5-2017

# Validation of Toolmark Comparisons Made At Different Vertical and Horizontal Angles

Chad R. Macziewski
*Ames Laboratory*, chadm@iastate.edu

Ryan Spotts
*Ames Laboratory*

L. Scott Chumbley
*Iowa State University and Ames Laboratory*, chumbley@iastate.edu

# Validation of Toolmark Comparisons Made At Different Vertical and Horizontal Angles


## Abstract

Numerous studies have focused on determining whether objective statistical methods can be used to discriminate between known matches and nonmatches when comparing laboratory prepared toolmarks. This study involved an analysis of striated toolmarks made as a function of varying vertical and horizontal angles of attack. Comparisons based on experimental data show that replicate toolmarks from the same tool show high correlation values at identical vertical and horizontal angles, with the correlation decreasing as the angular difference increases, especially for horizontal angular changes. Comparisons between nonmatching samples produce low correlation values that remain unchanged as horizontal angular differences increase. While complete statistical separation was not achieved between matching and nonmatching samples, there is evidence demonstrating that toolmarks can be identified if the variation in horizontal angle is within 10°. The experiment shows that computer-aided comparison techniques could be viable for identification with the proper statistical algorithm.



## Keywords

forensic science, toolmark comparison, comparison microscope, focus variation microscopy, statistical algorithm, striae, correlation function

## Disciplines

Forensic Science and Technology | Materials Science and Engineering

## Comments

This is the peer-reviewed version of the following article: Macziewski, Chad, Ryan Spotts, and Scott Chumbley. "Validation of Toolmark comparisons made at different vertical and horizontal angles." *Journal of Forensic Sciences* 62, no. 3 (2017): 612-618., which has been published in final form at DOI: 10.1111/1556-4029.13342. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving. Posted with permission.

**Validation of Tool mark Comparisons**

**Made At Different Vertical and Horizontal Angle**s

C. Macziewski[1], B.S.; R. SPotts, A. , L. Scott Chumbley[1*], Ph.D.

Iowa State University, Ames Laboratory

Ames, Iowa

[1]Ames Laboratory, Iowa State University, 2220 Hoover, Ames IA 50011

[2]Illinois State Police, Retired, 3112 Sequoia Dr., Springfield, IL 62712

*Corresponding Author

This work was supported by the National Institute of Justice and the U.S. Department of Energy (DOE), Office of Science, Basic Energy Sciences, Materials Science and Engineering Division. The research was performed at the Ames Laboratory, which is operated for the U.S. DOE by Iowa State University under contract number DE-AC02-07CH11358. Funding was provided by award number 2011-DNR-0230 from the National Institute of Justice.

**ABSTRACT:** This study involves a statistical analysis of tool marks made at varying horizontal and vertical angles. Samples were examined as a function of the twist of the tool at varying angles of attack. Comparisons based on experimental data show that replicate toolmarks from the same tool will show high correlation values at identical twist angles, and that this value decreases as the difference between the angles of creation increases. Comparisons between non-matching samples always produce low correlation values that remain relatively unchanged as the difference between the twist angles increases. While complete statistical separation was not achieved between matching and non-matching samples there is strong evidence showing that toolmarks can still be identified as long as the variation in twist angle is within ** degrees. The experiment has shown that development of a computer aided comparison technique could be viable if a proper statistical algorithm can be developed.

**KEY WORDS**: forensic science, tool mark comparison, comparison microscope, focus variation microscopy, screwdriver statistics, striae.

**Introduction:**

The forensic identification of toolmarks has been studied at length at Ames Laboratory / Iowa State University (AL/ISU) in an attempt to provide forensic examiners with data based on objective analysis that can serve to aid in the identification process and provide scientific evidence for basic assumptions upon which their craft is based. The main problem this research has been attempting to address is the ever increasing need for "proof of guilt" in court depositions. Starting back in 1993 with the case of Daubert V. Merrell Dow Pharmaceuticals, Inc. and continuing to today with the 2010 National Academy of Science (NAS) report the testimony of expert examiners has been called into question. It requires hours of training and peer-reviewed examination in order to verify an examiner as an expert that is allowed to testify in court. This paper presents additional data in a continuing effort to ascertain whether objective systems, without human bias, can be employed that mathematically support, or refute, the assumption upon which comparative examinations are based, namely, that every tool has a unique surface that creates a unique mark that can be used to identify it.

