A Comparison of Bloodstains on Fabric: Characteristics of Impact Spatter

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ABSTRACT

The objective of this research was to examine and compare the characteristics of impact bloodstain patterns on different fabrics. Crimes scenes often involve bloodstains on items of clothing so it is important to understand the behavior of blood on fabrics. Impact spatter was simulated with a mousetrap and human blood. Fabrics include acetate, acrylic, cotton, linen-cotton blend, nylon-lycra blend, polyester, silk, vinyl, and viscose-polyester-spandex blend. Comparisons were made between the fabric and control spatter, between spatter on different fabrics, and between spatter on different textures of the same fabric composition. The results showed vast differences in all comparisons. Future research should be conducted on more fabric types, different simulations of spatter, and other bloodstain mechanisms.

INTRODUCTION

Bloodstain pattern analysis (BPA) involves the use of bloodstain evidence to aid in the determination of how a crime occurred. A bloodstain pattern analyst must understand the fluid mechanics of blood and the mathematical formulas to aid in reconstruction as well as understand how blood reacts with various targets or substrates upon which the blood is deposited. Bloodstained clothing is a common type of evidence in a multitude of crimes. By examining the bloodstains on clothing an analyst can refute or verify witness statements, reconstruct the crime, and help convict or exonerate a suspect. Unfortunately, there is little research on how different clothing fabrics interact with bloodstains.

The importance of research on bloodstains and fabrics was evident in a criminal case, *Camm v. Indiana* (2009). One controversial aspect of this murder trial addressed in appeal involved bloodstains on the defendant’s t-shirt. BPA experts for the state agreed that the spots were from a combination of high velocity spatter while the t-shirt was in close proximity to the blood source and transfer. However, experts for the defense argued that all of the stains were transfer when the defendant made contact with the victims. The defense argued further that only “eight tiny stains” were noted on the t-shirt and the science of BPA was not advanced enough to draw conclusions from eight stains. The court ruled that the experts testified based on scientific evidence and the shirt was allowed into evidence. If more research on the subject of impact spatter and transfer stains on clothing existed this evidence may not have been so controversial.

In 1998 B. Karger et al. published research on the effects of three fabrics on contact, pressure, and projected bloodstains. The researchers found that rough surface textures decrease the characteristics of bloodstains as compared to the control, paper. Irregular spots were seen on 100% cotton, 65% polyester / 35% cotton, and 85% polyester / 15% cotton fabrics. Karger et al. suggested a reference collection of bloodstains on various fabrics be created.

Misty Holbrook conducted research to distinguish impact and transfer bloodstains on eleven fabrics (2010). She compared the size, shape, and penetration into the fabric of the stains. Impact spatter was simulated using a rat trap device. Most of the spatter ranged from 0.1mm to 3.8mm; 100% polyester had as large as 6.0mm and 1.0mm as the smallest spot. Holbrook found that the most distinctive feature of the bloodstains on fabric versus those on the control surface was the shape of the stain, not the size of the stain. The lowest level of shape distortion was observed on smooth fabrics: 100% rayon and 100% nylon. She found that absorbent fabrics (cotton, cotton blends, and silk) with dense weaves did not significantly affect shape. Stains spread over more than one thread showed slightly more distortion than those confined to one thread. Stains distorted by threads occurred on a ramie/cotton blend, wool, and acrylic fabrics. Holbrook observed the most drastic distortion on the 100% polyester fabric with spots elongated with the weave of the fabric. The impact spatter research by Holbrook was the inspiration for the study described in this paper. Holbrook also examined transfer stains, mimicking the size and shape of impact spatter, on the same fabrics. Because of time constraints, similar studies were not conducted for this paper. Holbrook suggests careful examination of multiple stains before a determination of mechanism is made when considering bloodstained clothing as evidence.

Other than Karger and Holbrook, most research deals with the development, detection, and visualization of blood on fabrics. Research on the visualization of blood on dark or patterned fabrics was conducted by Schuler et al., (2012). While the research focused on the use of near-infrared reflectance hyperspectral imaging for visualization of stains on dark fabrics, Schuler also provided a detailed description on the simulation of impact spatter. The researchers created a “spatter apparatus” that worked similarly to a mousetrap. The apparatus allowed for a reproducible simulation of impact spatter. A similar device was used in a study on impact spatter conducted by de Bruin et al., (2011). Schuler also discussed why visualization of bloodstains is so critical. For a bloodstain pattern analyst to accurately interpret bloodstains, he must see the physical stain details: shape, size, characteristics, location, overall distribution. He must also understand the relationship between the stains and the substrates they exist on.

In 2009 the National Academy of Sciences (NAS) and the National Research Council published a report requiring increased standards in the forensic science community, including the discipline of BPA, (Committee 2009). The Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) published a response to the NAS report, specifically addressing a number of recommendations. The following is SWGSTAIN’s response to recommendation six of the report: “SWGSTAIN advocates research and development that advances measurement, validation, reliability, and information sharing,” (SWGSTAIN Response). In addition to the response to the NAS report, SWGSTAIN developed a list of research needed in the BPA community. The first research project involves research regarding small stain blood spatters, as seen in high velocity impact spatter. The second research proposal suggests further study in the effects of fabric on bloodstains, (SWGSTAIN 2011).

The purpose of this research is to examine and compare how blood interacts with various fabrics that may be present at a crime scene or worn by a victim, suspect, or witness. The documentation of stain sizes, shapes, and characteristics on eleven fabrics will aid bloodstain pattern analysts in understanding how fabrics affect bloodstains. This particular experiment focused specifically on impact spatter, which occurs when an object strikes liquid blood, (SWGSTAIN 2009). The stain sizes, shapes, and characteristics were compared between fabrics and controls, between different fabric compositions, and between textures of the same fabric compositions. Edge characteristics, or the features around the outside of the stain, examined include: satellite spatter, a smaller bloodstain that originated from a main parent stain due to the blood impacting the surface; spines, linear projections connected to the parent stain when satellite spatter fails to form; pooling; and the wicking of blood by the threads of the fabric, (SWGSTAIN 2009; Bevel and Gardner 2002).

This study began with the hypothesis that sizes and shapes of bloodstains will vary with different fabrics and textures. Size did not vary greatly from the control spatter on butcher paper. Stain shapes, however, were found to be vastly different not only on different fabric compositions, but also on different textures of the same fabric composition.

MATERIALS AND METHODS

Eleven common fabric compositions were chosen to represent possible clothing involved in bloodstain pattern analysis and one additional fabric was chosen as an upholstery example. All clothing was purchased at a second hand store in Rapid City, SD. All articles were washed with Tide® detergent with Febreeze® and tumble-dried. Clothing was documented for fabric composition, style description, size, and brand name (all according to the manufacturer's label). All clothing was visually inspected for existing stains, though none were noted. Photographs of the clothing, including close-ups of tags, were taken. Each piece of clothing was cut into 8"x8" sections. The upholstery sample was purchased at Hobby Lobby in Rapid City, SD. It was cut into 8"x8" sections and visually examined for any existing stains. Clothing and fabrics are listed below:

100% Acetate- lining of silk dress, light blue, Natural Instincts®

100% Acrylic- sweater, off-white, Bobbie Brooks®

100% Cotton- denim jeans (2 pairs), light wash blue, Riders® and Christopher & Banks®

100% Cotton- tee shirt, white, StudioWorks®

55% Linen / 45% Cotton- long sleeve button down shirt, orange, Jones New York Sport®

90% Nylon- spaghetti strap tank, blue, Mossimo Stretch®

100% Polyester- rain coat, tan, Blair®

100% Polyester- fleece, tan, Old Navy®

100% Polyester- long sleeve button down shirt, blue, Joanna®

100% Silk- dress, blue and green plaid, Natural Instincts®

100% Vinyl- textured upholstery fabric, white, Damask® Vinyl Home Décor Fabric

48% Viscose / 44% Polyester / 8% Spandex- spaghetti strap tank, yellow/green, Weekenders®

Human whole blood was drawn by a phlebotomist into vacuum vials containing EDTA and anti-coagulants. 1mL of blood was used in each run.

A Tomcat® brand mousetrap was utilized to simulate impact spatter. The end of the mousetrap was covered in aluminum foil attached to the trap with duct tape. This was to prevent the blood from soaking into the wood of the trap. The mousetrap was anchored to a wooden block to prevent movement during the run.

A reproducible method was created. A large cardboard box, 24” x 20” x 14”, was selected as a “blood box” to control messes and ensure a constant horizontal distance from the trap in each run. A position equidistant from the back, left, and right sides of the box was marked to ensure reproducible distance. The trap was 10.25” from each side of the box for each run. 1mL of blood was measured into a graduated cylinder to control the volume of blood used in each run. The blood was applied directly to the trap with a pipette. By using the same brand of mousetrap, variability in velocity and force was minimized. Only two traps were used throughout this experiment.

A test run of the simulation was run using a target of butcher paper, no fabric samples. Pieces of butcher paper were taped to three sides of the box (back, left, and right) with labels for orientation. 1 mL of blood was placed directly onto the trap. The trap was placed in the outlined area, equidistant from all sides of the box. The trap was set off with a long swab from underneath the snap bar to allow for full contact with the blood pool. The butcher paper was removed from the box. It was confirmed that this method accurately simulated impact spatter. Areas with large amounts of spatter were noted for fabric placement. Standards were created for the fabric runs by cutting sides of another box to make a removable, sturdy mount for each side of the simulation box. The areas of high spatter found on the test run butcher paper were marked with permanent marker and masking tape. Identical fabric placement could then be achieved for each run.

For each run a piece of fabric, measuring 8”x8”, was stapled to a clean piece of butcher paper. The paper and fabric were taped to the removable mounts so that the fabric would be in the area of high spatter previously marked. Each fabric piece was checked to ensure it laid flat against the mount. Each mount was placed in the simulation box and the tops of the mounts were taped onto the box to reduce movement of the boards. The trap was set and 1 mL of blood was measured and dropped onto the end of the trap. The trap was then placed in the outlined area to ensure equal distances to the vertical fabric surfaces. The trap was triggered with a long swab from underneath the snap bar. The mounts were then removed from the box and the butcher paper was detached. The spatter was allowed to dry completely before any photography or analysis occurred.

After the spatter had dried, overall photographs of the fabric and control regions were taken with a macro lens on a Nikon® D300S. The camera was mounted on a photo stand to ensure photographs at exactly 90° to the surface of the fabric and paper. Scales were included.

Ten representative spatter spots were selected on 60 control regions, giving a total of 600 control spatter stains analyzed. Each spot was labeled A-J and measured in millimeters. After five regions of independent width and height measurements gave exclusively circular spatter, only width measurements were recorded for the remaining 55 regions. The measurements were later analyzed for spatter size range and average. Representative and abnormal spots were photographed with the same camera and lens as the overall photographs. Millimeter scales were included in the photographs.

Ten representative spatter spots were selected on 10 regions of each fabric, giving a total of 100 spatter stains analyzed per fabric, 1100 total stains over all fabrics. Each spot was labeled A-J and was measured in millimeters. Width and height measurements were recorded. The measurements were later analyzed for spatter size range and average. Representative and abnormal spots were photographed with the same camera and lens as the overall photographs. Millimeter scales were included in the photographs. Finally, spots were observed under a microscope at 10x. No equipment was available to photograph the stains microscopically, but detailed observations were noted for each spot. Spot shapes and characteristics were compiled and analyzed.

Fabric pieces were washed and re-used if necessary. Samples were only re-used if a visual examination of the fabric after washing confirmed that no stains remained.

RESULTS

Overall

Control spatter ranged from 0.1mm to 4.0mm. All fabric spatter ranges were within the control range, (Table 1). The average spatter sizes were similar to that of the control: 0.8mm. However, while the control spatter was circular, there were variations in the fabric width and height, (Fig. 1).

Differences in stain shape were observed. All control stains were circular. The shapes found on the eleven fabrics included “irregular” at 59.00%, round/oval at 16.64%, and rectangle/square at 5.00%, (Table 2). While shape observations are subjective, consistency was achieved by using one person to make observations throughout the research.

Most of the fabric spatter, 71.45%, showed no characteristics (satellite spatter, wicking, pooling, spines, weave affect). The most common characteristic observed in the fabric spatter was wicking, 10.45%, (Table 3).

Control

Control samples spatter sizes ranged from 0.1mm to 4.0mm. All control stains were circular. The average stain size was 0.8mm. No stain characteristics were seen in the control stains.

100% Acetate

All stains on the acetate fabric were diamond shaped. There was wicking on each stain, but the length of wicking varied. Wicking length was unrelated to the size of the stain. (Fig. 2-6)

100% Acrylic

The majority of stains, 96%, on the acrylic fabric had an irregular shape. 2% of the stains were diagonal lines, and 2% were round/oval. Another distinguishing feature of the acrylic fabric was the location of the stain. The fabric allowed for three levels of stain location: the bottom of the fabric, the middle, and the very top of the fibers. The majority of stains, 43%, were found on the bottom. 38% were seen over all layers, 16% were on the top of the fibers, and 3% were observed exclusively on the middle layer. (Fig. 7-11)

100% Cotton: denim

70% of the stains seen on the denim fabrics had an irregular shape. Other shapes included round/oval, diagonal lines, and diamond shape, (Fig. 12). Satellite spatter was observed in only 2% of the denim stains. (Fig. 13-17)

100% Cotton: t-shirt

The majority of the stains (69%) on the 100% cotton t-shirt was irregular. Other shapes included round/oval, rectangle/square, and diagonal lines, (Fig. 18). Only two stain shapes were affected by weave. One stain exhibited satellite spatter and one stain showed wicking. (Fig. 19-23)

55% Linen / 45% cotton

Of the stains on the 55% Linen / 45% Cotton fabric samples, 77% had irregular shape. Other shapes include round/oval and rectangle/square, (Fig. 24). 18% of stains exhibited pooling, 8% showed satellite spatter, and 1% was affected by the weave of the fabric. (Fig. 25-29)

90% Nylon / 10% lycra

70% of the Nylon / Lycra blend stains had irregular shape. Other stain shapes include round/oval, rectangle/square, arrow, and diamond, (Fig. 30). Pooling occurred in 7% of the stains, weave affect was seen in 6%, satellite occurred in 2%, and wicking was seen in only 1% of the stains. (Fig. 31-35)

100% Polyester: coat

The 100% polyester coat fabric samples did not yield a wide variety of stain shapes: 67% had irregular shape, 24% were round/oval, and 9% were rectangle/square, (Fig. 36). Many stain characteristics were seen on this fabric. Only 33% of stains did not exhibit any characteristics. The most common characteristic was pooling at 39%, (Fig. 37). (Fig. 38-42)

100% Polyester: fleece

A large majority of the stains on the 100% polyester fleece had irregular shape: 90%. The remaining 10% of the stains were round/oval. A more distinguishing feature of stains on this fabric is the location of the stain. The fleece was nubby, allowing for stains to fall on top of the nubby fibers, toward the middle of the fabric, at the base of the fibers, or spanning more than one layer, (Fig. 43). No stains exhibited any characteristics like satellite spatter, spines, or wicking. (Fig. 44-48)

100% Polyester: shirt

58% of stains on the 100% polyester shirt fabric samples had irregular shape. 38% of stains were round/oval in shape, (Fig. 49). Only 17 of 100 stains showed characteristics: 13 had pooling, 3 had wicking, and 1 had satellite spatter. (Fig. 50-54)

100% Silk

The majority (48%) of the stains on the 100% silk fabric had irregular shape, though almost all were affected by the weave of the fabric, (Fig. 55). Two major characteristics were observed with the stains: 32% had satellite spatter and 30% had pooling. The remaining 38% of the stains showed no characteristics. (Fig. 56-60)

100% Vinyl

The vinyl fabric samples were included in the data for this research. The stains did not soak into the fabric at all; the spots flaked off and were very difficult to measure.

48% Viscose / 44% polyester / 8% spandex

68% of the stains on the 48% viscose / 44% polyester / 8% spandex had irregular shape. 20% of the stains were arrow shape, (Fig. 61). Only 11% of the stains had a wicking characteristic. The other 89% had no characteristics. (Fig. 62-66)

DISCUSSION

Control versus fabric

The size range of the spatter on the fabrics stayed within the range observed on the control samples. Control samples spatter sizes ranged from 0.1mm to 4.0mm. The smallest spot measured, width-wise, was found on the 100% polyester coat at 0.1mm. The smallest spot measured, height-wise, was found on the 100% acrylic at 0.1mm. The largest spots measured, width-wise and height-wise, were found on the 48% viscose / 44% polyester / 8% spandex, both at 3.2mm. The consistency of the stain ranges over 1700 measurements suggests that the mousetrap mechanism was a reproducible way to create impact spatter.

