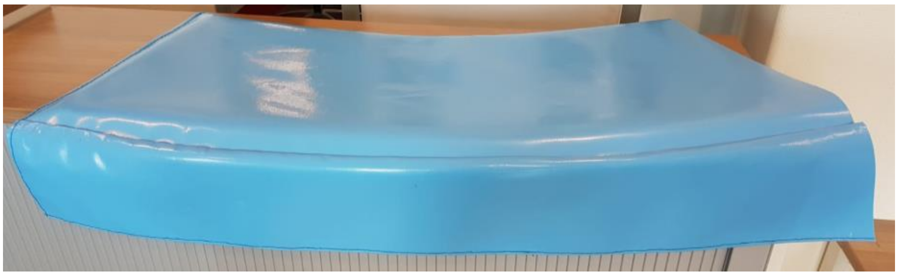


Figure 27 - Front look of the final prototype.

Figure 28 - Side view of the final prototype.

3.5. Evaluation

Evaluation of chosen material is conducted with functionality aspects give a more significant portion of the consideration. Since the material is the outdoor used type of fabric, further laboratory tests performed are mostly related to the issues often occurred when the safety pads are being used. There are three materials such as company current safety pads cover fabric (BERG Elite and Champion PVC) and the NICOLON C888 as the chosen alternative fabric which will be evaluated in this section. Moreover, these three materials will be compared and analysed to get understanding of the material performance.

3.5.1 Functional evaluation test results

- Tensile test result

The results of the tensile tests by DIN 53357 are following the material supplier and company test standard for tensile. The tests results will be used to check the validation of information provided by the supplier as well as compared the current company material, and the chosen alternative which is shown in Table 10 below with the details can be seen in Appendix 6 – Evaluation of NICOLON C888, BERG Champion PVC, and BERG Elite PVC.

Table 10 - Tensile test results of BERG Toys PVC and NICOLON C888.

Fabric material samples	**Tensile (N/5 cm)** *(Test Conducted by the researcher)*		**Tensile (N/5 cm)** *(Data provided by the supplier)*		**Elongation (mm)**	
	Warp	Weft	Warp	Weft	Warp	Weft
BERG Champion PVC coated Polyester	1332	1107	1100	900	49.9	49.4
BERG Elite PVC coated Polyester	2414	1468	2200	1800	41.1	40.6
NICOLON C888 LDPE coated HDPE	1919	1419	1900	1500	42.1	38.9

Table 10 shows if BERG elite PVC has the highest tensile strength in both warp and weft direction, followed by NICOLON C888 and BERG Champion PVC on the last position. There is no significant difference between the data from the test results and the supplier data sheet except for the weft strength of BERG Elite PVC which has 400 N lesser strength compared to the data provided by the supplier of the material. For the elongation of the netting fabric, BERG Champion shows high elongation in which the fabric netting can stretch until almost 50 mm before the netting broken off while BERG Elite PVC and NICOLON C888 fabric netting have broken when it is stretched approximately 40 mm.

- Tear test result

The tear test is executed by following DIN 53363 following the material supplier test standard for tear. The tests results are used to check the validation of information provided by the supplier also to compare the current company material, with the chosen alternative as shown in Table 11 with the details available in Appendix 6 – Evaluation of NICOLON C888, BERG Champion PVC, and BERG Elite PVC.

Table 11 - Tear test results of BERG Toys PVC and NICOLON C888.

Fabric material samples	Tear (N) *(Test Conducted by the researcher)*		Tear (N) *(Data provided by the supplier)*	
	Warp	Weft	Warp	Weft
BERG Champion PVC coated Polyester	194	122	180	130
BERG Elite PVC coated Polyester	134	112	250	250
NICOLON C888 LDPE coated HDPE	202	156	-	-

From the tear strength, the NICOLON C888 shows the highest strength in both warp and weft direction followed by the Champion PVC which has almost the same strength in the warp direction and a bit lesser in the weft direction. For the ELITE PVC, the tear strength does not only show a much lower strength compared to the other fabric but also when it is compared with the data sheet provided by the supplier. The supplier data sheet states if the tear strength supposed to be 250 N in both warp and weft direction but after several tests conducted the results never shows to be higher than 150 N especially in the weft direction.

A study shows that adhesive coat and adhesion between the base fabric and the coating will have a significant influence on the tear strength properties. Higher adhesion coating can limit PES yarns mobility to distribute the strength over a broader area from tearing force, thereby reducing the tear strength. In some cases, the degree of reduction may be so high as to render the fabric (Eltahan, 2018). Thus, it needed to be re-clarified with the supplier.

- Adhesion test result

The result of the tensile test is shown in Table 12. In the ASTM method, the test results that we got is still justified to be multiplied by two. Thus it can be compared with the data of adhesion test from the supplier of BERG safety pads. Since the supplier of PVC coated PES stated in (N/50 mm) unit, and the researcher conducted the test in (N/25 mm).

Table 12 - Adhesion test results of Tencate NICOLON C888.

Fabric material samples	Adhesion (N/25 mm)	Adhesion (N/50 mm) (x2)
Tencate NICOLON 1	18.63	37.23
Tencate NICOLON 2	19.61	39.23
Tencate NICOLON 3	17.65	35.30
Mean	18.63	37.26

The average of the adhesion of Tencate NICOLON C888 with 25 mm width sample is 37.26 (N/50 mm), and the result of the adhesion with 50 mm width sample is 38.25 (N/50 mm). Since the difference is found to be not significant, the data from the ASTM method by using 25 mm width sample is proven to be possibly justified. After that, we compared the data of the test results of all materials such as shown in Table 12.

From the adhesion, we found if the company PVC coated fabric still has higher adhesion than the alternative NICOLON C888 coated fabric. Besides, it also can be influenced by the weight of the coated since the NICOLON C888 has much lighter weight than both of the PVC which makes the coating of the NICOLON C888 thinner than the PVC coated fabric. Nevertheless, so far there is no minimum standard requirement of the coating applied to the fabric for the protective edge application especially the relations with the lifetime of the coating. Hence, the further investigation needs to be conducted to see the influence of the adhesion strength to the appearance of the bubbling or peeling on the coating especially after the fabric exposed to the outside weather for a few years.

Table 13 - Adhesion test results of BERG Toys PVC and NICOLON C888.

Fabric material samples	Adhesion (N/50 mm)
BERG Champion PVC coated Polyester	60
BERG Elite PVC coated Polyester	90
NICOLON C888 LDPE coated HDPE	37.26

- Low temperature bending test result

After conducting the cold bending test for three times in 4 hours duration under temperature -25.2^{0}C to -25.8^{0}C below is the summary of the test result with the pictures of the test can be seen in Table 34 - BERG PVC and NICOLON C888 samples with magnification after cold bending test in Appendix 6 – Evaluation of NICOLON C888, BERG Champion PVC, and BERG Elite PVC.

Table 14 - Low-temperature bending test results of BERG Toys PVC and NICOLON C888.

Material	Results
BERG Champion PVC coated Polyester	The folded spots are visible but only slightly seen in the magnification view. No sign of cracking in the folded spot
BERG Elite PVC coated Polyester	The folded spots are visible, especially in the weft direction. Also, in the weft direction, there is a small cracking almost appeared in the folded part.
NICOLON C888 LDPE coated HDPE	The folded spots are visible, especially in the weft direction. There is a bulking of the coating also appeared in the folded spots instead of the cracking which does not appear.

From the test results, BERG Elite PVC and NICOLON C888 are more fragile to crack in the low temperature compared to BERG Champion PVC. Further investigation needs to be conducted because in the reality when the product exposed outdoor BERG Elite safety pads shows significant less cracking compared to BERG Champion PVC. Thus, the cause of the cracking is suspected to be happened not only because of the cold temperature but also the lifetime of the plasticisers inside the PVC polymer. For the NICOLON C888, the cracking which appeared is also possible to happen since the PE plastic itself has less flexibility property in general. Thus, a further investigation needs to be performed to observe the performance of the coating in maintaining its flexibility and properties against cracking.

- Martindale abrasion test result

The abrasion resistance results can be measured quantitatively from the total of weight loss, decreasing of fabric thickness and qualitatively by visually observed the surface appearance after the fabric samples received abrasion treatment from the machine, the quantitative results are shown in Table 15 below, and the details calculation can be checked in Table 35 - Calculation of Martindale abrasion test results for BERG PVC and NICOLON C888 samples of Appendix 6 – Evaluation of NICOLON C888, BERG Champion PVC, and BERG Elite PVC.

Table 15 - Abrasion resistance test results of BERG Toys PVC and NICOLON C888.

	Percentage of weight loss (%)	**Mean of percentage for thickness decreasing (%)**	**Abrasion reach the fabric netting inside the coating**
BERG Champion PVC	6.59	8.72	2 of 3 samples, the netting is seen after 5000 rubbing
BERG Elite PVC	4.9	5.13	From 3 samples, the netting is not seen after 5000 rubbing
NICOLON C888	3.6	0.7	For 1 sample, the netting is seen after 3000 rubbing, other two after 4000 rubbing

The abrasion test shows if NICOLON C888 with LDPE coating might have the better resistance against abrasion compared to PVC plastic coating. When BERG Champion and Elite compared, the Elite has better resistance than the Champion. However, the NICOLON C888 has a much lower thickness and coating weight compared to BERG Elite & PVC. Thus, the abrasion has reached the netting inside after 3000-4000 rubbing, followed by BERG Champion which the abrasion reach the netting of two samples after 5000 rubbing and the Elite comes up with the highest resistance for abrasion. In order to improve NICOLON C888 performance, it is better to increase the coating weight to create a thicker surface of the coated fabric.

- 1000 hours UV & rain test result

Table 16 - Test results of UV & rain resistance in folding condition for BERG Toys PVC and NICOLON C888.

	Colourfastness index after 1000 hours	**Sign of cracking or damage in the folded spot**
BERG Champion PVC	4	The folded spots are clearly visible
BERG Elite PVC	4/5	Microscopic crack
NICOLON C888	4/5	The folded spots are clearly visible with bulking of the polymer also clearly visible

After 1000 hours of exposure under UV and rain, all the materials can comply with the company standard for colourfastness $\geq$ 4, with BERG Elite and NICOLON C888 shows a slightly better result than BERG Champion. By stimulation in which the fabric material was folded and exposed for 1000 hours in the machine, it became clear that approximately comparable damages could be obtained. The result is BERG Elite PVC indicates a microscopic cracking, while BERG Champion and NICOLON C888 do not show a sign of cracking even if NICOLON C888 polymer tends to bulk on the surface. Nevertheless, even by using UV and rain exposure in combination with folding treatment, BERG Elite still shows more tendency to crack compared to other two materials. From the research, it estimated if, after 1000 hours exposure in the machine, the migration of plasticisers especially on BERG Champion fabric is not yet happened. Thus, this testing method still needs further trial and development.

3.5.2. Expressive and aesthetic information evaluation

In this evaluation, the price is the first that needs to be considered. It can be divided into the material cost and the production cost. The NICOLON C888 as the new prototype fabric cover material has a price for 3 USD per square meter, the price stance between BERG Champion (2 USD), and BERG Elite (4 USD) with the new design still uses the same foam and threads. By reviewing the raw material cost, the prototype could be possible to be implemented in mass production with affordable price. Otherwise, the additional expense may come from the production cost since the material is stiffer than BERG PVC. It may need few of special treatment, for instance, the process of using the hot air may be necessary to make the skirt part of the safety pads able to bend down also to increase the flexibility of the fabric in the curved part of the protective edge. The additional part given in the new design might add the production time, but not the price in a significant way especially if we compared it to BERG Elite in which the design model also has some additional part given.