AFTE (Association of Firearm and Tool Mark Examiners) defines striated toolmarks as being created by force and movement of a tool in a direction approximately parallel to the surface being acted upon AFTE ref. Previous work by Pretraco et al. and Zheng et al. has shown that by using a surface profilometer to obtain topographical data it is possible to identify the unique striations left by tools using the cross correlation function (CCF) and looking for a critical CCF value. Further investigation to the validity of using the CCF or other algorithms has been done at AL/ISU (ref), where researchers have been able to identify matches and non-matches using a comparison algorithm generated by Dr. Max Morris and described in (ref). This algorithm utilizes a Wilcoxon Rank Sum test statistic to compare different samples. It generates a critical value which can be compared to critical values of known matches and non-matches in order to confirm a match. Later work employing the generation of virtual toolmarks based upon characterization of actual tool surfaces has shown that this algorithm can correctly identify matches of striations from screwdriver tips made at varying vertical degrees Ryan reference as long as the angle difference between the actual mark and the generated mark is within about ten degrees, and in most cases the routine was able to identify the unknown angle to within 5-6 degrees.

In an extension of the previous work, this paper attempts to use the algorithm to identify matches from screwdriver tips at both varying horizontal and vertical angles. The profile of any tool can be thought of as containing topography consisting of peaks and valleys, similar to a small-scale mountain range, and when the tool is used to make a mark the inverse topography of the part of the tool in contact with the surface is left behind as a toolmark. If the entire tip of the tool were impressed on the substrate an impression mark is left behind, consisting of height data (z) over an area of extent x by y. If only a portion of the tool is in contact with the surface and the tool is dragged across the surface, striations are produced indicative of where the highest “mountains” in the mountain range contacted the surface. The result is a striated mark consisting of vertical (z) data over an area x by y, however, the surface data changes little in the y direction and can be considered a constant if 1) the angle the tool makes with the surface (vertical angle) and 2) the twist of the tool (horizontal angle) do not change during the dragging process.

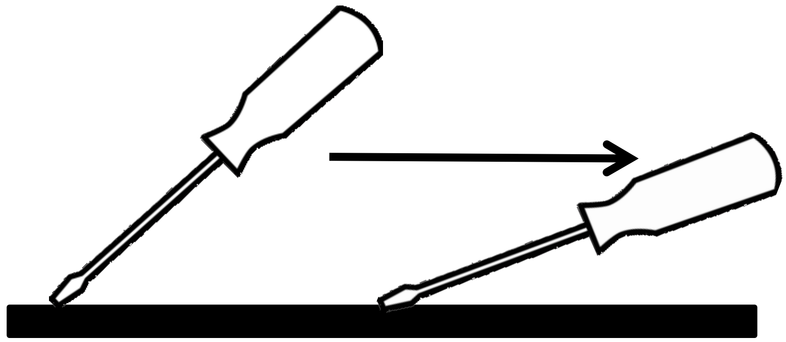
In order to understand differences angular orientation (i.e vertical and horizontal angles) makes, a simple visual analogy will be used.  Consider the form of a word, like the one shown below in Figure 1. Imagine this word is the mark that a tool left behind when held nearly perpendicular to the plan of the paper. Changing the vertical angle (read as the angle the tool made with respect to the vertical direction, perpendicular to the plane of the paper) alters the image, and it will appear to be squished when viewed form above, as seen below. This leads to a decrease in the amplitude difference between peaks and valleys in a mark, and can affect how a computer algorithm determines a match. Similarly, if the horizontal angle changes (read as the angle the axis of the tool makes with respect to the direction of travel) there will also be a shift in the image, this time it will appear to be squeezed or fore-shortened with respect to the original.


