

A Comparison of Class Characteristics Among Several Crosscut Shredders

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Although a handful of papers have been written on the re-assembly of shredded documents, little is known about how shredders of different makes and models operate. The purpose of this project was to distinguish crosscut shredders of different makes and models by determining the manner in which they shred. A total of seven shredders were evaluated by means of their paper shred and machine characteristics. Several of these characteristics include mean width and length of the shred, physical appearance of the shreds, width of the shredder throat and the type of cutting mechanism within the machine. Three of the seven shredders were of different makes, while two pairs of machines were of the same make and model. The two primary objectives of this research were: first, to analyze the output of the seven shredders; and second, to determine and compare the class characteristics of each individual shredder. It was also expected that possible indications of individual characteristics might be detected between the shredders of the same make and model.

Introduction:

Late in 2011, one of the authors received a small bag of crosscut shredded documents as evidence in an identity fraud investigation. While working the case, he discovered some features of the shredded paper fragments that had not been previously reported in the literature. These features, he believed, would facilitate the re-assembly of shredded documents. (see Olson, this issue). Based on the size and shape of the shredded particles and the pattern they produced, some assumptions were made about the operation of shredders in general. To test these assumptions, this study was conceived, in which shredders of different makes and models would be examined. The shredders tested were either in use at the IRS laboratory or were personal shredders belonging to employees.²

Background

Paper shredders were first marketed in Germany during the late 1950's (Woestendiek 2002). At

that time, shredders were only available to government organizations. Since then, they have been used extensively by businesses, and in more recent times, by individuals to keep financial and personal information secure, and to guard against identity theft. Crime labs have occasionally encountered individuals and organizations involved in unlawful acts who have attempted to free themselves from incriminating evidence via shredding. Thus, there is a need for the Forensic Document Examiner to be able to reassemble shredded documents.

Before understanding the "process" used to assemble shredded documents, it is important to know the mechanics of paper shredders, in particular, crosscut shredders. All shredders have two oppositely-rotating cylinders armed with sharpened metal cutting surfaces. As paper passes between the two cylinders, cutting surfaces cut or tear through the paper. Strip cut machines cut a sheet into strips down the length of the sheet, while crosscut shredders have additional blades to cut those strips into smaller pieces. Plas-

¹Disclaimer: the views expressed in this article are the employee's own and do not represent the government.

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tic or metal wedges between the teeth strip out the shreds of paper from the rotating cylinders, which then fall into a collection basket. Cross-cut shredders are preferred for more sensitive documents because they cut in two dimensions and produce smaller particles. Various specifications and requirements for shredded papers exist. For example, the US Government has a system of specifications for various sizes of shredded fragments to meet different security classifications (Brassil 2002).

There are particular terms to describe the components and products of crosscut shredders. For example, while some experts in the industry call the shredded paper pieces “fragments” or “particles” (Hartnett and Romanovich 2012, and Parkinson and others 2012), shredding machine brochures use “shred” or “shreds” (Cummins Allison 2012), which are the terms used in this paper. Many shreds have a distinctive shape, caused by the shape of the shredder’s cutting surfaces. For example, a shred will often have one end with a pointed arrowhead or caret (^) shape, while the other end has a notched arrow tail shape. “Arrowhead” and “arrow tail” are terms coined by one of the authors to define these shapes (Figure 1).

Instead of calling the barbs on the cylinders “teeth,” some manufacturers refer to them as “cutter tips.” The slot into which paper is fed is known as the “throat” or mouth of the shredder. The wedges that remove the paper from the rotating cylinder have a couple of names. Some manufacturers call them “strippers” (Hartnett and Romanovich 2012), while others call them “combs” (Parkinson and others 2012).

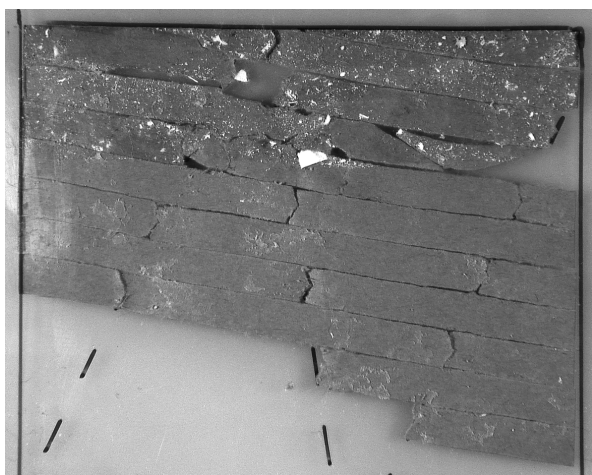


Figure 1. Shredded document showing distinct arrowheads and arrow tails.

The cylinders of a shredder have two configurations: “positive profile” and “negative profile” (Hartnett and Romanovich 2012, and Parkinson and others 2012) (Figure 2a and 2b). Positive profile or “stacked” cylinders are composed of toothed metal discs arranged on an axle and separated by spacers. Each disc has a few v-shaped cutting surfaces which protrude like the teeth on a circular saw blade, but there are far fewer of them, often only two to four per disc. This type of cylinder is cheap to produce and is found on less expensive shredders. Negative profile cyl-



Figure 2a. Example of “positive profile” cylinders in the Brinks S9855W.



Figure 2b. Example of “negative profile” cylinders (photograph courtesy of Martin Yale Industries).

