DETERMINATION OF MORPHOLOGICAL FEATURES AND ELEMENTAL PROFILES ON BULLET HOLES FOR FORENSIC FIREARM INVESTIGATION

UMA RASHMIKA A/P BOMINATHAN

UNIVERSITI SAINS MALAYSIA

2024

DETERMINATION OF MORPHOLOGICAL FEATURES AND ELEMENTAL PROFILES ON BULLET HOLES FOR FORENSIC FIREARM INVESTIGATION

by

UMA RASHMIKA A/P BOMINATHAN

Thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

September 2024

ACKNOWLEDGEMENT

First and foremost, praises and thanks to the Almighty, for His showers of blessings and grace throughout my studies and I finally succeeded in completing my postgraduate research project. I want to express my deepest gratitude to Dr. Chang Kah Haw, my supervisor at the School of Health Sciences, Universiti Sains Malaysia who trusted me and has given me inspiration, strength, and the chance to complete this thesis. To work and learn under his direction was a wonderful honour and privilege. Dr Chang Kah Haw has been very patient throughout my journey and is very attentive to me regardless of his busy schedule and most of all spending his time in helping and guiding me to produce this thesis, as well as during the experimental and laboratory works. I would also like to extend my appreciation to Professor Madya Dr. Ahmad Fahmi Lim bin Abdullah for his continuous support and restless encouragement during the hardest time, as well as in the process of getting the research materials and approval from authorities and who have instructed me over the last years.

I would like to express my deepest appreciation to the Royal Malaysia Police for providing me with the facilities and assistance needed during my shooting experiment at the Shooting Range at Perlis. A special mention to ASP Mohamad Salihon bin Ibrahim, Insp Muhammad Syafiq bin Zakaria, and Konst/D Meor Abdul Ash Arif bin Abdul Malek for all the assistance. I want to express sincere thanks to my parents and entire family members for their support, prayers, and sacrifices. I'm grateful to everyone for this incredible journey.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

%	percent
º	degree
g	gram
grs	grains
kV	kilovolt
m	meter
nm	nanometer
ppm	parts per million
g/cm3	grams per cubic centimeter
μg/ml	microgram per millilitre
μM	micrometer

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
DESI-MS	Desorption Electrospray Ionization mass spectrometry
F	fluorine
Fe	iron
FMJ	Full metal jacketed
GECO	General Engineering Company of Ontario
GSR	gunshot residues
ICP-MS	inductively coupled plasma-mass spectrometry
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
SE	secondary electrons
SEM-EDX	Scanning electron microscopy and energy disperse X-ray
SMG	submachine gun
S&B	Sellior & Bellot
Sn	tin
Zn	Zinc

PENENTUAN CIRI-CIRI MORFOLOGI DAN PROFIL-PROFIL UNSUR PADA LUBANG PELURU BAGI PENYIASATAN SENJATA API FORENSIK

ABSTRAK

Pembinaan semula tempat kejadian yang komprehensif bagi kes berkaitan senjata api memerlukan penyiasat forensik untuk memeriksa lubang kesan yang ditinggalkan pada pelbagai permukaan untuk mengesahkan sama ada lubang tersebut dihasilkan oleh anak peluru, dan seterusnya untuk menentukan sama ada lubang tersebut dibuat oleh amunisi tertentu. Perkembangan reka bentuk dan teknologi amunisi juga boleh membawa kepada perbezaan pada lubang kesan, terutamanya daripada amunisi bukan konvensional. Kajian ini bertujuan untuk mencirikan lubang kesan peluru yang disebabkan oleh pelbagai amunisi berkaliber .38 dan 9 mm melalui cara fizikal dan cara kimia. Ciri-ciri morfologi pada enam permukaan iaitu Perspeks, papan lapis (*Plywood*), papan formika (*Formica)*, kepingan logam kabinet, gipsum (*Gypsum*) dan kepingan logam pintu kereta yang lazim ditemui di tempat kejadian penembakan akibat hentaman peluru telah diperiksa. Kemudian, sampel yang diperoleh dari lilitan dalaman lubang peluru diperiksa dengan menggunakan plasma ganding teraruh-spektrometri jisim (ICP-MS) dan spektrometri serapan atom (AAS) untuk menentukan profil unsur dan dibandingkan antara lubang peluru yang disebabkan oleh lapan jenis amunisi yang berbeza iaitu Winchester .38 SPL, CBC .38 SPL, SME .38 SPL, SME 9 mm, GECO 9 mm, Advance Rotation Extreme (ARX) 9 mm, Ruag Ammotech 9 mm dan Sellier & Bellot 9 × 19 . Melalui pemeriksaan fizikal, lubang bulat sempurna telah diperhatikan dengan hentakan sudut ortogon, kecuali lubang peluru yang dihentam oleh anak peluru daripada ARX dan GECO yang menghasilkan kesan kelopak seperti bunga di pinggir kawah. Sebaliknya, anak peluru jenis jaket logam penuh (FMJ) dan peluru ubah bentuk berjaket (JDP) lebih cenderung untuk memindahkan bahan mereka ke dalam permukaan lilitan lubang peluru, membentuk gelang logam. Dalam kajian ini, prosedur menekap dibuktikan berkesan untuk memulihkan sisa surih dari lubang peluru. Melalui pengesanan ICP-MS, plumbum didapati sebagai komposisi utama dalam enam jenis peluru, kecuali dalam ARX dan GECO yang tembaga telah mendominasi komposisi unsur. Antimoni, arsenik, besi, bismut, perak, timah, dan zink telah dikesan sebagai komposisi minor dalam anak peluru. Walaubagaimanapun, daripada sampel yang diperolehi dari lubang peluru, hanya empat unsur iaitu antimoni, kuprum, plumbum dan zink berjaya dikesan. Penghuraian oleh analisis komponen utama (PCA) telah membentuk enam kelompok dalam plot skor dengan tanda impak profil unsur yang serupa cenderung untuk berkumpul rapat. Model skor PCA-analisis pembezalayan linear (LDA) telah mencapai pengelasan betul keseluruhan sehingga 85.4% dalam meramalkan peluru yang berhentam ke atas suatu permukaan. Kesimpulanya, pemeriksaan fizikal dan analisis kimia yang teliti telah membantu dalam membezakan lubang kesan peluru oleh peluru yang berbeza. Maklumat penting sedemikian mempunyai potensi besar dalam penyiasatan forensik, terutamanya dalam kes tembakan.

