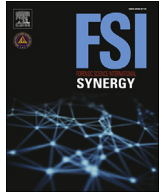




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## Interpol review of fibres and textiles 2016–2019

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## ABSTRACT

This review paper covers the forensic-relevant literature in fibres and textiles from 2016 to 2019 as a part of the 19th Interpol International Forensic Science Managers Symposium. The review papers are also available at the Interpol website at: <https://www.interpol.int/content/download/14458/file/Interpol%20Review%20Papers%202019.pdf>.

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## 1. Introduction

This review deals with relevant research and development topics in the field of forensic examination of fibres and textiles. It is a continuation to our previous review [1] from 2016 and covers publications between June 2016 and the end of December 2018. Publications from the year 2019 are not included in the present review.

## 2. General

17 years after the second edition, a third edition of the number one forensic fibre handbook 'Forensic Examination of Fibres' is available [2]. The handbook is edited by James Robertson, Claude Roux and Kenneth G. Wiggins† and contains contributions from several well-known authors. The new edition highlights quality assurance and expanded topics among which 'Fibres, Yarns and Fabric: An Introduction to Production, Structure and Properties', 'Textile Damage' and 'Raman Spectroscopy'. The documentation includes many coloured images providing valuable illustrations.

Another influencing book covering forensic materials science is provided by Max M. Houck with 'Materials Analysis in Forensic Science' [3].

The situation of fibre evidence in Germany and the UK was discussed at the 2017 European Textile and Hair Group (ETHG - ENFSI working group) meeting in Leiden [4]. The surplus value of fibre evidence, although undisputed among forensic scientists, is

not always recognized by police and legal representatives. Both countries had undertaken action in the form of surveys, working groups or presentations of fibre evidence to police and legal representatives in an attempt to understand and respond to the perceived situation. The importance of collaboration with universities for extended studies is highlighted. Other countries such as Belgium are supported by the presence of forensic advisors that work closely with the magistrates and are well aware of the strength and weaknesses of all forensic disciplines.

Bitzer et al. [5] give an insight into the introduction of these forensic advisors in Belgium and their role in the criminal justice system. Bitzer [6] further investigates the decision process to involve a forensic advisor in a study that focusses on homicide, robbery and burglary cases. It turns out that the number of traces or objects collected at the crime scene is one of the main variables leading to the involvement of a forensic advisor.

## 3. Case reports

Unfortunately no case report was published during the 2016–2019 period. The publication of case examples should be encouraged in order to inform forensic fibre practitioners about the possibilities (type of offence, scenario, kind of contacts, etc.) and limitations of fibre examination. In our own opinion we learned enormously from presentations about casework during forensic meetings and always use practical examples to train people (magistrate, police officer or crime scene operator) about the role of fibre evidence in criminal cases.

Some casework was reported during the ETHG meetings (ENFSI working group) in Leiden (2017) and in Zurich (2018), but this data is not accessible outside the working group. Presentations

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concerned fibre examination, mostly in murder cases, as well as textile damage analysis for which an increasing trend could be suspected.

## 4. Damage analysis

### 4.1. Textile damage

An entire book dedicated to forensic textile science [7] is now available since 2017. It provides an introduction to textiles and to their role in forensics. Different types of textile damages are also explained and illustrated in separate sections written by various well-known authors.

Sloan et al. [8] reported on the situation in Australia and New Zealand giving an historical and recent state of the art in the field of textile damage examination. In Australia, knives are the most frequently used weapon in crimes such as murder, attempted murder and robbery. The stabbing mechanism involves a complex interaction between the implement, layer(s) of fabric, skin and underlying tissues. The action and force used will also have a significant impact on the creation of the damage. A Textile Damage Working Group (TDWG, forensic laboratories around Australia and New Zealand) was convened after it was acknowledged that numerous improvements were required in the evidence type in terms of consistency and training. Early work saw the creation of a standardized glossary of terms and established a tiered structure for casework authorization. Another function of the TDWG is to ensure best practice, which is achieved through sharing outcomes from research conducted across the country. The Australian Federal Police (AFP) forensics laboratory is finalizing the implementation of a layered synthetic simulant (rubber/polyurethane), providing an ideal simulant for forensic stabbing experiments. The future of the evidence class in Australia will be strengthened by a current endeavour of the TDWG in establishing a standardized national examination framework. This will provide an opportunity to increase the consistency across different laboratories, and will allow an additional benefit of interagency interoperability to be realized.