**Figure 1: On top is the reference mark, on bottom is the mark at a vertical angle shift of 30 degrees**

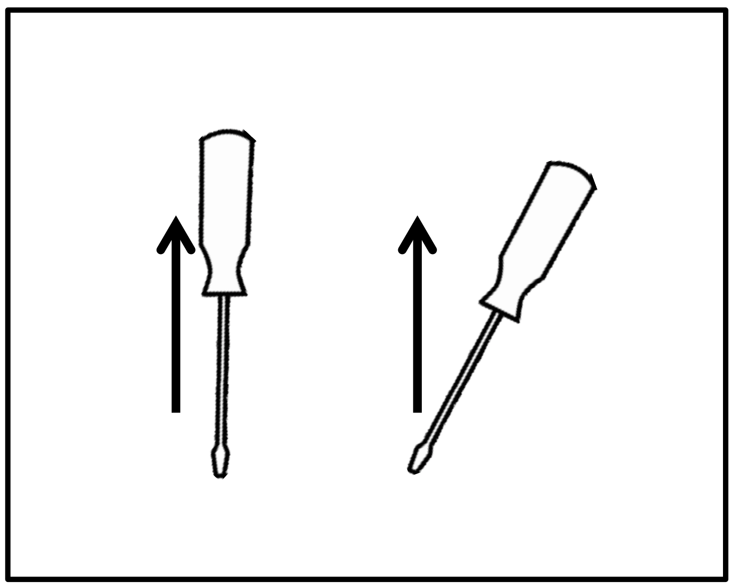
Finally, mixing both a vertical and horizontal change would produce both a shortened and flattened profile, making it look very different from the initial mark, or word in case of the analogy of Figure 1.

## Experimental Methodology

For this experiment 10 sequentially made screwdriver tips were obtained, and details concerning the tips used, their manufacture and acquisition can be found elsewhere (ref). Both sides of each screwdriver tip were used to make test marks at vertical angles of 40, 55, and 70 degrees, as well as at horizontal rotation angles of 0, 10, 20, and 30 degrees, Figure 1.



a.



b.

Figure 2: Example of change in a) vertical angle and b) horizontal angle. Direction of travel used in creating the mark as indicated by the arrows.

The test marks were created using the setup shown in Figure 3. Each angle pairing had five replicates made for each of the samples.

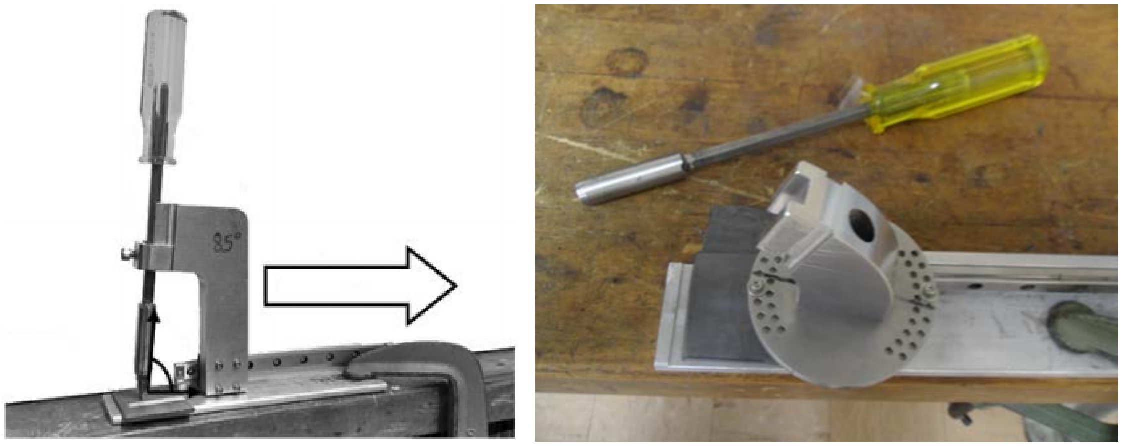


Figure 3: Apparatus used to make the samples. a) overall view; b) close-up showing jig used to provide controlled twist angles

The test marks were made in lead, as this medium creates a durable mark while the softness of the material has a minimal effect on the hardened steel of the tool, ensuring proper replication. The striae created were measured using a focus variation microscope with a vertical resolution of 990 nm and horizontal resolution of 3.914 µm at a magnification of 10x. Each scan took approximately five minutes to run and produced a 3D image similar to the one shown in Figure 4. The dimensions of the image are approximately 7 µm by 2 µm.