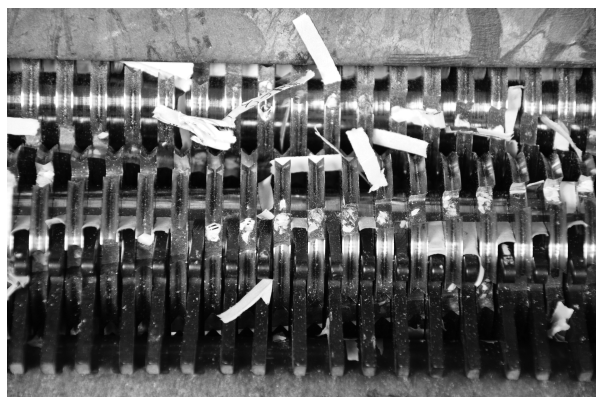


Figure 3a. Example of V-shaped cutting edges in the Intimus 502.

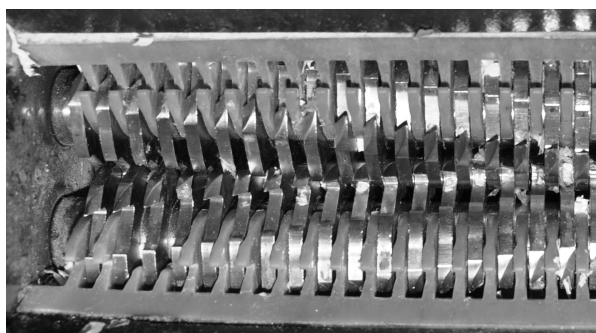


Figure 3b. Depiction of diagonal or slanted cutting tips in the Fellowes C-120c.

inders, on the other hand, are solid metal, with grooves cut into them. Their cutting surfaces can be v-shaped or diagonal (Figure 3a and 3b). (V-shaped cutter tips produce the arrowhead/arrow tail shapes, while diagonal surfaces do not.) Because these cylinders are solid metal, negative profile machines are generally more expensive to produce; however, they are also more rugged and dependable than their cheaper counterparts. Positive profile cylinders use the sharpness of the cutter tips to shred a document whereas negative profile cylinders rely on both sharpness and tension. Creating tension is fundamental for this form of cylinder because the document needs to be stretched over the surface of the cylinder before cutting. However, for both types of cylinders, the cutter tips are arranged on the cylinder in a helical pattern. A typical shredder has two cylinders: one cylinder shaped in a right-handed helix; and the other, a left-handed helix. (Figure 4, see also Figure 2b).

Some earlier papers have discussed reassembling torn papers and strip-cut shredded paper (Hammond 1994 and Schuetzner 1997). The chal-

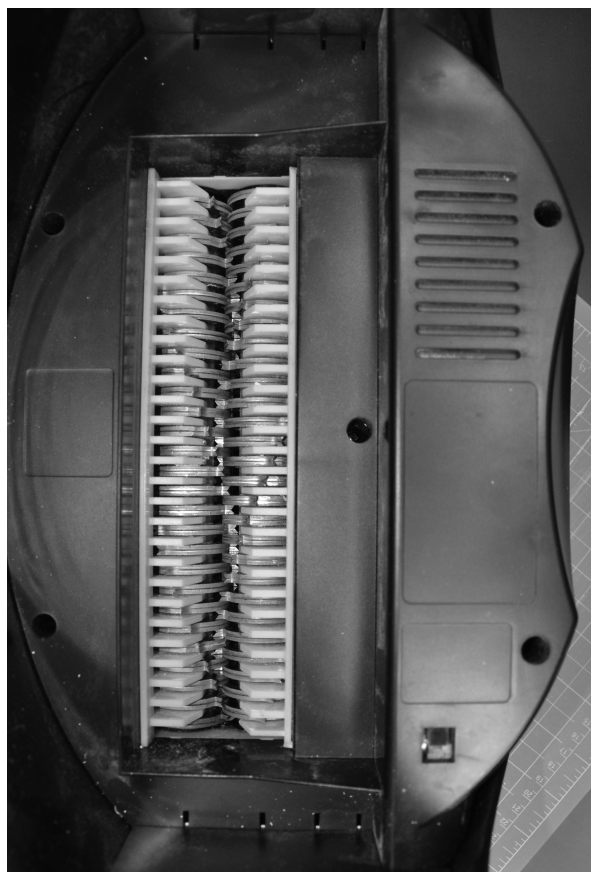


Figure 4. A helical shape is shown here in the Fellowes DS-1 positive profile shredder.

lenging task of reassembling a crosscut shredded document is much easier if a process is followed. The authors suggest a process comprising four basic steps: 1) sorting the shreds based on physical characteristics (color, texture, and ink color); 2) making some rudimentary measurements of their width and length; 3) associating shreds with similar patterns; and then, 4) assembling the document and predicting where the remaining pieces could fit (see Olson in this issue for a more detailed description of the reassembly process). It was assumed that machines by different manufacturers would operate differently. Some differences between shredders are apparent when comparing the machines. Others are only apparent from an examination of the shred. The following factors were the focus of this study:

- Shredder Characteristics
 - Manufacturer make and model
 - Location of manufacture
 - Width of shredder throat
 - Configuration of rotating cylinders
 - Cutting surface dimensions

- Mean angle of crosscuts relative to the shredder mouth
- Shred Characteristics
 - Mean width and length
 - Advertised size of shreds compared to their actual size
 - General shape (arrowheads/arrow tails)
- Relating the shreds' appearance to the

condition of shredder's mechanics

Materials and Methods

Machine Preparation

Seven crosscut paper shredders of the following makes and models were examined: Intimus 502 (two machines), Fellowes 120c-2 and Fellowes C-120c, Royal HT3SL, Fellowes DS-1, and Brinks S9855W (Figures 5a, 5b, 5c and 5d).

