TECHNICKÁ UNIVERZITA V LIBERCI
Fakulta textilní

Use of LASER for printing secured tag for implementation of traceability in textile

Diplomová práce

Studijní program: N0723A270001 Textilní inženýrství
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Katedra oděvnictví

Liberec 2022

TECHNICKÁ UNIVERZITA V LIBERCI
Fakulta textilní

Zadání diplomové práce

Použití laseru pro tisk zabezpečeného štítku pro implementaci sledovatelnosti v textilu

Jméno a příjmení:	**Bc. Emma Fačkovcová**
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Studijní program:	N0723A270001 Textilní inženýrství
Zadávající katedra:	Katedra oděvnictví
Akademický rok:	**2019/2020**

Zásady pro vypracování:

1. Analýza provedení laserového tisku na různých textilních materiálech.
2. Optimalizace nastavení laseru podle kvality sledovatelného potisku.
3. Testování odolnosti a trvanlivosti (test mechanického namáhání a praní)
4. Aplikace laserového sledovatelného potisku (QR kód) na autosedačky, oděv a technické textilie.

Rozsah grafických prací:	dle rozsahu dokumentace
Rozsah pracovní zprávy:	cca 60 stran
Forma zpracování práce:	tištěná/elektronická
Jazyk práce:	Angličtina

Seznam odborné literatury:

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Datum zadání práce:	26. února 2020
Předpokládaný termín odevzdání:	16. května 2022

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14. května 2022 Bc. Emma Fačkovcová

Poděkování

Ráda bych poděkovala svému vedoucí diplomové práce Ing. Adnan Mazari PhD. za vstřícnost, podnětné rady a trpělivost při zpracování problematiky a vypracování práce. Jsem vděčná také všem pracovníkům laboratoří Textilní fakulty za pomoc a zajištění podmínek měření, hlavně Ing. Marie Kašparové Ph.D. která mi s ochotou pomáhala při práci s laserem. Také děkuji všem svým blízkým a rodině která mi byla oporou po celou dobu studia.

Anotace

Diplomová práce se zabývá technologií zabezpečených štítků ve formě QR kódů zhotovených pomocí gravírování laserem pro implementaci transparentnosti a sledovatelnosti v oděvním a textilním průmyslu.

První rešeršní část je zaměřena na průzkum problematiky transparentnosti v oděvním a textilním průmyslu. Zkoumá používané technologie v průmyslu umožňující sledovatelnost prvků zásobovacího řetězce, jejich výhody a nevýhody.

Druhá část popisuje tři fáze experimentu gravírování QR kódů na textilie. Zjištěná data jednotlivých testů jsou vyhodnocena a na jejichž základě jsou komentovány výsledky, doporučení a závěry.

Klíčová slova:

QR kód, laser, transparentnost, zabezpečený štítek, sledovatelnost

Annotation

The thesis discusses the topic of a new technology of secured tags in form of laser printed QR codes to help apply transparency and traceability into the textile and clothing industry.

First research part focuses on research of transparency issues in the clothing and textile industry. Technologies used in the industry to enable traceability of supply chain elements are examined and their advantages and disadvantages are described.

Second part of the thesis describes three phases of the QR code engraving experiment on textiles. The obtained data of individual tests are evaluated and on the basis of which the results, recommendations and conclusions are commented.

Key words:

QR code, laser, transparency, secured tag, traceability

Content

List of abbreviations

B2B		Business to Business
B2C		Business to Customer
TRU		Traceable Resource Unit
OECD		Organisation for Economic Co-operation and Development
RFID		Radio frequency identification
QR		Quick response
SCM		Supply chain management
PLM		Product lifecycle management
ERP		Enterprise resource planning
EAN		European Article Numbering
LASER		Light Amplification by Stimulated Emission of Radiation
NGO		Non-profit organization
SoS		System-of-system approach
KES		Kawabata Evaluation System
MIU		Coefficient of friction
SMD	[μm]	Geometric roughness
Ne		Number English
px		Pixels
dpi		Dots per inch
μm		micrometre
mm		Millimetre
cm		Centimetre
kg		kilogram
gsm		Gram per square meter
CO_2		Carbon dioxide
KrF		Krypton difluoride
UV		ultraviolet
CO		Cotton
PES		Polyester
PU		polyurethane
EME		Elastomultiester
kWh		Kilowatt hour
W/cm^2		Watt per square meter

min		minute
mm/min		Milometers per minute
°C		Degrees Celsius
N		Newton
[µs]		microsecond
n/a		No answer, non-applicable
Jpg		Joint photographic Experts Group
Tiff		Tagged Image File Format
bmp		BitMaP

Introduction

The clothing and textile industry is one of the biggest industries worldwide with its value $673.9 billion in 2019. [1] However with the rising size of the industry the transparency is becoming a problem in many areas. It is often criticised for unsecure and untraceable supply chain, unclear data on manufacturing of raw materials or garments or when trying to find data on how ethical or ecological is the manufacturing of products.

This thesis focuses on finding a solution to traceability in the textile industry with laser printed tags. The technology of laser printing on textile will be discussed and put in test. Important characteristic of traceable tags is durability which will also be tested on materials commonly used in clothing and automotive industry.

A laser printed tags need to be easy to produce, unique in each variation in addition to being secure. For the new technology to become successfully used in the industry it must not only be effective but also low-cost, durable, and easy to implement in the already running business.

1. Traceability in the textile industry

Traceability according to ISO 9001:2015 is “the ability to identify and trace the history, distribution, location, and application of products, parts, materials, and services. A traceability system records and follows the trail as products, parts, materials, and services come from suppliers and are processed and ultimately distributed as final products and services”. Traceability system allows access to information for all involved activity and products as well as information on material, components, processing, carbon footprint and logistics movement.

Global supply chains not only in textile industry have become largely untraceable due to lack of transparency and information unevenness. It has become difficult for supply chain partners to identify and track all the suppliers or outsourced work done through sub-suppliers. Due to unclear insight into the industry and reluctance to improve traceability many unfortunate events in the past years occurred and raised concerns from the public over sustainability and safety of the supply chain. [2]

Industries, activists, government, and non-governmental organizations are raising their voices over this matter. Moreover, consumer's interest in sustainable products is growing. The bigger the lack of transparency, the bigger grows the desire to know the facts about product raw material, origin, environmental and ethical footprint, and details of manufacturing practices. [3,4] Thus, more consumers adopt more sustainable purchase choices and prefer to support transparent companies sharing reliable information about their supply chain. They want assurance that the conditions at which products are manufactured guarantee safety.

Non-transparent supply chain is not only a problem for consumers and their interests. Untraceable supply chains offer an opportunity for intrusion of counterfeits as well as Intellectual Property attacks. Textile and automotive industries and manufacturing companies vulnerable to such attacks are already losing due to counterfeit products in brand identity and in the form of finances. Counterfeit products damage the economy and brand image and often are produced and sold in immoral environment causing physical harm.

As reported by the Organisation for Economic Co-operation and Development (OECD), counterfeit products in global trade valued for €338 billion in 2013, which is nearly 50% higher than found in 2008 and 2009. These sales have impact on the job market and revenue collections. The most sensitive industries to counterfeit goods are food, pharmaceuticals, leather goods and handbags and clothing and textile fabrics. [5,6]

Observatory report from the year 2007-2012 completed by the European Union Intellectual Property Office showed that the textile and clothing industry lost around 9,7% of sales (€26,3 billion) of revenue per year in the sector and 36 300 jobs. In reaction to these challenges the OECD suggests in their guidelines to implement traceability system to reach sustainable level of information symmetry, security and accountability in the textile and clothing supply chain. [13] According to Rapid Alert System (RAPEX) for dangerous non-food products in Europe, textile, clothing, and fashion products are in the top five most notified products. [19]

Traceability implementation in supply chain is useful solution to the challenges in the industry – supply chain visibility, inventory management, risk management, recycling, trend forecasting, transparency, and product branding. It could also ensure safety of products and manufacturing processes before further counterfeits. Management responsible for product quality should be able to identify the product and raw materials and possible safety concerns such as contaminated dyes, materials, or potential carcinogenic products before reaching consumers. [23] Traceability is therefore more commonly adopted in the food and pharmaceuticals supply chain industry as the effect of these goods is directly on the health of consumer. It is also part of standard legal obligation in most countries of the world – in the EU covered by General Food Law and in the United States by the U.S. Food and Drug Administration.[5]

Despite being one of the biggest industries worldwide employing millions of workers and directly affecting consumers, traceability in textile and clothing industry is still voluntary. Many brands advertise themselves and their sustainable practice of sharing even the smallest of information as transparent. Catastrophic events in latest years such as Rana Plaza in Bangladesh or Syrian child refugees working in textile industry in Turkey [9] gained international attention mostly of the authorities and customers and started the discussion about unethical practices and opaqueness of the supply chain. [10] In consequence to such events government, industries, researchers, and NGOs are developing regulations, guidelines and specific technologies for traceability implementation in the textile and clothing supply chain. [5,11]

To implement traceability into functioning supply chain is not as straight forward and simple. Despite many benefits it is still less implemented. Some reasons for it are lack of dedicated and inexpensive technologies considering the complexity of textile and clothing supply chain, missing awareness, and understanding of stakeholders of the benefits of traceable system and no rules and regulations on traceability. Applying traceability greatly depends on the information sharing, accuracy and efficiency of product tracking and authentication. This requires skilful management and connection of processes, subsystems, and synchronization. [12] Common approach is through system-of-system approach (SoS) which focuses on developing defence systems, transportation systems and aircraft systems. However, there is limited research on systems focusing on human activities and material and information exchange. [5] It is necessary that during the physical products exchange, the supply chain partners share related traceability information while securing that information and product. A system of gathering and secured sharing (information traceability system) and a safe system for physical product exchange which protects the products from being lost or copied (product traceability system) is needed.

Since traceability is still rather voluntary in the textile and clothing supply chain, brands adopt it to share information about their supply chain in aim to be seen as more sustainable and share it as green certifications, eco labels, carbon footprint data or details of their suppliers. [14,15]

2.1 Applying traceability

To build a traceable supply chain various types of information is necessary to record at each stage of product transformation, from raw materials until the stage of reaching customer. Implementing traceability has proven to be beneficial for consumer confidence in the product quality and safety, simply by providing information of the product such as its origin, composition, quality etc. [16]

A study on modelling traceability information [17] classifies traceability information as related to product, process, and quality. Product information includes name, origin, specifications, and composition of the final product as well as information related to raw materials. Process information covers all information about manufacturing of the product. Quality information includes data on product quality and accompanying information. Another category covers data on the social and environmental impact of the product in each of its transformation stage. This category mostly covers the ethical and ecological concerns. The authors of this study suggest than it is not necessary to record and share all the traceability information with all actors of the supply chain and the customers. Since there is not a lot of research on the views on traceability from the customers' or businesses' perspective or preferences it is difficult to judge if this opinion which sounds contrary to the purpose of a traceability system is correct. There should be a division of essential and non-essential information and what should be understood by each category for each actor of the supply chain. [5]

Another study [18] on traceability classifies two sets of traceability information. A set of information to be shared between customers and end-users on a business-to-customer

(B2C) level and another set of information to be shared among the actors of supply chain on a business-to-business (B2B) level. At the B2C level, information related to origin, composition, details on manufacturer/supplier and product sustainability were considered most important. At the B2B level, the most important information was considered details on manufacturer/supplier, product specifications, quality certification data, composition, and origin information. For both B2B and B2C level the most crucial elements were overall ranking, composition, origin, and manufacturer/supplier information. Least important elements for both B2B and B2C level were process-related information like machine ID, time stamps and data on sales and costs. [8]

In the study, risk management was found to be the most significant factor influencing implementation of traceability in the clothing and textile supply chain. In a multi-tier supply chain such as in clothing and textile industry, traceability can help with risk management. It helps brands to plan and to know if they will receive the product in expected quality on time.

The second most influential factor was product authentication as reaction to problems with counterfeit products. According to the experts of the study, most of the solutions until now are hard to implement into the production system with RFIDs being hard to produce in large quantity, high cost of durable and washable tags and complicated programming. Label printers that can produce RFIDs and barcode tags cannot print and program the durable tags. 2D codes and barcodes that are easy to produce are also very easy to copy or counterfeit.

As the third most influencing factor emerged supply chain visibility. Traceability can clear the insight into the in-shored and re-shored production and better monitor all actors of the supply chain and their activity. With such data quality certification becomes easier process and allows effective monitoring of quality. Certification schemes are also more independent and equally applied when each step is tracked and recorded.

Market surveillance was another important factor for implementing traceability into the supply chain. With lack of traceability, responsible border surveillance authorities and customs cannot easily verify the origin and authenticity of products when crossing the borders.

Following factors in the study were related to marketing, transparency, and product recall. Sharing information with customers can be used for marketing purposes and to show concerns for sustainability of a brand, create a positive image and use it as advantage. Being transparent brand allows to record information on the origin of materials and the impact on environment, animal welfare or social impact.

The data collection does not end by reaching the consumer. Tracing the reactions of customers, warning signs, and following of the products help the product data management and sales forecasting. Traceability information was found not to be relevant during the use and maintenance of the product, but during the purchasing decision making.

To give customers the transparency of their footprint it is necessary to implement traceability in the post-sales level. Collecting relevant data on their behaviour such as using/not using, maintaining/not maintaining, recycling, upcycling, or discharging the textile products allows to communicate it with the current user. To apply the sharing business, the product – its tag should record and store data on maintenance – number of washes, mistreatment etc. while the garment is being shared. Such data is also necessary for recycling at the end of lifecycle of the product. [5,18]

1.1.1. Traceability on B2B and B2C level

Information of product related to its origin and composition are already considered to be the most important elements to transparently share with customer and surveillance authorities. Government regulations such as EU TC legislation already made it compulsory to visibly communicate this information. But the set regulations do not reach to all tiers of the supply chain such as manufacturer/supplier details, social and environmental sustainability data such as certifications, and audit report, recycling data or carbon footprint data. This information is also very important and shared together with origin and composition details. [5]

Traceability relevant information is not only sourcing location but also the social and environmental footprint –footprint of virgin oil extraction for use of synthetic materials, agricultural methods of production, soil regenerative performance of the plantation – rotation cycles, water consumption of organic cotton, pesticides, fertilizers etc. Because of not sharing such data and properly communicating with customers, sustainability aspects are often ignored and create blind spots. Therefore, it is important to share footprints of production as well as social and economic footprint of all tiers of the supply chain. Customers should not be only informed of the positive sustainability information, which are often used for marketing, but all relevant factors positive or negative should be transparent. Data on carbon emission during transport starting from raw material to the place of purchase as well as environmental and social footprint should be shared at B2C level.

Even more important than other sustainability information is recycling related information. The customer should be familiar with where to send the product after the end of usage. This knowledge would be helpful for both B2C and B2B. It would help to close the loop of the material which is the most important part of being transparent. Navigating the customers to how to dispose their used garments helps not only them but also the entire recycling industry.

Communication of traceability and overall data on the product is limited to the storage capacity of the tag or traceability system. With this limitation, brands can choose how much and which information they will share with the consumer. It is important to distinguish which data is important on each level B2B and B2C. On B2C level, customers and end-users do not require data on timing, tracking and sales data or machine ID. They rather search for information on quality and certifications, audit reports, product, and material specification, tracking data, origin, composition and manufacturer details – although these are also among the most important one to share on B2C level. It allows all actors of the supply chain to have better visibility, accountability, and control over the activity of supply chain. It helps and prevents incomplete specification and quality problems and issues in the production. On B2C level the social-environmental sustainability is not the first and most important as on the B2B level. The least important was found to be also data related to product costing, sales data, process details, machine ID and manufacturing details as this information is sensitive and specific for each business and they do not want to share it.

1.2. Textile and clothing supply chain

The supply chain of textile and clothing industry is very complex due to numerous materials, possible variations, processes and involved actors. Each year many collections are produced – typically 5-6 collections per year but with fast fashion brands the numbers are higher. In each of these unique collections new materials are used as well as new styles, silhouettes, structures, and colours and usually they are not repeated in the next season or collection. This discourages the industry from modularization in the supply chain and results into using numerous materials, intermediate products, and suppliers. Each of the materials has different characteristics and needs to be traced each time individually.