Figure 4: Show a and b images, same tip but at 2 different twist angles

Once scanned the images were cleaned, masked, and analyzed using the program MANTIS, currently under development at AL/ISU [ref previous work]. This program uses the statistical algorithm developed at AL/ISU and described previously [ref]. Briefly, the algorithm finds the region of highest correlation that exists between two data sets based upon two parameters, called the search window and the validation window. When the algorithm begins to compare two samples it searches for regions with the highest correlation, the size of the region being defined by the search window. The algorithm then attempts to verify the validity of this comparison by making identical rigid shifts and random jumps to different regions on both samples and comparing the correlation of the rigid shift comparisons to those that result from the random jumps. The size involved in each comparison is as defined by the validation window. This is repeated many times, both for the rigid shift comparisons and the random jumps and the results obtained between those regions are compared. For both matching and non-matching samples the profiles compared during the random jumps should not correlate at all, thereby providing a baseline value for a non-match, while the rigid shifts should have high correlation for true matches, little to no correlation for non-matches. Once all of these calculations have been made a final numerical value (termed T1) is returned. Regions of high correlation will return a large T1 value, where T1 denotes *****. Low T1 values indicate little or no correspondence between the compared regions.

Numerous comparisons of the cleaned data files were conducted, and a summary is listed in Table I. Note that comparisons of replicate marks made using the same screwdriver tip constitute known matches, while comparisons of different tips are known non-matches.

Table I: Comparisons conducted

| Conditions of Comparison | Known Matches | Known Non-matches |
|---|---|---|
| Vertical angles and Horizontal Angles the same | X | X |
| Vertical angles held constant, vary Horizontal angles | X | X |
| Horizontal Angles constant, vary vertical angle | X | X |
| Vary both vertical and horizontal angles | X | |

**Results**

Comparisons of known matches involving replicates of the same sample made at identical horizontal and vertical angles are shown in Figure 5. In all cases the average T1 statistic shows a high value of between 6 to 8. As twist angle increase the spread of the data and the number of outliers both increase.

