1 Introduction

1.1 Overview of contents

The term ‘tool mark examination’ is often applied to cover a wide range of possible forensic examinations. However, whilst the term implies that you must have some type of tool or instrument before you can proceed, this is not the case at all as we shall see. Throughout the book we will use the term ‘tool’ to cover all instruments, tools or other objects that have come into contact with another surface.

As the term suggests, it primarily applies to examinations involving marks that have been made by a tool or tools used by a person in order to commit an offence, where usually both the scene mark(s) and suspect tool(s) are available to the examiner for consideration, to determine whether or not the tool submitted was the one used. Chapters 2–6 will mainly deal with this type of typical tool mark examination, concentrating on the important aspects used by the examiner such as how tools are made and what features may be found on their surfaces, the type of tool marks that can be found at scenes of crime, the laboratory techniques that can be used to examine them and how results can be interpreted and evaluated. The principles that we will cover in these chapters, as well as here in Chapter 1, also provide a solid framework for the scientific investigation of other related forensic examinations described.

The basis of all tool mark examinations is that when one object comes into contact with a softer material, then evidence of the contact may result. Put simply, if the contact forces the two objects together without any movement then an impressed mark in the softer material will result; this may be a direct representation of the surface of the harder object that has been in contact. If however, there is some form of movement between the two objects then a dynamic mark will result. The dynamic mark will consist of a series of parallel

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lines, which are often referred to as striations (made up of ‘striae’). In general terms there are four main types of action that produce striated marks:

- sliding marks, which are sometimes also known as scratch marks, for example where a tool slips across the surface;
- cutting marks, where a single bladed tool such as a knife slices through an object;
- cutting marks, where a double bladed tool is used to sever an object;
- stabbing marks, where a tool is forced into a material.

In many instances a mark will consist of a combination of both impressed and dynamic detail, both of which have been produced by and directly relate to surface features on the harder object at the time the mark was made.

‘Tool marks’ therefore could also be found on the surface of a variety of manufactured items. This includes marks on the surface of those very tools and instruments that have been used to commit an offence. Hand tools such as screwdrivers, case openers and bolt cutters, to name but a few, are mass produced items that are shaped, moulded and finished by various processes during manufacturing. The machines, moulds and other equipment that form a finished hand tool are ‘tools’ themselves (albeit larger ones) and have the ability to leave marks of various descriptions on the finished manufactured item. Assessing how these manufacturing marks on the surface of tools were made and their evidential significance is a fundamental stage in the interpretation and evaluation of routine tool mark comparisons.

Therefore, it follows that other mass produced items will also have ‘tool marks’ upon their surfaces. For example, items such as screws, nuts and nails, where the item has been somehow shaped, moulded, gripped or cut to achieve the final shape and finish. However, for the purposes of this book, these will be referred to as ‘manufacturing marks’ and when considered alongside typical tool marks, the more general term ‘marks’ will be used. (This should not be confused with other forensic disciplines where marks are examined such as fingerprints, footwear marks or tyre marks.) In a forensic examination, such manufactured items may be seized from a crime scene and there is a necessity to compare them with a suspect population of similar items. In these sorts of circumstances, the tool mark detail on the surfaces of the items under examination needs to be assessed, and an evaluation made on whether or not they have come from the same source. For examinations such as these, the same equipment and techniques used for routine tool mark examination can be applied. The main difference is in how the results are interpreted and evaluated, which will be discussed in Chapter 7, although the same fundamental principles that we will see in Chapter 6 still apply.

In this book we will also cover what are known as 'physical fits'. This term refers to broken or torn items where the pieces can be demonstrated to have once been joined together, and therefore formed part of the same item. What the item is and how it was broken/torn can alter the information and laboratory techniques used in order to reach a conclusion. In general though, physical fit examinations fall into four main categories.

1. Broken items that can be obviously fitted back together; otherwise known as 'jigsaw' fits. A tool mark examiner would not necessarily be required to demonstrate this sort of physical fit.

2. Broken items where the pieces require routine tool mark examination techniques to demonstrate that the pieces fit together and thus to form a conclusion. The detail may require a microscopic comparison and use of casting.

3. Broken, torn or cut items where knowledge of manufacture and type of marks left on the surface of the item need to be taken into account in order to support a fit. Typically, these sorts of examinations require techniques more commonly associated with routine tool mark examinations or manufacturing marks, particularly those relating to plastic film items.

4. Items that were originally fitted together or were in contact for a period of time. Typically these examinations involve a consideration of what material has been transferred or is a result of the contact.

The categories of physical fit that fall under the auspices of tool mark or manufacturing mark examinations will be dealt with in Chapter 8.

Plastic manufactured items, such as plastic film, bags and adhesive tape, can also exhibit features of manufacture caused by the machinery and processes used to make them. As with other mass-produced items such as screws, examinations tend to focus on whether crime scene and suspect items came from the same source. However, in this particular area, different examination techniques are normally applied in order to visualise the detail (but the need to understand how the detail has originated during the manufacturing process remains the same). Another critical factor in the interpretation and evaluation of these sorts of manufacturing marks is knowledge of how rapidly the detail changes. Chapter 9 will cover aspects of forensic examination in relation to the manufacture of plastic film items, including physical fits (as described above under category three) involving this sort of material.