Unlike BERG PVC Elite and Champion fabric cover, the NICOLON C888 tends to have more cracking in the curved part due to less flexible material property. Even if the new design has been able to reduce the cracking, but the problem may still appear when the safety pads are used for a more extended period. Thus, in the aesthetic perspective review, the safety pads will show a hideous appearance faster than BERG PVC Elite and Champion. This issue can also lead to a shorter lifetime of the safety pads product, considering, the safety pads are mainly trampled when being used. The solutions offered might be to modify the NICOLON C888 by increasing the weight of the PE-LLD coating to improve the softness and flexibility property.

It is suggested for the implementation purpose. The dark colour is preferred for the safety pads since the darker shade will be likely to have a better UV resistance compared to the bright colour also it can hide the stain on the surface better than the shiny colour. However, in the developing process, the researcher uses the bright blue cover fabric for the prototype design. Since it is the currently available material from Tencate as the supplier and the researcher only has limited time to finish the prototype, but it is possible to request to company supplier to produce the dark colour fabric cover especially for mass production needs.

Finally, the environmental aspect is also the primary consideration for the new concept design in which complying with the C2C regulation becomes the main goal. Furthermore, when the protective edge has no longer used, it is expected to not end as unrecycled waste. The new prototype is designed to have better recyclability than the current BERG protective edge. All the parts used in the new design are made of polyethylene-based plastic which includes the fabric cover (LDPE coated HDPE fabric), the foam (EPE), and the threads (Polyester). Using all similar base plastic material is expected can simplify the safety pads recycling process also reducing the energy used to recycle the safety pads. The company can also label the safety pads for instance with “made of 100 % PE” mark to give information to the costumers about the materials used in the safety pads. This information may be beneficial not only to customers but also the one in waste processing to deal with the safety pads waste. Moreover, the new prototype design has also eliminated the PVC and plasticisers like phthalates in the material composition. Also, ensure if the safety pads contain no other restricted substances listed according to Cradle to Cradle regulations.

Chapter 4 - Conclusions & Recommendations

4.1. Conclusions

This graduation assignment shows the step by step process to realise an alternative design for BERG trampoline protective edge with similar or better performance concerning functional, expressive and aesthetic properties requirement of the company.

After identifying the current BERG safety pads material and analyse the problem need to be solved. The using of Lamb & Kallal framework is proven to be an effective tool to guide the research design process while the Product Breakdown System helped to categorise the fabric cover part into fabric structure, inside netting and fabric coating. Furthermore, after testing and discussion, the Tencate NICOLON C888 appears as the final decision for the safety pads fabric cover. NICOLON C888 is made of HDPE netting fabric and coated with LDPE plastic polymer. Further functionality laboratory testing, expressive and aesthetic analyses of NICOLON C888 are then conducted then compared with BERG PVC Elite, and Champion to observe whether the chosen material could have similar or better performance than BERG fabric cover. Overall results of functionality laboratory testing of three materials along with the expressive and aesthetic information are shown in the table below.

Table 17 - Overall functional testing results, expressive and aesthetic information of BERG current fabric cover material and alternative fabric cover Tencate NICOLON C888.

Specific Requirement	BERG Champion	BERG Elite	NICOLON C888
Tensile Strength (N/5 cm)	Warp: 1332	Warp: 2414	Warp: 1919
	Weft : 1107	Weft : 1468	Weft : 1419
Tear Strength (N/5 cm)	Warp : 194	Warp : 134	Warp : 202
	Weft: 122	Weft: 112	Weft: 156
Adhesion (N/5 cm)	60	90	37.26
Low-Temperature Bending	No sign cracking	Visible small cracking (weft direction)	Bulking in the folded spot instead of cracking
Martindale Abrasion Resistance (%)	Weight loss: 6.59 Thickness decreasing: 8.72	Weight loss: 4.9 Thickness decreasing: 5.13	Weight loss: 3.6 Thickness decreasing: 0.7
Martindale Abrasion Resistance (Visual observation)	Abrasion reach inside netting mostly after 5000 cycles	Abrasion does not reach inside netting after 5000 cycles	Abrasion reach inside netting mostly after 3000 to 4000 cycles
Colourfastness after 1000 h UV & Rain	4	4/5	4/5
Cracking after 1000 h UV & Rain	The folded spots are clearly visible	Microscopic crack	The folded spots are clearly visible with visible bulking of the polymer
Price ($/m^2)	2	4	3.02
Recylability	Hard but possible	Hard but possible	Easy and highly possible
C2C Restricted Substance List	PVC, phthalates	PVC, phthalates	-
Odourless	No odour	No odour	No odour
Thermal insulant (W/K.m)	0.19	0.19	0.33

<u>Note: For convenience purpose in reading the table and comparison of each material, the researcher categorise each property with three different colour; first (Light Blue), second (Blue), and third (Dark Blue) that indicates the rank of material quality from one another.</u>

Table 17 shows results of the materials as follow. First, for the strength of the fabric netting, laboratory test indicates if the tensile and tear strength of all samples achieve the standard requirement except for BERG Elite PVC, tear strength shows a much lower number which is less than 150 N compared to the data provided by the supplier that stated 250 N for the tear strength. Second, for the coating, NICOLON C888 shows the lowest adhesion strength compared to the company's PVC material. Then, a low-temperature bending test is conducted to observe the cracking possibility of the plastic in cold weather. The result shows PVC Elite is the only one with the sign of cracking. However, in reality, the PVC Elite displays less cracking compared to PVC Champion. After that, the abrasion test shows NICOLON C888 has better resistance against abrasion compared to PVC Elite & Champion since NICOLON C888 is much thinner than PVC coated fabric, the abrasion has reached the netting inside before 5000 cycles. Lastly, the observation of materials after exposed for 1000 hours with UV & water shows BERG Champion has slightly less colourfastness compared to BERG Elite & NICOLON C888, while for the folded samples, BERG Elite is the one that shows microscopic cracking. Even if after all, the researcher still has not found any exact method that can precisely measure the lifetime of the material especially to trigger the cracking in the material to happen. Thus, it might lead to further research in finding a more advanced method to test the material.

The expressive information indicates all the material has an affordable price to be mass produced with material cost still under 5 USD per square meter. It is just the PVC cannot comply with the C2C regulations since it contains PVC and phthalates also, the material is hard to be recycled. The NICOLON C888 otherwise contains no restricted material and technically more accessible to be recycled even for the whole safety pads includes the foam since it composed of 100% PE. Finally, the aesthetic aspects show a good result with all the materials are not easily transfer heat and expose no distinctive odour. From overall evaluation process, the conclusions can be drawn with NICOLON C888 has marginally more advantages compared to BERG PVC Elite and BERG PVC Champion.

The new chosen material needs a design modification since it has the low flexibility or rigid property compared to the PVC material. An adjustment is conducted to reduce cracking in the curved part of the safety pads by giving additional fabric between the upper and bottom layer to minimise the folding between the layers. Also, hot air treatment is given to the skirt part of the safety pads so it can bend down like the PVC coated fabric.

In brief, after all the research, prototype design, and evaluation process, the 100% PE based material safety pads with NICOLON C888 as the new fabric cover is still the best option that offered by the researcher considering functional, expressive and aesthetic aspects although the researcher also realises if this concept will need further improvement and testing.

4.2. Recommendations

As the results of the experiments in this research have been shown in the previous chapters, several recommendations for further implementation are explained:

a. The final safety pads prototype still requires further testing to see the product durability. Simulation of usage when the product is applied such as trampling on the safety pads can be performed to see if there is a weak part of the sewing or in the design.
b. Designing a company testing procedure by setting up new criteria to address common issues in the field such as coating cracking and peeling. Since these problems happened due to several factors which still hardly known, modifying evaluation method and performing a series

combination of testing in one fabric sample may give more promising results that suitable with BERG requirements compared to rely on the testing results from a single test of ISO, ASTM, and DIN. For example, a specimen can first be exposed to the UV & rain test then continued to be tested with cold temperature folding test and flexing test.

c. Performing the flexibility test is highly recommended at the beginning every time the company looks for the alternative fabric cover material. It should be prioritised since the flexibility appeared to have significant influences in the prototype development. The Bally resistance flexing test is the one suggested. It is highly recommended for the company to have the Bally flex test machine since it can be used with a combination of UV & rain resistance test or low-temperature folding test to observe the potential of cracking in fabric cover especially that happened caused by plasticisers migration in the PVC coated fabric.
d. TPU coated fabric actually can become an alternative material since it shows promising results in the functional test. However, the company needs to find a method to lower the fabric cost, for instance by finding another supplier. Moreover, the TPU can become a future eco-friendly material since currently, the researcher and few companies have started to develop and produce the palm oil-based polyurethane which more sustainable and renewable compared to the petrochemical-based plastic polymer.
e. Regular control and assessment of the data provided by the supplier are necessary because after evaluating BERG Elite PVC fabric, the property like tear strength shows significant differences between supplier datasheet and laboratory test result. Clarifying the test method and procedure used by the supplier may also be important besides of knowing the test results.
f. Establishing a development facility that equipped with a sewing machine is not a must but may be important to support a development process product like protective edge. It may also help in the trial for the new design model of the trampoline part. Since the threads used by the company have a high thickness or diameter, it is not possible to use the regular sewing machine. Thus, at first phase of prototype development, the threads need to be changed with the yarn for apparel at the second phase, at last, the researcher decides to hand-sewing the prototype so the company's original thread for stitching the safety pads can be used.

Chapter 5 – Research Reflection

Finding alternative material for the safety pads trampoline was not an easy way, weeks of literature research has been conducted to find the promising available material. PVC still so far the best market options for coating material due to its lower price compared to other material and satisfied performance provided. This quality makes all the company still finds it difficult to switch from PVC even if research and C2C regulation have displayed the negative impact of PVC in health and environment aspects.

After research, several alternatives have come into my mind. Since the investigation is also conducted for the commercial purpose of the company, thus the best possible options mostly not feasible to be applied. The obstacle faced to find the alternative material such as; alternatives material which is chosen still in research scale, the material combination desired is not affordable for instance the silicone coated fabric where it is typically only available with the fibreglass in the inside netting. So that the material can be accessible for the targeted market, the production and the material cost should not be significantly high. Even after testing all the material the TPU coated appeared to be shown the best one, it cannot be chosen since the material price from the supplier is three times higher than company current material PVC Elite.

The material properties in theory also may differ with the one provided by the supplier since many factors also may affect material properties such as the producing method, pre-treatment and after-treatment of the fabric along with chemical substance addition that improves or decrease the desired features from the original material.

After all, the graduation project in BERG Toys has deeper my understanding regarding technical coated fabric properties and behaviours, especially for outdoor applications. By BERG supports and Saxion facilities, I learn to conduct new testing method based on ISO, ASTM, and DIN standard also modify the test to suit the company need and material types in which I have never performed.

The experiments appeared to be continuous trial and analysis particularly to understand and develop a test that can show two most significant issues of the fabric cover in the field namely material lifetime and fabric cracking, even if it is high allegedly happening due to a migration of plasticisers, especially in PVC. As for in the developing of a prototype, trials and error are faced by the student in finding the most suitable design to deal with a less flexible material such as NICOLON C888 that tend to crack in the curved or edge positions. However, I manage to finalise the design that can solve this issue. At the last moment of the project, I received other new materials, a more flexible PE-LLD from Tencate, and cheaper PP coated fabric from Novolter, but time limits made it impossible for me to investigate this material further. Therefore, hopefully, these materials can also be BERG future alternative materials.

