Physical Changes in Polyester Mesh
During Tensioning

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The physical parameters of woven screen printing fabric have been the subject of many technical articles over the years, and a topic of discussion of manufacturers and screen printers alike. Mesh count, thread diameter, fabric thickness and mesh opening size are used by printers as a basis for decisions on the selection and purchases of screen printing mesh. These physical dimensions have become the very same information manufacturers use to characterize their product, and because of this, these numerical specifications have become common, understood terminology throughout the industry.

But these mesh parameters are much more than just descriptive adjectives, as they signify the physical attributes of the screen, a tool that is essential to the process of screen printing.

The screen is, in fact, such a vital part of the process that its dimensions affect virtually every area of screen making and printing operations. The calculation of an ink deposit estimate and fine line halftone dot to mesh ratio totally relies on this information. Mesh opening size determines the pigment particle size that can be printed, and the smallest dot or line that can be supported.

The thread size and mesh count relationship is responsible for the strength characteristics of a particular fabric which influences tension levels and stability. In addition, the resulting stencil thickness of both direct emulsion and capillary film is dependent on the mesh opening size and fabric thickness.

The Screen Printing Technical Foundation, recognizing the significance of mesh attributes, has completed a study to determine the physical change mesh undergoes when tensioning free mesh to working tension levels. Four major dimensions were monitored in this investigation, including mesh opening area, thread diameter, mesh count and fabric thickness. Measurements taken before, during, and after tensioning on many meshes have provided information on the reaction and interaction these four parameters demonstrate during stretching. With this type of insight into polyester fabric, the screen printer will be better equipped to make decisions concerning mesh selection for any particular printing application.

Definition of Physical Dimensions of Screen Printing Fabric

Let us first review and define the typical measurements provided and used in the screen printing industry. The first and most familiar dimension is the mesh count (Mc) of the fabric. Mesh count is simply the number of threads present in a unit length, which is generally either an inch or a centimeter. The actual measurement and standard that is used by the fabric mills is in centimeters, making this the more accurate of the two.

The mesh count represented in inches has two areas where error occurs. Inaccuracy enters in first when Mc/cm is converted mathematically to Mc/inches, and second when manufacturers use their own designations based on approximations to represent a specific fabric. For instance, a 150/cm mesh when converted becomes equal to a 381/inch mesh, but many manufacturers label it a 390/inch mesh.

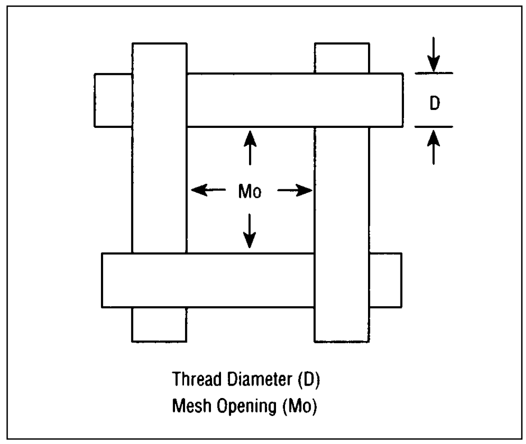

Figure 1. Theoretical representation of the thread diameter and mesh opening screen dimensions.

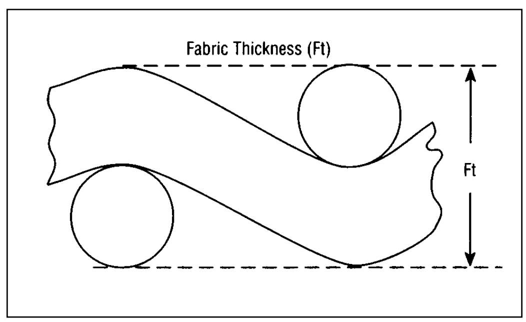

Figure 2. Theoretical representation of the fabric thickness screen dimension.

Thread diameter (D) usually accompanies the mesh count specification, and can be defined as the diameter of the fibers that make up the mesh (Figure 1). The mesh opening (Mo) of the fabric, also illustrated in Figure 1, is the linear distance between two threads and indicates the size of the openings in the fabric. The measurement of the total thickness of a mesh after it is woven

For clarification purposes a glossary has been included at the end of this report.

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Formulas For Calculating Percent Open Area*

$$\% \text{ Open Area} = (1 - McD)^2 \times 100$$

or

$$\% \text{ Open Area} = (McMo)^2 \times 100$$

or

$$\% \text{ Open Area} = \left[\frac{Mo^2}{(D+Mo)^2} \right] \times 100$$

***Note:** Variables must be in the same units (English or metric) for correct result.

Figure 3. Three formulas that produce a value for percent open area.

is commonly referred to as fabric thickness (Ft) and is depicted in Figure 2.

In addition to the mesh opening size, a calculation called percent open area is typically included in the specifications of a fabric. Percentage of open area is derived from dividing the total amount of open mesh area in a unit area by that unit area. Several formulas can be used to calculate this number, depending on what information is available to you (see Figure 3). Each of the three formulas will give a slightly different percentage for a specific fabric, but the percentages stay within 1-2% of each other. The percentages also vary a small amount when the same calculations are performed with metric units and also English units; again, due to the previously mentioned error that occurs when converting metric to English. Simply put, the results are only as accurate as the numbers used in their computation.

A brief look at the manufacturer's supplied information on mesh opening size and percent open area indicated some surprising inconsistencies. When five different manufacturers' information was compared for a specific mesh count and thread diameter, five sets of different numbers emerged (Table 1). It would seem logical to expect that a specific thread size woven at a specific mesh count would always produce the same opening size and percent open area, yet the manufacturers' information does not reflect this.

There can be two possible explanations for this incongruity, one being that some manufacturers measure those parameters while others calculate them from the mesh count and thread diameter information. The second possibility is that the formulas used in these calculations differ from the ones presented in this report. The vital question remains, which number reflects reality?

SPTF's investigation of these various aspects of mesh sought to answer this question for all the parameters mentioned. The study went a step further and also addressed the more important question—what happens to the physical dimensions of the mesh during tensioning.

Five Manufacturers' Specifications *Table 1*
for a 305 Mesh Count with a 35 Micron Thread

Manufacturer, Country	Mesh Opening Size	%Open Area
Trippett & Renaud, France	48 Microns	31%
NBC Industries, Japan	48 Microns	34%
Swiss Silk Bolting Cloth, Switzerland	50 Microns	37%
Saati, Italy	48 Microns	33%
Nippon Tokushu Fabric, Japan	52 Microns	36%

The set of numbers provided by the manufacturers we assume represent the free state of a mesh, but it stands to reason that stretching the fabric will cause these numbers to change. SPTF research has proven just that, and has supplied answers to the questions put forth in this report.

Testing Methodology

The chosen focus of this particular study deals exclusively with monofilament polyester screen printing fabric due to its dominance and widespread use in industry. The four types of measurements; mesh opening area, thread diameter, mesh count and fabric thickness, that were performed in the various tests this report will cover, were accomplished with precision measurement equipment including a video analysis system, a magnetic induction instrument, and a mesh counting microscope. These devices, and their use in our experiments, will be covered in more depth as each parameter is discussed in the progression of this report.

Several different studies were conducted to compile the data presented here. A preliminary investigation on nine meshes was performed where measurements of the four dimensions were taken on free mesh and then again after final working tension was achieved on that mesh. The results of this work demonstrates clear differences between these two stages and justified further research in this area.

At this point, the mesh measurement efforts were directed toward identifying the relationships and trends these parameters exhibited as a function of tension. This was accomplished by tensioning fabric on a roller frame to progressively increasing tension levels with measurement of the four dimensions being performed at each level. Readings made at increments of 5 N/cm allowed curves to be graphed that illustrated the mesh's reaction to greater and greater tension.

The resulting correlations and relationships made evident by this information have given a truly insightful glimpse into the inner mechanics of polyester mesh. Several different fabrics were tested using this procedure and will be presented to support some general

Figure 4. With SPTF's Mesh Stress/Strain Tester uniform tension is applied to fabric while mesh parameters are monitored for change on an image analysis system.

conclusions on dimensional changes caused by tensioning of screen printing fabric.

A final area to explore was the repeatability of these changes on one specific mesh count. This type of testing required that additional control be added to the tensioning phase of our experimental condition, which was achieved by utilizing SPTF's Mesh Stress/Strain Tester (Figure 4). With this device, very uniform and repeatable tension can be applied to screen printing fabric. Through the use of in-line force gauges, tension levels can be measured very accurately, and can be duplicated on successive pieces of fabric. By reproducing a tensioning sequence on five different pieces of mesh of the same thread count and manufacturer, and measuring each of the mesh variables at each tension level designated (increments of 100 Newtons per linear foot total force applied or 3.48 Newtons per centimeter were used), repeatability characteristics were determined.

Only one type fabric and mesh count was tested in this fashion which will provide a basis for some generalized determinations on the repeatability of mesh parameter change on polyester screen printing fabric.

Identical experiments on other meshes are being conducted on a continuing basis with the Mesh Stress/Strain Tester to create a more comprehensive data base. The time intensiveness of this endeavor does not enable us to support the conclusions proposed here with volumes of data, but rather with an assumption based on available evidence that for the most part, polyester mesh reacts similarly from manufacturer to manufacturer and mesh count to mesh count. The accuracy and the amount of information put forth in discussions to follow is believed to be sufficient for this purpose.

As a more exhaustive data base is established, SPTF hopes to write other insightful updates on the topic, and eventually publish a chart of actual specifications at various tensions for all major meshes on the market.

The intention of the information introduced in this report is to increase an awareness and understanding of polyester mesh parameters, and incite printers to measure and monitor the fabric's physical characteristics before, during and after tensioning.

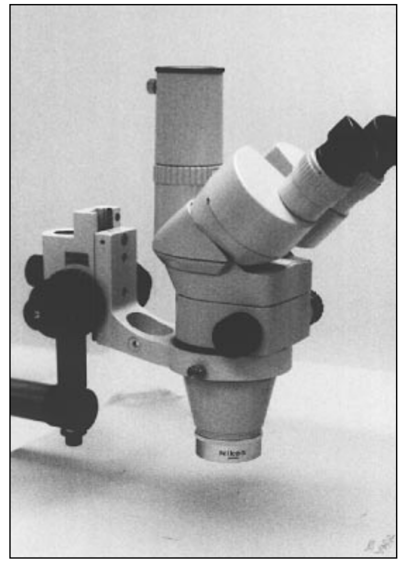

Figure 5. A stereo zoom microscope equipped with an eyepiece reticule for measuring thread diameter and mesh opening size.

Data from the three studies just described will be divided into five specific categories. The four measured mesh variables will be covered individually and discussed in terms of the method of measurement, free mesh versus tensioned mesh, trends occurring during the tensioning process and the repeatability of these trends in polyester mesh. The fifth topic will consist of a comparison between actual measured mesh dimensions and manufacturer's supplied information.

Mesh Opening Area

The measurement of mesh openings posed a unique challenge of finding a precise measuring device capable of accuracy on the micron level and sensitive enough to reflect small changes as well. In the course of SPTF's three-year investigation of mesh openings, several types of instruments were evaluated on the above criteria before settling on a system that provided the degree of confidence the work demanded.

The first method of measurement examined involved a stereo Zoom microscope capable of 189X magnification (Figure 5). Mesh opening dimensions were obtained by the operator through the use of an eyepiece reticule. The number of gradations, each having a calibrated value of 1.2 microns at full magnification, that spanned the width of the opening were counted, and the linear size of the opening was then calculated.

Some disadvantages found with microscope measurement include a dependence on operator accuracy and repeatability, high time consumption, operator eye strain, and questionable sensitivity to change, which again hinges on the operator.