Whilst this book aims to cover a wide range of examination types encountered in this particular field of forensic science, it cannot be a catch all for all of the weird, wonderful and unusual examinations that the authors have encountered in their collective 129 years of forensic experience. However, the fundamental principles of more typical marks' examinations, which we shall describe in this book, can be applied to any type of examination that falls, no matter how tenuously, into the categories of marks described. Our aim is to cover a broad selection of more commonly encountered examination types and some tried and tested, best practice techniques and methods based on our knowledge and experience of doing work of this kind. However, such work is not without its limitations and Chapter 10 will attempt to capture some of the ways in which other experts in this field are striving to make improvements.

1.2 A brief history of tool marks

At this juncture, it is useful to put tool mark examination into an historical context, as it is a traditional area of work that has been in use for longer than may be expected. There has been an appreciation that marks can be related back to tools from early times, although there were few written texts on the subject. One frequently quoted example comes from 12th century China, where the different shapes of wound caused by cutting instruments such as sickles were considered but it had little impact on the courts, even in China. The first book to have a major effect was written by Hans Gross in 1891, published in 1893 as two volumes, entitled *Handbuch für Untersuchungsrichter als System der Kriminalistik*. This was later translated into various languages, including English (see Gross, 1907) and has been republished many times.

Gross was a professor of law at the University of Graz in Austria and was also a practising judge. The book was written from his experience as a judge and details some of the best physical, as distinct from circumstantial, evidence that was presented. Tool marks are not given in a specific chapter but feature under the heading of *Theft – Burglary and House Breaking*, in Chapter 17. In this Gross says that it is necessary to describe, record (here by drawing) and take mouldings of all the damage done by the thief. The example is given of a tool, where the impressed tip detail indicated that a screwdriver, rather than a chisel, had been used and examination with a hand lens showed that one corner was damaged. A sketch was made and later a screwdriver used in another burglary was connected to this scene using the recorded information. There is no mention of using microscopes here but they are mentioned in Chapter 5 Section vii, dealing with firearms together with a comparison microscope. This goes with the caution that '. . . microscopic examinations can only be made by really skilled experts'.

All the basic steps of tool mark examination are present in this work and it remained in print until 1934. During the period 1891–1934, the courts increasingly recognised the value of scientific evidence but there were no large laboratories in existence and equipment was both limited and often awkward to use. After 1945 there was a large surge in scientific research, both in universities and industry. Forensic science benefited from this and the investigation of tool marks and firearms was improved through the development of better designed equipment, especially optical equipment.

In 1953 Paul L. Kirk, who was by that time a Professor at the University of California in forensic science, wrote an influential textbook called *Crime Investigation*, which includes sections on tool mark examination. He recognised the need to cast marks found at scenes of crime, when the item with the mark cannot be taken to a laboratory and suggested ways of achieving this. By the time of the last update and reprint in 1974, two-pack silicone materials were being suggested for casting, with the added comment that there was the need to colour the surface to obtain good reflectivity for comparison purposes. There are detailed discussions relating to types of tools and the importance of what are now called class characteristics together with individual characteristic detail.

The book makes a clear distinction between 'compression marks', called impressed marks in this book, and 'sliding marks', here called dynamic or striated marks or further divided into sliding, cutting or stab marks depending on the action used. The method given for the examination of impressed marks is to use macro photography of the individual scene mark and the test mark, then to use side by side comparison of the photographic images. A comparison microscope (also known as a comparator or comparison macroscope[1]) with long focal length lenses is suggested for examining striated marks, with the comment that photography using the comparator is not always successful. Examination of physical fits is also included in the text.

There is a discussion of what is meant by a 'tool mark match', together with an increasing set of references to papers dealing with this topic in the reprints. There is recognition of the problems involved in 'matching' and the need for training and experience. In relation to striated marks, although by implication impressed marks as well, Kirk says 'There is a need for conservatism – no witness can truthfully state "This is the only tool on earth that could have made this mark"'. In the 1974 edition there is a reference to the work by Biasotti (1964), *The Principles of Evidence Evaluation as Applied to Firearms and Tool Mark Identification*, which contains some of the first references for objective methods for evaluating striated marks.

In 1958 J.E. Davis published *An Introduction to Toolmarks, Firearms and the Striagraph*. This gave more information than Kirk's book but, apart from introducing the striagraph, which did not enter general use, added little new.

[1] The term 'comparator' will be the one mainly used throughout this book.

While Kirk makes clear in his introduction that his book was written for 'laboratory criminalists', most of the later authors write for more general audiences. H.J. Walls, a director of the Metropolitan Police Forensic Science Laboratory, London, UK, wrote a book entitled *Forensic Science: An Introduction to Scientific Crime Detection*, the first edition appearing in 1968. He states in the introduction that the book is intended for non-specialists. There is a general discussion of tool marks, which does not go into any great detail about the methods used in their examination. In dealing with the problem of matching marks, he noted that there is rarely a 'perfect' match between test and questioned marks. In an unreferenced aside on striated marks he notes that tests in the United States showed that a correspondence of over 70% of the striae could be found for suitable marks made by the same tool but was less than 25% in marks made by different tools.

In 1969 the Association of Firearms and Tool Mark Examiners (AFTE) was formed in the United States. This provided a forum for those examiners, separate from the various forensic science groups already in existence. Its journal and publications did much to raise the profile of this area of forensic work and, eventually, to promote an international approach.

