ANALYTICAL INVESTIGATION OF CORROSIVE AGENTS IN RELATION TO COTTON TEXTILE DAMAGE ASSESSMENT

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ANALYTICAL INVESTIGATION OF CORROSIVE AGENTS IN RELATION TO COTTON TEXTILE DAMAGE ASSESSMENT

by

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Dissertation submitted in partial fulfilment for Degree of Bachelor of Science (Honours) Forensic Science

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CERTIFICATE

This is to certify that the dissertation entitled **"ANALYTICAL INVESTIGATION OF CORROSIVE AGENTS IN RELATION TO COTTON TEXTILE DAMAGE ASSESSMENT"** is the bona fide record of research work done by Ms. **"SITI NUR AIEFIKA BINTI KHAIRI"**. During the period from October 2024 to January 2025 under my supervision. I have read this dissertation that in my opinion 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 Bachelor of Science (Honours) Forensic Science.

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DECLARATION

I hereby declare that this thesis is the result of my own investigation, except where otherwise stated and duly acknowledge. I also declared that it has not been previously or 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 and promotional purposes.

Signature:

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Date: 24/2/2025

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ABSTRAK

Serangan asid sering berlaku dengan niat jahat untuk mencederakan mangsa dengan menggunakan bahan menghakis yang mudah diperoleh dan murah. Fabrik pakaian adalah salah satu permukaan yang bersentuhan dengan bahan menghakis yang digunakan, menjadikan pengenalpastian bahan tersebut penting untuk memberikan petunjuk dalam menghubungkan pelaku kepada jenayah serangan asid. Oleh itu, kajian ini menyelidiki pencirian bahan kimia yang menghakis dan hubungannya dengan kerosakan tekstil.

Hubungan antara sampel bahan menghakis dengan tekstil jenis kapas dikaji dalam selang masa setiap 5 minit pada tempoh 15 minit. Kawasan koyakan dan kawasan penyerapan yang berlaku pada tekstil kapas diambil kira sebagai kesan tindak balas. Asid gred makmal dan produk komersial turut dimasukkan dalam penyiasatan analisis, di mana pengukuran pH dan pencirian kimia sampel bahan menghakis dilakukan menggunakan spektroskopi ATR-FTIR. Hasil kajian menunjukkan trend keasidan sampel melalui pengukuran pH. Selain itu, pencirian kimia sampel diperoleh melalui analisis komponen utama (PCA), yang mengelompokkan sampel berdasarkan ciri kimia unik pada setiap sampel yang digunakan.

Penemuan ini memberikan implikasi dalam kes serangan asid untuk mengenal pasti bahan menghakis sebagai bukti. Selain itu, kajian ini juga membantu dalam mengenal pasti bahan menghakis dengan menggunakan peralatan analisis serta memerhati hubungan antara bahan menghakis dengan tekstil kapas apabila bersentuhan.

ANALYTICAL INVESTIGATION OF CORROSIVE AGENTS IN RELATION TO COTTON TEXTILE DAMAGE ASSESSMENT

ABSTRACT

Acid attacks cases occur commonly with the ill intention to hurt the victim by utilising corrosive substances that are easily obtained and cheap. Clothing fabrics are one of the surfaces that are in contact with the corrosive agents used making identification of the corrosive substances vital to provide clue in connecting the perpetrator to the crime. Therefore, this study investigates the chemical characterization of corrosive agents and the relation to textile damage.

Relationships of corrosive substance samples with cotton textile were studied over time interval of every 5 minutes in spend of 15 minutes. The tear area and absorption area occurred to the cotton textile were taken into account as the effect. Lab graded acids and commercial products were included in the analytical investigation, whereby pH measurements and chemical characterization of the corrosive substance samples by using ATR-FTIR spectroscopy was performed. Resulting in observation of the acidity trends of the samples through the pH measurement. In addition, the chemical characteristics of the samples was achieved through principal component analysis, clustering the samples according to selected features of each sample unique chemical characteristics.

These findings provide implications for acid attack cases in identifying corrosive substances evidence. Furthermore, identifying the corrosive substance by utilising analytical instrument and observation the relationship between corrosive substances with cotton textile in contact.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Acid attacks, often called vitriolage, are a heinous kind of violence in which corrosive substances are purposefully used to cause physical and psychological injury to victims (Kaur & Kumar, 2020). The physical, mental and social well-being of the victims is significantly impacted by these attacks, which frequently result in serious injuries like deformity, blindness and permanent disability. Acid attacks which disproportionately affect women in many parts of the world and are frequently the results of rejection, jealously or interpersonal conflicts, are also classified as gender-based violence, yet it still occurred to other genders as well over similar disgraced reasonings (Calcini, 2022).