The Intimus machines were of the same make and model. The two Fellowes shredders (120c-2



Figures 5a-5d. Four of the shredders tested in this study: a) Intimus 502, b) Fellowes DS-1, c) Royal HT3SL, and d) Brinks S9855W.

and C-120c) were from the same manufacturer, and it was confirmed by Fellowes that although the two were from different model years, their internal parts were the same.

All seven paper shredders were checked for proper operation and the teeth cleared of paper debris prior to analysis. Blank sheets of colored paper (other than blue) were fed through each shredder to attempt to loosen any shreds caught in the strippers and/or teeth. Then a second cleaning was performed. This procedure was conducted to eliminate cross-contamination from any previ-

ous shredding activity.

Paper Specimen Preparation

A specimen "document" was created to be shredded by each machine as follows: a blue 8.5"x11" sheet was used as the substrate. A three by five inch yellow Post-It™ note was written or stamped on in ink by one of the authors. (The other author had no knowledge of the image that needed to be reassembled). The Post-It™ was then attached to the blue sheet parallel to the ruling lines (Figure 6a).

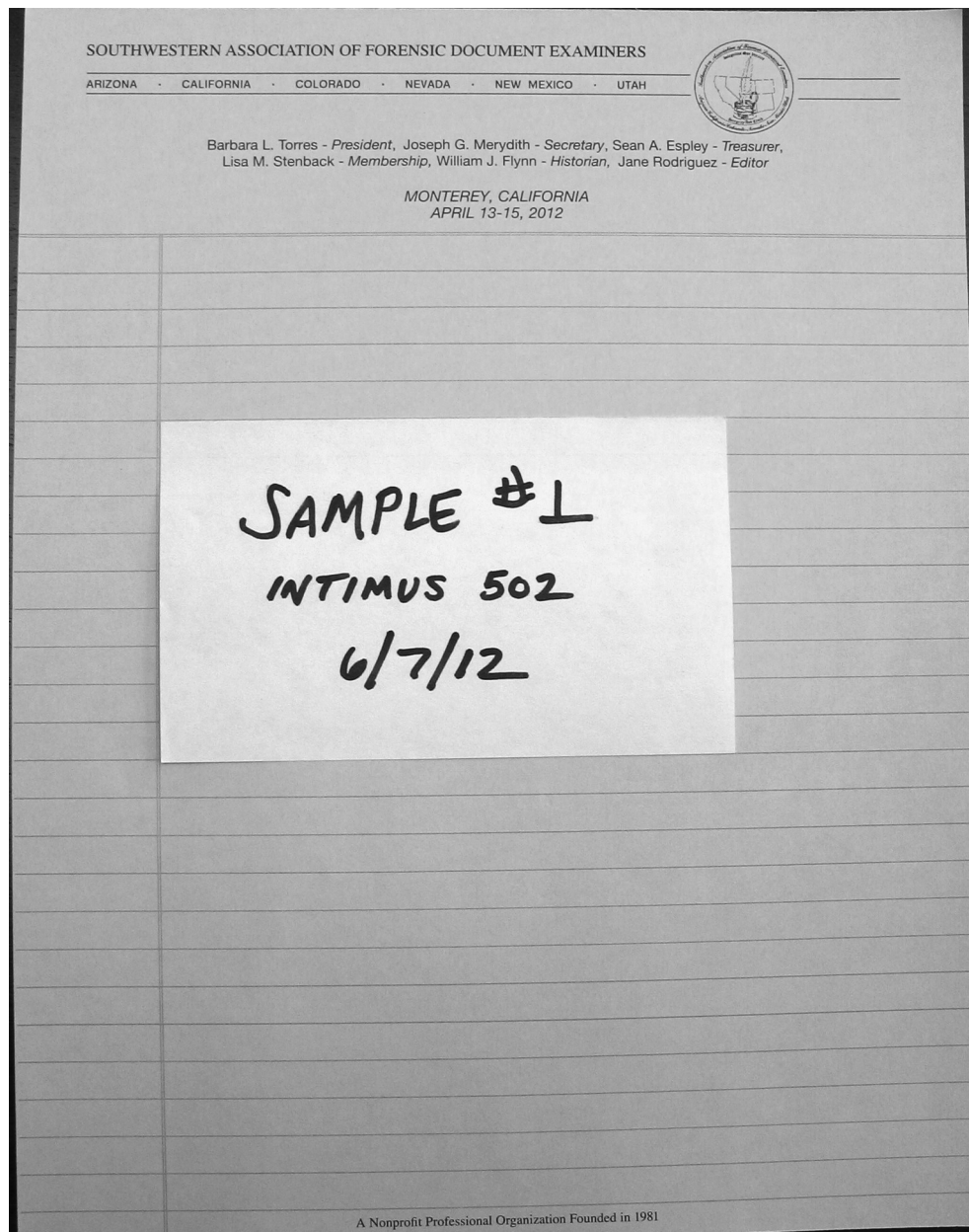


Figure 6a. Specimen example.