Since that time, forensic science has expanded as a university subject and a number of textbooks have been written to meet the demands of these courses. They often seek to be informative for other groups as well, such as scene of crime examiners, police and the legal profession, but rarely go into much detail about tool mark examination. Given the problems associated with interpreting and evaluating tool mark evidence this is, perhaps, not that surprising. A different reason lies in the developments in analysing body fluids and materials, where it is now possible to discriminate between millions of people in the best circumstances. At a crime scene these biological materials would be sought first, as they have a tendency to degrade and decompose and so could be rapidly lost, depending on the circumstances of the case and environmental conditions. This type of evidence can also often provide significant answers to an investigation rapidly. Generally tool mark evidence will not degrade and so collecting it may not be considered a priority. In some instances though, it may not be collected at all, which may be because it has not been detected or because a conscious decision has been made.

Preconceived ideas about limitations in the value or usefulness of tool mark evidence, along with the time and cost associated in examining it, may all be factors in its demise as a key forensic discipline, at least currently in the United Kingdom. However, tool marks can often provide vital and strong evidence of association as well as eliminate a suspect item, which can prove critical as an investigation progresses. What we think has been lacking, and which we will seek to provide in this book, is a text that deals predominantly with tool mark examination as it is presently practised, to help raise general awareness of the capabilities of this type of evidence.

1.3 General aspects of marks' comparison

At a fundamental level, a marks' comparison can be considered to be a comparison of the 'unknown' with the 'known'. The unknown items are those bearing marks recovered from the crime scene, which could be casts or original items. The known is a control item, which could be one taken from the suspect, such as a tool, or a population of items for reference, such as a bag of screws or roll of plastic bags that has been recovered during the course of an investigation for comparison.

The aim of the comparison process is therefore to determine what features and detail of the crime scene mark(s) differ or correspond to those on the control item(s). However, it is a fairly straightforward process to do a comparison of features, but much more difficult to interpret what the outcome means if one does not know what the features and detail are or how they were obtained. One of the most important aspects of any marks' examination is having equipment and techniques that allow you to visualise the, often microscopic, detail so that you are best placed to evaluate the significance of the findings.

Another critical aspect of a comparison is to understand the manufacturing processes associated with the 'control' item. There are three classes of features that an examiner will need to consider.

Class features	Features that are common to all items of a particular type.
Sub-class features	Features that are not unique to one particular item, but allow some discrimination between groups of tools with the same class features. They arise during manufacture, but are not necessarily introduced deliberately. The source of sub-class features may change over time.
Individual/unique	Characteristic features arising at random during the manufacturing process or through normal use.

To interpret and evaluate the findings it is therefore necessary to know and understand the types of features and detail produced during manufacture and use, how they will be represented in a mark and how to differentiate between the different types, as this will determine what you are able to say about the comparison. Other aspects may also need to be taken into account, such as how common a particular type of tool is considered to be, or the quantities that mass produced items are made in and how widely distributed they are.

Often the limiting factor in a marks' comparison is the quality of the scene mark. Detail that may be present on a tool may not be replicated in a mark for many reasons, such as the physical properties of the substrate. If it is only slightly softer than the tool the detail of interest may not be replicated in full.

If the substrate is very soft then it may be extensively damaged and, in the case of paint, may become smeared and any detail is obscured. If the surface of the substrate is textured it may interfere with any detail left by the tool or at the very least make it difficult for the examiner to reliably identify the important detail left by the tool.

The comparison of tool marks, and marks in general, is still a subjective area of forensic science, but there is an expectation by the courts that there is consistency amongst experts. It is therefore important to recognise that all experts must have knowledge of the relevant manufacturing processes, use the appropriate equipment and techniques to maximize the visualisation of the detail and have the skills and experience to undertake an examination. In any subjective examination difference of opinions will occasionally occur. The difference may only be slight and may be due to the difference in experience between the two experts. However, occasionally the difference will be significant and on occasions may even be to the extent that one expert will say the tool was responsible and the other that it was not the tool. With this in mind, the importance of an independent critical findings check by a second tool mark expert should not be underestimated. However, this is not always sufficient and a third expert may be required to undertake a check to decide the debate.

1.4 Training requirements for examiners

There are certain qualities that help make a good marks' examiner and some of the more important ones include good pattern recognition, a logical and methodical approach to work, good manipulation skills and an eye for detail. However, the most important factor is good training and coaching by an experienced examiner. To become a competent tool mark examiner takes time and controlled exposure to tool mark cases (with trainees in the other areas of marks' training having the equivalent exposure to relevant cases), which normally are mock/dummy cases to begin with, but after the individual has demonstrated their ability they may become an assistant to an experienced colleague and shadow them for a period of time.

The academic qualifications required to become a forensic practitioner in marks will vary around the world. In some countries a degree is normally required before being employed, although there are many examples in the United Kingdom where individuals have shown their expertise over a number of years as an examiner and have eventually been authorised to be a court reporting scientist. It may be useful at this point to clarify what is meant by a forensic examiner and a court reporting scientist. The court reporting scientist is the person with responsibility for planning the examination, evaluating the findings, writing the final statement and presenting the evidence in court if required as the expert witness. A forensic examiner is a person who is deemed technically competent to undertake the examination and comparison, which could be the court reporting scientist or another trained individual.