The entire process from the fibre to finished product is long and complicated and partners of supply chain are usually located in different parts of the world. Typically, the production segment of supply chain with actors providing raw materials and product manufacturing is located in developing countries which offer semi-skilled workers with low wage. The actors from the end of the supply chain like buyers, retailers and customers are usually located in developed countries with higher incomes. These factors make supply chain and tracking challenging and creates opaque network with lack of information that is not always shared between the partners. Together with that, supply chain of textile and clothing industry has voluntary guidelines and limited regulations and standards. This unfortunately opens the opportunity for the suppliers to often follow unethical practises to reduce the production costs and remain untraceable. Some of the practises are child labour, unhealthy working conditions, and marginal salary. Opaque supply chains also allow autonomy to offshore suppliers to choose their own policies and standards for sharing information on production.

Because of the complexity of supply chain, it becomes very difficult to identify the real products and distinguish from counterfeit products due to lack of product traceability. On top of that, most products in textile and clothing industry are low in prices with variety which discourages the use of expensive technologies for efficient monitoring of supply chain. [5]

1.3. Influencing factors of traceability implementation

As stated in OECD report [13] applying traceability leads to smooth functioning of the textile and clothing supply chain and allows to address and deal with the issues and problems of the industry mentioned above – product counterfeits, lack of visibility etc. Even though traceability has many benefits it is still less adopted evolving mechanism in the textile and clothing supply chain.

Some reasons for it are lack of inexpensive technology developed for the complex supply chain of textile and clothing industry, lack of awareness and consensus about the benefits of traceability system and missing traceability rules and regulations applied universally. [5] Therefore is traceability only partially accepted by brands and has voluntary measure.

From organizational-policy perspective traceability is seen as tool to enhance transparency and visibility in the supply chain. From another perspective it can act as competitive advantage to boost market sales and create a positive image of the brand. [26] It is a tool to monitor supply chain operations by tracking and tracing products traversing the supply chain. Since traceability is still new and not well studied mechanism, there are not as many comparable cases to promote traceability.

2.3.1 Types of traceability

Supply chain recognizes two types of traceability:

Internal traceability

The focus of internal traceability is on keeping record and capturing information to the product within company, manufacturing plant or certain operation. In internal traceability the data is collected, and product is internally tracked from the moment of receiving raw material or intermediate product from supplier, throughout all processes in company until it is shipped and delivered to the next actor in the supply chain. The purpose and advantage of it is improvement of productivity, monitoring of production and cost reduction. It allows insight into the production and movement of the company and operations.

Internal traceability determines the external traceability. It is necessary to have internal traceability on individual company level to be able to implement traceability externally throughout the whole supply chain and its many actors.

External traceability

External traceability is also referred to as chain traceability. The focus is on the entire supply chain outside of the individual actors, which also considers the geographic locations of each supply chain partner. It highly depends on the internal traceability in each company and therefore is challenging to establish and requires partners to participate and cooperate at all stages of the supply chain. The purpose and advantage of external traceability includes efficient product recall, better quality monitoring, product marketing and ensuring compliance with government requirements and regulations. [5]

2.3.2. Absence of regulations for single traceability system

One of the reasons why traceability in textile and clothing supply chain is still voluntary is the lack of formal regulations for traceability. In other sectors especially food and pharmaceuticals there is a set minimum level for traceability. As a result, there are multiple traceability standards, guidelines and approach which are not only difficult to navigate and accept within the industry but also difficult to grasp for the consumers. Developing such standards and guidelines would require support and consensus from actors in the supply chain – especially brands and retailers.

Transparency represents the extent to which are information shared among all supply chain actors while visibility is the level to which a buyer can trace details of production and suppliers involved in the production. Partners of supply chain use both transparency and visibility to inform themselves before making purchases. Both are vital parts of sustainable supply chain. To establish such sustainability an effective mechanism that would connect all actors of supply chain is needed. Since the network of actors is widespread in many countries, it is necessary to implement synchronized rules to reach market demands and reduce the lead time. Visibility and transparency of supply chain allows benefits by providing insight into the production and its activities and by that reduce costs and synchronize all activities.

To improve transparency and visibility at the same time, companies can choose to share information among their customers and other businesses. Mostly the information shared is related to the product, its origin, composition, and specifications; quality reports and certifications; process that products went through; and social and environmental impact along with carbon footprint. Brands are using traceability to portrait themselves as sustainable and answer the anti-sweatshop and other ethical campaigns. But even if brands chose to share any data, if there is no government regulation, it is not fully reliable source of information as the company itself can chose to exclude some attention-grabbing information.

2.3.3 Data management

To safely capture, access, evaluate, report, and share data and simultaneously handle privacy and security it is necessary to follow protocols of data management. Managing product transformation data is a key factor for traceability and requires cooperation among different production and data management systems – Supply chain management (SCM), Product lifecycle management (PLM), Enterprise resource planning (ERP). The size and variability in the textile and clothing supply chain, which involves many actors and various data systems, and non-existent standard of data management protocol results in limited and less effective exchange of information.

The guidelines for security are applied only nationally. The supply chain of textile and clothing industry is stretched internationally therefore sharing data internationally becomes challenging. As a result, most transactions have wrong or incomplete information. Even if some possible rules for traceability data capturing and exchange will be applied, there is a necessity for incorporating principles of security and data privacy. [5]

Traceability system is based on information that needs to be captured and securely shared among all actors of the authorized supply chain, who have the right to view information. Each actor of the supply chain takes the raw material as input from another partner and performs operations on it to create final product which is passed to the next partner in the supply chain. This process is repeated until the finished product arrives to the retailer, who takes the finished garment as input. Each stage of this process generates large amount of information that is important for data management and traceability. All this information is a vital asset of the supply chain, and it is necessary for each partner to efficiently capture data, control it and protect its confidentiality.

Now, there is no exact classification of traceability information that needs to be shared among supply chain actors at the business-to-business and business-to-customer levels. Due to this fact it is complicated to establish a complete traceability system. Unsecured sharing of information and data without restrictions and rules applied among all supply chain members can result into financial and legal risks. [20] Sharing sensitive information brings another risk to some of the partners, especially the suppliers. Suppliers are hesitant to make alterations in their own information systems as it can raise the costs of their manufacturing process and the sensitive information such as their suppliers or know-how, that are source of their competitive advantage which they do not want to share.

Such sharing of sensitive data requires thorough planning, classification of the essential traceability information and framework of secure information sharing to arrange traceability in the supply chain and ensure that the interests of stakeholders are considered. [12]

2.3.4. Product maintenance and security

During the use of product especially maintenance processes like washing and drying have a big impact on durability of the product and later possibilities of recycling. Maintenance processes also influence the durability of tags attached to the garment. In the traceability system it is beneficial and essential to share all the maintenance instructions with the customer. The traceability mechanism can be programmed to record all the processes the garment goes through during its use and adjust the maintenance instructions accordingly. All this data can later serve in decision making process of recycling the garment. [12]

A big concern and problem in the supply chain is counterfeit products. Currently to secure product in the supply chain from replication, the most used mechanisms are QR codes, barcodes, and radio frequency identification (RFID). These mechanisms are used to track and trace products in the supply chain especially during transport.

The tags attached to the product encode data to allow product identification, tracking and exchange of information. Tags are usually printed and attached to the product or its packaging and carry the footprint of product moving in the supply chain. To complete traceability, it is required that the tag carrying all the necessary information gathered throughout the production remains on or with the product throughout the supply chain and ideally even throughout the whole lifecycle. [5]

Since the tag is such essential carrier of data it needs to be secured and should be unclonable and the encoded data should be safe from copying on similar tag and at the same time the tags itself should be protected from being attached to counterfeit products. With such counterfeit issues happening, the customers have difficulties distinguishing genuine products from counterfeits. Barcodes, QR codes and RFIDs are good for carrying data but only provide little security and are easy to copy. Along with that, in clothing and textile tags are usually destroyed or detached from the product especially after reaching the final consumer. RFID tags based on electronic chip affect privacy of the customer due to the long-range readability (up to 12 m) and become problem during recycling.

It is necessary to protect both product and information in the textile and clothing supply chain. This requires secure technologies to protect and distinguish between counterfeits and original products. The textile and clothing products make up almost 5-7% of all counterfeit products traded on all markets. Usually, lower quality materials are used in counterfeit production since it requires lower investments. This brings a potential health threat to all consumers who are not aware of the risks of purchasing such products. If traceability is strongly established in the supply chain, it allows safe and easy brand authentications.

2.3.5. Sales factors and marketing

Even if traceability and transparency is not yet strongly defined and requested by the public authorities, there are strong regulations for safety of the product. Authorities such as Administrative Cooperation Group and the Rapid Alert System (RAPEX) observe and track products on the market and monitor if they follow the applicable law. This requires knowing all the relevant information of the product such as its history, origin and composition. Traceability in the supply chain allows open communication and connection between the supply chain partners and by that allows tracking and tracing of the product at every stage of the supply chain. By authorities approving of the product, the consumers are protected and looked after knowing that the product they are purchasing has been thoroughly checked on each stage of its production. If a problem occurs with traceability mechanism, products can be easily recalled and identified.

Authorities researching the market and the conditions of production together with traceability mechanism serve as market surveillance and recall management. A transparent overview of the market, tracking and tracing of the products and management of all data allows more precise sales forecast. In textile and clothing industry forecasting is very challenging and crucial especially due to its short cycle. To lower the risk and help inventory management and improve customer service, effective forecasting is necessary. Current textile and clothing industry is very dynamic and by implementing traceability businesses can reach up to date data collection and statistics on their inventory, sales, orders, and logistics. All this data improves forecasting.

In clothing industry, life cycle of collection is getting shorter and shorter. Manufacturers are battling with fast changing trends in fashion, the order sizes are declining, and they must compete with global competition. It is required by manufacturers to optimize their production and create multiple styles with various materials and designs all at the same time and at lower costs. Internal traceability allows tracking and tracing of materials and material movement to reach the point of resource utilization. Traceability can be applied in other areas of the supply chain too - material handling and management, inventory, and product tracking.

It is becoming crucial for the costumers to know more information about their products. Customers want to make conscious decisions and buy ethical products. With the growing concern of the environmental and social impact of fashion garments business need to adjust. If customers can trace back the history of textile products and details of its production by using traceability mechanism, it can create a positive brand image, be an advantage over other brands and boost sales and attract customers. Customers trust more the brands who transparently share details of their products and assure safety and quality of the products. Research shows positive correlation between brand positioning and traceability. [21]

Traceability system can play a significant role in risk management. In the supply chain risks come in form of cost volatility, financial issues, supplier failures and natural and manmade disasters. Risk management implements strategies to identify, forecast, control, detect and soften the risk in all stages of the supply chain while maintaining continuity and profitability while reducing vulnerability. Traceability can early on detect threats in product quality, delays, excess or low inventory, issues with logistics while tracking the products. The risk comes with managing suppliers too and can be overcome by collecting, analysing, and managing suppliers and supplies information.

2.3.6. Certification

The leader of the supply chain determining the rules is in most of the supply chains the buyer. The government may set regulations to follow, but buyers request the strictest traceability requirements according to their perception of market demands. [12] The buyer can impose requirements to share any accessible information and level of traceability in the supply chain to meet the competition on the market, protect their interests and minimize risk. They can request certification of product and technologies from the suppliers to meet open standard. Examples of open standards with traceability requirements are GS1 Global Traceability Standards, ISO 22000, British Retail Consortium Global Standards. [5]

There are various certification systems covering stages of the supply chain. Commonly known certificates also among consumers are Fair Trade, Organic Cotton, OEKO Tex and Carbon certificates. Certifications address ethical, sustainability and safety concerns. To acquire certification for the product it requires information documentation, process awareness, tracking and level of traceability in the supply chain.

Based on auditing, three categories of certification systems are recognized. Self-proclaimed or first party certification issued by the business itself. Such certification is practiced in small supply chain where the only actors of supply chain are customer and supplier and they are in direct contact, have relationship and mutual trust. Second party certification requires intermediate supply chain partner who has a close relationship with the supplier and guarantees the quality and safety of the products and provides this information to the customer. This category of certification is like product branding. Third party certification is common in complex supply chain with many involved actors. It involves third party who is trusted to perform audit of production process to make sure that the products and processes comply to the standard conditions. For a third party to perform a thorough check in the supply chain, maximum traceability is required to capture relevant information at each supply chain stage.

1.4. Technologies for traceability

There are many definitions of traceability in international regulations (EU Regulation 178/2002) and standards (ISO22005). However, most of the definitions define traceability as "ability to trace" but do not involve definition of what it means "to trace". Authors in [22] therefore define traceability as "the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications". "That which is under consideration" in traceability definition is referred to as Traceable Resource Unit (TRU). Along the supply chain TRU can be any traceable object – typically it is a trade unit (a bag, a bottle, or a box), a logistic unit (a pallet or a container) or a production unit (a lot or a batch).

In internal traceability – internal units are defined by the company and identified by specific internal codes by the company and not necessary generally understood outside the company. Trade units that are being exchanged across the supply chain between partners must be identified in a way that is understood by both trading partners. In traceability system there must be a way of identifying the TRUs and be able to track and trace them as they move through the supply chain and record all attributes related to TRUs.

Traceability system components according to [22], can be defined as:

1. Mechanism for identifying TRUs
2. Mechanism for documenting transformations and connections between TRUs
3. Mechanism for recording the attributes of the TRUs

The identification mechanism must be chosen according to the identifier code type and its structure and uniqueness. There are many options for choosing the identifier. TRU identifiers are usually numeric or alphanumeric and length varies from few characters (in internal identification) to a couple of hundred characters (used where the code is read from a computer chip for example for electronic product identification). Using a structured code allows more detailed identification. Simple sequential codes without structure are most often used internally, whereas different parts of code with inherent structure can have different meanings.

Use and production of tags is regulated. Global organization GS1 defines codes to avoid re-use of numbers. It also defines how the numbers can be printed in which format to be readable by machine, this includes barcodes. For traceability, the most important attribute of identifier is its uniqueness and granularity. For the code to function as intended, it must be unique in the context of its use. The context can be production facility, manufacturing company, supply chain, nationally or globally.

GS1 defines Global Trade Item Number (GTIN) codes which are unique codes on national or global level and most trading standards refer to them and are used also at the sale stage to consumer. Codes vary depending on which TRU are they going to be associated with. Some codes are to be used on only one TRU and other codes are meant for many TRUs (all same products of a certain brand from the same producer will have the same GTIN code). For example, if the code refers to a production batch that results in many TRUs it can become problematic for traceability. The code refers to a batch of products and not only one TRU. Therefore, from the perspective of traceability, TRUs are not distinguishable. However, in reality the TRUs are distinguishable even if they share properties such as origin, location and composition. In the supply chain though, they follow different paths and are physically separated entities. Technologies such as RFID chips and media that can carry longer codes allow one to one connection between codes and TRUs. Such one-to-one relationship between codes and TRUs strengthens the traceability system. It also allows new characteristics of the TRU to be linked to the unique code enlisted in the traceability system. If the one-to-one relationship is not established, it becomes difficult to link and record attribute values for the TRU since the code is shared with several TRUs, while the attribute value may not be applicable to all of them (for example, location of the TRU at given time).

Granularity in the context of codes and identifiers stands for the amount of product referred to by the identifier. Fine granularity of the code implies that the identifier refers to a small amount of product, coarse granularity of the code is the opposite. Fine granularity allows accurate traceability and smaller number of products to recall if anything happens along the supply chain.

1.4.1. Product identification methods

There are many ways an identifier can be associated with a TRU. Most commonly it is done through marking the TRU directly or on its label. As discussed above, for traceability it is necessary to ensure the label with identifier is securely attached on to the TRU. The marking is usually done in text to be readable by humans coming to contact with the TRU at each stage of the supply chain. The marking can be done in a form of machine-readable codes such as barcodes or QR codes or RFID codes which are on the rise especially in the B2B transactions with the RFID chip being attached to the TRU or the packaging the TRU is in. It is most often used for tracking the product on its way along the supply chain.

Track of TRUs can be done through computerized traceability system which keep track of exact TRU location and is associated with the TRU indirectly. The identifier is known in the IT system (e.g., on a conveyor belt) but is not physically attached to the TRU. [22]

The most used technology for identification is use of barcodes, QR codes and RFID. All systems are used for carrying large amounts of data in small format. When choosing the best technology, it is important to consider the parameters of each system and economic complexity. Product identification systems offer speed and are cost and labour saving.

Barcodes are one dimensional pattern of parallel spaces and bars arranged to represent 10 digits. The information is readable with electronic reader, laser or CCD scanner that sends the information to a system where it is stored and processed. [45] They require line of sight to be read and can be only read individually and cannot be read if damaged or dirty. Disadvantage of barcodes is impossibility to read the barcode from any angle, low data volume and impossibility to fix mistakes. Manual tracking is required which creates spaces for human error. Barcodes are used in many different areas such as in manufacturing stage, retail, grocery stores and during transport of products.

