



General Forensics

Investigating diversity in polymer-based identity cards using ATR-FTIR spectroscopy and chemometrics



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ABSTRACT

Polymer identity cards are a key target for counterfeit production, posing significant economic and security threats. Examination of suspect identity cards is largely based on visual features, but could potentially exploit diversity in the card composition. This preliminary study investigated the chemical diversity amongst Western Australian driver's licences using attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy and chemometrics. Differences were observed between three series of issue, potentially due to variations in the adhesive or printing materials. Analysis of three licences issued by authorities outside of Western Australia also highlighted variations between jurisdictions. This warrants further investigation into the chemical composition of identity cards as a possible tool to assist expert examination.

1. Introduction

The use of polymer-based (plastic) cards has become routine in modern society, with most individuals owning several such cards for financial, security or identification purposes. Identity cards such as driver's licences are a major target for counterfeit production, accounting for 50% of fraudulent documents detected in the European Union in 2015. [1] These counterfeits can be used in facilitating organised crime, or to obtain legitimate forms of identification such as passports. This poses significant economic and security threats on an international scale [2,3].

In Australia, driver's licence cards are a de facto means of personal identification. These are issued by specific licensing authorities managed by state and territory governments. Licence cards generally consist of a polymer base with printed information on one or both sides, covered with a laminate film (Fig. 1). The base can be a single or multi-layer system comprising polymers such as polyvinyl chloride (PVC), polyethylene terephthalate, or polycarbonate [4–6]. Many European cards use polycarbonate due to its high durability, whilst PVC is thought to be used in Australia due to its lower cost and ease of mass production. The layers are fused through heating or by using adhesives such as ethylene vinyl acetate (EVA), polyurethane, or polyolefin [4,7]. Additional security features such as holographic

overlays, laser engraving or radio frequency identification tags may also be present.

Forensic examination of identity cards largely relies on visual inspection of the printing and security features. These examinations often make use of a stereomicroscope or specialised viewing system, such as a video spectral comparator. However, the chemical composition could also be probative in the examination of suspected fraudulent cards. Attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy is an ideal means of chemical profiling as it is simple, robust and readily portable. This approach has successfully been applied to the analysis of polymeric paints, [8,9] food packaging films [10–12], and textile fibres [13–15]. However, to the best of our knowledge, its application to characterising polymer identity cards has not been reported in the open literature.

This preliminary work used ATR-FTIR spectroscopy and chemometrics to investigate the level of chemical diversity amongst Western Australian driver's licence cards. Chemometric methods are a useful means of decoding multivariate data and allowing more objective conclusions to be drawn. The potential structural differences between cards was further investigated using synchrotron infrared microscopy. An understanding of these variations could assist in developing complementary tools for expert examination of suspect identity cards.

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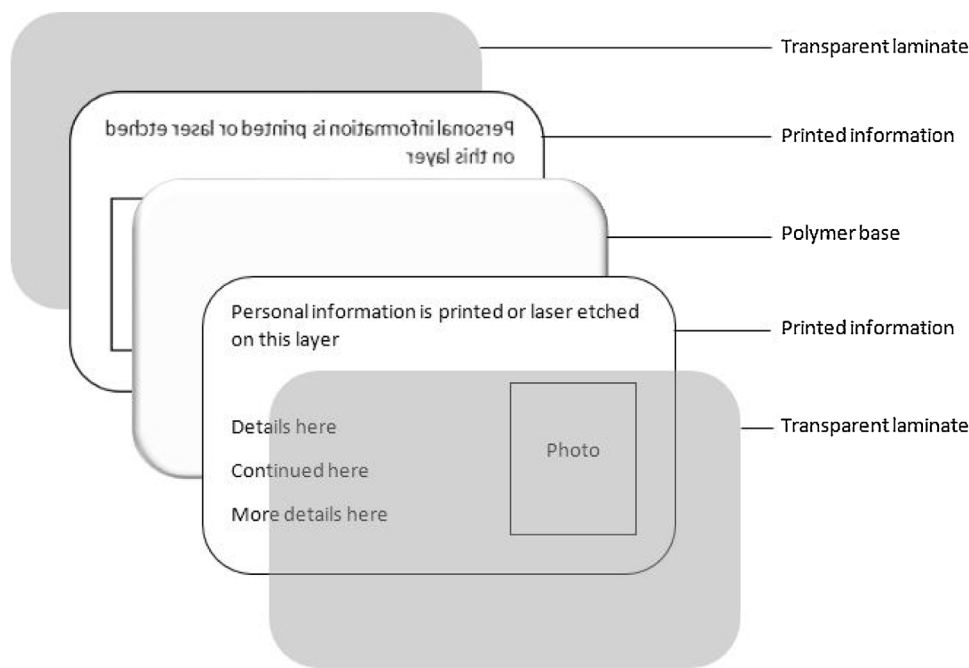


Fig. 1. General layer structure of a polymer identity card.

2. Materials and methods

2.1. Sample collection and preparation

All driver's licence cards for this study were temporarily donated by individuals. 38 Western Australian C Class (car) driver's licences were initially examined to assess the chemical variation amongst a single type of identity card (Table 1). Currently in Western Australia, licence cards are produced by a single manufacturer and distributed to individuals on the licensing authority of the Department of Transport (Department of Transport, personal communication, July 27, 2020). The obtained license cards were classified as belonging to one of three primary series; those that began distribution in 2001, 2011, and 2014 (Figure S1).

