PHYSICAL AND CHEMICAL CHARACTERISATION OF BULLET IMPACT HOLES ON SHEET METAL SURFACES BY 9 MM CALIBRE BULLETS

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by

SYAMSUL ANUAR BIN ABD MALIK

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CERTIFICATE

This is to certify that the dissertation entitled PHYSICAL AND CHEMICAL CHARACTERISATION OF BULLET IMPACT HOLES ON SHEET MEETAL SURFACES BY 9 MM CALIBER BULLETS is the bona fide record of research work done by Mr. SYAMSUL ANUAR B ABD MALIK during the period from February 2019 to August 2019 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Master of Science (Forensic Science).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledge. I also declare that it has not been previously for concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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Date:

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometer
Al	aluminium
ARX	advance rotational extreme
ASTM	American Society Testing and Materials
BSE	backscattered
Ca	calcium
CABL	composition analysis of bullet lead
Cu	copper
F	fluorine
Fe	iron
FMJ	Full metal jacketed
GSR	gunshot residues
ICP-MS	inductively coupled plasma-mass spectrometry
ICP-OES	inductively coupled plasma-optical emission spectroscopy
JDP	Jacketed deform projectile
JHP	Jacketed hollow point
LRN	Lead round nose
NAA	neutron activation analysis
NATO	North Atlantic Treaty Organization
Ni	nickel
P	phosphorus
Pb	lead
Pb-Sb-Sn Alloy	lead-antimony alloy
PULAPOL	Police Training Centre Kuala Lumpur
SE	secondary electrons
SEM-EDX	Scanning electron microscopy and energy disperse X-ray
SMG	submachine gun
Sn	tin
SSMS	spark source mass spectrometry
WDXRF	wavelength dispersive x-ray fluorescence
Zn	Zinc

LIST OF SYMBOLS

%	percent
º	degree
g	gram
grs	grains
kV	kilovolt
m	meter
mm	milimeter
ms^{-1}	Meter per second
nm	nanometer

CIRI-CIRI FIZIKAL DAN KIMIA BAGI LUBANG IMPAK PELURU YANG DISEBABKAN OLEH PELURU BERKALIBER 9 MM KEATAS PERMUKAAN LEMBARAN BESI

ABSTRAK

Penyiasat forensik kini menghadapi cabaran untuk menentukan lubang peluru dan juga jenis peluru yang telah menyebabkan kerosakan pada suatu sasaranm terutamanya dalam kes-kes yang melibatkan tembakan pandu lalu, serangan hendap dan tembakan bersilang yang berkaitan dengan kenderaan, dengan peningkatan trend dalam kes pembunuhan yang mangsa berada dalam suatu kenderaan. Dengan pelbagai jenis peluru yang terdapat di pasaran, sama ada dengan kaliber yang sama atau berbeza, adalah sukar untuk mengenal pasti suatu lubang peluru dengan pastinya, and juga menentukan jenis peluru yang menghasilkan lubang tersebut. Sehubungan dengan itu, kajian ini bertujuan untuk mencirikan lubang-lubang impak peluru yang disebabkan oleh amunisi berkaliber 9 mm pada dua pintu automotif yang berlainan secara fizikal dan kimia. Dalam kajian ini, teknik visual dan makroskopik telah digunakan untuk memerhati ciri-ciri morfologi lubang-lubang impak, serta penggunaan kaedah mikroskopi elektron pengimbasan-serakan sinaran-x bertenaga (SEM-EDX) untuk menentukan kandungan unsur tak organik daripada sampel yang dipulihkan semula daripada lubang-lubang impak. Perbezaan besar antara lubang peluru berjaya diungkapkan melalui pemeriksaan fizikal dengan memerhatikan ciri-ciri unik pada setiap lubang peluru dari segi diameter lubang peluru, ketinggian kawah peluru, kesan kelopak bunga, corak pinggir kawah kesan peluru, corak lilitan dalaman, pembentukan mahkota atau cincin berlogam, serta taburan sisa surih peluru di sekitar lubang peluru. Selain itu, analisis unsur mendedahkan

bahawa anak peluru tertentu yang mempunyai kandungan unsur tak organik yang berbeza, seperti yang diperlihatkan dalam anak peluru polimer (ARX) yang tidak mengandungi plumbum tetapi dengan kehadiran sulfur, yang telah dipindahkan ke atas lubnag peluru. Kuprum dan zink dikesan dalam semua peluru kecuali anak peluru berhidung bebulat berplumbum (LRN) dengan ciri tidak bersalut. Kesimpulannya, ciri-ciri morfologi pada lubang impak yang dihasilkan boleh membolehkan penyisihan anak peluru tertentu, and SEM-EDX selanjutnya dapat membezakan anak peluru tidak bersalut daripada lubang peluru yang diperbuat oleh anak peluru bersalut. Lubang peluru yang disebabkan oleh pelbagai jenis amunisi berkaliber 9 mm dapat dicirikan melaluipemeriksaan fizikal dan analisis unsur, and hal ini mempunyai potensi yang besar dalam penyiasatan bahan bukti forensik yang sering dijumpai dalam kes-kes penembakan.