Afterword by the Company

BERG Toys is a company that was founded 33 years ago. The aim of the company has always been to make high-quality products and to be the market leader is the top segment of the outdoor toys that we make. However, what consumers consider “top segment products” has changed over the last 33 years. The most obvious changes are the colors and design, but there is also the use of materials (as little plastic as possible in the past, but now plastics can be high quality as well especially if it upgrades the design), the production location (needed to be “made in Holland”, but high-quality products can also be made in Asia now), etc.

For the product group of trampolines we are now working on a number of these challenges, but for the future of the trampoline protective padding, we lacked the knowledge and time to get us to the next innovation. This time it is not the colour or the design, but in order to be ready for the future, we need padding that lasts for as long as possible and is produced in a more sustainable way.

We needed someone with a good knowledge of textiles and chemicals, and an analytical mind to do a lot of research and testing. Since this is new territory for the trampolines, we also need someone who is not afraid to think out of the box to find solutions.

From his credentials and interview, it became clear that Galang has the perfect background with knowledge of textiles and chemicals. Due to his extensive preparation for the assignment, he demonstrated in the first week that he has an analytical mind and is not afraid of thorough research. The bonus for us was that he also has the capability to think out of the box, which he showed in finding a new solution of sewing the padding material that was a lot stiffer than we normally use.

Of course, there is still a lot of testing and developing left before the product can reach the market – as with any innovation. But we have made a big step forward that we wouldn’t have made without Galang.

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APPENDIX

Appendix 1 – Lists of demands and List of requirements details information (Functional, expressive, and aesthetic aspects)

1.1. Functional

Table 18 - Details list of functional demands and requirements.

Level	General Demands Descriptions	Specific Requirement
Requirement	Weather resistance: It should last for at least 2 years outside (e.g., UV resistance, rain, cold, etc.). The netting shall maintain 80% of their initial tensile strength (according to EN ISO 13934-1 (50mm clamp) after exposure to light and UV, according to ISO 11507, for a minimum period of 1000 h (tensile strength retention)).	Waterproof Properties
		Tensile Strength
Requirement	Tearing: The padding should not easily tear while children are playing or walking on it	Tear Strength
Requirement	UV resistance: No discolouration according to BERG internal requirements. (Weather Resistance - discolouration grade >4 after 1000 h based on (ISO 11507 / ISO 105A))	Lightfastness
Requirement	Resistant to mildew, rotting, and insects	Biological resistance
Requirement	The material should withstand temperatures from -20C to +70C	Temperature Resistance
Requirement	Abrasion resistance: The padding material should not break or tear while being used (e.g., buttons, zippers, etc. may scrape the surface of the material)	Abrasion Resistance
Requirement	The material should be difficult to burn (According to ASTM test procedure)	Flammability
Wish	If it is coated the laminated plastic polymer should not be easily peeled off and should not has "bubbling" on the fabric surface	Adhesion (if it is coated)
Requirement	Long aging resistant, the material should have the capability to keep its properties even after being exposed outdoor more than two years	Lifetime

1.2. Expressive

Table 19 - Details list of expressive demands and requirements.

Level	General Demands Descriptions	Specific Requirement
Requirement	Price: The total padding price should not exceed the current cost with more than 20%	Complete Safety Pads End Product Price
Wish	Price: The full padding price should not exceed the current price	
Requirement	Feasibility of the material to be mass produced. The categorization can be divided into three different level: a) Material is readily available in the market; b) It is possible to make the fabric desired, but it still not finds yet. Thus, the current material still need more research and development; c) It exists only in theory and research so far, it will be a bit difficult to purchase/ develop into a real product	Feasibility of Production
Requirement	Chemical legislation: The material should follow the requirements of the EU and BERG internal requirements	Is there any Toxic Substances
Requirement	Safety legislation: The padding should support the requirements of the EU and BERG internal requirements	Is There Any Other Restricted Substances
Wish	Fit within the cradle to cradle certification (e.g., no material from the banned substances list; must be recyclable)	Recyclability
Wish	Cleaning: the padding material should be easy to clean	Cleaning

1.3. Aesthetic

Table 20 - Details list of aesthetic demands and requirements.

Requirement	The material should be available in different colours	Visual Design
Wish	It should be possible to add different colours or prints to the padding	
Requirement	Thermal insulation: the padding material should not absorb heat especially when it is exposed under the sun, to prevent children from burning their skin when they touch the safety pads	Thermal Insulant
Requirement	Odour: the material should not emit a distinctive odour	Odourless
Wish	The material should not feel uncomfortable to the skin (e.g., should not cause friction injury to the skin)	Texture Design
Wish	The material should not be too slippery (to cause children to slip and fall)	Texture Design

Appendix 2 – Overall fabric material ordered samples information

Table 21 - Details information of fabric material sample order.

Name of Material	Supplier	Fabric Material	Coating/ Finishing
Champion PVC coated PES (3P) *(Berg Toys Current Fabric)*	Sioen, China	PES	PVC © + Phthalates
Elite PVC coated PES (3P) *(Berg Toys Current Fabric)*	Plato, China	PES	PVC © + Phthalates
Silicone rubber coated glass fabric SIL 020 R	Fiberflon, Germany	Glass	Silicone ©
Silicone rubber coated glass fabric SIL 025 R		Glass	Silicone ©
PTFE glass fabric 216.13		Glass	PTFE ©
PTFE glass fabric 216.15		Glass	PTFE ©
NEOPRENE COATED NYLON NN1-RED & Black	Point North, UK	Nylon	Neoprene rubber ©
WATERPROOF RIPSTOP NYLON PU COATED NR6-NAVY & Olive		Nylon	PU ©
1000 DENIER CORDURA D10-BURGUNDY		Nylon	PU ©
1.9 oz PU coated Ripstop Nylon - Charcoal Gray & Dark Olive	Ripstop by the roll, U.S	Nylon	PU backside, DWR front with UV and FR treatment
1.6 oz HyperD PU4000 - Coyote & Dark Olive		Nylon	Sil/PU mix one side, multi-pass PU4000 other side
SILICONE COATED RIPSTOP NRS-OLIVE-GREEN	Point North UK	Nylon	Silicone ©
SILNYLON RIPSTOP NR400-RED		Nylon	Silicone © (Both sides)
WATERPROOF PU COATED POLYESTER PV2-FLO ORANGE & GREY		PES	PU ©
500D UV RESISTANT POLYESTER P500UV-BOTTLE-GREEN		PES	PU ©
1.1 oz Silpoly PU4000 - Racing Red & Foliage Green	Ripstop by the roll, U.S	PES	Sil/PU mix one side, multi-pass PU4000 another side
1.43 oz Dyneema Composite Fabric - Olive Green & Blue		UHMWPE	Non-woven Nylon laminates
NICOLON C888	Tencate, the Netherland	HDPE	LDPE
TPU coated fabric	Novolter, China	Polyester (20%)	TPU (polyurethane) 80%

2.1. Champion PVC coated Polyester *3P* (BERG Toys BV current fabric)

Supplier : Plato, Guangzhou, China
Price : $ 3.62 per linear meter
Thickness : 0.55mm
Total weight : Fabric netting 100 g/m^2 + Coating 510 g/m^2 = 610 g/m^2
Production method : "hot laminated"
Details : PES woven netting, laminated PVC plastic film & Phthalates plasticizers

Figure 29 - Champion PVC coated fabric.

2.2. Elite PVC coated Polyester *3P* (BERG Toys BV current fabric)

Supplier : Sioen, Belgium
Price : $ 4 per linear meter
Thickness : 0.55mm
Total weight : Fabric netting 160 g/m^2 + Coating 470 g/m^2 = 630 g/m^2
Production method : Coated
Details : PES woven netting, coated PVC, phthalates & Laquer finishing

Figure 30 - Elite PVC coated fabric.

2.3. Silicone rubber coated glass fabric SIL 020 R

Supplier : Fiberflon, Germany
Price : $ 20.46 per m^2
Thickness : 0.23 mm
Total weight : 340 g/m^2
Production method : Coated
Details : Fibreglass fabric & Silicone coated

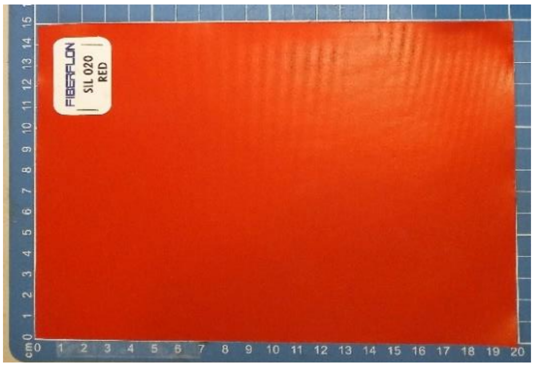


Figure 31 - SIL 020 R.

2.4. Silicone rubber coated glass fabric SIL 025 R

Supplier : Fiberflon, Germany
Price : $ 22.37 per m^2
Thickness : 0.28 mm
Total weight : 400 g/m^2
Production method : Coated
Details : Fibreglass fabric & Silicone coated

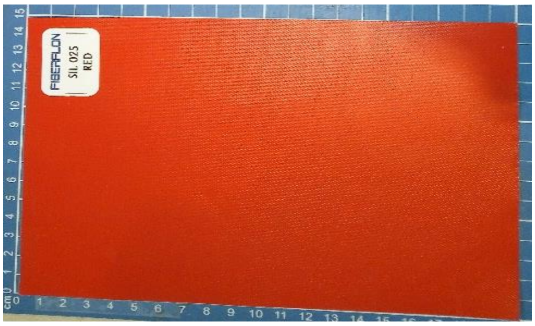


Figure 32 - SIL 025 R.

2.5. Tencate NICOLON C888

Supplier : Tencate, the Netherland
Price : $ 3.02 per m^2
Thickness : 0.5 mm
Total weight : Fabric netting 157 g/m^2 + coating 183 g/m^2 = 340 g/m^2
Production method : Coated
Details : HDPE fabric & LDPE coated

Figure 33 - NICOLON C888.

2.6. TPU coated fabric (1)

Supplier : Novolter, Ningbo, China
Price : $ 12 per m^2
Thickness : 1.04 mm
Total weight : 895 g/m^2
Production method : Coated
Details : PES (20%) & TPU coated (80%)

Figure 34 - TPU coated 1.04 mm.

2.7. TPU coated fabric (2)

Supplier : Novolter, Ningbo, China
Price : $ 8.5 per m^2
Thickness : 0.54 mm
Total weight : 447 g/m^2
Production method : Coated
Details : PES (20%) & TPU coated (80%)

Figure 35 - TPU Coated fabric 0.54 mm.