Three driver's licences issued in New South Wales, Australia; Victoria, Australia; and Lausanne, Switzerland were examined to compare licence cards from different jurisdictions, as it was expected that these may contain different polymers (Table 2). An additional Western Australian licence card from each series, as well as three non-C Class licenses, were also obtained for validation purposes (Table 2). These licences are issued by the same licensing authority and were assumed to differ only in the printed information.

A 2001 series Western Australian driver's licence was used for synchrotron-source spectroscopic imaging. Microtomed cross-sections approximately 7 μm thick were taken by placing between two pieces of polyethylene to prevent the layers from splitting. 20 μm thick cross-sections were taken from a card of each series to compare their physical structure.

2.2. Attenuated total reflectance infrared spectroscopy

Spectra were obtained using a Nicolet iS50 FTIR spectrometer equipped with an iS50 ATR attachment (single-bounce diamond crystal).

Table 1
Summary of Western Australian C Class driver's licences used in this study. [16–18].

Series	Number of Cards	Issued From	Introduced Features
2001	10	May 2001	Compulsory photographs and signatures
2011	4	November 2011	Unique serial numbers, barcodes, watermarks, embossed information
2014	24	July 2014	Laser engraved information, holographic overlay

Each card was thoroughly wiped with isopropanol and a lint-free tissue to remove any contaminants prior to analysis. Measurements were taken over the 4000 – 600 cm^{-1} range in absorbance mode, with a resolution of 4 cm^{-1} and co-addition of 32 scans unless otherwise specified. Data collection was performed using OMNIC software (version 9.1.24), with an air background spectrum obtained prior to each sample.

Spectra were first collected from both faces and the cross-sectional edge of a single licence card, to determine whether 'bulk' spectra representing the layer structure could be obtained. Spectra for the remaining cards were collected from the cross-sectional edge. This was first done by manually holding the corner edge of the card onto the ATR crystal (Figure S2). Two custom card holders were then designed to hold either the corner or the side of the card in contact with the ATR crystal (Fig. 2). For the first card holder, manual downward pressure was applied to the card to maintain sample-crystal contact. The second design incorporated a weight to maintain consistent downwards pressure along the length of the card, and a co-addition of 128 scans was used. The card holders were designed in SketchUp Pro 2014 and the appropriate parts 3D printed in acrylonitrile butadiene styrene (ABS) using an UP Box 3D Printer, or laser cut from colourless poly(methyl methacrylate) (PMMA). Each holder was measured to fit precisely over the diamond ATR plate.

2.3. Synchrotron Fourier transform infrared imaging

Cross-sectional mapping was completed at the infrared microspectroscopy (IRM) beamline at the Australian Synchrotron, Melbourne. The beamline consists of a Bruker Vertex 80v FTIR spectrometer and Hyperion 2000 IR microscope (Bruker Optik GmbH, Ettlingen, Germany) with a 20 \times objective and liquid nitrogen cooled mercury cadmium telluride (MCT) detector. High-resolution maps were collected using a germanium crystal ($n_{\text{Ge}} = 4.0$) ATR attachment, using a 0.5 mm pinhole and step size of

Table 2

Additional licence cards used in this study for comparison and validation purposes. Western Australian Photo Cards are an alternative means of identification for those who do not possess a driver's licence, and possess the same level of security. [19].

Identifier	Card Type	Licensing Authority
WAHV2014	Heavy Vehicle Class Licence	Department of Transport (Western Australia, Australia)
WALP2014	Learner's Permit Licence	Department of Transport (Western Australia, Australia)
WAPC2014	Photo Card	Department of Transport (Western Australia, Australia)
WADL2001	C Class Licence (2001 Series)	Department of Transport (Western Australia, Australia)
WADL2011	C Class Licence (2011 Series)	Department of Transport (Western Australia, Australia)
WADL2014	C Class Licence (2014 Series)	Department of Transport (Western Australia, Australia)
NSWDL	C Class Licence (issued between 2012–2014)	Roads and Maritime Services (New South Wales, Australia)
VICDL	C Class Licence (issued between 2008–2012)	VicRoads (Victoria, Australia)
SWISSDL	Car Licence (issued 2013)	Service des Automobiles (Lausanne, Switzerland)