Tool mark examinations and the other related examinations that will be covered in this book, are not always undertaken by the same individuals or groupings of individuals. In some countries, such as the United States, tool marks are routinely done alongside firearms' and ballistics' work. It could be said that ballistics is a specific example of a tool mark as it involves consideration of the same types of class, sub-class and characteristic detail, often using the same comparison microscopes. With plastic packaging materials the expertise may reside within a drugs' department, as this is where the plastic materials are most frequently encountered. In our experience, marks' and traces' work is frequently encountered together and therefore physical scientists and chemists may work closely together. Here we mean 'traces' to be particulate in nature (rather than biological), which may require chemical, as well as microscopic, analysis, such as paint recovered from tools.

It is our view that the best and most successful approach to training examiners in tool marks or manufacturing marks is to develop a modular approach. A training course should identify the skills and knowledge required and must be tailored to achieve this desired outcome, in assessed stages where the scientist is deemed competent before proceeding. For example, in a traditional laboratory set-up where examiners and court reporting scientists work on cases together, it would not be necessary to train an examiner in all aspects of interpretation and evaluation. However, it would be necessary to train a reporting scientist in the technical aspects of examination. Each module should have an expected standard to be passed. For example, with casting techniques it would be expected that casting would be carried out to replicate the maximum detail with minimal air bubbles. It is recommended that an examiner becomes a competent microscopist, as this is a key aspect of most examinations.

Once each stage of the training programme has been passed and competency gained in each particular skill, then there should also be a programme in place to assess ongoing competency. Proficiency tests could be used for this purpose. These are set exercises that are focused on one particular aspect of the job and can be carried out on a regular basis. Training records should be kept, which are contemporaneous and demonstrate initial and ongoing competency.

The book does not provide a training programme as the authors recognise that one programme will not address everyone's needs and may not be appropriate for all organisations. However it is hoped that the content and discussion within the various chapters will provide a structure that identifies the competencies, skills, knowledge and experience required by a practitioner to undertake the work to the level of an expert.

1.5 Good forensic practice

It has been identified in many countries that there is an expectation by the general public, as well as the courts, that an expert witness will perform their work to a certain standard and behave in a certain way that meets the requirements of the legal system. In some cases these have been stated, an example being the UK Forensic Science Regulator's *Codes of Practice and Conduct* (2011). There are also other documents that provide guidance as to what is expected from an expert, for example, *The Criminal Procedure Rules* (Ministry of Justice, 2012).

Certainly within the United Kingdom (Association of Forensic Science Providers, *Standards for the Formulation of Evaluative Forensic Science Expert Opinion*, 2009) it is useful to try and ensure that any evidence that is presented is:

- logical
- transparent
- balanced
- robust.

In any forensic discipline it should be remembered that it is essential to ensure that good forensic practice is followed and for this area of forensic science it is no different. The application of sound principles of forensic conduct with regards to these examination types must be undertaken in a way that recognises the following.

- The importance of the chain of continuity from the crime scene to the court.
- The integrity of the any item being examined must be maintained.
- The potential of contamination occurring and steps taken to minimize the risk. This will include using the correct packaging and the protection, removal and retention of other significant forensic evidence such as fingerprints, DNA and other trace material.
- Any examination undertaken has to be scientifically valid and an examination should not be undertaken without the scientist understanding what is being compared and what the findings really mean.

- Only validated techniques are used in the examination. This is to say that any equipment or technique has been shown to be suitable and to produce the expected results/findings. Also, that the examiner is aware of the limitations or any critical settings of the equipment.

1.6 Examination and comparison strategy

In the following chapters of this book the examination and comparison of marks to tools is covered in depth; however, it is useful to summarise the strategy used in any comparison at this point as it establishes the approach that is taken. When dealing with any case there are a number of stages that are part of the examination process and should be considered by the practitioner, as follows.

1. Essential background information about the type of crime and any eyewitness account or other information that may be of use.

2. Location, enhancement and recovery from the crime scene – the crime scene examiner can provide significant information regarding the scene including the location of the mark(s).

3. Submission to the laboratory. Four stages of examination, which can be covered by a term used to describe the methodology for the examination of friction ridge detail in latent fingerprints '**ACE-V**' (SWGFAST, 2011):

   (a) **A**nalysis

   (b) **C**omparison

   (c) **E**valuation

   (d) **V**erification

1.6.1 Analysis

Analysis is the assessment of a tool mark (or material that can be considered to be 'unknown') to determine suitability for comparison. Factors considered include the following.

- Assessment of the information supplied and the question being asked by the submitting authority, whether or not there is any other information required before commencing.
- Assessment of material that has been supplied and if there any other considerations, such as the recovery of DNA, fingerprints or other trace materials.
- Development of an examination strategy derived from an assessment of what detail is present and how it should be enhanced to visualise it more clearly.
- Deciding what test marks are required.

1.6.2 Comparison

Comparison is the direct side by side observation of the relevant detail of interest to determine whether or not the detail is in agreement or different. This process will also involve interpretation of what the detail is and how it came to be present on the surface of the tool.

1.6.3 Evaluation

Evaluation is the formulation of a conclusion, based upon analysis and comparison of the relevant detail, by weighing up what the findings mean with respect to the prosecution and defence arguments. This will be covered in more detail in Chapter 6.

1.6.4 Verification

Verification is the independent examination by another qualified examiner. In any subjective marks' area within forensic science it is important that there is a final step in the process, which critically reviews the findings, the verification stage. This may also be known as a 'critical findings check'.