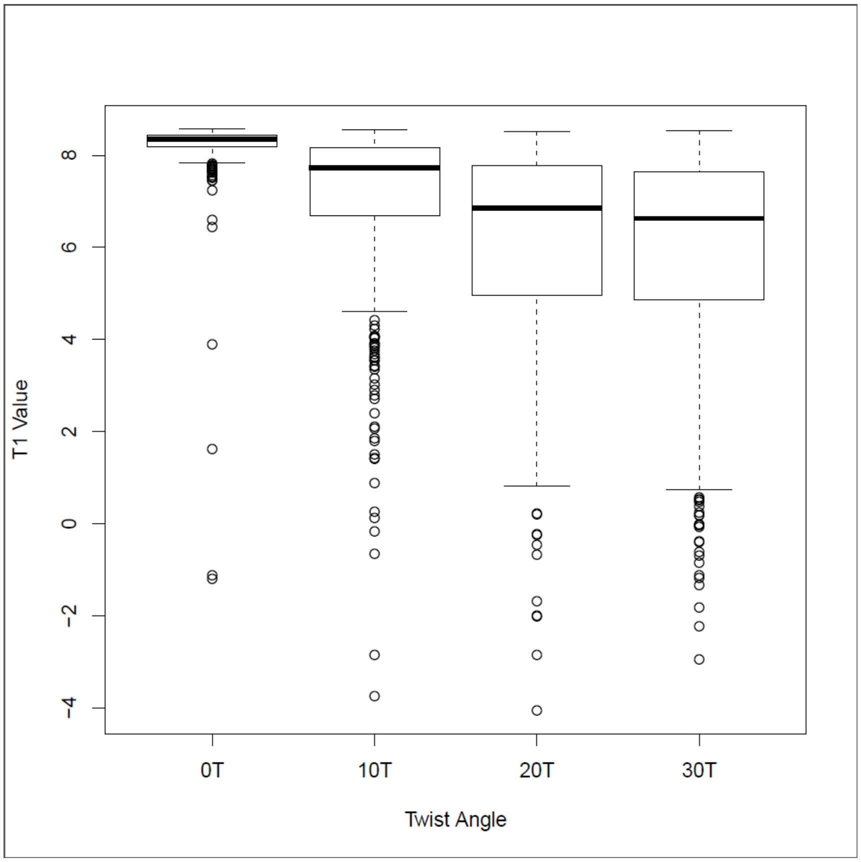



**Figure 4: All known matches for samples made at constant vertical and horizontal angles**

This grouping is tightest for samples made at a horizontal angle of zero degrees and widens as the horizontal angle is increased. This is most likely caused by the compression of striations along the profile caused by the horizontal angle. If too much compression occurs the resolution of this setup could possibly affect the algorithms ability to calculate a match or non-match.

Results for known matching comparisons where only the vertical angle is held constant and the horizontal angle was allowed to change are shown in Figure 5. The results show that as the difference in horizontal angle between two samples increases the T1 value decreases from the perfect match case, but still retain a high correlation value until the difference exceeds 10 degrees. At large enough differences it can be seen that even known matching samples can appear to have non-matching results.

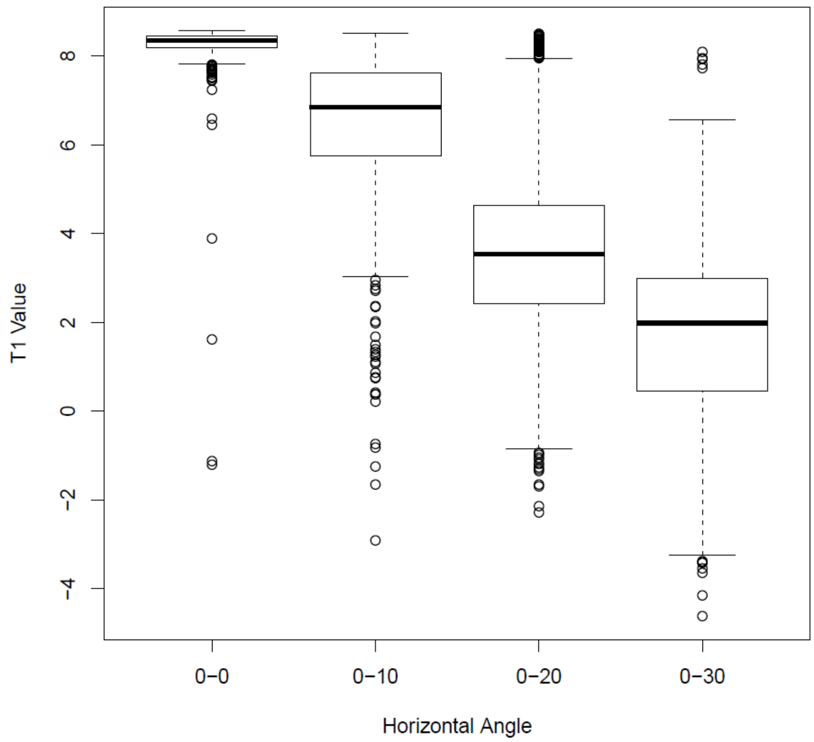



**Figure 5: All known matches for samples made at a constant vertical angle with varying horizontal angles**

Similarly, results for known matching comparisons where only the horizontal angle is held constant and the vertical angle was allowed to change are shown in Figure 6. These results show that as the difference in vertical angle between two samples increases the T1 value decreases rapidly from the perfect match case.  These results agree with the more extensive previous study

[ref] which showed that at vertical angle differences greater than approx. 10 degrees even known matching samples can appear to have non-matching results.