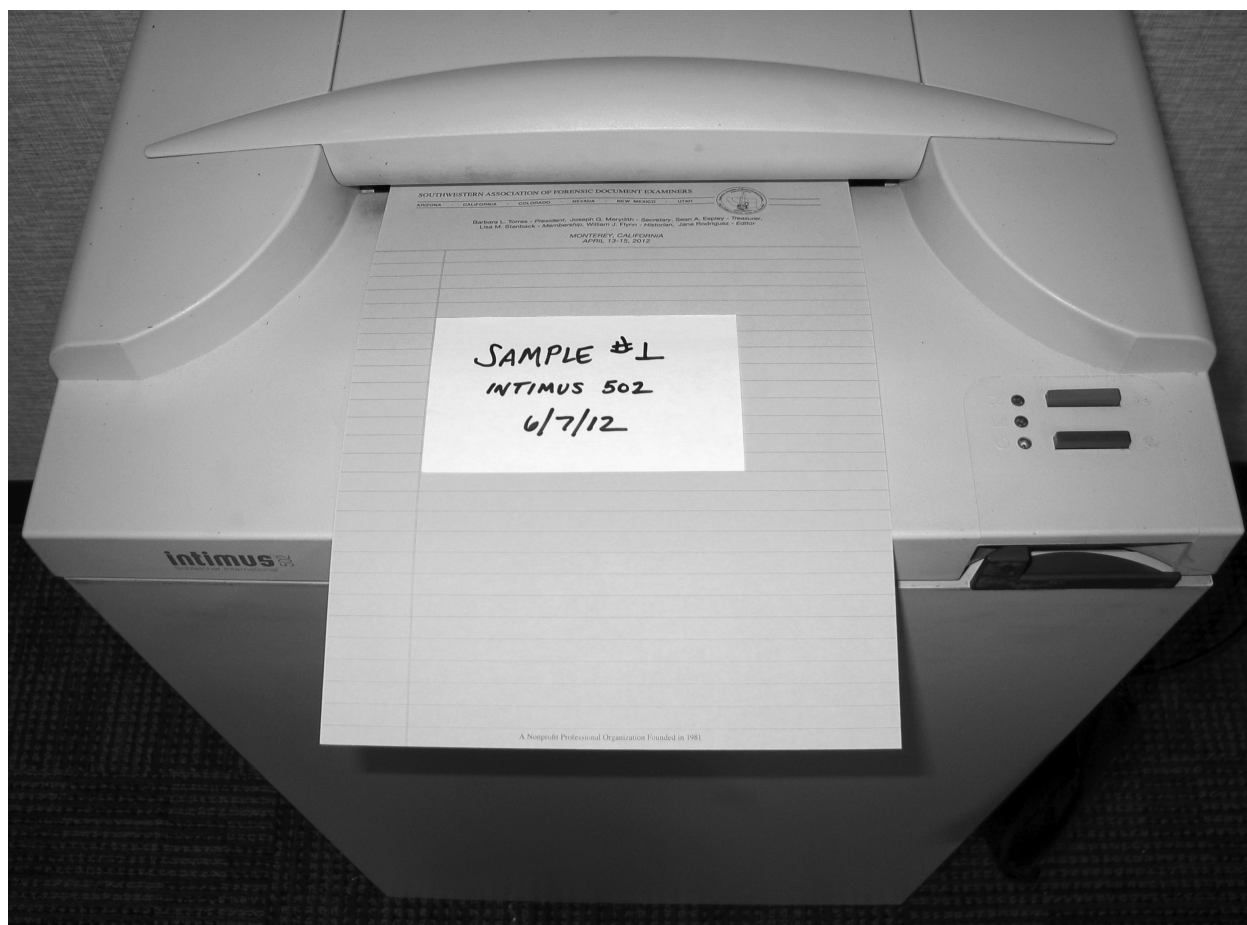


Figure 6b. Orientation of specimen sheet as it is fed into the shredder.

For consistency, the specimen was fed through each shredder in the same manner (that is, with the top of the document entering the shredder first, in a portrait orientation) (Figure 6b). (In the case of the Royal HT3SL shredder, whose throat was too narrow to accommodate letter size paper, the edges of the specimen document were folded in to the center so that the Post-it™ was shredded in the same orientation as the others.)

Shredder Analysis

A number of shredder characteristics were recorded for this experiment, namely: width of the shredder's throat, configuration of the blades and teeth, and the angle of crosscuts relative to the shredder's mouth. The width of the shredder's throat was determined either by measuring the opening.

Paper Shred Assembly

After a shredded specimen was collected from the

shredder's basket, it was taken to the work table. A work area was selected with a surface color that would contrast with that of the shredded paper, and which also would be free from drafts and heavy foot traffic (Schuetzner & Comella 1997).

The shreds were spread out on the work table, and then separated based on color, size, shape, and writings. A pair of tweezers was used to manipulate and position individual pieces. Any shreds that didn't originate from the specimen document (i.e., they remained in the machine from a previous shredding event) were discarded. The presence of shred originating from a previously shredded document occurs when paper releases wedged shred from the cylinders; this creates a mixture of both wanted and unwanted shred.