Use of EAN (European Article Numbering) barcodes is monitored by EAN International. Two-dimensional (2D) barcodes were developed to improve the linear barcodes. 2D barcodes are stacked linear barcodes with bigger data capacity thanks to condensed linear barcodes. They can store more information than one-dimensional (1D) barcodes as they consist of a combination of dots and spaces arranged in a 2D array or matrix in lieu of bars and spaces. [45]

It is possible to read them with laser or CCD scanners. 2D barcodes can also be matrix barcodes formed by polygonally arranged data cells with big data capacity and high recording density. Matrix barcodes are readable from all angles. 1D code can store up to 85 characters however 2D code can store over 7000 characters.

Every barcode begins with a special start character and ends with a special stop character. The characters help to recognize if the barcode is read forward or backward. Each character in a barcode is represented by a pattern made of wide and narrow bars. Photosensor in scanner translates the barcode into electrical signals and measures the width between the bars and spaces. The pattern is translated back into characters and sent into computer or reader. [46]

QR codes are example of 2D barcodes and are defined by ISO/IEC 18004:2006 standard. Becoming more commonly used especially for communication directly with customer as well as in production. They are readable with a Smart phone by using QR code application and provide information about product, on banner or in leaflets or magazines. They can be used on business cards or everyday products. Recently some tamper-proof barcode indicators have been designed. Each QR code is composed of black (logical "1") and white (logical "0") modules distributed over a square net of fields. Size of a field is the size of the module. As stated in the ISO/IEC 18004, the size of one module is 4x4 pixels with a print resolution of 300 dpi. This size ensures readability by most optical devices.

The QR code can be read by an imagining device such as camera or scanner and processed until the image is interpreted. The data is extracted from horizontal and vertical patterns in the image. Storage limitation of QR codes depends on the used encoding mode (numeric, alphanumeric or byte-binary), version (indication of the overall dimensions of the symbol, 1-40) and error correction level (L, M, Q, H). [45] Based on a steady-state test [47], it was found that the QR code readability is not directly affected by the number of coded characters or by the error correction level. QR code readability is however, affected by the size of modules.

RFID tags come in different sizes, shapes, and capabilities. They are usually attached to boxes or pallets. The tag has a small antenna which emits a radio frequency signal that is picked up and read by wireless RFID reader. It is useful during transportation of product in big quantities and tracking of shipment of goods. However, there are technical challenges that need to be overcome. RFID chips also only carry a pre-defined code. On the other hand, active RFID tags that use battery can record environmental parameters such as temperature, pressure, GPS location or humidity, but are more expensive.

RFID technology offers many advantages in identification and traceability systems such as the amount of data that can be contained in a tag, high reading speed of data, possibility of simultaneous reading of multiple tags and non-contact reading of data. The biggest disadvantage of this technology is its high price. It is one of the main reasons why it is not widespread as the price of an RFID tag would greatly increase the price of a single product. [47]

<table>
<tr><th colspan="3">1.Authentication Technology</th></tr>
<tr><td colspan="3">Feature-based identification techniques are useful for differentiating the original product from counterfeits [25]. These are most widely used technologies for product authentication but do not support product tracking. Moreover, most of these technologies required sophisticated and expensive equipment or an expert with discerning eye for product validation</td></tr>
<tr><td>1.1. Direct authentication</td><td colspan="2">1.2. Security features-based authentication</td></tr>
<tr><td>Inherited physical, chemical, or visual properties, e.g., diamonds, leather goods, gems etc. [26-27]</td><td colspan="2">Externally added features [26] that can be
a) Overt: Visible to the naked eye and vulnerable to attack, e.g., holograms and micro-engraving,
b) Covert: Invisible to naked eyes, requires a special device for authentication, e.g., digital watermarking, ultraviolet (UV) sensitive inks
c) Forensic: Chemical or biological features, required sophisticated instruments for reading and analysis [28-30]</td></tr>
<tr><th colspan="3">2.Track and trace technology</th></tr>
<tr><td colspan="3">Based on the principle of unique identifier in the form of tracking tags [31], track and trace technologies are extensively used for freight tracking in logistics operations. These are mature technologies with relatively low investment, high readability and with high level of standardisation. However, they are extremely prone to counterfeiting or illegal reproduction</td></tr>
<tr><td>2.1. RFIDs</td><td>2.2. Barcodes/QR codes</td><td>2.3. Miscellaneous</td></tr>
<tr><td>Contactless, electronic tags consisting of an electronic microchip for data storage and antenna for communication [32]. Find wide application due to its long-range readability, small size, low-cost and high memory storage; however, they can easily be cloned, requires a special device for reading, and are usually removed or deactivated at the point of sale to prevent privacy issues</td><td>Machine-readable optical pattern used for data representation. Printed or attached in the form of labels or stickers, are a systematic arrangement of codes describing something about the associated product. High readability and low cost, find wide application in fast-moving commercial products. However, they can be easily copied and applied to counterfeit products and lack authentication method [33]</td><td>Magnetic strip cards, magnetic ink character recognition (MICR) code or magnetic barcode are some examples of other miscellaneous technologies useful for product tracking. They are remotely sensed and decoded using magnetic sensing technologies. Find application in the packaging industries, banks and in transportation industries in metro or tram tickets [34]</td></tr>
</table>

3.Secured Traceability Technology		
Technologies that can track and trace product and capable of authenticating the brand or product identity without the threat of easy clonability. Presently, most of the secured technologies are relatively expensive and used in high-value product with more profit margins. They also find application in pharmaceutical or food products, contamination or counterfeiting of which can lead to serious health consequences.		
3.1. Secured RFIDs	3.2. Secured barcodes/QR codes	3.3. Miscellaneous
a. Watermarking and RFID-based self-validation system (WARDS): two-factor authentication system. Uses scanned watermark information from labels along with product's identification code from RFIDs as a two-factor authentication system [25] b. Physical unclonable function (PUF) based RFIDs: RFID IC chip equipped with PUF to prevent product clonability [35] c. Fingerprinting RFID tags: prevent cloning by using physical attributes or features based on minimum power responses measured at multiple frequencies [36] d. other examples can be found in [37-38]	a. Cryptographic barcode [42] for traceability and brand authentication in the textile industry. Printed directly on the surface of textile and tested against deformation due to the unstable textile surfaces b. QR code and a digital signature [43] for fishery product. The system uses weight of individual fish as their digital signature c. Micro taggant [44]: lithographically fabricated to consider the QR code pattern for traceability on pharmaceutical industries	a. Yarn-based traceability tags by [39] used yarn-based feature to secure traceability system b. Permanent sub-surface tattoo [40] developed for leather products for traceability and counterfeits reduction c. SigNature® T [41] protects the product using unique molecular-based tagging of each textile and clothing product.

Table 1: Various technologies for traceability adopted from [24]

1.4.2. Ideal traceability system

Traceability in its nature is centred around an item – its tracking, tracing, collecting data and connecting each product with its information. In this context, the traceability tag plays important role in tracking and identifying the product and allows it to be traced back. As the most important part of the traceability system, a tag is also the weakest and most vulnerable to be copied or replaced. Therefore, it is necessary to build a strong security system for the tag to protect the stability of traceability system. [48] The whole system can be dysfunctional if the tag is copied, washed away or detached and attached on counterfeit product. In an ideal traceability system, each product is tagged with a secured tag.

An ideal secured tag is hard to replicate but easy and inexpensive to integrate in the production and should remain with the product throughout its life cycle. In the textile and clothing supply chain, it is common for the materials to be combined and transformed into singular product. With this knowledge, a single tag may not be sufficient to cover the complete supply chain. The secured tags should be integrated with the intermediate products throughout the whole supply chain, at each stage before passing to the next level. Along the supply chain, data is collected and stored in a database, which includes all data about the product/intermediate product and its current stage. At the final manufacturing stage, the tag should carry all manufacturing data from previous stages. [24]

2. Performance of LASER printing on different textile materials

2.1. LASER

Laser is considered to be one of the most significant technical inventions of the second half of the 20th century. LASER stands for Light Amplification by Stimulated Emission of Radiation. It is a source of electromagnetic radiation with its characteristic values being phase coherence, monochromaticity, high intensity and low divergence of the radiation beam. It is a light source generating light with only one wavelength, not the whole spectrum. If the laser emits radiation in multiple wave lengths it is called multimodal. Laser radiation emits continuously or impulsively with beams lasting tenths of seconds to picoseconds. [49]

Every laser generator has laser active environment where the radiation strengthens; source of drawing for triggering active environment and resonator creating feedback between the active medium and the radiation that leads to laser oscillation. Laser beam is created by stimulated emission. Source of light in laser emits light with large number of atoms. In the active environment the atoms get in the excited state and must stay in excited state for longer time to get into metastable level.

For laser beam formation it is necessary to have a source of light in the system. With a light gleam the atoms move from base state through excited state to metastable level. When stimulating red light photon is created all excited atoms return to their base state while radiating the excess energy in photons. When another stimulating photon enters active environment, the light strengthens. Optical resonator and two mirrors are used to keep photons in active environment long enough to gather energy. One of the mirrors is silver plated, impermeable, and reflective. The second mirror is semipermeable. Photons created by stimulated emission reflect from mirrors and gain enough energy to grow the light intensity inside the resonator. After reaching a certain level of energy a light impulse gets through the semipermeable mirror as a laser beam. After photons excitation atoms return to their original state and after another light gleam the cycle repeats.

All lasers function on the same principle of stimulated emission, however the device can be built with different construction and characteristics. Lasers can be divided into categories based on criteria such as:

- State of the active environment: solid, liquid, gas, semiconductor
- Wavelength: submillimetre, infrared, visible light, ultraviolet, x-ray
- Excitation by optical radiation, electric field, chemical reaction, electron beam, etc.
- Number of energy levels: two, three and multi-level

- Operating mode: pulse, continuous

2.1.1. Lasers according to state of active environment

The active medium in solid-state lasers are crystalline or amorphous insulators with admixtures of suitable ions, the excitation is usually optical. These lasers can operate in various modes and under different operating conditions, are stable and low maintenance. The radiation of solid-state lasers has wavelength in the field of infrared and visible light. The most well-known is the ruby laser with its active medium being a synthetic ruby crystal.

The active medium of liquid laser is a solution of various organic dyes. Using several types of dyes and methods of nonlinear optics can be achieved all wavelengths from 300 nm to 1500 nm. Liquid lasers are therefore used in spectroscopy. The disadvantage is the short life of the active environment, which gets easily decomposed by heat and light.

Gas lasers can have active environment made of atoms, ions, or molecules. They can operate in wide range of wavelength in continuous or pulsed mode. The active environment is homogeneous which ensured excellent parameters, however there is a disadvantage of relatively low power of gas lasers. The most common types are red glowing helium-neon HeNe lasers and infrared CO_2 lasers. Lighting effects are provided by blue and green glowing argon laser. Excimer lasers use UV radiation as a powerful source.

Semiconductor lasers are diodes that are electrically pumped. So-called laser diodes have a very small dimensions which can be seen as advantage however their beam is more divergent than with other types of lasers. The efficiency of diodes is high (up to 50%) and the power can be easily changed by alternating the electric current. [50]

2.1.2. Laser printing

One of the applications of laser is in laser printers. Typically, such printers are used to print on paper however it is also possible to print on textile. These printers use a focused beam or light to transfer text and images on surface. Laser beam fires at the surface of a cylindrical drum with electrical charge, typically positive. Areas hit by laser beam have reversed electrical charge. By reversing the charge in certain areas of the drum, the laser beam prints patterns onto the photoreceptor.

Once the pattern is created on the drum, it is coated with toner from a toner cartridge. The positively charged toner clings to areas of the drum that have been negatively charged by laser. When the material passes through the printer, the drum is given a strong negative charge, which allows the toner to transfer and stick to the surface. [51]

3.2 Laser application on textile materials

The characteristics of textile fibres are often modified by various technologies and treatments such as UV light, plasma ai. One of the most studied technologies is modification of material surface with laser. Laser radiation is often used for treating textile materials by affecting characteristics of fibres and textile surface. With laser radiation, it is possible to change fibre morphology and its chemical and physical properties. While setting the laser beam it is important to take in valuation the composition, thickness, and basis weight of treated textile material and according to that set the right time of exposure (pixel time). Important setting of the laser beam is resolution [dpi] which represents intensity of laser beam on the surface of material [W/cm^2]. Another parameter is pulse length [µs] which represents the time required to create one laser dot in which the laser beam reaches the position of the dot at each pixel. The longer the time exposure, the bigger the energy and higher burning rate. [52]

3.2.1. Laser radiation effect on polyester fibres

Materials like polymers, woods and metals modified by laser irradiation have been shown to exhibit physical and chemical changes in its surface. Polymers with well-oriented structure tend to develop ripple or grooves structures with dimensions in the range of micrometres. Polymers that are highly absorbing like polyester can generate change of character of the surface. Chemical and physical values get affected too.

In 2006 study [51] the effect of laser radiation on polyester fibres was studied. The included properties were fibre weight and diameter, tensile strength and elongation, yarn abrasion, bending, surface chandeliers, wetting, air permeability and crystallinity. The material was irradiated with an excimer laser (KrF gas) with wavelength 248 nm with various intensity. After irradiation the treated material was tested for tensile strength and elongation, yarn abrasion, bending properties, surface lustre, wetting and air permeability.

The results showed that laser radiation had no effect on bulk structure of polyester fibres due to low penetration depth. The effect of the treatment on the bulk and structural properties are limited. Surface characteristics such as air permeability and wetting increased, which can be useful for everyday garments but would be a disadvantage for waterproof garments. Laser beam treatment on polyester material can be useful when knowing the final use of the material beforehand. [51]

3.2.2. Laser radiation effect on cotton fibres

Laser radiation is often a substitute to traditional chemical treatment. In case of cotton, it is often used as a substitute for traditional techniques treating denim. Clean and dry physical treatments have more advantages than chemical wet processing. As an alternative it can lower the costs of energy, chemicals and water consumption or even eliminate it completely. For surface finishing method, computer-controlled laser treatment is commonly used and established dry ad physical method.

CO_2 laser can modify properties and surface of synthetic material, and it has been also tested to treat cotton. It can modify different materials and substrates and change the physical and chemical properties.

In 2011 research [52] CO2 laser was used for treating cotton fabric with various resolution (40-60 dpi) and pixel time (100-120μs) to see the according change of fabric properties. Followingly, the treated materials were then dyed with direct dyes. Direct dyes are water soluble and have good light fastness. Due to the inadequate wet colour fastness of direct dyes, dyed cotton fabrics were after treated with a cationic fixing agent.

Cotton fibre in the untreated state has a smooth surface. After the irradiation an uneven structure was created with some grooves and wrinkles. Laser radiation caused an uneven structure on the treated cotton fibre with various sizes of pores and even cracks causing a sponge like structure.

Due to this some weak points have been created and treated fabric becomes slightly weaker in comparison with the untreated fabric. Fabric weight and strength decreased with increase of resolution and pixel time. Weight loss increased with an increase of pixel time and resolution up to 14%. Laser treatment resulted in reduced tearing strength for all samples.

It was also found that treated samples were lighter in colour after dyeing than untreated samples. Along with that yellowing was observed in all samples and in nearly the same extent under different parameters. Surface morphology of cotton fibre and low stress mechanical properties were modified.

Dyeing performance of the treated samples was evaluated in terms of dyeability, colour fastness and rate of exhaustion. Laser radiation was found to reduce the amount of absorbed direct dye by the fabric and caused higher reflectance. With increased pixel time the colour strength decreased. There is an indication that the laser treatment might cause colour fading on cotton and increase the time of half dyeing in comparison with untreated cotton sample. Colour fastness to washing remained the same as the untreated sample with all different settings of resolution and pixel time.

2.2. Testing the durability and lifetime

One of the most important properties of a tag used for traceability is its durability and longevity. The durability of laser printed tag depends on the used technology as well as the materials. It is important to put in test the textile material for its composition, structure, and surface. The longevity should be tested depending on where exactly the tag will be placed. Laundering of products can also cause mechanical damage. [53,54] Textile finishing can improve the abrasion resistance by applying coating or by lowering the frictional resistance. [55,56] Tags should be tested for washing, abrasion, and mechanical damage.

Washing

A laser printed tag, or any printed tag is fixed on the surface of the textile material. Therefore, it is necessary to know the characteristics of used material to estimate whether it is suitable for such use and to establish appropriate care instruction for product. Every testing method and evaluation of characteristics subjects to norms.