A digital linear gauge was the next piece of equipment tested (Figure 6). The device consists of a 15-60X adjustable microscope with a hairline crosshair reticule attached to a precision linear gauge controlled by a micrometer dial, and read-out on a digital display in microns. The resolution of the linear scale is 1 micron,

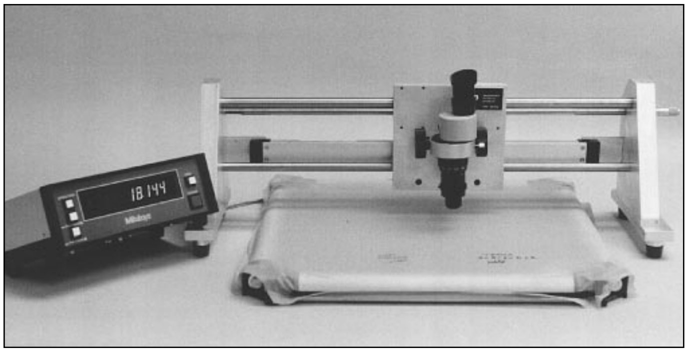

Figure 6. Digital Linear Gauge being used to measure thread diameter and mesh opening size.

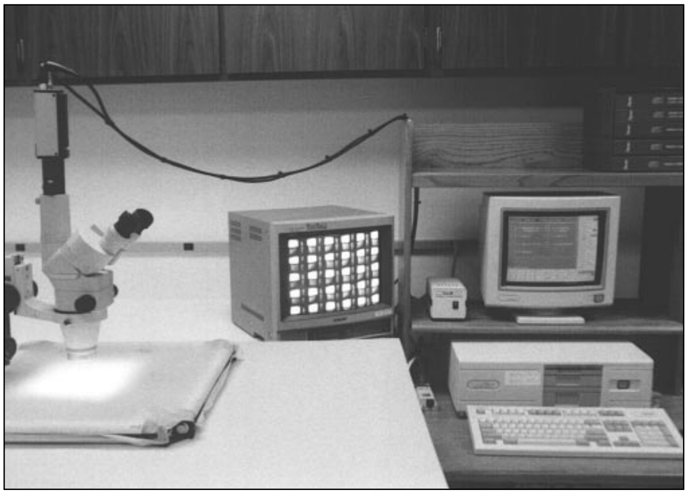

Figure 7. An image analysis system capable of measuring mesh opening area and thread diameter automatically and to an accuracy of a half of a micron.

and the realized accuracy is plus or minus 2.5 microns. A measurement is made by placing the crosshair on one side of the opening with the micrometer dial, zeroing the digital readout, moving the crosshair to the opposite side, and reading the display.

As with the microscope, several disadvantages were discovered with the linear gauge system also. Operator dependency of the accurate and repeatable placement of the crosshair to establish the boundaries of the opening was a variable, not to mention high time consumption, operator eye strain, and insufficient magnification for high mesh counts.

Both of the instruments just described have a couple of limitations in common. First, both are subject to the skill of an operator, and second both are only capable of linear measurements. As we will soon see two linear dimensions do not account for the irregular shape of mesh openings. In general, neither configuration proved to have sufficient accuracy or ability in reflecting change to the degree necessary to establish the level of confidence SPTF demanded.

The final measurement method selected was a computerized image analysis system shown in Figure 7, and does not exhibit any of these undesirable characteristics.

Simply explained, image analysis begins with a video image of the mesh obtained through a microscope which is then computer enhanced to achieve the required clarity. At this point the desired "objects" or areas to be measured are identified and selected for analysis. Up to 37 different parameters including mesh opening area, can be obtained by the computer on each object in a matter of milliseconds. A number of graphing functions and trend identifying representations can then be utilized in the software to aid in the examination of the data. SPTF's particular system has many more capabilities than what has been mentioned here, including a precision manual measurement option accurate to one half of a micron. Thread diameter research, covered later in this report, was carried out utilizing this feature.

The measurement method of video or image analysis affords many advantages over the microscope and linear gauge. One obvious improvement is the removal of the operator variable, which was replaced with the consistency of a computer. Enhancement and analysis procedures can be automated to increase speed and repeatability of measurement. Readings are taken in a fraction of the time required by the other two instruments. The amount of data that once took a day to generate, literally can be completed in 10 minutes with greater accuracy. Many data points may now be obtained in a short period of time increasing statistical confidence and the relevance of the results. SPTF currently employs a video camera and microscope arrangement to magnify up to 470x with system calibration ensuring an accuracy of one half of a micron.

Couple these beneficial characteristics with the complete tensioning control offered by SPTF's Mesh Stress/Strain Tester, and an entirely new approach to mesh measurement has been created (Figure 4). SPTF is currently employing this mesh testing system to analyze and define other characteristics, including breaking strength, yield point, elongation and tensioning procedures. Discussion of these findings is beyond the scope of this report, and will be covered in other SPTF research papers.

SPTF's research on mesh opening was performed exclusively with the computerized image analysis technique and, therefore, measurements were taken as an area in units of square microns. Magnification and enhancement of mesh opening areas produces quite a different picture of the mesh than what is illustrated in Figure 1. Instead of an easily definable geometric situation, we find very complex opening shapes which vary with manufacturer, mesh count and type of weave. At least three different distinctive shapes have been encountered so far and are shown in Figures 8, 9 and 10.

With these irregularities being present, it becomes obvious that one and two dimensional linear

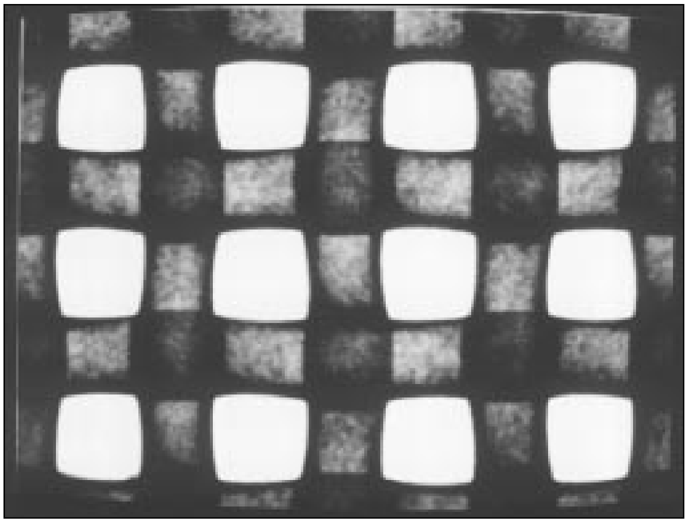

Figure 8. A 200/55 mesh with mesh openings exhibiting a square like shape.

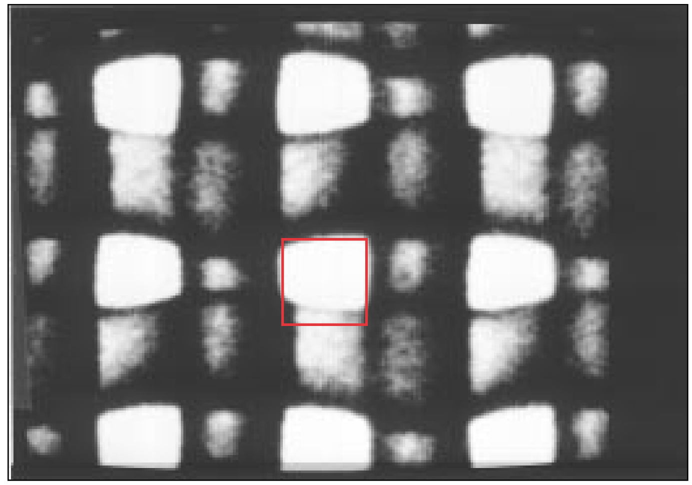

Figure 11. Image of a Saati 305/40 mesh at 0 N/cm with a superimposed image of the manufacturer's specified mesh opening size over an actual mesh opening.

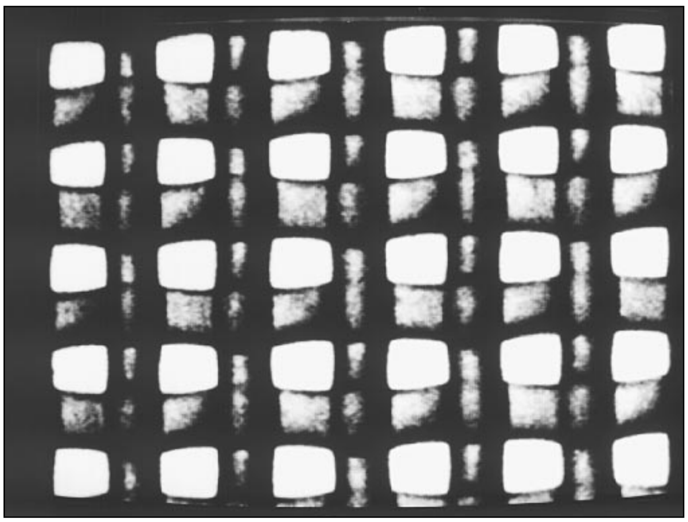

Figure 9. A 305/40 mesh with rectangular shaped mesh openings.

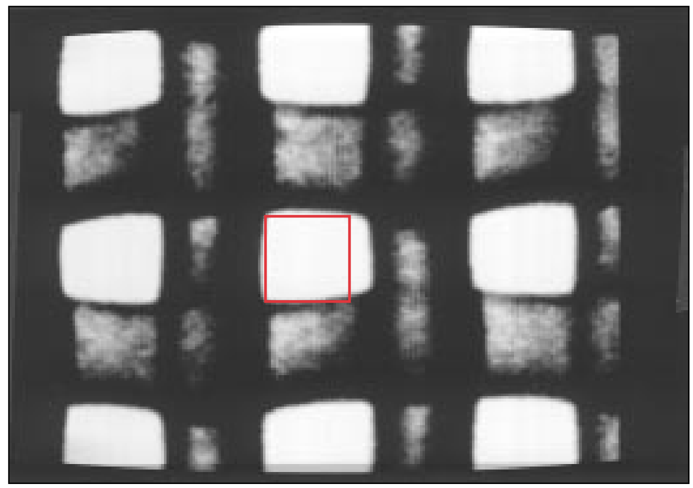

Figure 12. Image of a Saati 305/40 mesh at 35 N/cm with a superimposed image of the manufacturer's specified mesh opening size over an actual mesh opening.

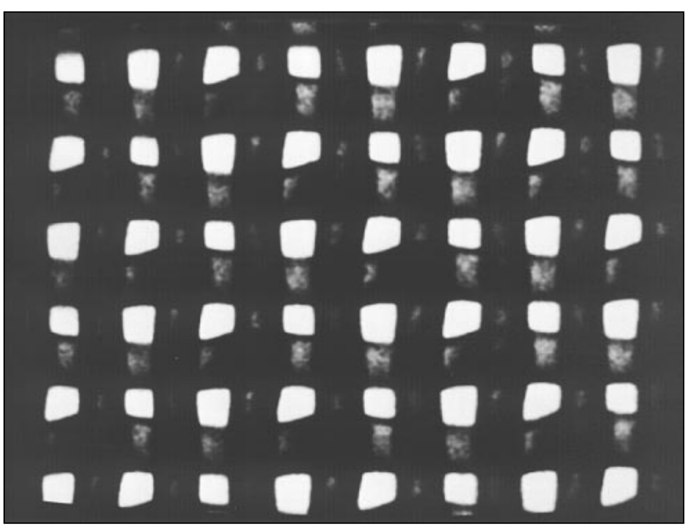

Figure 10. A 390/34 twilled weave mesh displaying extremely irregular and erratic sized mesh openings.

measurements do not represent reality and cannot accurately be used to compare opening sizes. By measuring the total area of these openings, however, the unsymmetrical area previously unaccounted for is included in the measurement and sensitivity to change in shape and size is enhanced.

Manufacturers typically supply a single number for mesh opening size, making an assumption that they are square when, indeed, they are not in many cases. In Figure 11 a 305/40 mesh in its free state is pictured, and a square of the size the manufacturer specifies is superimposed over an actual opening. The difference in shape and size is apparent, and in this case the actual opening is smaller than dimensions given by the manufacturer. When the same mesh is tensioned to 35 N/cm, and the same square put over the opening, as seen in Figure 12, the opening is much larger than the manufacturers information implies. In addition, the actual opening is rectangular in shape rather than square as suggested by a single number specification.