Despite the fact that the first reports of acid attacks in Southeast Asia region began with Cambodia and consider as sex-based violence in which women being targeted more, Malaysia included as much as recent incidents has been reported (Calcini, 2022; Waldron, et al., 2014). However, personal grievances, domestic disputes, or acts of retaliation are frequently the cause of incidents in Malaysia (Khalid, et al., 2015). For instance, a Malaysian footballer, Faisal Halim suffered a fourth degree burned from the acid attack on 5th of May 2024, Kuala Lumpur until he needed skin graft surgery, this attacked further affected his movement, speech and mental health (Msar, 2024; Reuters, 2024). It was also noted that the acid used by the perpetrator in the Faisal Halim's case was concentrated sulphuric acid and yet the perpetrator was not being apprehended (Msar, 2024).

Another case occurred in recent years involving a 22-year-old student was attacked with sulphuric acid by her alleged friend in Kelantan on May 3rd, 2024, where the victim suffered critical injuries to the face, eyes and other body parts (Razali, 2024; Ramendran, 2024). The perpetrator was not just charged under Section 326 of Penal Code that could convict the suspect up to two years of jail sentence and a fine, or whipping, but she also was charged with Section 3 of Corrosive and Explosive Substances and Dangerous Weapons Act 1958 that leads to up to three years imprisonment and whipping (Razali, 2024). Section 3 of Corrosive and Explosive Substances and Dangerous Weapons Act 1958 relating to possession of corrosive or explosive substance for the purpose of causing hurt where the Act that "Any person who carries or has in his possession or under his control any corrosive or explosive substance in circumstances which raises a reasonable presumption that he intends to use or intends to enable some other person to use such substance for the purpose of causing hurt shall be guilty of an offence and shall on conviction be liable to imprisonment for a term not exceeding three years and to whipping" . Hence, more attention should be paid to this issue, especially with regard to the chemicals used and their effects, as there is a lack of thorough data on acid attacks in Malaysia.

Depending on their affordability and accessibility, different corrosive substances are employed in acid attacks around the world. Since corrosive substances are readily available in commercial and industrial sectors, sulphuric acid, nitric acid, formic acid and hydrochloric acid are the most widely used chemicals in acid attacks (Khalid, Yusoff, Ismail, & Isa, 2015; Kaur & Kumar, 2020). Similar trends can be seen in Malaysia, where hydrochloric acid commonly used in cleaning products while sulphuric acid in batteries and household chemicals is being turned into weapons. When these compounds come into contact with skin, deep burns, dehydration and serious tissue damage would be the after effect, furthermore, the effects sometimes become worse by excessive concentration and inappropriate handling (Verma & Gill, 2022).

Acid attacks have terrible and varied effects, victims may have severe tissue damage, scarring and sometimes even loss of function in the affected areas. Facial injuries frequently result in deformity, blindness and damage to lips and nose which could hinder breathing and eating (Byard, 2020; Mittal, Singh, & Verma, 2021). Moreover, acid attacks will cause severe psychological damage in addition to physical harm such as social isolation, depression, suicical and severe symptoms of PTSD (Kaur & Kumar, 2020; Mittal, Singh, & Verma, 2021). This is due to their injuries making it difficult for them to work or connect with others, victims usually experience social shame and financial difficulties.

Nevertheless, acid's corrosive properties also have an adverse effect on fabrics, where during acid attacks, textiles exposed to corrosive substances frequently exhibit serious damage, such as discolouration, fibre deterioration and structural weakness. Examining these interactions sheds light on the forensic analysis of acid attacks and gives vital information for determining the kind and quantity of corrosive substances utilized. In the context of acid attacks, this study attempts to analytically examine the physical and chemical effects of corrosive substances on textiles. The research aims to improve techniques and advance knowledge further prevention of acid violence by examining the corrosive substances used both internationally and in Malaysia, as well as their effects on fabrics.

1.2 Problem Statement

The occurrence of corrosive substances using acid in violence using misconduct is still a major problem both internationally and in Malaysia. These attacks frequently use readily available chemicals and cheap, such as hydrochloric acid and sulphuric acid, which are converted into weapons of violence from commercial, residential or industrial uses (Kaur & Kumar, 2020). The availability of corrosive substances is still a major worry in spite of awareness campaigns and legal actions.

Recent incidents of acid attacks in Malaysia have brought attention to the need for a better comprehension of the chemicals involved and how they harm human tissues as well as fabrics from the clothes. The chemical analysis of corrosive substances and their interaction with textiles is still poorly understood, despite the fact that forensic investigations frequently concentrate on identifying the offenders and their motivations. In order to help with more successful first respond of acid attack cases to victims and better preventative measures, this gap restricts the capacity to establish crucial forensic evidence that could connect the substances used to its source.

Furthermore, victims also suffer greatly from the damaging effects of acid on fabrics since ruined clothing frequently contains important forensic evidence. In order to develop more effective study procedures and preventative measures, it is crucial to comprehend how corrosive substances interact with textile materials. Without this information, the reconstruction of acid attack incidents for investigation purposes and confronting the growing prevalence of acid attack violence may be a huge challenge in the forensic science community.

Therefore, by doing an analytical study of the commonly used corrosive substances in acid attacks and their effects on textiles, this research aims to close the gap. By doing this study, improvement in forensic technique and supporting large initiative aimed at preventing acid attack violence in Malaysia could be grasp.