The verification process should ensure that:

- The examiner has followed the appropriate documented examination process and applied the appropriate and relevant scientific methodology and techniques.

- The work and findings of the examination are reflected in the conclusion reported. The results must support the conclusion and clearly there should be no understatement or overstatement of the findings.

- The maximum evidence has been obtained, that nothing has been overlooked and there are no other marks that may change the outcome.

- The submitting authority's question has been fully addressed.

1.7 Environment and equipment

Tool mark examinations are best carried out in a suitable environment, with appropriate equipment available for use. Although it is acknowledged that this will not always be possible, we will try to summarise a desirable environment in which to carry out laboratory examinations.

Throughout this book, reference may be made to 'laboratory examinations'. This is to make a distinction from 'scene examination', which may or may not be carried out by different individuals. However, it is recognised that some practitioners of marks' examinations do not strictly carry out their work in a laboratory as such (meaning either a room designed as a laboratory, or a wider organisation such as a forensic provider), although we would recommend this, as a stricter framework of protocol with respect to many aspects of the forensic process can be applied, controlled and monitored.

1.7.1 Basic requirements

A workbench or desk, preferably with good overhead lighting and an easily cleaned top, is required for the initial examination. Good health and safety procedures and anti-contamination procedures should be followed so the bench should also have electrical sockets placed so that equipment cables do not foul the working surface and allow for proper cleaning of the surface. The working surface needs to be cleaned before starting the examination. A further sensible precaution is to cover the work surface before starting the examination with a sheet of heavy paper, such as brown wrapping paper (also referred to as Kraft paper), which can be obtained in large rolls.

The workbench should be provided with a stereomicroscope with a magnification range of around times 8 to 30. The optics for the microscope needs a long working length (i.e. long focal length) and a good depth of field. The microscope should be mounted on a long arm microscope stand and have a flexible light source that can provide directional lighting rather than a ring source.

It is useful to have secondary light source available, fibre optics are often employed here, as they can be used for other examinations than tool marks.

1.7.2 Examiner's 'toolbox'

The examiner will need some hand tools; these can either be part of the bench equipment or part of the examiner's personal kit. A minimum list comprises a solid ruler, whose calibration can be traced back to a recognised authority, a flexible steel ruler, a knife or scalpel (scalpel blades can be disposed of to prevent contamination), scissors, tweezers and a probe (preferably with disposable needles). A hand lens with a magnification between times four and eight can also be useful. Vernier calipers (again with a traceable calibration) can help when measuring cylindrical objects. A chinagraph pencil can also be useful for marking tyres, for example.

Equipment to record the examination is needed; the main record is often on loose sheets of A4 paper held in a binder labelled with a reference given by the laboratory or by the submitting organisation. The A4 sheets are often pro formas, as there is standard information to be entered on each sheet, such as the type of item being examined and the item's reference, the date of the examination and the signature of the examiner(s). Many organisations also require the sheets to be numbered to ensure that none have been lost, which entails producing an index at the end of the examination. All entries on these sheets must be in ink and, where an alteration is needed, the text to be altered is lightly crossed through, so that it is still legible, the emendation made and initialled. Time can be saved by using a digital camera to record items and keep written descriptions to a minimum.

Other equipment that should be easily available is self-adhesive tape of different widths for repackaging exhibits, protective gloves and cleaning materials for the work surface. It is useful to have a waste bin, preferably with a foot-operated lid, close to the work bench.

1.7.3 Test mark and casting materials

When making a test mark with a submitted tool the examiner is trying to replicate the scene mark so that detail is reproduced and a comparison is possible. In most cases more than one test mark will have to be made so it is very important to use materials that do not change the detail that already exists on a tool or introduces new additional features. Therefore, the range of materials that are routinely used to undertake tool mark examinations includes: lead sheet and rod, modelling/dental wax and painted wood. On occasions it is necessary to use samples of the submitted material or even use the submitted item, a good example being plastic cable that has been cut. Other materials that it may be useful to have access to include those that will make the production, labelling and manipulation of casts produced in the laboratory easier, such as disposable paint brushes, backing paper and small wooden sticks such as toothpicks and lolly sticks.

The basic approach that has been developed over the past 20 plus years has been to develop procedures that enable the microscopic detail to be visualised and compared. Therefore, the development and improvement in microscopic equipment led to an increased use of casting materials. Many of these materials were originally designed for dental use but found an application in tool mark examination; in more recent years others have been specifically developed or modified for use in the forensic environment. So the use of casting materials has increased significantly not only to recover marks from a crime scene but also within the laboratory.

There are, however, a number of features that any material should have before it can be considered for routine use. It is recommended by the authors that any material that is being considered should be tested and validated for use. The important parameters that should be included in any assessment of a casting material are:

- dimensional stability over a long period of time;
- ability to capture and replicate very fine detail on the scale of microns;
- setting/curing characteristics;
- ease of use (includes mixing of the material to ensure all of the material hardens and removal from the mark without causing damage so that further casting is possible if needed);
- inert to a range of substrates;
- appearance under the microscope (opaque and not translucent);
- the ability to cast and recast the mark using another casting material but without loss of any detail.

Most of the current materials meeting these requirements are based on silicone rubbers. There are a number of sources for these, specialist stockists of scene of crime examination materials, engineering suppliers, jewellery equipment suppliers and dental supply houses.

