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Motorcycle helmets: What about their coating?

Michaël Schnegg *, Geneviève Massonnet, Line Gueissaz

University of Lausanne, School of Criminal Justice, Batochime, CH-1015 Lausanne-Dorigny, Switzerland

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ABSTRACT

In traffic accidents involving motorcycles, paint traces can be transferred from the rider's helmet or smeared onto its surface. These traces are usually in the form of chips or smears and are frequently collected for comparison purposes. This research investigates the physical and chemical characteristics of the coatings found on motorcycles helmets. An evaluation of the similarities between helmet and automotive coating systems was also performed.Twenty-seven helmet coatings from 15 different brands and 22 models were considered. One sample per helmet was collected and observed using optical microscopy. FTIR spectroscopy was then used and seven replicate measurements per layer were carried out to study the variability of each coating system (intravariability). Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were also performed on the infrared spectra of the clearcoats and basecoats of the data set.

The most common systems were composed of two or three layers, consistently involving a clearcoat and basecoat. The coating systems of helmets with composite shells systematically contained a minimum of three layers. FTIR spectroscopy results showed that acrylic urethane and alkyd urethane were the most frequent binders used for clearcoats and basecoats. A high proportion of the coatings were differentiated (more than 95%) based on microscopic examinations. The chemical and physical characteristics of the coatings allowed the differentiation of all but one pair of helmets of the same brand, model and color. Chemometrics (PCA and HCA) corroborated classification based on visual comparisons of the spectra and allowed the study of the whole data set at once (i.e., all spectra of the same layer). Thus, the intravariability of each helmet and its proximity to the others (intervariability) could be more readily assessed. It was also possible to determine the most discriminative chemical variables based on the study of the PCA loadings. Chemometrics could therefore be used as a complementary decision-making tool when many spectra and replicates have to be taken into account.

Similarities between automotive and helmet coating systems were highlighted, in particular with regard to automotive coating systems on plastic substrates (microscopy and FTIR). However, the primer layer of helmet coatings was shown to differ from the automotive primer. If the paint trace contains this layer, the risk of misclassification (i.e., helmet versus vehicle) is reduced. Nevertheless, a paint examiner should pay close attention to these similarities when analyzing paint traces, especially regarding smears or paint chips presenting an incomplete layer system.

1. Introduction

When involved in traffic accidents, motorcyclists can be very severely injured or killed [1–4], due to the lack of physical protection and to the comparatively small size of their vehicle [5,6].

Because of this, traffic accidents involving motorcycles represent an important part of the cases handled by forensic science laboratories. Many studies have been carried out in the area of traffic accident reconstruction, the majority concerning the dynamic of the accident. A large variety of traces can be collected on the accident scene for identification and/or comparison purposes for example liquids (such as oil and petrol), paint (chips or smears), glass fragments and skid marks [4,7–10]. To help in the reconstruction of the events of a traffic accident, the attribution of the different traces to each item involved is essential. It is thus important to have knowledge about the composition of these different elements that can induce traces during a traffic accident (e.g., automotive paint, tires).

Whenever a motorcyclist is injured, it is crucial to collect his equipment [4], in particular the helmet. Indeed, during the

* Corresponding author at: École des Sciences Criminelles, UNIL, Batochime, CH-1015 Lausanne-Dorigny, Switzerland. Tel.: +41 021 692 46 18; fax: +41 021 692 46 05.
E-mail address: Michael.Schnegg@unil.ch (M. Schnegg).

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collision, traces might be exchanged between the helmet, the vehicles, road and traffic signs [11]. The role of this protective equipment is crucial, as the head is often subject to severe injuries [12]. In forensic science, the most important helmet parts are usually the external ones (i.e., those in contact with the vehicles and/or the other elements). These include the shell, visor and ventilation system pieces. The shells are often coated, can present various graphics and are constituted of thermoplastic polymers. Three types of polymers are currently used by the manufacturers: polycarbonate (PC), acrylonitrile butadiene styrene (ABS) and composite material such as Kevlar, glass or carbon fiber [5,13,14]. Although composite shells are extremely resistant, ABS shells are still frequently encountered due to their more accessible price and ease of production [13]. Literature concerning the composition and the resistivity of helmet shell is abundant [15–17]. In contrast, very little has been published on the coating systems of helmets. To the knowledge of the authors, only two studies referred to the coating system. These studies mentioned that the coating system of helmets was multi-layers, but, did not give any further details [8,18]. To overcome the lack of information in this field, this work focuses on the analysis of the coating systems applied on helmet shells.

This work focuses on two main aspects: first, 27 helmets were analyzed to allow for the physical and chemical characterization of the helmet coating systems. This part allowed investigating whether helmets of different brands and/or models could be differentiated based on their coating systems. The information provided by this part of the research (e.g., occurrence of a given layer of the coating system) will assist the expert during the evaluation process. Indeed, when a paint trace recovered in a traffic accident is not differentiated from a helmet coating, it is important to assess the evidential value of this correspondence.