Area measured with an image analysis system is not calculated with one length and one width, but rather is obtained with a precise process performed by the

Mesh Opening Area Change *Table 2*
When Tensioning to Recommendeed Levels

Mesh Count	*Mesh Opening Area Free Mesh**	*Mesh Opening Area Tensioned**	*Tension*	*% Change +*
60/145 Tetko-Pecap	74,480	76,639	18.8 N/cm	2.90
109/80 Intern'l Fabric Corp-PES	13,820	14, 519	16.0 N/cm	5.10
158/65 Saati-Saatilene	7700	8199	13.0 N/cm	6.50
160/55 Jelliff-Super Strong	10,887	15,052	36.0 N/cm	38.30
206/50 Tetko-Pecap	4324	5081	22.5 N/cm	17.50
254/40 Trippette & Renaud-Monocron	2906	3262	12.0 N/cm	12.30
280/38 Tetko-Pecap	2178	2518	15.0 N/cm	15.60
305/40 Intern'l Fabric Corp-PES	1348	1570	16.5 N/cm	16.50
305/40 LE Tetko-Pecap LE	995	1328	25.6 N/cm	33.50
305/40 LE Saati-Hitech	1009	1436	24.3 N/cm	42.30
305/35 LE NBC Industries-SR	1580	1958	22.4 N/cm	23.90
355/35 Saati-Saatilene	648	765	12.0 N/cm	18.10
390/35-TW Saati-Saatilene	738	798	13.0 N/cm	8.13
420/33-TW Tetko-Pecap	466	614	13.0 N/cm	31.80
460/30-TW Trippette & Renaud-Monocron	351	422	12.0 N/cm	20.20
508/30-TW Saati-Saatilene	164	273	12.0 N/cm	66.50

TW - Twill Weave
LE - Low Elongation

** Mesh opening area in square microns*
Average calculated from 120 mesh opening measurements

+ Represents change from the average free mesh opening area to the averaged tensioned mesh opening area

computer which figures in all the space the opening encompasses. The dynamic nature of this method of measurements provides the sensitivity to change needed to closely monitor mesh opening reaction to stretching. Several other measurements, including shape factor, ferret's diameter, anoistrophy and orientation available on SPTF's image analysis system are currently being used to further define mesh opening shapes and their relationship to each other in progressive research on the physical parameters of screen printing fabric.

Several observations were made in the course of the research on mesh opening area that are significant. The first general conclusion was that mesh opening size increases when tension is applied to a fabric. A range of mesh counts from 60/145 to 508/30 thread per inch were tested to determine the change in mesh opening area when they were tensioned to recommended levels.

Mesh Opening Area Change *Table 3*
When Tensioning to Breaking Point

Mesh Count	*Mesh Opening Area Free Mesh**	*Mesh Opening Area Tensioned**	*Tension*	*% Change +*
255/40 LE NBC Industries - SR	2947	3623	47.7 N/cm	22.9
260/40 Tetko-Pecap	3011	3903	55.8 N/cm	29.6
305/34 Jelliff-Super Strong	1881	2351	39.4 N/cm	25.0
305/34 LE Tetko-Pecap LE	1759	2267	46.0 N/cm	28.9
305/34 Tetko-Pecap	2074	2793	36.3 N/cm	34.7
305/35 LE NBC Industries-SR	1768	2297	39.4 N/cm	29.9
305/35 LE Ulano Mesh	1721	2082	36.2 N/cm	21.0
305/40 LE Saati-Hitech	1269	1958	62.6 N/cm	54.3
305/40 LE Tetko-Pecap LE	1396	1929	49.4 N/cm	38.2
390/31 LE Tetko-Pecap LE	856	1224	46.3 N/cm	43.0
390/34 LE-TW Saati-Hitech	636	1017	59.1 N/cm	59.9
390/34 LE-TW Tetko-Pecaple	619	951	62.6 N/cm	53.6
390/35 LE-TW Ulano Mesh	732	1079	49.3 N/cm	47.4
390/35-TW Saati-Saatilene	835	1196	46.0 N/cm	43.2

TW - Twill Weave
LE - Low Elongation

** Mesh opening area in square microns*
Average calculated from 120 mesh opening measurements

+ Represents change from the average free mesh opening area to the averaged tensioned mesh opening area

Measurements performed with image analysis were first taken in the free state, then the mesh was stretched and stabilized with a common tensioning procedure and they were measured again. The results are shown in Table 2.

The last column indicates the percent change in opening size that occurred from the mesh's free state to the tension level listed. A few trends can be identified from the percent change data listed in Table 2. In the lower mesh count (60-158) we see that the openings do not enlarge as much as compared to the higher mesh counts taken to the same or lower tension levels. The three low elongation fabrics tested were taken to much higher tensions and exhibited a much higher percentage of change in mesh opening size. Very high mesh counts having a twill weave demonstrated excessive change when brought to a tension of only 12-13 Newtons per centimeter. An extreme case of this is the 508 fabric which changed 66.5% when tensioned to only 12 Newtons per centimeter.

Change in Mesh Opening Area
254/40 Mesh

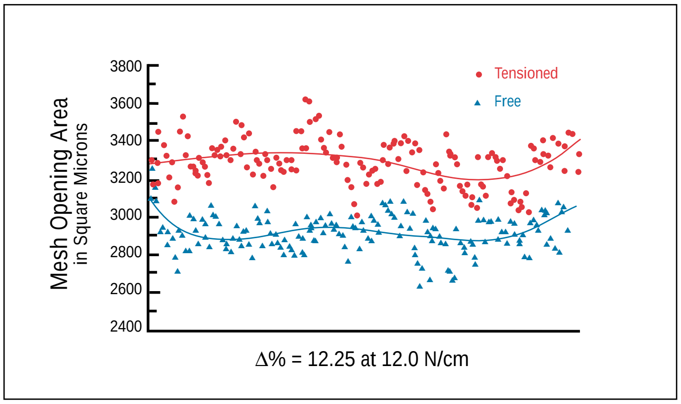

Figure 13. Plot of individual mesh opening measurements on both free and tensioned mesh for a 254/40 fabric. Both sets of data are curve fitted and show a change in mesh opening area of 12.25 percent at 12 N/cm.

Frequency Histogram of Mesh Opening Area
254/40 Mesh Tensioned to N/cm

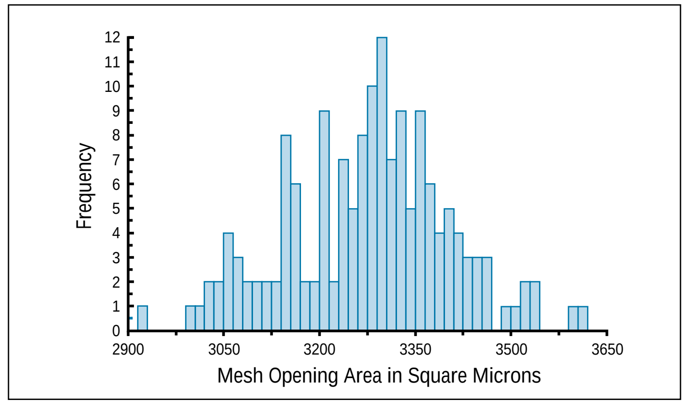

Figure 14. Frequency histogram of mesh openings for a 254/40 mesh tensioned to 12 N/cm. The distribution of the data closely resembles a bell-shaped curve indicating normal variation.

Change in Mesh Opening Area
460/30 Twill Weave Mesh

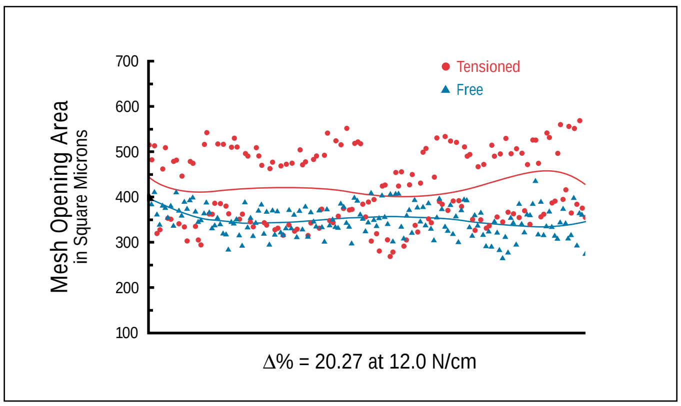

Figure 15. Plot of individual mesh opening measurements on both free and tensioned mesh for a 460/30 twill weave fabric. Both sets of data are curve fitted and show a change in mesh opening area of 20.27 percent at 12 N/cm.

Frequency Histogram Of Mesh Opening Area
460/30 Mesh Tensioned to 12 N/cm

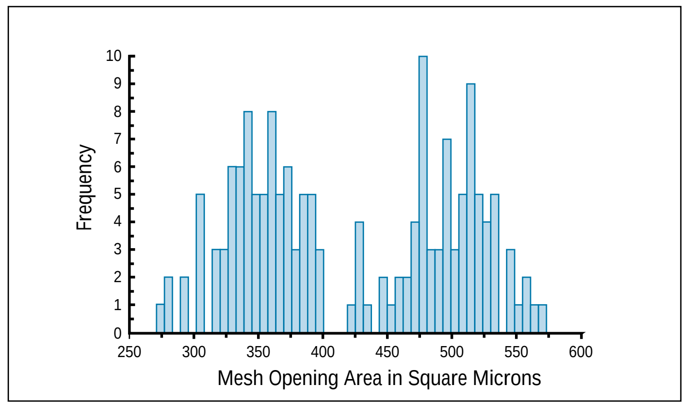

Figure 16. Frequency histogram of mesh openings for a 460/30 twill weave mesh tensioned to 12 N/cm. The distribution of the data exhibits two separate groups of sizes, each having their own bell shape curve.

The listing of data in Table 3 is similar to Table 1, except that these meshes were brought up to the breaking point in a progressive tensioning procedure on the Mesh Stress/Strain Tester. Measurements were taken on free mesh and at the tension achieved just before the breaking point of the fabric in order to get an idea of how great a change the mesh experienced when greatly exceeding the recommended tension. The meshes tested range from a 260 to a 390, and tensions reached were from a low of 36.2 N/cm to a high of 62.6 N/cm. Mesh opening size change varied from 21.0% to 59.9%. In looking for a relationship among the mesh counts between tension level and percent change, no such correlation was apparent. In other words, two different mesh counts, both reaching the same particular tension level do not necessarily reflect the same percent change in their mesh opening sizes.

Another interesting observation in this study was made when we compared plain weave mesh openings to twill weave mesh openings. Both free and tensioned mesh opening area data for a 254/40 plain weave mesh is shown in Figure 13 along with a frequency histogram of the tensioned mesh opening area data in Figure 14. The histogram demonstrated the characteristics of a bell shape curve indicating a normal variation in the data.

In Figures 15 and 16 representing a 460/30 twill weave mesh, the histogram and graph are very different in that two distinct mesh opening size groups are present in the tensioned measurements. These two groups each have their own normal frequency distribution, evident in Figure 16. Data on other twill meshes has proven this trait to be a characterizing “fingerprint” of meshes woven in a twill format.

Change in Mesh Opening Area
305/40 Low Elongation Mesh—Manufacturer A

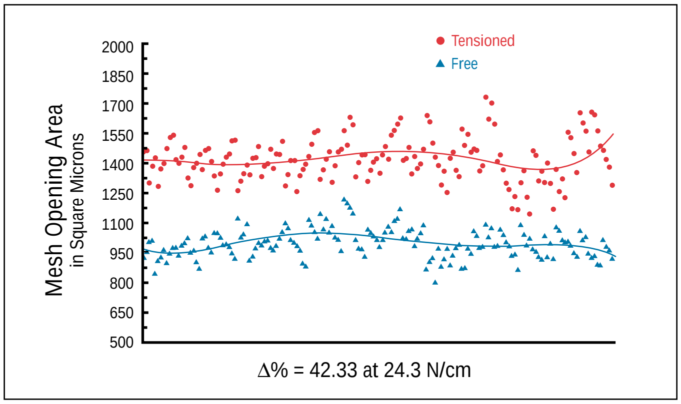

Figure 17. Plot of individual mesh opening measurements on both free and tensioned mesh for a 305/40 LE fabric. The opening size variation around the curve fitted line increases when the mesh is tensioned.