The average spatter sizes on the fabrics were similar to that of the control: 0.8mm. The largest discrepancy in average spatter size occurred in the average height of spatter on 100% cotton (denim jeans) at 1.2mm. The smallest average spatter occurred in the average width of 90% nylon / 10% lycra and the 100% polyester shirt; both averaged at 0.7mm. A range of 0.5mm in the stain averages also suggests reproducibility in the mechanism.

The largest differences between the controls and the fabric spatter were seen in stain shape, not size. While all of the control stains were circular, only 16.64% of the 1100 fabric stains analyzed were round or oval. Many of the stains had variations in height and width, with almost all fabrics showing a slightly larger average height than average width. The majority of the stains, 65.00%, had irregular shape. Other stain shapes include diamond, rectangle/square, arrow, and diagonal lines. The differences in shape were due to the differences in surface texture. While the control sample (butcher paper) surface was smooth, all fabrics had a degree of texture and weave affecting the spatter. This is an important trend to consider. While stains on smooth, or fairly smooth, surfaces may be used to calculate angle of impact and area of origin, the shapeless stains on textured surfaces would make reconstruction extremely difficult. Very few stains on the fabric (16.64%) had the characteristic round/oval shapes that are required for reconstruction calculations.

Another difference between the controls and fabric spatter were in the stain characteristics. The control stains were round with no other characteristics. Stains on the fabrics exhibited satellite spatter, wicking, pooling, spines, and some were affected by the fabric weave. Most of the fabric spatter, 71.45%, showed no characteristics. The most common characteristic observed in the fabric spatter was wicking, 10.45%. The 100% acetate fabric samples showed wicking characteristic in 100% of the stains, (Fig. 3-6). The presence of these characteristics is also due to the texture of the fabric. All the wicking observed occurred along the threads of the fabric. The weave affect created distorted edges to the stains. Pooling occurred when the stain could not be absorbed into the fabric, either because of a larger volume in the particular spot or because of a dense weave to the fabric. The dense weave of the 100% polyester coat and the 100% silk created pooling in 39% and 30% of the stains, respectively. The 100% silk also exhibited satellite spatter in 32% of the stains. This could also be due to the weave. Satellite spatter was seen in 17% of the stains on the 100% polyester coat.

Different fabric compositions

The most distinctive fabrics were 100% acetate, 100% silk, 100% acrylic, and 100% polyester (fleece). The 100% acetate was the only fabric not dominated by irregular stains: all of the stains on this fabric were diamond shape. All of the stains exhibited wicking. They were the most distinct stains and showed the largest difference to the control stains, (Fig. 2). Only 48% of the silk stains were irregular; the rest of the stains were strongly affected and shaped by the weave of the fabric. This fabric exhibited many geometric stains like squares and rectangles and diamonds, (Fig. 59-60). The 100% silk stains also had many characteristics like satellite spatter and pooling. This was due to the tight weave of the fabric. The 100% acrylic and 100% polyester fleece had similar stains. Both of these fabric samples had fibers that extended from the base of the fabric. While the knit of the acrylic was soft and layered, the fibers of the fleece were nubby. The separation of the weave and fibers allowed for stains to be located on multiple layers of the fabric, (Fig. 67). The rest of the fabrics showed irregular stains with few characteristics. It is important to study more types of fabric composition types to observe more trends and impact spatter characteristics.

Different fabric textures

Fabric composition alone did not affect the stains; fabric texture strongly influenced shapes and characteristics. This trend was most evident with the three clothing items of 100% polyester, (Fig. 68). The coat had a dense weave and slick texture. The fleece had a nubby fiber weave with layers of the fibers exposed. The shirt had a fairly dense weave and a soft, smooth texture. In all three textures, the most prevalent stain shapes were irregular, followed by round/oval. Only the coat and the shirt showed any stain characteristics. The coat had more stains with pooling (39%) than stains with no characteristics (33%). While the shirt had more stains with no characteristics (83%), pooling was observed in 13% of the stains. Because of the layered texture to the fleece, it was difficult to distinguish any characteristics to the stains. Observations were made on the location of the stains for the fleece, with the majority of stains located at the base of the fibers.

Another example of the differences caused by fabric texture can be seen in the 100% cotton samples, (Fig. 69). These two articles of clothing did not exhibit as extreme differences as the 100% polyester clothing. The white 100% cotton t-shirt was smoother than the 100% cotton denim jeans. The rougher texture of the denim jeans created a larger number of stains with irregular shape (72%) and only 15% round/oval stains. The t-shirt had a slightly larger percentage of round/oval stains (22%) and fewer stains of irregular shape (69%). Neither type of clothing exhibited many characteristics: the denim jeans had satellite spatter on 2% of stains and the t-shirt had satellite on 1%, wicking on 1%, and weave affect on 2% of stains. Most of the stains on the t-shirt absorbed just below the top fibers. The stains on the denim jeans did not exhibit this characteristic. These examples demonstrate the importance of studying more textures of fabric of same composition.

CONCLUSION

This research shows that the only trend present in impact spatter on fabric is the irregularity of stain shape. While all of the stains were under 4.0mm, 65% had irregular shape. This characteristic must be taken into account when examining bloodstains on clothing. An examiner must consider both the type of fabric and the texture of the fabric and how the two affect the bloodstain. Angle of impact and other methods for reconstruction would be difficult to determine based on the shapeless stains. More research should be conducted comparing the appearance of stain shapes on fabrics at different angles of impact. A larger collection of fabric types and stain observations should be created, perhaps building upon Karger’s idea of a reference library, (1998).

FUTURE CONSIDERATIONS

There are many possible ways to build upon this research in the future. More fabric types should be analyzed. Only eleven fabrics were chosen for this research because of time constraints. Future research should not only build upon this library of data, but also verify the data. Other mechanisms of spatter simulation should also be looked at. This research produced spatter consistent with a high to medium velocity impact. Low velocity impact, expirated, transfer, and other spatter types should be examined on fabrics. Other research ideas include: different distances to the target, vertical versus horizontal drying positions, stain-treated or pre-treated fabrics, upholstery fabrics, and more fabric textures within one fabric composition.

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APPENDIX

Note: All scales are millimeter.

Table 1: Spatter size ranges per fabric composition

Fabric	Width Minimum	Width Maximum	Height Minimum	Height Maximum
Control	0.1	4.0	0.1	4.0
100% Acetate	0.3	3.0	0.4	3.0
100% Acrylic	0.2	2.0	0.1	2.4
100% Cotton (Denim)	0.2	2.8	0.4	3.0
100% Cotton (Tee)	0.2	2.8	0.2	3.0
55% Linen / 45% Cotton	0.2	3.0	0.2	2.2
90% Nylon / 10% Lycra	0.2	1.8	0.2	2.0
100% Polyester (Coat)	0.1	1.8	0.2	2.0
100% Polyester (Fleece)	0.2	1.8	0.2	1.8
100% Polyester (Shirt)	0.2	1.8	0.2	2.8
100% Silk	0.2	2.3	0.2	2.4
48% Viscose / 44% Polyester / 8% Spandex	0.3	3.2	0.3	3.2

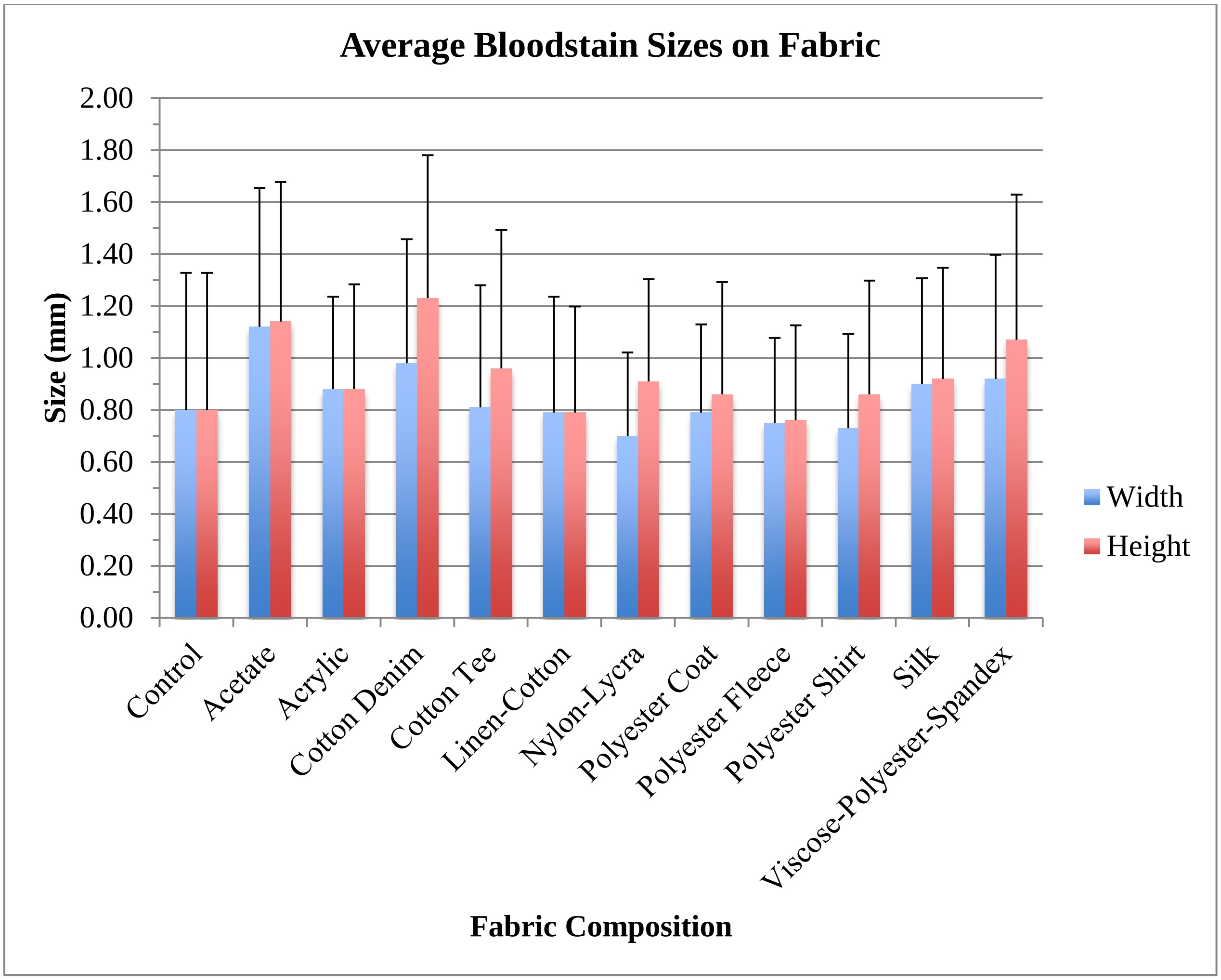

Figure 1: Bar graph of spatter size averages per fabric composition (including positive error lines for standard deviation)

Table 2: Stain shapes by count and percentage over 11 fabrics

Shape	**Count**	**Percentage**
Irregular	715	65.00
Round/Oval	183	16.64
Diamond	107	9.73
Rectangle/Square	55	5.00
Arrow	24	2.18
Diagonal	16	1.45
Total	1100	100.00

Table 3: Stain characteristics by count and percentage over 11 fabrics

Characteristics	Count	Percentage
None	786	71.45
Wicking	115	10.45
Pooling	107	9.73
Satellite	64	5.82
Weave Affect	27	2.45
Spines	1	0.09
Total	1100	100.00

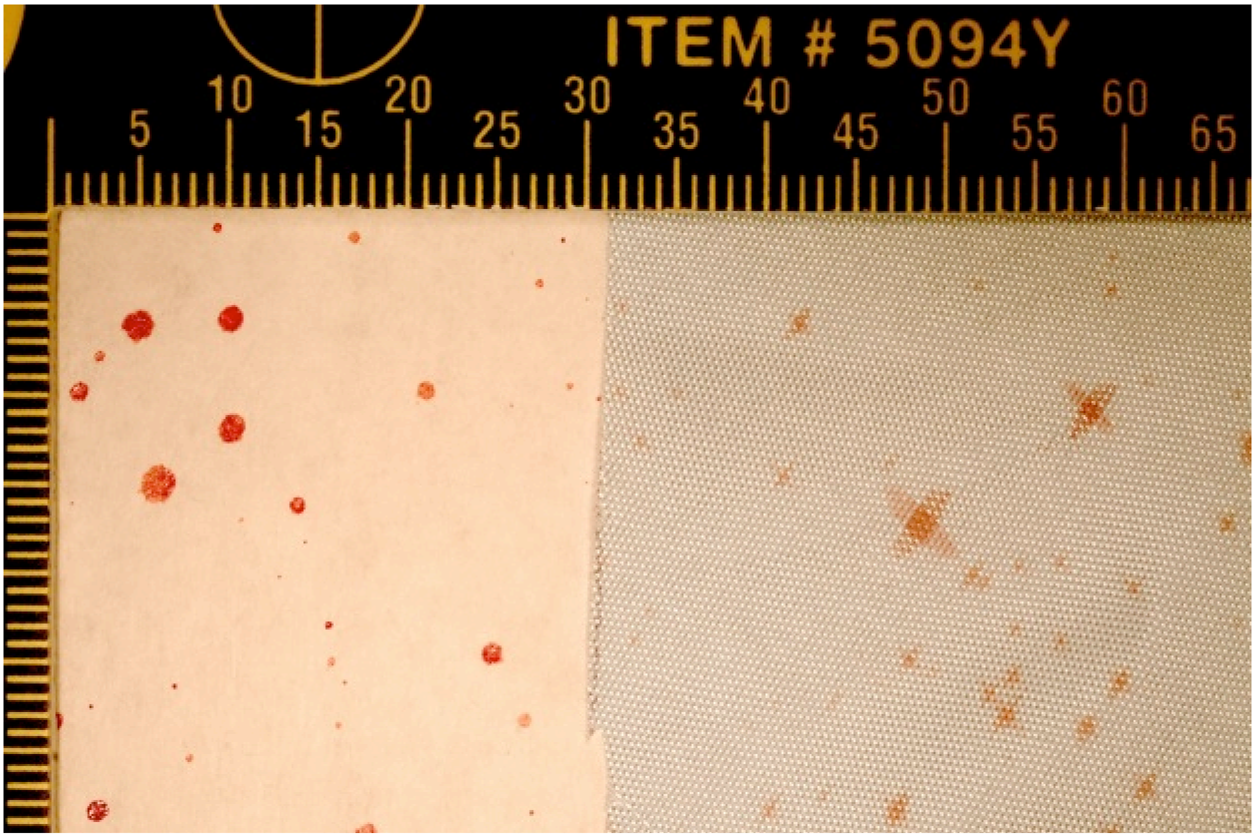

Figure 2: Control (left) and 100% Acetate (right)