1.3 Aim of Study

1.3.1 General Objectives

To perform analytical investigations of corrosive agents in relation to textile damage.

1.3.2 Specific Objectives

1. To examine the effect of different corrosive substances on cotton textiles.
2. To measure the pH value of corrosive substances using pH strip and pH meter.
3. To identify the chemical characterization of corrosive substances by using ATR-FTIR spectroscopy.

1.4 Research Questions

1. How do different concentrations of different corrosive substances affect the litmus strip and pH measurements.
2. Can ATR-FTIR spectroscopy be used as a fast technique to reliably identify corrosive substances.
3. Is acid damage pattern on cotton fabric similar for all types of acids.

1.5 Significance of Study

The significance of this study is to addresses critical gaps in forensic science by focusing on analysis of corrosive substances commonly associated with acid attack violence in Malaysia. The significance of this study lies in addressing lack of comprehensive databases, understanding corrosive substance effects on textiles, raising awareness and prevention efforts. Comprehensive investigations and databases on corrosive substances used in acid attack are severely lacking in Malaysia. The goal of this research is to create a fundamental database by identifying and characterizing the corrosive substances in a simple manner which will aid identifying corrosive substances to crimes and spot usage trends.

Other than that, there is still little knowledge regarding corrosive agents and textiles interactions, which limit the comprehension of burn damage patterns resulting from both interactions. In order to help forensic scientists reconstruct acid attack cases and distinguish between deliberate acts of violence and unintentional harm, this study offers vital insights into the physical changes in textiles. Moreover, these results of the study able to be used in educating public and forensic community about risks associated with corrosive substances and risks of misusing it. Therefore, this research can be used to inform of stricter restrictions and educational purposes that aim to decrease the prevalence of acid attack in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Corrosive Substances

Corrosive substances are chemical agents that carries properties that may cause damage and or gradual destruction to living tissue and materials upon contact (Shandil, et al., 2023). Relatively, chemical properties of corrosive substances vary from pH levels, reactivity and oxidizing nature, where these substances exhibit extreme pH values as acids possess lower than pH 7 and bases possess higher than pH 7 (Hopkins, Neville, & Sanders, 2021; Silverstein, 2000). Corrosive substances could portray a vigorous reaction with materials such as metal, organic materials and other compounds that making the reaction producing gases, heat and other by-products (Gupta, 2016). According to the Corrosive and Explosive Substances and Offensive Weapons Act 1958 (Act 357) considered corrosive substances as substances that able to cause hurt on human body through corrosive action. The corrosive substances listed under this Act are sulphuric acid, nitric acid, hydrochloric acid, formic acid, acetic acid, phenols, ammonia, potassium hydroxide and sodium hydroxide (Corrosive and Explosive Substances and Offensive Weapons Act 1958 (Act 357), 2006). In this study, the corrosive substances that are acids are being utilised alongside the commercial products. (Anon., 2006). A chemical agents considered as corrosive as the substances carries properties that may cause damage or destruction to the environment, materials and skin in contact with, commonly the chemical agents will be labelled with corrosive symbols such as shown in **Figure 2.1**.

Figure 2.1 Corrosion symbol (Department of Occupational Safety and Health Malaysia, 2024)

These corrosive substances are readily available for the industrial purposes or domestic uses, where each type carries specific purposes that is useful for the right intention (Khalid, et al., 2015). Most common applications of corrosive agents in the industry include sulphuric acid, nitric acid, formic acid and acetic acid. Sulphuric acid commonly used in fertilizer production, mineral processing, wastewater treatment and chemical synthesis, meanwhile nitric acid used to produce explosive, fertilizers and metal processing (Chandrasekaran, 2017; Mperiju, et al., 2023). Both formic and acetic acid frequently utilized in textile processing, leather tanning and act as preservatives (Alhamad, et al., 2020). Formic acid or locally known as 'cuka getah' is also prevalent in rubber industry process, while hydrochloric acid and acetic acid become one of the corrosive substances that found to be in most common domestic used chemicals. For instance, hydrochloric acid could be found as part of ingredients in household cleaning agents with the aim to remove scale and rust (Goyal, et al., 2018). Meanwhile acetic acid is present in vinegar which multipurpose for cooking and cleaning (Alhamad, et al., 2020).

Since these substances are widely used in industrial and domestic scope, even in Malaysia, making it increasingly available and accessible to be purchased.

Subsequently, this led to potential of misuse for criminal activities such as acid attacks. However, the regulations work surrounding corrosive substances are enhance with its own regulatory framework by Malaysia's Environmentally Hazardous Substances (MyEHS) scheme, where they aim in monitoring and control the importation, exportation, manufactured and use of hazardous chemicals (Anon., 2025).

