Chemical Properties of Selected Plastic-Tipped Bullets

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ABSTRACT

Fragments of plastic-tipped bullets are often found in wound tracts of unlawfully killed wildlife. Using color, Fourier transform infrared spectroscopy analysis coupled to the statistical power of discriminate analysis and x-ray fluorescence spectrometry, we were able to characterize the polymers found in common commercially available plastic-tipped bullets. The data is surprising because the high quality control used by the manufacturers provides an opportunity for forensic class character determination.

Introduction

The National Fish and Wildlife Forensic Laboratory is charged with assisting law enforcement in prosecuting wildlife crime. Typical victims seen in the Lab include bears, eagles, wolves, etc. In recent years, veterinary pathologists have observed and collected colorful plastic fragments associated with the gunshot wounds. Sometimes the color and shape of the polymer pieces are sufficient to give an indication of the caliber and manufacturer of a plastic-tipped projectile. Such is the case with some of the Nosler Ballistic Tip® bullets, due to a color code assigned to different calibers, however, white tips are used for all the calibers of Nosler Accubond® bullets and olive-drab green is used by Nosler in all calibers of their E Tip® bullets. Hornady uses red-colored tips for all of the bullets sold under the Hornady brand. Hornady also furnishes bullets to other ammunition manufacturers with different colored tips. Hornady V-Max® bullet tips loaded in 17 HMR cartridges are black for CCI and Federal Premium® labeled boxes, gold in Remington boxes, silver in Winchester boxes, and red in Hornady boxes [1, 2, 3]. A previous study considered the physical properties of selected polymer-tipped bullets [1].

Plastic-tipped bullets are designed to have excellent aerodynamics and offer increased terminal velocity and a flatter trajectory. A plastic tipped bullet is in essence a hollow-point bullet that has a pointed plastic tip. Upon impact, the polymer tip assists in expansion of the bullet nose [3, 4].

Rigid polymer tips were originally used to replace exposed lead tips in pointed (spitzer) style bullets. The purpose was to prevent deformation of the bullet tip, which may affect accuracy and trajectory. Damage to the bullet tip could occur to exposed lead tips during handling, loading into the firearm, or from recoil battering the bullet tips in the magazine. Additionally, the polymer tip helped to expand the nose of the bullet upon impact [2]. The hard plastic-tipped bullets could not be used in rifles with tubular magazines because of the possibility of the hard tip detonating the primer of another cartridge in the magazine during recoil. Conventional bullets for tubular magazine rifles were flat tipped or rounded to prevent detonation of primers due to recoil. The cartridges were classed as short range because of the poor aerodynamic shape causing velocity loss and rainbow trajectories. More recently, Hornady added soft polymer tips in their LEVERevolution® Flex Tip® bullets to cartridges primarily used in tubular magazines [3]. The soft-tipped bullets allow more aerodynamic, pointed bullets to be used in tubular magazines, without the possibility of detonating a primer that the bullet tip is resting on in the magazine. The results have been flatter trajectories and higher terminal velocities. The 2010 Hornady catalog lists the 30-30 Winchester, 308 Marlin Express, 338 Marlin Express, 32 Winchester Special, 357 Remington Magnum, 35 Remington, 44 Remington Magnum, 444 Marlin, 45 Colt, 45-70 Government, and 450 Marlin cartridges loaded with Flex Tip® bullets. Hornady also uses the Flex Tip (FTX)® bullets in their SST® Shotgun Slug and muzzle-loading bullets [5].

The purpose of this study was to determine if it is possible to associate the remnants of evidentiary plastic fragments, suspected of being from plastic-tipped bullets, to a manufacturer through the analysis of the chemical properties of the polymers. The plastic component of these bullets was analyzed using three analytical instruments. A video spectral comparator (VSC) was used to determine color and ultraviolet characteristics, a Fourier transform infrared spectrometer (FTIR) was used to characterize the type of polymer used and a statistical tool (discriminate analysis [DA]) was used to distinguish FTIR spectral differences. Lastly,

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X-ray fluorescence (XRF) was used to analyze elemental composition.