- ISO 3759:2011 — Specifies a method for the preparation, marking and measuring of textile fabrics, garments, and fabric assemblies for use in tests for assessing dimensional change after a specified treatment, e.g., washing, dry cleaning, soaking in water and steaming.
- ISO 3175-1:2017 — Textiles — Professional care, dry cleaning and wet cleaning of fabrics and garments — Part 1: Assessment of performance after cleaning and finishing
- ISO 5077:2007 — Determination of dimensional change in washing and drying
- ISO 7768:2009 — Textiles — Test method for assessing the smoothness appearance of fabrics after cleansing

Abrasion test

The wear resistance of textiles is important in both uses, for clothing and automotive. Abrasion and wear influence the appearance, longevity of textile as well as the readability and durability of tags on the product itself. Common problems are piling of fabric from staple fibre yarns or felting of woven fabrics because of rubbing which complicate the readability of a tag. Too harsh treatment and abrasive stress can result into destruction of materials by tearing the yarn.

To test the durability of textiles and its finishing, various methods are used. One of the most common tests for apparel and home textiles is the Martindale abrasion test according to ISO 12947-1. Specific weight load is applied, and a standard test fabric (wool) is rubbed on the textile sample's surface. The degree of abrasive wear is checked at a given time intervals and judged by the occurrence of a visible damage of fibres or the test sample. Employing this test, it is easy to establish the characteristics and suitability of given material with respect to wear resistance. For example, seat covers for furniture in private use should withstand 15 000 rubbing cycles without any damage, seat covers used in workplace must guarantee higher durability and should withstand at least 35 000 cycles. [57]

There are various methods for mechanical abrasion testing with according to norms.

Testing method	Requirement	Abrasive
Martindale	ISO 12947-1:1998	Standard wool fabric
Wyzenbeek	ASTM D4157	Cotton fabric, plain weave
Schopper abrasion tester	GME Standard 60345	Emery paper

Mechanical test

Mechanical properties of textile materials can be defined as response to mechanical action from external forces to thrust, pressure, bending, twisting and cutting. They include fibre strength, elongation, elasticity, wear resistance, tensile strength, ultimate strain. Determination of mechanical properties is subject to standards:

ISO 13934-1:2013 – Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method

ISO 13934-2:2014 – Textiles — Tensile properties of fabrics — Part 2: Determination of maximum force using the grab method

ISO 13938:2019 – Textiles — Bursting properties of fabrics

3. Experimental part

In the previous chapters, the importance of traceability and steps to implement traceability were discussed. Various technologies commonly used to label and trace units in the supply chain were described together with their advantages and disadvantages.

This thesis focuses on introducing a new technology useful for implementing traceability. The technology of laser printed tags could possibly replace the currently most used technology of barcodes and paper tags which are used to label products during manufacture stage and later.

The purpose of the experimental part of this thesis is to test the technology of laser printed tags and find the optimal end use in clothing or automotive industry. In theory, such tag should represent a durable, easy to manufacture and inexpensive alternative.

The experimental part can be divided into three stages: Test 1, Test 2, Test 3:

Test 1 – testing and trying the technology of laser engraving on wide spectrum of textile materials to define groups of materials suitable for further experiment and eliminating those groups that are found to be not suitable according to given values. Main parameters were level of surface damage, destruction of material and readability of engraved QR code. The result of Test 1 was finding groups of materials that can be described as “suitable” and defining the values and characteristics of these “suitable” groups.

Test 2 – test of device settings, different influence of variable intensity of laser beam, different size resolution and format of the QR code. Test was done on the materials from “suitable groups” from previous Test 1. Main parameters were lowest possible level of surface damage while maintaining easy readability of QR code. Result of Test 2 was to find optimal device settings for each material group.

Test 3 – test of longevity and durability of the QR codes in use. Engraving of QR codes with optimal device settings was applied to a chosen group of textile materials. These QR codes were later tested on washing, their frictional and tensile properties to determine how suitable is the technology in long term.

Figure 1: QR code used for engraving

At first a QR code was created by QR code generator [58] to be used in the experiment. A single QR code can hold up to 7089 numeric characters, 4296 alphanumeric characters or 2953 bytes. The capacity depends on the code version and error correction level. [59] The storage capacity of a single QR code is much higher than a storage capacity of a regular barcode, which is another advantage of this technology.

3.1. Test 1

The first experimental part was conceived in a way to test the widest variety of materials commonly used in automotive industry and in clothing industry with the goal to observe how these materials react to laser beam.

The research of the subjected materials was based on the composition – synthetic fibre based, and natural fibre based; structure – woven, knitted or nonwoven; colour and pattern; surface description and other characteristics such as elasticity or thickness. QR code was engraved on the surface of the textile materials (Table 2). After the engraving, performance of materials was evaluated as for its destruction and readability of QR code. Based on this evaluation it was possible to determine which key character values are connected to successful engraving of readable QR code and low damage of material. It was also possible to describe which characteristics of materials lead to complications during engraving process such as laser beam reflection, surface melting or unreadable QR code, making the material or material group unsuitable for the laser engraving technology.

Figure 2: Creality3D CP-01 3in1 [60]

The machine used for the experimental part was Creality3D CP-01 3 in 1. This device allows 3 different settings – CNC cutting, laser engraving and 3D print. For this experiment laser engraving setting was used.

Laser engraving parameters [60]	
Working area	200 x 200 mm
Supported filament	Wood, paper, plastic, feather etc.
Laser power	Less than 0,5 W

Table 2: parameters for Creality3D CP-01

The technology of laser printed tags is aimed to be used in both clothing and automotive. The testing materials were chosen within this perspective.

Sample n.	Type	Composition	Colour
1	Plain weave	100 % Cotton	White
2	Plain weave	100% viscose	White
3	Satin weave	100% polyester	White
4	Knit	95% cotton 5% lycra	White
5	Alcantara	68% polyester and 32% polyurethane	Black

Table 3:tested samples in part 1 of experiment

After the engraving and evaluation of the results it was possible to describe main characteristic values of materials with best performances – readable QR code.

- Smooth surface of sample or very soft structure
- Non perforated
- No visible colour pattern in structure
- Higher thickness
- Light or white colours of sample
- Mate surface
- Higher content of natural fibres

Best performing were engravings on textile surface with low or no shine, white colour creating higher contrast between the surface and QR code which is key for readability. Important value which determined the level of destruction of the sample was elasticity of material and the composition. Samples composed with natural fibres or higher ratio of natural fibres were more resistant to destruction compared to synthetic fibres prone to melting under high heat. Elasticity of knitted samples caused higher damage to the engraved QR code.

3.2. Test two

Based on the knowledge from Test 1, the plan of second experimental part was drawn. Laser machine used during this part of experiment was Marcatex 150 Flexi (Table 4). This laser device was chosen for the possibility to adjust strength of laser beam and complex settings possibilities.

Device	Marcatex 150 Flexi
Type	CO2 laser
Regime	Pulse regime
Power	100 W
Class	4 B
Wavelength	10,6 µm
Working area	800 x 800 mm

Table 4: Marcatex 150 Flexi settings

3.2.1. Engraving settings

Important value that determines the outcome is settings of engraved picture. QR codes are very sensitive on retaining the original shape to be readable. The engraved picture was applied in different formats to test the outcome.

The used laser machine recognizes following formats: tiff, jpg or bmp. The maximum size of engraved picture is 80x80 cm. For this experiment 3 different sizes were used: 50 x 50 px, 100 x 100 px, 200 x 200 px.

Resolution of the file highly determines the readability of QR code. For this experiment two different resolutions of picture were used 32 dpi and 64 dpi. During the experiment it was found that the 64-dpi resolution, regardless the size of picture is not suitable at all due to deformation during engraving (Figure 3). After this discovery, for majority of experiments only the resolution 32 dpi was applied.

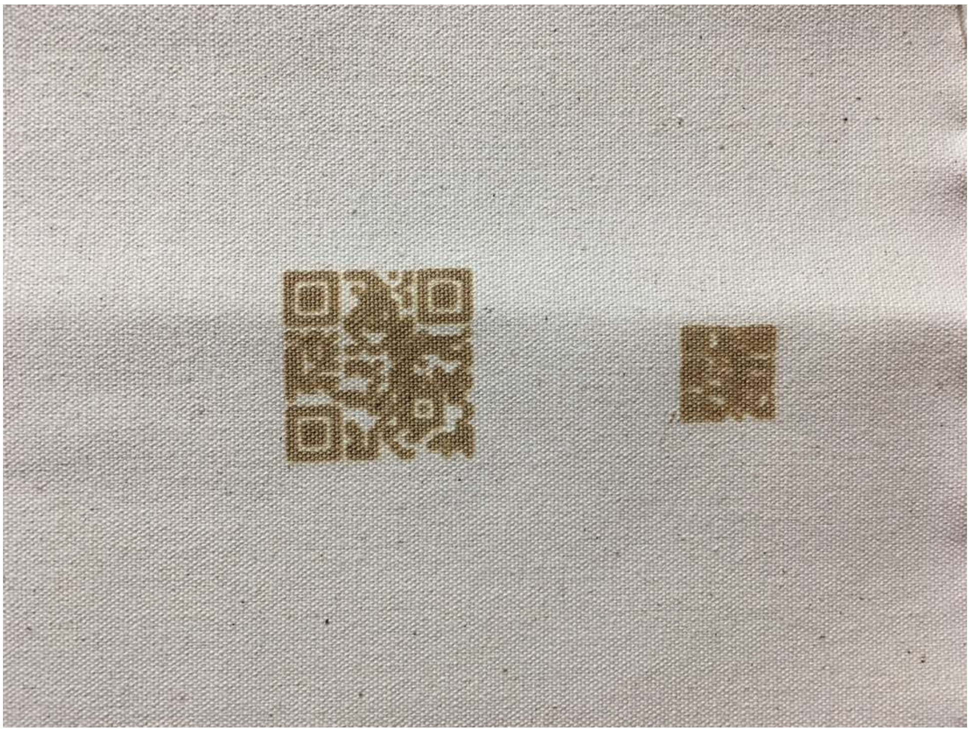


Figure 3: deformation of QR code in 64 dpi resolution.

Left – picture size 100 x 100 px, resolution 64dpi.
Right – picture size 50 x 50 px, resolution 64 dpi

3.2.2. Material samples

The criteria for material samples were set based on the results in first testing. Important values of the samples were

- No visible pattern
- Light colours
- Low elasticity
- Variety of structures
- Variety of thickness
- Variety of different material compositions

The following table (Table 5) represents all the samples in experiment.

Sample	**Composition**	**Type**	**Colour**	**Pattern**	**weight**
A	100%CO	Plain weave	white	-	300gsm
B	100%CO	Plan weave	navy	-	300gsm
C	CO/PES	Faille	white	-	Medium
D	synthetics	PU coating	white	-	180gsm
E	100%CO	twill	white	-	lightweight

F	CO/ synthetics	corduroy	blue	Structured stripes	medium
G	Animal leather	leather	pale	brushed	medium
H	synthetics	woven	brown/grey	stripes/jacquard	heavyweight
J	synthetics	woven	Light brown	jacquard	heavyweight

Table 5: List of samples and characteristics

Each of these materials was put in test – QR code was engraved on the surface of each of them under various settings – different picture size and picture resolution, various speed, laser intensity and repetition. Each sample was evaluated after the engraving to determine how did it perform under different laser machine settings. Important parameters were readability of the QR code without damage, mild deformation of the sample. The overall results of the experiment are showed below. Each sample marked as "readable" was easily recognized by reading device. Samples marked as "n/a" were not recognized by the reading device.

Sample	size	resolution	readability of QR code	repetition	damage	laser intensity
A	50 x 50 px	64dpi	n/a	1x	deformed QR code	150px
	100 x 100 px	64dpi	n/a	1x	deformed QR code	150px
	50 x 50 px	32dpi	readable at 4x	1x, 3x, 4x, 5x	-	150px
	100 x 100 px	32dpi	readable at 3x	2x, 3x	-	150px

Figure 4: Engraving of sample A (test 2)

From top to bottom:
Column 1: 32 dpi 50x50px, engraving 4x, 3x, 5x, 1x
Column 2: 32dpi 100x100 px, engraving 2x, 3x
Column 3: 64dpi 100x100 px and 64 dpi 50x50 px

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
B	50 x 50 px	32 dpi	readable at 10x	1x, 2x, 4x, 6x, 10x	-	150px
	50 x 50 px	32 dpi	n/a	2x	-	250px
	50 x 50 px	32 dpi	n/a	2x	-	450px
	100 x 100 px	32 dpi	readable at 9x	7x, 8x, 9x	-	150px

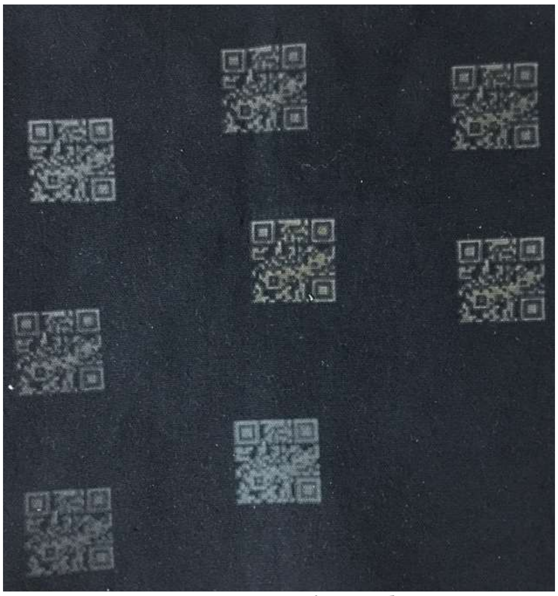


Figure 5: Engraving of sample B (test 2)

Engraving of size 50x50 px

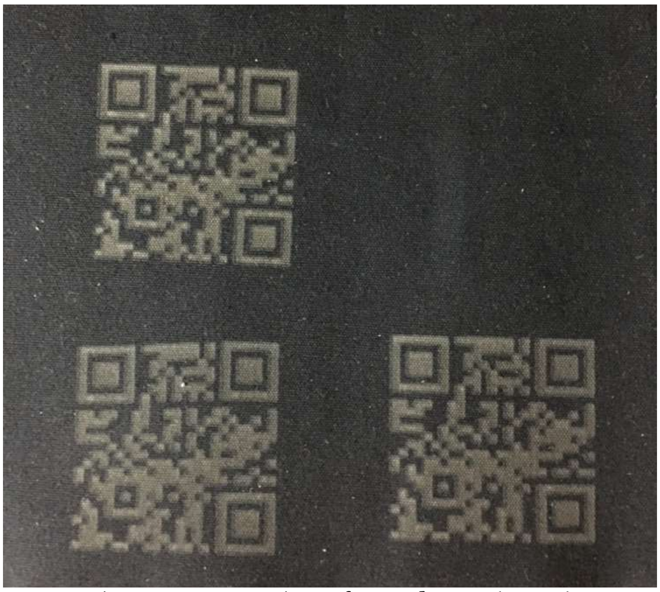


Figure 6: Engraving of sample B 2 (test 2)

Engraving of size 100x100 px

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
C	100 x 100 px	32 dpi	readable at 8x	1x, 2x, 4x, 6x, 8x, 9x	-	150px
	50 x 50 px	32 dpi	readable at 4x	1x, 2x, 4x,	-	150px

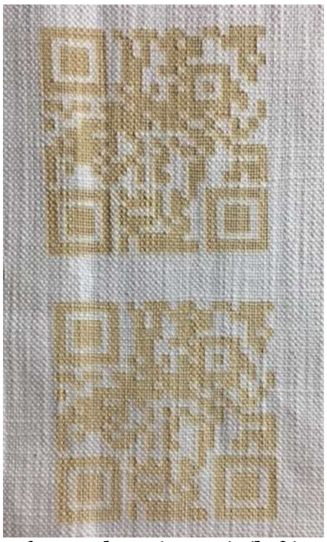



Figure 7: Engraving of sample C (test 2) (left)

Figure 8: Engraving of sample C 2 (test 2) (right)

Left - Top – 50x50 px, 32dpi, 2x, Bottom – 50x50px, 32 dpi, 4x

Right - Top to bottom: Engraving at size 100x100px, 32 dpi, laser intensity 150 px –4x, 2x.