Mesh Opening Area

	Free Mesh*	Tensioned*
Average	1009.0	1436.0
Standard Deviation	73.4	111.3

**Values in square microns*

The data on mesh opening area has also provided an indication of the uniformity in opening sizes of screen printing fabrics. In comparing Figures 17 and 18 a distinct difference in the uniformity of mesh opening area can be visually identified, and is supported by the statistical data as well. The 305/40 LE mesh represented in Figure 17 shows a greater spread or variation in mesh opening area when tensioned than the 305/35 LE depicted in Figure 18. The standard deviations below each graph also supports this difference with the 305/40 LE mesh having a value of 111.3 square microns compared to the 305/35 LE at 64.9 square microns.

Change in Mesh Opening Area
305/35 Low Elongation Mesh—Manufacturer B

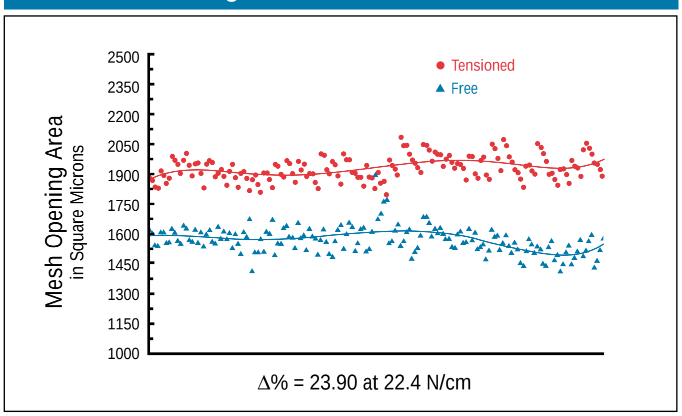

Figure 18. Plot of individual mesh opening measurements on both free and tensioned mesh for a 305/35 LE fabric. The opening size variation around the curve fitted line decreases slightly when the mesh is tensioned.

Mesh Opening Area

	Free Mesh*	Tensioned*
Average	1580.0	1958.0
Standard Deviation	70.2	64.9

**Values in square microns*

It is interesting to note that the standard deviations of both meshes in the free state are very close in value. Only after tensioning did the difference in uniformity become evident. Mesh opening uniformity and consistency is **one** attribute that may be useful in classifying the quality of a specific mesh. The effect this characteristic has on print quality and uniformity has not yet been determined, so at this point this type of specification is more of an indicator of the process control instituted at the time of weaving.

In investigating the change in mesh opening as it relates to tension, a simple conclusion is quickly reached. The greater the initial tension, the greater the opening size becomes (Figure 19). All of the meshes tested by SPTF to-date exhibited this trend.

SAATI 305/40 LE
Mesh Opening Area vs Tension

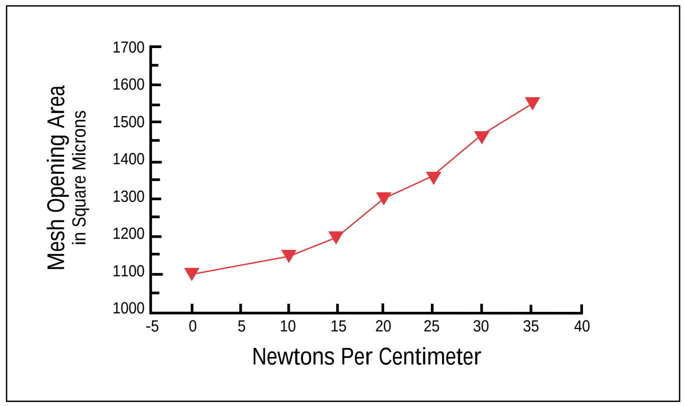

Figure 19. Average mesh opening size progressively increases as tension is increased on a Saati 305/40 LE mesh. Each point represents an average of 90 mesh openings.

Continued research and reasoning in this area have led to the theory that tension may be less of an indicator of change than the physical linear distance the fabric is stretched or a percent elongation measurement.

Tension, a measure of **deflection**, is typically measured in Newtons per centimeter and is very dynamic, changing due to the cold flow reaction of the polyester mesh as it relaxes. These variations occur until a fabric becomes "stable" at a specific tension level. Distance travelled or percent elongation of the fabric on the other hand is increased in order to achieve a specific initial tension on a fabric. But while tension drops during the relaxation period, the distance the fabric stretched to reach the initial tension level remains relatively unchanged with a mechanical and retensionable frame stretching system. (A pneumatic stretching system applies continuous force to the fabric which maintains the tension throughout the relaxation period by increasing the distance the fabric stretches.)

With these facts in mind it seems a logical conclusion that as mesh opening size increases in terms of distance, the distance the mesh is stretched (translated into percent elongation) is related in some predictable and repeatable manner. It follows that as tension fluctuates from fabric relaxation at a specific fixed point in the distance stretched, and that fluctuation varies with such factors as time, fabric, equipment and stretching procedure; it is not very useful as an indication of the physical changes in mesh that occur during stretching.

If elongation is indeed an accurate indicator of the changes in mesh opening area of a fabric, precise predictions of mesh opening size, and possibly other parameters, could be easily made based on the percent elongation the fabric held at any point in time. The **percent elongation** would become a link to the **physical state** of the fabric while **tension** in Newtons per centimeter would relate to **press parameters**. Such a relationship would allow the printer to quickly determine various mesh parameters based on the elongation of the fabric so reliable ink height estimates can be calculated, and an assessment of the suitability of the mesh can be made for a particular application.

SPTF research in this area is not extensive enough at this time to present any conclusive evidence to support or disprove the theory put forth here. However, information on this topic will appear in future SPTF reports as it becomes available.

Some disturbing questions were raised when a comparison of mesh opening area was made on fabrics of identical mesh count and thread diameter. The first two meshes matched are from different manufacturers, with one being a Low Elongation type of mesh and the other a regular fabric. A graphic representation of these presumed equivalents (Figure 20) demonstrates a distinct discrepancy in mesh opening area between the two. When we calculate the square root of the areas, we find a difference of about four microns initially, and growing to six microns at the highest comparable tension. This is a

Mesh Opening Area vs. Tension
Mesh Stress Strain Tester

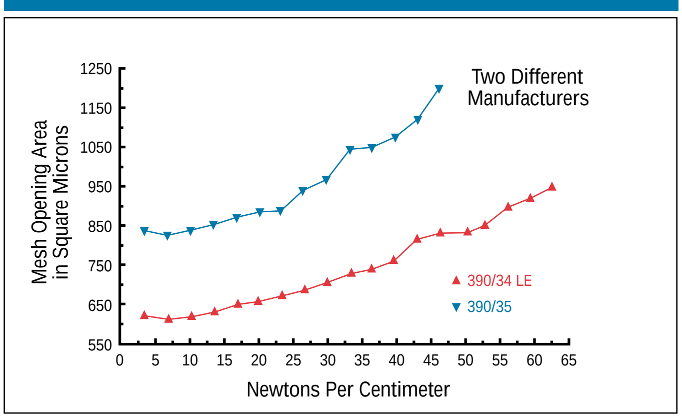

Figure 20. Difference in mesh opening area over a range of tension between two meshes with the same mesh count and thread diameter from different manufacturers. Each point represents an average of 12 mesh openings.

Mesh Opening Area vs. Tension
Mesh Stress Strain Tester

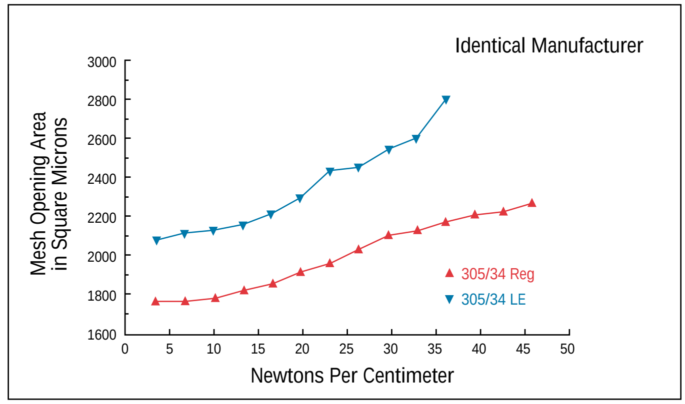

Figure 21. Difference in mesh opening area over a range of tension between two meshes with the same mesh count and thread diameter from the same manufacturer. Each point represents an average of 12 mesh openings.

significant conflict for two meshes that should be identical in this parameter, which is dictated by the thread diameter and mesh count. Another example exhibiting this variation can be found in Figure 21 and compares two fabrics from the same manufacturer, one being regular and one low elongation, with identical mesh counts and thread diameters. Again it is possible to compute an initial four micron offset which increases to six microns at the highest comparable tension.

A reasonable question to ask after considering the results of these comparisons would be how a specific number of threads, each of the same size, can be present in a specific linear length and produce two different size openings. Quite simply, it is not possible when dealing with constants, so it is rational to conclude that there is an error in these particular constants that the manufacturer is supplying*. The manufacturer's information on mesh opening size and percent open area does, however, reflect that there is a difference between the compared meshes.

Another important point that must be included in this discussion is that not all comparable meshes exhibited such a drastic difference in mesh opening area. But the question remains, what information reflects reality, and what does not.

If nothing else, these facts should encourage the printer to carefully scrutinize the information presented to him instead of accepting it so readily as truth.

The next aspect of mesh opening under investigation is the repeatability of the change that occurs as different sections of fabric of the same mesh are tensioned the same way. As described earlier in this report under Testing Methodology, five pieces of the same mesh were tested on the Mesh Stress/Strain Tester and measured during the tensioning process for changes in the mesh

**These differences are in no way exclusive to any one fabric manufacturer and are only used here to illustrate the need for standardization in the industry worldwide as well as the need for incoming quality control by printers.*

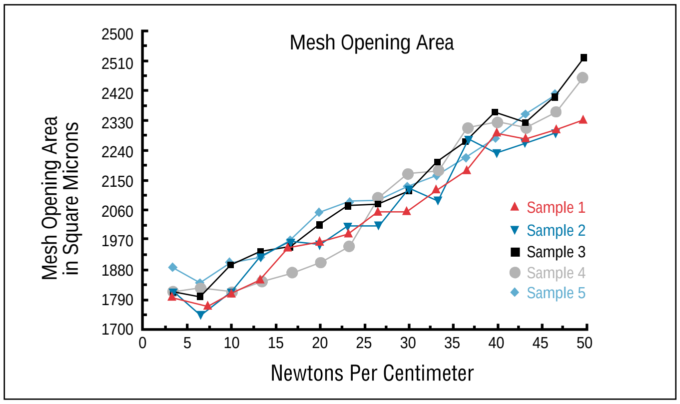

Figure 22. Repeatability of mesh opening area change in 5 samples. Each point represents an average of 12 mesh openings.

opening area. The results of one mesh are shown in Figure 22.

Generally speaking the opening size remains within plus or minus 1.5 microns of the average throughout the tension range indicated. In the data presented here, mesh opening size varies around 7 percent initially and gradually improves to approximately 5 percent at the highest tension level achieved. In other words, two screens stretched at different times using identical tensioning procedures will have mesh open areas that are within 5-7 percent of each other over the full range of possible tensions (using this particular fabric).