Video Spectral Comparator

A video spectral comparator (VSC) is an imaging system typically used for the analysis of documents. This instrument is a multi-spectral imaging system that uses a camera, light sources, viewing filters, and spectrometer (9-nm resolution) to allow for visualization under alternate light sources or spectral acquisition (Vis-NIR, 400-1000 nm). This spectral data can describe and measure color. While developed as a tool for the analysis of documents, we have used it for determining color in fibers, paint, ivory, pelts, skin and many other evidentiary items. In this research, the VSC (Foster and Freeman VSC®6000 [6]) was used to visualize the plastic tips of bullets under various light conditions and to determine if ultra-violet (UV) illumination induced a color change in the polymer [6].

Infrared Spectroscopy

Fourier transform infrared spectroscopy (FTIR) is a non-destructive analytical tool that, when used in examining polymers, stands out for its robustness, ease of sample preparation, simplicity of operation, and the ability to make structural elucidations [7]. The resolving power of FTIR has been applied in such diverse fields as forensic fiber identification [8, 9] and natural polymers such as hair [10] and sea turtle keratin [11].

Discriminant analysis of vibrational spectra (Raman or infrared) has been successfully used to extend the limitations inherent in vibrational data. Examples include confirmation of edible oils and fats [12], sub-typing of nylon polymers [13], geographic sourcing of medicinal plants [14], forensic identification of fingernails vs. toenails [15], the forensic identification of fiber blends [9] and the identification of sea turtle keratin from bovid horn [11]. This method has also proven to be useful in distinguishing polymer bullet tips that may commonly be encountered in wildlife crime investigations.

X-ray Fluorescence Spectrometry

X-ray fluorescence spectrometry (XRF) is a non-destructive analytical tool that can provide rapid, multi-element measurements of solid or liquid samples. It has been used in a wide variety of analytical disciplines including cadmium and lead detection in hazardous waste sites [16], copper contamination of agricultural soils [17], as well as a method for distinguishing keratins from casein-based plastics [11]. High-energy x-ray photons excite the atoms in a sample, and the energy difference between the excited state and ground state are reflected in the emission. By operating under a vacuum there is an increased sensitivity to elements lighter than argon.

Methods

Reference polymer samples

Winchester (n=2), Nosler (n=17), and Hornady (n=3) provided reference polymer tips used in their respective bullets (Table 1). Dupont [18] provided a reference sample of Delrin® 500P, a polyoxymethylene (POM) acetal homopolymer, and Ticona [19] provided copolymer samples of Celcon®POM (M25, M90, and M270 natural).

Reference plastic-tipped bullets

Twenty-nine boxes of plastic-tipped bullets of various calibers and one box of plastic-tipped shotgun slugs were purchased locally (See Figure 1 and Table 2). Some of the plastic tips

Color	Tip Manufacture	Type of Tip	Polymer Identification
Red	Hornady	Not Available	Polyoxymethylene
Red	Nosler	7mm BT	Polyoxymethylene
Red	Nosler	Win OEM AB	Polyoxymethylene
Red	Nosler	7mm AccuBond	Polyoxymethylene
Red	Winchester	30 Cal XP3	Polyetherimide
Red	Winchester	12GA XP3	Polycarbonate
Red/Gold	Nosler	22 BT	Polyoxymethylene
Orange	Nosler	Norma AB	Polyoxymethylene
Orange	Noser	22 BT	Polyoxymethylene
Yellow	Nosler	270 BT	Polyoxymethylene
Green	Nosler	30 BT	Polyoxymethylene
Green	Nosler	27 Cal E-Tip	Polyoxymethylene
Green	Nosler	E-Tip	Polyoxymethylene
Blue	Nosler	25 BT	Polyoxymethylene
Blue	Nosler	8mm BT	Polyoxymethylene
Blue	Hornady	Not Available	Polyoxymethylene
Purple	Nosler	243 BT	Polyoxymethylene
Brown	Nosler	264 BT	Polyoxymethylene
Brown	Hornady	Not Available	Polyoxymethylene
Grey	Nosler	30 Cal BST	Polyoxymethylene
Grey	Nosler	CTBST	Polyoxymethylene
White	Nosler	AccuBond	Polyoxymethylene