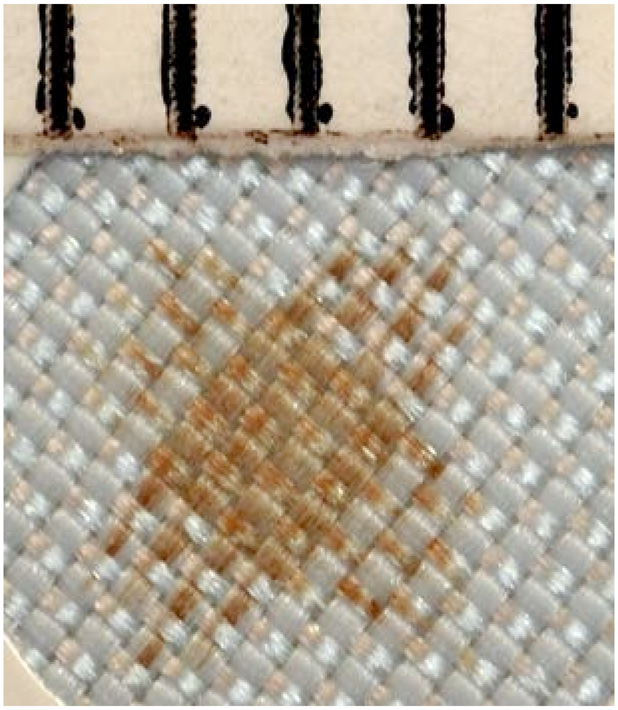

Figure 3: 100% Acetate; Wicking

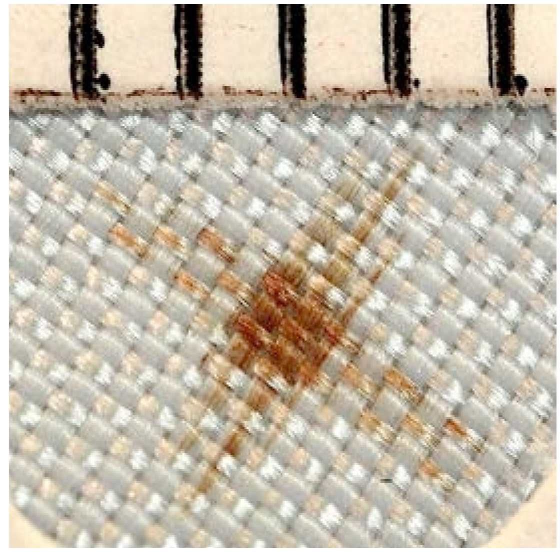

Figure 4: 100% Acetate; Wicking

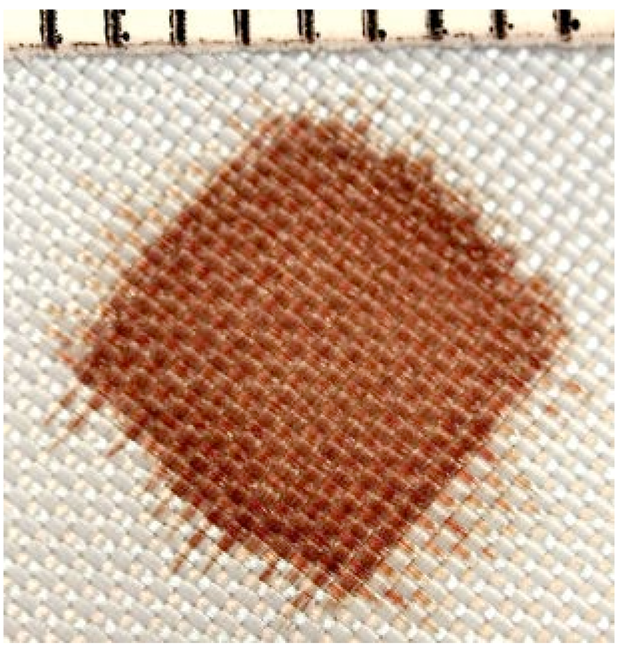

Figure 5: 100% Acetate; Wicking

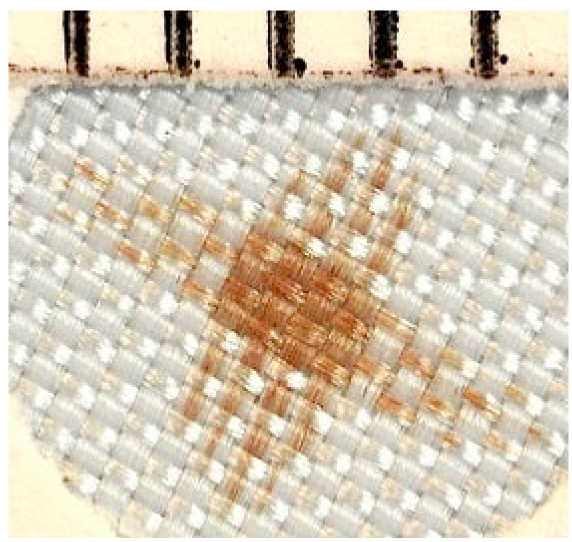

Figure 6: 100% Acetate; Wicking

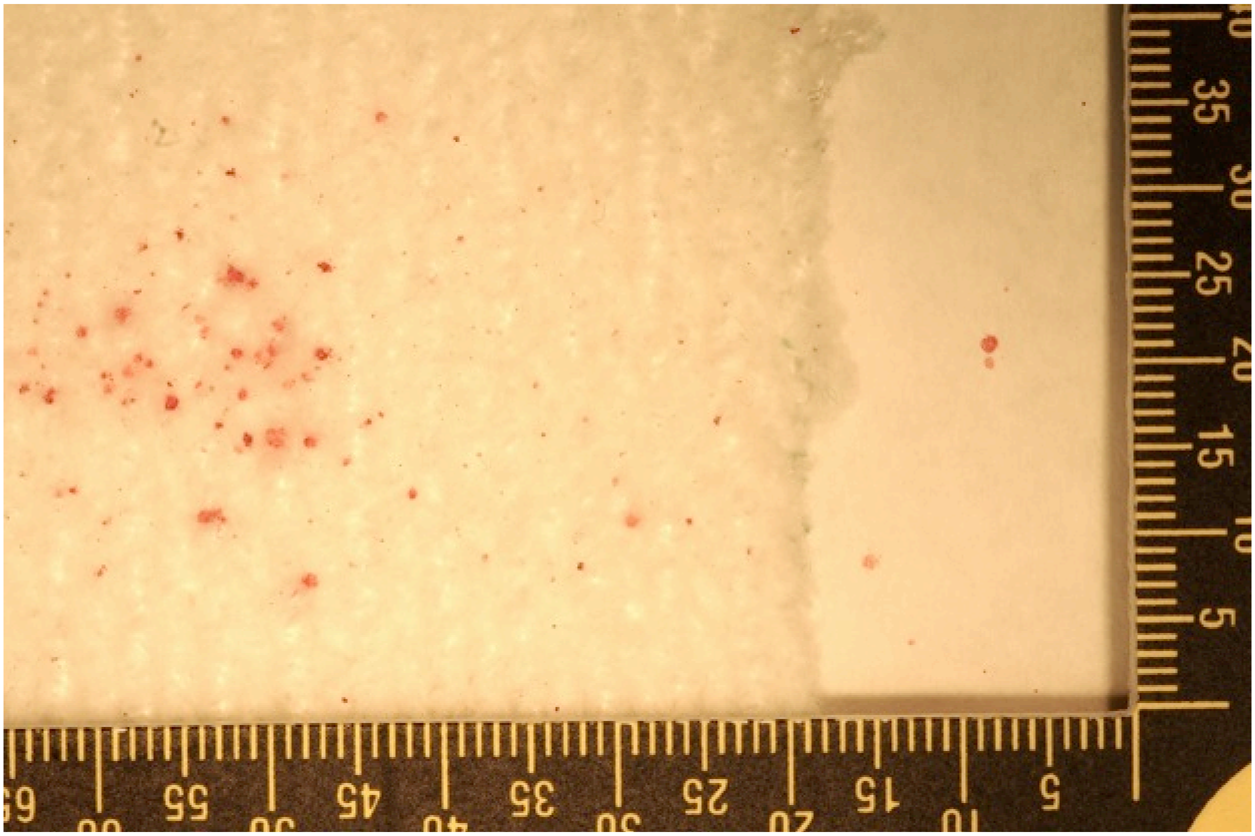

Figure 7: 100% Acrylic (left) and Control (right)

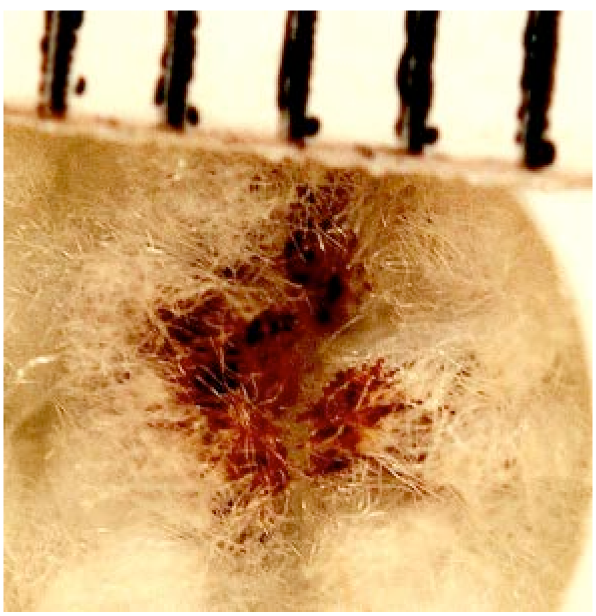

Figure 8: 100% Acrylic

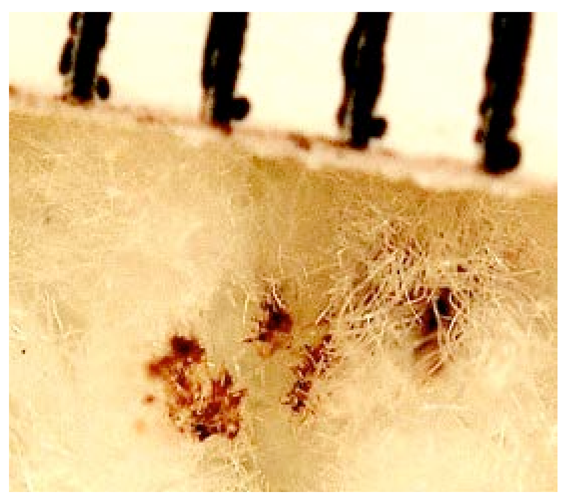

Figure 9: 100% Acrylic

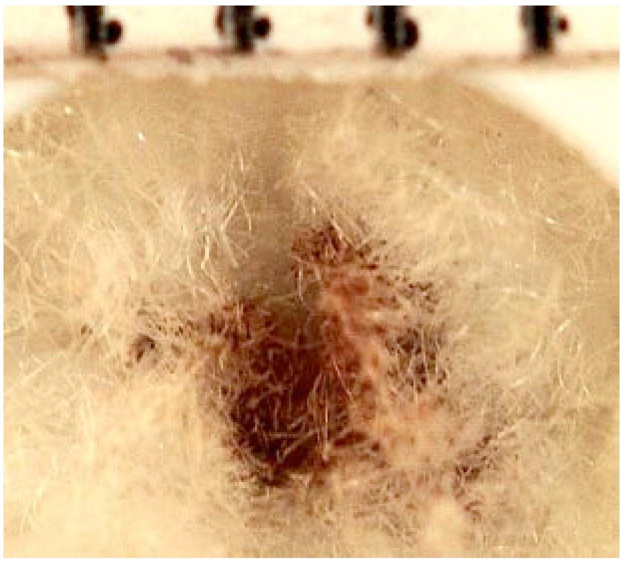

Figure 10: 100% Acrylic

Figure 11: 100% Acrylic

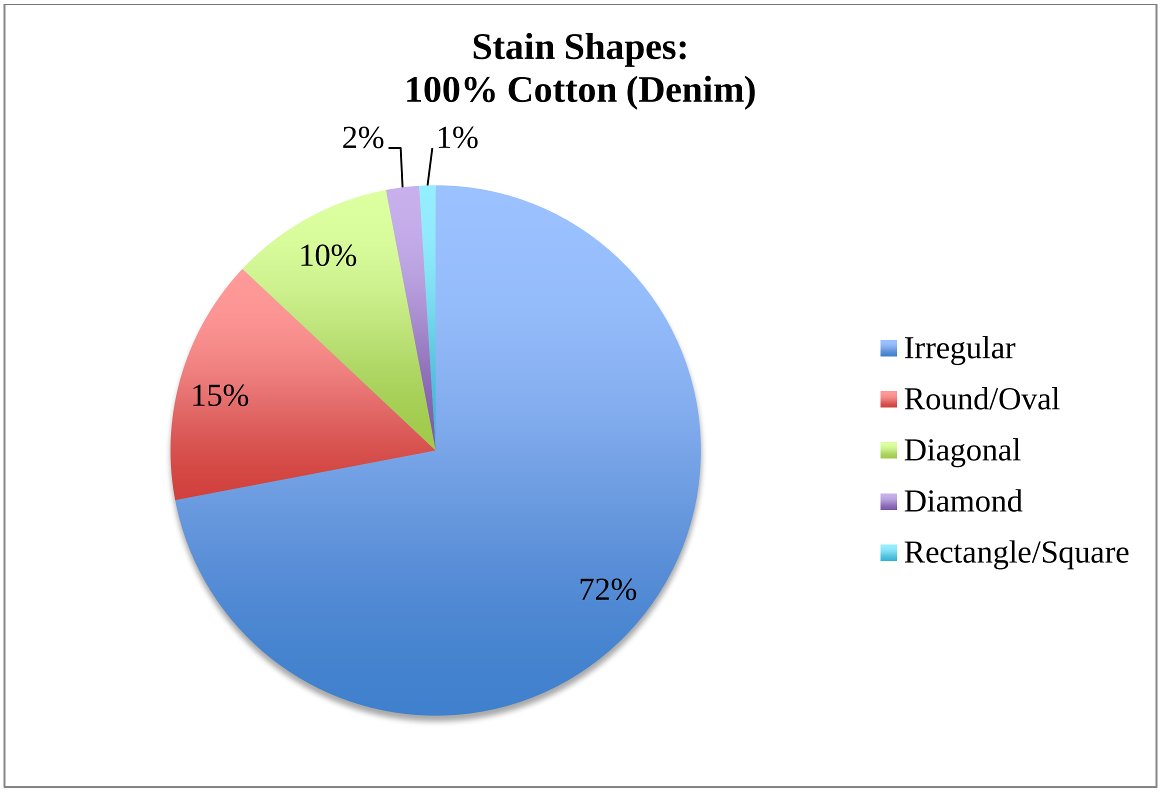

Figure 12: Stain shape percentages for 100% Cotton, Denim

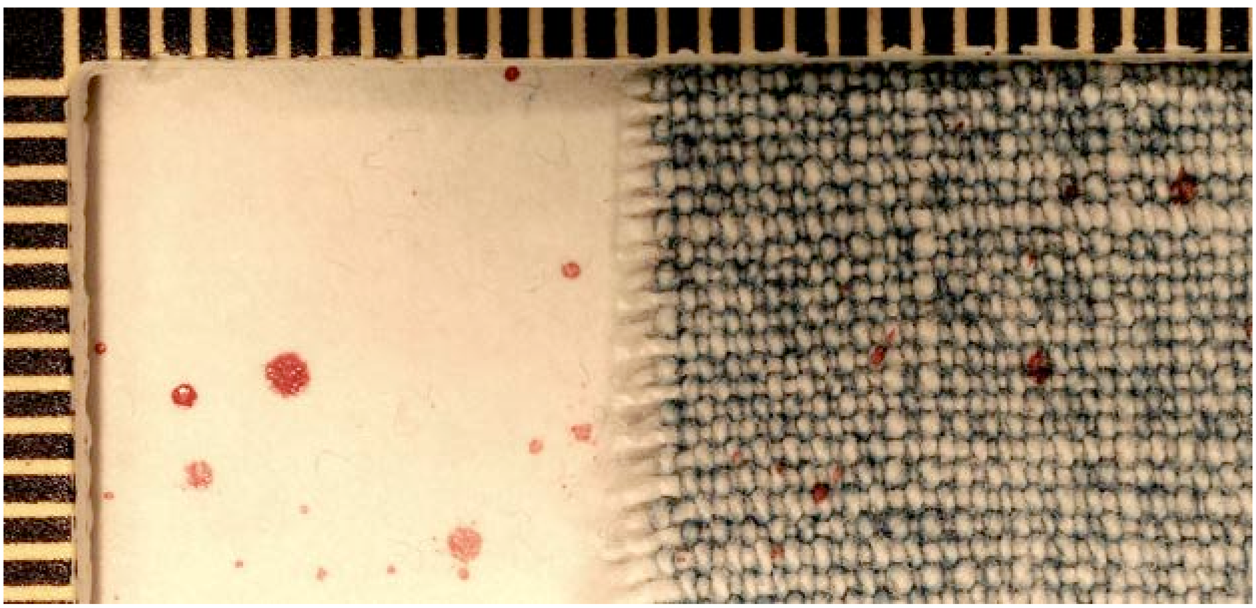

Figure 13: Control (left) and 100% Cotton- Denim (right)

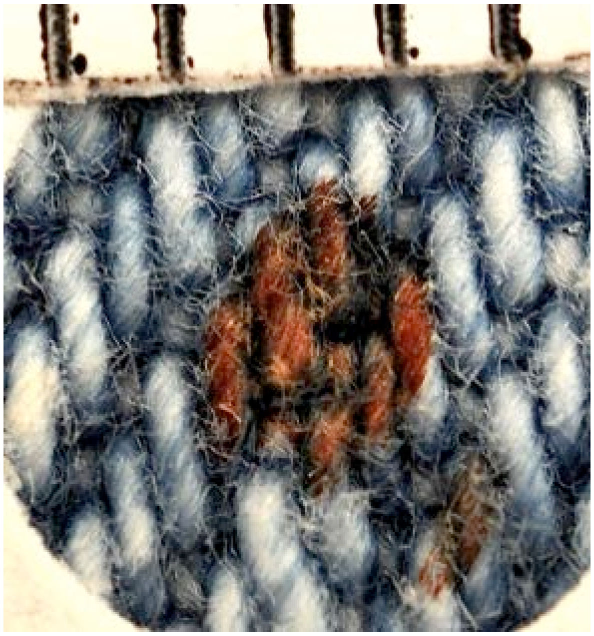
Figure 14: 100% Cotton (Denim)