There is a range of silicone rubbers that will meet the requirements above. The choice will depend on other local demands. Two-pack systems comprising base and hardener are the most flexible but need both experience

Figure 1.1 A single-pack system for casting.

and practice to use effectively. Thoroughly mixing the hardener with the base without introducing significant bubbles needs practice. In a single-pack system, depressing the plunger automatically mixes the base and hardener in the correct proportions in the disposable nozzle (Figure 1.1). These are far easier to use but care is needed in selecting the correct type for the conditions involved. In cold conditions, such as outdoor marks in winter, a quicker setting variety is needed than for the warmer conditions indoors or in summer. With two-pack systems the amount of hardener can be varied to take account of the temperature. Shelf life is also a consideration; when the silicone rubber no longer cures in the recommended time the pack must be thrown away; it should always be tested for setting time before use. With a two-pack system, using a fresh batch of hardener will often solve the problem.

Other casting materials have been used and references to these can be found in books, especially in older books such as *Crime Investigation* by Kirk (1953) or *Forensic Science* by Walls (1968). Some of these would no longer be acceptable, such as dental plaster or plasticine. Others, known generically as 'moulage', could still be used, provided that they are dimensionally stable and reproduce fine detail. They all suffer from the same problem, that they are mobile liquids when applied and thus require a containing wall to be built round the mark. This is best done with self-adhesive aluminium tape or plasticine; in fact, this technique can be useful even when using a silicone rubber.

The following list of casting materials is not comprehensive and is based on the authors' experience. Other materials are available and it is always worth experimenting to determine if there are better options. The list is in alphabetical order of the trade names that the materials are sold by.

- **Isomark**™: This silicone material is sold in a number of different grades, which cure at different rates. It is normally sold in cartridges that are used with an applicator 'gun', which mixes the base and hardener as the material is extruded through a nozzle. The quicker setting thixotropic materials work well in vertical or overhead marks, which make them especially useful for casting scene marks. It can bond to some materials, such as plastics or rubber, and should be tested on a small area of the substrate bearing the mark before use if there is any doubt regarding its ease of removal after curing. The slower curing, more fluid, grades are useful for casting horizontal, large areas of mark or deeply recessed ones.

- **Mikrosil**™: This a two-pack silicone system, comprising a base and hardener, that is mixed as needed. Some experience of the system is needed but it can be used in a wide variety of situations, both at a crime scene and in the laboratory.

- **Permlastic**™: This is a two-pack material, the base comprising a polysulfide material, which is used by dentists to recast from silicone rubbers. It is incompatible with Isomark casting material, on which it does not cure properly, but it can be used to recast from other silicone rubbers. It is not the best material for taking primary casts, as it is not very fluid, but can be used as an intermediary when making recasts from silicone rubber casts, for making replicas of metal tool parts or where the examination involves the physical fit of one part to another. Casts made with Permlastic will degrade in a relatively short time and are not suitable for long term storage.

- **Silcoset**™: This trade name covers a wide variety of products. The two of interest here are Silcoset 105 and Silcoset 101, whose primary listed purpose is for encapsulating items, with casting being a secondary use. They are both two-pack materials and a number of curing agents are suggested; for tool mark work the tin-based condensation curing agent is to be preferred.

- **Silmark**™: Similar to Mikrosil in that it is a two-pack system.

1.7.4 Larger equipment

In many tool mark cases, the detail that is compared is microscopic and can only be viewed on equipment that allows the detail to be resolved and visualised by the examiner. One of the most important aspects is to have lighting that allows the examiner to have complete control of the angle and direction of the light. In an ideal world, all examiners involved in tool mark work would have up-to-date comparators, but this is not always the case. Many examiners have to use old equipment and old lighting, which can limit the type of detail that can be compared. Other techniques have been utilised in the past and these have mainly been photographic based, but this approach is specialised and does have limitations.

1.7.4.1 The comparator In essence an optical comparator comprises two microscopes that are joined by a bridge that allows the user to view both sample images side by side (Figure 1.2). The key parts of the instrument are the objective lenses. As the samples will be viewed in reflected light, the lens needs to have a working distance that is as large as possible to allow for effective lighting. Additionally, the lens needs the numerical aperture to be as small as possible to give a good depth of field. Both of these requirements are best met with objectives giving low magnifications.

Owing to the comparison aspect of the work, there is a very important factor that must be considered, no matter what equipment or method is being used to undertake the comparison. There is a need to ensure that one is comparing like with like. This means that the equipment is balanced and calibrated so that the examiner can establish the magnification and also be confident that when detail is different or when it matches it is an accurate reflection and not an artefact due to an error in the set-up of the equipment.

A pair of calibrated scaled graticules can be used for this purpose (Figure 1.3). Depending on the comparator model being used and the protocols adopted, these are used to check the balance of the comparator prior to use. A record should be kept in the notes and in auditable written/computer records relating to the comparator when this is done. Some models of comparators will also have a light to indicate that they are balanced, but these should still have the balance checked periodically to ensure that it has not drifted and to show that the equipment is working properly.