PHYSICAL AND CHEMICAL CHARACTERISTIC OF BULLET IMPACT HOLE ON SHEET METAL SURFACE BY DIFFERENT TYPE 9MM CALIBRE BULLET

ABSTRACT

Forensic investigators are currently facing challenges to determine bullet holes due to the variety of bullet type that have caused damage on a target, especially in cases involving drive-by shooting, ambush shooting, as well as cross fire shooting related to vehicle. It is rising trend in murder cases where the victim was sitting inside a vehicle. With a variety of bullet types available in the market, whether with the same or different calibres, it is difficult to definitely confirm a bullet hole, and also to determine the bullet types that caused that hole. In view of this, this study was aimed to characterise bullet impact holes made by 9 mm calibre ammunition on two different automotive doors through physical and chemical means. In this study, visual and macroscopic techniques was used to observe the morphological features of impact holes, as well as the application of scanning electron microscopy-energy dispersive x-ray (SEM-EDX) method to determine the inorganic elemental composition of samples recovered from the impact holes. Substantial differences among the bullet impact holes were successfully disclosed upon physical examination by observing the unique characteristics on each bullet hole, in term of the bullet hole diameter, height of the bullet crater, petalling effect, radial edge pattern, internal circumference pattern, crown or metallic ring formation, as well as the distribution of bullet dust residues around the bullet hole. Besides, elemental analysis revealed that certain projectile could have contained different composition of inorganic elements, as observed in polymer (ARX)

type bullet with no lead was detected but with the presence of sulphur, which have been transferred to the bullet hole. Copper and zinc were detected in samples recovered from impact holes made by all projectiles, except lead round nose (LRN) type projectiles due to unjacketed property. In conclusion, morphological features of the produced impact holes could allow for exclusion of certain projectile types, and subsequently SEM-EDX further discriminated unjacketed projectile from those bullet holes made by jacketed projectiles. Bullet hole produced different types of 9 mm calibre ammunition could be characterised through physical examination and elemental analysis, possessing great potential in investigating the forensic evidence frequently encountered in shooting cases.

CHAPTER ONE: INTRODUCTION

1.1 Study Background

In Malaysia, firearm related crimes frequently draw a lot of public attention as they are particularly serious, and therefore need the greatest investigative effort by the investigators to recover and examine every potentially analysable trace in a scene. In recent years, a rising trend on drive-by shooting cases was evident in our country. According to a Criminology analyst, Dato' Akhbar Satar, the current trend is probably due to the existence of contract killers or assassins' group in Malaysia, who had been hired to carry out such criminal activities. Usually, the favourite spots for the activities are taking place at specific places, such as roadside, traffic light junction or in front of shop premise, where the murderers are easy to escape and run away from the crime scene.

Till July 28th, 2016, there were 16 cases involving drive-by shooting and killing were reported (Israr, 2016). Amongst, a businessman was gunned down by drive-by shooting involving consecutive six shots at Sungai Rasau toll while he was driving on June 2016. On 13th July 2016, another businessman was shot several times when he was waiting inside his car at a junction during the shooting-by event. In 2018, several other cases were reported by the media. One of the cases was occurred on 26th of May 2018 in Jalan Kulim, Bukit Mertajam's traffic light junction where one man wearing mask fired nine shot to a business man who stopped his car at the junction and fled from the scene (Safini, 2018), According to the witnesses, the firearm used was a semi-automatic pistol. The victim suffered three injuries, with one to the arm, and another two on his upper chest and shoulder but luckily, he survived the incident. The forensic investigating team has successfully recovered 11 spent bullet cartridge cases at the crime scene.

In drive-by shooting cases, in addition to fired projectile as well as the ejected cartridge case, if there is any, an impact target substance could possess also high evidential value. Utmost encountered forensic evidence in such case will be on the car door whenever a bullet had passed through that particular surface. The fundamental elements in forensic shooting investigation are to determine whether a bullet impact hole, through discovery and identification, could help in revealing the shooting scenario and subsequently providing the important information for forensic investigation. More specifically, details such as the numbers of shooters or firearms involved in one case, the model or ammunition used in the shooting, the location where a shooter stay during an event, as well as other important information which could be used to link a shooting event to a suspect (Haag and Haag, 2011c). Usually in criminal trials, human life is at stake when its related to firearm and the identification evidence in firearm related evidence is of great importance when admissibility is to be questioned (Serhant, 1931).

"*Every contact leaves a trace*". This Locard's Principles of Exchange is a key principle underlying forensic firearm investigation that enables forensic scientists to link the suspects to victims, to physical objects, and also to crime scenes. In a shooting scene where firearm and metal surfaces were involved, the key challenge to law enforcement authorities is to establish the answer for the question "what caused this?" by scientifically determining whether or not an impact mark on the metal surface is made by a projectile. If there are multiple bullet holes found in a shooting scene, such as police-criminal shootout, the next question arisen is "how to differentiate bullet holes made by different projectiles shot by different person in a shooting scene" without any doubt or possibility that it can be caused by another projectile weapon. In view of this, this study focused on forensic evidence to be recovered upon the interaction of bullet with the sheet metal of car door to establish the physical and chemical characteristics on the bullet impact holes upon perforation by different types of bullets of the same calibre. The examination on the physical damage on a bullet hole, as well as the chemical analysis of the trace residues, such as bullet wipe a target, shall aid in answering the above questions.

1.1.1 Bullet geometry and design

A bullet is manufactured with different intended features, giving class characteristics including the caliber, weight, composition, design and cannelures, base–heel–nose shape, as well as other subtle features (Haag and Haag, 2011a). A bullet is designed in such a way to suite a particular firearm and also serves the desired functions and conditions. One major aspect of bullet is the different nose shapes, or also known as bullet nose geometry, among the various types of bullets. Figure 1.1 illustrates the different type of bullet nose geometry, from top left (a) Polimer bullet – advance rotational extreme (ARX) design, (b) Jacketed hollow point (JHP), (c) Lead round nose (LRN), (d) Full metal jacketed (FMJ), (e) Jacketed deform projectile (JDP) and (f) Hexagon. The common geometry available in the marketplace nowadays, either used by law enforcement authorities or individuals are the FMJ, JHP, LRN, JDP, as well as the wad/semi-wadcutter types (Haag and Haag, 2011a). Figure 1.2 shows the examples of several types of 9 mm caliber bullets with different nose geometry in profile and oblique views.