DETERMINATION OF MORPHOLOGICAL FEATURES AND ELEMENTAL PROFILES ON BULLET HOLES FOR FORENSIC FIREARM INVESTIGATION

ABSTRACT

A comprehensive scene reconstruction of firearm-related case requires forensic investigators to examine the bullet holes left on various surfaces to confirm if it was produced by a projectile and to subsequently determine if it was made by a specific ammunition. Evolvement of the design and technology of ammunition could have also led to the variation in bullet hole, particularly from non-conventional ammunition. This study was aimed to characterise bullet impact holes caused by various .38 and 9 mm calibre ammunition through physical and chemical means. Morphological features on the six commonly encountered surfaces such as Perspex, Plywood, Formica Board, metal sheet (cabinet), gypsum dan metal sheet (car door) within a firing scene due to the impacts of projectiles were examined. Later, sample recovered from the inner circumferences of bullet holes were examined by inductively coupled plasma-mass spectrometry (ICP-MS) and atomic absorption spectrometry (AAS) to determine the elemental profiles and compared among the bullet holes caused by the eight different ammunition types, namely Winchester .38 SPL, CBC .38 SPL, SME .38 SPL, SME 9 mm, GECO 9 mm, Advance Rotation Extreme (ARX) 9 mm, Ruag Ammotech 9 mm, and Sellier & Bellot 9 × 19. Through physical examination, perfect circular holes were observed with orthogonal angle impact, except for bullet holes impacted by the projectiles from ARX and GECO with the production of flower-like petalling effect at the edge of crater. On the other hand, full metal jacket (FMJ) and jacketed deform projectile (JDP) tends to transfer their materials onto the inner circumference of bullet holes, forming metallic rings. Stubbing procedure was found effective in recovering trace residues from bullet holes. Through ICP-MS detection, lead was found to be the major composition in six types of projectiles, except in ARX and GECO where copper dominated the elemental composition. Antimony, arsenic, bismuth, iron, silver, tin, and zinc were detected as minor composition. However, from the samples recovered from bullet holes, only four elements, namely antimony, copper, lead, and zinc, were successfully detected. Decomposition by principal component analysis (PCA) formed six clusters in the score plots in which impact marks of similar elemental profiles tend to cluster closely. The developed PCA score-linear discriminant analysis (LDA) model had also achieved an overall correct classification up to 85.4% in predicting the projectiles that impact a surface. To conclude, a thorough physical examination and chemical analysis aided in distinguishing the bullet impact holes made by different ammunition. Such important information possesses great potential in forensic investigation, especially in shooting cases.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

During the investigation of crimes involving gunshots and bullet holes, crime scene specialists must be aware of holes and defects in target materials. A common question for crime scene technicians is if a hole was made by a bullet. More detailed examination will be carried out once identified as a bullet hole. Holes on surface at crime scenes are of great relevance, and numerous attempts are made to analyse the attributes of these holes to determine the type, speed, and angle of the projectile that most likely caused the hole. This study focuses on determining the morphological features seen on bullet holes as well as the elemental profiles generated on bullet holes.

1.1.1 Firearms-related Criminal Cases

Gun violence is frequently associated with violent crimes worldwide, such as robbery and murder. In addition to commonly encountered firing cases, there has been a noticeable increase in drive-by shooting incidents in our country recently. Therefore, investigators must focus their fullest investigative efforts on identifying and analysing every trace that is useful for further analysis at both the scene and laboratory (Blakey et al., 2018; Charles et al., 2023).

In Malaysia, the use of firearms in crimes is not very common compared to the United States and the European countries. A study by Rabiatul Adawiyah et al. (2018) stated that firearm-related deaths in Klang Valley were highest in 2009 and the trend of the incidence was irregular for the 11 years. Firearm-related crimes frequently are particularly serious. Hence, they always draw a lot of public attention. The greatest investigative efforts are required and supported by the investigators to recover and examine every potentially analysable trace in a firing scene (Serol et al., 2022; Charles et al., 2023).