Mesh open area is important to many vital aspects of screen printing, making its measurement a point of concern and value. Opening size will dictate the maximum pigment particle size that can be printed, and define the smallest possible percent dot that can be carried on the fabric. Shear rates experienced during printing are a function of opening sizes and, therefore, openings become indirectly responsible for determining the range of printable inks based on rheological properties, including viscosity. In addition, the achieved surface profile and thickness of an applied direct emulsion stencil are dependent somewhat on opening size of a mesh.

Thread Diameter

The screen printing industry has long theorized that mesh opening size enlarges because the threads stretch and thin during stretching. SPTF research has proven such a speculation to be far from the truth. Let us examine the threads more closely to find out what really occurs when tension is applied to polyester screen printing fabric.

The image analysis system described earlier was used to measure and monitor thread diameter in all SPTF's testing. Measurements were made, in most cases, at a magnification of 470 power on both the warp and weft threads, and are accurate to within half a micron. Extreme care was taken during the measurement process to read the thread diameter in the center thread area between two openings. The purpose in doing this was to eliminate as much as possible measuring the flare of the thread that occurs near the intersections or knuckles. An illustration of thread measurements taken with SPTF's image analysis system can be seen in Figure 23.

Notice in Figure 23 that the thread diameter measurements in both warp and weft do not match the thread diameter specification we are given by the manufacturer. The actual measured diameters of 57.9 microns warp and 59.6 microns weft are in fact larger than the 55 micron diameter that is specified for this particular 200 thread per inch fabric.

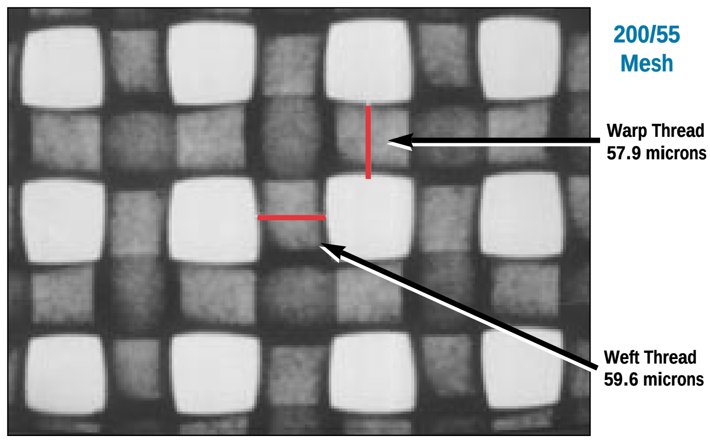

Figure 23. Image analysis measurement technique for thread diameter.

Virtually all of the meshes SPTF tested exhibited the same conflict between the measured and specified thread diameters. A feasible explanation to account for this discrepancy rests in the probability that the manufacturers specification indicates the diameter of the thread after it is originally extruded, whereas the actual measured value reflects a flattening process that the thread undergoes during the weaving and heat setting stages of the fabric's manufacturing.

It should be understood that as the thread flattens in height it also increases in width, and no mass or volume is necessarily lost or stretched out, but rather is redistributed into an ellipsoid shape (Figure 24). If this is indeed the case, the top view diameter of the thread would be wider than the original extrusion diameter while the height of the thread would be smaller. SPTF's thread measurements verify an increase in width, and the fact that the measured fabric thickness is significantly thinner than two times the extruded thread diameter further supports this theory.

To address the question of whether thread diameter thins during the tensioning process, SPTF measured 13 mesh counts before and after tensioning and compared them to determine if there was a significant decrease in

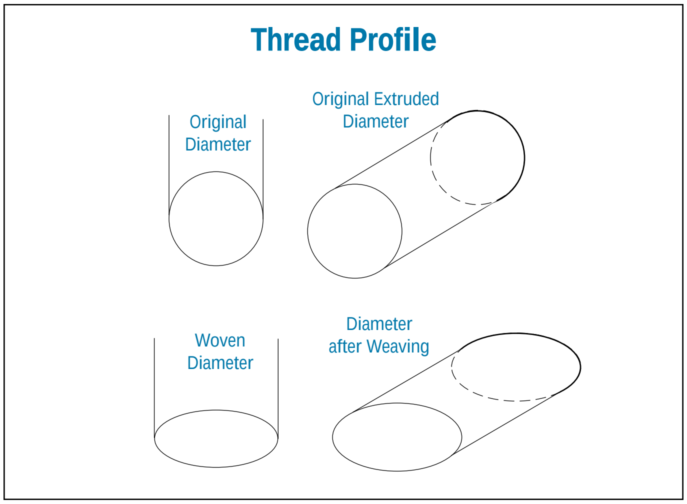

Figure 24. Thread profile before and after weaving.

diameter. From Figure 25 depicting this data we can determine that there was no significant decrease in thread diameter achieved from the mesh's free state to its final working tension.

Measured Thread Diameter
Free vs. Tensioned Mesh

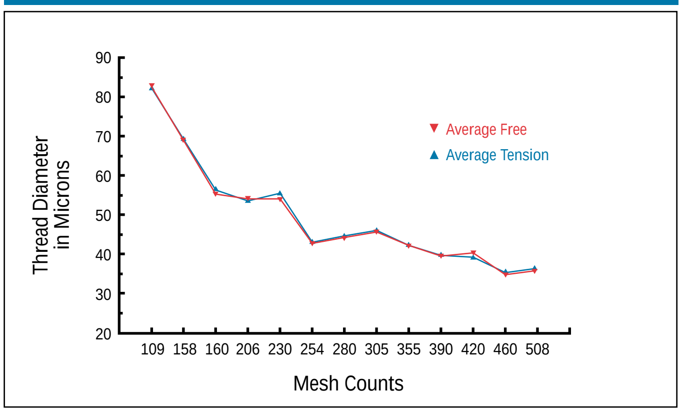

Figure 25. Average thread diameter measured free and tensioned on 13 mesh counts.

Manufacturer's Mesh Count/ Thread Diameter	Diameter* Free Mesh	Diameter* Tensioned	Tension in N/cm +
109/80	82.1	81.2	16
158/65	68.6	69.0	13
160/55-LE	54.8	55.8	36
206/50	54.0	53.5	22.5
230/48	54.0	55.0	12.75
254/40	42.7	42.9	12.0
280/38	43.9	44.3	15.0
305/40-LE	45.7	46.0	24.3
355/35	42.4	42.2	12.0
390/35-TW	39.9	40.0	13.0
420/33-TW	40.4	39.4	13.0
460/30-TW	35.7	35.6	12.0
508/30-TW	35.8	36.1	12.0

** Each point represents an average of 10 warp and 10 weft measurements*
+ Average of warp and weft tension

SAATI 305/40 LE
Average Thread Diameter vs. Tension

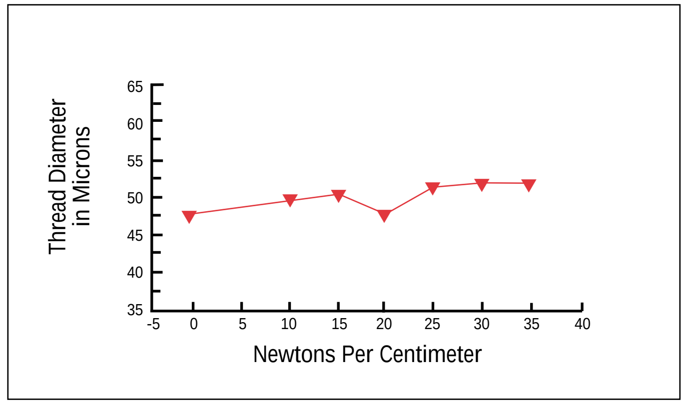

Figure 26. Average thread diameter remains virtually unchanged as tension is increased on a Saati 305/40 LE mesh. Each point represents an average of 10 warp and 10 weft measurements.

SPTF carried this experimentation a step further and monitored the thread's diameter on one screen at various stages throughout the tensioning process. The results, seen in Figure 26 clearly show that thread diameter was maintained in this particular fabric from its free state up to 35 N/cm virtually without change. Other fabrics tested by SPTF exhibited the same behavior without exception. It is reasonable to conclude then that thread diameter does not thin during tensioning as a general rule. However, it is worthy to mention the fact that SPTF has not yet investigated the effects of super high tension levels (100-130 N/cm) on mesh at this time. Therefore, it is possible that threads exposed to this great amount of force could respond by thinning in thickness from the stress. Further research in this area is in order and the results will be included in future SPTF publications.

Up to this point an average thread diameter consisting of both warp and weft thread measurements has been presented, but SPTF made another interesting observation when the warp and weft measurements were compared. The comparison, pictured in Figure 27, made evident slight differences in the diameter of the warp thread and the weft thread in several of the meshes tested. Where differences occurred, the weft thread measured thinner than the warp, which is proven in the graph and the actual data. A possible explanation for this difference could be that since the warp fibers are under a greater stress than the weft during the weaving process, they undergo a greater degree of flattening or widening than the latter.

The final point of analysis on thread diameter was again the repeatability of the change, or in this case the lack of it. Results of one mesh tested in the fashion previously described can be found in Figure 28.

We can see that the fine fabric samples varied only two microns throughout the range of tension which extended up to 50 N/cm. In addition, the lack of change in thread diameter during tensioning is again supported here in all

Measured Thread Diameter on Tensioned Mesh
Warp vs. Weft

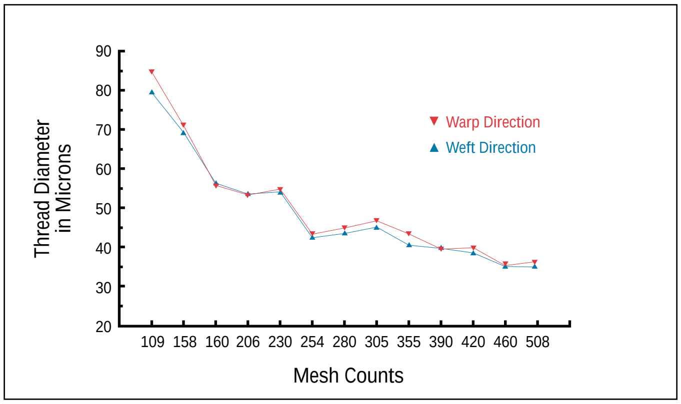

Figure 27. Warp and weft thread diameter at tension on 13 mesh counts.

Manufacturer's Mesh Count/ Thread Diameter	Warp Thread Diameter *	Weft Thread Diameter *	Tension in N/cm +
109/80	83.6	78.8	16
158/65	70.3	67.7	13
160/55-LE	55.6	56.1	36
206/50	53.3	53.6	22.5
230/48	54.6	53.9	12.75
254/40	43.3	42.6	12
280/38	45.0	43.7	15
305/40-LE	46.8	45.1	24.3
355/35	43.6	40.8	12
390/35-TW	39.7	40.2	13
420/53-TW	40.1	38.8	13
460/30-TW	35.7	35.5	12
508/30-TW	36.8	35.4	12

** Each point represents an average of 10 measurements*
+ Average of warp and weft tension

five samples. Although the variation seems to reduce as higher tensions are achieved on the fabric, the overall differences remained at approximately 5 percent of the total diameter. The screen printer can therefore expect the thread diameter to vary no more than 5 percent from screen to screen.

Monofilament threads are the sole material used in creating the porous woven mesh utilized in the screen printing process, and as such, their interaction with each other in the woven product has a direct relationship to the strength of the fabric. Mesh strength affects such things as yield points, achievable tensions and useful fabric life.

Mesh structure, including mesh opening area and fabric thickness, is determined from the threads and their frequency (mesh count). One important example of the usefulness of this information is when attempting to mathematically calculate the smallest dot a screen can sufficiently support for printing. Inaccurate information in this computation would be misleading.

As the threads essentially are the screen, their importance and the importance of understanding them cannot be understated. It is clear that thread diameter should be a matter of concern to the screen printer.