Despite the regulatory framework, perpetrator of corrosive substance used in acid attack will find their way to obtain the corrosive substances and misuse for heinous act. Therefore, in relevance to specific corrosive substances used in acid attacks which are sulphuric acid, hydrochloric acid and nitric acids, this acid commonly used in acid attacks due to accessibility and availability either can be purchased from physical store or even on online platform (Mofatt & Rhimes, 2020). Another accessible method of acid attack perpetrator obtained their substances is from common commercial products that have already existed in household such as drain cleaners in which contain significant amount of concentrated acids or alkalis, alongside battery acid which consist of sulphuric acid which is easily available as it commonly used in automotive batteries (Hopkins, et al., 2021).

2.2 Acid Attack Violence and Forensic Relevance

Although acid attacks occurred all around the world, it is much more common in countries like Bangladesh, India, Pakistan and Cambodia (Kaur & Kumar, 2020). Despite Malaysia has a lower frequency of this attacks, recent cases could increase the concerning trend as reasons behind of the attacks may be from personal grudges, jealousy, interpersonal disputes or as an act of retaliate, it is still difficult to comprehend the extend of this issue due to Malaysia's lack of comprehensive national statistics on acid attacks (Khalid, et al., 2015).

Looking into recent acid attacks cases occurred for the past two years, such as on May 5, 2024, an acid attack in Kuala Lumpur left Malaysian football player Faisal Halim with fourth degree burns that required skin graft surgery (Msar, 2024; Reuters, 2024). The attack also had an impact on his speech, movement and mental health. Additionally, from observation that the offender in the instance of Faisal Halim used concentrated sulphuric acid, however the offender was never captured (Msar, 2024).

In another recent incident, on May 3, 2024, a 22-year-old student in Kelantan was splashed with sulphuric acid by her supposed friend. The victim sustained injuries to her face, eyes, and other body parts (Razali, 2024; Ramendran, 2024). The offender was charged with Section 3 of the Corrosive and Explosive Substances and Dangerous Weapons Act 1958, which carries a maximum sentence of three years in prison and whipping, in addition to Section 326 of the Penal Code, which carries a maximum sentence of two years in prison and a fine (Razali, 2024).

On November 8, 2023, a 19-year-old teenager suffered severe injuries to her face, body and legs resulting up to 70% burns overall from acid attack after finished her shift at a clinic in Kuala Lumpur by a man acting as an e-hailing driver (Nawawi, 2023; Nizam, 2023). On the same year, July 6, a couple sustain injuries to several parts of their body after being splashed with liquid known to be acid by an unknown woman at their resident in Kuala Lumpur (Malaymail, 2023; Bernama, 2023). Few days prior to previous case, another acid attack case was reported, July 4, 2023, Kuala Lumpur, where a 37-year-old man suffered a first-degree burn on right shoulder and back after being splashed with acid by a woman due to interpersonal dispute as the offender claimed to be provoked by the victim’s persistent harassment (FMT Reporters, 2023; The Vibes, 2023). Furthermore, formic acid was found to be one of the common corrosive substance used in acid attacks occurred in 2011 in Malaysia as accumulated in the study by Khalid, Yusoff, Ismail and Isa (2015) this is due to formic acid is easily purchase as no identification or business license needed in purchasing formic acid because formic acid is a common synthesized in processing rubber making it accessible (Khalid, et al., 2015).

Other than underwhelming of reported cases upon acid attacks occurrence in Malaysia, the identification of corrosive substance or acid used by the perpetrators also are lacking according to personal communication with Plastic Surgeon Department of Hospital Pakar Universiti Sains Malaysia. Likewise, forensic scientists or medical technicians may be facing challenges in understanding full extend of the issue, focusing on the importance of local research to address this form of violence effectively. Due to lack of corrosive substances used in acid attack in Malaysia, instead the most commonly used corrosive substances in acid attacks worldwide would be sulphuric acid, nitric acid and hydrochloric acid (Byard, 2020; Kaur & Kumar, 2020). This is due to availability and affordability in industrial and domestic aspect of usage. Similar in Malaysia, this acids can be easily purchase and have access to alongside it being available in commercial products like rubber vinegar, battery acid and cleaning agents which often could be misuse in acid attack.

Therefore, identifying the chemical composition of corrosive substances used in acid attack cases is important in forensic investigations, this is because important evidence that could link the case to the perpetrator and or the source could be obtain. For instance, the trace residue on clothing, physical effect and changes to the clothing can be analyzed to confirm type of acid involved in the acid attack case. Thus, such forensic evidence could aid in criminal prosecutions alongside guiding medical interventions for victim.

Accurately identifying the corrosive substance used, especially when it interacts with textile materials, is still a main challenges in forensic investigations of acid attacks. Hence why sophisticated analytical method are needed to aid distinguishing different types of acids that are commonly contributed in acid attacks cases as techniques such as ATR-FTIR spectroscopy and pH testing are essential to discriminate the chemical properties.