Appendix 3 – Samples cutting planning

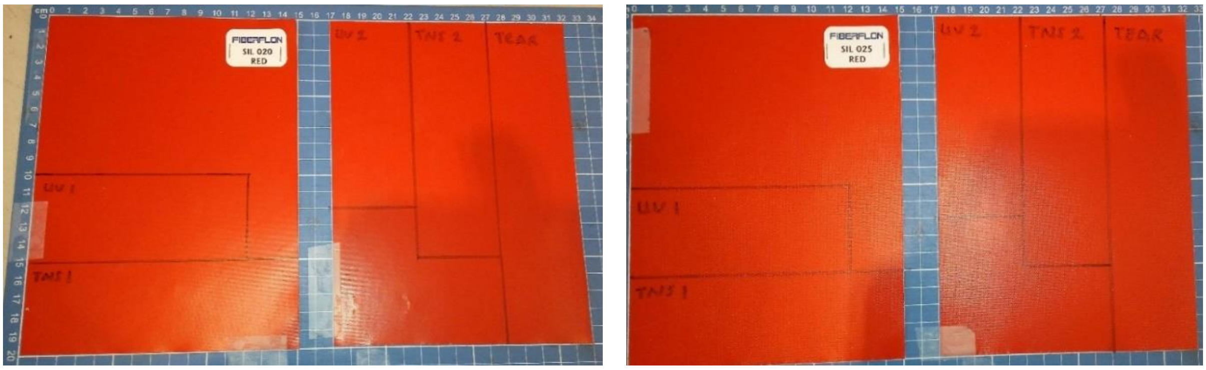


Figure 36 - Silicone rubber coated glass fabric SIL 020 R and SIL 025 R, 15 x 20 cm, 2 pieces of each.

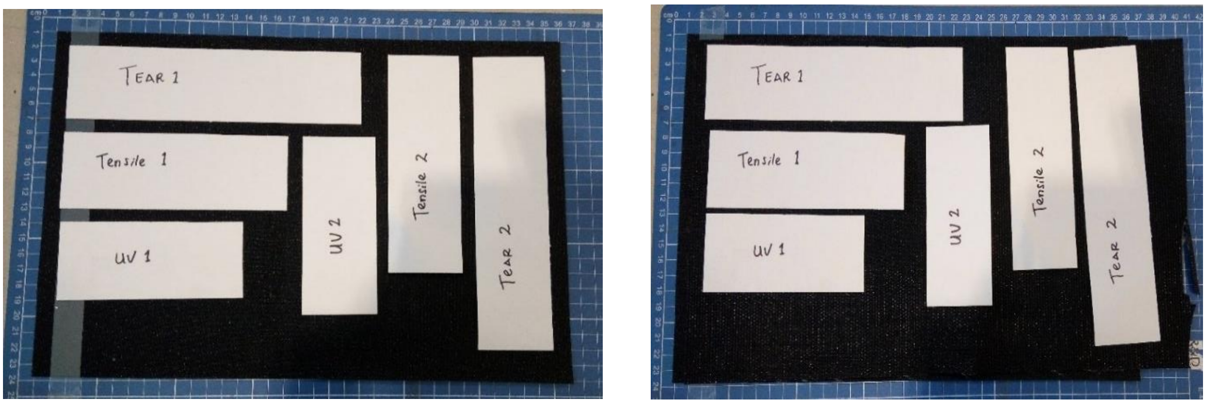


Figure 37 - TPU coated polyester Novolter Fabric 0.54 mm & 1.04 mm, 35 x 22 cm, 1 piece.

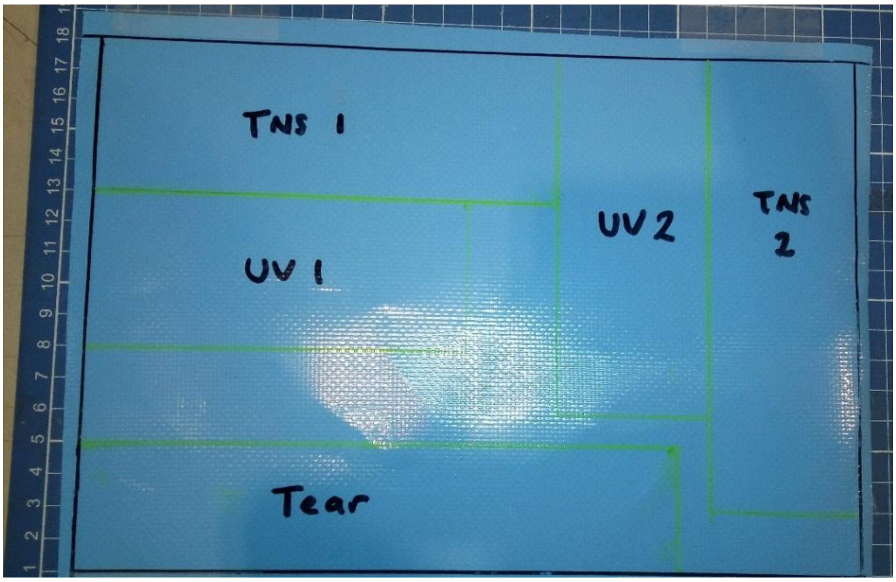


Figure 38 - Tencate NICOLON C888 HDPE coated LDPE sample fabric 26 x 18 cm, 1 piece.

Appendix 4 – Martindale abrasion resistance test tools

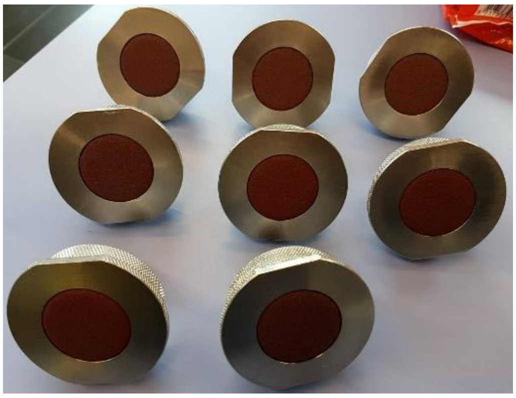


Figure 39 - Cut sandpaper for the abrasion.

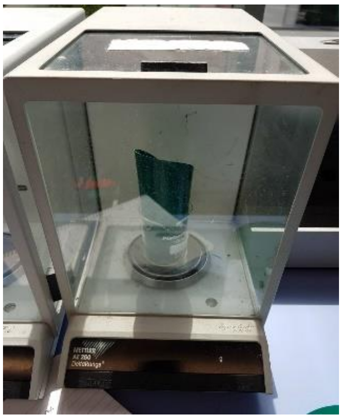


Figure 40 - Analytical balance.

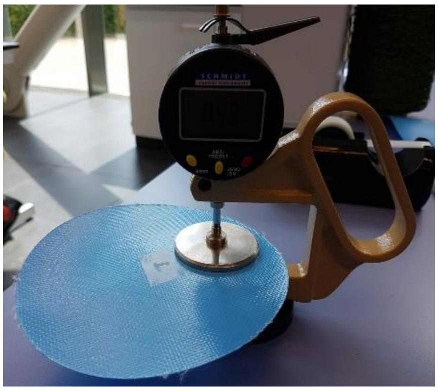


Figure 41 - Thickness gauge.

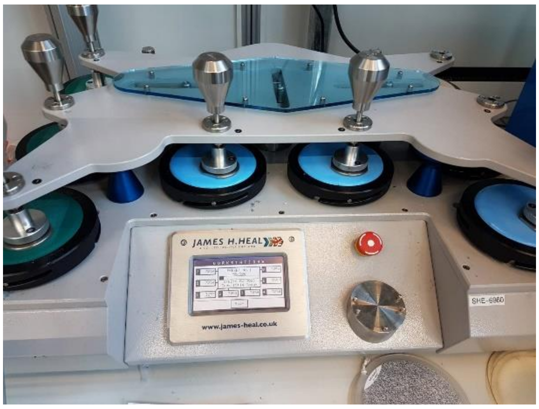


Figure 42 - Martindale abrasion tester machine.

Appendix 5 – Overall tensile and tear strength results of seven chosen fabrics samples

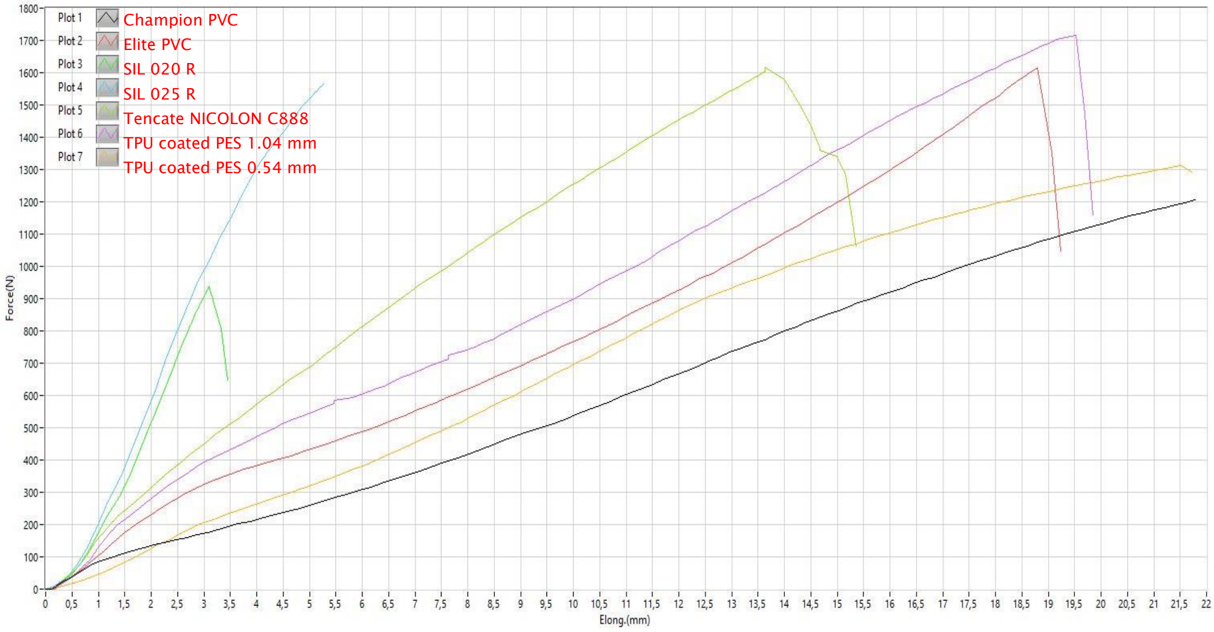


Figure 43 - Tensile test results of samples fabric in the warp direction.

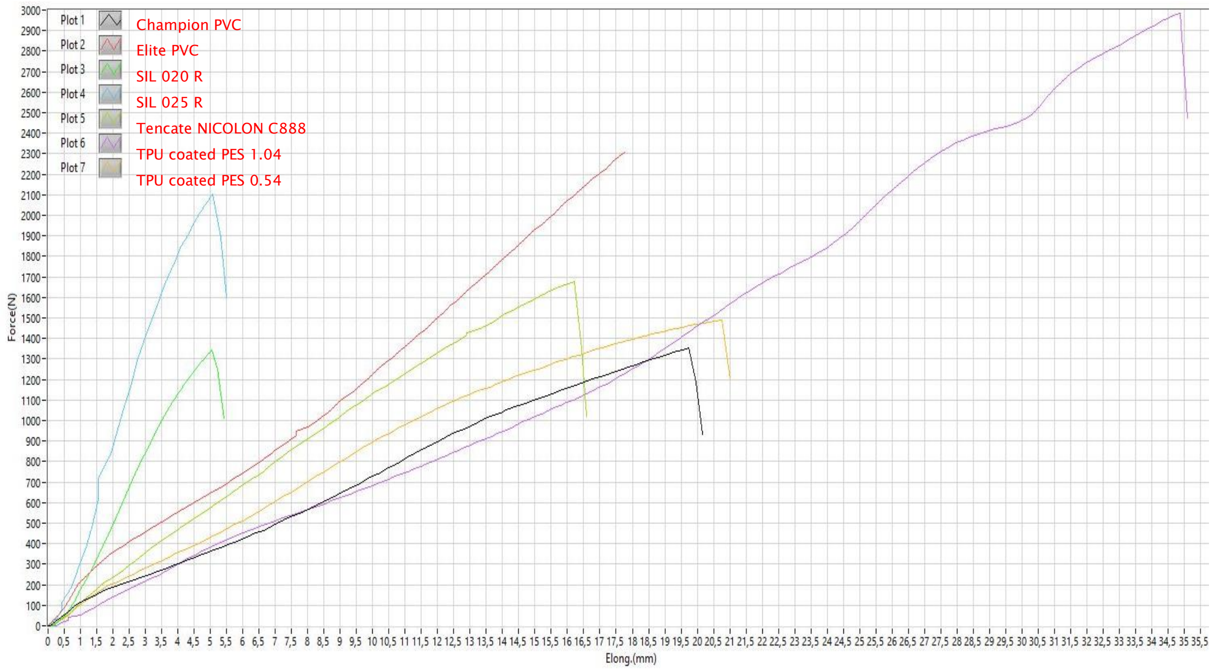


Figure 44 - Tensile test result of samples fabric in the weft direction.