When a firearm is involved, the crime scene investigator must find out what was going on when the weapon was fired. This was accomplished by investigating the firearm-related evidence found at the crime scene and theorizing on how the crime might have happened using logic and judgment. Even yet, forensic investigators have various testing and analytical tools at their disposal, regardless of how detailed a crime scene may be. An analyst might be able to gather a lot of information from even a single bullet hole, such as the determination of the shot direction through the implementation of trajectory rods and the approximation of close-range distance using gunshot residue (GSR) test like modified Griess test (Serol et al., 2022). Since fired bullets are not always retained or are damaged in some situations, determining the kind of bullet used in gunshot entry wounds could be accomplished by analysing the trace element composition.

Nowadays, shooting cases are common and can happen everywhere, including Malaysia. It was noted our country is equipped with strict firearm control laws (Firearms (Increased Penalties) Act 1971); however, firearm-related cases occur. During a shooting case, especially a complex one, there are numerous surfaces from which bullets may penetrate, perforate, or even ricochet (Kerhoff et al., 2015). Common materials struck by a bullet include glass (Vermeij et al., 2012; Hirakawa et al., 2016; Mattijssen et al., 2016a), wallboard (Karger et al., 2001), wood (Mattijssen et al., 2016a), concrete (Hu et al., 2009), and any surface covered by cloth or fabrics (Glattstein et al., 2000). Over the years, research has been conducted to study the behaviour of bullets discharged from firearms and the factors that influence their trajectory. Previously published articles and technical aspects on various aspects of shooting scene examination have undoubtedly provided significant contributions to forensic investigation, but investigations of the impact of a bullet against certain surfaces, such as Perspex, plywood, and metal sheets, which are more common in Malaysian settings, are still lacking.

The successful prosecution of firearm criminals may reduce crime rates and subsequently safeguards societal well-being in general. Therefore, research to investigate the exchange mechanism upon impact of the various bullets, especially those fired from newly developed ammunition against the varying surface materials commonly found in Malaysia settings would provide new details while reducing the gap of practice between crime scene investigation and laboratory analysis.

1.1.2 Types of Ammunitions

A bullet is a kinetic projectile shot from a gun. An ammunition consists of a bullet and a cartridge, which consists of three parts, namely a casing, primer, and the propellant powder. There are numerous sizes, shapes, and bullet designs for ammunition. Rimfire and centrefire are the two types of igniting methods used in the ammunition as to propel the bullet away from the muzzle. In rimfire cartridges, the primer is located inside the rim of the case head. A separate primer was placed in the middle of the case head of the centrefire cartridges (Hirakawa et al., 2016). In term of the nose shape, there are six main types of bullets in the market that have been diversified over a period, namely the full metal jacketed (FMJ), hollow point (HP), soft point (SP), jacketed hollow point (JHP), Wadcutter (WC), and ballistic tip (Birkett et al., 2021; Ravreby., 1982; Nattapontangtawee et al., 2015; Monturo., 2019)

Amongst, the FMJ bullets are more common. Generally, each bullet has a separate outer shell made of tougher metal surrounding a soft centre, usually lead. They also come in a variety of popular forms, including FMJ boat tail, FMJ flat nose, and FMJ truncated cone. HP bullets possess distinctive cup-shaped indentation at the tip of the bullet. They are distinct in that, after striking their target, they "mushroom" or "bloom" outward. SP bullets, on the other hand, are made by surrounding a soft lead core with a hard jacket while leaving an exposed lead tip. They have the characteristics of both hollow points and full metal jackets. While JHP bullets have hollow tips that are similar to HP, they also have a hard outer casing similar to FMJ rounds. However, it was noted that the indented tip may or may not be fully jacketed. The bullet forms a mushroom or flower-blooming shape at the tip when it strikes a soft tissue target. WC bullets are unjacketed, flush fitting with the cartridge case, cylindrical, and have a flat nose. They are often found in revolver cartridges. Lastly, the ballistic tip bullet is a type of jacketed hollow-point bullet with a hard plastic (polymer) insert into it. It can consistently expand in soft tissue by resembling the aerodynamic profile of a full metal jacket spitzer (Haag, 2015; Penn-Barwell et al., 2017; Monturo, 2019). With the availability of various types of bullets, their impact and consequences on any surface materials might vary, needing exploration.

1.1.3 Impact of Bullets (Perforation, Penetration, Ricochet)

Perforation is the complete penetration of a bullet on the target surface and the complete traversal of the target thickness by the bullet. According to Awerbuch and Bodner back in 1974, the perforation process can be divided into three different phases. They considered a bullet's effective mass since some of the target material moves with it during penetration, the bullet's deformation during penetration, and the target material's improved strength at high loading rates (Kılıç et al., 2013; Lesuer et al., 2001)

Plug creation and ejection are the two main processes involved in the perforation of the target surface. Perforation is entirely caused by plug formation when the thickness of the plug equals that of the target surface. A bullet with a reasonably high terminal velocity can penetrate a plate under circumstances that exceed the ballistic limit, such as a thinner target plate or a higher initial velocity (Awerbuch et al., 1974) During perforation, the first stage is that of the immediate impact of the bullet on the target and the second is that of the progress of penetration. The plug (or fragments) travels in a path to the target plane, where the bullet continues in its original direction, and the bullet's tail fragments go in the direction indicated. Furthermore, the bullet hole will widen because of the rotation of bullet. A bullet with a higher impact velocity will produce perforation together with the resultant unrestrained bullet and plug motion, whereas a bullet with a lower velocity might only result in only bullet contact (Bell., 1989)