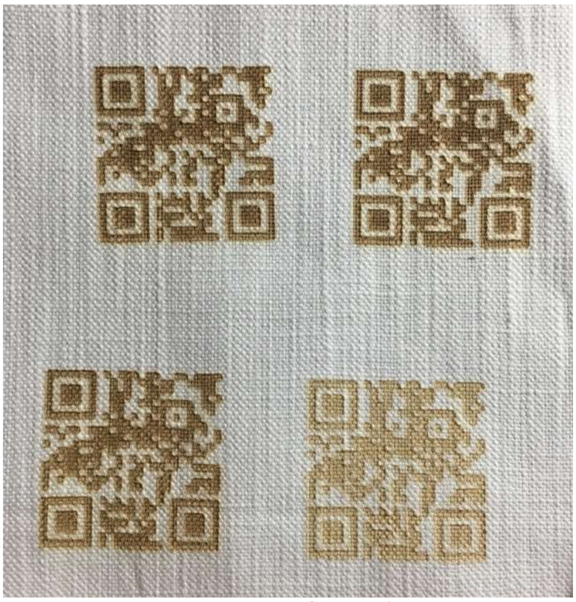


Figure 9: Engraving of sample C 3 (Test 2)

Left to right, top to bottom: Engraving at size 100x100px, 32 dpi, laser intensity 150 px – 8x, 9x, 6x, 1x.

Sample	**picture size**	**resolution**	**readability of QR code**	**repetition**	**damage**	**laser intensity**
D	**50 x 50 px**	32dpi	n/a	1x, 3x, 5x	material curves under heat and destroys because of PU layer on face.	150px
	100 x 100 px	32dpi	n/a	2x		200px
	100 x 100 px	32dpi	n/a	7x, 10x		150px

Figure 10: Engraving of sample D (test 2)

Top to bottom: Engraving at size 50x50px, 32 dpi, laser intensity 150 px – 3x, 1x, 5x.

Figure 11: Engraving of sample D 2 (test 2)

Top to bottom: Engraving at size 50x50px, 32 dpi, laser intensity 150 px – 7x,10x.

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
E	200 x 200 px	32 dpi	readable	2x	sample immediately destroyed after manipulation	150px
	200 x 200 px	32 dpi	n/a	1x		150px

Figure 12: Engraving of sample E (test 2)

Engraving at size 200x200 px, 32 dpi, laser intensity 150 px – 1x.

Figure 13: Engraving of sample E 2 (test 2)

Engraving at size 200x200 px, 32 dpi, laser intensity 150 px – 2x.

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
F	**100 x 100 px**	32 dpi	n/a	1x, 4x	low	150px

Figure 14: Engraving of sample F (test 2)

Top to bottom: Engraving at size 100x100px, 32 dpi, laser intensity 150 px – 1x.

Figure 15:Engraving of sample F 2 (test 2)

Top to bottom: Engraving at size 100x100px, 32 dpi, laser intensity 150 px – 4x.

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
G	50 x 50 px	32 dpi	Readable at 3x	1x, 2x, 3x,	-	150px
	100 x 100 px	32 dpi	readable at 2x	1x, 2x	-	150px

Figure 16: Engraving of sample G (test 2)

Left to right, Engraving at size 50x50px, 32 dpi, laser intensity 150 px – 3x, 2x, 1x.

Figure 17: Engraving of sample G 2 (test 2)

Left to right: Engraving at size 100x100px, 32 dpi, laser intensity 150 px – 2x, 1x.

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
H	50 x 50 px	32 dpi	n/a	1x, 4x	Burnt at 4x	150px
	100 x 100 px	32 dpi	n/a	1x	-	150px
	100 x 100 px	32 dpi	n/a	4x,	Burns and melting on surface	150px
	100 x 100 px	32 dpi	n/a	10x	Melting in deeper layers	150px

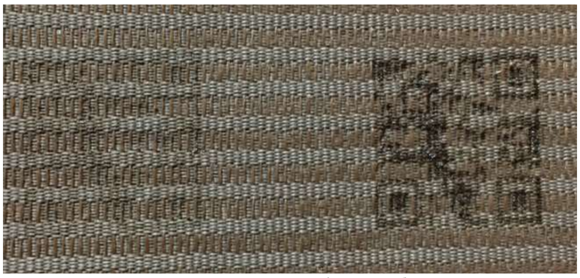


Figure 18:Engraving of sample H (test 2)

Left to right: Engraving at size 50x50px, 32 dpi, laser intensity 150 px – 1x, 4x

Figure 19:Engraving of sample H 2 (test 2)

Left to right, top to bottom: Engraving at size 100x100px, 32 dpi, laser intensity 150 px – 4x, 1x, 10x.

Sample	picture size	resolution	readability of QR code	repetition	damage	laser intensity
J	**50 x 50 px**	32 dpi	n/a	1x	-	150px
	50 x 50 px	32 dpi	n/a	4x, 8x	melting on surface due to structure.	150px
	100 x 100 px	32 dpi	readable at 4x	2x, 4x, 8x	Melting on surface and in deeper layers	150px

Figure 20:Engraving of sample J (test 2) (left)
Figure 21:Engraving of sample J 2 (test 2) (right)

Figure 20: Left to right, top to bottom: Engraving at size 50x50px, 32 dpi, laser intensity 150 px – 1x, 4x, 8x.

Figure 21: Top to bottom: Engraving at size 100x100px, 32 dpi, laser intensity 150 px – 2x.

Figure 22:Engraving of sample J 3 (test 2)

Left to right: Engraving at size 100x100px, 32 dpi, laser intensity 150 px –4x, 8x.

3.2.3. Conclusion of test 2

The results of experiment were interpretated based on readability of QR code and level of damage of sample. From the results of the experiment, it can be concluded that best performing were samples engraved multiple times (2 and more times) at lower intensity (150 px). Higher intensity of laser beam (250px) creates environment with higher temperature. It is therefore better to avoid reaching the melting point of fibre or point of significant heat damage. Lowest used laser intensity was 150 pixels. Higher intensity (200px, 250px) was applied as well but overall, most suitable was repeated engraving under lower intensity (150 pixels). The moist suitable format for engraving was found to be jpg format with size 50 x 50 pixels or 100 x 100 pixels and resolution 32 dpi.

The best performing materials (sample A, B, G) were of natural origin with smooth even surface and higher weight (up to 300 gsm). Synthetic materials are more prone to melt under the laser radiation and burn in deeper layers. Melting not only damages the surface but even small, melted areas cause light to reflect from the surface which makes it difficult if not impossible for a device to register and read the QR code. Samples H, I, J were more prone to this problem also due to the woven structure and lustrous sheen.

Structure of the woven textile with longer connecting threads which reflects more light offers even bigger area for burns. Synthetic materials are also more prone to deform and change shape under heat such as in case of sample D with PU coating which caused the sample to curve under radiation which not only affected readability but also quality and sharpness of engraving. Readability of QR code was also defected by various structures or patterns such as in case of samples F and I. Conclusion and recommendations for materials are presented below.

Material recommendations	
Composition	Natural fibre-based materials (>90%) ideally cotton.
Visible characteristics	Solid colours that can secure contrast between surface and engraving – from white to deeper tones. Without print or colour patterns
Structure	Smooth surface without perforation. Mate finish Thickness > 0,4mm Weight > 250 gsm Inelastic Woven

Engraved picture	
Size	50x50 px or 100x100 px Size of finished engraving can be 4cm and bigger depending on the end use.
Format	Jpg
Resolution	32dpi
Laser machine	
Intensity	150 px
Repetition	2-10 x

Table 6: Material and engraving recommendations based on Test 2

3.3. Test 3

Based on the knowledge from 1st and 2nd test and with consideration of the end application of this technology, test 3 was planned. Possible use of the technology of laser printed secured tags is application on clothing. In such cases, it matters where is the secured tag located – 1) shell fabric – QR code can be incorporated into the design of the garment. 2) Lining fabric – inside of the garment, such as back yoke. 3) Pocketing – QR code can be easily hidden in the pocket and accessed only when necessary. Depending on the character of the garment, different kind of 4) shell fabric can be used, including durable technical textiles.

It is important to consider influence of utility properties of the garment or accessory where technology might be applied. The silhouette of product and its utility properties can have great influence on the longevity of QR code secured. Therefore, it is necessary to test its performance at simulated use.

Materials typically used in automotive industry such as for car seat covers or seat belts, did not perform optimally in Test 1 or Test 2 due to melting synthetic fibres or lustrous sheen of satin weave which reflected the laser beam. However, all upholstery type materials, from natural fibres performed well in the tests. It can be suggested that the technology could be also applied on car seat covers from natural fibre-based material.

Chosen materials for Test 3 were denim samples with different thickness, weight, colours, and surface treatment. Laser engraving is commonly used in denim garment production to create desired looks instead of using chemicals or special washing treatments. These samples were subjected to QR code engraving with found optimal settings from Test 2. Different intensity and repetition of engraving was used to later determine which of the settings performs best not only to get a readable QR code, but also in washing and longevity test to find out how the laser engraving affects the original material. The plan for Test 3 is to examine which material characteristics and laser machine settings are most suitable for the technology after user load (washing test, friction test and tensile strength test). Following table (Table 7) is the list and description of materials for this experimental part.

Fabric Code	**Warp Yarn Count (Ne)**	**Weft Yarn Count (Ne)**	**Composition**	**Warp Sett (cm)**	**Weft Set (cm)**	**Weight (gsm)**	**Thickness (mm)**	**Density (g/cm3)**
X1	7,6/1 CO	6/1 CO	%100 CO	24	19	396	0,69	0,57
X2	9,4/1 CO	12/1 DualCore	%95 CO, %3,5 EME, %1,5 Elastane	32	17	295	0,62	0,47
X3	10/1 Co	13,1/1 Corespun	%97 CO %3 Elastane	34	20	326	0,56	0,58
X4	10/1 CO	13/1 Corespun	%98 CO, %2 Elastane	31	22	311	0,52	0,59

Table 7: Materials used for Test 3

3.3.1. Washing test

Test report

A) Washing report was done according to the International Standard ISO 6330:2012 Textiles – Domestic washing and drying procedures for textile testing.

B) Washing machine used for the test was Electrolux EWT 1011, top loading machine with horizontal axis. Leading denim garment producers (61) recommend washing denim cold on a gentle cycle, to maintain the colour and avoid shrinkage. (62) From table below (Table 8) showing washing possibilities for washing machine used in the experiment, the 6th programme was picked – 2,5kg load, temperature 30 C.

Program Washing type	Load	Possible options	Temperatures	Approximate consumptions		
			°C	liters	kWh	min
COTTON + prewash **COTTON** White or color, for example normally dirty work clothes, bed linen, table linen, underwear, towels.	5,0 kg	Delayed start Quick wash (excepted on E60°) Rinse plus Spinning	90 E 60 (*) 40	63 42 58	2,10 0,95 0,65	140-150 140-150 115-125
SYNTHETICS Synthetic fabrics, underwear, color fabrics, non-iron shirts, blouses.	2,5 kg		50	57	0,90	85-95
DELICATE For all delicate materials, for example curtains.	2,5 kg		40	52	0,60	65 - 75
HAND WASH Very delicate washing marked «wash by hand».	1,0 kg	Delayed start Spinning	30	53	0,30	45 - 55
WOOL Machine washable wool marked «pure wool, washable in machine, non shrinking».	1,0 kg		40	53	0,35	50 - 60
FLASH For only slightly dirty materials, except for wool.	2,5 kg		30	43	0,30	30 - 40
EASY IRONING	1,0 kg		40	65	0,40	85 - 95
Rinse Hand washed washing may be rinsed with this program.	Depending on the nature of textiles.	3 rinsings with liquid additive. Spin drying.		42	0,05	30 - 40

(Data provided for guidance and subject to change depending on usage conditions)

(*) Reference program for tests according to standard IEC 456 (E60° Cotton program).

Table 8: washing possibilities for Electrolux EWT 1011 [67]

C) Drying method for denim garments recommended by leading denim garment producers (61) is line drying (62). Which was used in the test.

D) Detergent picked for the test was based on the ISO 6330:2012 was a non-phosphate powder detergent with optical brightener and with enzymes. Table below shows detail composition of used detergent.

Composition
15-30 % anionic surfactants
Oxygen based bleaching agents
5-15% zeolites
<5 % nonionic surfactants
polycarboxylate
phosphonates
soap
optical brighteners
enzymes
parfums (benzyl salicylate, linalool, hexyl cinnamal)

Table 9: detergent composition

E) Total air-dry mass of the specimen was 0,22 kg, total air-dry mass of the ballast was 1,244 kg. Total air-dry mass of specimen and ballast 1,464 kg.

F) Deviation from the specified procedures according to ISO 6330:2012 – Washing machine used in the test was top loading with horizontal axis, instead of front loading.

G) Detail specification of the ballast used in the test is described in Table 10 below.

Item	**Ballast**
Yarn	100% cotton
Fabric construction	Plain weave
Fabric mass	1,244 kg
Piece size	220 x 140 cm

Table 10: Composition and specification of the ballast

Specimen used in the washing test are listed in the Table 11 below.

Specimen	**Textile sample ***	**Colour**	**Laser intensity**	**Engraving repetition**
S1 S2 S3 S4 S5	X1	Light blue	250px	1x 2x 3x 4x 5x
S6 S7 S8 S9 S10 S11 S12	X2	white	150px	2x 3x 4x 5x 6x 7x 8x
S13 S14 S15	X2	white	250px	3x 5x 8x
S16 S17	X2	grey	150px	1x 2x

S18 S19				3x 4x
S20 S21 S22 S23 S24 S25	X3	blue	150px	1x 2x 3x 4x 5x 6x
S26 S27 S28	X3	red	150px	2x 3x 4x
S29 S30 S31 S32	X4	orange	150px 250px	2x 1x 2x 3x
S33 S34 S35 S36 S37 S38 S39 S40 S41	X4	blue	250px 150px 200px	1x 2x 1x 2x 1x 2x 3x 4x 5x

Table 11: specimen from washing test

*From table 7

The principle of the washing test was to determine how textile washing influences the readability of the QR code. All the samples subjected to the test were washed in the same conditions, in one batch. Specimen were evenly distributed in the mass with the ballast in the washing machine drum and detergent was added into the drum and washing cycle was started. After the end of the washing, all specimen and ballast were immediately removed from the washing machine and line dried. Specimen were unfolded with the fabric length in the vertical direction to avoid distortion. Drying took place in conditions with still air.

After the specimen reached dried state, they were examined. Before the washing test all the QR codes of the secured tag were recognized and readable by reading device. Results of the washing test can be summarized by diving the specimen into three groups based on how the material sample and secured tag changed after the washing cycle – secured tag washed out and/or became unreadable, material damaged due to engraving and/or washing, secured tag kept readable on material. Results of the washing test are displayed in the Table 12 below.

Specimen	**Material**	**Result**	**Intensity, repetition**
S1	X1	Secured tag is readable, material unchanged.	250px, 1x
S2	X1	Secured tag is readable, material unchanged.	250px, 2x
S3	X1	Slight visible damage of material.	250px, 3x
S4	X1	Material damaged with small holes.	250px, 4x

S5	X1	Material damaged with holes in the whole surfaces of engraved QR code.	250px, 5x
S6	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	150px, 2x
S7	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	150px, 3x
S8	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	150px, 4x
S9	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	150px, 5x
S10	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	150px, 6x
S11	X2	QR code slightly washed out, lack of contrast, unreadable. Material quality maintained.	150px, 7x
S12	X2	Material slightly damaged.	150px, 8x
S13	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	250px, 3x
S14	X2	Material slightly damaged.	250px, 5x
S15	X2	Material damaged, QR code unrecognizable.	250px, 8x
S16	X2	QR code washed out, lack of contrast, unreadable. Material quality maintained.	150px, 1x
S17	X2	QR code readable, quality of material maintained.	150px, 2x
18	X2	QR code readable, slight material damage.	150px, 3x
S19	X2	Material damaged.	150px, 4x
S20	X3	QR code washed out, lack of contract, unreadable. Quality of material maintained.	150px, 1x
S21	X3	QR code readable, quality of material maintained.	150px, 2x
S22	X3	QR code readable, quality of material maintained.	150px, 3x
S23	X3	QR code readable, quality of material maintained.	150px, 4x
S24	X3	QR code readable, quality of material maintained.	150px, 5x
S25	X3	Material slightly damaged, but QR code readable.	150px, 6x
S26	X3	QR code readable, quality of material maintained.	150px, 2x
S27	X3	QR code readable, quality of material maintained.	150px, 3x
S28	X3	Material damaged, but QR code readable.	150px, 4x
S29	X4	Material damaged, QR code unrecognizable.	150px, 2x
S30	X4	QR code readable, quality of material maintained.	250px, 1x
S31	X4	Material damaged, QR Code unrecognizable.	250px, 2x
S32	X4	Material damaged, QR code unrecognizable.	250px, 3x
S33	X4	QR code readable, quality of material maintained.	250px, 1x
S34	X4	QR code readable, quality of material maintained.	250px, 2x
S35	X4	QR code readable, quality of material maintained.	150px, 1x
S36	X4	QR code readable, quality of material maintained.	150px, 2x
S37	X4	QR code readable, quality of material maintained.	200px, 1x
S38	X4	QR code readable, quality of material maintained.	200px, 2x
S39	X4	QR code readable, quality of material maintained.	200px, 3x
S40	X4	Material damaged, QR code unrecognizable.	200px, 4x
S41	X4	Material damaged, QR code unrecognizable.	200px, 5x

Table 12: results of the washing test

Light coloured materials or side of material did not perform sufficiently and did not keep readable secured tags after the washing test even if engraved repeatedly 2-3 times. (Figure 23). This was mainly due to lack of contrast between the surface and engraved QR code which is one of the main requirements for recognition by the reading device.