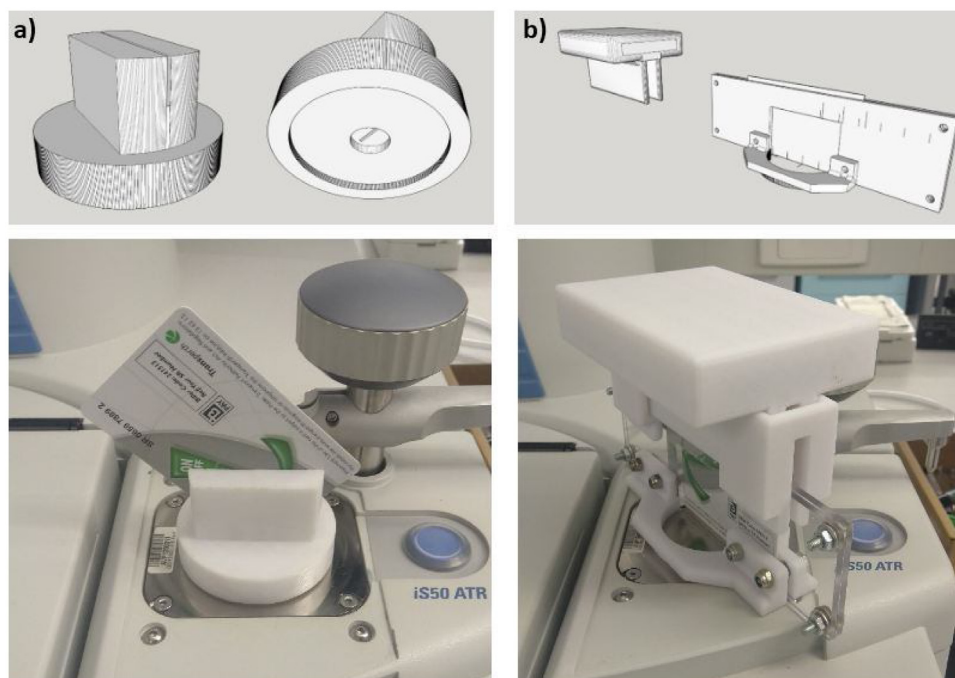


Fig. 2. Custom-designed card holders designed to maintain consistent positioning of (a) the card corner; or (b) the card side on the ATR crystal. Top view shows designs in SketchUp Pro 2014; bottom view shows assembled holders mounted over diamond ATR plate of Nicolet iS50 FTIR spectrometer.

3 μm . An air background spectrum was first collected using 12 co-added scans, with sample spectra subsequently recorded with 32 co-added scans. All data collection was performed using OPUS software version 7.50, under 19 % relative humidity.

2.4. Data analysis

Chemometric data pre-processing and analysis was performed using the Unscrambler[®] X 11 software (Camo Software AS, Oslo, Norway). Spectra were interpolated to a 1 cm^{-1} step size, and the 2340–1800 cm^{-1} region removed due to high absorbance from the diamond ATR crystal in this region. A baseline correction and range normalisation were then applied to account for variations in the sample contact pressure.

Spectra were mean-centred and subjected to principal component analysis (PCA) using the non-linear iterative partial least squares algorithm. Samples were plotted using the first three principal components (PCs) to visualise the distribution of the samples and identify any outliers. A multiclass support vector machine (SVM) model was constructed for the initial set of 38 Western Australian driver's licences, using a linear kernel to avoid over-fitting. The multiclass model consisted of binary classifiers for each pair of issuing series, which were treated as separate classes. Additionally, a linear discriminant analysis

(LDA) model was built using the Mahalanobis distance measure and scores derived from the first three PCs (accounting for 86.6 % of variance in the dataset). Both models were used to assign the additional set of nine cards to the most similar series for comparative purposes.

FTIR imaging spectra were baseline corrected and analysed using Bruker OPUS v7.0 and CytoSpec 2.00.03 software (Cytospec Inc., Boston, MA, USA). Images were further processed with ImageJ 1.50i software.

3. Results and discussion

3.1. Physical card structure

Microtomed cross-sections of licences from each series were examined under 10x magnification to compare their physical structure (Fig. 3). Both the 2001 and 2014 series appeared to have information directly printed onto an opaque base, sandwiched between two laminate layers. Two base layers were visible in the 2014 series, possibly to accommodate the introduction of new security features. The 2011 series possessed a distinct five-layer system, with a thin opaque layer containing printed information sandwiched between two transparent base layers, followed by the protective laminates. The 2011 series featured clear panels as part of their design, which would explain the use of transparent base layers. All three