As the full dissipation of system kinetic energy occurs, the bullet remains embedded in the target, known as penetration. Penetration of a bullet on target surfaces differs according to the various parameters that are investigated, such as the mechanical and constitutive properties of the bullet and target materials, their densities, the geometrical data of the bullet's nose, and its impact velocity (Krafft., 1955). There is significant deformation and a high strain rate throughout the bullet impact and penetration process. Penetration of a bullet through a target surface occurs when kinetic energy is consumed. It is demonstrated that the initial kinetic energy of the bullet divided by its frontal area and the inherent structural characteristics of the target are the basic parameter controlling bullet penetration into materials.

According to previous studies, a bullet's ability to penetrate is mostly determined by the kinetic energy of its hard steel core (Forrestal et al., 2010; Hazell., 2020). The penetration depth of a bullet could be directly related to bullet mass and bullet velocity, and inversely related to bullet diameter (Fackler et al., 1988). Also, the larger, heavier bullets typically penetrated a target substance more deeply than smaller, lighter bullets (Stone., 1994). The material damage process is very complex when the bullet penetrates the target plate quickly, and it is important to consider the influence of parameters such significant deformation, high strain rate, and temperature softening. Additionally, the rotation speed of a bullet has a certain influence on the penetration performance (Wu et al., 2023). A bullet's shape might also affect its flight characteristics, ability to penetrate, and behaviour when it penetrates the target (Rhee et al., 2016). Nowadays, a bullet's penetrating ability could be measured using numerical techniques based on Finite Element Analysis. Such analysis could predict the penetration depth for a wide range of impact velocities with accuracy and less computational time (Kılıc et al., 2015).

The term "ricochet" refers to the unintentional or deliberate rebounding of a bullet off any surface during shooting incidents (Nishshanka et al., 2020). Bullet ricochet off a surface in a shooting environment occurs under various circumstances and are influenced by a wide range of factors. Nishshanka et al. (2020) showed that incident angle of the bullet being fired affects the ricochet phenomena. When a bullet ricochet can be useful as evidence, shooting investigators shall analyse the bullet to determine its pre- and post-trajectories, impact site characteristics, bullet shapes, and evidence traces on the bullets and surfaces to extract as much information as possible from the incident (Haag and Haag, 2011). Although ricochet of bullet is a probable phenomenon seen in a shooting scene, this study did not cover such aspect but focused only on orthogonal angle or 90° shooting. Surface materials were tested if they could stop the passage of bullet leading to penetration or being perforated by the bullet.

1.2 Problem Statement

In the current practice of firearm examination in Malaysia, markings on bullets or cartridge cases are examined using a comparison microscope and computerised Integrated Ballistics Information System (IBIS) by the Royal Malaysia Police. On the other hand, gunshot residues recovered from a suspect, usually from the hand or clothing materials, are analysed by scanning electron microscopy in couple with energy dispersive X-ray (SEM-EDX) technique for their morphology and chemical compositional determination at the Department of Chemistry Malaysia. In a case involving a firearm, investigators are required to identify a bullet, a cartridge case, or other ammunition components as having been fired by that particular firearm, excluding all other firearms (Blakey et al., 2018; Charles et al., 2023). However, in an actual forensic scenario, the evidence recovered from a real crime scene is not always in an ideal condition, which allows for straightforward forensic determination, as seen in drama series or movies. In many circumstances when confirmation is needed at the court of law to establish an offense of a criminal, a firearm may be absent, cartridge may not be recovered from the scene, and bullets may be completely lost or severely deformed.

With that, certain key questions require knowledge exploration, especially regarding the distribution of impact holes and traces on any surfaces at a crime scene. First, is an impact hole or hole found on a surface made by a bullet or other object? This question is crucial for understanding whether a case involved any firing activity. The forensic investigators shall seek scientific proof to confirm that an impact hole or hole was made by a bullet either by physical or chemical means. In certain instances, they are required to understand the fundamental aspects of the interaction that occurs between a bullet and a surface, which leads to the confirmation of an impact hole or hole caused by the bullet.

Even though many of the previously described works might have been conducted in confirming a shooting incident and aiding to reconstruct the crime scene, a thorough analysis of the bullet impact holes needs to be performed to reach a credible forensic judgement for each cases investigated. The rapid growth of a variety of ammunition on the market has been made possible by current developments and innovations in the weapon and ammunition sectors, meeting the requirements of both manufacturers and users. In addition, there have been more drive-by shooting incidents, particularly now that the source of the firearm and ammunition is unclear. Therefore, a detailed physical examination of bullet impact holes including the measurements of diameter of entry and exit holes, crowning, petalling effect, bullet wipe, as well as the elemental determination on such evidence demands further investigation. Most studies either focus on one or two types of target surface materials or use a certain type of conventional bullet. This did not provide vast information about the bullet impact holes. Therefore, this study largely focused on the examination of impact holes using physical and chemical approaches to confirm their striking on a surface. The trace residue transference during the formation of the impact hole on six surface materials struck by the bullet based on local settings was explored. It deserves exploration to keep pace with the current developments in firearm and ammunition aspects, particularly with newly developed ammunition, which is lacking in exploration.