Figure 15: 100% Cotton (Denim);


Figure 16: 100% Cotton (Denim); Satellite

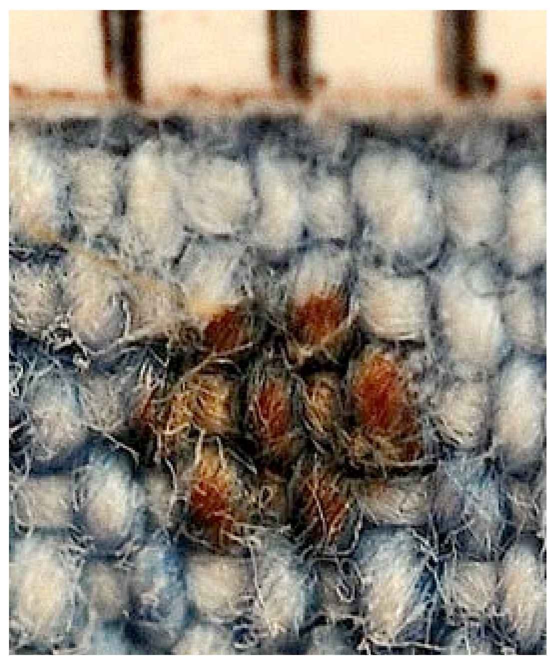
Figure 17: 100% Cotton (Denim)

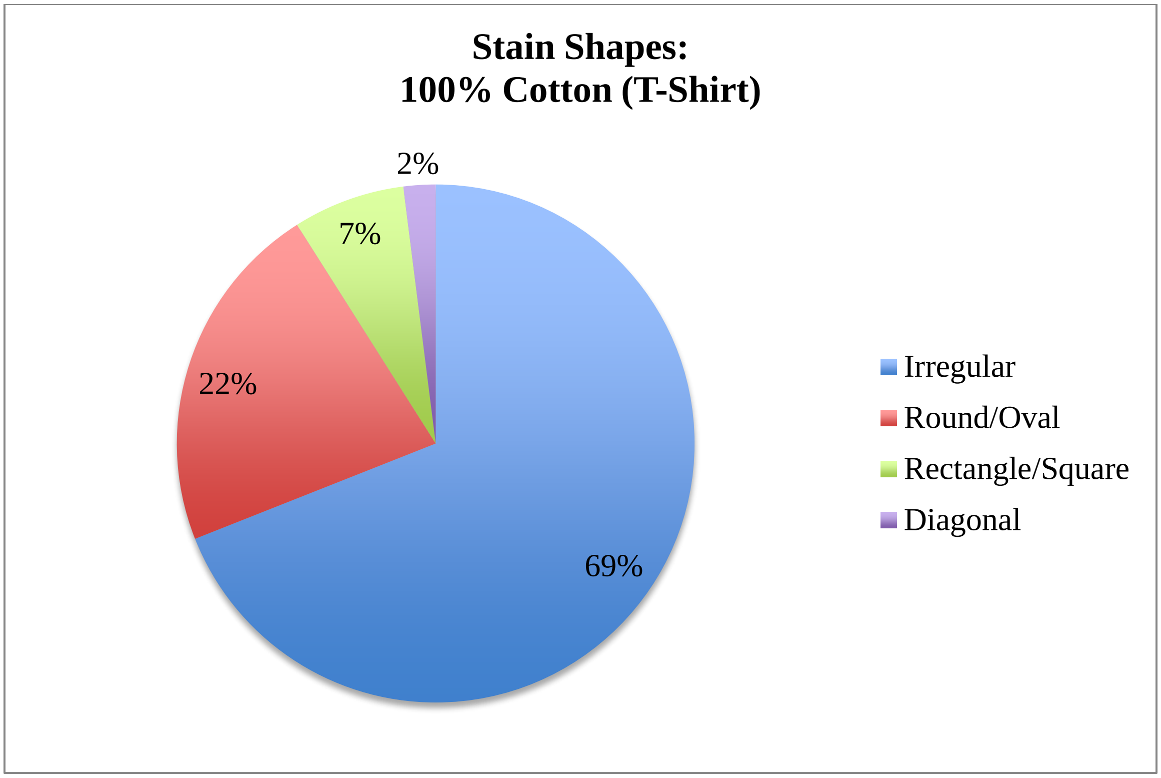

Figure 18: Stain shape percentages for 100% Cotton, T-shirt

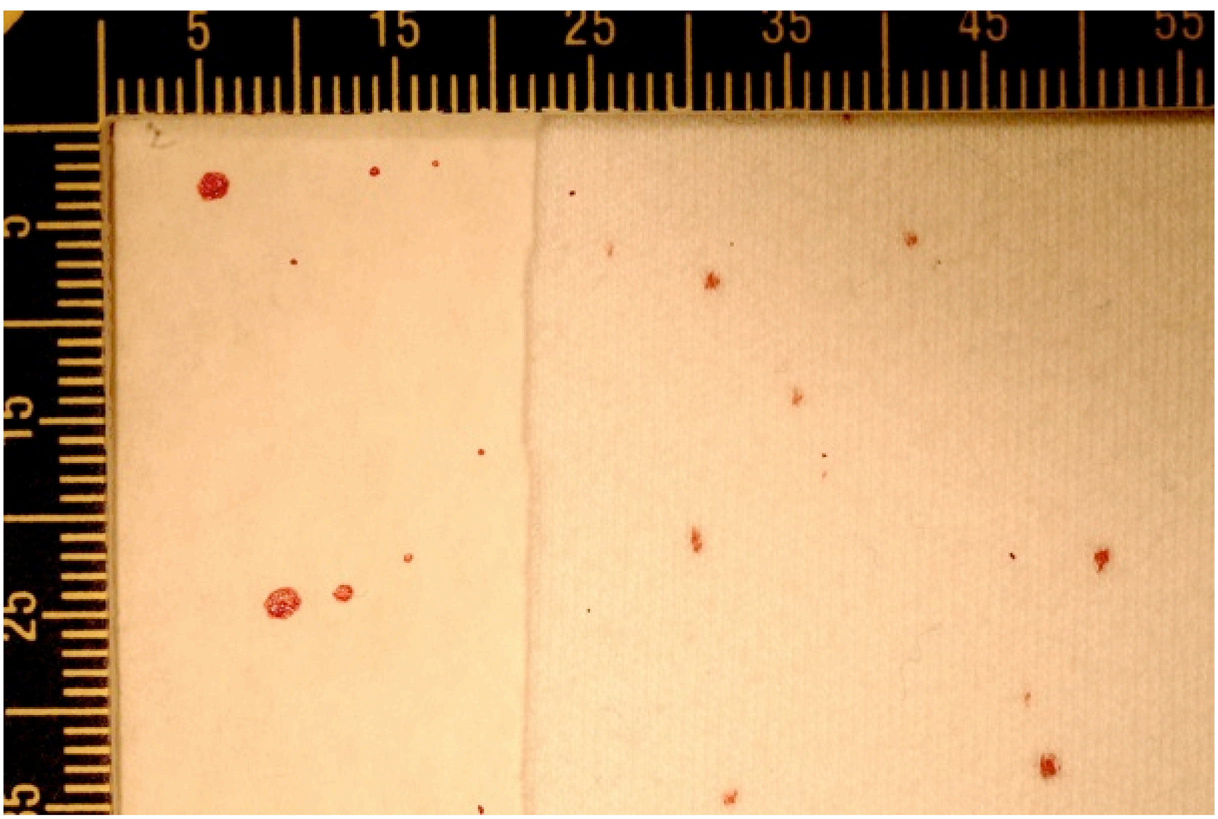

Figure 19: Control (left) and 100% Cotton- T-shirt (right)

Figure 20: 100% Cotton (T-shirt)

Figure 21: 100% Cotton (T-shirt)

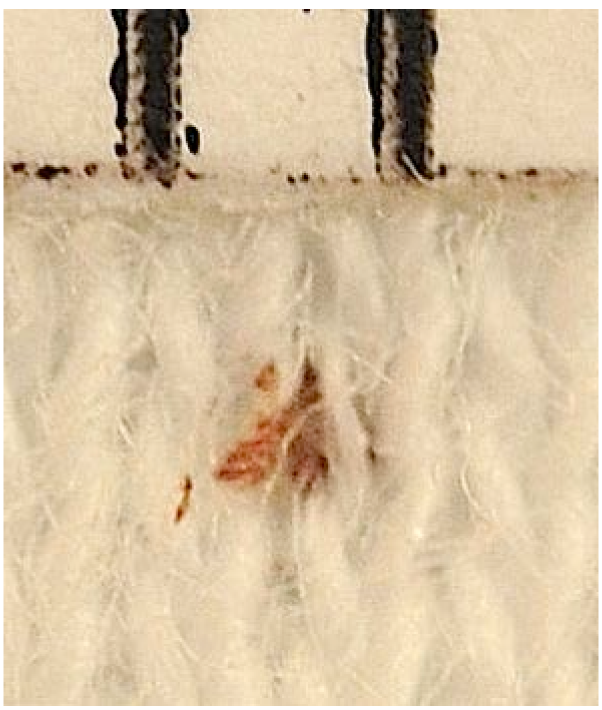

Figure 22: 100% Cotton (T-shirt)

Figure 23: 100% Cotton (T-shirt)

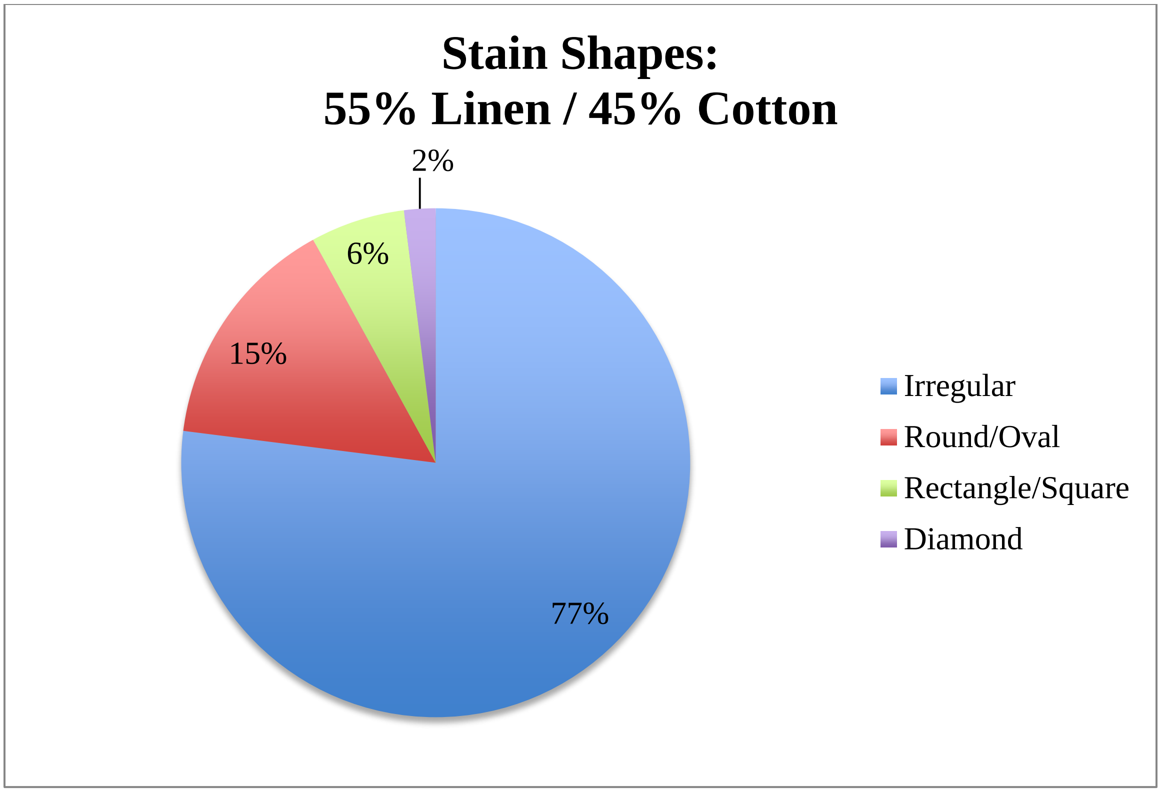

Figure 24: Stain shape percentages for 55% Linen / 45% Cotton

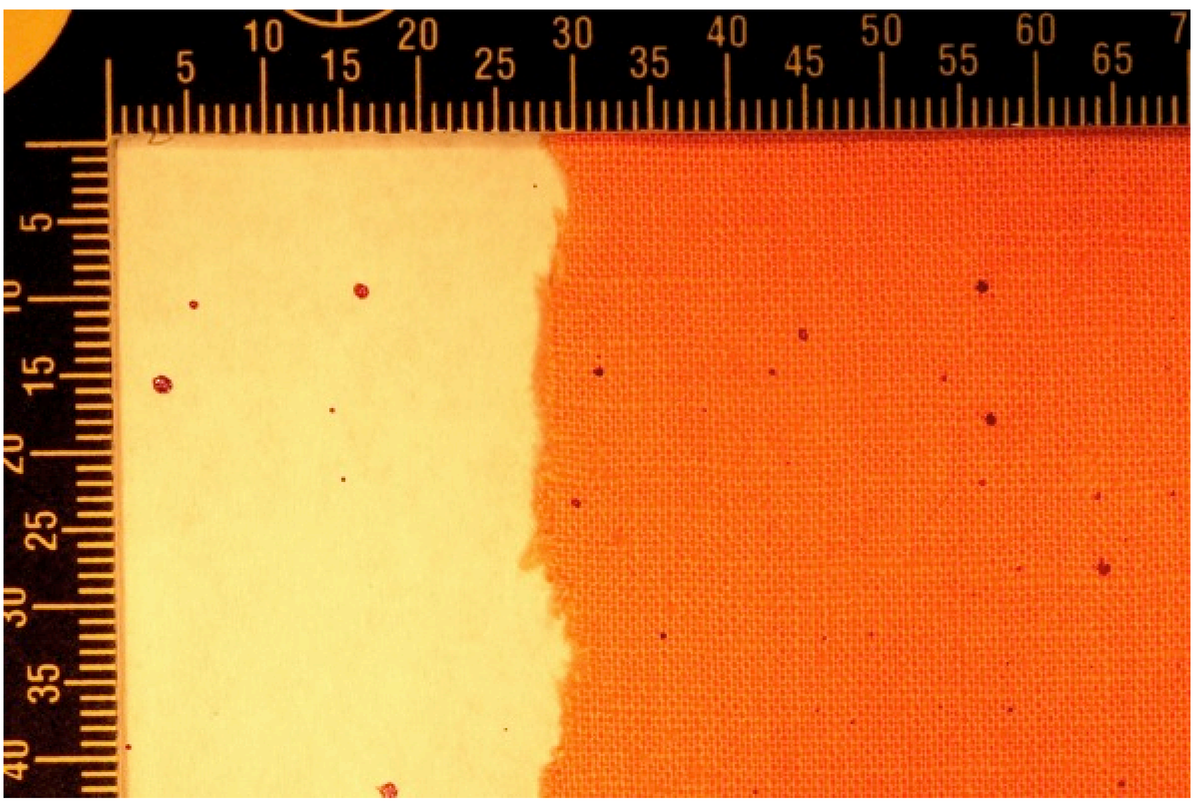

Figure 25: Control (left) and 55% Linen / 45% Cotton (right)