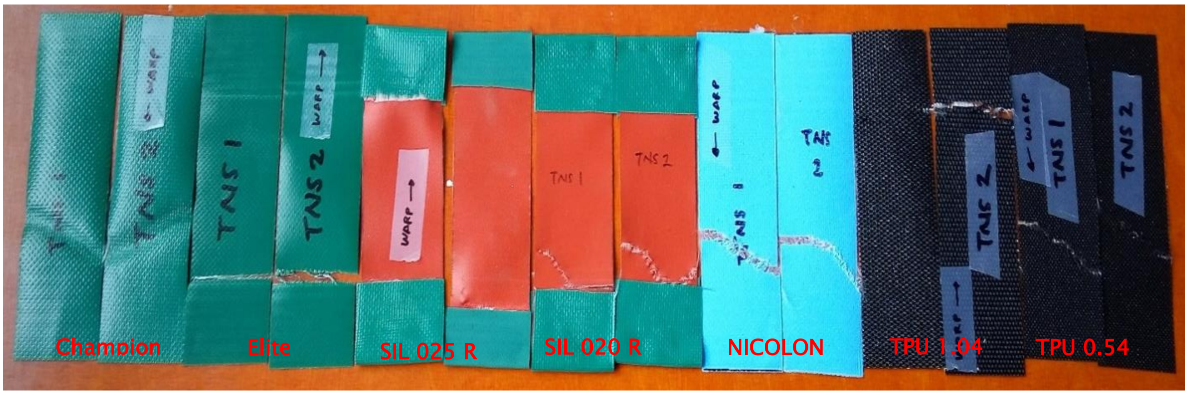


Figure 45 - Samples fabric after the tensile test.

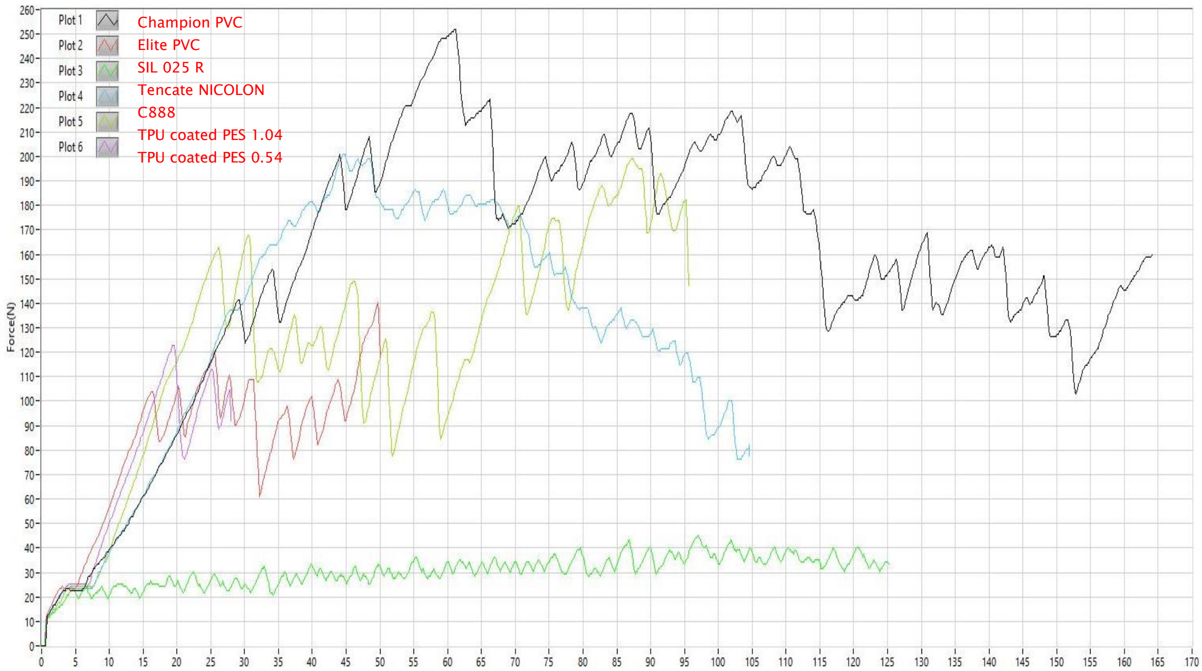


Figure 46 - Tear test result of samples fabric in the warp direction.

Appendix 6 – Evaluation of NICOLON C888, BERG Champion PVC, and BERG Elite PVC

6.1. Tensile test results by DIN 53357 standard method

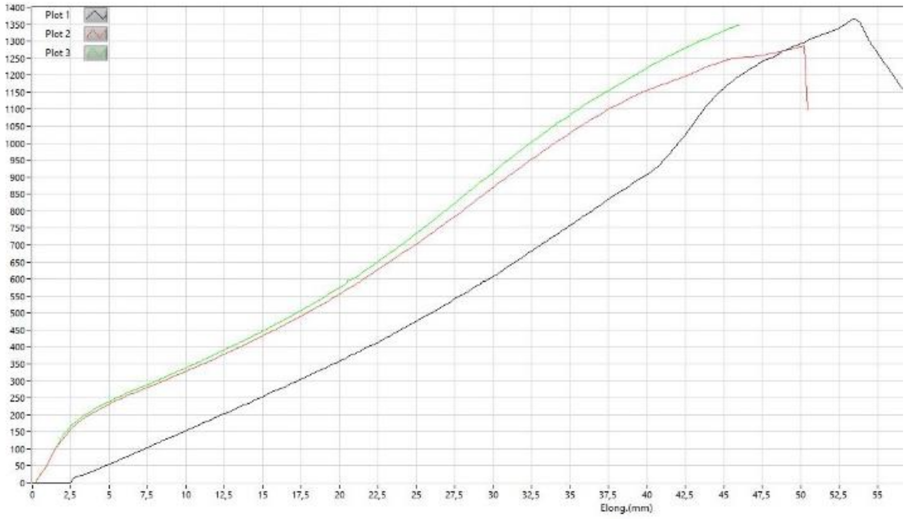


Figure 47 - PVC Champion tensile strength in the warp direction.

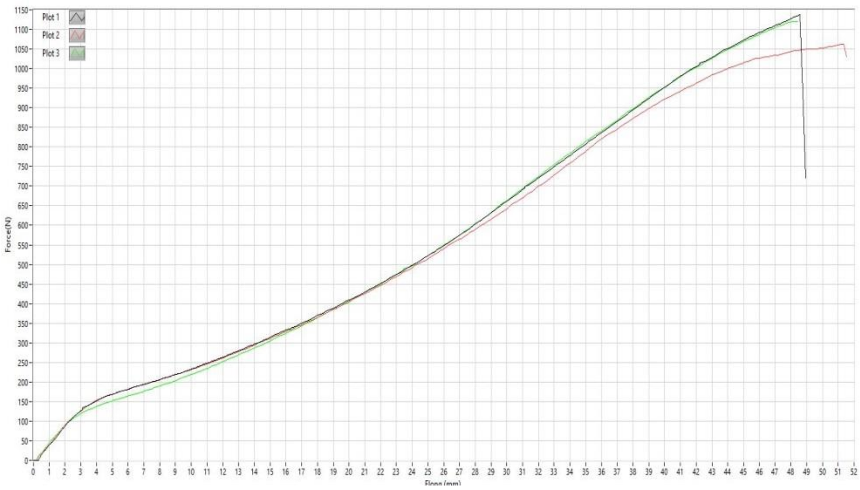


Figure 48 - PVC Champion tensile strength in the weft direction.

Table 22 - Tensile strength calculation of PVC Champion in the warp direction.

#sample	Direction	Tensile Strength (N/5cm)	Elongation (mm)
1	Warp	1366.07	53.46
2	Warp	1284.67	50.21
3	Warp	1347.43	45.98
Mean		1332.72	49.88
Standard Deviation		42.64	3.74
Data from supplier stated warp tensile strength is 1100			

Table 23 - Tensile strength calculation of PVC Champion in the weft direction.

#sample	Direction	Tensile Strength (N/5cm)	Elongation (mm)
1	Weft	1137.57	48.57
2	Weft	1063.04	51.34
3	Weft	1120.90	48.27
Mean		1107.17	49.39
Standard Deviation		42.65	1.69
Data from supplier stated weft tensile strength is 900			

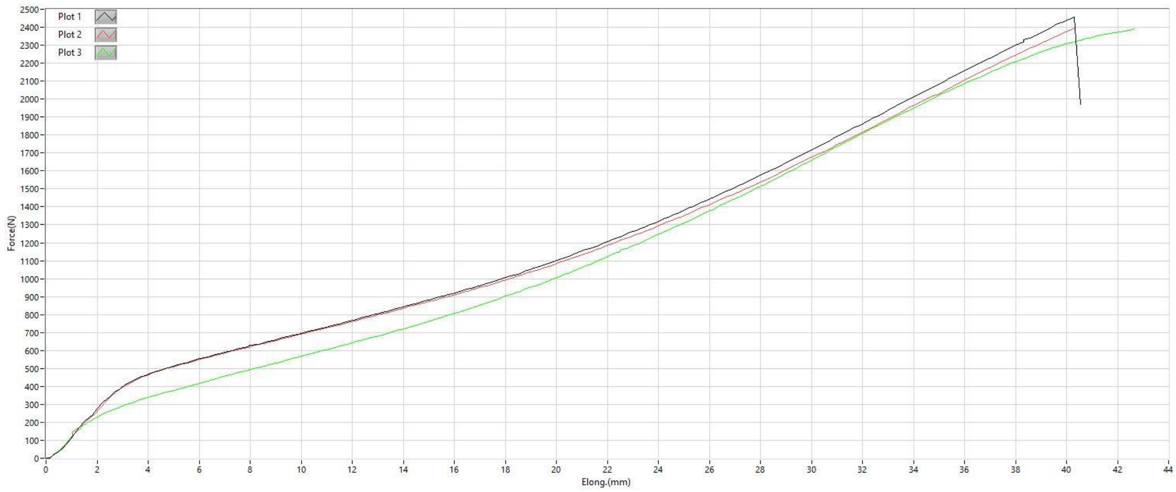


Figure 49 - PVC Elite tensile strength in the warp direction.