1.3 Aim and objectives

This study was aimed to characterize bullet impact holes caused by various 9 mm and .38 calibre ammunition on the varying surface materials through physical and chemical means. To achieve the aim, the objectives are set as follows:

i. To determine the morphological features of impact holes on target surfaces caused by various bullets.
ii. To establish a sampling protocol for the elemental detection of impact holes caused by various bullets.
iii. To determine the elemental profiles of the traces recovered from impact holes on target surfaces caused by various bullets.
iv. To differentiate between the impact holes caused by the bullets on the varying target surfaces through chemometrics.

1.4 Scope of the study

The study focused exclusively on ammunition carrying .38 and 9 mm calibres for the exploration of morphological characteristics and determination of elemental profiles, focusing on the bullets. These two types of calibres were focused as they are commonly found in Malaysia used by law enforcement and collected at crime scenes. The ammunition used in this study also covered both common and uncommon ammunition. The uncommon ammunitions were newly developed ammunition which declared to have a non-toxic composition, and their determination would provide useful information for firearm-related cases.

Note also that only six surface materials were used to study the impact holes; however, they were common constituents in household and vehicular settings in Malaysia. The distance of shooting was fixed at a distance (3 meter between shooter and target) and the same angle (90° levelling between shooter and target). The variables are then analysed and tabulated and detailed to provide information on the bullet holes physical and chemical analysis.

In term of analytical method, bulk analyses were considered to determine the elemental profiles of trace residues sampled from the impact holes. Identification of gunshot residue (GSR) particle originated from the primer was not the key concern in the current study as the trace residues on the impact hole could be contributed by the contact of bullet with a surface material. Therefore, bulk analytical techniques, including the inductively coupled plasma-mass spectroscopy (ICP-MS) and the atomic absorption spectroscopy (AAS) were found more suitable to the experimental design in this study. Gold standard for GSR testing by the scanning electron microscope-energy dispersive x-ray (SEM-EDX) spectroscopy was not considered due to the limited transfer of these residues to the impact holes and impracticality to detect the existence of three-element particles consisting of lead, barium, and antimony.

1.5 Significance of the study

This study could provide a better understanding of the characteristics of impact holes made by a bullet for forensic opinion to be based on a more defensible court proceeding. This provides insight into the issue of whether the contact between a surface material and a perforating bullet would cause material loss from the contacted surface and therefore provide a link between the alleged impact holes with firearm and ammunition because of material exchange or trace residue transference.

Crime scene investigation will benefit from the crucial information provided by the entry and exit bullet hole traces. When no cartridge case or bullet was found at the crime scene, it is extremely important to use a physical examination to determine the features of the impact hole created by a particular bullet to support forensic investigations related to shooting incidents. Furthermore, the characteristics of bullet holes vary based on the type of firearm, the bullet, its weight, velocity, and the characteristics of the firearm barrels. During the examination of bullet impact holes, in certain cases, in addition to class and individual marks, there could be the appearance of characteristics in providing information about the ammunition being fired from a firearm.

A study of gunshot traces, with a focus on morphological and elemental analyses of both conventional and non-conventional ammunition, has important implications for forensic science, criminal investigations, and the legal system. This work could improve the value of forensic evidence through such analysis, increasing accuracy and reliability.

Subsequently, the outcomes of this study would allow for the improvement of practice in firearm investigation, especially on the planning of correct sampling strategies and evidence preservation, as well as laboratory analysis for indicative determination. It would aid in solidifying the scientific foundation of firearm-related investigation and lend greater investigative capability to solve forensic problems.

CHAPTER 2

LITERATURE REVIEW

2.1 Type and Composition of Ammunition

A typical metallic ammunition consists of four parts, namely the bullet, primer, propellant powder, and cartridge case. A bullet, sometimes called a projectile, is a component of firearm ammunition that is expelled from the barrel during shooting. The primer, the ignition device of the cartridge, lies in the bottom of the cartridge case. The propellant powder is inserted inside the cartridge case and the bullet or projectile lies in the cartridge case mouth (Chang et al., 2013).

An explosive within an ammunition starts the process when the firing pin hits it. The activator helps with the whole ignition process and is an energy source that keeps the flame going and guarantees enough time to fire the propellant powder make up primer (Birkett et al., 2021). It was noted that either the case's rim (rimfire) or the case's center (centrefire) can be filled with primer (Hirakawa et al., 2016).

The most crucial element in a cartridge that controls power or energy is propellant powder. In the market, a lot of different forms and chemical compositions for propellant powder are available. When propellant powder is confined in a cartridge case inside a firearm's barrel, it burns quickly rather than exploding. As pressure rises within a cartridge case, the rate of burning increases. As the bullet exit a firearm's muzzle, the internal pressure within the barrel will then drop. Conventionally, the propellant powder's original form was the black powder, which was created by combining sulphur, charcoal, and potassium nitrate (Lee., 2020).

Recently, smokeless powder has become more common, consisting of nitrocellulose as its core composition replacing black powder (Chang et al., 2013; Serol et al., 2022).