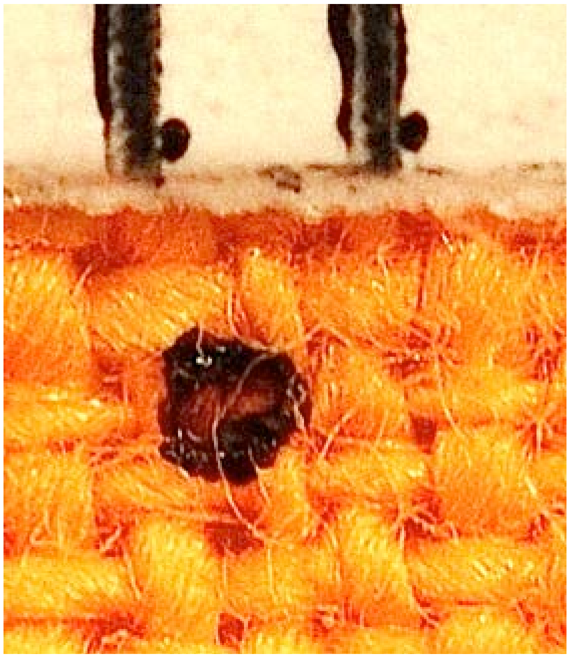

Figure 26: 55% Linen / 45% Cotton; Pooling

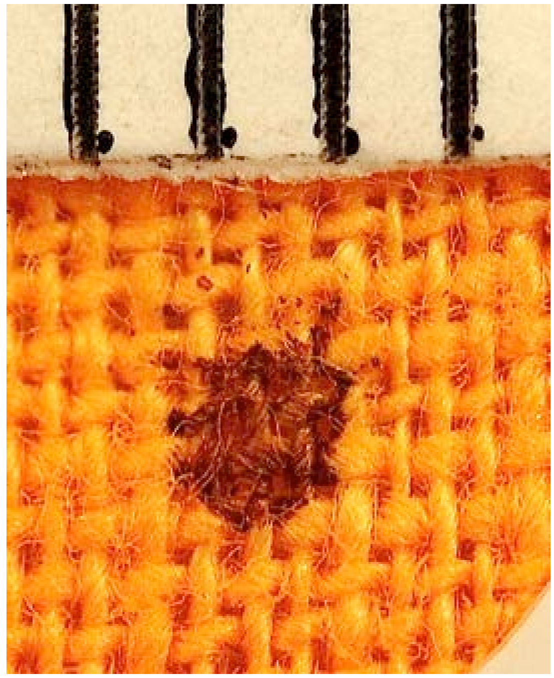

Figure 27: 55% Linen / 45% Cotton; Satellite

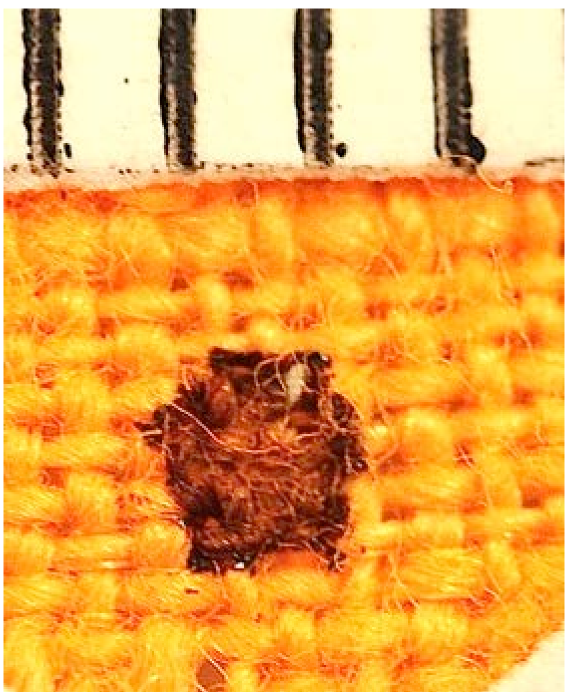

Figure 28: 55% Linen / 45% Cotton

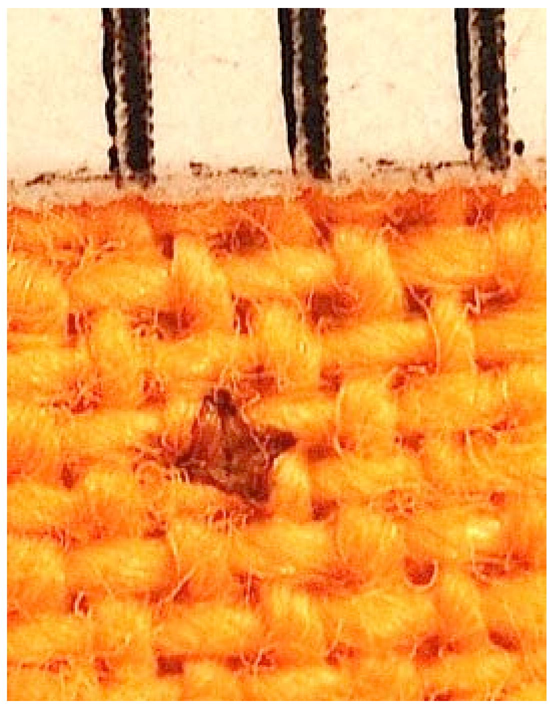

Figure 29: 55% Linen / 45% Cotton

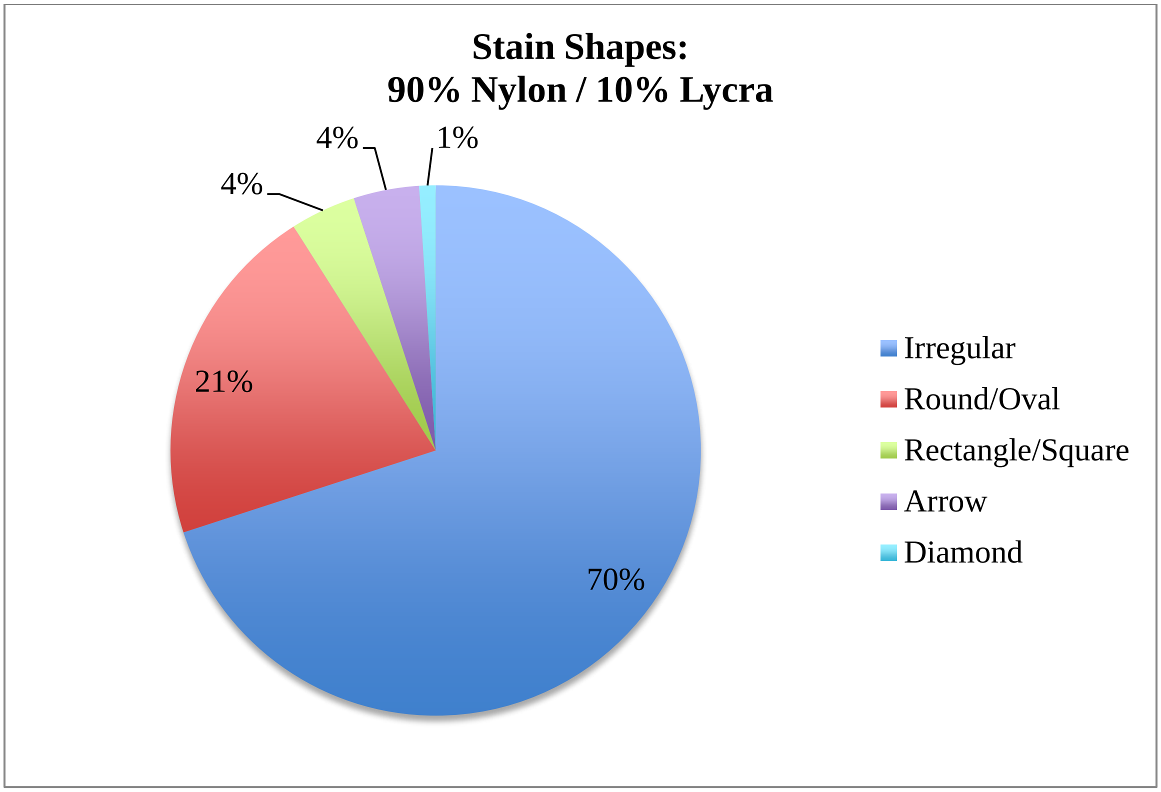

Figure 30: Stain shape percentages for 90% Nylon / 10% Lycra

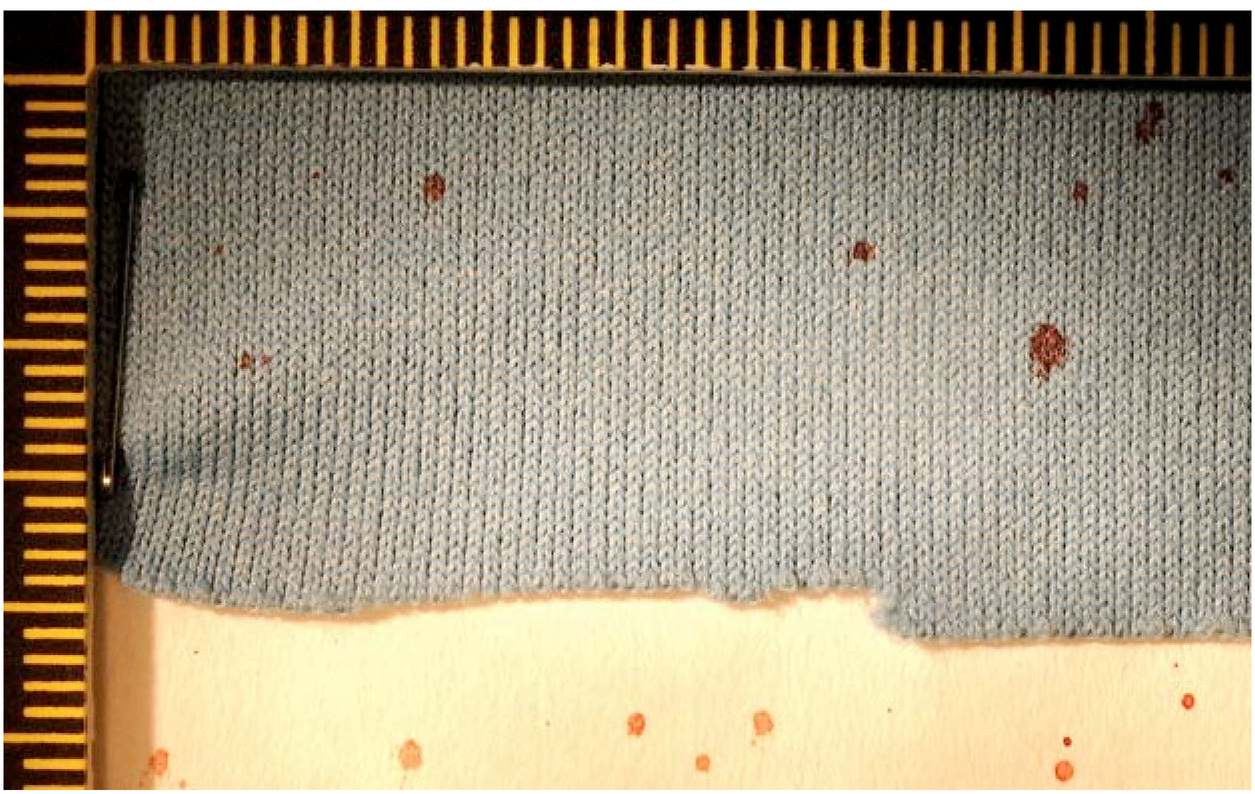

Figure 31: Control (bottom) and 90% Nylon / 10% Lycra (top)

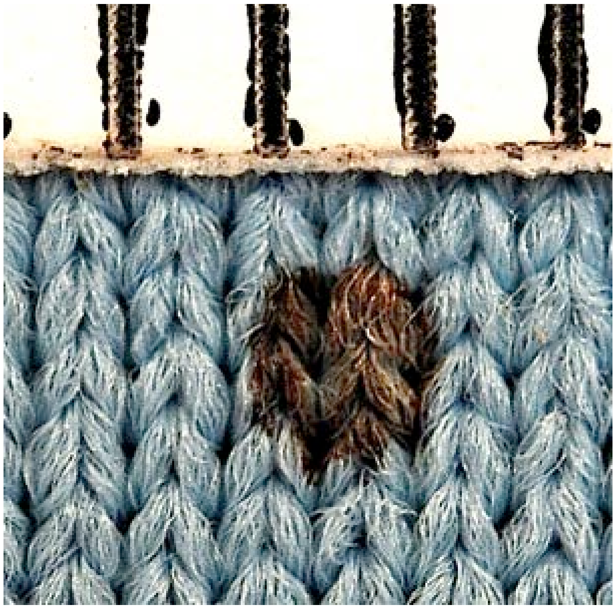

Figure 32: 90% Nylon / 10% Lycra

Figure 33: 90% Nylon / 10% Lycra

Figure 34: 90% Nylon / 10% Lycra

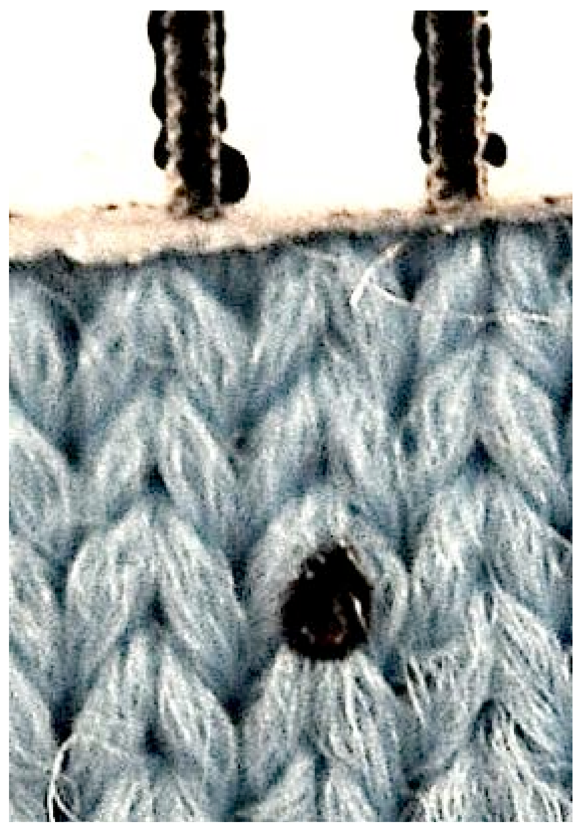

Figure 35: 90% Nylon / 10% Lycra; Pooling

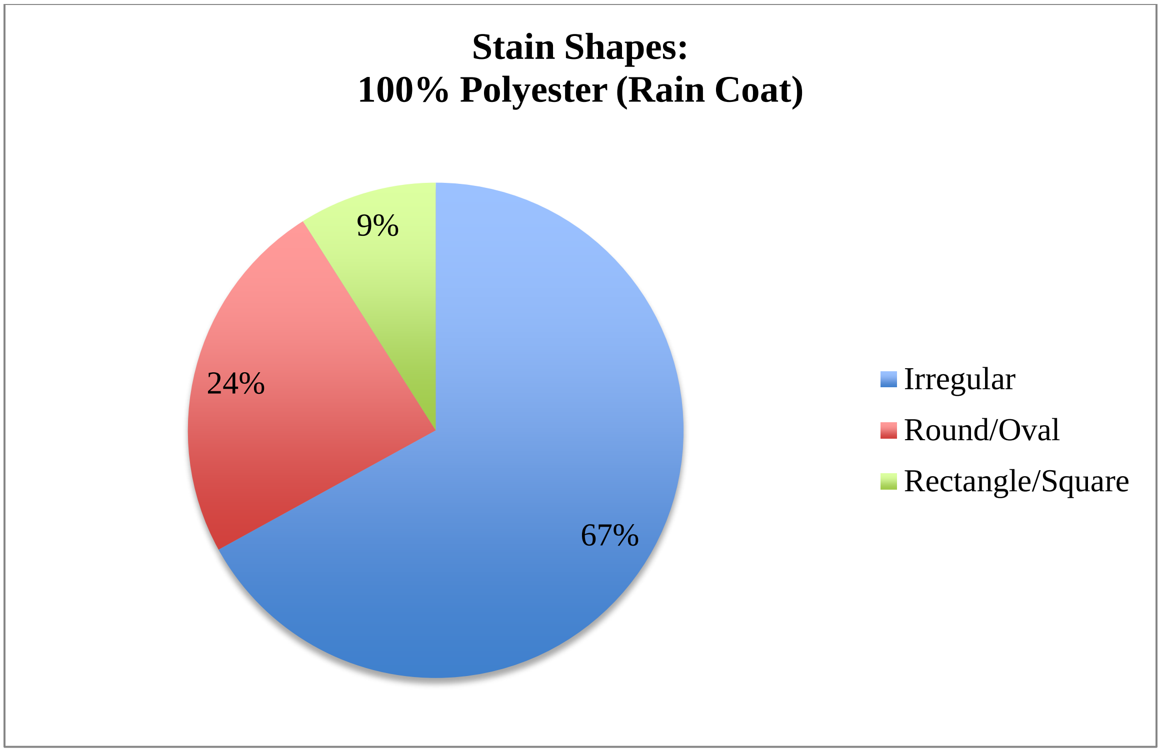

Figure 36: Stain shape percentages for 100% Polyester (Rain Coat)