A critical review on recent advances (1998–2018) in forensic textile damage analysis was published by Williams [9]. He noticed some excellent work conducted on improving various aspects of textile damage analysis. But he also pointed out the quality and the lack of consistency across the discipline as one of the major challenges. He suggested that a clear and robust interpretational procedure needs to be developed. A recent repository (Research4Justice) may allow for access to a viable data set to be used within an interpretational framework. Another challenge remains the distinction between crime related damages and those related to normal wear.

For improving textile damage analysis Schotman et al. [10] proposed a classification scheme used for casework in their laboratory. This scheme was refined after a validation study conducted on known damaged samples by six examiners. Indeed the validation highlighted that at least two (or more) examiners provided erroneous answers for 15% of the damaged samples. Errors were attributed to insufficient knowledge (for a specific type of damage), overinterpretation and ambiguity of terminology. The authors strongly encourage examiners – even experienced ones – to make use of collaborations and/or simulations.

Concerning stabbing Benson et al. [11] developed a horizontal stabbing machine with an interchangeable knife holder to simulate stab events. The machine provides reproducible stab performance independently from (a) human volunteer(s) in simulation experiments. Creating textile damage under standardized conditions will assist the current practices of textile damage analysis, and improve investigations in stab events when examining weapons of interest.

Another study [12] concerned the development of stab resistant protective clothing. Metal coated woven fabrics were tested under vertical stabbing loads. A model was elaborated to test various parameters of both the textile and the knife. In case of high velocity stabbing the model suggests that the influence of the blade geometrical property (blade thickness) is limited.

Concerning ballistic impact Carr et al. [13] investigated the influence of a bleeding layer on the appearance of the textile damage. The bleeding layer did not affect the perforation of the fabric specimen (hole size) but affected the appearance of the textile damage by a dispersion of the bullet wipe. McPhee et al. [14] studied the appearance of damages caused by different types of arrowheads in clothing. Depending on the textile properties the clothing first reduced to a certain extent the penetrative capacity of the arrows. All of the arrow types caused damage to the clothing. The greatest damage originated from a bladed broadhead while a blunt arrowhead caused the least damage and penetration.

### 4.2. Fibre damage

The degradation of natural and synthetic textiles was investigated during summer and winter seasons [15]. The pure cotton fabric was visually clearly degraded and the polyester fabric not (apart from some discolouration). The blended fabric (cotton – polyester) degradation was somewhere in-between in appearance. FT-IR measurements were conducted to support visual observations. Degradation patterns were noticed in the spectra of the pure cotton fabric but less distinct in those of the blended cotton fabric. The polyester part of the blended fabric might have inhibited the degradation of cotton. Polyester spectra did not show any sign of deterioration. A season's effect could be noticed on the rate of degradation, beginning at a later stage during winter.

Nizio et al. [16] designed an experiment for producing a natural training aid for cadaver-detection dogs. A set of cotton fabrics was buried together with six pig carcasses and a second set of control samples was buried separately. The carcasses were exhumed after 1, 3, 6, 12, 18 and 24 months. Up to 6 months the surrounding soil was wet (remains of soft tissue), then the carcass tends to progressively skeletonize (surrounding soil more and more dry). After one month burial the textile sample associated with the carcass was very discoloured. Then only the textiles located underneath the carcass were preserved but becoming smaller over months. After 24 months, the textile was almost completely disintegrated except the seams and small sections attached to the seams. The authors suggest that the moisture (presence of soft tissue) improved the preservation of the cotton samples. Indeed the control samples were found to degrade more rapidly and were already disintegrated (except seams) after 12 months.

## 5. Significance of evidence

Schwendener et al. [17] studied the presence of background fibres in body bags used in Australia. Indeed if the trace recovery is not performed at the scene, this could rise contamination issues during the manipulation and transportation of a body prior to the recovery. The authors examined fifteen body bags from four Australian jurisdictions or laboratories and detected impurities such as fibres and unidentified particles in each examined body bag, with an estimated average of 3603 coloured fibres and 1429 unidentified particles. In addition, in some cases pieces of fabric, hairs and parts of insects or feathers were also observed. Previous to the study a survey was conducted to examine the standard procedures of trace collection throughout Australia. It was found that in 22 out of 38 services trace recovery is sometimes, normally or always carried out at the morgue. Therefore, it is crucial for

forensic scientists to be aware that background fibres can be present in relatively high amounts in a body bag.