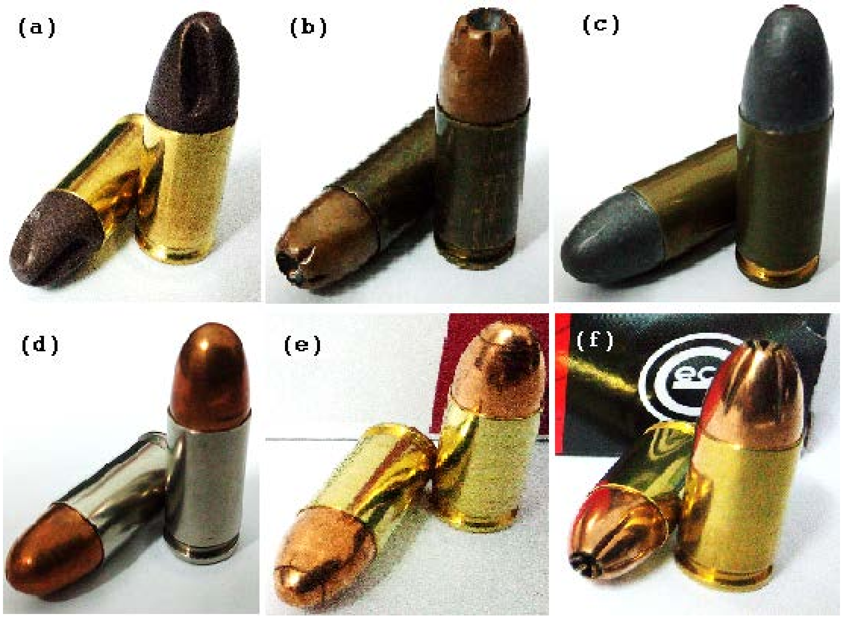

Figure 1.1. A different type of bullets nose shape.

Figure 1.2. (a) Profile and (b) oblique (base) view of different type of bullets. From left to right: cannelured Winchester aluminum-jacketed bullet; nickel-plated Winchester JHP bullet; Russian FMJ bullet with copper-washed finish over steel jacket; Remington JHP bullet with scalloped jacket; Federal Hydra-Shok bullet; Winchester Black Talon bullet with black copper oxide finish; CCI-Blount Gold Dot JHP bullet; Remington Golden Saber bullet with brass jacket (Haag and Haag, 2011a)

In fact, certain class characteristics which allow the discrimination of different types of ammunition could be seen, on the basis of the manufacturers. These bullets could have been made up of different materials, using different materials. Additionally, the effect upon impact by bullets with physical variations could produce industrial features, specifically when the shape and materials of the bullets are varied (Haag and Haag, 2011a). Different materials have been reported their uses in manufacturing bullets, such as copper-zinc alloys, copper, aluminium, lead, as well as nickel, giving different properties to the bullet (Haag and Haag, 2011b). Note that all the bullets are soft in nature, regardless of the compositions, although their hardness would be varied with different materials. Examples of varying bullet deformation features upon impact on target are illustrated in Figure 1.3.

Figure 1.3. Selection of bullets from Figure 1.2 after discharge into a tissue simulant. Top row: unfired specimens. Middle and bottom rows: two examples and views of each bullet after discharged (Haag and Haag, 2011a).

1.1.2 Bullet Impact Hole on Sheet Metal

Nowadays, shooting cases are not uncommon and they can happen everywhere including Malaysia even there is strict firearm control laws Firearms Act (increased penalties) 1971. According to Haag and Haag (2011c), sheet metal of motor vehicle, especially the car door could be one of the important forensic evidence encountered in shooting incident. Being designed to be adjacent to a passenger in the car, it protects the passengers from the external impact, but a successfully perforated bullet through the sheet metal could hit and injure the individual inside that car.

A car door is commonly made from cold rolled sheet metal which is commercially available cost-effective material, its being used in and applied in many applications (Durmuş *et al.*, 2011). The thickness of car sheet metal usually manufactured as 22 gauge (0.82 mm) (Nennstiel, 1986). Today, it is common to have 1 mm thickness instead, in majority of the cars produced. Also, the latest technology adapted usage of aluminium material in the production of modern small and medium size car model, such as being use by BMW 6 series, Audi A2/A8 series, Honda NSX and Jaguar. The usage of this material are due to increased strength from reinforce ability, reusability/recyclability, mass production capability and reducing vehicle weight (Hirsch, 2004).

From the sheet metal which was used as an impact target, the nature of bullet holes produced by perforated bullets could probably point to their respective bullet calibres, weight, nose shape, impact velocity, as well as the impact angle (Haag, 1997). Due to the fact that a sheet metal can be deformed plastically, hold the circumference shape of the projectile, and subsequently bends toward the projectile's travelling vector, all projectiles discharged from firearms are able to perforate any particular thickness of metal surface (Haag and Haag, 2011c), given that they carry adequate impact velocity. Indentation and stretching line can be clearly observed at the entry point, while the bending out of metal is evident at the exit side of impact hole (Haag and Haag, 2011a). Therefore, the formation of bullet hole, via physical examination and chemical analysis, could provide important information on a shooting case, and also for the reconstruction of the shooting event. In contrary, if the velocity of a projectile is less than the threshold velocity to perforate a metal surface, the metal would only endure an amount of distortion due to its malleable nature (Haag and Haag, 2011b). In this case, threshold velocity refers the velocity that required for a perforation to occur on impact against a target surface. Figure 1.4 shows an example of the deformation of sheet metal on the entry point of the bullet impact hole that bends towards the travel direction of that projectile. On the other hand, the exit point of a bullet hole showed the bending of metal away from the metal surface, as demonstrated in Figure 1.5.

Figure 1.4: The bullet entry point on sheet metal shows the direction of projectile travel.

Figure 1.5: The bullet exit point shows metal deformation bend in the same direction of the traveling bullet.