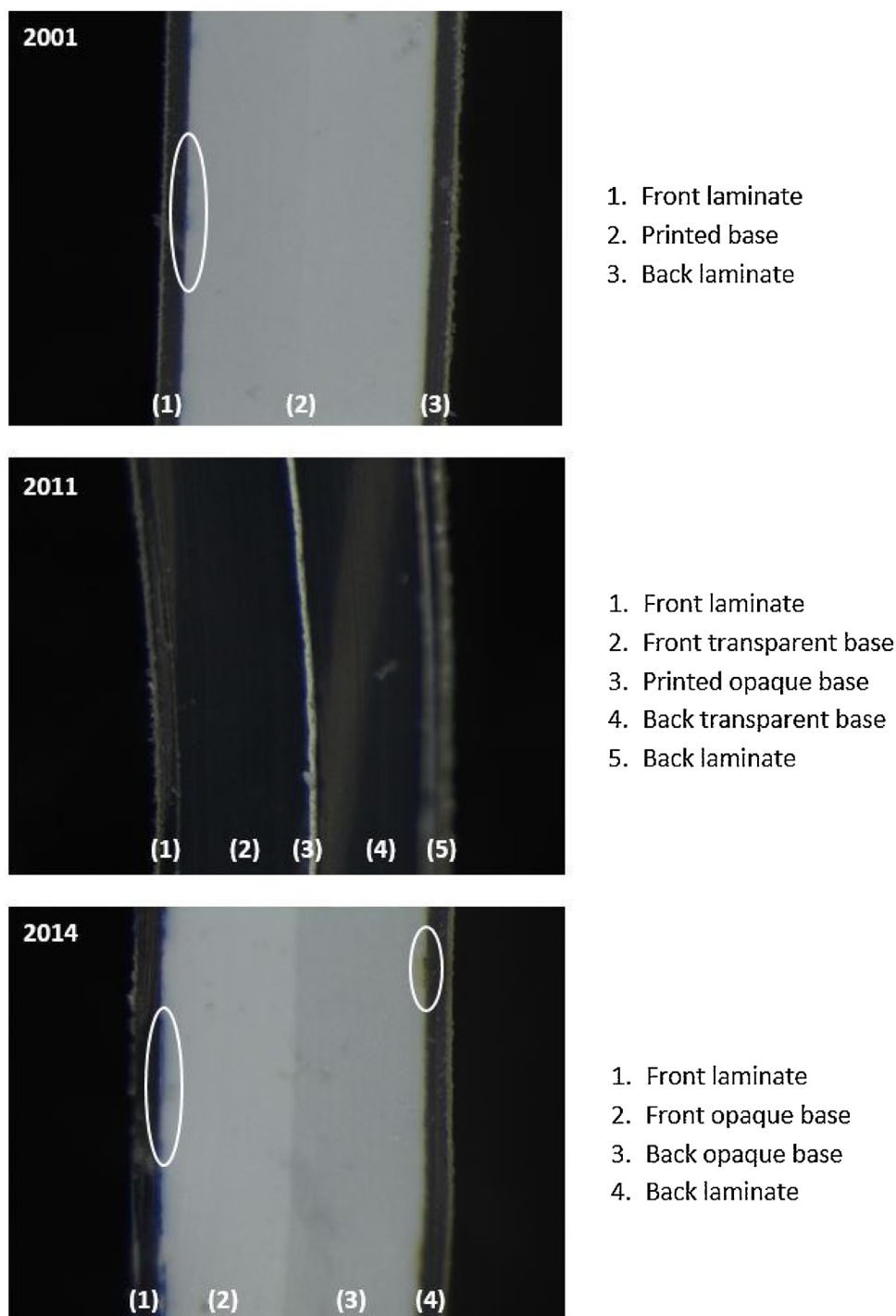


Fig. 3. 20 μm microtomed cross-sections of 2001, 2011 and 2014 series Western Australian driver's licence cards viewed under 10x magnification, showing physical layer structure. Circles show information printed onto base layer. 'Front' and 'back' refer to each face of the card as per Figure S1.

cards also showed signs of wear and tear on the laminate, including some potential discolouration. This could affect characterisation of the cards if applying ATR-FTIR to the front or back face of the cards.

Although each of these series could be distinguished on the basis of their physical structure, this required cross-sectioning of the cards, which may not be appropriate in an operational context. Spectroscopic analysis was thus carried out to determine whether differences could be detected in the chemical composition. This could also be relevant where two licence cards share a similar physical structure but make use of different polymers.

3.2. Preliminary considerations

Spectra were first collected from the front, back and cross-sectional edge of several cards to see whether a different profile was obtained (Fig. 4). It was expected that spectra taken from the front and back faces would represent the laminate film due to the low penetration of the evanescent wave, whereas a cross-section may allow bulk information on the layer system to be obtained.

Spectra taken from either face of the card did not appear substantially different. Several characteristic absorption bands were observed indicating

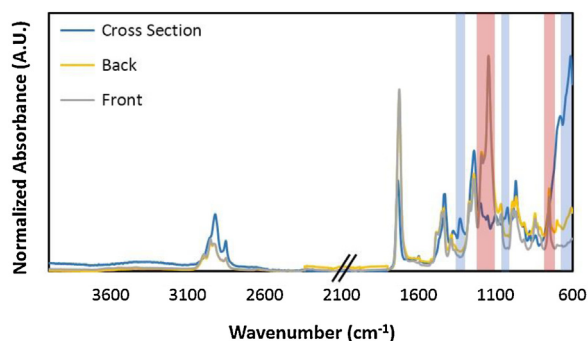


Fig. 4. Normalized ATR-FTIR spectra from the front, back, and cross-section of a Western Australian driver's licence. Absorbance bands at ca. 1335 cm^{-1} , 1020 cm^{-1} and 611 cm^{-1} (blue shaded) were consistent with PVC; whilst bands at ca. 1143 cm^{-1} and 752 cm^{-1} (red shaded) indicate PMMA.

the presence of PMMA (Table 3). This is likely used as a laminate due to its high scratch resistance, UV resistance and optical clarity; [20] extending the durability of the card without obscuring the printed information.

Cross-sectional spectra exhibited clear spectral differences and additional absorbance bands (Table 4), indicating multiple layers. Bands at ca. 1423 cm^{-1} , 1335 cm^{-1} , 962 cm^{-1} and 611 cm^{-1} were consistent with PVC [22,23]. Others however are likely related to minor components such as inks or adhesive materials. For example, the band at 1625 cm^{-1} was attributed as being most likely due to a benzophenone; commonly used in polymer production as photoinitiators or UV blockers [4,24,25]. The stretches at 2850 cm^{-1} and 1020 cm^{-1} on the other hand are consistent with EVA [21,26]. This polymer is commonly found in hot-melt adhesives and can be used as a bonding material in polymer identity cards [7,27]. Due to the bulk spectra and unspecified composition of the cards, these assignments cannot be made with certainty. However, as the purpose of this investigation was to compare the cards rather than identify their composition, further investigation was deemed unnecessary.

All subsequent spectra were collected across the edge of the card. This was initially done via handheld contact; however, the flexibility of the cards posed challenges in maintaining consistent positioning. Two custom card holders were thus prototyped to minimise movement of the card, by holding the corner or side onto the ATR crystal. Spectra from the side edge of the card exhibited weak peak intensities and relatively low signal-to-noise compared to those collected from the corner (Fig. 5). This is likely due to indentations along the length of the card, in combination with the downwards pressure being spread across the ATR plate. Both of these factors would have reduced the direct sample-crystal contact. Consequently, all data analysis below uses spectra collected using the corner edge card holder. This approach was also found to give reasonable reproducibility between measurements taken at each corner (Figure S3).