Table 1

Figure 1

were sampled from loaded cartridges, and others were selected randomly from boxes of bullets, such that each box provided a sample size of 20 polymer tips. The only exception was Hornady SST® FTX® which had five plastic-tipped slugs. The boxes of bullets were from the following manufacturers: Nosler (n=11), Hornady (n=7), Federal Premium® (n=6), Winchester (n=2), FNH USA (n=1), CCI (n=1), Remington (n=1), and Sierra (n=1). Some of the brands of ammunition utilize plastic-tipped bullets of their own fabrication, others use plastic-tipped bullets manufactured by other companies (See Table 2). The sampled populations were not a complete sweep of all manufacturers that distribute plastic-tipped bullets or the colors used.

Video Spectral Comparator (VSC)

A Foster and Freeman VSC®6000 (v. 6.5 with HS updates [6]) was used to determine color variation within each box of ammunition. Each box was viewed using the auto exam function of the software, which varies illumination sources and filters to produce various viewing conditions to determine consistency. The viewing conditions included visible, absorbance, transmission, spot fluorescence, near-infrared, and ultraviolet (312 nm and 254 nm).

Fourier Transform Infrared Spectroscopy (FTIR)

Shavings of the plastic bullets were used for FTIR analysis. A Nicolet 6700 FTIR (Omnic™ 8.2 software) equipped with a Smart iTR™ accessory was used to study the spectral properties of each polymer tip (n=585). Collection parameters for the iTR™ analysis consisted of 80 scans at a resolution of 4 nm, which resulted in data spacing of 1.928 cm-1 under autogain control. The final format was recorded in log (1/R) vs. wavenumber (cm-1) with a spectral range of 4000-840 cm-1. No correction was performed on the resulting spectra. A background spectrum was collected every 25 minutes [20].

Discriminant Analysis

The Omnic™ Specta™ (1.0.0) HR Specta Polymers and Plasticizers by ATR library was used to identify the material of the tips. TQ Analyst™ (v.8.3) software package (Nicolet) [21] was used to perform discriminant analysis (DA) on samples of the same color. Discriminant analysis was performed over various spectral regions to determine if separation was achieved based on the performance index.

Discriminant analysis is a multivariate statistical method that assists in the classification of spectral data into distinct groups.