In order to determine the cause that produced an impact hole, and subsequently predict the possible projectile on the basis of the type, make, model and calibre, it is preferable to look for fired cartridge case or spent projectile at the crime scene. Regardless of the firearm used, projectile discharged has the potential to be found at the scene of a shooting, being stopped by any object or even by a victim’s body. However, it may be distorted or fragmented on impact with a surface, or even completely lost from the scene. For fired cartridge cases, they are only restricted to those firearms which eject the casings upon each shooting, and potentially recovered. Such forensic evidence may not always be recovered, or even if so, they are not always in ideal conditions which may greatly impede positive determination. Therefore, the sheet metal, especially the door car whenever a shooting-by event, could be potential forensic evidence, serves to provide clues for the investigation of criminal cases.

1.1.3 Scanning electron microscopy and energy disperse X-ray spectroscopy (SEM-EDX)

Scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDX) technique is one of the powerful tools for particle analysis, particularly from the view of forensic science. It is well known that inorganic constituents of gunshot residues (GSR) are readily analysed by SEM-EDX for identification purpose, and it continues to be routine procedure in most forensic laboratories to date. Note that GSR analysis was covered by ASTM method through the detection of particles with high atomic number elements by SEM backscattered electron signals and EDX spectra. SEM provides the morphological features of any particle observed under the microscope while the elemental profiles of such particle could be determined by EDX. In addition to detection of GSR particles, it is also being utilised to determine the chemical constituents on various residues around entrance holes for ballistic applications (Ravreby, 1982).

In brief, SEM is a method involving high-resolution imaging of surfaces up to more than 100,000× magnification power to produce grey scale image. The technique employs electron beams, usually backscattered (BSE) and secondary electrons (SE), in order to obtained important information regarding a sample (Antonis, 2018). On the other hand, EDX included elemental analysis based on the generation of characteristic x-rays in atoms of the sample by the incident beam electrons, resulting in two fundamental physical events, namely elastic scattering and inelastic scattering (Scimeca *et al.*, 2018). These x-rays are characteristic for the element from which they originated, and therefore, indicating the presence of detected element in the sample. Due to its non-destructive nature, it always preferable as compared to other common analytical methods in determining the physical appearance and elemental profile of trace evidence deposited on a substrate (Hu *et al.*, 2009).

1.2 Problem Statement

As the number of sophisticated crimes using firearms arises, the forensic investigators face challenges in determining specific bullet hole was made by specific ammunition type, to allow for linkage between that bullet hole with the projectile or fired cartridge case recovered from a scene of crime. Moreover, the evidence recovered is not always in an ideal condition which allows for straight forward forensic determination, and in many circumstances, firearm may be absent, cartridge may not be recovered from the scene, and bullets may be completely lost or severely deformed. In such cases, the confirmation of a bullet hole is definitely important.

In order to assist in forensic investigation, particularly involving drive-by shooting, two key problems need exploration, which covered the physical appearance of the impact marks and traces distribution on metal surfaces. Firstly, the variations on the effects upon striking of projectile onto a target could be due to numerous factors, including the metal composition of a target. The confirmation of the source that had made an impact mark on a particular metal surface is important for accurate reconstruction of a crime, especially a firearm related case. Secondly, it is unknown whether or not traces from a projectile could be transferred to the peripheral of an impact mark made by a projectile, and *vice versa*. Hence, the morphological examination and chemical analysis shall allow the investigation on the occurrence of exchange between both contacting materials. In fact, this study enables the address of court-related questions as to whether or not a hole was caused by a projectile, and what type of ammunition could contribute to the formation of that bullet hole, if it was determined as a bullet hole.

1.3 Aim and Objective

This study was aimed is to characterise the bullet impact holes made by different types of 9 mm calibre projectile, hit on car doors through physical and chemical analyses. In order to achieve the aim, the objectives of the study are as follows:

1. To differentiate the morphological features of bullet impact holes upon impacted by different types of 9 mm calibre bullet through visual examination.

2. To detect and differentiate the trace residue recovered from bullet impact holes, if any, upon impacted by different types of 9 mm calibre bullet through SEM-EDX.

3. To establish the possibility to identify a bullet impact hole based on the output from physical examination and chemical analysis.

1.4 Significance of Study

In brief, this study focuses largely on establishing the possibility to link a bullet impact hole with the projectile that impacted on, and subsequently perforated through the surface. Since the physical appearance on a sheet metal could be varied due to the utilisation of different ammunition during shooting activities, as well as the transference of trace elemental residues from the projectile to the impact surface remained unclear, this study could serve to provide a clue on the deformation and trace residue transfer mechanism taking place on the impact marks.

This study could contribute to the evidence concerning the deformation pattern and damage characteristic of bullet impact holes made by each different types of 9 mm calibre bullet on automotive sheet metal. The elemental profiles of bullet trace residue retrieved from the bullet impact hole could also become a reliable indication that an impact hole could have been caused by a certain type of bullet. Important information retrievable from the physical examination and chemical analysis could be determined, allowing for the improvement of practice in firearm related investigation, especially on the planning of correct sampling strategies and evidence preservation, as well as laboratory analysis for indicative determination in Royal Malaysia Police and Department of Chemistry Malaysia whenever an impact hole is encountered.

1.5 General Approach of Research

In general, there were five phases of research implemented throughout the study. The five phases of the study are as follows:

i. Phase One: Sample collection phase with the application of permission to obtain the ammunition, purchasing of samples, and approval of permitted premise for shooting activities.
ii. Phase Two: Shooting experiment with sampling of impact marks on two different sheet metal surfaces at gazette shooting range assigned by authority.
iii. Phase Three: Physical examination of bullet impact hole, involving visual examination and photography.
iv. Phase Four: Chemical analysis on the trace residue recovered from impact holes, including sampling of residues using carbon tape and subsequent analysis by SEM-EDX.

v. Phase Five: Characterization of the bullet hole, in relation to the projectile that made the hole based on the experimental outcome from physical examination and chemical analysis.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Serious and organised crime is a threat to our national security. Unquestionably, crime involving firearm is particularly serious where criminals use firearms as killing weapon to cause injuries or death. Though firearms, imitation firearms and ammunition are described clearly in the Arms Act 1960 (Act 206), while the penalties in the usage of firearms to commit certain offences and to make special provisions relating to the jurisdiction of court are provided in Firearms (Increased Penalties) Act 1971 (Act 37), nevertheless, unlawful carry, possess or use a firearm or ammunition still occur. In Malaysian legal context, "any person who at the time of his committing or attempting to commit or abetting the commission of a scheduled offence discharges a firearm with intent to cause death or hurt to any person, shall, notwithstanding that no hurt is caused thereby be punished with death."