2.3 Acids

Acids are chemicals that, when dissolved in water, protons or hydrogen ions (H^+) is released, subsequently increase concentration of hydrogen ions in the solution based on the Bronsted-Lowry theory (Munegumi, 2013). Acids have the capacity to turn blue litmus paper to red, have sour taste, and able to have reaction with bases producing salts and water, this characteristic define the acids properties (Dziezak, 2016). Given that an acid's or acid group's dissociate defined by the ionisation constant which also known as pK_a, the expression for the ionisation constant at a given temperature is as follows:

$$K_a = \frac{[H_3O^+][A^-]}{[\mathrm{HA}]}$$

An acid's strength is indicated by its ionisation constant, the higher the K_a value, the more hydrogen ions are released per mole of acid in the solution, thus the stronger the acid. Moreover, acids can be categorised according to several characteristics, including source, strength and concentration. This most common classification in distinguishing strong and weak acids is depending on the acids ability to dissociate in water.

Acids that are completely dissociate in water producing each ion are to be considered as strong acids. This is due to the indication of almost every acid molecule in the aqueous solution releases hydrogen ions (H^+) (Silverstein, 2000). Acidity measurement is a crucial part of the process of identifying acidity level of corrosive substances, these measurements are expressed in terms of pH, which is negative logarithm of concentration of hydronium ions as follow:

$$\text{pH} = \log_{10}\frac{1}{[H_3O^+]} = -\log_{10}[H_3O^+]$$

The concentration of hydrogen ions is positively correlated with a lower pH value. An acidic solution with a hydrogen ion concentration greater than 10^{-7} M is indicated by a pH values less than 7, meanwhile an abasic solution with a hydrogen ion concentration less than 10^{-7} M is shown by a pH value greater than 7. A solution considered as neutral when the concentrations of the hydronium and hydroxide ions are equal. Moreover, it is also critical to keep in mind that a pH unit difference corresponds to a tenfold change in hydrogen ion concentration because the pH scale is logarithmic.

Strong acids carry properties such as having very low pH values, less than pH 3, these acids considered as highly corrosive and reactive due to very high concentration of free hydrogen ions (H^+) (Dziezak, 2016). Strong acid also able to conduct electricity in aqueous solutions as it is composed of abundance of ions. For instance, sulphuric acid is a highly corrosive acid that commonly used in batteries and industrial process, hydrochloric acid where contain in stomach acid naturally and become one of main ingredients in cleaning agents that commonly used in household cleaning products. Other than that, nitric acid commonly used in fertilizers and explosives manufactured, subsequently these strong acids considered as inorganic acids.

In contrast, acids that partially dissociate in water to release part of hydrogen ion (H^+) is considered as weak acids as the rest of acid molecules remain undissociated

(Dziezak, 2016). Weak acids have properties that are contrast than strong acids, having higher pH values between pH 3 and pH 7, these acids tend to be less corrosive and reactive and poor at conducting electricity, due to having lower free ions concentrations (Dziezak, 2016). For example, acetic acid which is one of the main components of vinegar, and formic acid that is commonly used in leather tanning and act as preservative. These examples of weak acids may be considered as organic acids.

2.3.1 Organic Acids

Organic acids are acid that contain carbon atoms in their molecular structure and commonly have carboxyl group (-COOH) that act as acidic functional group (Alhamad, et al., 2020). There are few characteristics that contribute to an acid becoming organic acids, the structure of the acids consists of carbon, hydrogen and oxygen atoms where the acidic hydrogen commonly attached to carboxyl group (Alhamad, et al., 2020). As mentioned above, most organic acids are considered as weak acids as they are partially dissociating in water (Alhamad, et al., 2020). Moreover, organic acids can be found in living organisms naturally such as citric acid from citric fruits and formic acid can be found in ants stings. The reactivity of organic acids is considered as less corrosive than inorganic acid. Examples of organic acids that being utilized in this study are lab graded formic acid and acetic acid.

2.3.1(a) Formic Acid

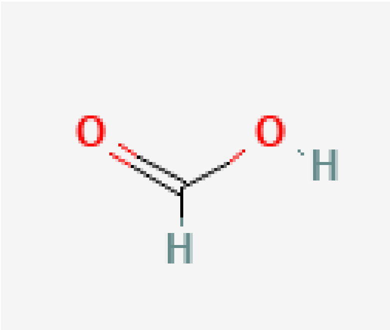

Figure 2.2 Molecular structure of formic acid (National Center for Biotechnology Information, 2025)

Formic acid with molecular formula of HCOOH and molecular structure as shown in **Figure 2.2**, is a colorless liquid that carries a pungent smell that can be produced naturally in ants or industry manufactured by combination of methanol and carbon monoxide and further hydrolyse (Alhamad, et al., 2020).

An acid's strength is indicated by pK_a value, which is logarithmic measure of acid dissociation constant (K_a), which formic acid has the value of 3.75. This value indicates that concentrations of its protonated (HCOOH) and deprotonated ($HCOO^-$) ions are equal at pH value of 3.75 (Sit, et al., 2023). Weak acid typically has pK_a value ranges between 1 and 7, therefore, formic acid pK_a value categorized it as weak acid.