TETKO 305/34 LE
Mesh Stress Strain Tester

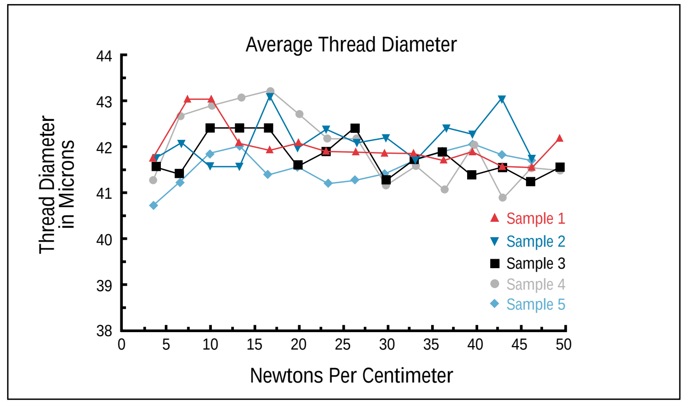

Figure 28. Repeatability of thread diameter on 5 samples. Each point represents an average of 3 warp and 3 weft measurements

Mesh Count

The task of measuring mesh count is a simple process that can be done with a variety of instruments. A device suited to measuring this parameter must address two elemental points for any kind of accuracy to be maintained. First, it must magnify the threads to the point that they are countable, and secondly, some type of calibrated reticule or gauge must be present in the viewing area to accurately determine the distance over which to measure.

SPTF's instrument of choice for this measurement was Tetko's Mesh Counter pictured in Figure 29. The mesh counting device is simply a 60 power microscope with a crosshair stationed over defined areas of view. The accuracy of the count is dependent on the operator and distance measured, but this particular instrument assists the operator by defining the distance to measure and by offering a crosshair reference reticule that easily moves over the defined area at the operators command. Several

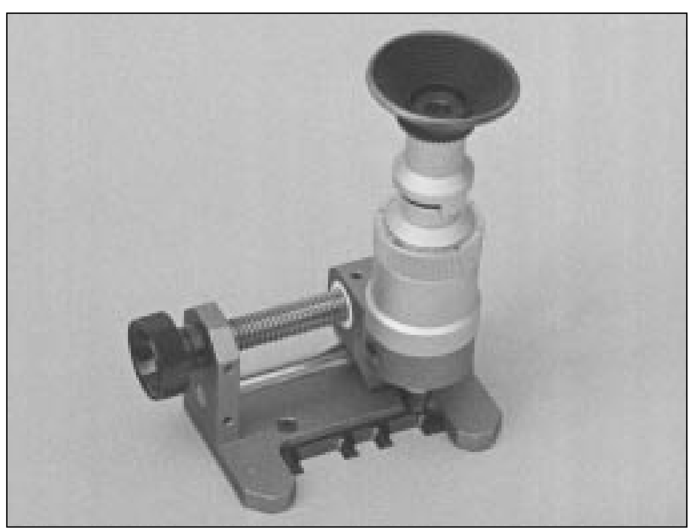

Figure 29. Tetko's Mesh Counter used for measuring mesh count in SPTF's research.

Procedure for Determing Mesh Count Per Centimeter

Table 4

Tetko Mesh Counter

1. Position fabric, free or tensioned, on light table.
2. Locate the 10 mm measuring area and move the microscope to the left edge of that area with the thumb screw.
3. Focus the image and position the reticule crosshair on the left edge of the 10 mm area.
4. Place microscope on the mesh so that the left side of a thread is touching the left edge of the 10 mm area, and the threads are parallel and perpendicular to the crosshair.
5. Using the reticule as a reference, move the microscope to the right with the thumbscrew and count the number of threads in the 10 mm measuring area. If there is only part of a thread inside the measuring area at the right edge, count it as a whole thread if 50% of it is showing, or don't count it if less than 50% is showing.
6. Measure and record the mesh count in both the warp and weft direction. (The direction the microscope moves is the direction of the fabric you are measuring.)

Conversions

Threads/inch x .394 = threads/cm   Threads/cm x 2.54 = threads/inch

Measured Mesh Count
Free vs. Tensioned Mesh

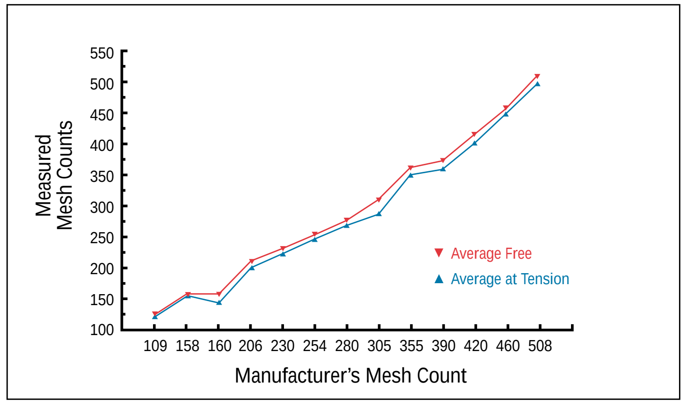

Figure 30. Average mesh count measured free and tensioned on 13 mesh counts.

Manufacturer's Mesh Count/ Thread Diameter	Mesh Count Free Mesh*	Mesh Count Tensioned Mesh*	Tension in N/cm +
109/80	127.0	123.2	16
158/65	158.8	156.2	13
160/55-LE	157.5	143.5	36
206/50	212.1	201.9	22.5
230/48	233.7	226.1	12.75
254/40	255.3	248.9	12
280/38	278.1	271.8	15
305/40-LE	309.9	289.6	24.3
355/35	363.2	354.3	12
390/35-TW	374.7	362.0	13
420/33-TW	415.3	403.9	13
460/30-TW	459.7	452.1	12
508/30-TW	513.1	500.4	12

** Average of warp and weft mesh count*
+ Average of warp and weft tension

SAATI 305/40 LE
Mesh Count vs. Tension

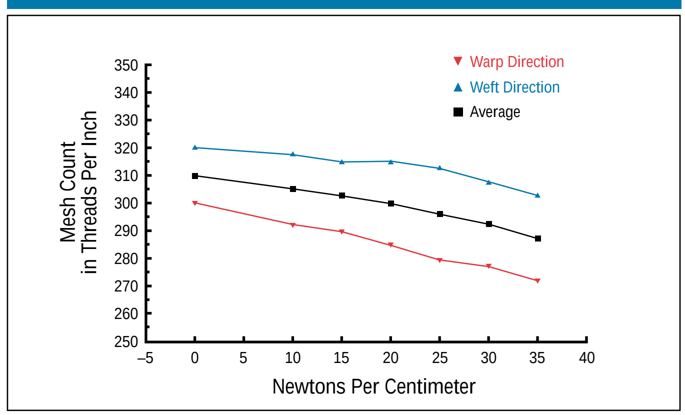

Figure 31. Warp, weft, and average mesh count change over a range of tensions on a Saati 305/40 LE mesh.

measurement widths are provided on the instrument including 10 mm, 1/4 inch and 1/2 inch.

The procedure developed for measuring mesh count in SPTF's testing is outlined in Table 4. The reader will notice that a 10 millimeter or 1 centimeter distance was chosen for this investigation, and is being recommended for mesh count measurement. The reasons for this choice are twofold. By measuring threads present in a full centimeter, no error is introduced to the final measurement by having to multiply it by 2 or 4 as would be required with a 1/2 inch count or 1/4 inch count. Accuracy is therefore ensured and can then be directly compared to the manufacturers information in centimeters, which as explained earlier, is the actual measurement practiced at the mills. Graphical representation of the information has been converted into inch values in order to present the data in terminology most commonly understood and recognized by the industry in the United States.

The change between free and tensioned mesh was again investigated in terms of mesh count as seen in Figure 30. The overall result for all tested meshes was a drop in mesh count from the free to tensioned state. When one mesh's response was tracked through the tensioning process we find a steady decline in mesh count as a function of tension (Figure 31). The warp and weft directions are shown individually here, as well as the average of the two, thus revealing, in this case, a 20-25 thread per inch difference in the two directions. Other meshes tested in this fashion exhibited similar distinctions, as Figure 32 depicts. In some instances warp mesh count is greater than the weft mesh count, and in some cases the reverse is true. The lower mesh counts tested seem to have less differences between the two fabric directions than the higher mesh counts. No pattern or trend has yet been discovered for these discrepancies.

The repeatability of the change in mesh count was again a point of investigation, and was determined in the

Measured Mesh Count on Tensioned Mesh
Warp vs. Weft

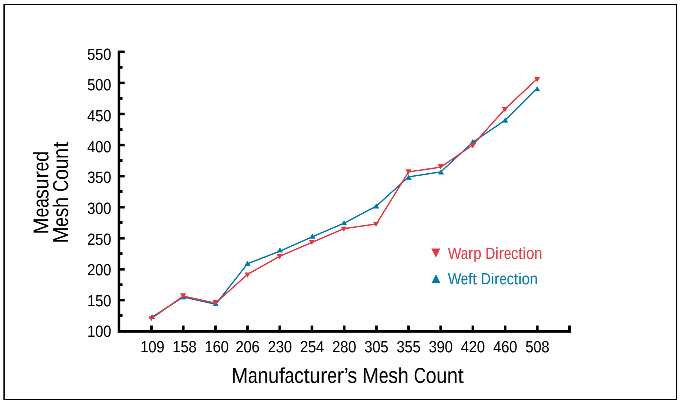

Figure 32. Warp and weft mesh count at tension on 13 mesh counts.

Manufacturer's Mesh Count/ Thread Diameter	Warp Mesh Count	Weft Mesh Count	Tension + in N/cm
109/80	121.9	124.5	16
158/65	157.5	154.9	13
160/55-LE	144.8	142.2	36
206/50	193.0	210.8	22.5
230/48	221.0	231.1	12.75
254/40	243.8	254.0	12
280/38	266.7	276.9	15
305/40-LE	274.3	304.8	24.3
355/35	358.1	350.5	12
390/35-TW	365.8	358.1	13
420/33-TW	401.3	406.4	13
460/30-TW	459.7	442.0	12
508/30-TW	508.0	492.8	12

+ Average of warp and weft tension.

same way as the other parameters that have already been discussed. The results, found in Figure 33, are exceptionally repeatable over the entire range of tensions the fabric was subjected to. The variance ranges only 1-2 percent of the average mesh count throughout the experiment. The five samples in fact vary only 1-2 percent from the average, which provides the printer

TETKO 305/34 LE
Mesh Stress Strain Tester

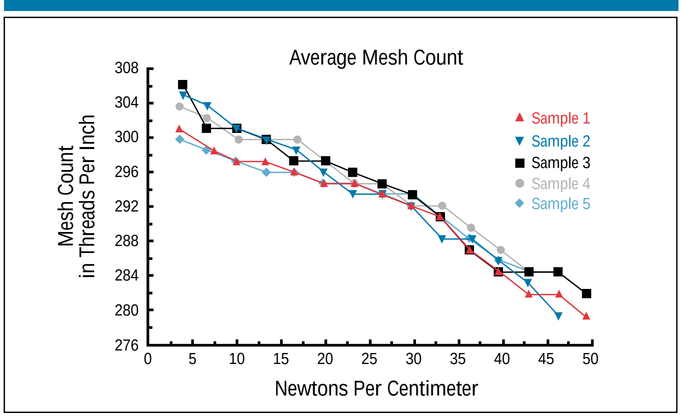

Figure 33. Repeatability of mesh count change on 5 samples. Each point represents an average of warp and weft mesh count.

confidence that different screens, stretched to the same tension using identical procedures, will have the same mesh count to within 1-2 percent of each other. We can also notice that this particular fabric demonstrated a steady decline in mesh count to the final 50 N/cm, at which point a once 305 mesh has become a 280.

The parameter of mesh count becomes important to the screen printer when discussing image definition, halftone and four color process, and moire. Aside from these considerations, the mesh count is the main nomenclature by which screen printers make fabric selections in purchasing and printing. The accuracy of this number must therefore be considered, and the change occurring during tension should be understood.