When evaluating the results from perspective of laser intensity or repetition of engraving – the higher the intensity the greater the damage of material as a side effect, same with repeated engraving at lower intensity. The specimen with secured tag engraved repeatedly, were prone to slight or severe damage and breakage of threads. Mostly, holes from damage formed in the areas of QR code where the laser beam hit bigger surface. In few cases the visible damage to naked eye did not affect the readability however in case with higher damage the sample was impossible to read (Figure 23 right).

Even if repeated engraving at higher intensity allows for better contrast between the surface and QR code allowing for better recognition and readability, such setting did not perform well in the washing test. Best performing was secured tags engraved at lower intensity with repetition of 2-5 times.

Figure 23: Washed out samples (X2 material) and damaged sample X1

Figure 24: Readable undamaged samples after washing test

3.3.2. Friction test

For the friction test KES-FB (Kawabata Evaluation System for Fabrics) was used. The system was made for measuring mechanical values of textile without destruction. It consists of four modules – KES FB1, 2, 3, 4. Each module measures different value [64]:

- Module FB1 measures shearing
- Module FB2 measures bending rigidity
- Module FB3 measures compressional properties
- Module FB4 measures friction properties

All modules relate to computer to evaluate results of the measurement. The entire system measures 16 characteristic mechanical values of textiles. Originally was the KES system made to measure hand feel, however nowadays it is used to measure mechanical properties. The downside of the system is exclusivity to materials with limited thickness. Despite this limit is the system considered very precise.

Size of the specimen is 20x20 cm for all 4 modules. Optical sensors watch correct positioning of the specimen and thanks to connection with computer are all data directly transferred and saved. [63]

For the experiment module 4 was used for the surface properties of friction (resistance/drag) and surface contour (roughness) test (KES-FB4). In the experiment samples are mounted horizontally on a plate. From one side sample is attached to a winding drum and from another side to tension mechanism. The drum rotates and shifts the textile sample. Device designed to mimic a finger – contactor is put on top of the sample to mimic finger movements and strokes usually performed by artisans and professionals judging the texture of fabrics. The movements in KES FB 4 are performed mechanically and therefor it is possible to measure objective numerical data. Targeted materials for this test are fabrics, cloth, paper, film or non-woven fabric. The measured data of surface friction and roughness are used to describe fullness, softness, smoothness, and crispness of the sample. [65]

Two sensors move on 30mm track and measure the track of central 20 mm. One of the sensors tracks surface friction coefficient and the other tracks geometrical unevenness. The results are interpreted by graphs. [66]

The system measures two main values

- MIU – coefficient of friction, from 0 to 1 – higher value of MIU corresponds to greater friction or resistance and drag.

- SMD – geometric roughness, micron – higher value of SMD corresponds to geometrically rougher surface. [63]

Sets of two samples were measured and compared – original materials (“a" samples) and materials with engraved QR code (“b" samples). Measured values MIU and SMD were compared to describe how the laser engraving affects surface roughness and friction. Sensors moved at a speed 1mm /sec.

Sample	**Textile sample ***	**Colour**	**Laser intensity**	**Engraving repetition**
1a	X2	Grey	Original sample	
1b	X2	Grey	250px	1x, 2x, 3x, 4x
2a	X2	White	Original sample	
2b	X2	White	250px	2x
3a	X2	White	Original sample	
3b	X2	White	250px	3x
4a	X2	white	Original sample	
4b	X2	white	250px	4x
5a	X1	Blue	Original sample	
5b	X1	Blue	250px	3x, 5x, 6x, 7x
6a	X1	Blue	Original sample	
6b	X1	Blue	250px	2x, 3x, 4x
7a	X3	Dark blue	Original sample	
7b	X3	dark blue	150px	2x, 3x, 4x, 5x
8a	X3	Red	Original sample	
8b	X3	Red	150px	2x, 3x, 4x
9a	X4	Blue	Original sample	
9b	X4	Blue	200px	2x, 3x, 4x, 5x
10a	X4	orange	Original sample	
10b	X4	orange	250px	1x, 2x

Table 13: list of samples used in friction test

Important values to describe the change from original sample and sample with engraving was SMD value which represents surface roughness. The higher the SMD value, the more is the surface uneven. The difference of SMD and MIU values between original and engraved samples was evaluated to determine how does to surface roughness (SMD) and friction (MIU) change after engraving. Table 14 describes changes of MIU and SMD values. From the results it can be said that the higher the repetition of engraving, the higher the surface unevenness. Samples 5b,6b,9b,10b were all engraved with intensity 200-250 px and the increase of surface roughness increased by 46 - 83%. 65- 83% increase of roughness was in case of samples with 4 times repeated engraving.

The change of friction (MIU value) between original and engraved sample was not as dramatic as changes in surface roughness. Difference of MIU value moved from 1,4-14%. 14% difference in friction was in the case of sample with 83% increase of roughness. The sample was from material X1 – which is material with 5% synthetic fibre composition. Other samples from different materials (with 0-3,5% synthetic fibre composition) engraved at same settings (250px and repeated engraving) did not show such increase in surface roughness. It results show that increase of synthetic fibres in the textile influences not only the possibilities for engraving but also the performance of the sample in test.

sample	MIU	MIU difference %	SMD	SMD difference %
1a	0,193	-4,15	5,52	17,19
1b	0,185		6,469	
2a	0,151	1,32	5,753	-17,12
2b	0,153		4,768	
3a	0,147	4,76	4,708	17,95
3b	0,154		5,553	
4a	0,153	-8,49	4,983	8,245
4b	0,14		5,394	
5a	0,152	-5,92	2,405	65,36
5b	0,143		3,977	
6a	0,235	-14,042	3,615	83,62
6b	0,202		6,638	
7a	0,134	2,99	2,598	46,96
7b	0,138		3,818	
8a	0,16	-3,13	4,324	15,77
8b	0,155		5,006	
9a	0,14	-1,43	3,355	46,14
9b	0,138		4,903	
10a	0,165	-1,82	5,169	31,26
10b	0,162		6,785	

Table 14: Results of KES -FB4 test

Figures 23-42 are graph results from the KES FB4 test. Two sets of graphs original sample and engraved samples are side by side to visually represent changes of MIU value (graph above) and SMD value (graph below).

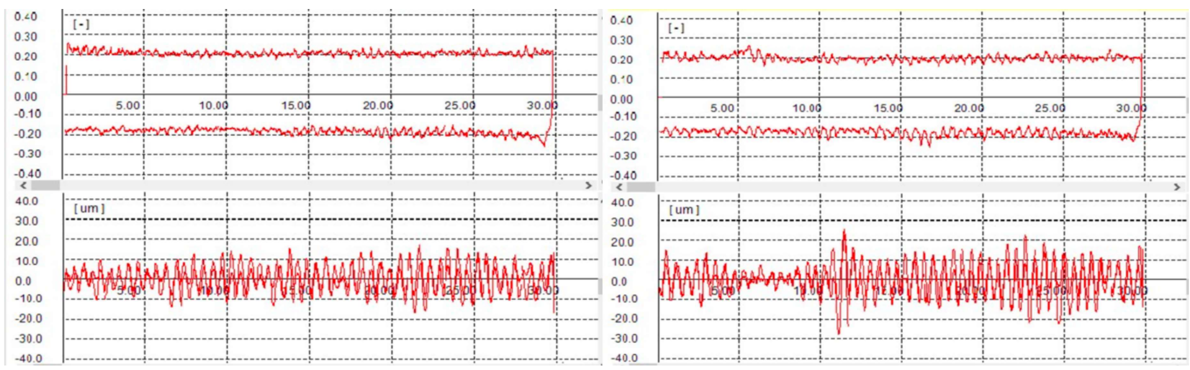
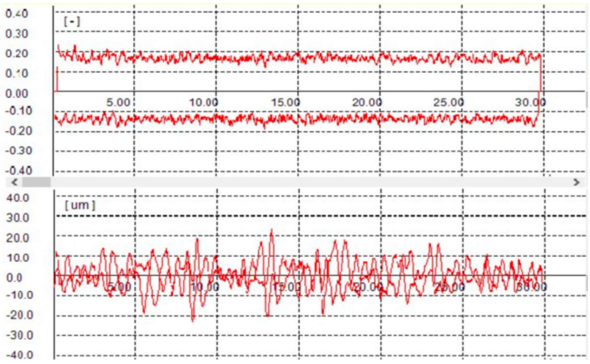


Figure 25: Sample 1a KES-FB4 test (left)

Figure 26:Sample 1b KES-FB4 test (right)



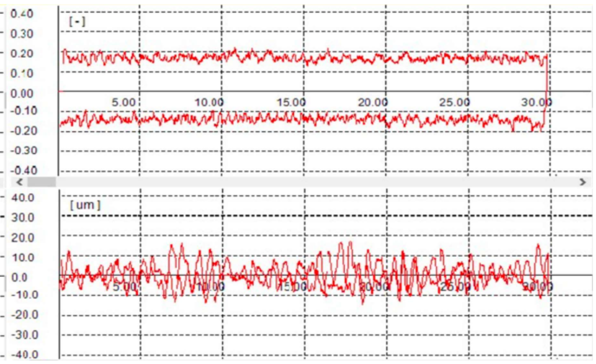
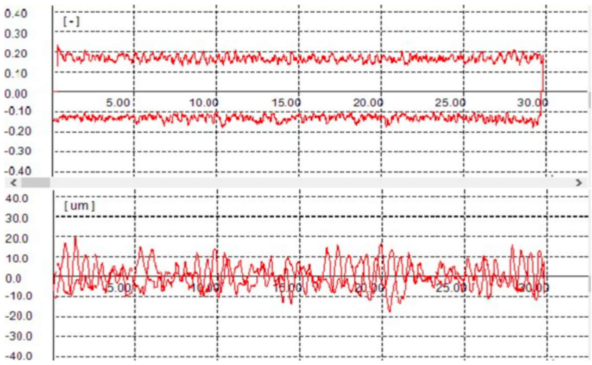


Figure 27: Sample 2a KES-FB4 test (left)

Figure 28: Sample 2b KES-FB4 test (right)



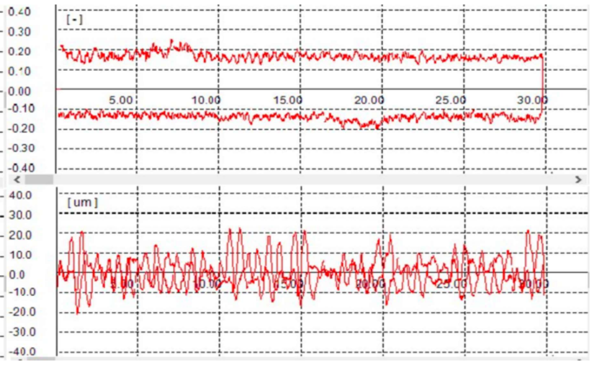
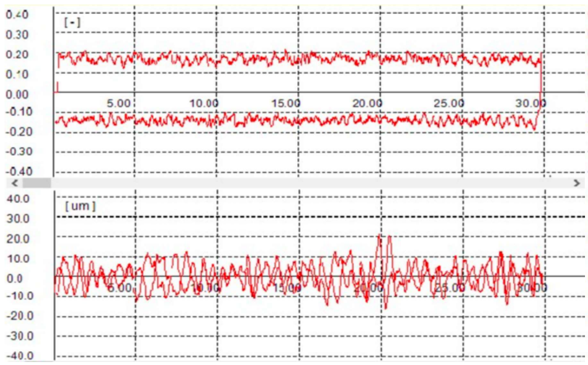


Figure 29: Sample 3a KES-FB4 test (left)

Figure 30: Sample 3b KES-FB4 test (right)



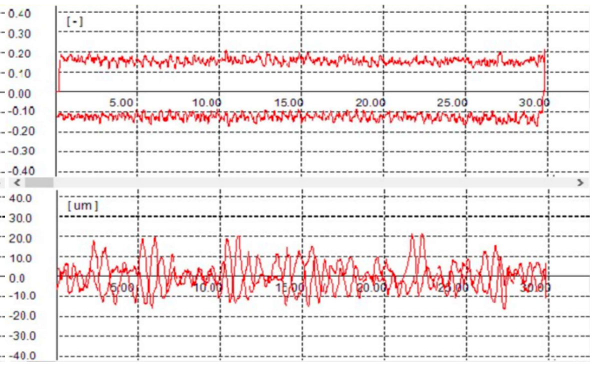
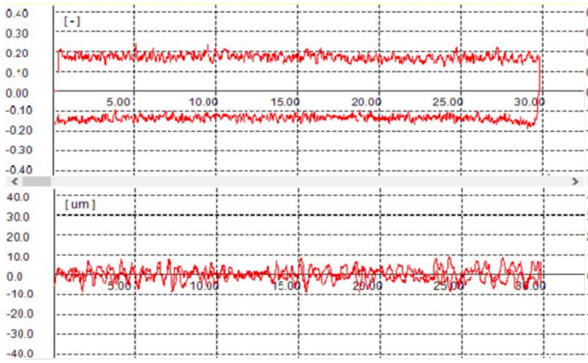


Figure 31: Sample 4a KES-FB4 test (left)

Figure 32: Sample 4b KES-FB4 test (right)



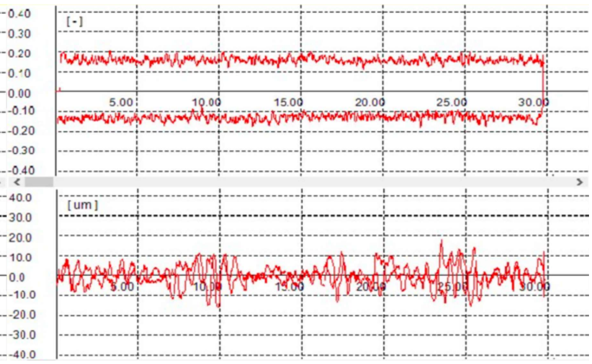
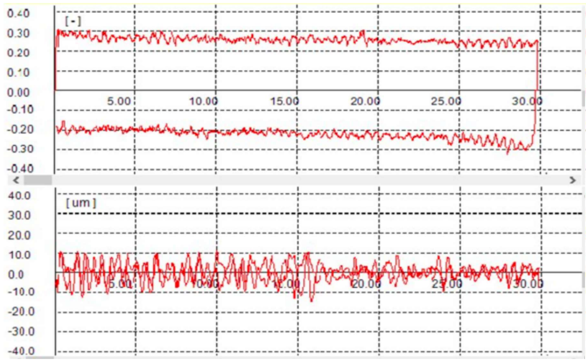


Figure 33: Sample 5a KES-FB4 test (left)

Figure 34: Sample 5b KES-FB4 test (right)



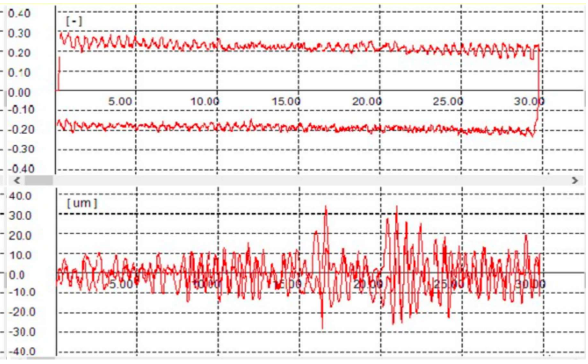
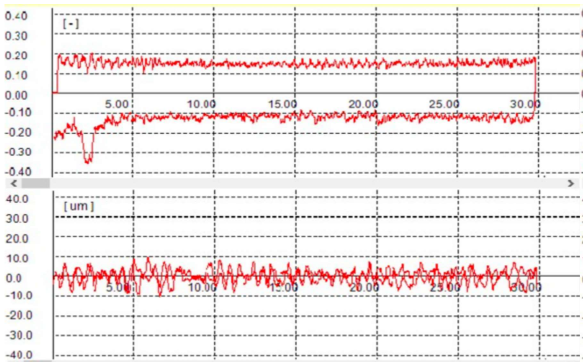