Corrosiveness property of formic acid can be explained as the acid release protons to react with metals, thus produce hydrogen gas and this acid considered as most active organic acid (Alhamad, et al., 2020). Due to formic acid being highly miscible in water making it useful in a wide range of industries, such as preservative in silage, leather tanning and textile finishing. However, since formic acid is sold in commercial marketplaces and for rubber business, possibilities of formic acid being abused in acid attacks are highly likely (Khalid, et al., 2015).

2.3.1(b) Acetic Acid

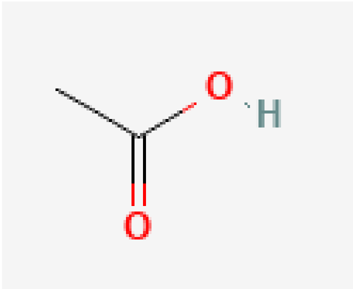

Figure 2.3 Molecular structure of acetic acid (National Center for Biotechnology Information, 2025)

Acetic acid with molecular formula of CH_3COOH and molecular structure as shown in **Figure 2.3,** is vinegar's active ingredient that may be formed synthetically or through bacterial fermentation (Alhamad, et al., 2020). At greater concentrations, acetic acid corrosive properties are significant whilst still being weaker than formic acid (Alhamad, et al., 2020). The corrosivity reaction occurs from reaction of acetic acid with bases and metals resulting in release of hydrogen gas and salts.

The acid dissociation constant, pK_a value measures the acid's susceptibility to donate a proton (H^+), where acetic acid has pK_a value of 4.76 which considered as weak acid. This is because, the value indicates that concentration of acetic acid (CH_3COOH) and its conjugate base acetate (CH_3COO^-) are equivalent at pH 4.76 (Sit, et al., 2023). Therefore, comparable with formic acid pK_a value (3.75), acetic acid is way weaker than formic acid as the lower the pK_a value, the stronger the acid is and faster at donating proton.

Acetic acid is found to be very useful in food preservation, textile processing and dyeing as well as commonly used in household vinegar with concentration of about 4% to 8% (Sit, et al., 2023).

2.3.2 Inorganic Acids

Inorganic acids are acids that do not contain carbon atoms in their molecular structure, which consist of hydrogen combining with non-metallic elements or polyatomic ions instead as it also derived from mineral sources (Gupta, 2016). Characteristics of inorganic acids include the structure of the acid consist of simple molecules and lacking carbon-hydrogen bonds. As mentioned previously, most inorganic acids are considered as strong acids as the acid completely dissociate in water producing hydrogen ions (H^+) making it highly corrosive and react vigorously with metals and organic materials (Chandrasekaran, 2017). Since inorganic acids could be derived from mineral sources, it could be found naturally in non-organic processes such as sulphuric acid in volcanic emissions (Chandrasekaran, 2017). Inorganic acids used in this study include lab graded sulphuric acid, hydrochloric acid and nitric acid.

2.3.2(a) Sulphuric Acid

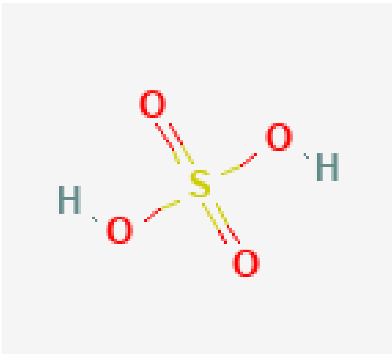

Figure 2.4 Molecular structure of sulphuric acid (National Center for Biotechnology Information, 2025)

Sulphuric acid is a strong acid with molecular formula of H_2SO_4 and molecular structure as shown in **Figure 2.3.2(a)**. With pK_a as low as -3, sulphuric acid able to dehydrate materials and tissues when it comes into contact and further reaction with water making the sulphuric acid undergo exothermic reaction with water (Yamada, et al., 2016). The exothermic reaction would increase the potential for injury. The acid dissociation constant, pK_a value of sulphuric acid, -3, indicates that this is a strong acid that is more readily to donate protons, as the lower pK_a value, the stronger the acid is and more quickly donating proton (Munegumi, 2013). Therefore, this shows that sulphuric acid is a strong acid that dissociate completely in aqueous solution.

In industrial aspect, sulphuric acid is commonly utilized in manufacturing of chemicals, batteries and mineral processing. However, if mishandle or usage of sulphuric acid with ill intention potential of getting injuries up to severe burns and permanent damage is highly likely (Sen, 2017). The similar effects could be occurred to textiles in the case of acid attack.

2.3.2(b) Hydrochloric Acid

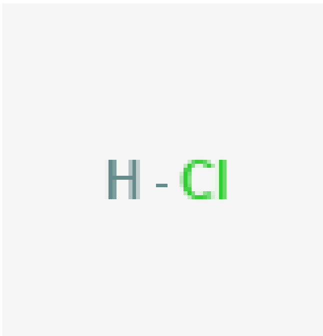

Figure 2.5 Molecular structure of hydrochloric acid (National Center for Biotechnology Information, 2025)

Hydrochloric acid, HCl with molecular structure as shown in **Figure 2.5,** is a colourless and extremely acidic solution with pK_a of -6.3. It is classified as strong acid due to the pK_a value which indicates that hydrochloric aicd dissociates nearly completely in aqueous solution. Therefore, the extreme acidic nature of hydrochloric acid could be explained by the fact that it releases protons quickly when dissolved in water, resulting in high concentrations of protons or hydronium ions released (Dziezak, 2016).