3.3. Diversity amongst Western Australian driver's licence cards

38 Western Australian driver's licences were examined to evaluate any inherent diversity present. It was expected that different issuing series

Table 3

Absorption bands and corresponding vibration mode assignments for ATR-FTIR spectra acquired from the front and back faces of a Western Australian driver's licence card; consistent with the presence of poly(methyl methacrylate). [21].

Absorption band (cm^{-1})	Assignment
2943	C-H stretch
1723	C=O stretch
1438	CH_2 bend
1392	CH_3 bend
1242	C-O stretch
1143	C-O stretch
752	CH_2 rock, C=O bend

Table 4

Absorption bands and corresponding vibration mode assignments for ATR-FTIR spectra acquired from the cross-sectional edge of a Western Australian driver's licence card.

Absorption band (cm^{-1})	Assignment	Possible component
2850	C-H stretch	EVA
1625	C=O stretch	Benzophenone
1423	CH_2 bend	PVC
1335	CH bend	PVC
1020	C-O stretch	EVA
962	CH_2 rock	PVC
611	C-Cl stretch	PVC

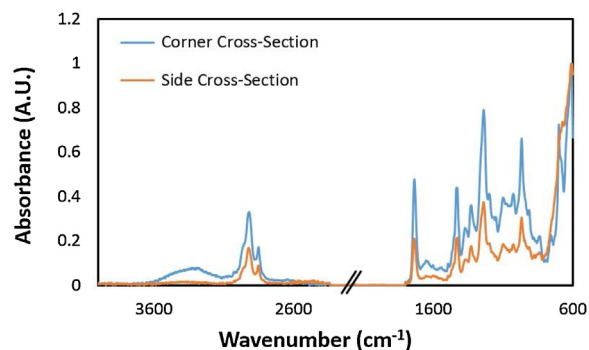


Fig. 5. ATR-FTIR spectra obtained from the cross-sectional edge of a Western Australian driver's licence, with the corner or side of the card held in contact with the ATR crystal.

may give different profiles, as the addition of new security features could require changes to the composition or layer structure. At the time this work was performed, there were two series of driver's licence valid within Western Australia; those that began distribution in 2011 and 2014. The previous 2001 series was also investigated to identify potential changes in card manufacture over an extended period.

PCA showed the 2011 series to be separable from the other cards using a combination of PCs 2-3 (Fig. 6a). The 2001 and 2014 series exhibited substantial overlap, although the 2014 series tended towards more positive scores along PC2. All three series also showed a high level of intra-class dispersion. This was expected due to minor changes and batch variations within each card series over time. Inspection of later PCs, or separate PCA of the 2001 and 2014 series (Fig. 6b), did not appear to improve separation.

Factor loadings (Fig. 7a) showed that PC2 was positive correlated with bands at ca. 1436 cm^{-1} and 1241 cm^{-1} , associated with CH_2 bending and CO- stretching in PMMA. Negative correlations were also seen in the CH- stretching region. Spectra from the 2014 series typically gave high absorbance at the 1436 cm^{-1} and 1241 cm^{-1} peaks, and low absorbance above 2800 cm^{-1} (Fig. 7b), thus obtaining more positive PC2 scores. This suggests a higher relative proportion of PMMA, such as a thicker laminate (although no substantial variations were observed under microscopy) or chain length variations in the polymers used. PC3 was negatively associated with the C-O and CO stretching regions (ca. 1730 cm^{-1} and 1240 cm^{-1}), resulting in the 2011 series obtaining more negative scores along this component. This similarly indicates variations in the proportion of the laminate or minor components rather than the polymer base, as all three series appeared to contain PVC. However, due to the unspecified composition of these cards, it is again difficult to determine exact differences leading to separation.

A multiclass SVM model and a three-PC LDA model were constructed from the initial sample set, treating each series as a discrete class. SVM is a boundary method that aims to construct a maximum-margin hyperplane between classes. This boundary is defined by 'support vector' samples that lie along the margin, and is hence oriented at samples that are difficult to

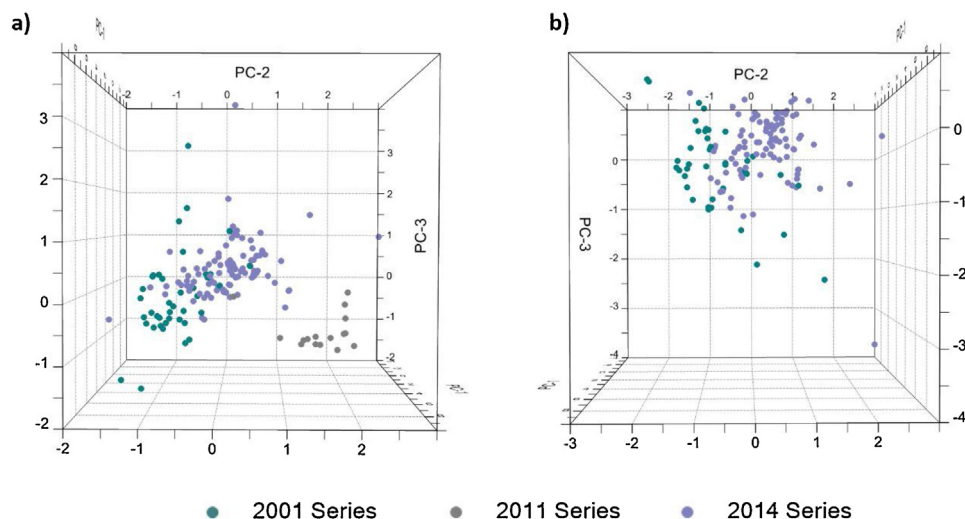


Fig. 6. Three-dimensional PCA scores plots of Western Australian driver's licences representing (a) 2001, 2011 and 2014 issuing series; and (b) 2001 and 2014 series only; based on their ATR-FTIR spectra.