Accomplices in case of firearm discharging, exhibiting or having a firearm or imitation firearm in the commission of a scheduled offence, trafficking in firearms and unlawful possession of firearms in Malaysia are also punishable with imprisonment, whipping or a fine. Hence, one shall never carry any firearm or its related components, or use them to in other crimes without any lawful excuse. Therefore, studies on forensic firearm investigation will benefit the law enforcement authorities across the nation to solve crime, and subsequently to promote better social well-beings in Malaysia. This chapter covered the literature published previously on the characteristics on bullet impact holes, and scientific procedures which have been carried out for the purpose of forensic investigation.

2.2 Type and Composition of 9 mm Caliber Bullet

A firearm is a weapon used to aim and discharge lethal projectile(s) from a barrel towards the target at high velocity due to gases produced through rapid and confined burning of propellant powders (Chang *et al.*, 2013; Dalby *et al.*, 2010; Meng and Caddy, 1997). Ammunition is a combination of projectile, propellant powder and primer packed in a cartridge case as a single unit precisely made to fit into the firing chamber of a firearm. The projectile or bullet is the part which protrudes out of the ammunition and is propelled out on firing (Wallace, 2018).

The projectiles are found to be in varying composition, base and nose shape, caliber, cannelures, weight and method of construction, giving their class characteristics which could allow for narrowing the types of projectiles into smaller groups. These parameters are usually different due to the desired performance and intended usage by the manufacturers (Ravreby, 1982). In certain situations, it could greatly provide a positive answer in shooting reconstruction cases (Haag and Haag, 2011a). For example, jacketed and unjacketed projectiles might give different morphological features on an impact hole, where forensic investigator could determine the possible types of ammunition which have been used to make that particular hole. According to (Kieser *et al.*, 2013), different projectiles made by different manufacturers bear dissimilar properties of material composition as several examples of the metallic composition of projectile was tabulated in Table 2.1.

Table 2.1. Bullets and their composition (Kieser *et al.*, 2013).

No	Bullet	Composition
1	7.62×51mm L2A2 Radway Green	Cu 93 % Zn 7 %
2	7.62×51mm L40A1 Radway Green	Cu 93 %, Zn 7 %
3	7.62×51mm 93B0311 DAG	Cu 17 % Zn t-1 % Sn 81 %
4	7.62x39mm 122gr Wolf	Cu 95 %, Zn 5 % Fe t
5	7.62×39mm Type 56 Chinese 71	Cu 90 % Zn 10 % Fe t
6	7.62×39mm BXN Czech	Cu 98 %, Zn 2 % Fe t
7	5.56×45mm L2A2 NATO Ball Radway Green	Cu 95 %, Zn 5 %
8	5.56×45mm 62gr Federal® Tactical® Bonded®	Cu 95 %, Zn 5 %
9	5.56×45mm M193 Buchsenpatronen	Cu 92 %, Zn 8 %
10	9×19mm FMJ 115gr Luger Sellier & Bellot	Cu 74 %, Zn 25 %
11	9×19mm DM11A1B2 Luger DAG	Cu 90 % Zn 10 %
12	9×19mm 126gr Luger PMC®	Cu 94 %, Zn 6 %

Dissimilarity in the composition of projectiles could be a milestone in shooting cases investigation. Early in 1982, bullet entrance holes analysis by Raverby using AAS and SEM stated that such analysis made on bullet residue on the target could provide the foundation for discriminating among the type of ammunition that have been produced the hole on the target, and such information could be a major vital information during forensic investigation, involving numerous types of ammunition from different type of firearm. Figure 2.1 shows different type and composition of bullet used by Ravreby (1982) in his study