The harsh byproducts are a readily combinations of hydrochloric acid with organic compounds and metals which is harmful to the environment. Despite the corrosivity properties, hydrochloric acid brought in few benefits in industrial descaling products and household cleaning products (Gupta, 2016). However, misuse of hydrochloric acid such as used in acid attack case will give effect to clothe textile where fibre swelling and hydrolytic cleavage becoming the two characteristics of burn marks produced from the interaction between hydrochloric acid and the fabric.

2.3.2(c) Nitric Acid

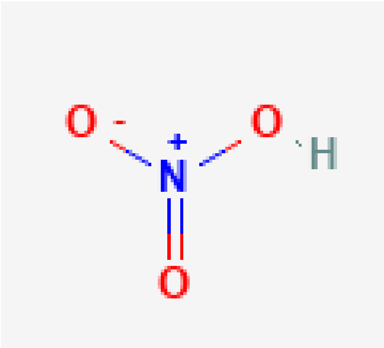

Figure 2.6 Molecular structure of nitric acid (National Center for Biotechnology Information, 2025)

Nitric acid, HNO_3 and molecular structure as shown in **Figure 2.6**, is a potent oxidizer with a pK_a of -1.3, whereby characterized by the reactivity and yellowish fumes. With pK_a value of -1.3, nitric acid shows clear signs of very acidic properties, due to the lower number of pK_a, the value quantifies the acid's capacity to donate protons. Therefore, nitric acid releases protons readily and dissociate completely in aqueous solution, indicating that it is a strong acid yet still not as strong as sulphuric acid and hydrochloric acid in comparison to the pK_a value.

When nitric acid comes into contact with any surfaces, it could cause serious oxidative damage and dissolves majority of metals (Committee on Acute Exposure Guideline Levels and Toxicology, 2013). Despite that, nitric acid is still found to be useful as it is extensively utilized in metal etching, explosives and fertilizer manufacturing (Ciesielczyk, 2020). In the case of an acid attack that uses nitric acid, it may cause yellowish staining on fabric clothes and severe fibre degradation on textiles (Tan, et al., 2015).

2.3.3 Commercial Products Containing Corrosive Substances

Everyday household products or industrial supplies that include strong acids, bases or other compounds that able to cause substantial chemicals reactions, tissue injury or material degradation are considered as commercial products containing corrosive substances (Verma & Gill, 2022). Despite it being widely utilized in homes, businesses and agricultural settings, these materials are also prone to misuse due to their corrosive nature, specifically in violent crimes like acid attacks. Strong acids like sulphuric acid, hydrochloric acid or bases like sodium hydroxide are found in many of these commercial products making them extremely reactive. Moreover, these commercial products can be easy to purchase for legal usage purposes, making them easily accessible, which in hindsight is a risk of these products being misused in acid attack crime.

However, there are still little to no detail studies done upon acid attacks with use products called by the public as rubber vinegar, battery acid and drain renovator solvent as weapons in the crime, to comprehensively understand the reasons of choosing the weapon and its chemical properties. In this study, commercial products being used as samples are rubber vinegar, battery acid (33% sulphuric acid) and drain renovator solvent.

2.3.3(a) Rubber Vinegar

Rubber vinegar or commonly known as ‘cuka getah’ has the main component of formic acid (HCOOH) which is in form of a liquid coagulant used in the rubber industry. Formic acid has a strong pungent smell and is a colorless liquid and because of its great solubility in ether, ethanol and water, it is relatively simple to combine with latex or efficient coagulation. Formic acid is known to be more efficient at lowering the pH of latex due to it is a stronger organic acid than acetic acid. The coagulation process is accelerated by the speedy aggregation of rubber particles caused by this rapid acidity.

In the rubber production industry, an essential phase in production of rubber is coagulated which is caused by this organic acid’s strong ability to destabilize the colloidal structure of natural rubber latex. Because of its greater coagulation efficiency, quicker action and capacity to create high-quality rubber with fewer impurities, formic acid is favored over other acids in order to turn liquid latex into solid rubber sheets or blocks that may be further processed into commercial rubber goods, rubber producers and companies utilizing it extensively (Hutapea, et al., 2022). Formic acid is preferred as the main component of rubber vinegar is due to it requires a lower concentration for effective coagulation, which makes it more cost effective for large scale rubber processing (Zhang, et al., 2017).