The importance of trace recovery at the scene is also pointed out by Schnegg & Massonnet [18] in their review on trace collection and will be discussed in the chapter 'Evidence collection'.

### 5.1. Transfer and persistence studies

A review covering transfer, persistence and detection parameters was written by Schnegg, Palmer & Massonnet [19]. The review is in French and overviews very well and completely the existing literature with respect to transfer, persistence and detection. The authors also discuss the interpretation level and more precisely the necessity of performing experiments to assess the parameters in a case scenario. They distinguish between simple actions (manual or with machines) and realistic case simulated actions. Although both provide important data, case simulated experiments can be crucial to correctly evaluate the transfer and persistence parameters in a Bayesian interpretation framework.

Schnegg et al. [20] provided a valuable contribution to the significance of evidence in a smothering case scenario. They performed simulated smothering experiments with a pillowcase as well as the legitimate scenario of sleeping on that pillowcase. The experiments were carried out with a total of 50 repeats for each scenario and by 5 individuals with two different pillowcases (both 100% cotton but with varying sheddability). The individuals were left a certain amount of freedom (as to the smothering technique, facial care and facial hair) to mimic realistic conditions. The results indicate that the amount of fibres transferred to the victims face is significantly higher in the smothering scenario compared to the sleeping scenario. However, the amount of transferred fibres is also highly impacted by the sheddability of the pillowcase. Therefore the sheddability of the donor fabric should always be assessed when interpreting results in a smothering case.

The strength of the fibre evidence in a case where a young victim was found underwater and where mostly single fibre traces were detected besides small amounts of fibre collectives indistinguishable from the parents clothes (mainly wool) was further assessed with experiments to evaluate the possible contamination with fibres from the river water [21]. Two homemade dummies were dressed in white cotton T-shirts and immersed during 15 days in the same river as where the victim was found. The experiments highlighted that fibre collectives could be brought by river water onto a victim, but this only concerned blue and grey-black cotton in low amounts (5 fibres or less).

The secondary transfer of fibres to seats and more specifically the effect of a time delay between the primary and the secondary transfer is investigated by Palmer et al. [22]. Two donor garments (composed of cotton and polyester fibres respectively) were used for the experiments. Transfer of the constituent fibres to a white acrylic top was simulated in a hug-scenario followed by a secondary transfer to a nylon tightly-woven seat. The experiment was repeated with different time laps between the primary and the secondary transfer, from 0 to 24 h. The results indicate that the number of fibres secondary transferred is inversely proportional to the time interval between the primary and secondary transfer. The authors also noted that the number of secondary transferred cotton fibres is higher (one order of magnitude) compared to the polyester fibres.

Slot et al. [23] consider the use of flock fibres as invisible tracers. Therefore, they studied the transfer and persistence of flock fibres during a car exchange, which is a frequently encountered scenario during criminal activities according to case reports by the Dutch police. The flock fibres are deposited by the use of a custom built spreading jar on a car seat (or model thereof), transferred to a

secondary surface (person or model thereof) and subsequently a tertiary surface (car seat or model thereof). Flock fibres were recovered in high numbers from the tertiary surface indicating that the proposed method can serve as invisible evidence. Additionally the authors report the effect of different parameters such as flock length and type of car upholstery on the transfer and persistence of the flock fibres.

## 6. Evidence collection/recovery

Schnegg & Massonnet [18] reviewed the collection of trace evidence at the crime scene. They rightfully stress the importance of collecting trace evidence at the very outset of a case. The authors review traditional fibre collection methods with especial focus on tape lifting techniques, such as 1:1 tape lifting. This crime scene technique offers great advantages over other techniques. Apart from its efficiency, it allows for preservation of the fibre distribution, which is important in relation to reasoning about the type of contact that took place during the commission of the crime. Especially, at the end of a criminal investigation, alternative scenarios are often proposed by the defence or two suspects may accuse one another. If proper evidence collection did not take place at the crime scene, the issues that arise in this final stage can never be examined.