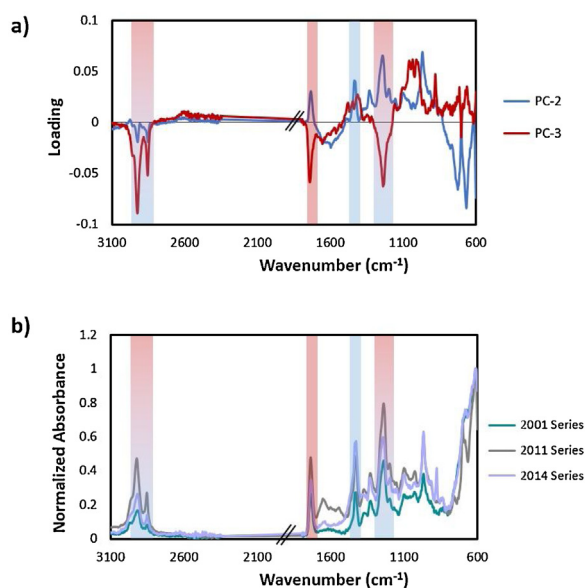


Fig. 7. a) PC2 (blue shaded) and PC3 (red shaded) factor loadings for three series of Western Australian driver's licences based on their ATR-FTIR spectra; and b) Normalized spectra from central samples of each series.

classify rather than those which are distinct [28]. LDA on the other hand models all samples in a dataset, constructing a discriminant function that maximises *inter*-class to *intra*-class variance [29,30]. Unlike LDA, SVM makes no assumptions about the covariance or probability distribution of the data, which is ideal where the sample size is limited [29]. However, as SVM is a binary classifier, discrimination between three or more classes requires the construction of multiple models.

The SVM model outperformed LDA, giving a 98.7 % discrimination accuracy (Table 5) compared to 79.6 % for LDA (Table S1). The SVM model was therefore used for all subsequent predictions. As expected, the only incorrect classifications were between the overlapping series, with two spectra from a 2001 series licence being misclassified as the 2014 series. This sample was identified as a support vector along the 2001/2014 class margin, explaining its ambiguous result. Nonetheless, the correct classification of all other licences indicates that the chemical variations between issuing series are sufficient to enable good discrimination. The greater discrimination achieved using SVM

Table 5

Predicted vs. actual issuing series of 38 Western Australian driver's licences using a linear kernel multiclass SVM. The overall discrimination accuracy was 98.7 %.

Predicted/Actual Series	2001	2011	2014
2001	38	0	0
2011	0	16	0
2014	2	0	96

compared to PCA is to be expected, as the purpose of this algorithm is to establish separation between known classes. PCA by contrast is an exploratory tool for extracting major sources of variation, regardless of whether this variation is useful in distinguishing particular categories.

3.4. Synchrotron FTIR microscopy imaging

To gain a better understanding of the basis for separation between licence series, an investigation into the structural differences was undertaken. This work was carried out at the Infrared Microscopy (IRM) Beamline at the Australian Synchrotron, Melbourne. Thin cross-sections approximately 7 μm thick were taken from a 2001 series Western Australian driver's licence for FTIR imaging (Figure S4). False-colour maps of the cross-sections were generated from selected integrated peaks, and then superimposed over an optical image of the sample to create a set of composite images (Fig. 8).

Inspection of these images revealed a small feature in both cards which appears to be positioned between the primary layers. Spectra extracted from this feature exhibited peaks centred at ca. 2850 cm^{-1} , 1740 cm^{-1} and 1650 cm^{-1} . These peaks were assigned as C–H stretching, C=O and N–H bending vibrations respectively. On the basis of these bands, this feature is suspected to be a polyester amide, which could be present as an adhesive or thermoplastic ink [31]. This further indicates that discrimination between licences may be related to minor components such as adhesives or printing materials, rather than the base polymer.

3.5. Prediction of additional licence cards

An additional set of nine licences were examined to assess the reliability of separation based on composition, and to compare cards issued in different jurisdictions. This additional test set included alternative (non-C Class) licences issued by Western Australia and three C Class equivalent licences issued by authorities outside of Western Australia.