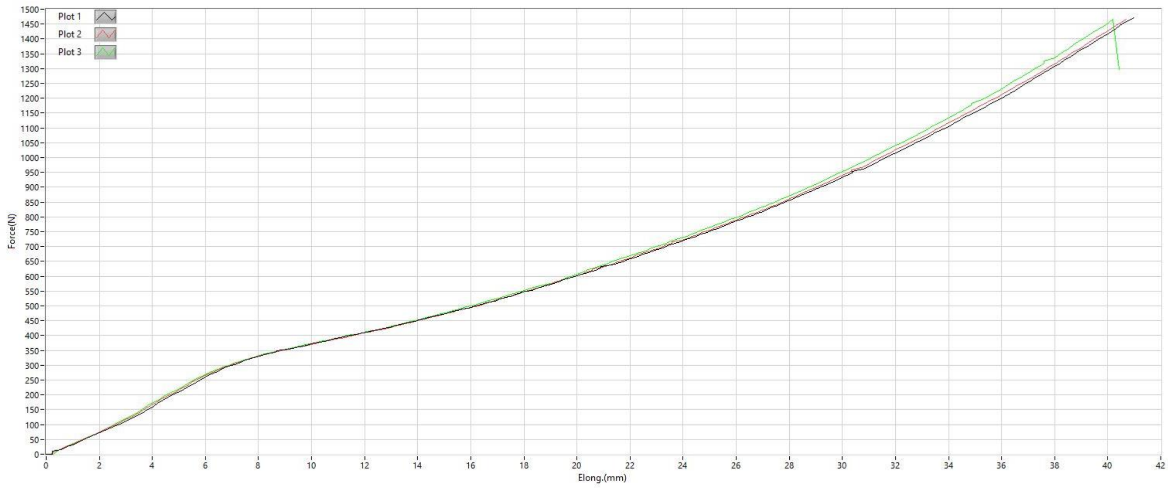


Figure 50 - PVC Elite tensile strength in the weft direction.

Table 24 - Tensile strength calculation of PVC Elite in the warp direction.

#sample	Direction	Tensile Strength (N/5cm)	Elongation (mm)
1	Warp	2456.57	40.3
2	Warp	2396.75	40.34
3	Warp	2389.88	42.65
Mean		2414.4	41.09
Standard Deviation		36.83	1.34
Data from supplier stated warp tensile strength is 2200			

Table 25 - Tensile strength calculation of PVC Elite in the weft direction.

#sample	Direction	Tensile Strength (N/5cm)	Elongation (mm)
1	Weft	1471.98	40.97
2	Weft	1467.08	40.70
3	Weft	1465.11	40.21
Mean		1468.06	40.62
Standard Deviation		3.05	0.39
Data from supplier stated weft tensile strength is 1800			

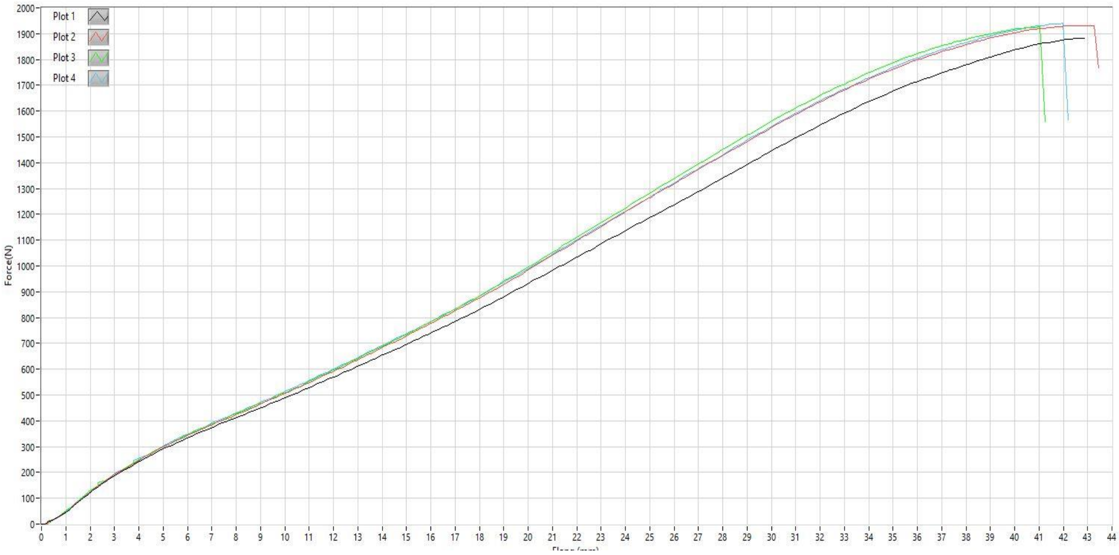


Figure 51 - Tencate NICOLON C888 tensile strength in the warp direction.

Table 26 - Tensile strength calculation of NICOLON C888 in the warp direction.

#sample	Direction	Tensile Strength (N/5cm)	Elongation (mm)
1	Warp	1882.88	42.86
2	Warp	1930.93	42.49
3	Warp	1926.03	41.03
4	Warp	1939.76	41.99
Mean		1919.89	42.09
Standard Deviation		21.8	0.79
Data from supplier stated warp tensile strength is 1900			

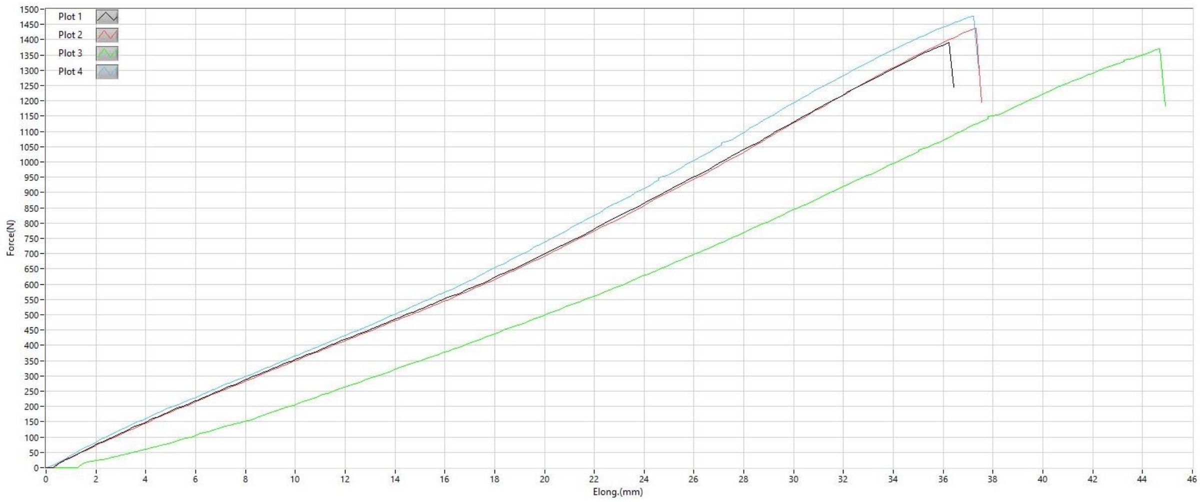


Figure 52 - Tencate NICOLON C888 tensile strength in the weft direction.

Table 27 - Tensile strength calculation of NICOLON C888 in the weft direction.

#sample	Direction	Tensile Strength (N/5cm)	Elongation (mm)
1	Weft	1390.58	36.22
2	Weft	1438.64	37.32
3	Weft	1370.97	44.69
4	Weft	1477.86	37.23
Mean		1419.51	38.86
Standard Deviation		48.2	3.9
Data from supplier stated warp tensile strength is 1500			

6.2. Tear test results by DIN 53363 Standard Method

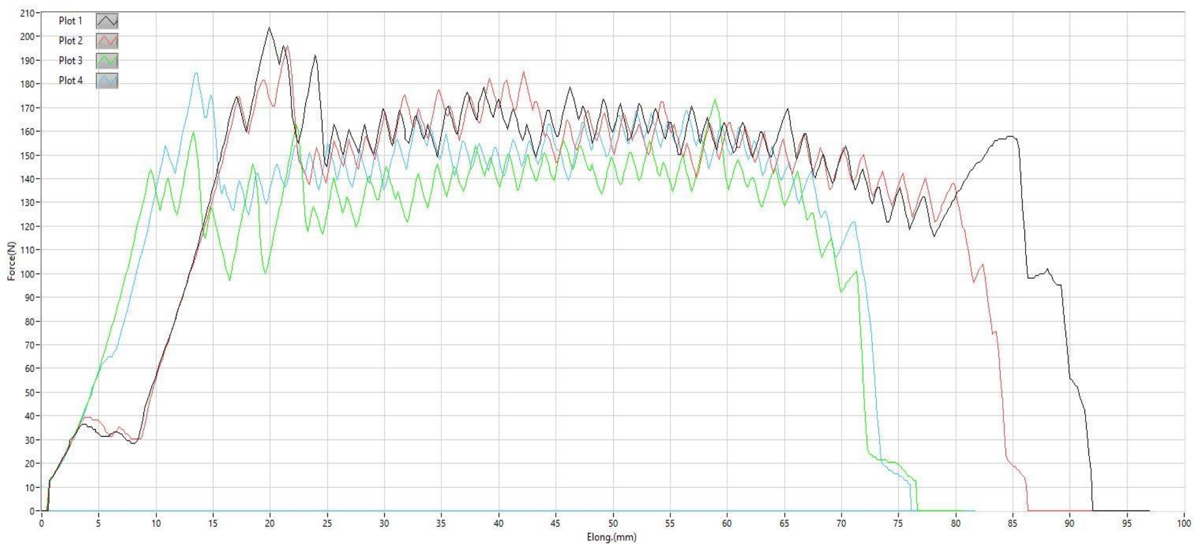


Figure 53 - PVC Champion tear strength in the warp direction.

Table 28 - Tear strength calculation of PVC Champion in the warp direction.

#sample	Direction	Tear Strength (N)
1	Warp	203.98
2	Warp	196.13
3	Warp	184.37
Mean		194.83
Standard Deviation		9.87
Data from supplier stated warp tear strength is 180		

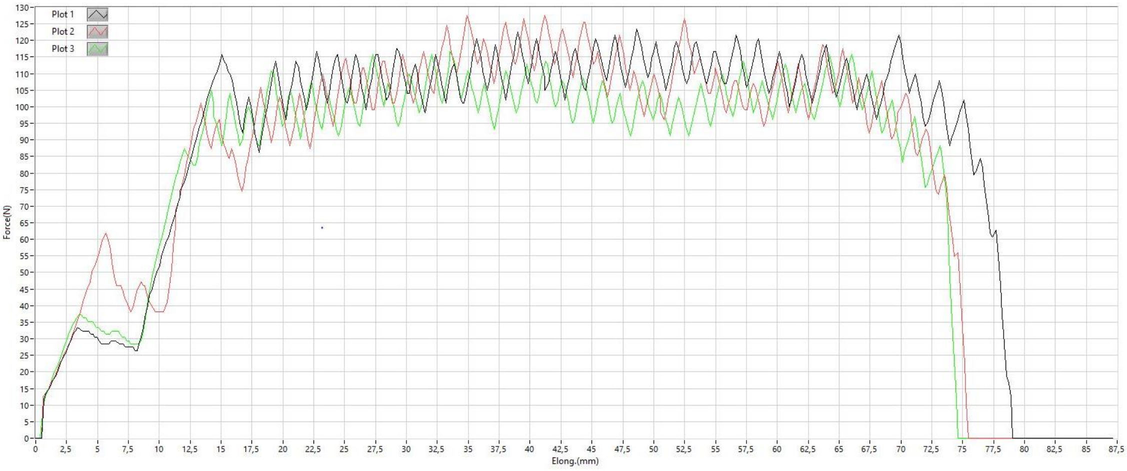


Figure 54 - PVC Champion tear strength in the weft direction.