Samlal-Soedhoe et al. [24] studied the simultaneous recovery of fibre traces and biological traces (saliva and skin cells) using a mini-tape lifting technique. These authors tested the fibre stability after a routine DNA isolation procedure. In most cases polyester fibres are not at all affected by DNA extraction. However, for cotton fibres, alterations are frequently noted, i.e. some components can be washed out. The fibre recovery of the mini-tape technique is somewhat lower (about 80%) than for the usual tape lifting, which could be compensated by extra taping after mini-taping. Also, after DNA isolation, fibres lost from the mini-tape can be retrieved on the filter of the DNA isolation vials.

Bucknell & Bassindale [25] examined the effect of the air displacement caused by surveillance drones on yarn fragments seeded on several common floor types. This study showed great disturbance and loss of yarn fragments on smooth surfaces (such as linoleum and vinyl tiles) at all tested drone flight heights (0.5–3.0 m) and all tested drone take off distances (0.5–2.0 m). Only rougher surfaces (carpet tiles and bath mats) can retain some of the yarn fragments. The authors draw prudent conclusions after these experiments with yarn fragments. However, in our opinion, using surveillance drones at a crime scene will inevitably have disastrous consequences for more volatile evidence such as individual fibre traces.

## 7. Instrumental methods

### 7.1. Automated fibre search

Wetzer & Lohninger [26] described a computer algorithm to separate fibre structures from the background noise using grayscale images. Furthermore, the different colour channels in RGB images are used to segment colour images that enable automated search. This preliminary work will be used to perform automated measurements using a confocal Raman spectrometer.

### 7.2. Microspectrophotometry (MSP)

Chemometric analysis on MSP spectral data has been applied by several authors.

Reichard et al. [27] examined the possibility of classifying 10 polyester fibre sets dyed with one and the same yellow disperse

dye of different dye loadings. Successful classification of the data sets occurred when 3 dye loading classes (low, medium and high) were considered.

Sauzier et al. [28] conducted research on 11 sets of acrylic fibres dyed with different combinations of basic dyes. The visible absorption spectra obtained with MSP were subjected to chemometric data analysis in order to provide a more objective comparison between known and questioned fibres. Correct exclusion was obtained 98% of the time, while correct inclusion occurred in 91% of all case scenarios.

Heider et al. [29] examined the possibility to distinguish between the fluorescence emission spectra caused by fluorescent whitening agents (FWAs) present in 7 different detergents. Fabric swatches of acid dyed nylon and basic dyed acrylic fibres were submitted to 5 washing cycles and the fluorescence spectra of individual fibres were recorded. Although the spectra were very similar, principal component analysis on the spectral data allowed to resolve 8 different detergent pairs for the nylon fibres and 5 different detergent pairs for the acrylic fibres. If a detergent pair was resolved, either correct classification or false negative exclusion of spectra took place. In none of the cases false positive inclusions were noted. No significant difference was found for testing the spectra of fibres coming from fabric swatches that were subjected to an extra washing cycle, hereby simulating the effect of 'extra washing after the crime'.

### 7.3. Raman and infrared spectroscopy

Best practises for fibre analyses by Raman spectroscopy were proposed by De Wael & Lepot in the third edition of the Encyclopaedia of Spectroscopy and Spectrometry [30]. Some practical examples are illustrated for dyed fibres as well as for undyed natural and man-made fibres.

The SERS technique used in combination with silver nanoparticles was investigated in order to (a) validate the use of the technique in forensic science [31] and (b) try to selectively quantify a binary mixture of two dyes with very similar chemical structure [32]. The technique was proven to be reliable for identifying molecules of forensic interest. A lack of repeatability and reproducibility were observed depending on the type of molecule to be analysed and more specifically to its interaction with the SERS substrate. The intensity of the spectra was always fluctuating and brought some degree of error in quantitation of dye mixture even when using calibration models.

The deterioration over time of polyurethane foam was studied in various conditions using Raman spectroscopy and other techniques [33]. Open air conditions often lead to obvious deterioration of the foam by a combined action of light and oxygen. In such severe conditions the discolouration of foam can easily be observed by optical microscopy or by colorimetry. Early stages of deterioration were only detected using vibrational spectroscopy by monitoring the relative intensity of specific bands. Raman spectroscopy was found more sensitive than infrared spectroscopy, especially for distinguishing storage conditions.