Most bullets are composed of lead. Bullets consist of a soft brass or copper-plated soft steel jacket with a lead-antimony alloy core. Some bullets are coated in a harder metal, typically copper-plated or copper alloy-plated depending on the manufacturers and intended uses. It was also noted that a bullet can be full-metal jacket or semi-jacketed whether the jacket fully encloses a bullet core. When a bullet hits its target, it expands, fragments, and deforms less when it is fully enclosed in a metal jacket (Adair et al., 2011). To keep the bullet from deforming and melting due to the high temperatures inside the barrel, the jacket is necessary when it travels faster than 2,000 feet per second. Additionally, FMJ bullets lessen vapour generation which is a crucial factor for indoor firing ranges. During the older times, the bullet's base was exposed, revealing the lead core. As time evolves, the bullet's base is covered, revealing either a hollow-point or a tiny bit of lead at the nose (soft-point) (Wallace., 2018).

Several factors, including material qualities, impact speed, target support location, bullet shape, and the proportions of the target and bullet, could affect how these targets and bullets react to each other after impact. The bullet’s shape affects its flight character, ability to penetrate, and behaviour after entering the target. Penetration is determined by the bullet’s surface area and shape (Lee., 2020). For instance, the "Spitzer bullet," which has a sharp tip and is intended to be less affected by wind shifts and to be sturdier in the atmosphere, slows down less and therefore remains more precise. Also, a goal of hollow point bullet design is to cause more distortion of the bullet upon contact, which will lead to more damage (Birkett et al., 2012).

A calibre is a unit of measurement used to express the diameters of bullets. Different calibres provide varying advantages and disadvantages for application. One of the most popular calibres globally is 9 millimetres, but there are various alternative standards (Creativeind, 2020). In this study, commonly used calibre in Malaysia were focused that are .38 and 9mm.

2.1.1 .38 Calibre Bullet

The .36 calibre percussion pistols were carried over into the cartridge era with the .38 calibre rounds, including the .38 Special. To be named the .38 Long Colt, .38 Smith & Wesson, and .38 Smith & Wesson Special were essentially extensions rising from the subject of the .36 calibre pistols, which became some of the most preferred for police and individual safeguard purposes. The propellant used in .38 SME ammo weighs 147 grams (Zain et al., 2021).

Riyono et al., (2019) reported that the research had been published whereby the examination of the morphology of the craters and the bullet deformation resulting from ballistic examination on the vehicle body plates utilizing weapons that implementing ammunition of .38 calibre. It was reported that the material used in .38 calibre bullets were softer in nature (Riyono et al., 2019). Upon impact, the .38 calibre bullet could exhibit the most deformation, indicating the highest level of damage and irregular shape changes. The impact holes caused by both the .38 and 9 mm calibres were explored in this study.

2.1.2 9 mm Calibre Bullet

To ensure that ammunition fits correctly into a firearm barrel, ammunition is often classified by the diameter of the bullet. Originally, ammunition size was classified by calibre. Calibre is the firearm's nominal bore diameter. Millimetres or inches are used to measure it. The cartridge was developed in 1901 by Georg Luger as an innovative chambering for his firearm, the Luger. He thus modified the case to accommodate a 9 mm (.355-in) bullet, with the original load being a 115-grain full metal jacket bullet with a velocity of around 1150 fps, an energy of 350 ft-lbs, and a chamber pressure of 34,000 to 35,000 psi. The bullet diameter of 9 mm (0.355 in), neck diameter, base diameter, rim diameter, and rim thickness of 9 mm are all measured in millimetres (Bryant., 2005; Bolton-King., 2017).

Calibre is an example of class characteristics that can be used when examining data from cartridge cases and ammunition to eliminate or screen out potential comparisons that couldn't have been fired from the same gun (National Research Council., 2008). The most widely used pistol calibre in the world, the 9 mm Parabellum. The calibre (diameter) of a bullet is commonly determined in millimetres across the world (5.56 calibre = 5.56 mm), however in the United States, it is typically 30/100ths of an inch, or 0.30 calibre, is the unit of measurement. The height of a loaded cartridge is 1.169 inches (29.69 mm) (Jenzen-Jones., 2018).

2.2 Bullet Hole

Bullet hole traces at the crime scene provide valuable information for investigations. Analytical investigations primarily focus on physical appearance, such as tears, gunshot traces, and bullet hole size. Bullet hole characteristics vary based on the types of firearms, bullet weight, speed, and barrel characteristics (Lepik, D et al., 2008). The identification of bullet holes and their impressions at the scene represents a vital witness component, potentially linked to the offender's gun(s). This enables the development of a database for forensic investigation of bullet damage.

2.2.1 Bullet Hole Characteristics

Investigators need to examine in detail the bullet hole and its characteristics to provide adequate information about the bullet hole for aiding in investigation and court proceedings. GSR, casings, and numerous bullet holes could be found all throughout indoor crime scenes; however, needing effort. Even experienced investigators might find these scenes difficult to work. With the searching for such evidence, ballistics-trained professionals could demonstrate examinations and analyse methodologies relevant to them, regardless of how comprehensible a crime scene may be. A well-trained professional will get an abundance of data from a single bullet hole, including trajectory rods to ascertain the shooting direction, and a GSR test that calculates the proximity and distance of shooting (Haag et al., 2020).