Color	Bullet Distributor	Polymer Tip Manufacturer	Lot #	Caliber	Grain	Type of Tip	n	Color change under UV light at 312nm	Polymer Identification	Elements Present	Semi-Quantification (%W± Variance)
Black	CCI®	Hornady	M13R19	17 HMR	17	V-Max™	9	-	POM	Ca, Cu, Fe, S, Si, Ti	Ca: 9 ± 12 Cu: 12 ± 12 Fe: 4 ± 1 S: 9 ± 2 Si: 4 ± 1 Ti: 61 ± 8
Black	CCI®	Hornady	M13R19	17 HMR	17	V-Max™	11	-	POM		-
Black	Federal Premium®	Hornady	B01S16	17 HMR	17	V-Max™	20	-	POM		-
Black	Remington®	Swift™	L24 SA29L	300 Rem. Ultra Mag	180	Scirocco™ Bonded	20	-	POM		-
Blue	Nosler	Nosler	114113121342 IH1F71	25	100	Ballistic Tip®	20	Green	POM	Cu,Si, Ti	-
Blue	FNH USA®	Hornady	1130969032	5.7 x 28 mm	40	V-Max™	20	Orange	POM		-
Brown	Nosler	Nosler	1342861861 KH12F72	6.5 mm	100	Ballistic Tip®	20	-	POM	Fe, Ti, Zn	-
Green	Federal Premium®	Nosler	NV15X540	300 WSM	150	Ballistic Tip®	20	-	POM	Cu, Ni, Si, Ti	Cu:10 ± 2 Ni: 14 ± 1 Si: 11 ± 2 Ti: 65 ± 4
Green	Sierra	Sierra	9276301440	22	40	Plastic Tip	20	-	POM	Ca, Cr, Ti	-
Green	Nosler®	Nosler	4164163670	30 Caliber	N/A	Plastic Tip	20	-	POM	Ca, Cu, Ti	Ca: 4 ± 1 Cu: 15 ± 3 Ti: 81 ± 2
Grey	Winchester®	Hornady	F06R03	17 HMR	17	V-Max™	20	-	POM	Al, Ti	-
Silver/Grey	Winchester®	Nosler	16WL52	7 mm WSM	140	Ballistic Silvertip®	20	-	POM	Fe, S,Ti	-
Orange	Nosler Custom®	Nosler	1359 60003 02011	22-250 Rem	55	Ballistic Tip®	20	-	POM	Fe, Si, Zn	Fe: 29 ± 6 Si: 39 ± 22 Zn: 31 ± 19
Orange	Nosler Custom®	Nosler	60001 02016	223 Rem	40	Ballistic Tip®	20	-	POM	Fe, Si,Zn	Fe: 28 ± 7 Si: 39 ± 14 Zn: 33 ± 11
Orange	Federal Premium®	Nosler	NOU47Z562	223 Rem	55	Ballistic Tip®	20	-	POM	Fe, Si,Zn	Fe: 28 ± 7 Si: 38 ± 12 Zn: 35 ± 15
Orange	Nosler	Nosler	1181 9531165 AE04F6-1	22 Caliber	55	Ballistic Tip®	20	-	POM	Fe, Si,Zn	Fe: 28 ± 6 Si: 36 ± 16 Zn: 36 ± 13
Purple	Federal Premium®	Nosler	NOU 5X724	243 Win.	70	Ballistic Tip®	20	-	POM	Ca, Si, Ti	-
Purple	Federal Premium®	Nosler	033X504	204 Ruger	32	Ballistic Tip®	20	Yellow	POM		-
Red	Hornady	Hornady	3102025	7mm-08 Rem	139	SST®	20	-	POM	S,Ti	S: 36 ± 6 Ti: 64 ± 3
Red	Federal Premium®	Nosler	U1T442	7mm-08 Rem	140	Ballistic Tip®	20	-	POM	Ca, Fe, Si, Ti	-
Red	Hornady	Hornady	E12S06	17 HMR	17	V-Max™	20	-	POM	S, Ti	S: 35 ± 4 Ti: 65 ± 4
Red	Nosler	Nosler	3323103670	7mm	150	Ballistic Tip®	20	-	POM	Fe, Zn	Fe: 23 ± 1 Zn: 77 ± 1
Red	Hornady	Hornady	3111056	243 Win	58	V-Max™	20	-	POM	S, Ti	S: 35 ± 4 Ti: 65 ± 4
Red	Hornady	Hornady	3060330	204 Ruger	32	V-Max™	20	-	POM	S, Ti, Zn	S: 33 ± 3 Ti: 37 ± 4 Zn: 30 ± 9
Red	Hornady	Hornady	J03K09	17 Mach 2	17	V-Max™	20	-	POM	S, Ti, Zn	S: 33 ± 4 Ti: 37 ± 4 Zn: 31 ± 5
Red	Hornady	Hornady	3101826	308 MAR EXP	160	FTX®	20	-	Polyester urethane - bis(phenylisocyanate) copolymer	Ca, S, Ti	-
Red	Hornady	Hornady	3110280	12 GA Shotgun	300	FTX®	5	-	Polyester urethane - bis(phenylisocyanate) copolymer	Ca, S, Ti	-
Silver	Winchester®	Nosler	16WL52	7 mm WSM	140	Ballistic Silvertip®	20	-	POM	Fe, S,Ti	-
White	Nosler Custom®	Nosler	60063 07008	300 WSM	180	AccuBond®	20	-	POM	Ca,Si, Ti	-
White	Nosler Custom®	Nosler	1326 60042 09017	7mm-08 Rem	140	AccuBond®	20	-	POM	Si, Ti	-
White	Nosler Custom®	Nosler	814551 60049 05906	308 Win	165	AccuBond®	20	-	POM	Si, Ti	-
Yellow	Nosler	Nosler	Not Available	270	130	Ballistic Tip®	20	-	POM	Ti	-

Table 2

The rationale of discriminant analysis in the present situation was to establish discriminant functions to characterize the forensic samples of polymer tips. The software (TQ Analyst™) compiles an average spectrum from the known samples, and then each is assigned a numerical score based on the deviation from the calculated spectrum. These numerical scores are then plotted to provide a graphical representation [21].