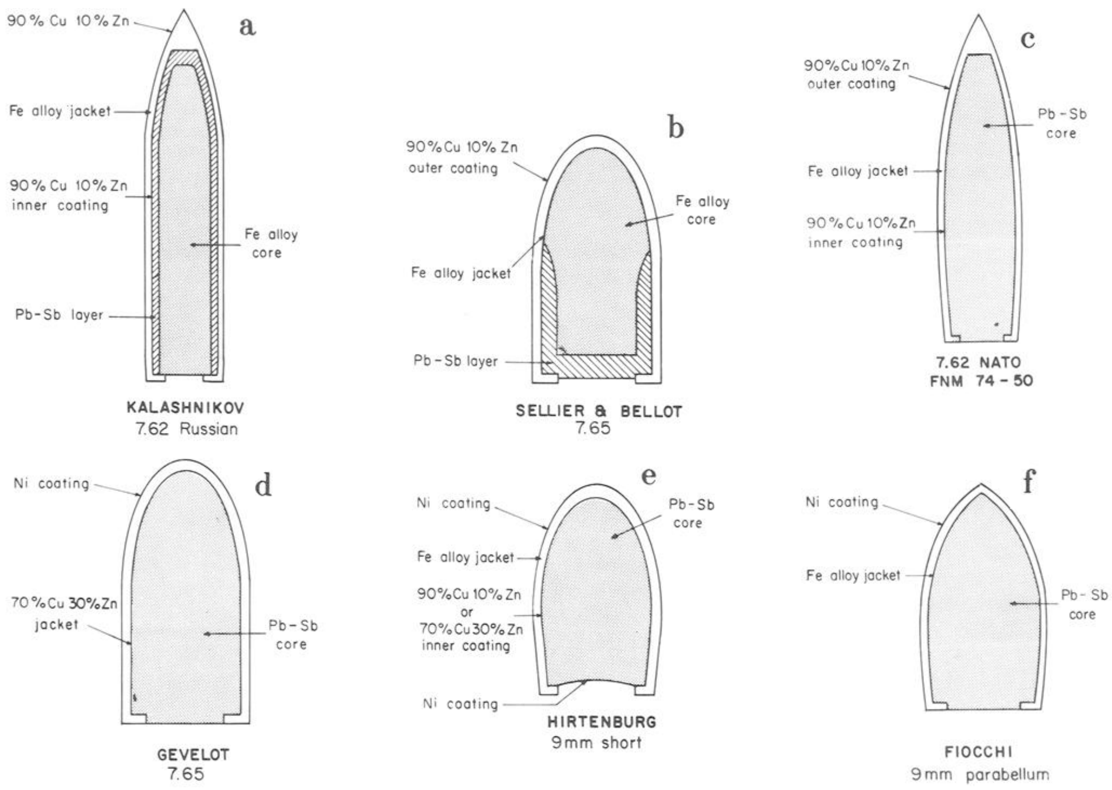

Figure 2.1. Diagram indicating 6 types of ammunition tested in the study (Ravreby, 1982).

Both authors, namely Ravreby (1982) and Kieser *et al.*, (2013) had suggested that bullet wipe occurrence is a certain occurrence on a target upon a bullet hole was formed, not only applied to primary target but also a secondary target. Regardless of bullet designs, including jacketed or unjacketed bullets, round or hollow nose shape, the micro-fragments of the trespassing projectiles could be left on the bullet wipe, and they were readily analysed by SEM-EDX to predict the bullet compositions. The composition of numerous elements from the infringing projectiles could be revealed through the analysis, and the data could be used to match the cause of a bullet hole to the ammunition type that made the protrusion. However, it was also noted that projectiles could be very similar in term of their respective composition, enabling only the narrowing down on the possible types of ammunition, or more specifically the projectiles.

2.3 Bullet Impact Characteristic on Thin Sheet Metal

Rapid population growth has led to physical expansion of more advanced housing development project and public facilities. Metal sheets have been based to fabricate countless everyday objects around us. In fact, most shooting cases were reported in cities by article *Shooting cases in 2016: a chronology* – Malay Mail, where wooden surface has become less common as a result of global urbanisation. More frequently, metal walls and gates made up of iron or stainless steel are seen in housing provision as opposed to wooden wall. Similar to window glass or walls of buildings, automobile bodies caused by impact of projectile are also important as evidence of forensic interest especially in firearm related cases. As an integral part of the modern society, it is not surprising with prompt increase in drive-by shooting, frequently happening in broad daylight in the middle of town spot as reported by Malay Mail on article *shooting in Setapak* .Therefore, two metal surfaces were used in this study to cater the Malaysian context by governing the frequency of their occurrence in drive-by shooting incidents.

According to Haag and Haag (2011c), automotive sheet metal is the most encounter material in shooting reconstruction cases, particularly for drive-by shooting or shootout incident in the middle of the town, usually between police and criminals. Sheet metals that used in vehicles were reported to have different thickness, ranging from 0.79 mm to 0.82 mm, depending on the manufacturers. However, it could also thicker than 1 mm, according to the intended uses of the vehicles, and also from the security aspects by the car manufacturers. Due to its malleable characteristic which can hold the projectile shape, it has become a favourite subject to be studied by other researchers. A study by Durmuş *et al.* (2011) on the *ballistic impact performance of cold rolled sheet metals* mentioned that there were different characteristics to be observed on the diameter of the front face deformation on the sheet metal surface upon the impact of projectiles, as well the depth of crater and the diameter of bullet hole formed. They also found that a unique fracture could be retrieved on the surface made by 9 mm standard North Atlantic Treaty Organization (NATO) specification projectile. Figure 2.2 illustrates characteristic of 9 mm bullet penetration on 1 mm thick sheet metal with H320LA, which was a type of low carbon cold rolled specification as a result of downloading the bullet muzzle speed.