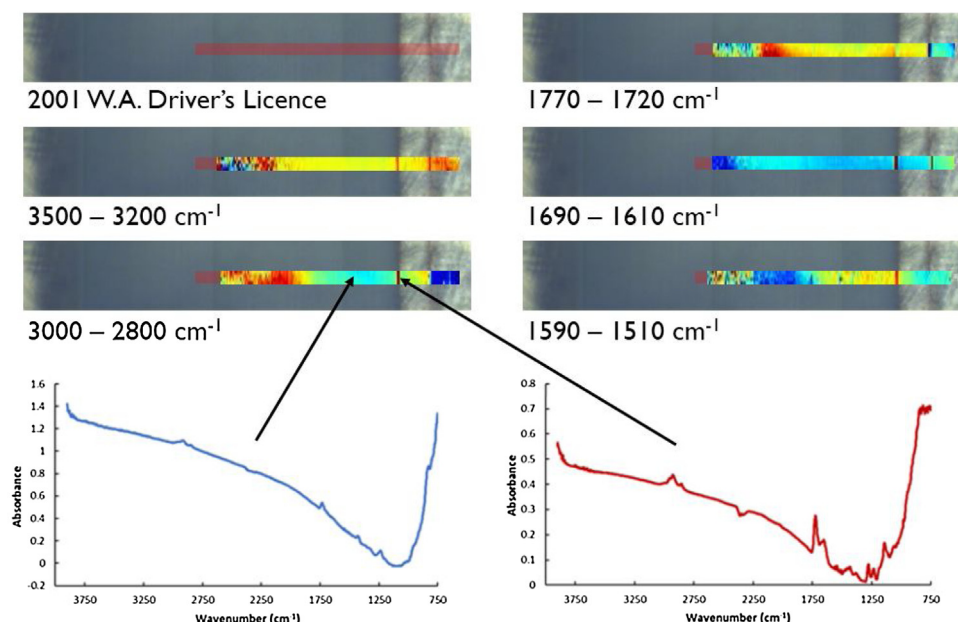


Fig. 8. Composite FTIR false colour images from cross-sections of a 2001 series Western Australian driver's licence, based on integration of selected infrared peaks. Representative spectra are shown for the core polymer (left) and a suspected adhesive or printed layer (right). Decreasing intensity from red to blue.

All licences belonging to one of the Western Australian series were correctly classified, including those of the similar 2001 and 2014 series (Table 6). This supports the theory that licence types issued by the Western Australia Department of Transport use the same card with different printed information. The correct assignments of the 2001 and 2014 licences also indicates that the minor variations between them are sufficient for discrimination and classification. Further work could examine whether this could be exploited for the purposes of screening suspect identity cards, to flag those warranting further examination.

The Victorian licence was associated with the 2011 Western Australian series, which was potentially consistent with its year of issue. Conversely, the New South Wales licence (issued prior to 2014) was assigned to the 2014 series, and the Swiss licence issued in 2013 to the 2001 series. This demonstrates the different card compositions used by separate licensing authorities within a given issuing period.

SVM will assign each sample to the most similar prior class, regardless of whether this can be considered a good 'fit'. Unlike some other classifiers such as LDA, SVM also does not provide distance metrics between predicted samples and their assigned classes. For this reason, it is important to examine other outputs such as PCA projection and the original spectra to identify any outliers.

When projected onto the PCA model of Western Australian licences (Fig. 9), the New South Wales and Swiss licences appeared to closely overlap with those of their assigned clusters. This would seemingly suggest that these licences are also PVC-based, with possible minor

variations in the adhesive or printing materials.

For the New South Wales licence, this was supported by visual inspection of the infrared spectra (Fig. 10a), which showed the same bands with differing relative intensities. By contrast, the Swiss licence showed substantial deviations from the 2001 Western Australian licences (Fig. 10b). In particular, the absorbance band at ca. 611 cm⁻¹ indicative of a C-Cl stretch was much less intense. Additionally, several bands were observed that are consistent with ABS (Table 7). [21] This polymer is a common base in certain plastic cards due to its high rigidity and impact resistance [31,32]. On that basis, it was concluded that the Swiss licence is likely a blend of ABS with PVC.

The Victorian licence appeared to form a distinct cluster from the 2011 series cards, which could indicate a different polymer base. Spectral examination showed that this licence likely contained PVC, but variations in the chain stretching regions indicate that a different laminate or adhesive may be present (Fig. 11). It is also worth noting that the 2011 group was represented by only four licences, giving limited indication of the intra-series variation that might reasonably be expected. These results further demonstrate the importance of examining the initial spectra to evaluate predictions made using chemometric models, and of obtaining a sufficiently representative sample set.

4. Conclusions

ATR-FTIR spectroscopy was successfully used to detect compositional variations amongst a set of polymer-based identity cards. Qualitative analysis suggests Western Australian driver's licences to be PVC-based with a PMMA laminate, although subtle variations were observed between issuing series. These variations appeared to be related to the relative proportions of different polymers, or minor components used in the printing or adhesive materials. This theory is supported by synchrotron FTIR imaging, which identified a potential adhesive layer suspected to be a polyester amide between the base and laminate layers. However, analysis of additional samples is required to confirm whether the adhesives in different cards can be distinguished, particularly using benchtop instrumentation.

Chemometric analysis showed the potential to exploit the chemical variations between licences for predictive purposes; successfully assigning six Western Australian licences to their corresponding series.

Table 6

Actual and predicted series classifications of nine additional licence cards using SVM model. N/A = Not Applicable.

Card Identifier	Actual Series	Predicted Series
WAHV2014	2014	2014
WALP2014	2014	2014
WAPC2014	2014	2014
WADL2001	2001	2001
WADL2011	2011	2011
WADL2014	2014	2014
NSWDL	N/A (Issued 2007–2013)	2014
VICDL	N/A (Issued 2008–2012)	2011
SWISSDL	N/A (Issued 2013)	2001