Lastly, each known sample is validated by determining the Mahalanobis distance of the sample from the average spectrum. Therefore, each polymer tip sample is assigned to the nearest group centroid based on its calculated Mahalanobis distance. The closer a specimen is to a particular centroid class, the higher the likelihood that it will be classified with that particular sample set.

An example of the discriminant analysis experiment is to look at two of the red plastic-tipped bullet samples from Hornady and Nosler. This set consisted of 20 Hornady V-Max® and 20 Nosler polymer tips that were characterized by the FTIR as being polyoxymetheylene (POM), a thermoplastic polymer commonly referred to as acetal or polyacetal. These polymer samples were used as a reference population to calculate the discriminant function of each type and to establish the performance index. The performance index is a measure of how well a discriminant analysis method can categorize spectra from calibration samples. The performance index of the discriminant analysis was 95.0 percent, which indicates that DA can differentiate between Hornady and Nosler POM polymers. Reliable categorizations occur when the performance index exceeds 90% [21]. As demonstrated in Figure 2, Hornady and Nosler POM polymers are segregated within their corresponding populations, thus FTIR and discriminant analysis can distinguish between the red Hornady and the red Nosler POM polymers, despite the fact that both have similar FTIR spectra.

Therefore, if an unknown red plastic was associated with wildlife mortality, and FTIR analysis indicates the plastic is a POM polymer, then the spectrum will be compared against the Hornady and Nosler sample set. The specimen will be classified as similar to Hornady if it falls within the centroid class made by the Hornady samples, or similar to Nosler if it falls within the centroid class made by the these polymer tip samples.

X-ray Fluorescence (XRF)

The plastic-tipped bullets were sampled by a transverse cut three-quarters through the polymer tip with a soldering iron equipped with a blade. The tip was then snapped off to achieve melt and break zones on the cross-section. The melt and break zones were analyzed with an Edax Orbis X-ray Fluorescence Spectrometer (XRF) equipped with an Apollo Silicon Drift Detector. The X-ray source was set at 30 keV and 300 µA with a 30-µm spot size and collection lifetime of 30 seconds. The Hornady FTX® polymer tips were shaved with a utility knife, and the shavings were analyzed under equivalent parameters. All samples were analyzed under vacuum to determine the elemental content. The analysis considered elements with higher atomic weights than sodium on The Periodic Table