Sometimes, crime scenes will be left with the bullet hole that serves as the only piece of proof. Examination of the bullet hole, specifically the bullet's morphology could reveal information about the shooter's position even if it is not possible to retrieve the bullet. Also, a single bullet hole could still reveal an extensive amount of information, encompassing the shot's trajectory, the estimated calibre of the ammunition fired, the estimated degree of collision, and even the distance range within the target and the firearm's muzzle (Haag et al., 2020). For instance, the distance between the muzzle and the target reduces as the shooter comes towards the target and an increase in bullet hole depth is expected (Lee., 2020).

Moreover, a bullet with higher velocity will contribute more destruction to the rear of the target materials than slower ones. It can also help to determine where the shooter was at even though there are numerous gunshots at the crime scene, and distinguish the distinct spots wherein the firearm was discharged, each with a varying depth (Shrivastava et al., 2021).

The bullet hole shapes, either round, oval, elliptical, or elongated could provide information on the angle of the bullet travelled from the muzzle. Assuming the impact angle is less than 90° the targets' ammunition holes might have an oval or elliptical shape. At a 90° angle of impact, the bullet holes on the target tend to be circular (Liscio., 2021). The direction of a bullet's emission can be determined from the measurements of the entry and exit holes. The position of the shooter can be determined by the angle of impact (Devi et al., 2016). Mattijssen and Kerhoff (2016) stated that bullet flaws may widen and become elliptical if the bullet impacts at a greater distance and angle or if it begins to tumble after hitting a surface in between before reaching its target.

Bullet wipe residue is a feature that bullet entrance holes predominantly exhibit while absent or very little found in exit holes. Bullet exit holes frequently have a diameter greater than the bullet's initial diameter. The angle at which the shot was discharged is directly correlated with the quantity and dimension of the wipes (Wallace, 2018). The bullet wipe around a hole will be rather uniform if a shot is fired on target material at a roughly 90° angle with nothing in the way of the bullet. When a bullet is aimed at the identical target material at a 150° angle, it will elongate and take on an oblong shape, and the bullet wiping motion will also follow this basic shape. An important feature which could point to an entry hole and provide the examiner/investigator with a possible site of origin is a bullet wipe. An entry hole's bullet wipe layer might range from a thick, black ring to a much lighter deposit (Warner., 1995).

2.2.2 Physical Examination on Bullet Holes

A detailed examination of the bullet hole shall be performed to observe its physical appearance, to determine if an impact is caused by a bullet, and even narrow down to the types of bullets or ammunition that could have made the impact. Through physical examination, bullet holes formed by the various bullets may be identified, offering significant potential for forensic evidence investigation commonly found in shooting incidents. Physical traits that could be observed during the initial assessment of the bullet hole and used for testing and interpretation include a hole on a target material, bullet wipe (a visible black ring around the perimeter of the hole), tear, evidence of a gunshot, and the dimensions of the entry as well as the exit bullet holes and diameter of the bullet hole, crowning and petalling (Nordin et al., 2020).

Based on the literature, most entry bullet holes will be smaller compared to the exit hole. The sizes measured at the entry holes on the metal sheet were slightly smaller while the exit holes were larger. The studies by Solehah Azman et al., (2014) supported the generally larger diameter in the exit hole when tested on sheet metal. This was because as the bullet expands after penetrating the surface, it takes on shape on the metal sheet surface and creates exit holes with a bigger diameter. Experimental work carried out by Hazeeq et al. (2016) demonstrated that the diameters of the entry bullet hole were relatively smaller than the exit bullet hole regardless of the distance where the bullets left the muzzle. On various surface materials, Nordin et al. (2020) reviewed the impact of bullets forming the smaller exit holes.

In addition to the expansion of the bullet, the exit hole's diameter could also be influenced by the direction in which the present bullet was penetrating the surface. This was due to the possibility that a bullet could undergo a significant change in spin when fired from various angles, resulting in variable bullet exit diameter holes. When a bullet strikes a target surface, it compresses that material on both sides while also pushing it aside. The target material was held together by the substance next to it. When the bullet entered the compressed material, it essentially bounced back, leaving the surrounding material largely intact. As a result, the bullet hole was essentially the size of the material that was "broken" by the path of the bullet which was pushed forward as it goes.

The bullet basically pulls on and tears the material as it passes through due to friction, especially as it exits the material. The exit hole appears as the pulling forces surrounding the metal sheet tend to separate because there is no longer any surrounding material to hold it in place. Because some of the surrounding material was torn away when the bullet exited, the exit hole is larger (Eksinitkun., et al 2019).

The entry hole created by a bullet depends on the angle at which it penetrates its target. Instead of comparing the entry and exit holes, the impact angle could be established through physical examination. The only impact angle that will result in a perfectly circular bullet hole is 90° impact. The general impact of an angle could be determined by looking at the bullet holes that are present at the crime scene. An oval or oblong hole could be produced by impacts with angles less than 90° (Waghmare et al., 2018). Depth of penetration should also be measured as the different nose shapes might affect the depth of an impact hole. Gupta et al., (2006) showed that bullets with hemispherical noses flawed the target surface most effectively, followed by bullets with ogive and blunt noses.