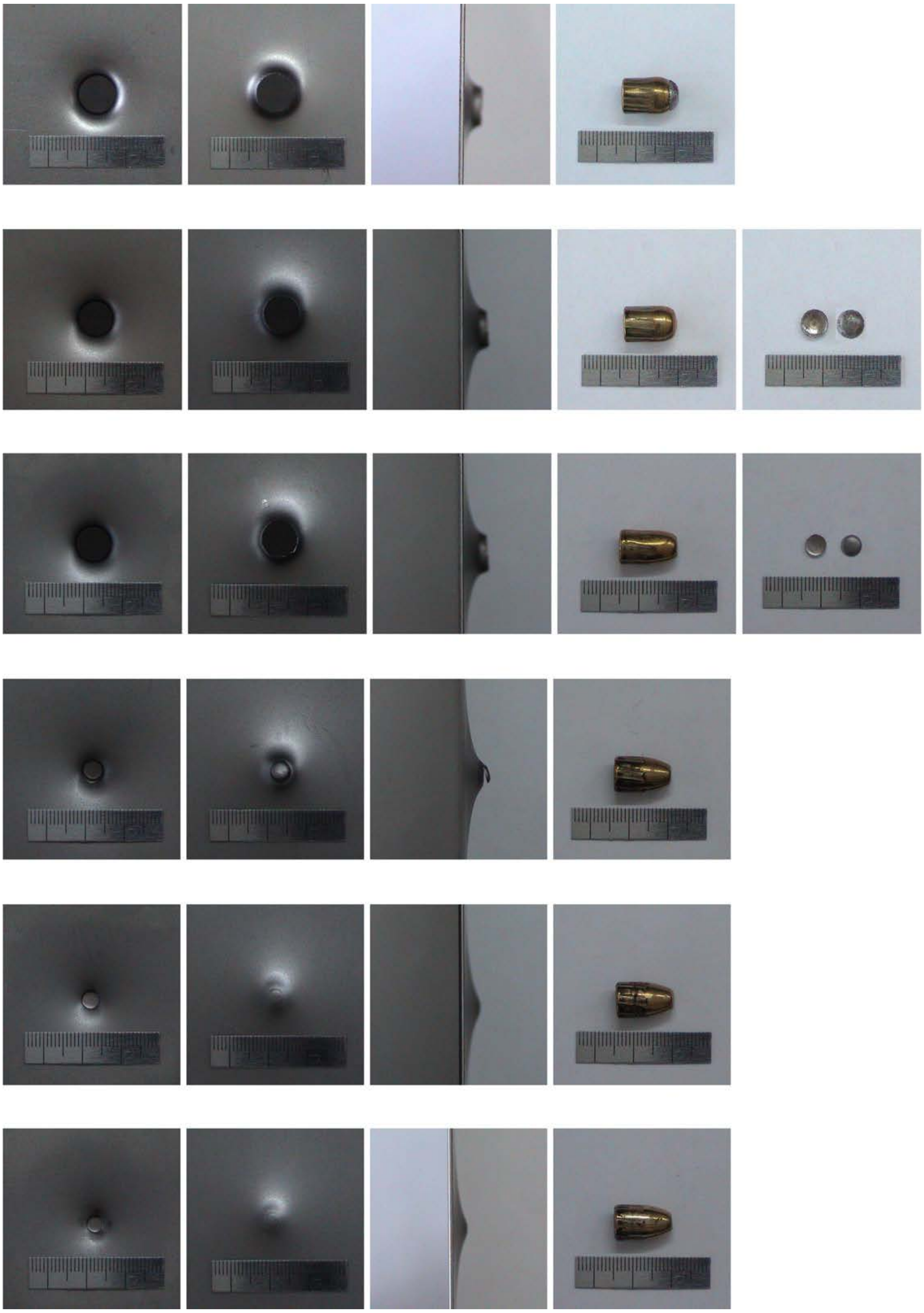

Figure 2.2. The dissimilarity of sheet metal and bullet deformation due to varies of bullet muzzle speed (Durmuş *et al.*, 2011).

In addition to that, Siso *et al.* (2016) in their study predicted the firing distance based on the bullet impact characteristics on thin sheet metal. Their experimental results revealed that bullet hole morphology occurred as a result of a bullet penetration through a target, contained special characteristic known as “crown” phenomenon. The phenomenon was caused by a bullet jacket being peeled away during penetration on the target and stranded around the edge of the entrance holes. Two types of caliber bullet were used in their study which is 5.56 × 45 mm and 7.63 × 39 mm. To simulate the automotive sheet metal, sheet metal of 1 mm thickness was used as target. The experiment made the distance as variable parameter by downloading gun powder weight, in order to imitate the firing distance. Figure 2.3 and 2.4 show the damage characteristics on the entry and exit points of the target by 5.56 caliber and 7.62 calibers respectively.

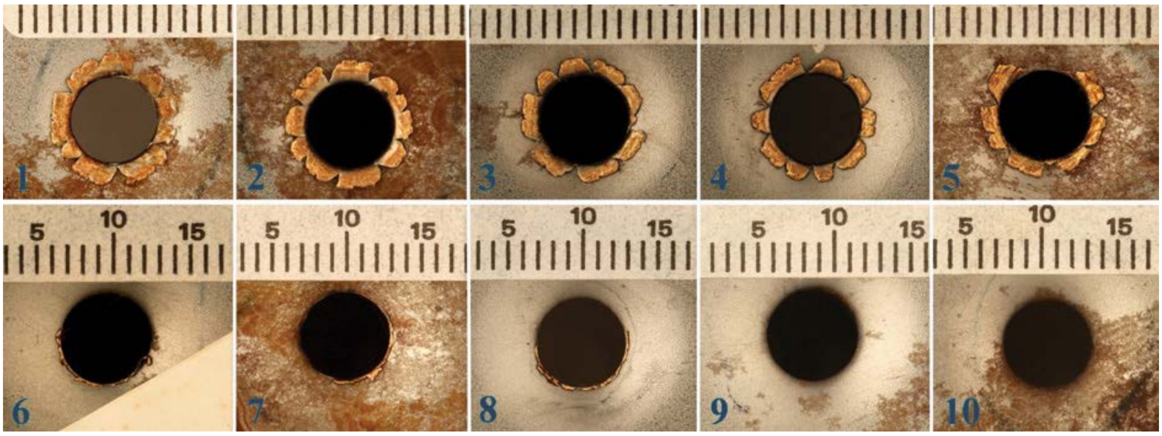

Figure 2.3. 10 bullet impact holes (entrance side) on a 1mm sheet metal target by 5.56x45mm with speed variation (Siso *et al.*, 2016).

The crown phenomenon was found only occurred at high velocity projectile with a speed of 700 m/s and above for 5.56 caliber bullet, as illustrated in image No.5 to No.1 in Figure 8 with increasing velocity. For 7.62 caliber bullet, it was found that crown were only developed on the target holes when bullet speed was travelled at 580 m/s and above, at the instance when it hit on the target (Siso *et al.*, 2016).