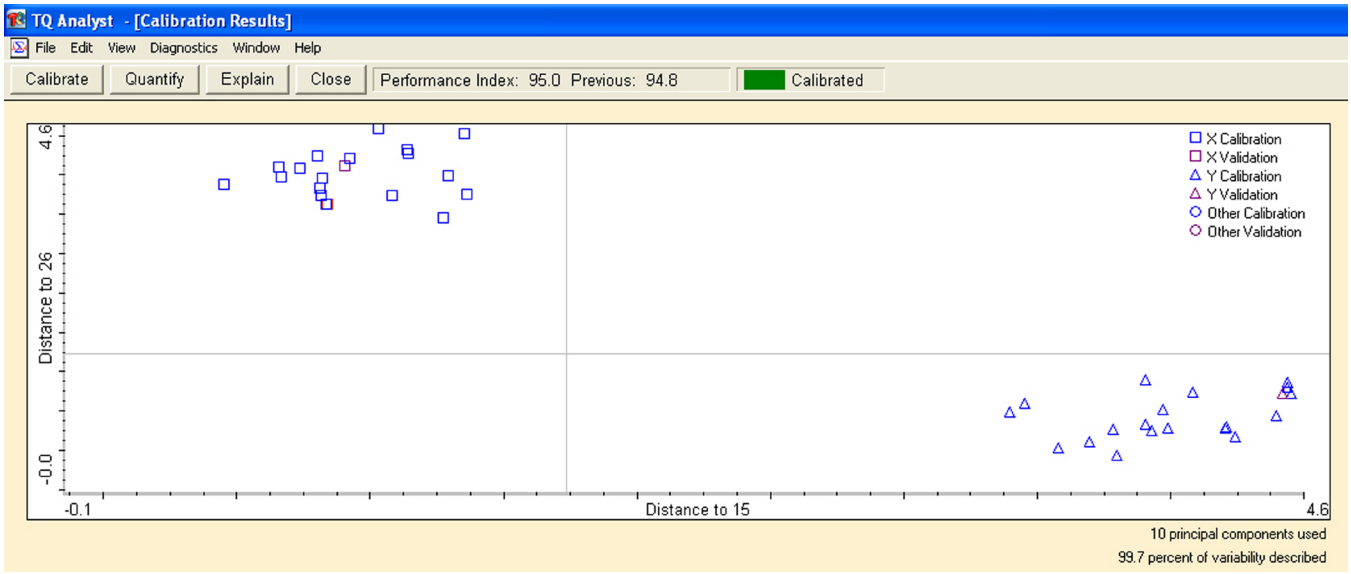

Figure 2

of the Elements. Semi-quantitative analysis was used to determine weight percent of select samples [22].

Results and Discussion

The results from commercial sources indicate that POM is the most common polymer being used in plastic-tipped bullets (See Table 1). POM polymers have been described and characterized by Chanda and Roy [23]. Additionally, we encountered a polyester urethane - methylene bis (phenylisocyanate) copolymer from Hornady. The analysis of the reference polymers obtained directly from manufacturers also identified POM as the most common polymer, although we also encountered a polyetherimide and a polycarbonate (See Table 1), which were not seen in the commercial ammunition. Although we are aware that POM is manufactured as a homopolymer [18] and as a copolymer [19], our analysis could not distinguish between these two polymer types.

The results of all the analysis are summarized in Table 1 and Table 2. Table 2 is sorted based on color, because the recovery of evidence and the subsequent analysis is guided by the original color of the polymer tips.

Black polymer tips

Within this study, there were three sources of black plastic-tipped bullets: CCI (17 HMR), Remington (Swift Scirocco™ Bonded 300 Rem. Ultra Mag), and Federal Premium® (17 HMR). Black plastic-tipped V-Max® bullets are loaded into 17 HMR cases under the labels of CCI and Federal. The V-Max® was identified as POM. Swift Bullet Company uses black polymer tips in all of their Scirocco™ line of bullets, which are also molded from POM. There was no appreciable difference observed with the VSC. Analysis by XRF showed that the CCI box contained two different batches of POM. Nine of the twenty polymer tips sampled contained silicone, sulfur, calcium, titanium, iron, and copper, while the remaining 11 exhibited none. XRF analysis of the Swift Scirocco™ plastic-tipped bullets also did not reveal elements present. Nevertheless, FTIR-DA was able to differentiate the two polymers that did not have elements present, i.e., CCI vs. Swift Scirocco™.

Blue polymer tips

The two sources of blue plastic-tipped bullets encountered were Nosler (25 cal) and Hornady (5.7 x 28 mm). Both tips were molded from POM. When viewed with the VSC at 312 nm and 254 nm, the Nosler tips had a green color, and the Hornady exhibited an orange color (See Figure 3). XRF analyses, as well as FTIR-DA, were also useful in differentiating these two brands.

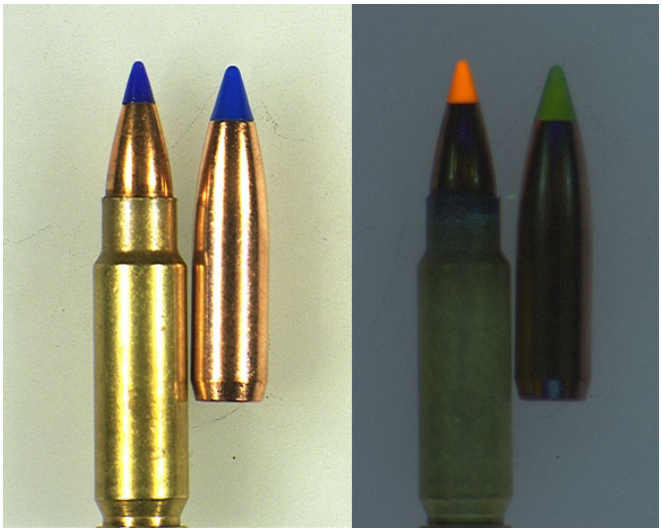

Figure 3

Brown polymer tips

Nosler 0.264-inch/6.5-mm bullets were the only encountered source of brown plastic tips. These tips are manufactured from a POM polymer.