Peets et al. [34] proposed a rapid classification of textile blends using ATR-FT-IR and principal component analysis (PCA). Blended fabrics appear inhomogeneous regarding the sampling area of the micro-ATR accessory and 25 spectra per sample were collected at different parts of the textile in order to get a realistic semi-quantitative composition of the material.

A rapid characterization of bicomponent fibres was achieved by FT-IR spectroscopy using different modes and accessories [35]. The study was conducted on sheath (polyethylene) – core (polypropylene) fibres. The ATR accessory can lead to the pure signal of the polyethylene (sheath) while other modes provided a mixed

infrared signal. By comparing different FT-IR modes bicomponent fibres could be detected and their complex composition solved.

The relationship between cross-sectional shapes and FT-IR profiles in synthetic wig fibres was investigated [36]. These two characteristics were found dependent contrarily to colour which was found to be independent. The study showed that most of the 41 collected wigs were blended into a variety of cross-sectional shapes (highest discriminatory power). The chemical composition within a given wig was mostly modacrylic (which was sometimes blended with PVC), polyester and polypropylene fibres were also observed. The cross-sectioning is thus important to increase the discriminating abilities of the FT-IR analysis.

### 7.4. Chromatography

Burnip [37] conducted research using ultra performance liquid chromatography and spectral analysis (UPLC-DAD) for the characterization of dyes from man-made fibres exposed to weathering and laundering effects. Dye detection of short-length acrylics, polyester and nylon fibres was possible after subjection to a range of controlled humidity and temperature conditions. Fabrics that were exposed up to one year to outdoor conditions contained less dye due to photo degradation. All original dye components were present, although the dye proportions had changed over time. The effect of laundering on dye detection was investigated for up to 50 washing cycles using different detergents, some with bleaches others with stain removers.

Groves et al. [38] revisited high performance thin chromatography HPTLC. The authors report of a validation of this method, examining the effects of different parameters on the retardation factor of eluted dye bands of a reference dye mixture. Out of 4 different brands of TLC plates, the EMD Millipore plate showed the best separation and least band broadening. Activation of the plates was found to be unnecessary and a saturation time of 2 h was sufficient to obtain reproducible results. A developing distance of 3.75 cm was optimal for band separation. The stability of the standard eluent was found to be 5 days.

The same authors [39] published work on the development of a dye reference library set up for dye identification. A collection of 300 relevant textile dyes was analysed by several analytical methods, based mainly on HPTLC and Raman microspectroscopy. Additionally, infrared microspectroscopy and MSP (UV-Vis and Vis) may be used in case the dye causes fluorescence. The building of such a reference database of dye characteristics is a step forward in the identification of textile dyes.

Hu et al. [40] described a HPLC-MS/MS method applicable on disperse dyed polyester and acrylic fibres of short length, after dye extraction with acrylonitrile. Extraction for other dye-fibre systems was not explored yet.

The application of a HPLC-DAD-MS method for dye analysis in case work was presented by Schotman et al. [41] The method was found to be robust and of high discrimination and is used in routine case work at the Dutch forensic institute.

Kato et al. [42] analysed fifty black polyester glove textiles by liquid chromatography/linear ion-trap tandem mass spectrometry (LC/LIT-MS<sup>n</sup>) and microspectrophotometry (MSP). The discrimination of the 1195 pairs was higher for the combination of LC/LIT-MS<sup>n</sup> and MPS (99.2%) compared to MSP alone (95.9%). Five kinds of disperse dyes were used on average to dye the black textiles.

### 7.5. Emerging techniques

Sultana et al. [43] reports of a method in which an automated microfluidics extraction device (MFD) is coupled to a quadrupole time-of-flight (Q-TOF) mass spectrometer for the analysis of acid

dyes extracted from their polyamide fibre substrates. The dyed nylon fibres are extracted with the in-house made MFD using pyridine/water (4:3 v/v) as extraction solvent. Then, the extract is introduced to the mass spectrometer with electrospray ionisation (ESI). MFD-MS is used for analysis of the elemental composition and isotopic distribution. MFD-MS/MS is used for successful structural elucidation of the dye compounds present in individual fibres of limited length. The total time for extraction and dye identification is kept under 12 min.