The depth of each bullet hole was not influenced by the shooting distance (Eksinitkun., et al 2019). However, distinct damage patterns corresponding to shooter distance and bullet velocity were noted on the substrates' backs (Lee., 2020). Lee (2020) compared the bullets' velocity against impact. Compared to slower bullets, high-velocity bullets left deeper bullet holes in target surface material, such as medium-density fibreboard and plywood substrates at all tested distances.

As described in section 2.2.1, studies showed that bullet wipes are likely to be present on a target after a bullet hole has been formed. Chisum and Turvey (2011) stated that bullet wipe was the material left behind after a gunshot hole that acquired the appearance of a black ring. Bullet wipe could be present on both primary and secondary targets. The micro fragments of the bullets that perforate the target material could be left on the bullet wipe, and they are easily studied by SEM-EDX to identify the compositions of the bullets (Ravreby., 1982). The type of ammunition used could be determined by analysing the different residues surrounding the entrance holes. The bullet wipe generally contained lead and carbonaceous residues from the bullet found nearer the defect's edge (Jason et al., 2014). Additionally, bullet metals like copper and zinc, lead from primer mixes containing lead (which frequently contain barium and antimony), and lead from bullets themselves could be present in the carbonaceous bullet wipe component (Levin et al., 2005). The bullet's composition might have also contributed to the intensity of the bullet wipe produced around the entry hole (Jason and Haag, 2014).

Forensic investigators could calculate the distance between the perpetrator and the target by examining patterns in the GSR left surrounding an ammunition hole (Geusens et al., 2019). After the bullet leaves the barrel, some particles of lead from the primer and bullet are frequently deposited surrounding the bullet hole. Various failure and damage processes, including petalling, cracking, spalling, and dishing, were noted on the target surface material during examination by Karamış (2016). The formation of a flower-like appearance around the crater's edge is known as the petalling effect (Siso t al., 2016). There are some petalling effect on the hole's exit side when the bullet pierces through and exits the target surface material (Karamış., 2018). A small hole was created during the initial stage of impact by the conical-shaped bullet, as documented by Gupta et al. (2007). The creation of petals resulted from the crack propagating well beyond the bullet's radius. It was noteworthy that segmented bullet hole circumferences were also a result of the petalling.

According to Xiao et al. (2010), the bullet deformation and fracture mechanisms, particularly the petalling are significantly influenced by the bullet hardness level (Xiao et al., 2010). The study by Teng et al. (2005) demonstrated the numerical results that hard (low ductility) bullets were susceptible to shear cracking, while soft (high ductility) bullets experience mushrooming and petalling. According to Gupta et al. (2007), ogive-nosed bullets did not form plugs or petals, failing to meet their targets. Such failure is common due to bullet with an ogival or conical nosed. Therefore, nose shape was said to not affecting the petalling on a target surface. However, the bending of petals could decrease with increasing target plate thickness. In other words, when a section of the material thinned, little petals appeared. The number of these petals increased as the target's thickness increased.

2.3 Bullet Impact on Different Surfaces

Both the bullet and the target experience compressive and tensile waves because of high-velocity bullet contact. Numerous phenomena, such as dissolving, solid-state phase transition, fracture, and degradation of plastic, could be caused by such wave propagation (Smith, 1994). Many factors, including target material characteristics, impact speed, bullet structure, and relative dimensions of the object hit by the bullet, could affect the extent to which bullets penetrate or perforate metal targets. The inflexible behavior of elements that interact with each other could influence penetration and perforation (Li et al., 2007).

Upon surpassing the elastic limit, plastic deformation, and the following occurs upon more than the substance's cohesion, causing the material to fracture (Preece et al., 2004). The metal sheet is a malleable material, that deforms and bends along the direction of the bullet's travel path rather than cracking on impact (Haag et al., 2011). The factors potentially affecting the deformation of bullets upon impact on the car door include bullet weight, nose shape velocity and the hardness of the bullet (Jacketed or non-jacketed). Because of the incompletely flat surface material and the nature of an automobile door design, the circular holes formed on the metal's surface were not discovered to be perfectly ideal even if they had an orthogonal angle impact. The sheet of metal was found to have bent outward in the direction the bullet travels and take on the shape of the bullet's nose as it penetrates the automobile door (Nordin et al., 2019).

According to Carlucci and Jacobson (2008), at low velocity, elastic strain maintained the target material in touch with the penetrator, and at high velocities, the material was ejected away from the bullet, causing the hole to become larger than the diameter of the bullet. Using an adhesive sticky sheet that could be applied against the entire area for GSR. The technique was intended for application on the skin of victims of firearm-related injuries, but it could also be applied to other materials, such as leather. This method's primary benefit was that it might be used to determine the firing distance (Ståhling et al., 2000). According to Dalby et al. (2010) the most popular method for removing inorganic residues from skin surfaces was tape lifts. Significant decreases in the recoveries of organic GSR during solvent extraction have been shown as a disadvantage of using carbon-coated adhesives.

The deformed object's physical characteristics area caused by a bullet impacting and penetrating a yielding material needs several elements, such as the bullet's material, geometry, impact angle, target material, and speed. The form of the damaged area