Green polymer tips

We encountered three sources of green, plastic-tipped bullets: Sierra (22 cal 40 grain BlitzKing), Federal Premium® (300 WSM Nosler Ballistic Tip®), and Nosler (30 caliber Trophy Grade Bullets™). All three polymer tips are manufactured with POM. XRF was able to distinguish the three classes based on their elemental composition (See Table 2). FTIR-DA also distinguished the polymer tips of the Sierra bullets from the tips of both the Nosler and Federal Premium® bullets. However, FTIR-DA could not distinguish between the polymer tips of the Federal Premium® and the Nosler bullets. It was interesting to note that the tips could be distinguished with XRF analysis but not FTIR-DA even though they are both from Nosler.

Grey polymer tips

Winchester ammunition and Nosler Combined Technology® Ballistic Silvertip® bullets are the only known sources of silver/grey plastic-tipped bullets [1]. Winchester 17 HMR cartridges are loaded with Hornady V-Max® bullets with a silver/grey tip and the Ballistic Silvertip® line of cartridges utilize bullets manufactured by Nosler with a silver/grey polymer tip. Bullets from Winchester 17 HMR V-Max®

cartridges and Ballistic Silvertip® 7-mm bullets were sampled. Both tips were molded from POM. The VSC gave equivocal results, but the analysis with XRF and FTIR-DA was able to distinguish the polymer tips. While both polymer tips contained titanium, the Ballistic Silvertip® also contained aluminum and the V-MAX® tips contained iron and sulfur.

Orange polymer tips

There are two sources of orange polymer tips: Nosler Ballistic Tip® (22 caliber, 22-250 Remington, and 223 Remington) and Federal Premium® (223 Remington). All of the orange polymer tips are produced using POM. Neither VSC, XRF, nor FTIR-DA analyses could differentiate the different sources. This result is not surprising since all of the orange tips are made by Nosler.

Purple polymer tips

Two boxes of ammunition containing purple plastic-tipped bullets were analyzed, which are sold by Federal Premium® (243 Winchester, 204 Ruger) with the Nosler Ballistic Tip®. Both tips were molded from POM. Visually, the 204 Ruger polymer tips appeared to be more of a reddish-purple than the 243 Winchester polymer tips. The two sources of purple plastic tips could be distinguished by XRF and/or FTIR-DA.

Red polymer tips

Three sources of red plastic-tipped bullets were analyzed: Hornady, Federal Premium®, and Nosler. Analysis indicates that Hornady uses two different types of polymer tips: POM and a polyester urethane - methylene bis(phenylisocyanate) copolymer. Federal Premium® and Nosler use tips molded from POM. Of the nine red polymer tip populations, only two could not be distinguished from one another with combined analysis, leaving eight different classes.

The VSC could not distinguish any color difference between the red tips. XRF analysis distinguished five major categories of plastics based on elemental composition (See Figure 4). Discriminant analysis was able to elucidate differences between each population with the exception of the two polyurethane tips (See Figure 4).

The polyester urethane - methylene bis(phenylisocyanate) copolymer tips by Hornady (308 cal. FTX® Marlin Express and 12 gauge 300 gr. FTX®, SST® shotgun slugs) were easily