The shreds were first oriented so that the arrowheads, if present, pointed in the same direction. Preliminary matches were then made among pieces from the yellow Post-It™, based on the designs or writing on the note. (Due to time constraints, only the Post-It™ notes were reas-

sembled during this project, rather than the entire specimen sheet). Once a reasonable cluster of shreds had been associated, it was assembled on the inside of a document protector (transparent acetate sheet). The shreds were held in place by repositionable glue. To assist in the association of the shreds, a stereo-microscope was used to verify a match in tear patterns. A transparent grid of lines ruled at the average width of the shred was placed underneath the document protector which helped to align them during reassembly (Figure 7). (For more detailed information regarding the reassembly process, see Olson in this issue.)

After a considerable amount of shreds had been reassembled, the overall pattern made by the crosscuts could be drawn on the reverse side of the document protector. Blue and red permanent marker lines were used to describe the crosscut lines and black marker was used to outline the borders of the note (Figures 8a and 8b). From this diagram, voids in the pattern became apparent, and missing pieces of a particular size and shape could be searched for in the remaining shreds.

Paper Shred Analysis

A number of shred characteristics were measured or determined qualitatively: mean width and length, arrowhead and arrow tail characteristics, and the overall physical appearance of the shreds. The mean length and width of the shred were determined using a Foster+Freeman VSC 5000 by taking measurements (in millimeters) of a sample of approximately 60 pieces and averaging the re-

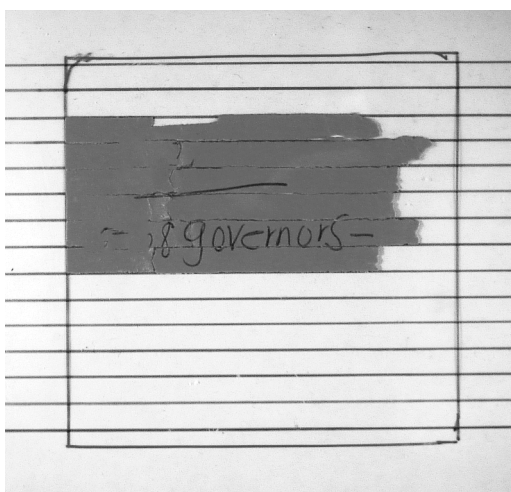


Figure 7. Transparent grid in alignment with the shreds.

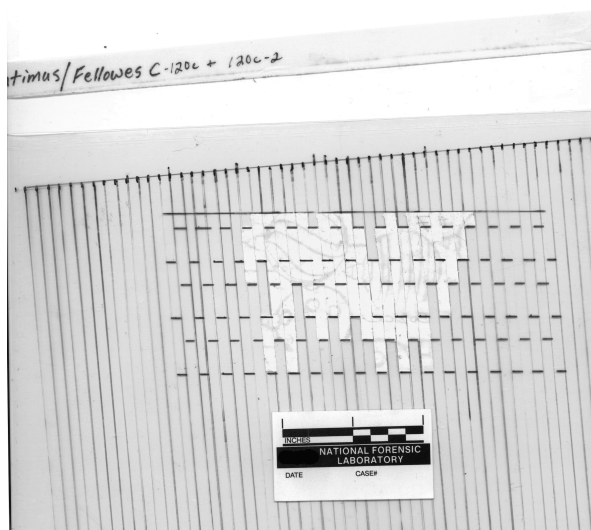


Figure 8a. Reverse side of the assembled document with cross-cut lines drawn in.

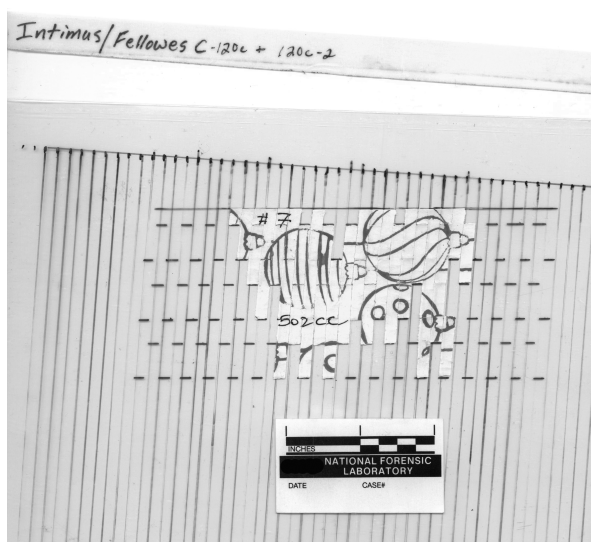


Figure 8b. Front side of assembled document with cross-cut lines drawn in.

sults (Table 1b). (The shred width was measured across the midpoint of each fragment. The shred length was measured along the long axis from the notch of the tail to the tip of the arrowhead.)