Fabric Thickness

Fabric thickness as illustrated in the beginning of this report in Figure 2 would literally be two times the thread diameter. However, with the new information that has been brought forth on thread diameter, a cross section can be developed (Figure 34) to more accurately represent reality. This image takes into consideration the flattening and widening of the threads which in turn cause the fabric thickness to be considerably thinner than twice the thread diameter.

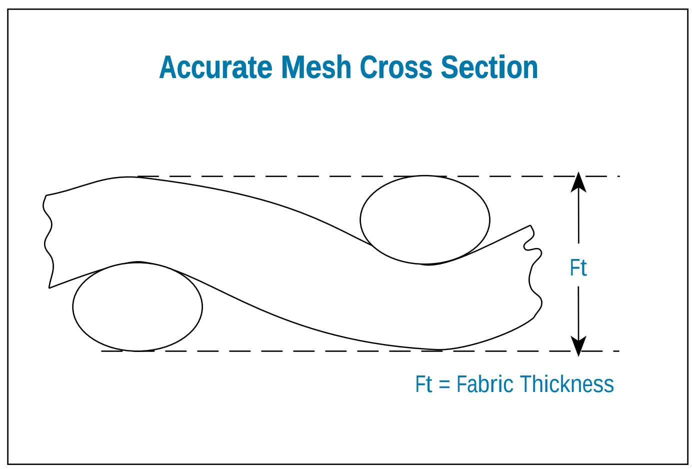

Figure 34. Mesh cross section depicting the actual fabric thickness dimension.

The particular problems associated with measuring the thickness of a tensioned mesh on a frame limit the type of instrumentation that can be used effectively. Free mesh poses little problem and a simple instrument such as a micrometer will work well, but no one prints with "free mesh." Unfortunately, a micrometer cannot reach into the center of a screen to measure fabric thickness, so other options must be explored.

There are a couple of readily available devices that are able to access the center of a screen and read thickness on the micron level with accuracy and ease. A "Deltascope" (manufactured by Fisher Technology) works on a magnetic induction principle and meets the above criteria

Figure 35. A magnetic induction thickness measuring device ("Deltascope") with mesh standards.

for measuring fabric thickness. The instrument pictured in Figure 35, consists of a digital readout, measuring probe, circular ferrous base and three calibration standards.

At this point it is necessary to present some research results SPTF has produced regarding the accuracy of a magnetic induction instrument, in this case Fisher's "Deltascope," when measuring polyester screen printing fabric. An initial investigation was conducted to verify the instruments thickness readings to the thickness readings of an already proven measuring device, which is the electronic micro gauge (more information on the electronic micro gauge can be found in an SPTF report entitled "Guideline to Wet and Dry Measurement Techniques, Part One).

The study was performed with the instrument calibrated using the three foils supplied by the manufacturer, and entailed measuring 33 mesh counts, from 94 to 460 threads per inch, which offered a range of thicknesses for comparison. These same mesh counts were then measured on our reference instrument, and the two sets of readings subtracted to determine if significant differences existed between the two devices. A curve fitted representation of the results of the process just described can be found in Figure 36. The black zero line indicates the reference instrument and the blue line shows the error that was discovered in the fabric thickness measurements taken with the "Deltascope." Notice that the error does not remain constant but increases on the left side of the graph where the low mesh counts are present. If the instrument would have produced a consistent offset from the reference, a corrective value could have been added to the measurements to bring them in line with the actual thickness. Because this was not the case, other corrective measures were explored to allow the instrument to become useable for this application.

The SPTF has developed a calibration method that significantly reduces the error discussed here. The red line in Figure 36 demonstrates the results of the new calibration technique compared to the reference instrument on the same 33 mesh counts. There is only a slight difference present and it is much more consistent throughout the mesh count range tested. The error reduction seen is significant and greatly improves the effectiveness and accuracy of the instrument in this application.

Extensive details on the new calibration method are beyond the scope of this report; however, a procedure can be found in Table 5 describing the steps to implement this technique. Simply explained, the calibration of the instrument is performed using screen mesh standards instead of the smooth polyester foils that are supplied by the manufacturer. By calibrating to the same type of material as what is being measured, screen mesh in this case, the electronic response that the instrument operates on is "tuned in" so to speak to the specific feedback that the mesh provides to it.

It is worthy to note that the "Deltascope" when calibrated with the polyester foils provides excellent readings on dry ink thickness of nonmagnetic coatings and nonmetallic substrate thicknesses, which are the applications the instrument was designed for. Research on its capability in this area can be found in SPTF's report entitled "Guidelines for Wet and Dry Measurement Techniques, Part Three."

SPTF's measurement of fabric thickness was carried out using the improved calibration method just described on both free and tensioned mesh for the same 13 mesh counts. A comparison of these two sets of measurement can be seen in Figure 37. A decrease in fabric thickness from free to tension was seen for each of the meshes tested. When tracking the responses of fabric thickness during the tensioning process it becomes plain that a

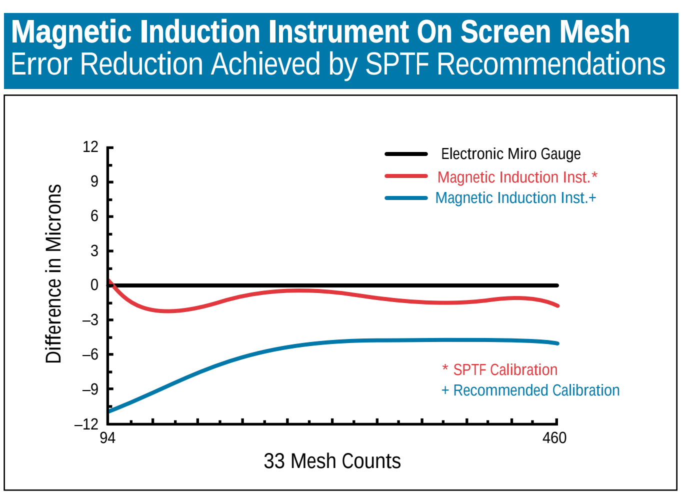

Figure 36. Reduction in the error seen from measuring fabric thickness with a magnetic induction instrument, by utilizing SPTF new calibration technique.

Calibration of Magnetic Induction Instrument
For Measuring Fabric Thickness *Table 5*

1. Select the meshes representing a cross section of the mesh counts used in your company. It is recommended that a mesh count at the high end, low end, and middle of the range be selected.
2. Acquire a small sample (3"x4") of each mesh count and take 10 measurements of fabric thickness in different spots on each sample with a micrometer accurate to at least 0.0001" (2.54 microns).
3. Calculate the average fabric thickness of the 10 readings for each mesh. These mesh samples will now be used as standards to calibrate the magnetic induction instrument.
4. Turn instrument on, hold probe in the air and press ENTER/CAL button.
5. Take 5 to 10 measurements on the ferrous measurement base. If the probe tilts or slips press DEL immediately.
6. Press ENTER/CAL to register results.
7. Place the lowest mesh count sample on the ferrous base and take 5 to10 measurements.
8. Press ⇑ or ⇓ and set display to the average fabric thickness for the mesh that was measured with the micrometer.
9. Press ENTER/CAL to register result.
10. Repeat steps 7 through 9 for the middle mesh count and the high mesh count.
11. After pressing ENTER/CAL following the third standard, you are ready to measure.

Procedure for Measuring Fabric Thickness with a Magnetic Induction Instrument

1. Calibrate instrument according to the above procedure. If instrument has been previously calibrated with mesh, check the calibration by measuring the mesh standards. If readings do not match the known fabric thickness of the samples, recalibrate the instrument.
2. Measure and record 10-20 readings in various places on the fabric (free or tensioned).
3. Press the RES button 5 times to obtain the mean, minimum and maximum thickness, standard deviation, and number of measurements. Record all pertinent statistical data.

Note: All measurements are represented in microns.

Conversions

Microns x 0.03937 = mils	Mils x 0.001 = inches
Mils x 25.4 = Microns	Microns x 0.001 = cm

Measured Fabric Thickness
Free vs. Tensioned Mesh

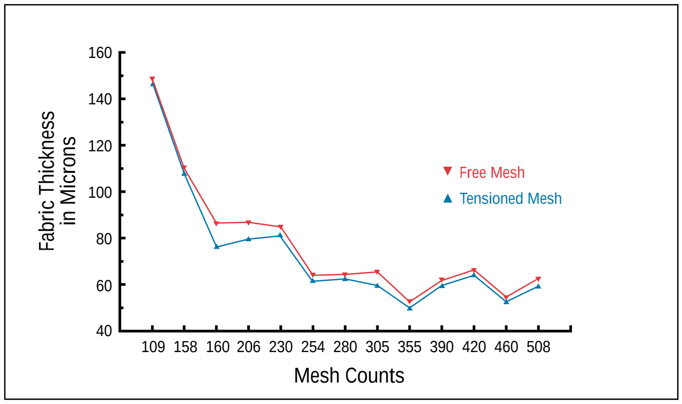

Figure 37. Average fabric thickness measured free and tensioned on 13 mesh counts.

Manufacturer's Mesh Count/ Thread Diameter	Measured Fabric Thickness Free*	Measured Fabric Thickness Tensioned*	Tension in N/cm +
109/80	148.0	147.0	16
158/65	110.0	108.0	13
160/55-LE	86.0	76.8	36
206/50	86.9	80.5	22.5
230/48	84.9	82.3	12.75
254/40	64.4	62.2	12
280/38	65.0	62.8	15
305/40-LE	66.1	60.8	24.3
355/35	53.3	51.1	12
390/35-TW	62.2	60.4	13
420/33-TW	66.6	65.2	13
460/30-TW	55.0	54.0	12
508/30-TW	63.2	60.3	12

** Average of 10 measurements. Fabric thickness values in microns.*
+ Average of warp and weft tension.

progressive decrease in thickness corresponds to each higher increment of tension achieved (Figure 38). A final analysis of repeatability in Figure 39 demonstrates the same phenomena and shows only a 2-3% variation from the average in the fabric thickness of five pieces of fabric through a range of 0-50 N/cm. Once again, this has demonstrated polyester screen mesh to be extremely repeatable.

Two main calculations that depend on an accurate fabric thickness measurement are an ink deposit estimate and stencil thickness. SPTF research has produced evidence that a direct correlation exists between the fabric thickness and the actual ink deposit. Because of this relationship, the fabric thickness offers an excellent indicator as to what ink deposit will be produced on a particular mesh. This makes the accurate measurement of this parameter vital if ink deposit estimates are to be kept valid. Stencil thickness is determined by subtracting the uncoated fabric thickness from the total measured thickness of the completed screen. Without an accurate fabric thickness, the value calculated would be erroneous.

Manufacturer Specifications Versus Actual Measured Dimensions

We have held off on comparing the measured mesh parameter values to the manufacturers specification up to this point so SPTF's measurement methods could be explained and validated and so the reader would understand the mesh parameter changes that occur throughout the tensioning process. With this knowledge a question arises as to the relevance and accuracy of the single number specification that is provided by the manufacturer. Does this number represent free mesh dimensions or tensioned mesh? Since we have discovered that progressively greater tensions produce more change (except in the case of thread diameter), parameter measurements should be supplied at various tension stages in order to truly understand the screen that the printer will end up with.

SAATI 305/40 LE
Fabric Thickness vs. Tension

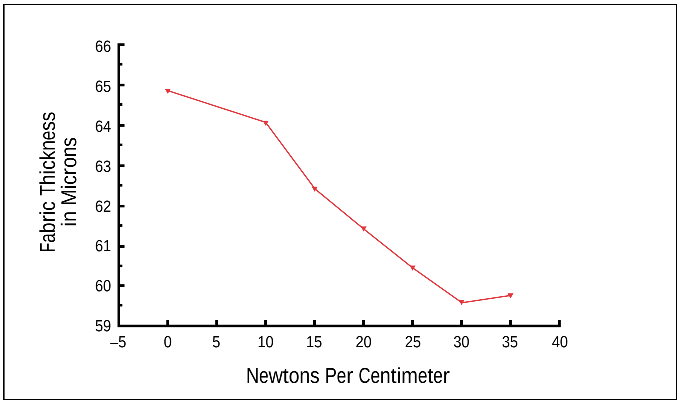

Figure 38. Fabric thickness change on Saati 305/40 LE fabric over a range of tensions. Each point represents an average of 10 measurements.