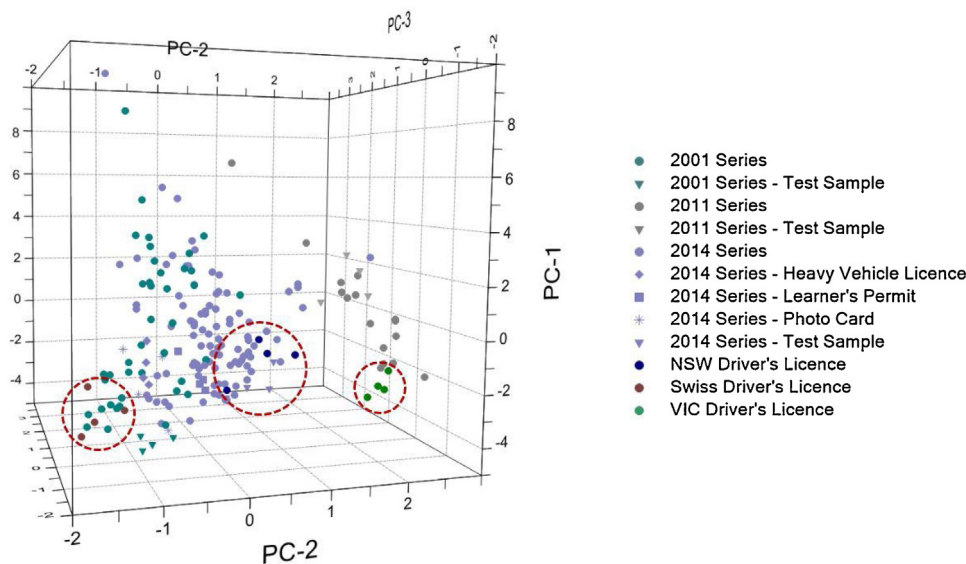


Fig. 9. Three-dimensional PCA projection plot showing distribution of additional ‘test’ licences compared to those issued in Western Australia, including three licences issued outside of Western Australia (circled).

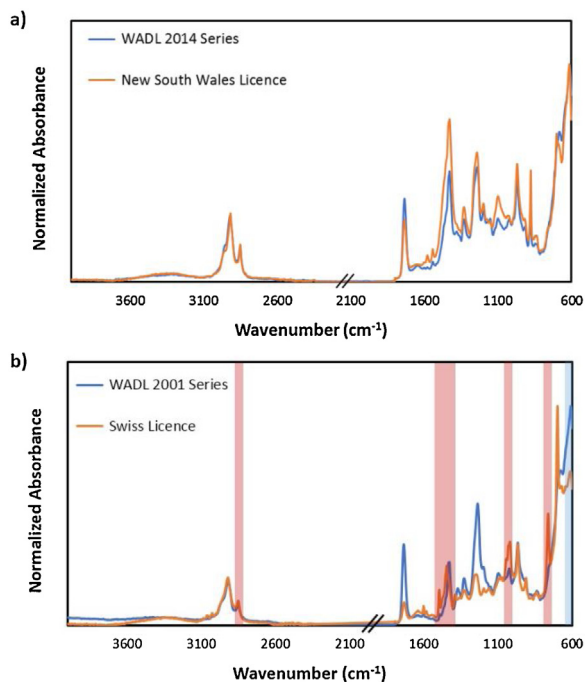


Fig. 10. Comparison of ATR-FTIR spectra from Western Australian licence series versus (a) New South Wales-issued licence, showing consistent absorbance bands with differences in relative intensity; (b) Lausanne-issued licence, showing substantially decreased intensity of the C–Cl stretch (blue shaded) associated with PVC and the presence of several bands associated with ABS (red shaded).

Prediction of two interstate licences confirmed that different states within Australia do not necessarily use the same card composition within a given issuing period, although all appeared to be PVC-based. A licence card issued by authorities in Switzerland was found to be markedly different to those in Australia, likely using ABS as a primary material. It would be of further interest to examine a wider range of licence cards to determine whether additional variations can be identified. Further cards are also needed to compare *inter-* and *intra-*group variation, as this will affect whether separation between licence types is feasible.

An improved understanding of the chemistry of these licences could assist in developing complementary tools for suspect identity card analysis. In particular, a simple and high-throughput screening method would be ideal for ‘frontline’ personnel, allowing them to identify cards with a composition inconsistent with their purported origin. This would enable more rapid and accurate referral of potential counterfeits to an expert examiner for further examination. A chemometric-based approach could also provide examiners with additional statistical support when reporting results.

Author Declaration

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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Declaration of Competing Interest

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Table 7

Absorption bands and corresponding vibration mode assignments for ATR-FTIR spectra acquired from the cross-sectional edge of a Swiss driver's licence card; consistent with ABS. [21].

Absorption band (cm^{-1})	Assignment
3000	C-H stretch (styrene)
2924	C-H stretch
1495	Aromatic ring stretch
1450	CH_2 bend
966	=C-H bend
763	Aromatic CH out-of-plane bend; =CH bend

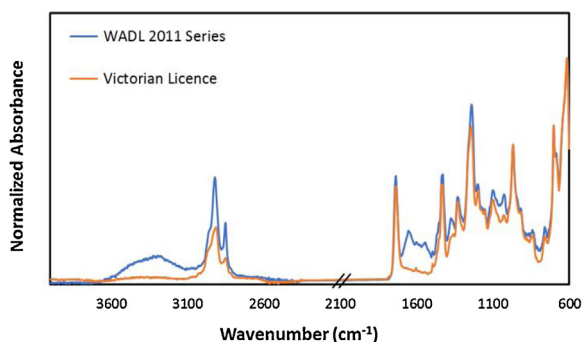


Fig. 11. Comparison of ATR-FTIR spectra from a Victorian-issued driver's licence and Western Australian 2011 series driver's licence. Variations can be observed in the chain stretching regions (ca. 1600 cm^{-1} and $> 2800 \text{ cm}^{-1}$).

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.fsir.2020.100149>.

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