This raises the question of what is the useful range of magnification required for a detailed tool mark examination? For most comparisons, objective lenses with magnifications in the range of from $\times0.5$ to $\times20$ with $\times10$ eyepieces should suffice. As the total magnification is objective $\times$ eyepiece this would give a range of $\times5$ to $\times200$. If the detail to be examined is in the millimetre to centimetre size range, then it becomes more difficult to obtain a large enough field of view with a microscope to show all the detail at the same time. However, with modern equipment it is possible to view the mark in sections and stitch together the images to show the entire mark. In some cases macro photography may be more useful. Detail smaller than a few microns (i.e. 1×10^{-3} mm) in size may be very variable and hard to reproduce in test marks. However, if the tool used has a reasonably reproducible action (such as a

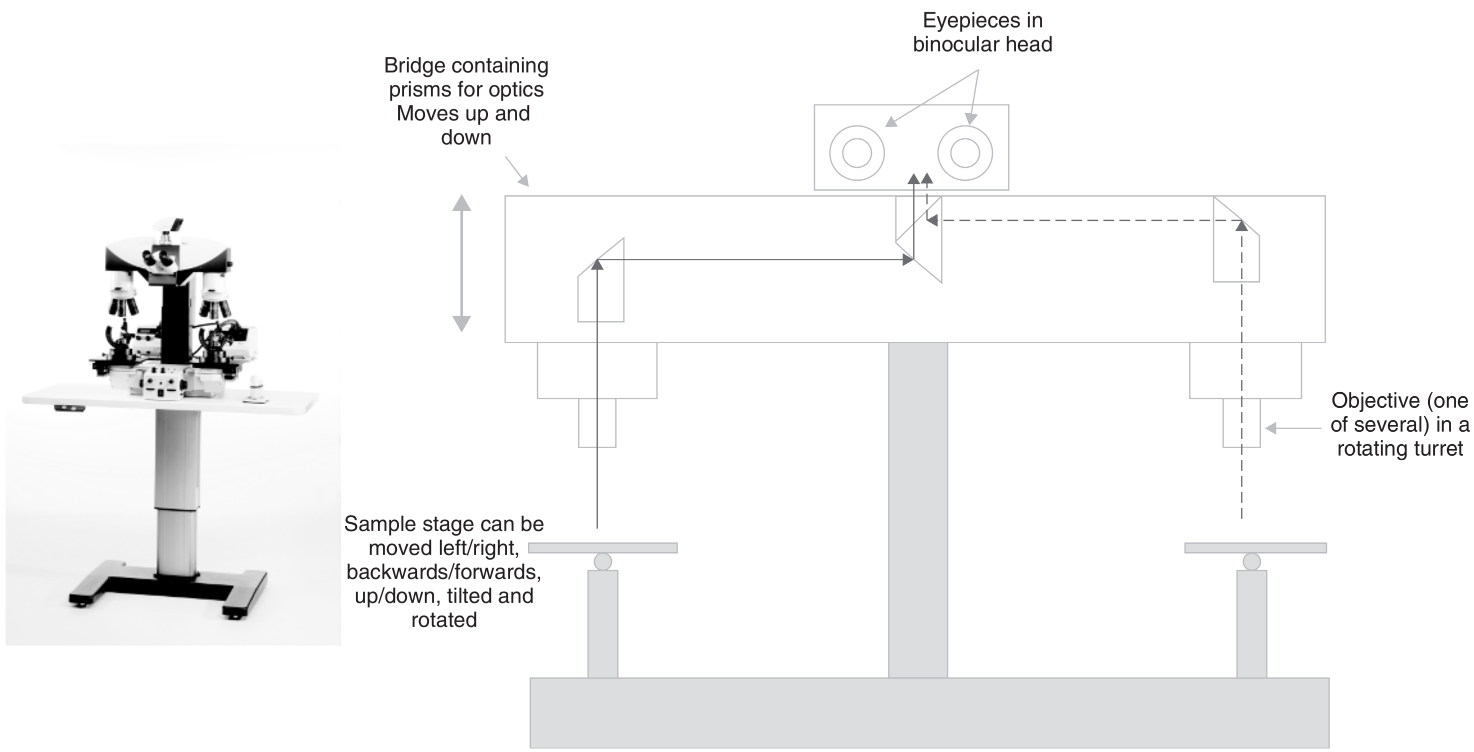

Figure 1.2 A comparator, set up for an examination of two bullets, is shown on the left (© Leica). A specimen holder is not usually required for tool mark purposes and fibre optic lighting is preferred. These alterations can be made to the general set up, as shown in Figure 1.4. A schematic diagram of how light passes through a comparator is shown on the right.

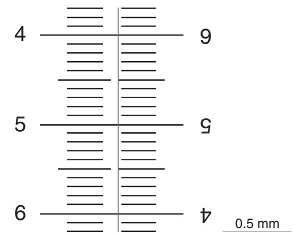

Figure 1.3 A balance check using scaled graticules, shows that the comparator is balanced as the scales line up exactly.

stapler or double bladed cutter) a series of test marks may be able to capture suitable detail. If necessary, it is possible to cast this detail and visualise it using a scanning electron microscope (SEM) rather than an optical comparator. Thus, detail at this level should not be ignored, but may be difficult to compare.

If the higher total magnifications, say from $\times 100$ to $\times 200$, are to be used then there may be problems due to building vibrations. Nearly all building structures have vibrations present, from wind pressure or traffic, if no other cause. The vibrations result in problems for the comparator, as the objective lenses are mounted some distance apart on the optical bridge, which allows the objectives to vibrate independently. At low total magnifications this is not very important, but it can result in image degradation at higher total magnifications. The severity of the problem will dictate what will need to be done, but it can easily be addressed by using a heavy table or some type of damping system, such as an anti-vibration mat. If the vibration problem is indeed significant, then some form of anti-vibration system is needed; complex systems, such as those used for laser optics may be required.