Cardoso Santos et al. [44] performed a study into the elemental composition of printed woven fabrics using laser-induced breakdown spectroscopy (LIBS) and chemometrics. Although it is not evident to apply this method in forensic case work, it shows great potential. A mapping of the elemental composition of the print on the fabric surface was obtained by using the first laser pulse and detecting the atomic and ionic emission lines. The elemental composition of the deeper layers, i.e. the fabric substrate, is obtained by consecutive laser pulses. The method has advantages over inductively coupled plasma optical emission spectroscopy (ICPOES) and the results were confirmed with wavelength dependent x-ray fluorescence spectroscopy (WD XRF).

### 7.6. Identification of fibres

Identification of vegetable fibres can sometimes cause difficulties. Summerscales [45] reviewed all forensic identification methods for commonly used bast fibres (flax, hemp, jute) and methods to differentiate them from leaf fibres (abaca and sisal). These authors describe a range of microscopy methods, such as bright field microscopy (morphology, cross sectional shape after microtomy), polarization microscopy (modified Herzog test, crystal test) and electron microscopy (external morphology). Spectroscopic techniques, such as infrared and Raman spectroscopy can also be used. Furthermore, some chemical, mechanical and thermal tests are described. Finally, DNA analysis allows for a clear differentiation between all vegetable fibres originating from different plant species.

## 8. Quality aspects

Validation or improvement of recovery or instrumental methods and in the field of damage analysis are mentioned in their respective chapters.

Förster et al. [46] conducted a photofading study on cotton dyed with three direct dyes, at different dye depths. Photofading occurred already after only a few minutes exposure to UV and visible light in each experiment, but this bleaching effect was more pronounced for the lighter shades.

During the ETHG (ENFSI working group) meeting in Zurich (2018) most participants said to be favourable of harmonising practises within Europe. This could be achieved through the update of the Best Practice Manuals (BPM), training of practitioners, the use of standards for working and reporting and a common interpretative framework.

Updating of the BPM is ongoing in most of the ENFSI working groups since 2019.

Thanks to European funding the Twinning Project (Serbia “Fight Against Organized Crime) connected an emerging fibre lab to an experienced lab giving support and training. The emerging lab developed a full working infrastructure from quite nothing and is now ready to apply for accreditation.

Another training programme is the Work Package G5 ‘Development of a Training and Education Concept for Forensic Hair and Fibre Experts’ which is part of the STEFA project (EU Direct Grant to ENFSI 2016) that will propose online learning for fibre and hair

practitioners. A survey was sent to ETHG working group members questioning the training occurrence and possibilities in their institutes. The working group members are generally allowed for max. 5 days of external training per year, and more in the case of internal training. All kind of practises proposed for training were said to be interesting, with a preference for fibre interpretation and fibre identification. All topics were said to be important for harmonization within Europe. The e-learning platform will first focus on trace recovery, reference material and microscopy. Other topics such as MSP and Infrared spectroscopy, will be developed in a second phase.

## 9. Textile industry/new fibres

New developments in the textile industry follow the trends exposed in our previous review [1]. General information and internet links on textile production and new products can also be found in that review.

The final chapter in the third edition of the handbook ‘Forensic Examination of Fibres’ [2], entitled ‘Future Trends for Forensic Fibre Examination’ also covers new fibre developments. Among other things ‘smarts textiles’, ‘nanomaterials’, ‘green materials’, ‘composite and bicomponent fibres’ and ‘recycled material’ are discussed.

Although not new, the trend versus eco-friendly fibres is expected to gain popularity as general awareness around ecology is increasing. Examples of eco-friendly fibres are:

- bamboo: cellulosic fibre or regenerated bamboo fibre (bamboo viscose)
- soy: regenerated fibre from protein source
- tencel (lyocell): regenerated fibre from a cellulose source
- flax and hemp (common)

It is not uncommon to come across recycled fabrics in forensic labs. As they are composed of a blend of many different fibre types they represent a challenge for the fibre examiner to identify and search its constituent fibre types. The 2017 ETHG collaborative exercise involved the characterization of a recycled fabric. The aim of this part of the exercise was to get an insight into the different lab’s strategy on dealing with these difficult known materials.