Once specimen documents from several machines were assembled and the crosscut patterns drawn, it became apparent that the crosscuts ran in different directions and/or were spaced differently (Figure 9). These crosscut patterns obviously had something to do with the cutting blade configuration, and could further characterize the machines. To document this feature, angles were measured between: a) the longitudinal

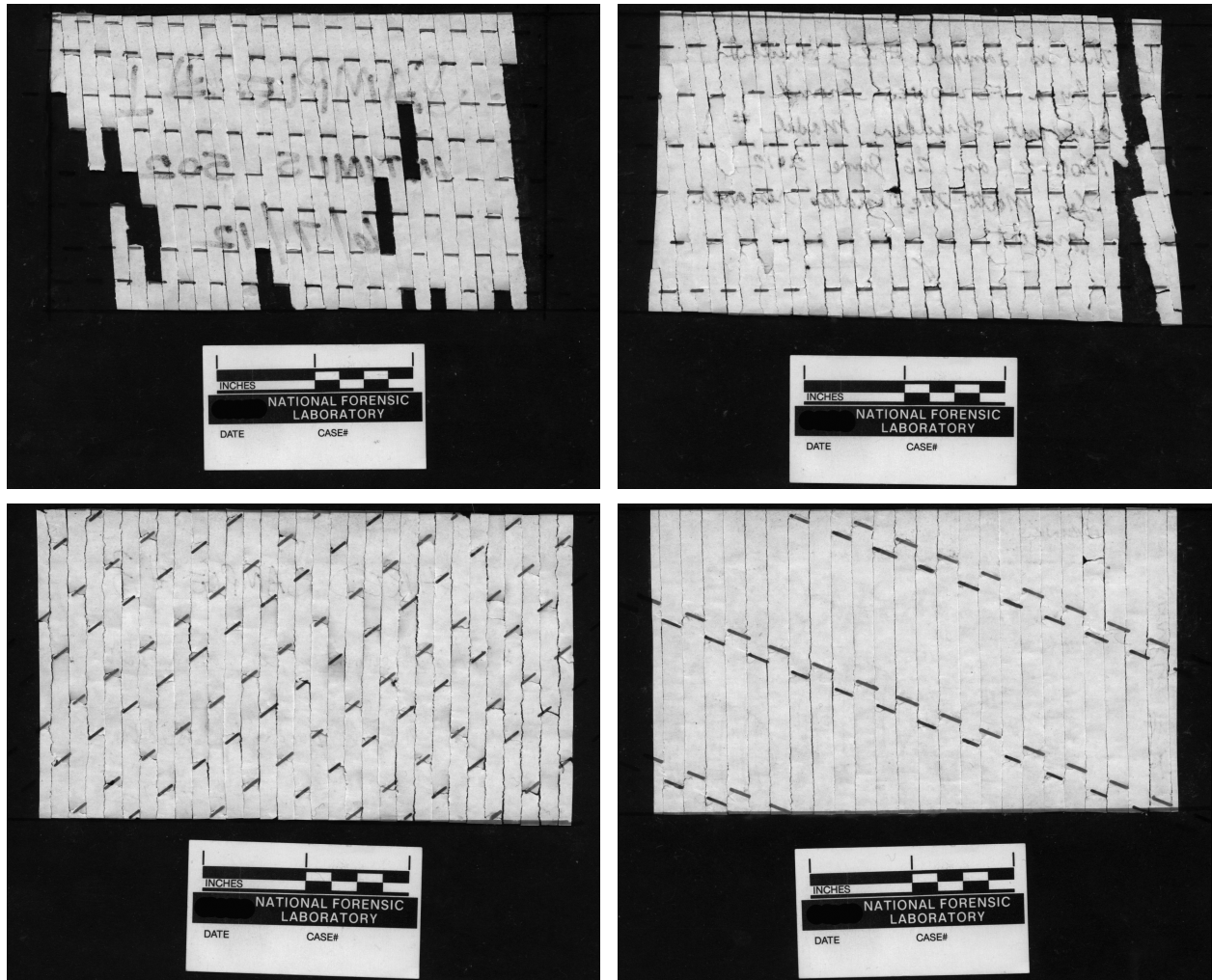


Figure 9a-9d. Diverse crosscut patterns on the reverse of specimens shredded by the: a) Intimus 502, b) Fellowes C-120c, c) Royal HT3SL, and d) Brinks S9855W.

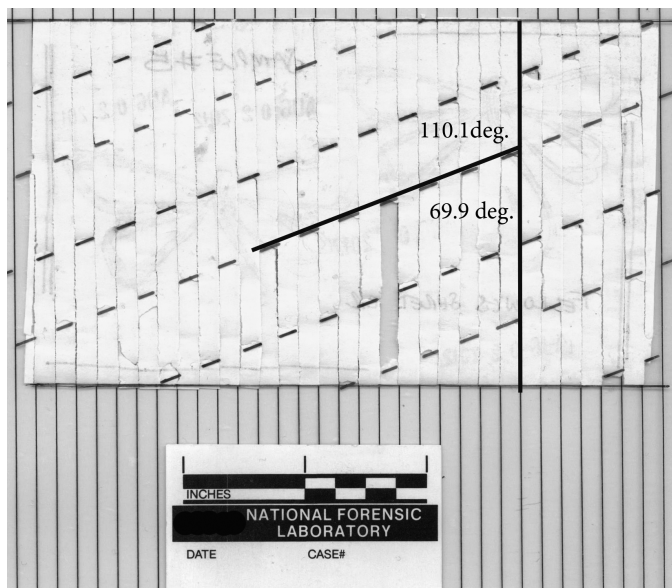


Figure 10. Angle measurements using VCS on the specimen shredded by the Fellowes DS-1.

cut that runs through the entire document, and b) the lines marking the crosscuts. They were measured on each specimen note at three different points using a Foster+Freeman Video Spectral

Comparator 5000, and then averaged (Figure 10).

The final assembled documents were scanned in color at 300dpi using a Fujitsu model #fi-4340C scanner and digitally saved for reference.