A number of different item stages are available for comparators. For tool marks the stages need to have three-dimensional (x, y and z) adjustment and have a rotatable stage head. This means that the stage can be moved smoothly to left and right (x axis), forwards and backwards (y axis) and up and down (z axis), as well as being rotated. In addition, it should be possible to tilt the stage with respect to the optic axis of the objective lens. This implies that there is some type of universal, or ball, joint just below the stage head and before the stage links into the x, y and z adjustments. It is possible to use a plastic material, such as plasticine or Blu-Tack™, to attach the item to the comparator stage and this can be used to orient the item with respect to the optic axis but, by itself, this may cause problems in obtaining the best illumination of the item that is to be examined. A tilting stage head can help overcome this problem.

In the process of comparing the mark, the stage needs to be moved in the x–y plane and this makes it necessary to have the lighting system attached to the stage (Figure 1.4), so that a constant level of illumination is maintained. The lights may be either independent or a single source with fibre optics to

Figure 1.4 A tool mark cast illuminated on a comparator stage. For most tool mark examinations the light will normally be at a shallow angle, rather than at 45° as shown here.

bring the light to each stage. In either case, the light beam produced should be as near parallel as possible. Single source lighting has some advantages if the comparator is to be used with camera systems. The single light source removes some of the problems involved with obtaining balanced light through both objective lenses, although modern lights are often much better in terms of balanced light. Some older models of comparator also have a focusing adjustment to narrow or widen the beam of light. However, more modern models do not.

Some laboratories have utilised features of the SEM as a specialised imaging and comparison tool (Sehgal *et al*, 1988), in some instances using a pair of SEMs to undertake the comparison (Katterwe *et al*, 1982). Each instrument is used to image the detail of interest and to compare the images produced side by side on the screen of the instrument. Otherwise individual screen images are printed and the printed images used for the comparison. In these cases, it is important to have a scale printed in with the image.

1.8 Quality assurance

In addition to having a verification process, there are various ways that forensic providers, individuals or organisations, can provide quality assurance to their customers and ultimately to the Criminal Justice System.

The UK Home Office's appointment of a Forensic Science Regulator in 2007/2008 was a step towards establishing and maintaining quality standards in line with ISO 17025 and European Union law, in a much more fragmented forensic market place, where, since the closure of the Forensic Science Service in 2012, there are now multiple private providers working alongside in-house police laboratories. The Forensic Science Regulator has produced a document called *Codes of Practice and Conduct* (2011), which details what is expected of all forensic providers and practitioners.

In the United Kingdom, the ultimate aim for organisations would be to gain the accreditation ISO 17025 via The United Kingdom Accreditation Service (UKAS) who are working very closely with the Forensic Science Regulator. It is acknowledged that this may be a much more difficult and lengthy process for smaller laboratories. A laboratory applying for this accreditation would have to show that they meet the required standards. The standards include:

- that there are up-to-date, controlled procedures documented for the work being carried out,

- that everyone who is doing this type of work has been trained and is competent to do so.

ISO 17025 provides a comprehensive international standard covering various areas that need to be addressed, including management structure, procedures and processes as well as technical requirements, such as training and equipment.

To begin at the beginning then, it is important to have scientific procedures documented and also to have training and on-going competency programmes in place. This will ensure that everyone carrying out the work is doing it to the required standard, following procedures, in a consistent manner.

There is an expectation that any organisation will be able to provide evidence that there is control regarding the quality of work being delivered. There are various approaches to demonstrating that work is being delivered consistently and to the standard required, and these include assessing a randomly selected sample of practitioners' cases against specific criteria (also known as 'dip' checks), method audits, competency tests, declared and undeclared trials.

It is less easy to regulate the training and competency of forensic experts who work alone. However, at the very least one would expect an 'expert' to carry out work within their acknowledged area of expertise and in accordance with a written code of practice. There have been some attempts to introduce regulation into the forensic field as a whole, to assure the courts and the general public that experts in court were indeed qualified experts who were trained, with sufficient experience of the subject matter to be able to offer a considered opinion. However, these attempts have been limited in terms of their impact thus far. For those experts working within an accredited organisation, this should go without saying, as they are regulated by their company and its accreditation process.

1.9 A brief summary

It is the authors' intentions in this book to provide those interested in this area of forensic science with the essential principles and knowledge required to carry out examinations of this type. We hope that the preceding information has been sufficient to give the reader a flavour of the basic foundations of marks' examinations that a would-be practitioner would have to consider before embarking on work of this nature. Clearly, amongst other prerequisites, there is a requirement for any practitioner to gain expertise in the use of the instrumentation available to them, which is fundamental to the visualisation of detail required for a meaningful comparison. To obtain the best results, this equipment should ideally be similar to that described in this book.

Whilst we hope that this book can provide guidance and clarity over the areas required to gain expertise in this interesting field of forensic work, it should not be seen as providing all the information on all aspects of it. However, hopefully, the contents will encourage greater understanding, perhaps raising some interesting discussion points amongst those involved in the various areas of work discussed, to aid development in this field.

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