TETKO 305/34 LE
Mesh Stress Strain Tester

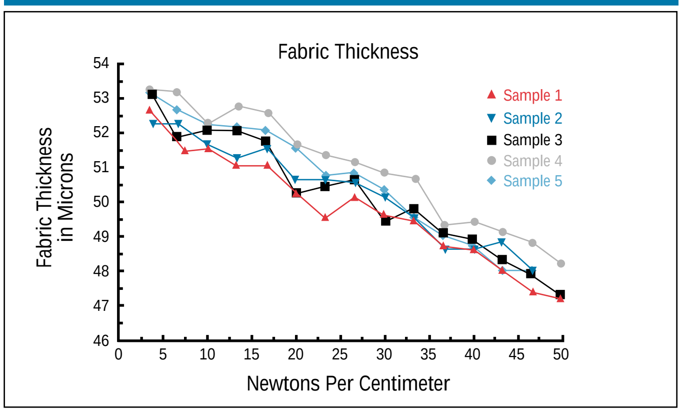

Figure 39. Repeatability of fabric thickness change on 5 samples. Each point represents an average of 10 measurements.

The question of the accuracy of manufacturers specifications must be answered by comparing their information to the actual measured values. The graphs and data charts in Figure 40, 41, 42 and 43 depict such a comparison for each of the four parameters that have been expanded on in this paper. There are differences present in virtually all the directly matched values, and one could expect these differences to increase as greater tension was applied to each of the fabrics tested.

Conclusion

It is important that the screen printer be aware of these inconsistencies when purchasing, selecting and tensioning polyester mesh. A better understanding of the inner reactions of the essential element of the process, the polyester screen, can only serve to improve the screen printer's ability to control various variables throughout the process.

Printers wishing to produce and reproduce a quality product should realize that success hinges on their ability to create a consistent and repeatable screen. By placing quality control measures on incoming mesh, the screen printer will be assured that a fabric possess acceptable characteristics to guarantee a screen will repeat past performance. The screen remains the main fundamental of the screen printing process, and those giving appropriate attention to it will be rewarded as the 21st Century ushers in an increasingly sophisticated and competitive marketplace.

Mesh Opening Area
Manufacturer vs. Measured

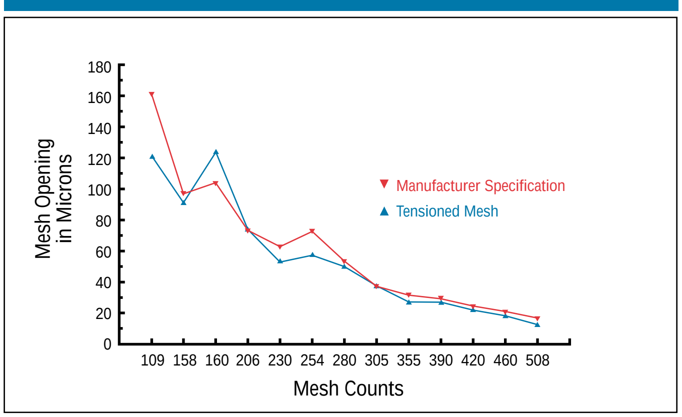

Figure 40. Comparison of measured mesh opening area to manufacturer's specification on 13 mesh counts.

Figuare 40 Table

Manufacturer's Mesh Count/ Thread Diameter	Manufacturer Mesh Opening	Measured Mesh Opening* (Tensioned)	Tension in N/cm +
109/80	160	120.5	16
158/65	96	90.5	13
160/55-LE	104	123.8	36
206/50	73	72.4	22.5
230/48	63	54.0	12.75
254/40	72	57.1	12
280/38	53	50.5	15
305/40-LE	38	37.9	24.3
355/35	33	27.7	12
390/35-TW	31	28.3	13
420/33-TW	27	24.2	13
460/30-TW	24	20.5	12
508/30-TW	20	15.7	12

** Average of 160 measurements* *+ Average of warp and weft tension*
Mesh opening values in microns (Value is square root of average area in square microns)

Thread Diameter
Manufacturer vs. Measured

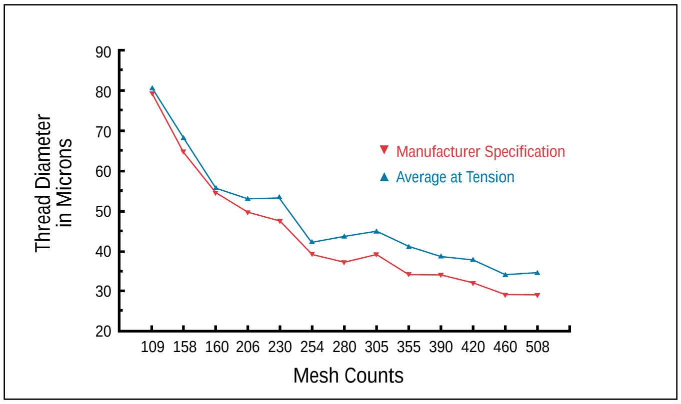

Figure 41. Comparison of measured thread diameter to manufacturer's specification on 13 mesh counts.

Figure 41 Table

Manufacturer's Mesh Count	Manufacturer's Thread Diameter	Thread Diameter Tensioned *	Tension in N/cm+
109	80	81.2	16
158	65	69.0	13
160	55	55.8	36
206	50	53.5	22.5
230	48	54.2	12.75
254	40	42.9	12
280	38	44.3	15
305	40	46.0	24.3
355	35	42.2	12
390	35	40.0	13
420	33	39.4	13
460	30	35.6	12
508	30	36.1	12

** Average of 10 warp and 10 weft thread diameters*
Thread diameter values in microns
+ Average of warp and weft tension

Mesh Count
Manufacturer vs. Measured

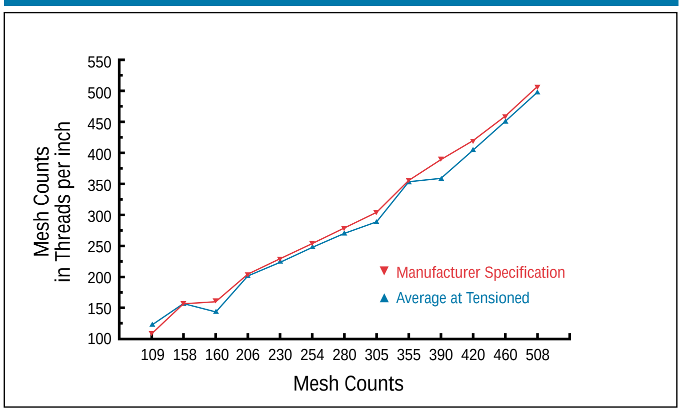

Figure 42. Comparison of measured mesh count to manufacturer's specification on 13 mesh counts.

Figure 42 Table

Manufacturer's Mesh Count/ Thread Diameter	Measured Mesh Count (Tensioned)*	Tensionin N/cm +
109/80	123.2	16
158/65	156.2	13
160/55-LE	143.5	36
206/50	201.9	22.5
230/48	226.1	12.75
254/40	248.9	12
280/38	271.8	15
305/40-LE	289.6	24.3
355/35	354.3	12
390/35-TW	362.0	13
420/53-TW	403.9	13
460/30-TW	452.1	12
508/30-TW	500.4	12

** Average of warp and weft mesh count*
Mesh count in threads/inch
+ Average of warp and weft tension

Fabric Thickness
Manufacturer vs. Measured

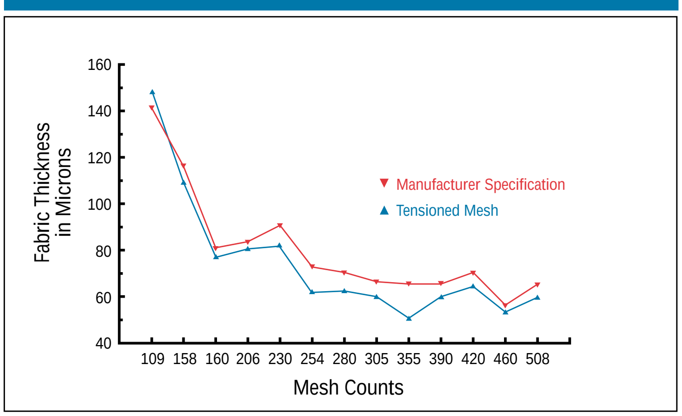

Figure 43. Comparison of measured fabric thickness to manufacturer's specification on 13 mesh counts.

Figure 43 Table

Manufacturer's Mesh Count/ Thread Diameter	Manufacturer's Fabric Thickness	Measured Fabric Thickness Tensioned*	Tension in N/cm +
109/80	140	147.0	16
158/65	115	108.0	13
160/55-LE	80	76.8	36
206/50	83	80.5	22.5
230/48	90	82.3	12.75
254/40	72	62.2	12
280/38	70	62.8	15
305/40-LE	66	60.8	24.3
355/35	65	51.1	12
390/35-TW	65	60.4	13
420/33-TW	70	65.2	13
460/30-TW	56	54.0	12
508/30-TW	65	60.3	12

** Average of 10 measurements*
Fabric thickness values in microns
+ Average of warp and weft tension

Definition of Terms

Accuracy - a generic concept of exactness related to the closeness of agreement between the average of one or more test results and accepted reference value.

Anisotropy - the vertical/horizontal projection where the vertical projection is the Ferret's Diameter at 90 degrees.

Bell Shape Curve - see Normal Frequency Distribution.

Breaking Strength - highest tension achieved before material rupture occurs.

Calibration - to standardize by determining the deviation from a standard so as to ascertain the proper correction factors.

Deflection - the distance of displacement caused from force of a known weight on the surface of a screen.

Deviation - the difference between the value of the controlled variables and the value at which it is being controlled.

Elongation - the initial length of the fabric divided by the expanded length caused from stretching. This ratio is reported as a percentage for both the warp and weft directions individually.

Ferret's Diameters - the projections of an object measured at specified angles.

Frequency Histogram - an arrangement of statistical data that displays the frequency of the occurrence of the values of a variable.

Mean - ($\overline{X}$) a measure of central tendency equal to the sum of the observations divided by the number of observations. Also known as a statistical average.

Micron - (µm) a metric unit representing one millionth (1/1,000,000) of a meter or 0.000039 of an inch.

NBS - acronym for the National Bureau of Standards.

Normal Frequency Distribution - an arrangement of statistical data that exhibits the frequency of the occurrence of the values of a variable in such a way as to display a symmetrical, bell shaped pattern centered about the mean.

Orientation - the angle of the longest chord of all chords which begin at the object's center of gravity, and end at the object's periphery.

Percent Change (Δ%) - indicates percentage increase or percentage decrease between two numbers.

Process Spread - the extent to which the distribution of individual data values of a process characteristic vary; often shown as the average, plus and minus some number of standard deviations ($x \pm 3\sigma$).

Range - the difference between the highest and lowest values in a data group.

Repeatability - the closeness of agreement between test results obtained under repeatable conditions.

Reticule - a system of lines, dots, crosshairs, or wires in the focus of the eyepiece of an optical instrument.

Shape Factor - is equal to (area/perimeter^2) x 4 π ; this is a measurement of the "sharpness" of an object, where a value of 1 corresponds to a circle and values approaching 0 indicate a straight line.

Spread - a general concept for the extent by which values in a distribution differ from one another. (Also see Process Spread)

Standard Deviation - a numerical value that measures the spreading tendency or dispersion of the data. A large standard deviation represents a greater variability than a small standard deviation.

Variation - the inevitable differences among individual outputs of a process.

Yield Point - a stress at which a marked increase in deformation takes place without increase in the load.

Δ% - symbol for percent change

µm - symbol for micron

$\overline{\mathbf{X}}$ - symbol for mean

LE - low elongation mesh

TW - twill weave mesh