Results

Shredder Characteristics-1

Shredder Make/Model	Capacity	Location of Manufacturer	Width of Throat	Type of Cylinders
Intimus 502	Large Capacity	Germany	26.04cm (10.25in)	Negative profile w/v-shaped blades
Intimus 502 (2)	Large Capacity	Germany	26.04cm (10.25in)	Negative profile w/v-shaped blades
Fellowes 120c-2	Light Capacity	China	24.10cm (9.49in)	Negative profile w/angled blades
Fellowes C-120c	Light Capacity	China	24.10cm (9.49in)	Negative profile w/angled blades
Royal HT3SL	Portable/desktop	China	12.70cm (5.00in)	Positive profile
Fellowes DS-1	Light Capacity	China	22.90cm (9.02in)	Positive profile
Brinks S9855W	Portable/desktop	China	22.90cm (9.02in)	Positive profile

Table 1a. Class characteristics of the shredders analyzed.

Shredder Characteristics-2

Shredder Make/Model	Blades All Same Width?	Actual Size vs. (Advertised Shred Size)	Angle of Crosscuts Relative to Shredder Throat	Shredder condition
Intimus 502	Multiple half-width blades on each end	3.94 x 18.65mm vs. (3.96 x 25.81mm)	Internal: 82.8 External: 97.2	sharp blades (well maintained overall)
Intimus 502 (2)	Multiple half-width blades on each end	3.93 x 19.64mm vs. (3.96 x 25.81mm)	Int: 85.2 Ext: 94.8	sharp blades (well maintained overall)
Fellowes 120c-2	Yes	4.01x24.15mm vs. (3.90 x 25.00mm)	Int: 95.3 Ext: 84.7	dull blades, bent strippers (poorly maintained)
Fellowes C-120c	Yes	4.02 x 25.50mm vs. (3.90 x 25.00mm)	Int: 83.6 Ext: 96.4	dull blades, (poorly maintained)
Royal HT3SL	1 half-width blade on each end	4.08 x 26.18mm vs. (3.96 x 25.40mm)	Int: 52.4 Ext: 127.6	brand new shredder (great condition)
Fellowes DS-1	1 half-width blade on each end	4.16 x 33.39mm vs. (3.97 x 34.93mm)	Int: 69.9 Ext: 110.1	sharp blades (well maintained overall)
Brinks S9855W	1 half-width blade on each end	5.06 x 38.25mm vs. (5.00 x 42.00mm)	Int: 67.0 Ext: 113.0	sharp blades (well maintained overall)

Table 1b. Additional characteristics of each shredder

Shred Characteristics-1

Shredder Make/Model	Mean Shred Width	Mean Shred Length	Arrowheads/ Arrow Tails	Appearance of Shred Ends
Intimus 502	3.94mm	18.65mm	somewhat distinct arrow tails but more distinct arrowheads	curled arrow tails and heads in the same direction (but both top/bottom)
Intimus 502 (2)	3.93mm	19.64mm	more distinct arrowheads (curled)	curled arrow tails and heads in the same direction (but both top/bottom)
Fellowes 120c-2	4.01mm	24.15mm	inconclusive (due to angled blades vs. v-shaped blades on the cutting cylinder)	curled in both directions (top/bottom of mouth)
Fellowes C-120c	4.02mm	25.50mm	inconclusive (angled blades)	variations in both direction, but U shape primarily
Royal HT3SL	4.08mm	26.18mm	distinct because it is a brand new shredder	variations, but majority curled towards top of mouth
Fellowes DS-1	4.16mm	33.39mm	distinct for both ends	variations in both directions, primarily on arrow-tail end
Brinks S9855W	5.06mm	38.25mm	distinct for both ends	variations in both directions, some S and U shaped

Table 2a. Characteristics of the shred***Shred Characteristics-2***

Shredder Make/Model	Physical Appearance of Shred
Intimus 502	relatively clean cut and compared with grid nicely
Intimus 502 (2)	relatively clean cut and compared with grid nicely
Fellowes 120c-2	poorly cut, torn more than sliced, did not compare to grid well
Fellowes C-120c	poorly cut, torn more than sliced, did not compare to grid well
Royal HT3SL	exceptionally clean cut and comparable to grid
Fellowes DS-1	relatively clean cut and compared with grid nicely
Brinks S9855W	exceptionally clean cut and comparable to grid

Table 2b. Physical size of shred compared with their physical appearance**Discussion**

By comparing and contrasting the data on Tables 1a, 1b, 2a, and 2b, the following characteristics were observed:

Several machines were fitted with narrower cutting surfaces or spacers at the ends of the throat. This design feature prevents wide papers from jamming (Parkinson and others 2012).

Most of the machines produced shred that was a different size from the advertised value. Manufacturers stated that the shred size was more or less a sales or marketing feature, and not a critical specification for this particular classification

of shredders (Hartnett and Romanovich 2012, and Parkinson and others 2012).

There was quite a range observed in crosscut patterns and the angles formed between the longitudinal cut and the cross cuts (Figure 9). The manufacturers explained that this pattern is a visual representation of what they call the “timing” between the cylinders, that is, the arrangement of the cutting surfaces on the opposing shafts or the distance between the blades on adjacent cutting tips (Hartnett and Romanovich 2012, and Parkinson and others 2012).

Differences were noted in the performance of the shredders which may be due to maintenance.