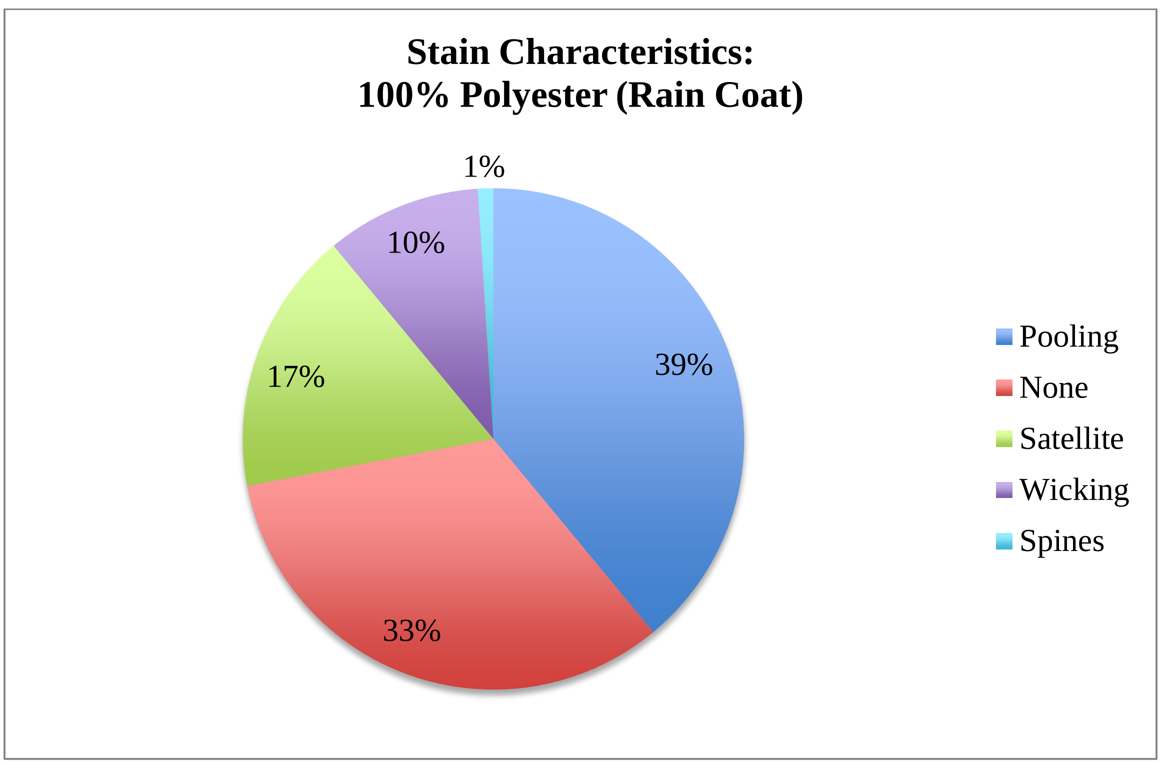

Figure 37: Stain characteristic percentages for 100% Polyester (Rain Coat)

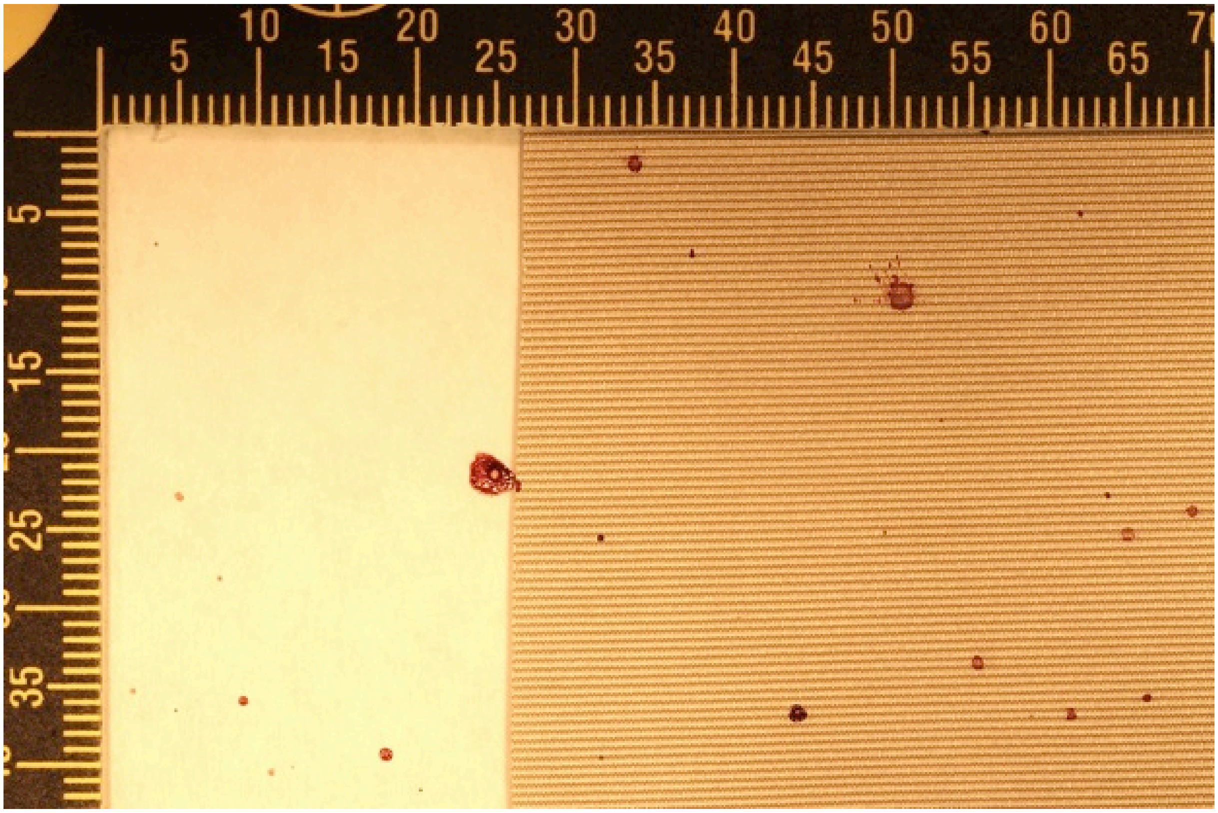

Figure 38: Control (left) and 100% Polyester- Coat (right)

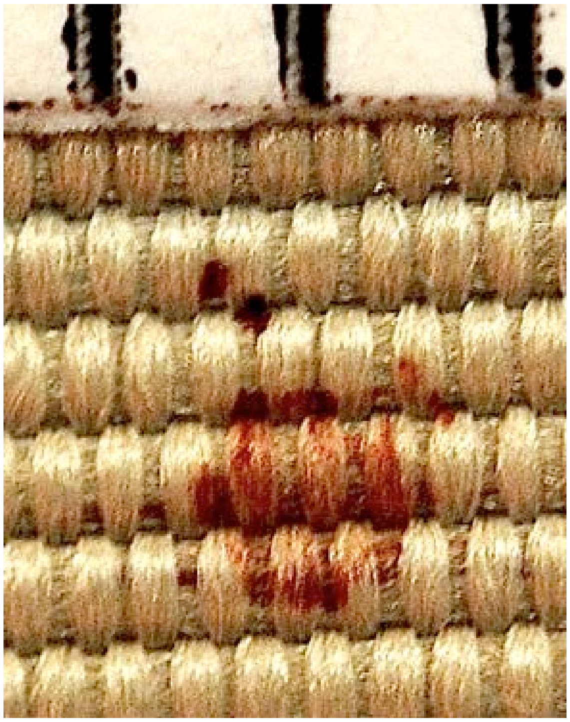

Figure 39: 100% Polyester (Coat); Satellite, some wicking

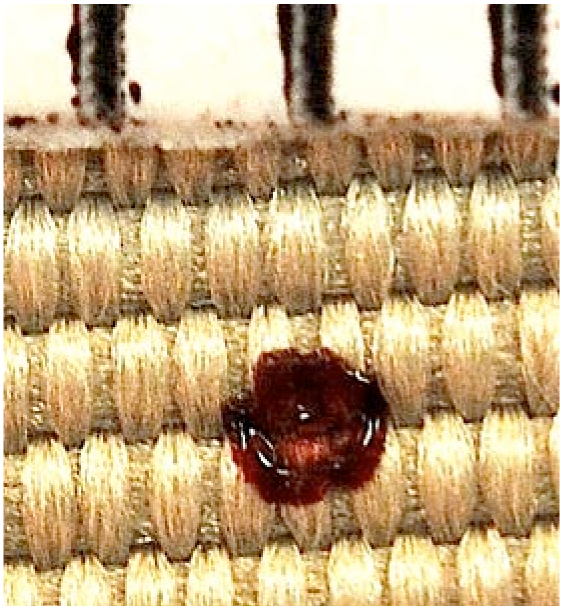

Figure 40: 100% Polyester (Coat); Pooling

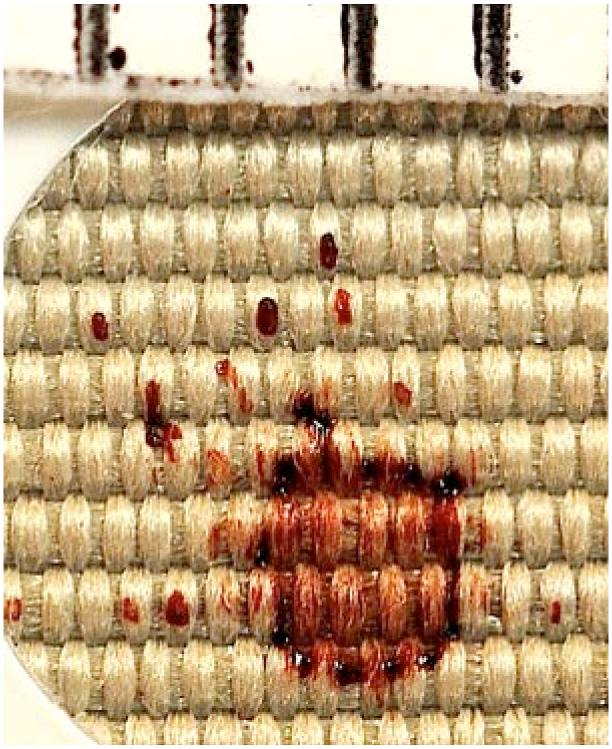

Figure 41: 100% Polyester (Coat); Satellite

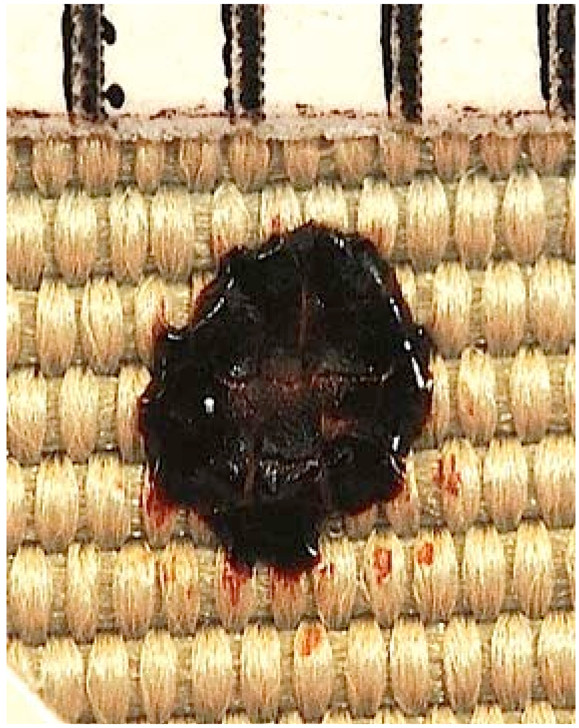

Figure 42: 100% Polyester (Coat); Pooling, some satellite

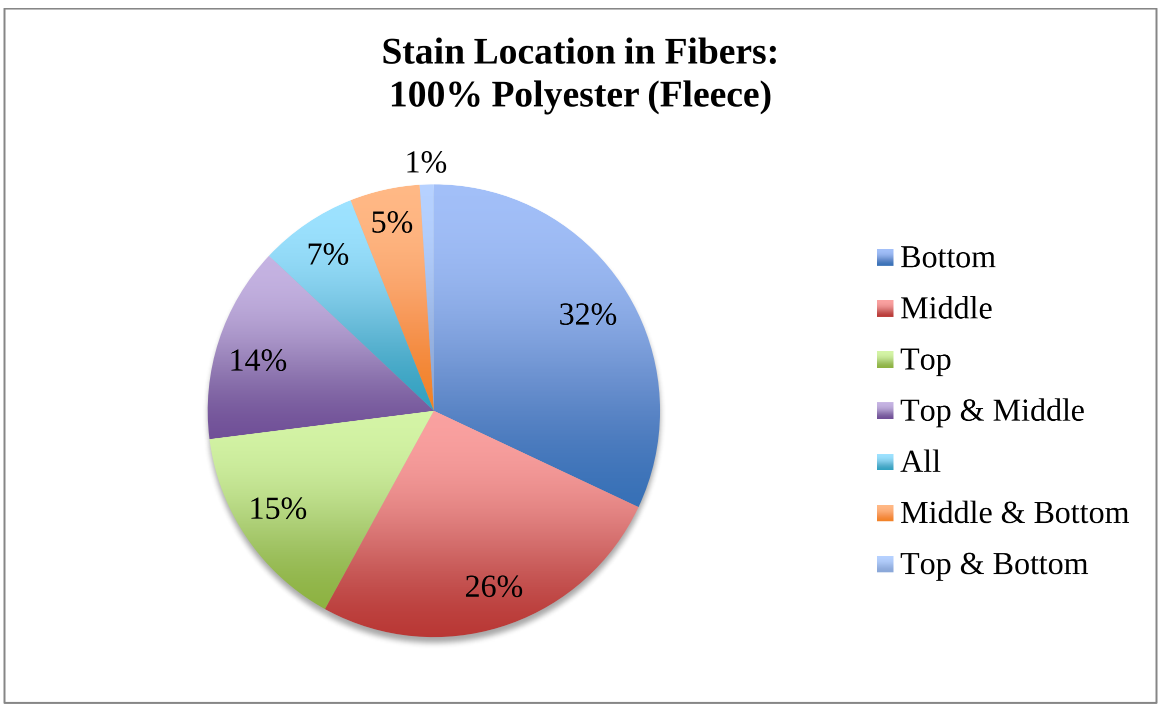

Figure 43: Stain location percentages for 100% Polyester (Fleece)

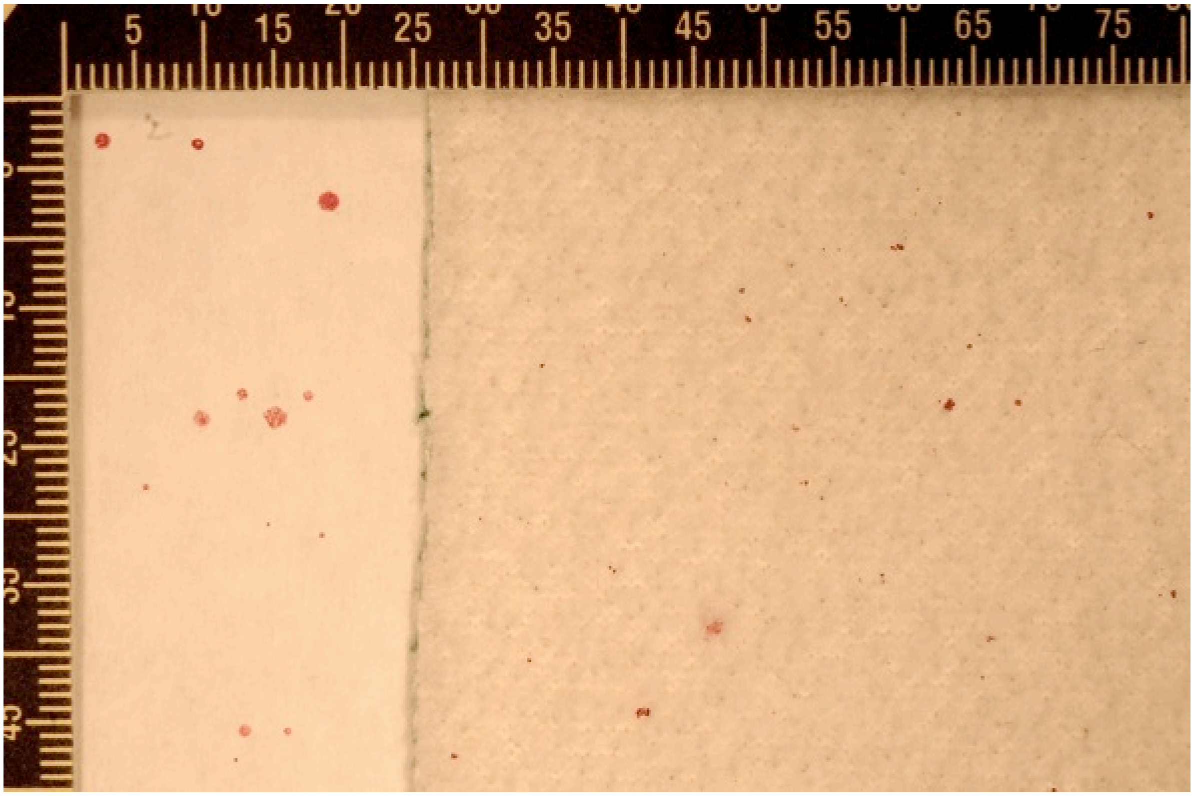

Figure 44: Control (left) and 100% Polyester- Fleece (right)