Figure 35: Sample 6a KES-FB4 test (left)

Figure 36: Sample 6b KES-FB4 test (right)



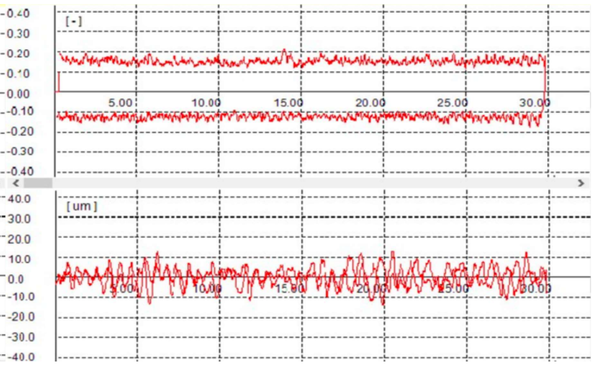
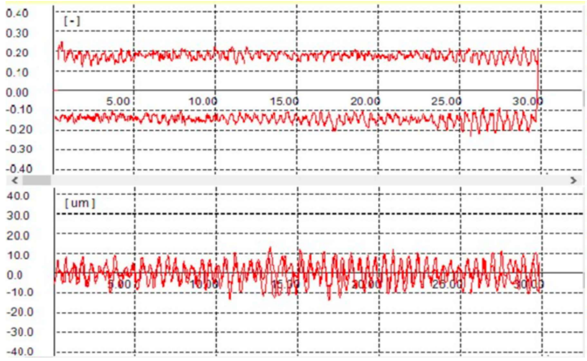


Figure 37: Sample 7a KES-FB4 test (left)

Figure 38: Sample 7b KES-FB4 test (right)



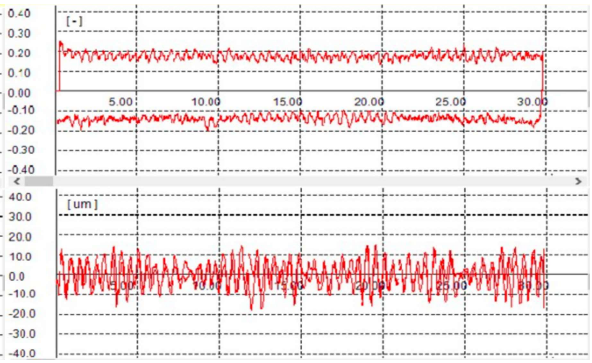
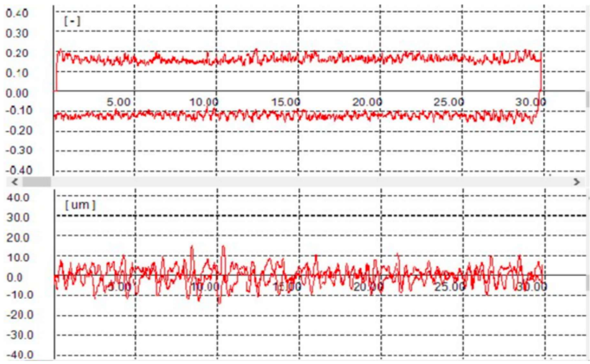


Figure 39: Sample 8a KES-FB4 test (left)

Figure 40: Sample 8b KES-FB4 test (right)



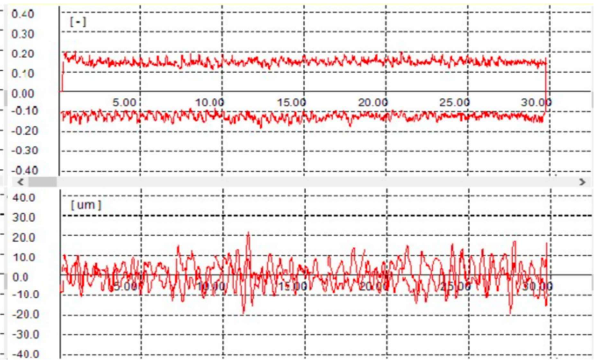
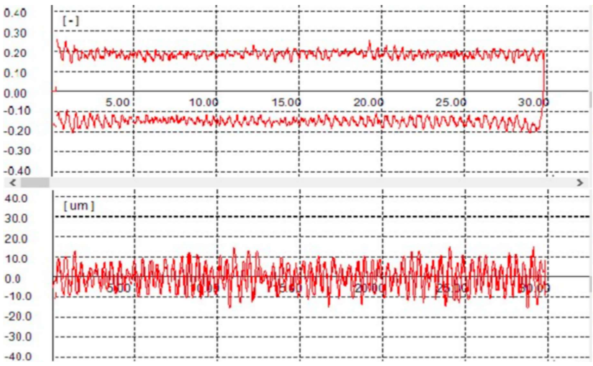


Figure 41: Sample 9a KES-FB4 test (left)

Figure 42: Sample 9b KES-FB4 test (right)



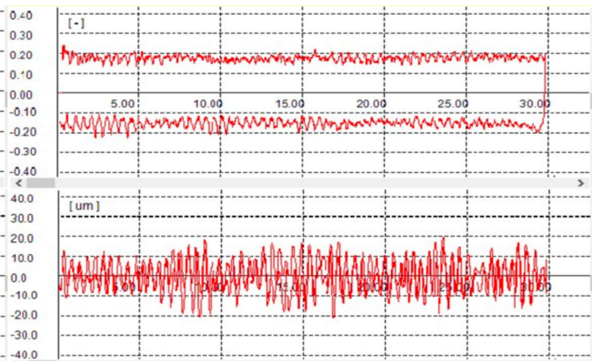


Figure 43: Sample 10a KES-FB4 test (left)

Figure 44: Sample 10b KES-FB4 test (right)

3.3.3. Tensile strength test

Test report

A) Tensile properties were measured according to the ISO 13934-1 standard: Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method. The test took place in the Laboratory of physiological comfort and special measurements at Department of Clothing Technology at Technical university of Liberec.

B) Size of the samples was 200 mm x 70 mm. 22 samples (Table 15) were subjected to the force and elongation test. Primarily all samples were cut and engraved (Figure 44) Each sample had warp threads removed from each side to achieve width of sample 60 mm. The removal of warp threads from side helped to achieve better results by preventing its breakage.

C) Strength testing machine used for the test was Testometric (Figure 43). The device is connected to computer with software WinTest Analysis. Software interpretates the measured results into graphs with stress-strain curve. The machine was set to zero preload, however the ribbed jaws used in the experiment naturally set some preload on the samples.

Figure 45: Testometric M350-5CT used for the tensile test

D) Speed of the test was 50 mm/min.

The principle of the test was to measure the maximum force of an original sample without engraving at breakpoint and compare it to maximum force at breakpoint of samples with engraved secured tag. The goal was to evaluate how great is the influence of engraving to the overall strength of the material. Each sample with and without engraving was tested under the same conditions.

Sample	**Textile sample**	**Laser intensity**	**Engraving repetition**
1	X2 (grey)	150px	2x
2			3x
3			original sample
4	X1 (light blue)	250px	1x
5			2x
6			original sample
7	X3 (red)	150px	2x
8	X3 (red)		3x
9	X3 (dark blue)		1x
10			2x
11			3x
12			4x
13			original sample
14	X4 (orange)	250px	1x
15	X4 (dark blue)	150px	1x
16		150px	2x
17		200px	1x
18		200px	2x
19		200px	3x
20		250px	1x
21		250px	2x
22			original sample

Table 15: samples used for tensile strength test

Figure 46: Engraving of the samples for force and elongation test

Graphs (Figures 45-48) and tables (Tables 16-19) below show measurements of tensile force applied on the samples and elongation of the samples. In the tables decline of maximum force applied to make the sample break is in the 4th column.

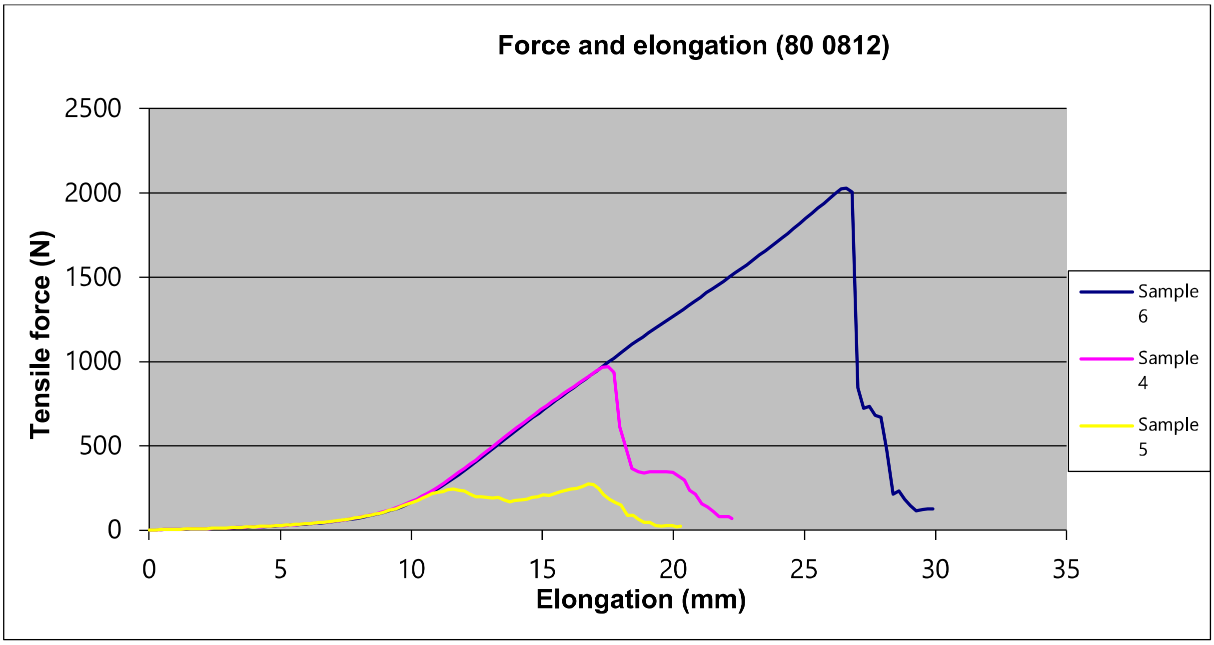


Figure 47: Force and elongation test material X1

Sample number	Maximum force(N)	Elongation at maximum force (mm)	Decline of tensile strength from original
Sample 6	2049,700	26,733	-
Sample 4	981,900	17,428	52,10%
Sample 5	277,430	16,828	86,46%
Min	277,430	16,828	-
Mean	1103,010	20,330	-
Max	2049,700	26,733	-
Centre deviation	892,321	5,554	-
Coefficient of variation	80,899	27,318	-

Table 16: Force and elongation test material X1

Material X1, is with high synthetic fibre compound (5%). The decrease of maximum force is 52-86%. Difference between each differently engraved sample is 34% so in the case of material X1 the result show influence of laser engraving settings and composition on the strength of the material.

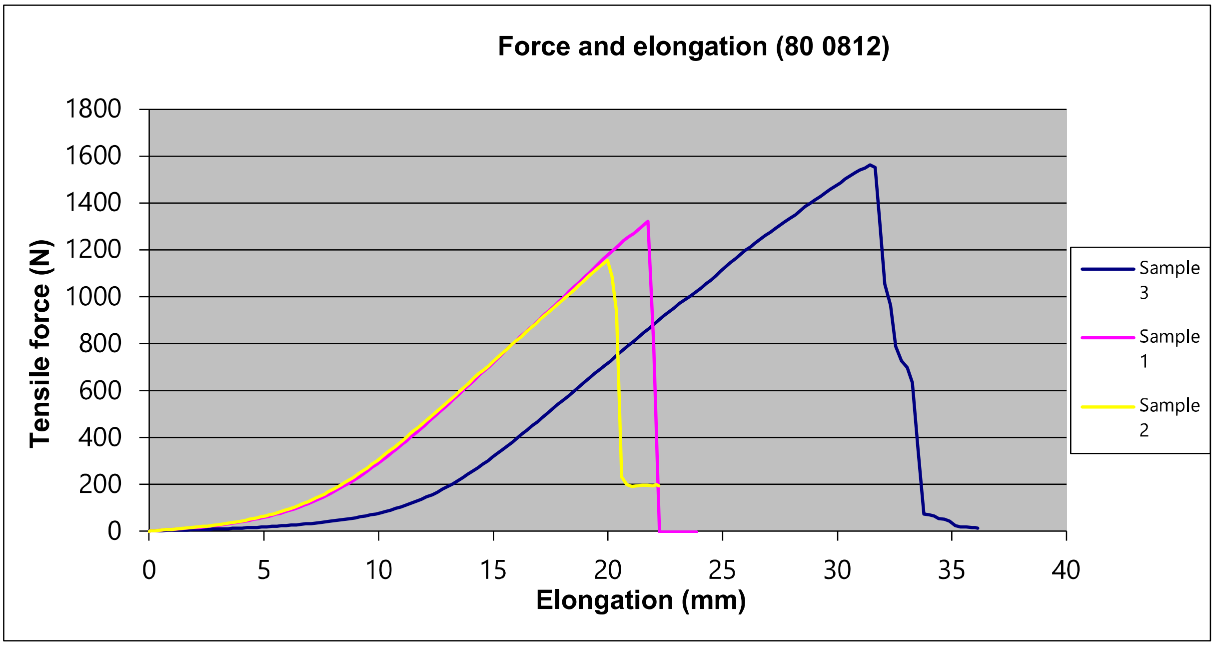


Figure 48: Force and elongation test material X2

Sample number	Maximum force(N)	Elongation at maximum force (mm)	Decline of tensile strength from original
Sample 3	1571,900	31,576	-
Sample 1	1333,300	21,934	15,18%
Sample 2	1157,600	20,040	26,36%
Min	1157,600	20,040	-
Mean	1354,267	24,517	-
Max	1571,900	31,576	-
Centre deviation	207,944	6,186	-
Coefficient of variation	15,355	25,234	-

Table 17: Force and elongation test material X2

In case of material X2, original sample was in direction of warp and samples with engraving were cut in direction of weft. This happened because of textile sample limitation. Measurements therefore do not represent decline of maximum force from original accurately. It can be however observed how the maximum force changes based on the engraved settings. In case of sample 1, engraving was repeated 2 times and in case of sample 2 engraving was repeated 3 times. Difference of maximum force between samples 1 and 2 is 13%.

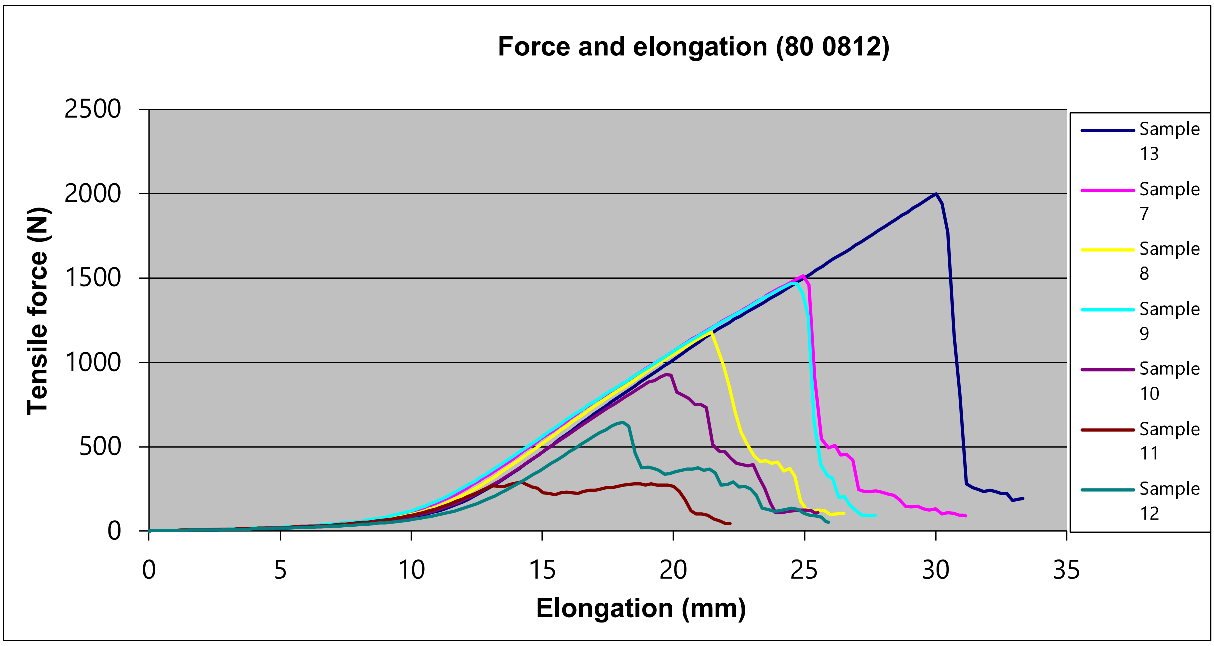


Figure 49: Force and elongation test material X3

Sample number	Maximum force(N)	Elongation at maximum force (mm)	Decline of tensile strength from original
Sample 13	2007,900	30,120	-
Sample 7	1522,500	25,061	24,17%
Sample 8	1186,200	21,453	40,92%
Sample 9	1472,700	24,707	26,65%
Sample 10	934,800	19,876	53,44%
Sample 11	292,420	14,205	85,44%
Sample 12	648,500	18,104	67,70%
Min	292,420	14,205	-
Mean	1152,146	21,932	-
Max	2007,900	30,120	-
Centre deviation	579,284	5,218	-
Coefficient of variation	50,279	23,790	-

Table 18: Force and elongation test material X3

In case of material X3, lowest decline of maximum force was at samples with only 1 repetitions of engraving (Samples 7,9). Samples with repetition 2-4 times (Samples 8, 10, 11, 12) had dramatic decline of maximum force with up to 85%. The results again suggest that low repetition of engraving at optimal intensity from 150-250 px does not influence the strength of the material as dramatically.