Figure 11. Curled ends on shreds from the same document, shredded by the Brinks machine: left, shreds with minimal or no curling; middle, shreds with one curled end; and right, shreds with two curled ends and/or major deformation.

Some produced shreds that appeared more torn than others, resulting perhaps from dull blades and bent or missing stripper teeth or combs. One paper in the literature suggested that all machines produce individualizing tear patterns (Brassil 2002); however, this study did not include an examination for these characteristics.

One important discovery was that whenever shreds exhibited the arrowhead and/or arrow tail shape, the arrow pointed in the direction the document was shredded. Therefore, if this shape is present, it is a useful sorting tool for aligning pieces in their “shred direction” (Figure 1).

It was observed during the sorting phase that many shred ends were curled in various directions (Figure 11). It was thought that this direction might indicate whether the document was face up or face down when it was shredded; however, no definite correlation was found.

Comparing Intimus machines

The two Intimus models (Figure 5a), both use negative profile cylinders (Figure 3a). This classifies them as higher-end models (Hartnett and Romanovich 2102, and Parkinson and others 2012). Of all the machines tested, these two cut the shred into the smallest sizes. There was a slight difference observed in the average length of shred produced (18.65mm for the first Intimus model versus 19.64mm for the second). This was not true for the average width, which only differed by one-hundredth of a millimeter. These two machines have similar, but not identical angles of crosscut. The first Intimus machine had

an average internal angle of 82.8 degrees while the second model exhibited an average angle of 85.2 degrees. The differences in shred length and cut angles may represent possible identifying features of these two shredders if found to be repeatable, however, much more testing is needed.

Comparing Fellowes 120c-2 and C120-c machines

Like the Intimus shredders, the Fellowes 120c-2 and C120-c models are higher-end machines that use negative profile cylinders and originate from the same country (Figure 3b). They cut the shred into slightly larger pieces than the Intimus - the average length from model 120c-2 was 24.15mm compared to 25.50mm from model C120-c. Much like the Intimus machines, the Fellowes models had very similar average shred width (differing by only one-hundredth of a millimeter).

An unexpected discovery was that the crosscut angles of these two machines mirror or complement each other. The Fellowes 120c-2 shredder had average internal/external angles of 95.3 degrees/84.7 degrees while the C120-c had internal/external angles of 83.6/96.4 degrees. Thus, the crosscut patterns as observed on the reverse of the assembled documents slant in different directions – the 120c-2 very slightly from NW to SE, while the C120-c slants from SW to NE. While the shred length difference between the two machines may indicate an individual characteristic, this difference in the crosscut pattern may instead be a class characteristic. The machines were from different model years and may have been constructed differently, although the

authors were told “the internal parts were the same” (Hartnett and Romanovich 2012). Further investigation into this will be conducted.

The major difference between the Intimus and Fellowes machines was the presence or absence of arrowheads. Although both machines are negative profile machines, the Intimus has V-shaped cutting surfaces; while the Fellowes has relatively flat, slanted, or slightly curved blades (Figure 3a, 3b). This latter type of machine does not produce a directionally shaped fragment, which makes the reassembly process from this type of shredder more difficult.

Comparing Royal HT3SL, Fellowes DS-1, and Brinks S9855W machines

These shredders all employ positive profile cylinders, characteristic of budget models, and they all originated from China. These machines showed differences in both shredder and shred characteristics. The Royal model produced shreds with an average length of 26.18mm, the Fellowes DS-1 shreds measured 33.39mm, and the Brinks shreds were the longest at 38.25mm. The Royal model shreds had an average width of 4.08 mm, while the Fellowes DS-1 and the Brinks model had average widths of 4.16 mm and 5.06, respectively. The crosscut patterns for these three machines also varied considerably. Because the shredders are all positive profile machines with v-shaped blades, their shreds exhibit distinct arrowheads and arrow tails.

Collective Comparison

For all the shredders examined, the length of the shreds varied more than the width. This can be supported by observing the mechanics of the cylinders and the crosscut patterns. The shred length is determined by the circumference of the cylinder and the space between the cutting surfaces, and there is more deviation in that aspect. The width of each piece of shred is set by the width of the cutting surfaces. Therefore, little deviation was found in the width of the Post-It™ shreds because each blade in the center of the throat is usually the same size.

However, due to the presence of narrower cutting surfaces at each end of the throat of several shredder models, it is believed that shreds of more than one width will be produced by certain shredders (here, all except the Fellowes negative

profile machines). That assumption could not be confirmed in this study, because the smaller-sized blades were always at the far ends of the throat, and the blue substrate of the specimen sheet was not reassembled.

Conclusions

The differences in shredder construction and condition can be seen in the differences in the appearance and dimensions of the shreds they produce. The size and shape of shred produced depends upon type of shredder mechanism (negative or positive profile), the shape of the cutting surfaces, the circumference of the cylinders, the distance between the cutting surfaces, and the angle created by the arrangement of the cutting surfaces as they spiral around the cylinder.

Shreds produced by a shredder using V-shaped blades will have a distinctive shape that will indicate the direction in which the document was shredded.

The different makes and models of shredders tested exhibited definite class characteristics; they could be discriminated based on the size and shape of the particles produced and the angle formed by the crosscuts.

There is some evidence to indicate that individual characteristics might be present between shredders of the same make and model (observed in the length of the shreds and the angle produced by the crosscuts); however, more research is needed.

Acknowledgements

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