Figure 45: 100% Polyester (Fleece)

Figure 46: 100% Polyester (Fleece)

Figure 47: 100% Polyester (Fleece)

Figure 48: 100% Polyester (Fleece)

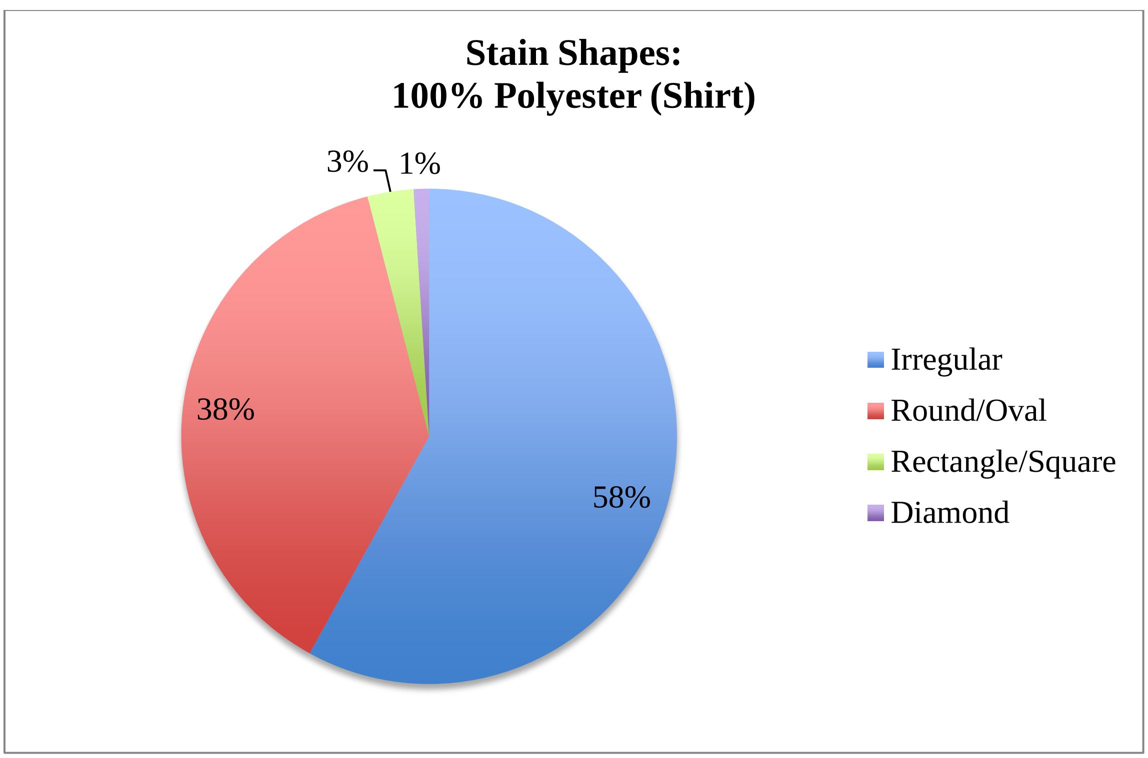

Figure 49: Stain shape percentages for 100% Polyester (Shirt)

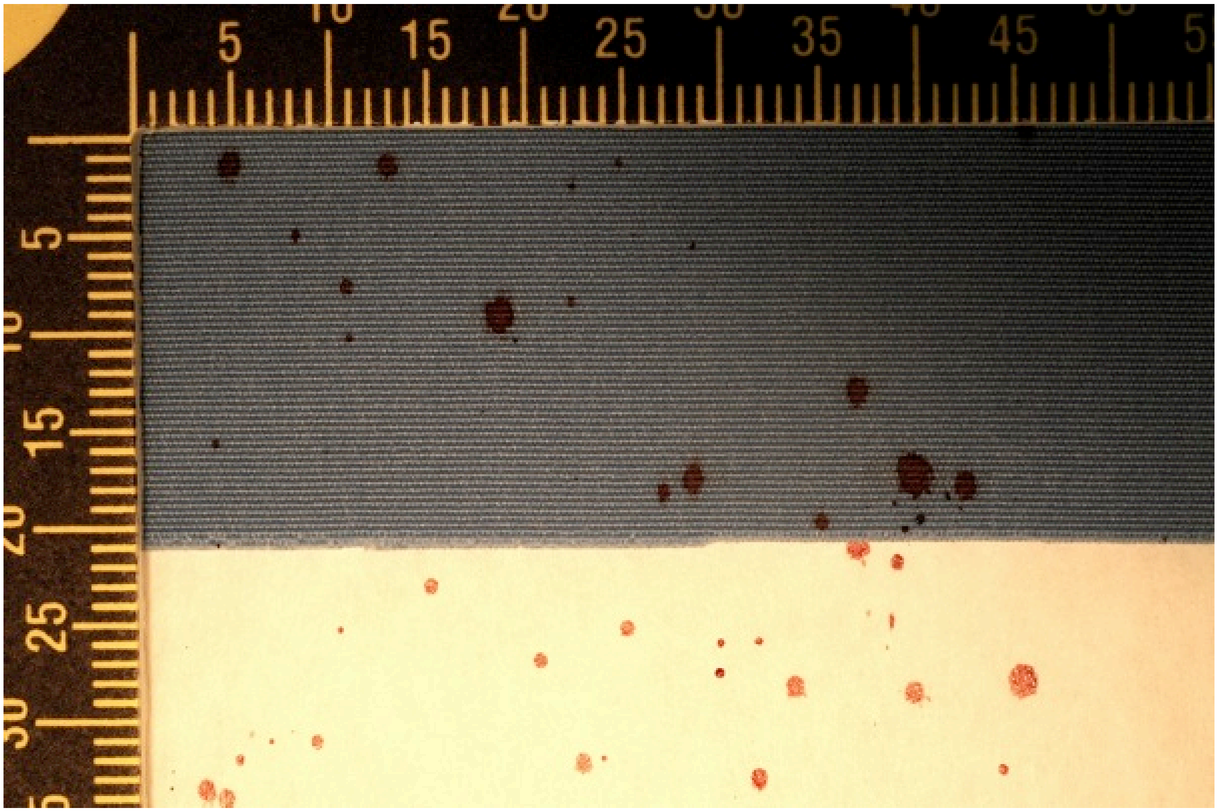

Figure 50: Control (bottom) and 100% Polyester- Shirt (top)

Figure 51: 100% Polyester (Shirt); Wicking

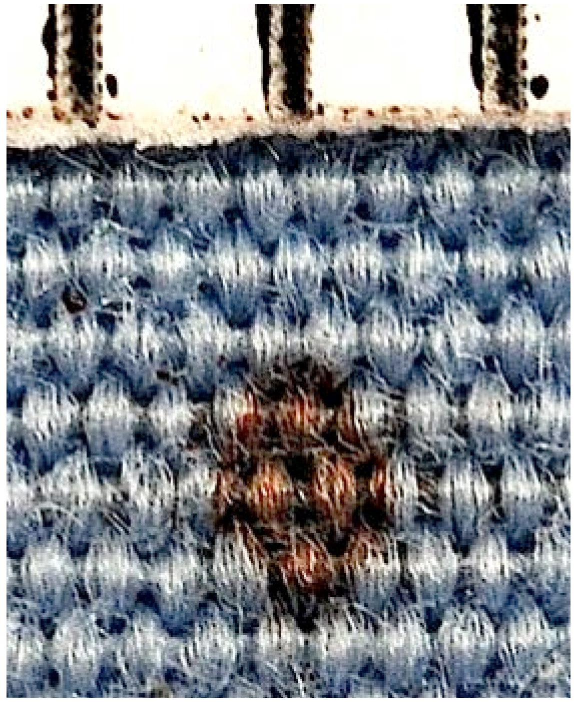

Figure 52: 100% Polyester (Shirt)

Figure 53: 100% Polyester (Shirt); Wicking;

Figure 54: 100% Polyester (Shirt); Pooling

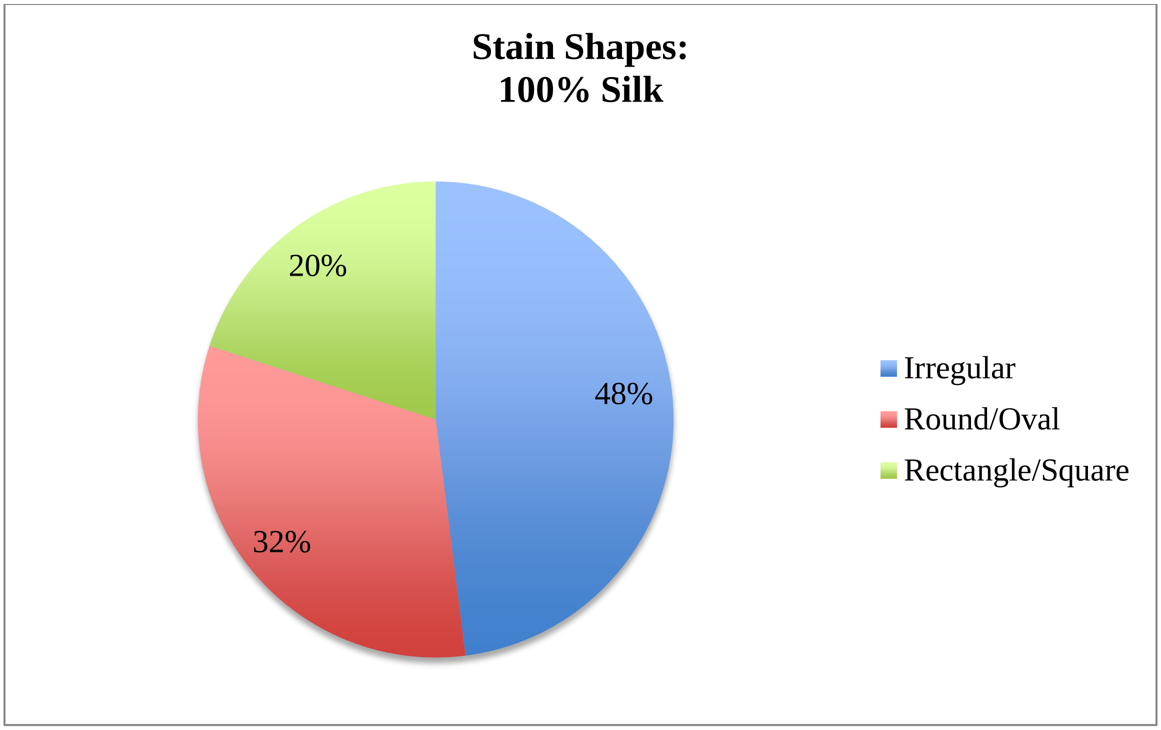

Figure 55: Stain shape percentages for 100% Silk

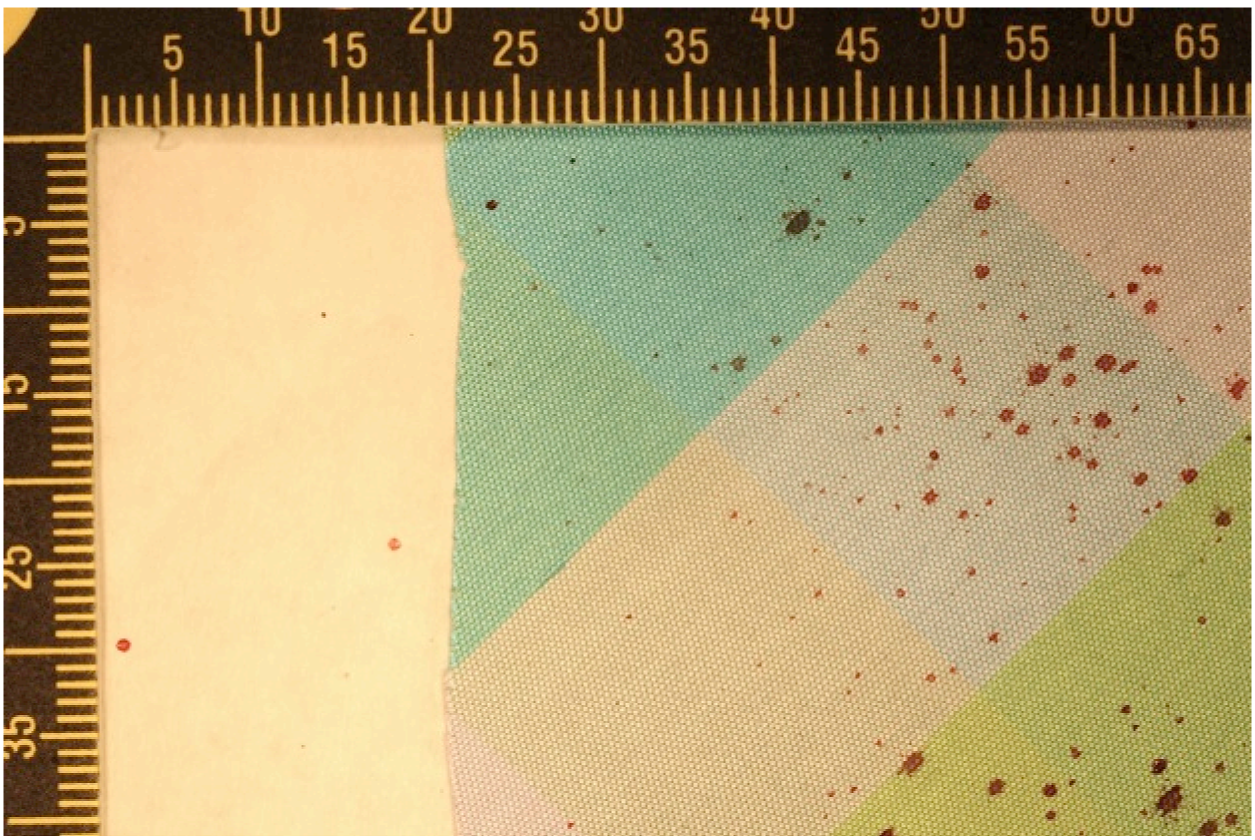

Figure 56: Control (left) and 100% Silk (right)