Table 29 - Tear strength calculation of PVC Champion in the weft direction.

#sample	Direction	Tear Strength (N)
1	Weft	123.56
2	Weft	127.47
3	Weft	116.7
Mean		122.58
Standard Deviation		5.45
Data from supplier stated weft tear strength is 130		

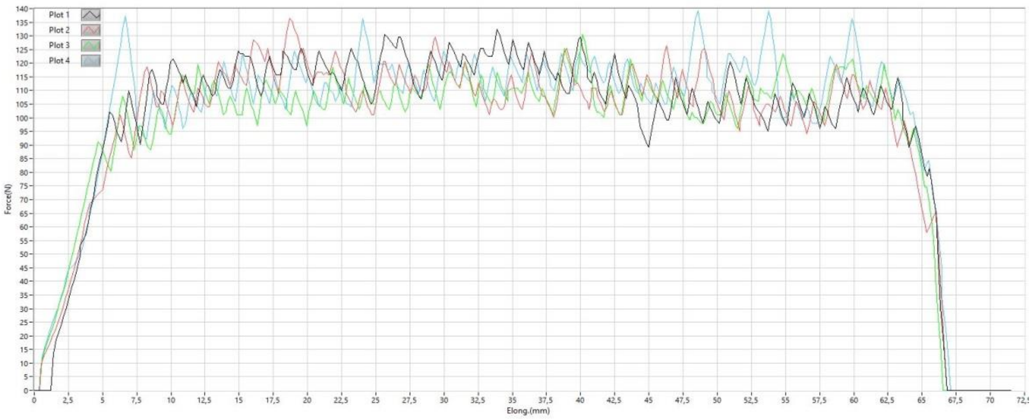


Figure 55 - PVC Elite tear strength in the warp direction.

Table 30 - Tear strength calculation of PVC Elite in the warp direction.

#sample	Direction	Tear Strength (N)
1	Warp	132.39
2	Warp	136.31
3	Warp	130.43
4	Warp	139.25
Mean		134.6
Standard Deviation		3.95
Data from supplier stated warp tear strength is 250 N		

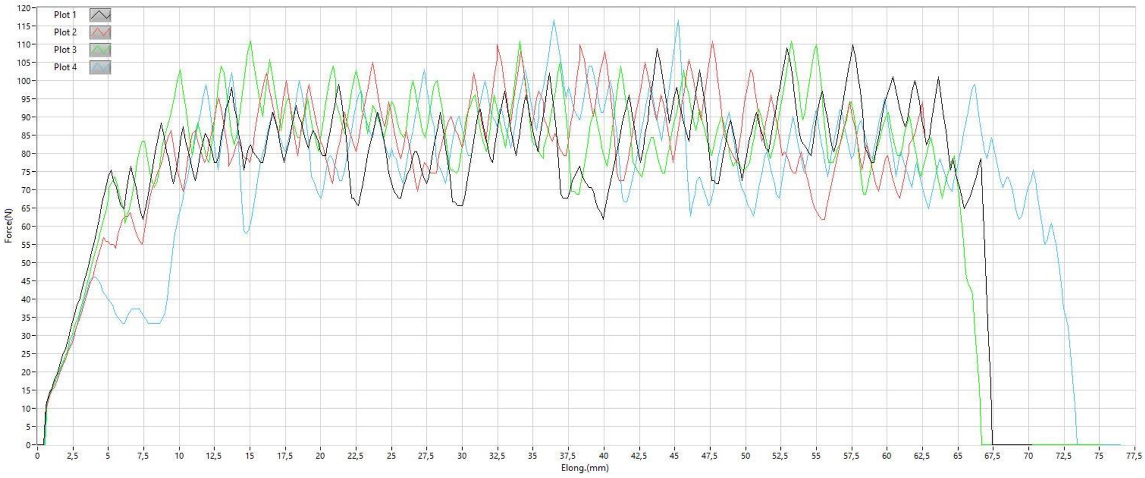


Figure 56 - PVC Elite tear strength in the weft direction.

Table 31 - Tear strength calculation of PVC Elite in the weft direction.

#sample	Direction	Tear Strength (N)
1	Weft	109.83
2	Weft	110.81
3	Weft	110.82
4	Weft	116.7
Mean		112.04
Standard Deviation		3.14
Data from supplier stated weft tear strength is 250 N		

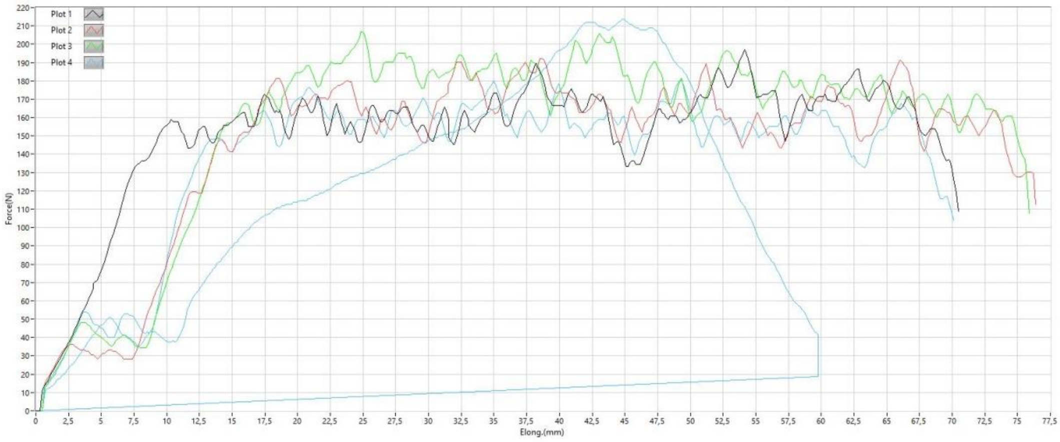


Figure 57 - Tencate NICOLON C888 tear strength in the warp direction.

Table 32 - Tear strength calculation of NICOLON C888 in the warp direction.

#sample	Direction	Tear Strength (N)
1	Warp	197.11
2	Warp	192.21
3	Warp	206.92
4	Warp	213.79
Mean		202.51
Standard Deviation		9.7

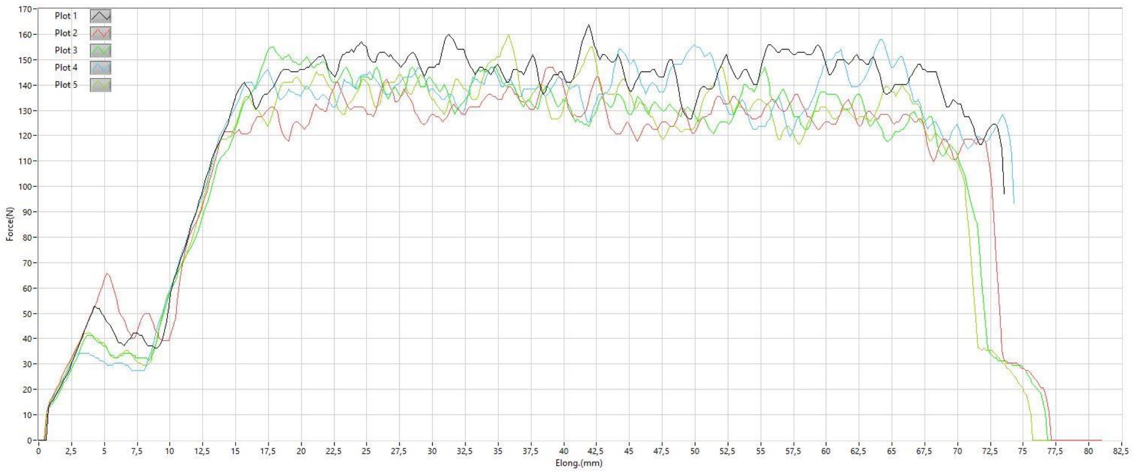


Figure 58 - Tencate NICOLON C888 tear strength in the weft direction.

Table 33 - Tear strength calculation of NICOLON C888 in the weft direction.

#sample	Direction	Tear Strength (N)
1	Weft	163.77
2	Weft	147.10
3	Weft	154.95
4	Weft	157.89
5	Weft	159.85
Mean		156.71
Standard Deviation		6.25

6.3. Adhesion test results of Tencate NICOLON C888

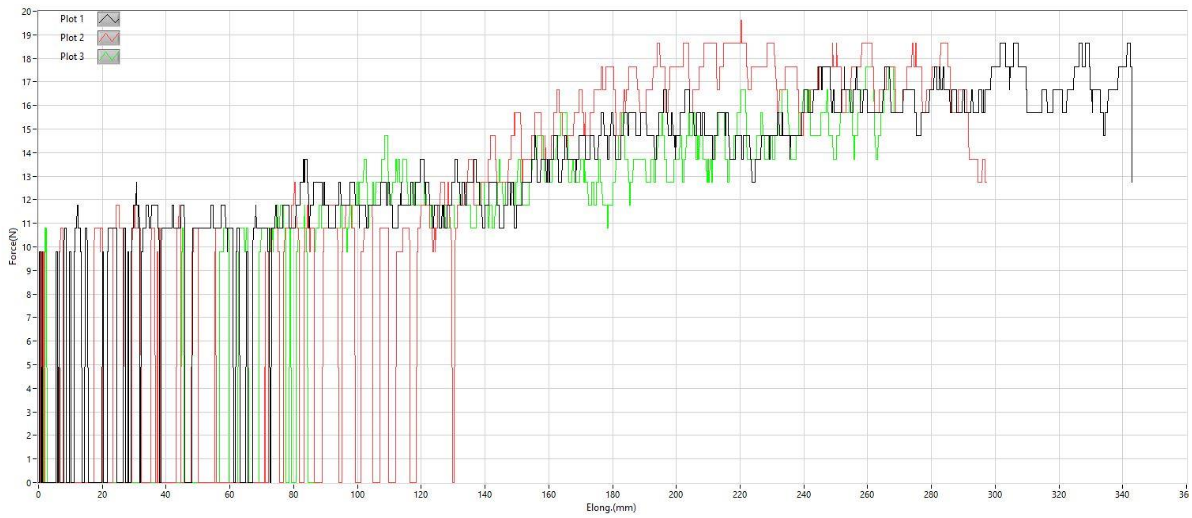


Figure 59 - Tencate NICOLON C888 adhesion strength in (N/ 25 mm).