Secondly, as traffic accident generally involve automotive vehicles, similarities between helmet and automotive coating systems were investigated to determine whether helmet and automotive coatings could be differentiated. This knowledge is important for the investigation of traffic accident involving for example both vehicle(s) and a motorcyclist.

2. Material and methods

2.1. Helmets

The sample set consists of 27 helmets from 15 different brands and 22 different models (Table 1). Three groups are of the same brand, model and color (Iota FP-03, Aero AR500 and Caberg Justissimo). Five color classes of coatings were observed: white ($n = 1$), blue ($n = 2$), red ($n = 2$), gray ($n = 7$) and black ($n = 12$) containing both effect and solid coats. Concerning the shell compositions, determined by infrared measurements, 15 helmets were in ABS and five were in polycarbonate (PC). The PC shells also contained the precursor monomer Bisphenol A (BPA). The other helmets ($n = 7$) were comprised of a composite material. According to the Swiss market, it is coherent to find these three different types of shells, as they are the most common materials used in the helmet industry. Moreover, the different proportions are in accordance with the current Swiss trend in which polycarbonate is more and more replaced by ABS and where composite helmets still remain expensive. Finally, it is important to notice that these helmets were still used shortly before the present research in order to be representative of the helmets currently worn on Swiss roads.

2.2. Sampling and optical observations

One fragment per helmet was taken with a scalpel in order to obtain the complete coating system including the polymer material of the helmet shell. However, composite shells were too rigid to be sampled by this technique and in these cases only the coating system was collected. If a graphic was present on the helmet, two fragments were taken (with and without the graphic). The fragments were included in a resin (Technovit 2000LC, Heraeus Kulzer) and cut into 5 μm thin sections with a Leica Jung Supercut 2065 microtome. The cross sections were then mounted on a glass slide using Gurr's mounting medium (XAM Neutral, BDH Laboratory Supplies, Poole, UK) for microscopic observations.

Cross sections were observed and characterized in transmitted light using a Leica DM6000B microscope with a 20× Fluotar objective. As advised in the literature [19,20], bright field, dark field and crossed polars were used.

Table 1
Characteristics of the helmet sample set.

Samples ($N = 27$)				
Number	Brand	Model	Coating color	Shell composition
01	Iota	FP-03	Effect gray	ABS
02	Iota	FP-03	Effect gray	ABS
03	Iota	FP-03	Effect gray	ABS
04	Iota	FP-03	Effect gray	ABS
05	Nolan	N61	Effect black	PC(BPA)
06	Aero	AR500	Solid black	ABS
07	Aero	AR500	Solid black	ABS
08	Suomy	Bargy Design	Effect gray	Composite
09	Caberg	Classico	Effect red	ABS
10	Caberg	Justissimo	Effect gray	ABS
11	Caberg	Justissimo	Effect gray	ABS
12	Lazer	LZ6 Katana	Solid black	ABS
13	iXS	HX600 Ch. II	Effect black	Composite
14	iXS	HRX352	Solid black	Composite
15	Shark	S650	Effect white	ABS
16	Shark	S600 Fizz	Solid black	ABS
17	Bieffe	B12	Effect black	ABS
18	Speed	Black	Solid black	Composite
19	C2000	Unknown	No coating	PC(BPA)
20	FM	Race	Solid black	ABS
21	FM	Wind Force	No coating	PC(BPA)
22	Shoei	RF-200	Solid black	Composite
23	New Hard	Unknown	Solid red	Composite
24	Araï	RX-7 Corsair	Effect blue	Composite
25	Lazer	Be-Bop Mendhi	Effect blue	ABS
26	Suomy	Joo	Effect black	PC(BPA)
27	Nolan	Unknown	No coating	PC(BPA)

2.3. FTIR measurements

The analyses were conducted on a Nicolet 5700 FTIR spectrometer coupled with a Nicolet Continuum FT-IR microscope from Thermo Scientific equipped with a Infinity Reflachromat 32× objective and a mercury cadmium telluride detector (MCT/A). Measurements were performed in transmittance mode, using KBr pellets on which a flattened coating section was deposited, with spectral range: 4000–650 cm^{-1}, resolution: 4 cm^{-1} and 32 co-added scans. An aperture of 29 μm × 55 μm was used, excepted for the shells, for which an aperture of 45 μm × 55 μm was chosen. All spectra were obtained with OMNIC 9.2 software from Thermo Scientific. In order to evaluate the intravariability, seven replicate spectra were collected for each layer of the coating systems.

2.4. Identification and visual comparison of FTIR spectra

The chemical composition of each layer was determined using characteristic peaks wavelengths referenced in the literature [21–23] and spectral reference databases provided by the Royal Canadian Mounted Police [24].