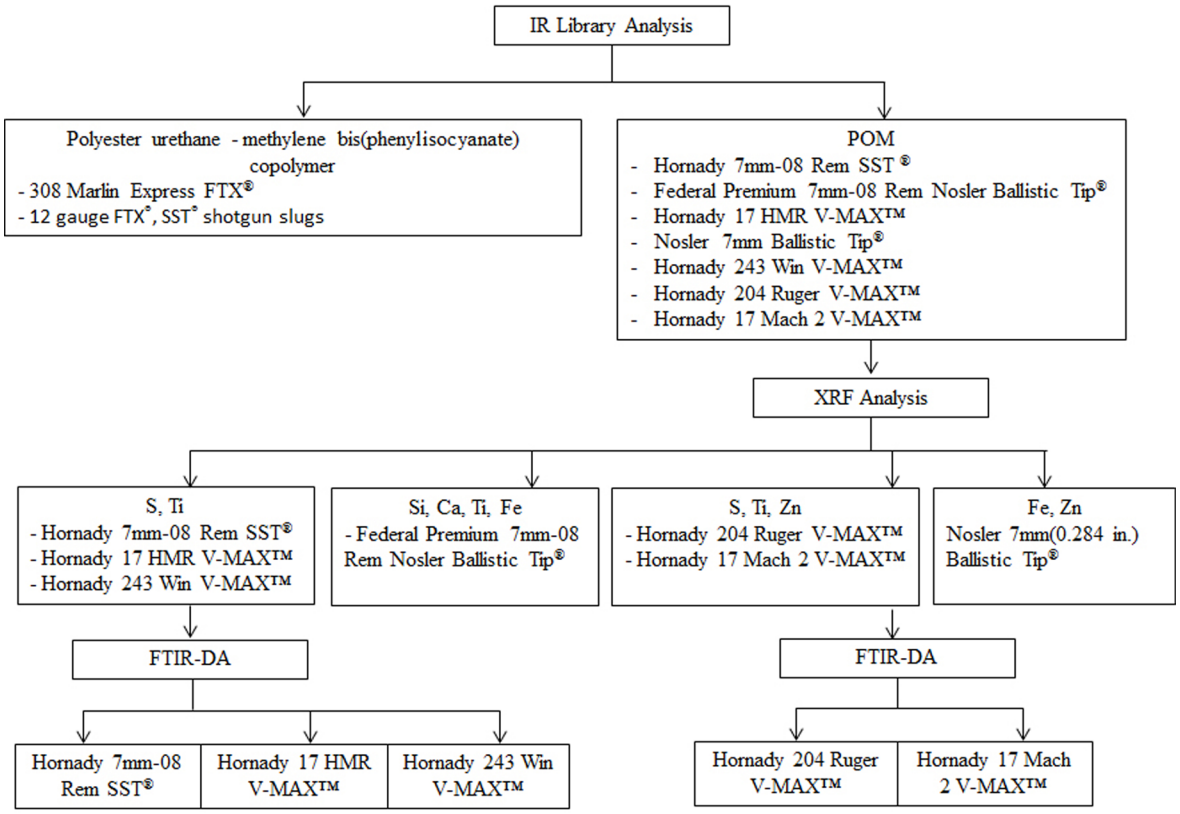

Figure 4

identified by FTIR. The XRF analysis of both boxes showed similar elemental composition (Table 2), and FTIR-DA could not differentiate them. This is expected given that they are both Hornady FTX® molded tips [5].

White polymer tips

The three boxes of ammunition containing white plastic-tipped bullets were analyzed, which are distributed by Nosler Custom® (300 WSM, 7mm-08 Rem, and 308 Win.). Each of the boxes contained Nosler polymer tips (Accubond®) molded from POM. The VSC, XRF, and FTIR – DA could not distinguish between these samples. This was to be expected as each of the samples contained Nosler Accubond® tips [2].

Yellow polymer tip bullets

One source of yellow plastic-tipped bullets was analyzed: Nosler (270 cal). These yellow tips are manufactured from a POM polymer.

Conclusions

Plastic-tipped bullets seem to be here to stay. Plastic tips have successfully replaced exposed lead points in rifle bullets and have been incorporated into some of the popular handgun cartridges as well as shotgun slugs and muzzle loader projectiles. Plastic tips have also been added to lead free bullets [24].

Using color, FTIR coupled to the statistical power of discriminate analysis, and XRF, we were able to characterize the polymers found in common commercially available plastic-tipped bullets. The data is surprising because the high quality control used by the manufacturers provides an opportunity for forensic class character determination. In only one instance, a box of ammunition indicated that the polymer originated from two different batches of POM (CCI® 17 HMR). The analysis of the black plastic-tipped CCI® 17 HMR is also a good reminder that the analysis of bullet polymers will continue to evolve, and that future batches may be composed of different polymers or the elemental profiles may reveal elements or ratios not encountered in this study.

Disclaimer

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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