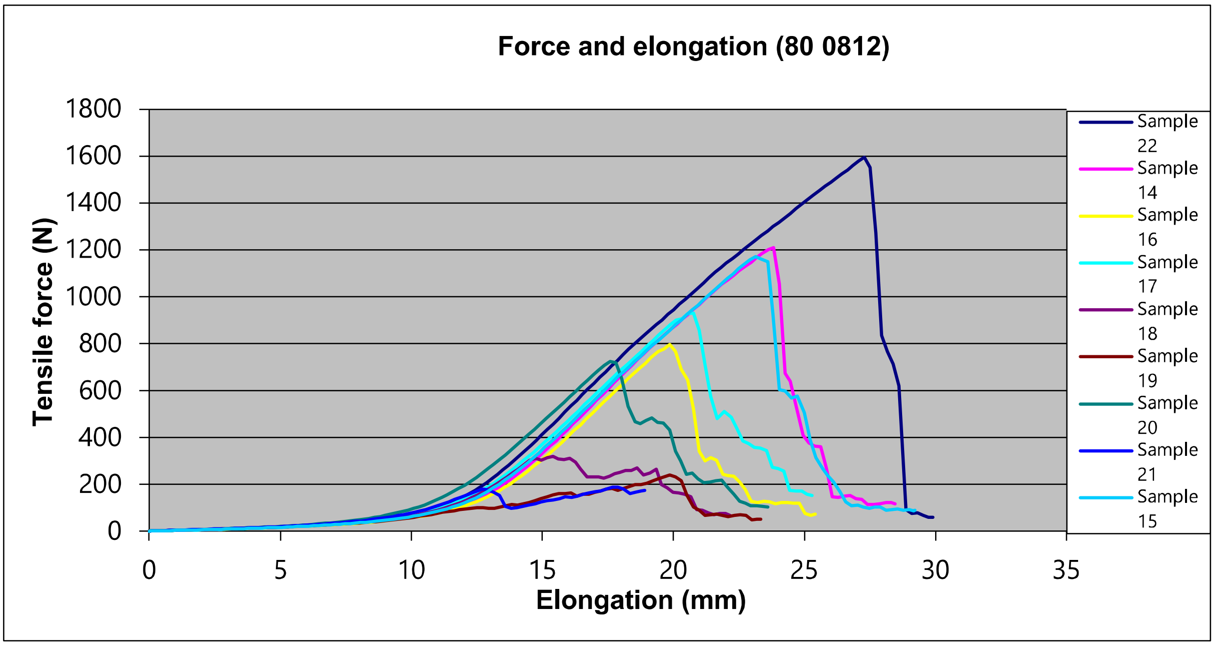


Figure 50: Force and elongation test material X4

Sample number	Maximum force(N)	Elongation at maximum force (mm)	Decline of tensile strength from original
Sample 22	1598,900	27,312	-
Sample 14	1216,200	23,832	23,94 %
Sample 15	1177,000	23,291	26,39 %
Sample 16	799,000	19,926	50,03 %
Sample 17	935,900	20,764	41,47 %
Sample 18	318,610	15,414	80,07 %
Sample 19	243,800	19,937	84,75 %
Sample 20	739,200	17,789	53,77 %
Sample 21	190,850	18,062	88,06 %
Min	190,850	15,414	-
Mean	802,162	20,703	-
Max	1598,900	27,312	-
Centre deviation	485,782	3,619	-
Coefficient of variation	60,559	17,483	-

Table 19: Force and elongation test material X4

In case of material X4, high loss of strength (80-88%) was in case of samples engraved at intensity 200-200 px with lower repetition – 2 to 3 times. These samples were on blue coloured side of the material. Samples engraved from orange side (Sample 14) of the material at intensity 200px lost its strength only by 23%. This suggest that the side of material either its face or back and composition of warp or weft threads can influence the results of strength test.

From the graphs it can be read that the higher the intensity of the engraving and higher the repetition the weaker the material becomes. By visual evaluation of samples after the test it can be seen, that engraved samples are prone to breakage mainly in the areas of strongest hit by the laser and around the outline of the engraving.

It has been also examined where are the samples most prone to breakage to evaluate where the weakest points of the sample are and how does the breakpoint area change compare to original sample without engraving. In case of samples with higher repetition of engraving (4 and 5x) the breaking area started in places with high density of laser engraving - where the engraved area is biggest. In case of samples with only one or two repetitions of engraving, those samples were prone to break in area around the outline of QR code. Figure below shows the weakest areas of QR code in red circle. These areas represent large continuously hit space with the laser beam.

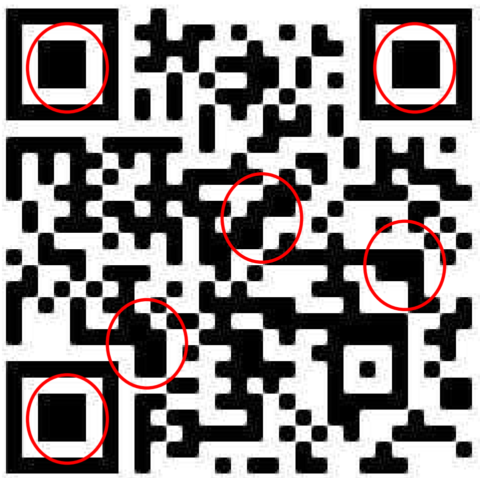


Figure 51: Representation of weakest areas of QR code.

Original samples of all materials without engraving, started to break closer to the jaws of machine. Figure 25 shows original samples from left to right material X1, X2, X3, X4. Parts of the samples that were clanged in the jaws of machine are visible as ribbed stripes. In case of samples from material X1 and X3, the break area is almost touching this space. In case of samples from material X2 and X4 the break area is also very close to the jaw area. Horizontal tearing is visible in all cases.

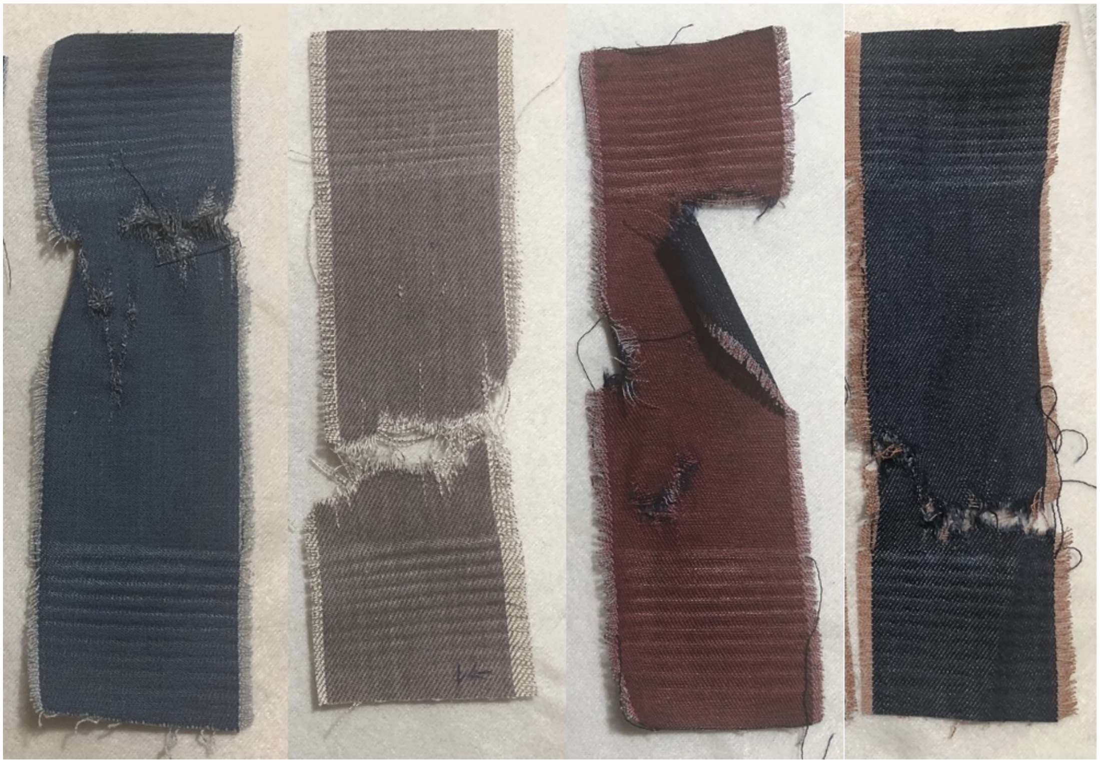


Figure 52: Original samples

Samples with engraving had the QR code located in the centre of the sample. All engraved samples started to break around the engraving either in the middle of the engraving or in the outline. Samples which were engraved only once or twice as opposed to repeated engraving three and more times were more prone to break in the area of outline of the QR code.

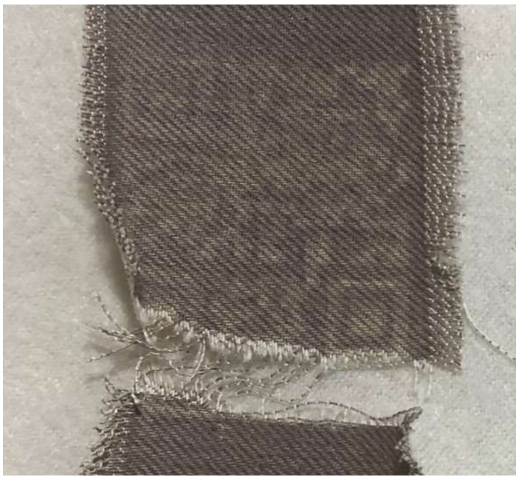


Figure 53: Horizontal break of sample 1

Samples with engraving started to break in patches in multiple areas at once. In case of orange sample, original sample started to break in areas closer to jaws of machine. samples with engraving started to break patchy and from centre towards the sides of the sample. In case of samples with engraving only 1-2 times, samples started to break horizontally as well (Figure 51). More damaged samples either by higher radiation or deformation of synthetic compound caused the sample to break in the middle of the sample in most engraved spots (Figure 52) shown on Figure 49.

Figure 54: Breaking of engraving in patches.

3.3.4. Conclusion of Test 3

Samples of chosen materials were engraved with optimal settings found in the test 2. After that each sample variation - material and engraving settings were put under washing test, friction test and tensile strength test.

Best performing were materials X3 and X4. The allowed for good contrast and gave option for using two sides of the material with different colours. Samples engraved on materials X1 and X2 at setting with only 150px intensity at low repetition had also slow decline of maximum tensile strength. Worst performing material was material X1, which had highest synthetic fibre compound – 5%. Due to this the inner structure of material damaged with engraving and was more prone to destruction by force or by washing. The samples of QR code engraved on material X1 also showed highest increase of material roughness in KES-FB4 test. Recommendations based on all three tests (1,2,3) are given in the Conclusion.

4. Conclusion

The goal of this thesis was to study and research the topic of traceability and transparency of the clothing and textile industry and which technologies are used to communicate and carry the information in the supply chain. Suggested alternative to commonly used technologies in this thesis was laser printed secured tags. The technology was researched and also put into the test.

The experiment shows that there is wide range of materials that can be found suitable for the technology of laser printed secured tags. The values and characteristics of these material groups were described in part one of the experiment – Test 1. Main values are natural fibre-based textiles, thicker to technical textiles, smooth surface, solid colours. The goal of the experiment was not to find all sufficient groups, but to identify the common values of suitable materials.

Upon finding and identifying the suitable materials, it was important to test the laser machine settings to recognize how does the laser intensity influence the secured tags. This part of experimental research is described in the Test 2 chapter. For all subjected materials it was possible to find optimal settings to get a readable QR code.

After identifying the materials and machine settings, the final experimental part Test 3 took place. This part of the experiment focused on examination of longevity of the QR codes by subjecting the samples to washing test, tensile strength test and friction test. Table below summarizes recommendations based on test 1, test 2 and test 3.

Material recommendations	
Composition	Natural fibre-based materials (>97,5%) ideally cotton.
Visible characteristics	Any solid colour
Structure	Smooth surface without perforation. Mate finish Thickness > 0,4mm Weight > 250 gsm Inelastic Woven
Engraved picture	
Size	50x50 px or 100x100 px Size of finished engraving can be 4cm and bigger depending on the end use.

Format	Jpg
Resolution	32dpi
Laser machine	
Intensity	150 px
Repetition	1-3 x
End use	
Clothing	Garments or parts of materials from natural fibre based woven textiles. Leather goods
Automotive	Removable car seat covers from cotton. Secured tag in form of QR code can be located on side of the seat where passenger does not touch or rub.
Technical textiles	Upholstery materials.

The research of the technology and its application into the industry can be further explored. There is space to deeply discuss how the technology could be implemented into the factory and supply chain. It can be discussed what could be the main purpose of laser printed secured tags – to communicate with customer, or to communicate the information in the supply chain etc. Figure 55 shows suggested placement of secured tags on garment. It is important to consider the characteristics of the garment or product where the tag will be used and how do they influence longevity of the code.

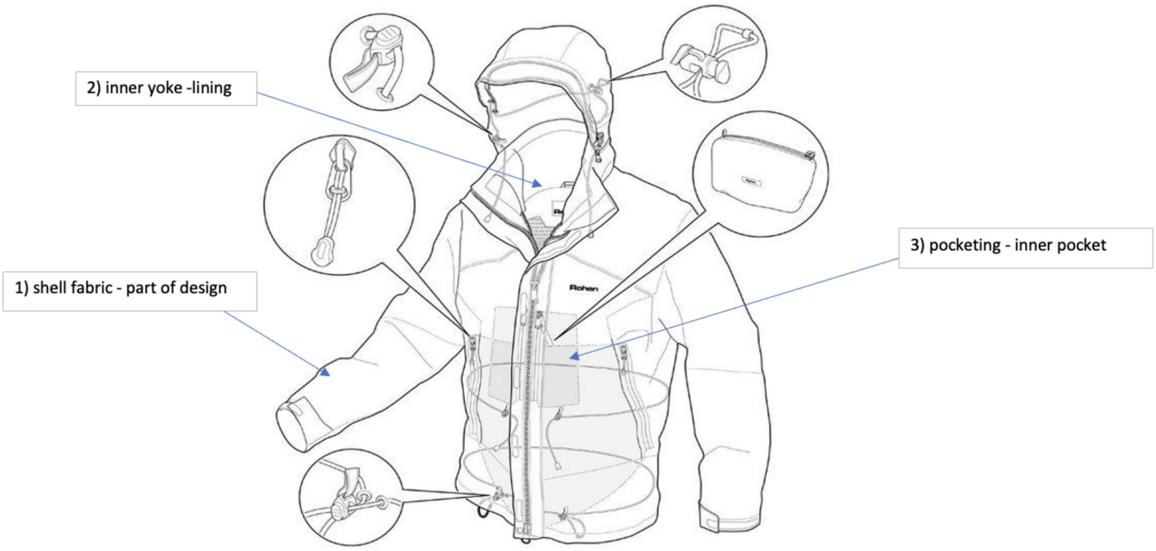


Figure 55: Suggested application of QR code secured printed tag

5. Resources

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