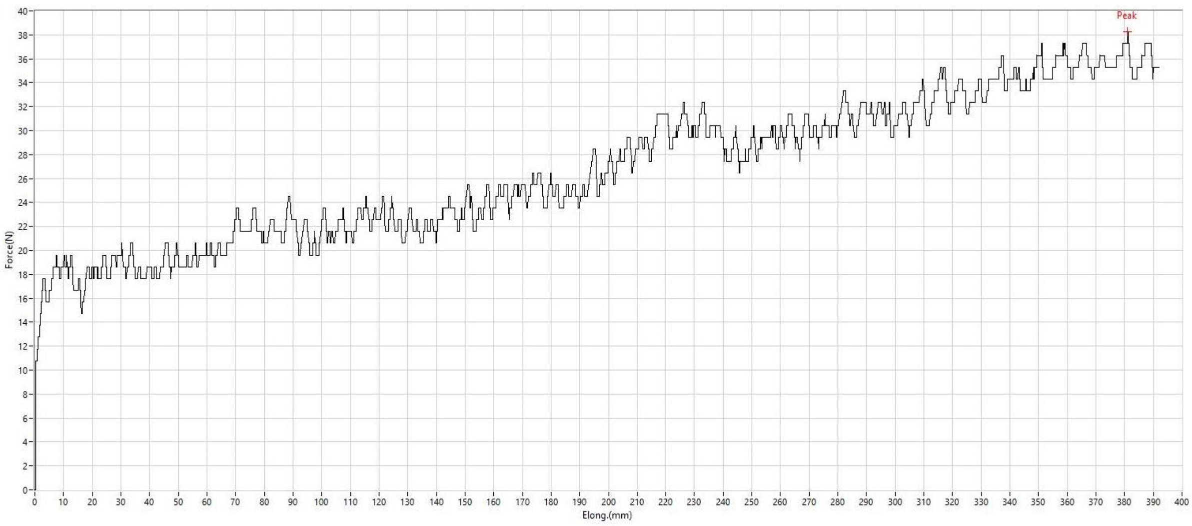
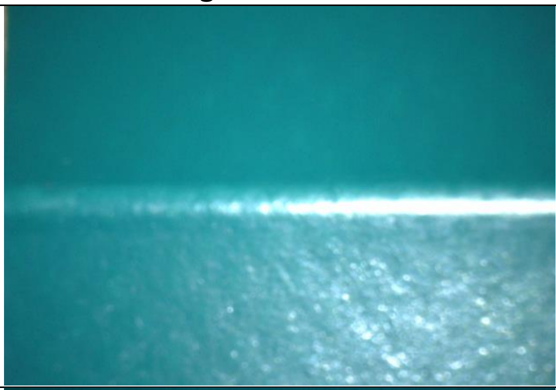
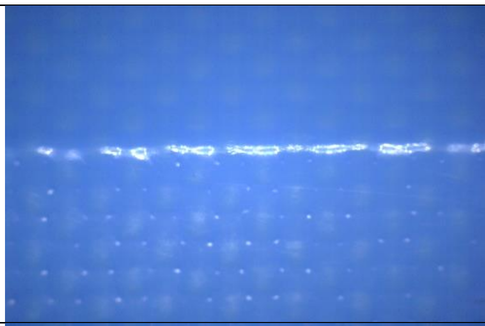
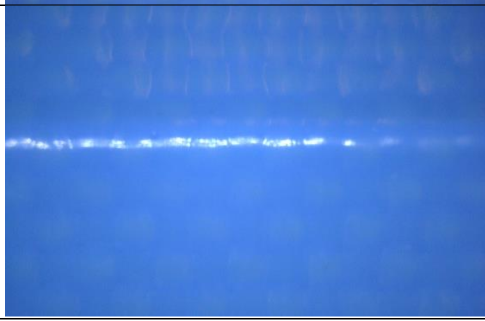


Figure 60 - Tencate NICOLON C888 adhesion strength in (N/ 50 mm).

6.4. Low temperature bending test

Table 34 - BERG PVC and NICOLON C888 samples with magnification after cold bending test.

Material	Sample Photo	Magnification Photo
PVC Elite Warp		
PVC Elite Weft		
PVC Champion Warp		
PVC Champion Weft		

Tencate NICOLON C888 Warp		
Tencate NICOLON C888 Weft		

6.5. Martindale abrasion test

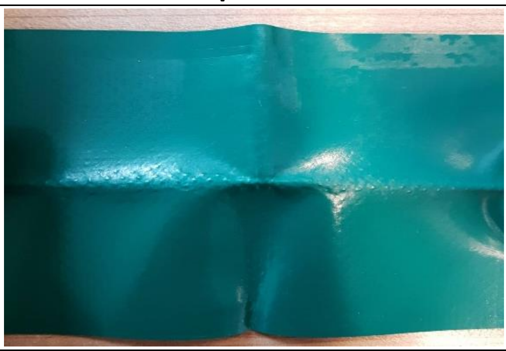
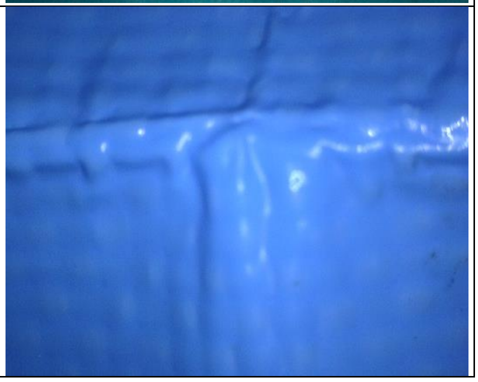
Table 35 - Calculation of Martindale abrasion test results for BERG PVC and NICOLON C888 samples.

		BERG Champion PVC		BERG Elite PVC		NICOLON C888	
		Before	After	Before	After	Before	After
Weight of Fabric (gram)	Sample 1	9.61	8.82	9.54	9.08	5.43	5.22
	Sample 2	9.42	8.67	9.60	9.13	5.48	5.31
	Sample 3	9.50	9.17	9.56	9.08	5.47	5.25
Total weight loss (gram)	Sample 1	0.79		0.46		0.20	
	Sample 2	0.75		0.47		0.17	
	Sample 3	0.33		0.48		0.21	
Percentage of weight loss (%)	Sample 1	8.25		4.79		3.76	
	Sample 2	8.01		4.87		3.15	
	Sample 3	3.50		5.05		3.89	
Mean of percentage of weight loss (%)		6.59		4.9		3.6	
Thickness of Fabric (mm)	Sample 1	0.57	0.52	0.52	0.50	0.48	0.48
	Sample 2	0.57	0.52	0.52	0.49	0.48	0.47
	Sample 3	0.58	0.53	0.52	0.49	0.48	0.48
Total thickness decrease (mm)	Sample 1	0.05		0.02		0	
	Sample 2	0.05		0.03		0.01	
	Sample 3	0.05		0.03		0	
Mean of percentage of thickness decreasing (%)		8.72		5.13		0.7	
Abrasion reach the fabric netting inside the coating	Sample 1	Netting seen after 5000 rubbing		Netting not seen after 5000 rubbing		Netting seen after 3000 rubbing	
	Sample 2	Netting seen after 5000 rubbing		Netting not seen after 5000 rubbing		Netting seen after 4000 rubbing	
	Sample 3	Netting not seen after 5000 rubbing		Netting not seen after 5000 rubbing		Netting seen after 3000 rubbing	

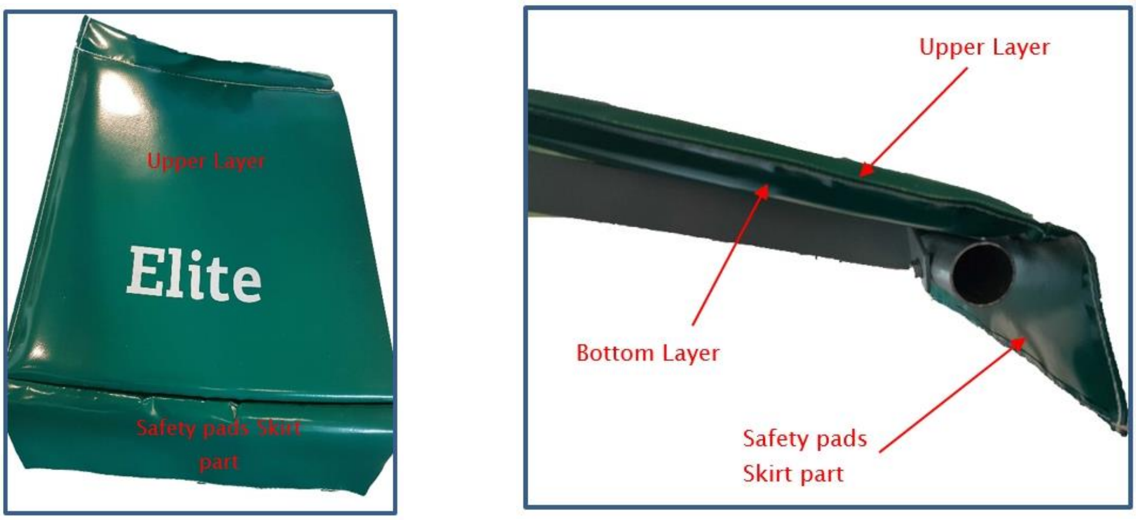
Figure 61 - Fabric samples after Martindale abrasion test.

6.6. 1000 hours UV and artificial rain test in folding condition

Table 36 - BERG PVC and NICOLON C888 samples with magnification after cold folding test.

Material	Sample Photo	Magnification Photo
PVC Elite Warp		
PVC Champion Warp		
Tencate NICOLON C888 Warp		

Appendix 7 – Prototype development process



(1) (2)

Figure 62 - Safety pads prototype model example (1) Top view, (2) Side view.

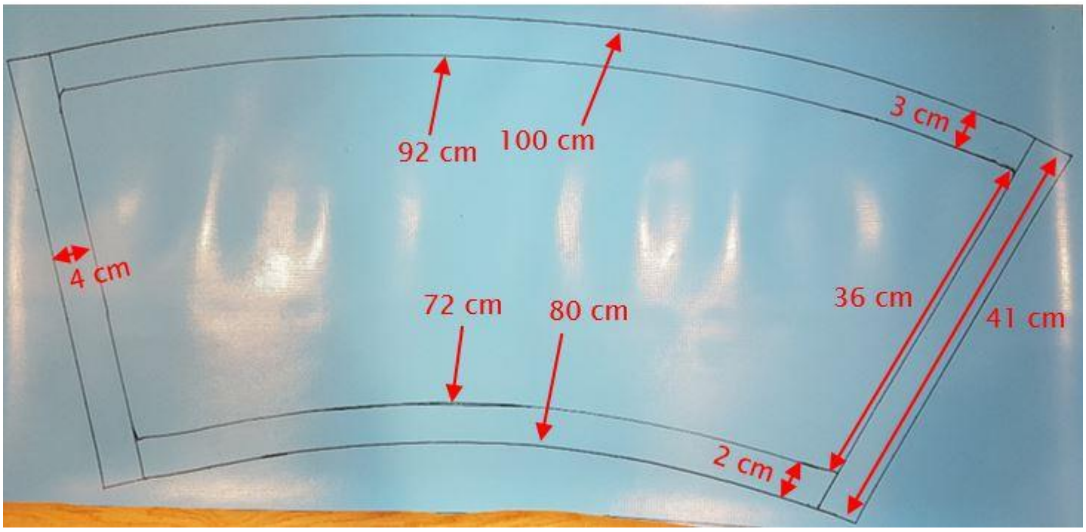


Figure 63 - Upper and bottom layer cutting model of the safety pads prototype.

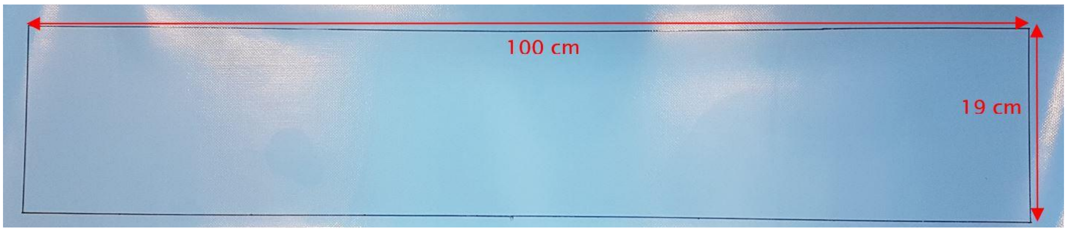


Figure 64 - Skirt part cutting model of the safety pads prototype.

Figure 65 - Additional part cutting of the safety pads prototype.