Figure 57: 100% Silk; Satellite

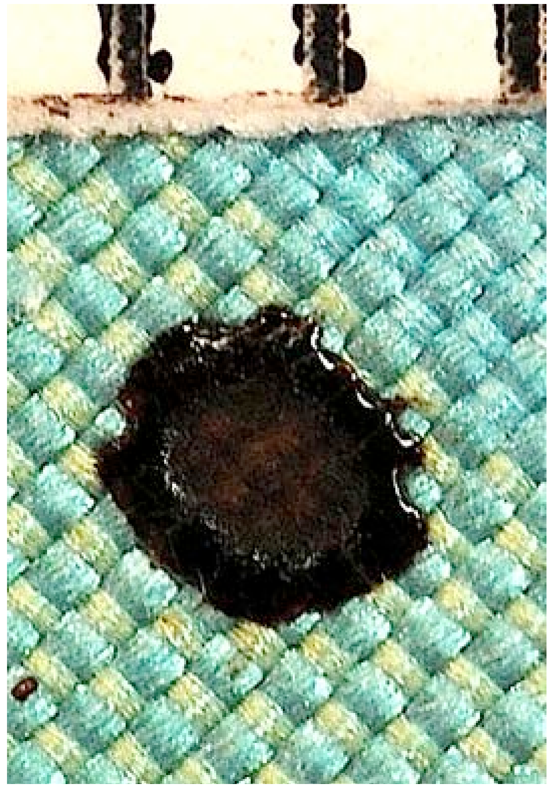

Figure 58: 100% Silk; Pooling

Figure 59: 100% Silk; Satellite

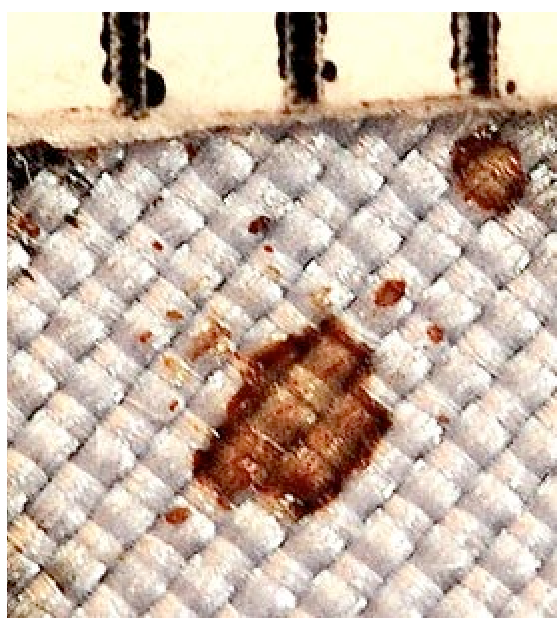

Figure 60: 100% Silk; Satellite

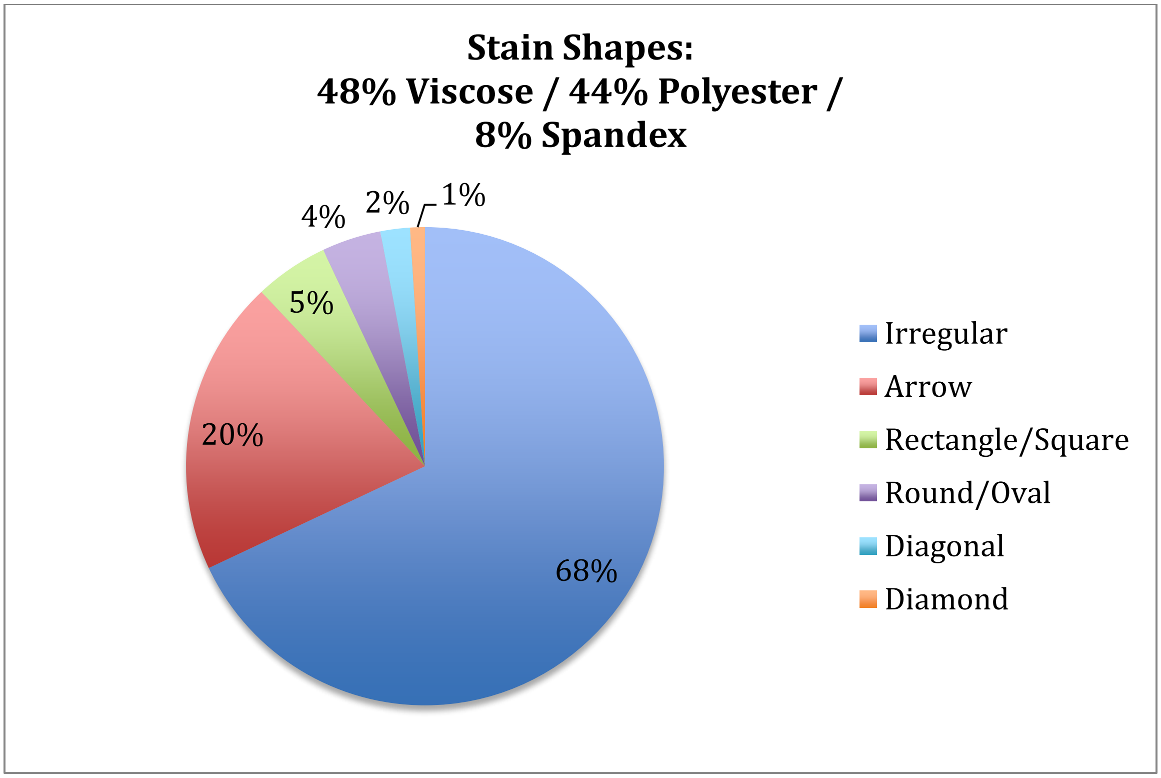

Figure 61: Stain shape percentages for 48% Viscose / 44% Polyester / 8% Spandex

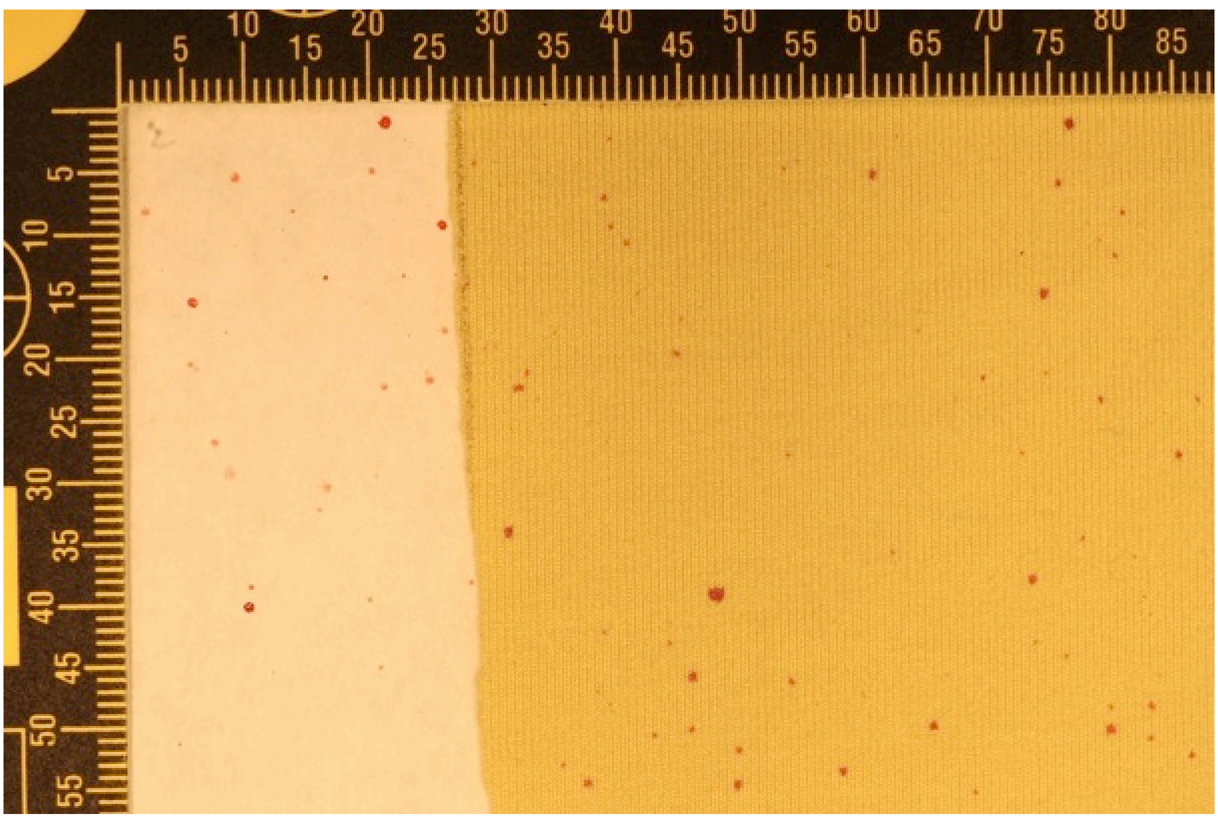

Figure 62: Control (left) and 48% Viscose / 44% Polyester / 8% Spandex

Figure 63: 48% Viscose / 44% Polyester / 8% Spandex

Figure 64: 48% Viscose / 44% Polyester / 8% Spandex

Figure 65: 48% Viscose / 44% Polyester / 8% Spandex

Figure 66: 48% Viscose / 44% Polyester / 8% Spandex

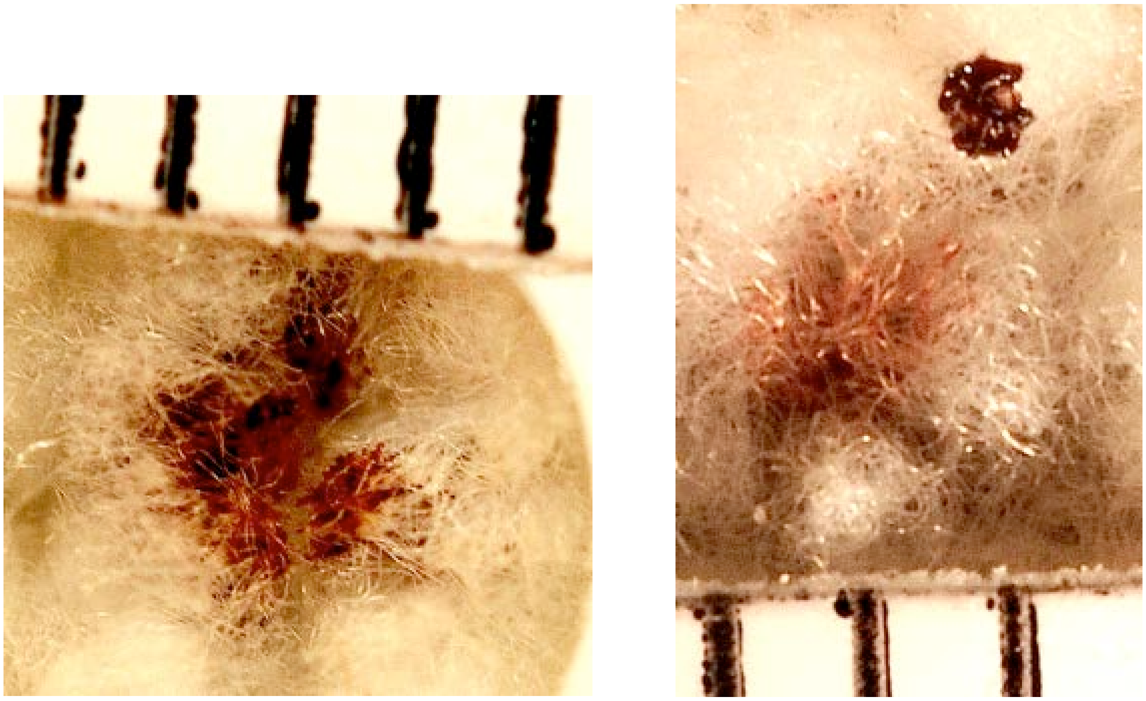

Figure 67: Similar stains affected by layered weave and fibers (100% acrylic, left; 100% polyester fleece, right)

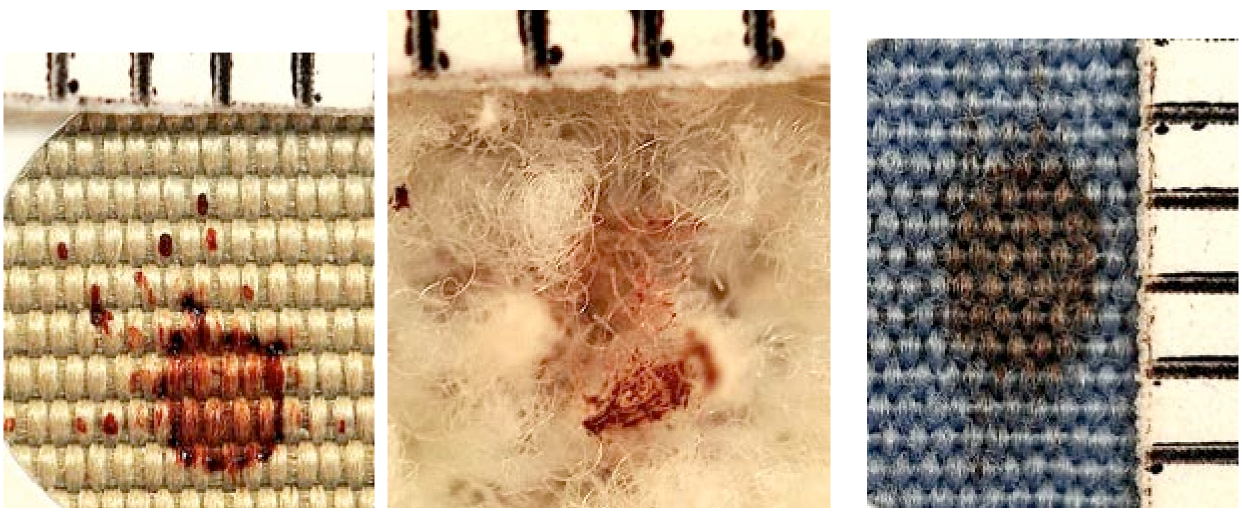

Figure 68: Differences in stain shapes and characteristics between three fabrics of the same composition (100% polyester coat, left; 100% polyester fleece, middle; 100% polyester shirt, right)

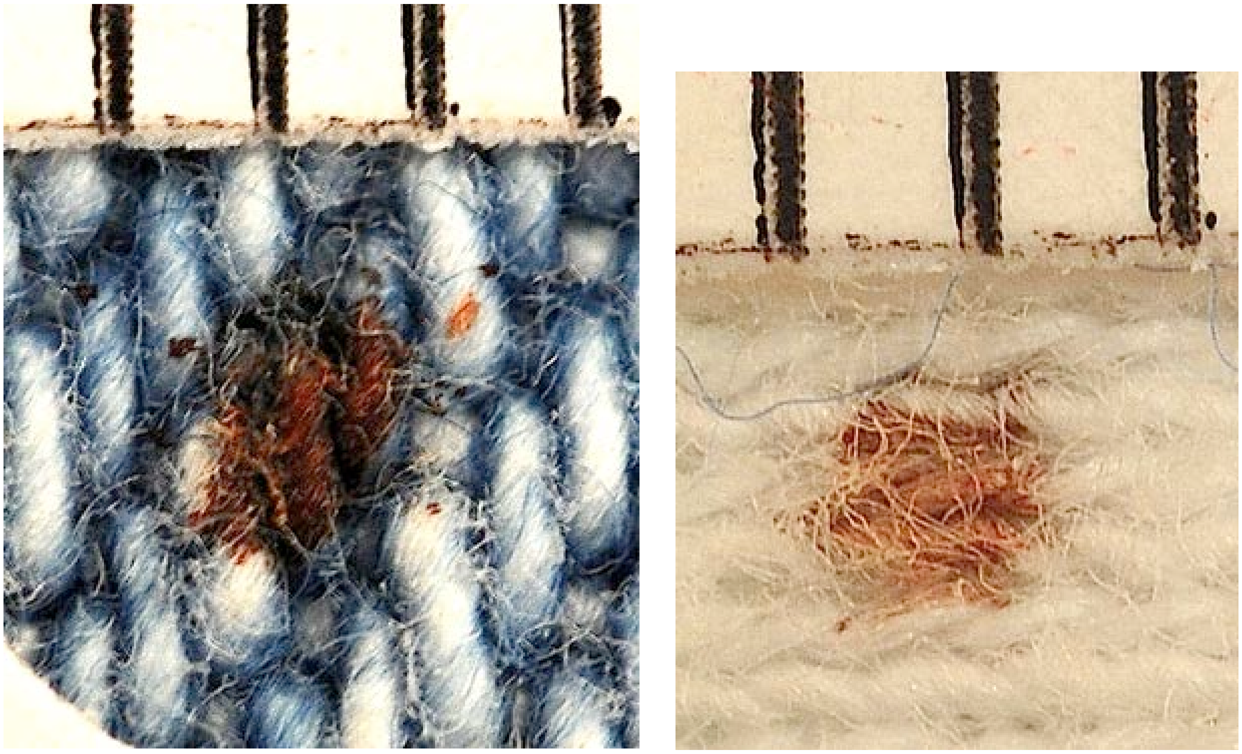

Figure 69: Differences in stain shapes and characteristics between two fabrics of the same composition (100% cotton denim jeans, left; 100% cotton t-shirt, right)