**Figure 6: All known matches for samples made at a constant horizontal angle with varying vertical angles**

Finally the non-matching samples (Fig. 7) all show a very low T1 value for all combinations of horizontal angles when vertical angles are set. This is as expected.

## Discussion

In the previous study done by Ryan Spotts once the difference in the angle of creation between two marks made from the same tip exceeds 10 degrees the ability of the algorithm to determine a match decreases (Ryan's Paper). This same phenomena is present in this study where large T1 values are observed for replicate marks made at the same angles, and these values decrease as angles are changed, becoming indistinguishable from a non-match. This decreasing T1 value can be explained by looking at how the algorithm determines a match. The algorithm looks at the topographical data and tries to see whether or not the profiles match in terms of spacing and depth of features. When the profile is significantly different the algorithm outputs a low T1, and when they are similar it outputs a high T1 value. Looking at the example given at the beginning of this paper it can be seen that as the angle of creation changes the features that are left in the lead samples will become distorted, affecting the algorithms output. This is not to say that the algorithm is obsolete, just that it cannot distinguish between true non-matches and matches made at significantly different angles. In order to improve the algorithms ability to separate out true matches and true non-matches it would be necessary to develop a way to distort the topographical data by scaling it in either the vertical or horizontal directions.

**Summary and Conclusions**

These low values somewhat allow for a statistical separation of matches and non-matches with this algorithm for marks made at different horizontal angles across sequentially made tool marks. There are a few possible explanations for the reduction of the T1 value as the horizontal angle increases. The first is that as with the vertical angle the further away from a perpendicular mark the more difficult it is to make a match. Secondly the compression of striae will alter the T1 value as the algorithm does not stretch or shrink the profiles when attempting to make a match. In either case although the T1 values are lower they are still on average higher than a non-match, which while statistically it is insufficient to label a match it does offer an indication that there may be a match at another angle.

**Refrences:**


1. Chumbley LS, Morris M, Kreiser J, Fisher C, Craft J, Genalo L et al. Validation of toolmark comparisons obtained using a quantitative, comparative, statistical algorithm. J Forensic Sci 2010;55(4):953-961.
2. Ekstrand, Laura D. and Zhang, Song, "Three-dimensional profilometry with nearly focused binary phase-shifting algorithms" (2011). *Mechanical Engineering Publications and Papers.* Paper 87.
3. Ryan's Paper Optimization of a Statistical Algorithm for Objective Comparison of Toolmarks Spotts, Ryan ; Chumbley, L. Scott ; Ekstrand, Laura ; Zhang, Song ; Kreiser, James Journal of Forensic Sciences, 2015, Vol.60(2), pp.303-314
4. Petraco N, Chan H, De Forest P, Crim D, Diaczuk P, Gambino C et al. Application of machine learning to toolmarks: statistically based methods for impression pattern comparisons. Rockville (MD): National Criminal Justice Reference Service; 2012 Jul. Document No.: 239048.Jim Krieser's Training Anecdote
5. Alicona Imaging GmbH. FOCUSvariation. English edition, 2013/14; http://issuu.com/alicona/docs/alicona_focusvariation_edition_4 (accessed Nov. 20, 2013).
6. Chumbley LS, Morris M, Kreiser J, Fisher C, Craft J, Genalo L et al. Validation of toolmark comparisons obtained using a quantitative, comparative, statistical algorithm. J Forensic Sci 2010; May;55(4):953-961.


All known matches where horizontal and vertical angles were identical between replicates were compared. Then all known matches were computed for replicate samples made at a set vertical angle (40, 55, or 70) and a horizontal angle of zero degrees were compared against replicates of the same sample made at horizontal angles of 10, 20, and 30 degrees. Finally all known non-matches for samples made at set vertical angles (40, 55, or 70) were compared against all replicates of different samples made at 0, 10, 20, and 30 degrees.