Misuse of rubber vinegar in acid attacks could be an alternative for industrial acids due to it being easily available as it is commonly used in the rubber production industry in Southeast Asia. Although there is not much research specifically on rubber vinegar abuse in acid attacks, formic acid’s corrosive properties can seriously harm tissue or material when it comes into contact with. Thus, the interaction of rubber vinegar with fabrics would result in weakening textile strength over time and leads to structural damage, discoloration to the fabrics also occur as part of the result.

2.3.3(b) Battery Acid

Commonly automobile and industrial batteries use battery acid as an electrolyte, which mainly is concentrated sulphuric acid. This is due to battery acid’s strong acidity and corrosive properties that work well maintaining and transferring electrical energy in the battery (Franke, et al., 2011). However, due to its accessibility, battery acid has become one of the most often abused corrosive substances in the case of acid attack. When it comes into contact with textiles, cellulose in textiles will react with it causing quick and permanent deterioration. Furthermore, the potential of secondary injuries during handling or attacks may be increased by the highly exothermic interaction with water and organic compounds (D'Alessandro, et al., 2020).

2.3.3(c) Drain Renovator Solvent

Drain renovator solvents commonly contain ingredients such as hydrochloric acid or sulphuric acid which intend to remove organic clogs from plumbing systems, such as hair and grease. Other than its main function, these solvents are frequently used in situations of acid attack due to high acid content and corrosivity properties (Song, et al., 2020). It may use often than not also due to the effect it gives to the victim, as the perpretrator may have intention to give minimal to average degree of injury, enough to hurt (Hopkins, et al., 2021). Nevertheless, drain renovator solvents are easily accessible in stores; hence perpetrators may use this solvent rather than industrial acids.

2.4 Interaction of Corrosive Substances with Textiles

Corrosive substances and textiles, especially cotton fabrics, interact through intricate chemical reactions that could degrade the materials, where forensic analysis requires an understanding of these interactions, particularly when acid attack cases are involved. When corrosive substances such as acids come into contact with textiles, chemical reactions that could deteriorate the material will occur which making it part of the mechanism of corrosive damage to textiles from corrosive substances. Such in study by Smigiel-Kaminska utilizes acids, the acids have the ability to hydrolyses cotton fibres' cellulose, subsequently lower the fabrics' tensile strength and eventually causes the fabrics to disintegrate. Discolouration, fibre deterioration and hole formation are the outcomes of the reaction (Smigiel-Kaminska, 2014).

Even at relatively small concentrations of acids at high temperatures could break down the interfiber structures of woven cotton (Cuiffo, et al., 2021). Studies have proved that different acids affect textiles to different degrees, such that, a study looked at how sulphuric acid, nitric acid and hydrochloric acids at different concentration affected cotton textiles reported that the damage that various acids produced have different observations (Smigiel-Kaminska, 2014). This study by Smigiel-Kaminska also pointed out that more study is required to fully comprehend the manner in which chemicals affect textile damage, particularly in field of forensics.

The chemical reaction between acid and cellulose fibres like cotton, linen, and rayon is called hydrocellulose, where the cellulose broken down thus further weakening the fibres and ultimately the fabric (Cuiffo, et al., 2021). Textiles undergo visible alterations as a result of exposure to corrosive substances. Visually, textiles may show sign of discoloration, staining or hole formation, but fibre breakdown can be observed under a microscope in the form of surface pitting, cracking or total dissolution of the fibre structures (Sharma, et al., 2024). These changes impair fabric's mechanical properties by decreasing the fabric tensile strength and elasticity, which are two attributes that could be crucial in forensic analysis in identifying the type of corrosive substance involvement.

2.4.1 Interaction of Corrosive Substances with Cotton Textiles

Cotton is particularly vulnerable to acid degradation since it is a naturally occurring cellulose fibre and cotton fibres can be severely damaged by acid exposure, which increase their vulnerability to mechanical injury (Carlysle-Davies & Bandara, 2022). It was proven that there are discernible variations in the way that acid damage to clothing appeared, the damage seems to be influenced by type of textile and the acid (Carlysle-Davies & Bandara, 2022). Such as, with hydrochloric acid, visible staining was observed after 24 hours while with sulphuric acid, color changes and some 'bubbling' action was noted on a cotton t-shirt (Carlysle-Davies & Bandara, 2022). Therefore, investigating textile damage and identifying possible acid may aid in acid attack cases investigation. Cotton's vulnerability to acid-induced damage was brought to light by this study on the negative impacts of corrosive substances on textile materials and fibres, highlighting on the need of comprehending these interactions in forensic examinations.

Understanding the impact that such corrosive substances can have on textiles is necessary due to acid attacks becoming well-known and there still seems no published papers that have addressed how corrosive substances affect fabrics (Williams, 2018). According to a study by Carlysle-Davies and Bandara, despite the findings being promising there are still more studies that need to be done regarding textile damage from corrosive substances, much more on the commercial product, since there is still a lack of research done upon it. Other than that, there is still also a lack of detailed study on the measurement of area of damage and detail description of observation. Understanding these interactions is crucial for forensic investigations due to the distinct damage patterns that might reveal the type of corrosive substance being utilized, which further aid with criminal profiling and legal proceedings.