A recent review on textile production and waste pointed out new challenges for textile industry [47]. The author stated that the linear economy model (take-make-waste) underlying the textile and clothing sector is nearing its end. Global production of cotton and polyester, the two key fibres for the textile industry, is predicted to grow by 40% in the next 5 years. The importance of the transition towards a circular economy has been noticed in the European Union (EU). A major momentum of this transition was the creation of the Circular Economy Package and its adoption by the European Commission on December 2, 2015. The Circle Economy estimates that an 84% increase in the demand for textile fibres in the next 20 years will stretch resources to their breaking point. Today, many consumers tend to purchase more than they really need and treat the lowest-priced garments as nearly disposable. Some estimates indicate that such garments are likely to be discarded after just seven or eight wears. Wearing clothes longer, effective recycling of textile waste and reusing it as raw materials could largely reduce the demand for the end products and fibres. At the moment only 20% of clothing waste is collected globally for reuse or recycling. The remaining 80% is landfilled or incinerated, which results in a great loss of energy and raw materials.

The 2018 CIRFS (European Man-made Fibres Association) report [48] stated the following trends: ‘the report shows continued and solid growth of the world’s man-made fibres industry while cotton

and wool shares stagnate. It confirms the strength of global production of man-made fibres, and their dominant share in world demand for fibres. Man-made fibres represented 75% of all textile fibres produced worldwide, this percentage going up to 81% in Europe'. The latest U.S. Department of Agriculture (USDA) estimates for 2018/19 [49] indicate: 'world cotton production is projected at 1% below the previous season. Although lower harvested area is expected in 2018/19, a record global yield is projected to keep the 2018/19 global cotton crop at the fifth highest on record. For 2018/19, cotton consumption is forecast to expand 3.8%, following a 6-percent growth rate in 2017/18. Consumer demand for cotton products is expected to remain strong in a number of countries, including the United States, supporting higher global consumption'.

## 10. Knots and ropes analysis

Chisnall [50] performed a knot survey on Figure Eight knots. This knot used to be wrongfully considered achiral. The chirality of this knot is explained and is compared with everyday knots such as overhand knots, half hitches and half knots. The majority of volunteers tied Figure Eight knots and Overhand knots of the same chirality. This correlation is less obvious for the chirality of Figure Eight knots and that of Half hitches or Half knots.

Chisnall also published on general insights of tying behaviour and knot sophistication [51].

## 11. Evidence interpretation

The debate on the interpretation of evidence is fed by a contribution by Arscott et al. [52] on the perception of verbal expressions of the strength of evidence. Previous empirical studies had reported some issues with regard to the use of verbal expressions. Arscott et al. choose a participant group of 230 individuals (lay people, legal professionals and people with some forensic or investigative knowledge) who were presented with a case summary and a verbal expression of the strength of evidence which was randomly varied. The participants were invited to indicate their perception of the strength of evidence on a scale from 0 to 19. The results indicate that the perceived strength of evidence generally followed the intended strength of evidence with some notable exceptions. These exceptions were mostly related to differentiating between the 'strong', 'very strong' and 'extremely strong'. The three groups performed in similar manners. The authors suggest that we may not be able to assume that decision-makers will be able to discern between these expressions.

This claim is disputed by Berger & Stoel [53] in their letter to the editor. They argue that the study wrongly assumes that all participants understood the concept of evidential strength, as in practice it is still common to encounter examples of misinterpretation and misapplication even by forensic scientists themselves. The authors suggest that the inherent problem is not the perception of the verbal expressions themselves but rather the level of education and understanding of evidence evaluation and basic decision theory of the people formulating and interpreting the verbal expressions.

The issue of training forensic staff is also addressed by Biedermann et al. [54] in their paper. They discuss the implementation of the ENFSI standard for reporting evaluative forensic evidence (so called M1 document) and strain the importance to act now to address the topics in forensic interpretation. Indeed, ENFSI has funded a series of projects that come under the general theme 'Strengthening the Evaluation of Forensic Results across Europe' (EU Direct Grant to ENFSI 2010 MP STEOFRAE) and that answer to an urgent need for the development of standards and guidelines for the evaluation and reporting. However, budgetary restraint at the forensic services, and different opinions across the forensic science

community cloudy and retard the strong united commitments. The paper overviews the core principles of the M1 document and explains why the initial standard was 'reduced' to a guideline. The resistance towards the standard was found to be more related to the receiving community not being adequately trained to understand the formulations rather than to the proposed framework for interpretation itself.