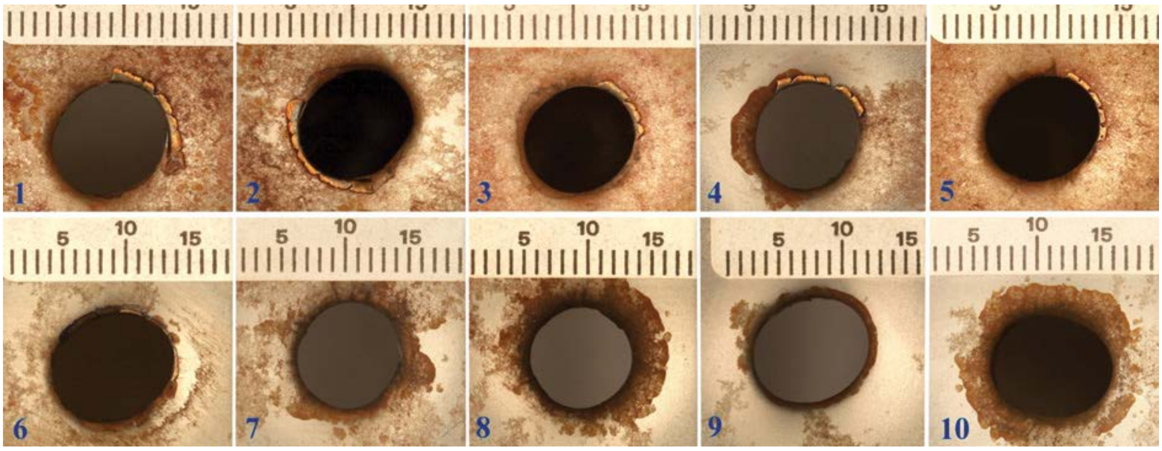

Figure 2.4. 10 bullet impact holes (entrance side) on a 1mm sheet metal target by 7.62x39mm with speed variation (Siso *et al.*, 2016).

Prominent crown's leaves could be seen on a target holes made by 5.56 mm calibre projectile, but less significant in those holes due to impacted by 7.62 mm calibre projectile. Such phenomenon was only happened on the entry side of the bullet hole and none was detected at the exit side face. The striping of bullet jacket happened when the projectile collides the target with adequate velocity above the threshold velocity, correlated with the distance of shooting. Siso *et al.* (2016) suggested that the number of crown's leaves produced by the bullet could be utilised to estimate the shooting distance where the projectile has been discharged.

Similarly, experimental work was carried out by Hazeeq *et al.* (2016) who studied on bullet hole made by 9 mm bullet fired from a semi-auto pistol and submachine gun (SMG) from varying distances. The target used in their experiment was 4 mm aluminum plate and shots were fired from distances of 15 m, 20 m, 30 m, and 35 m, respectively. The outcome of the study reported that the diameters of the entry bullet hole were relatively smaller than the exit bullet hole regardless of the distance where the projectiles left the muzzle. Figure 2.5 portrays the shapes and sizes of bullet holes fired from 9mm caliber semi-automatic pistol, captured from the entry and exit faces.

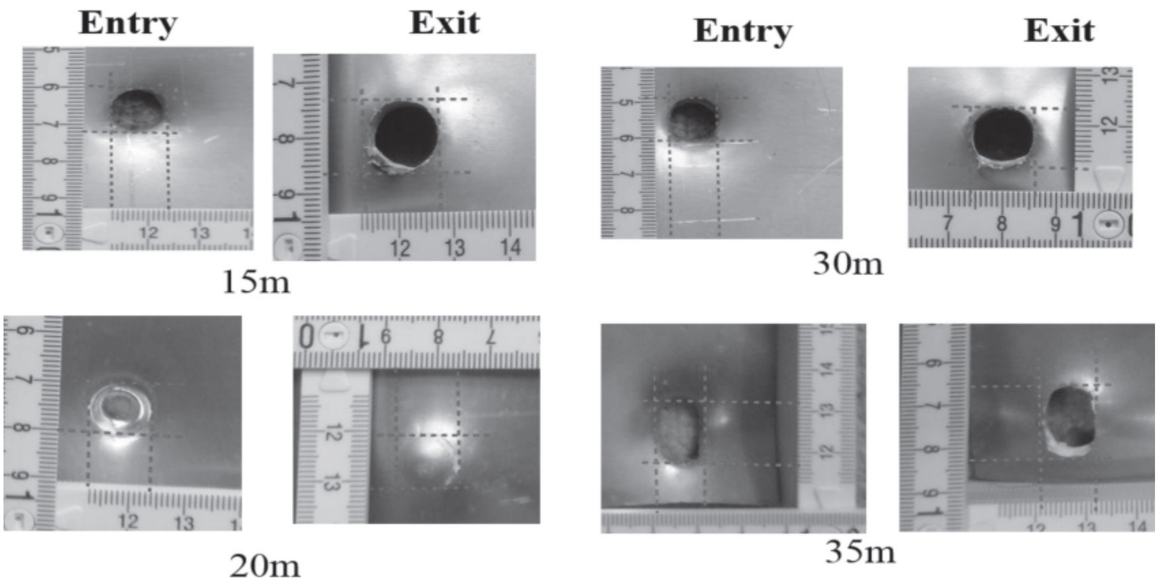

Figure 2.5. Bullet Holes by 9mm caliber bullet shot from a semi-automatic pistol from a various distance (Hazeeq *et al.*, 2016).

(Nattapontangtawee. *et al.*, 2015) investigated on bullet damage holes made by four different types of 9 mm projectiles with varying nose shape, namely lead round nose (LRN), hollow point (JHP) and another two different grain full metal jacket (FMJ) bullets. Shots were fired from a distance of 50 cm towards the sheet metal target. Table 2.2 shows the outcome of experiment, revealing that bullet types with different nose shape affected the bullet hole damage pattern. Hollow point bullet hole showed irregularity in diameter at entry point compare to other bullet hole made by nose shape projectiles. On the other hand, the damage pattern on the exit point revealed the different crater formation for all types of the projectiles utilised in the study.

Table 2.2. Bullet holes cause by 4 different types of 9 mm bullet (Nattapontangtawee. *et al.*, 2015).

Distance	Bullet Type			
50 cm	LRN	JHP	115gr FMJ	124gr FMJ
Entry				
Exit				
Diameter Ø				

Atkins *et al.* (1998), who studied on the perforation effect on sheet metal, reported that formation of multiple necks and cracks around perforations in ductile materials could be observed upon perforation of conical or round ended shape projectiles. In additional to that, the plugging and petalling were also the subsequent patterns to be happened during the perforation. Figure 2.6 shows the symptom of the necking, cracking and petalling on the sheet metal.