The topic of interpretation also takes in a more prominent place at the latest European Textile and Hair Group ETHG meetings. At the 2017 ETHG meeting in Leiden (The Netherlands) a workshop on Interpretation was organized [55]. The ETHG is extremely heterogeneous with respect to the level and experience of their members with the proposed framework for interpretation by the ENFSI guidelines. Therefore three sessions were organized simultaneously: Basic principles of Bayes, Formulation of hypotheses and Calculation of the LR with SailR. SailR is a software developed by a working group to calculate the LR at source level. At the 2018 ETHG meeting, Friedmann gave an update about reporting and testimony in USA [56]. In response to the PCAST report on forensic science in criminal courts (September 2016) new standards were developed and scientists are allowed to say that characteristics are consistent but they are not allowed to identify a source. In the future they will be allowed to use validated databases to assess the rarity of a trace.

Powell et al. [57] developed a spectral database for fibre evidence and use this database for evaluative comparison cases as well as investigative modus. The database was initially developed in response to a growing need for performing fibre comparisons in Western Australian 'major/serious crime' investigations. The database contains over 20,000 normalised and first derivative spectra of casework and was validated intra-laboratory as well as inter-laboratory. The database can be used to assess the rarity of a fibre type but a strategy was also established for large fibres cases where no comparison garment is available (investigative case). The database strength is that it allows for cross-comparisons between all fibres in order to identify distinct fibre groups in an investigative case.

The database was presented to representatives of the Australian and New Zealand laboratories at the Chemical Criminalistics SAG Fibres Database Workshop organized by ChemCentre in Perth, Australia (September 2018). The goal of the workshop, beside increasing inter-laboratory collaboration and knowledge-sharing, was the future sharing of data between labs to increase the size of the database. A discussion on the evaluation of fibre evidence was intended and common practises with respect to the interpretation of fibre evidence in Belgium and New Zealand were presented. The database was very well received and the workshop ended with a discussion on the way forward to promote the use of the database.

## 12. The future

More than ten years after unsuccessful tests of the Maxcan Fiber Finder new efforts are now deployed to provide automatic search of fibres on tapes. A recent publication is provided in the section 'Instrumental methods'. A new project financed by the European Commission (H2020-SEC-2016-2017, Grant nr786913) has recently started: SHUTTLE, acronym for 'Scientific High-throughput and Unified Toolkit for Trace analysis by forensic Laboratories in Europe'. The SHUTTLE toolkit will consist of an automated microscope that will acquire high quality images of recovered microtraces on tapes. The acquired images will be processed automatically (classification algorithm) and an overview of available microtraces will be reported. The data will be stored in a computer database, thereby facilitating future data analysis, such as sourcing of microtraces and forensic comparisons. The project will

focus on blood, skin cells, gunshot residues, hairs, fibres, and saliva.

The development of fibre databases is also very crucial for both automatization and interpretation purposes. The actual (old fashioned) way to build databases is to collect reference pictures and spectral data from known fibre samples (each sample being a record of this database). Nowadays, data processing (artificial intelligence, machine learning ...) are very efficient in providing automated search on CCTV images for instance. Such data treatments could also be valuable for processing microscopic images in a forensic context. This will involve the development of accurately documented image databases. Databases also remain important to evaluate the rarity of fibre evidence and to be able to report balanced conclusions in an objective way (as largely discussed in the chapter 'Evidence interpretation').

Chemometrics are more and more often used in the forensic community (a) for discriminating data and (b) for providing an objective comparison of data. These techniques are very convenient to use for highlighting small or even tiny variations in spectral data for instance. However, care must be taken not to use them as a 'black box'. Validation studies remain important to carry out both on the software used and the processed data.

### 13. Summary

Several studies related to forensic fibre examinations were published in the period 2016–2019. A considerable amount of research was dedicated to transfer and persistence studies as well as other studies contributing to the significance of fibre evidence. An increasing interest in the field of damage analysis is observed. Several authors report on the need for consistency and simulations when dealing with textile damage analysis. The publications relating to high-performance chromatography for fibre analysis show that this technique is suitable for fibre dye identification and that it can be applied in casework. There is a global trend towards harmonization and standardization with training as an important step in this process. In the case of fibre evidence, a EU funded project started which involves the development of an e-learning platform with harmonized and widely-supported courses. The importance and urgency of correct training is also stressed by several authors with respect to the concept of evaluative reporting.

### Disclaimer

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### Declaration of Competing Interests

The authors declare that they have no conflicts of interest.

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