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Studio practices for shaping and heat-setting synthetic fabric

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Heat-setting of synthetic fabrics is an industrial stabilization process that has been adapted by designers to create dimensional textures through shaped-resists and non-industrial heat-setting methods. The paper overviews heat-setting properties, physical resist techniques, and presents an experiment to determine best practices for heat-setting physically resisted polyester fabric. Two polyester fabrics, organza and lining, were gathered and secured to a wooden dowel and heat-set under four heating conditions: steaming in a pressure cooker, boiling in a pot of water, dry heat in a conventional oven, and radiation waves in a microwave oven. Pre- and post-treatment lengths were analyzed using GLM for two-way ANOVA and post hoc tests. Based on results from the statistical analysis and visual evaluation, steaming in a pressure cooker is recommended for sheer fabrics such as organza and dry heat from a conventional oven for lining weight fabrics.

Keywords: thermoplastic; heat-set; physical resist; shibori; polyester

1. Introduction

The shaping and heat-setting of synthetic fabrics has been practiced by artists, designers, and textile engineers since the 1980s, with Japanese artisans leading the way by combining traditional shibori physical resist methods with heat-setting processes. Shibori is a Japanese word that refers to a variety of ways of shaping fabric and securing it before dyeing (Wada 2002). The areas secured resist the dye, thus shibori is a physical resist or a shape-and-resist technique.

When the resist is released, dyed patterns are visible on the cloth and the dimension created from the binding is traditionally pressed flat. Heat-setting is a process of heating fabric to temperatures at or above the fiber's glass transition temperature; the temperature at which the amorphous (e.g., unorganized) regions of a fiber distort and can be reshaped upon cooling (Kadolph 2010). When combining shape-and-resist techniques with heat-setting, the fabric is shaped and secured and then instead of being dyed it is heat-set to retain the shaping. The result on polyester and other synthetic fabrics is a permanent, resilient, three-dimensional texture.

Fabrics made from synthetic fibers are suitable for heat-setting, due to their thermoplastic nature. This means that the bonds that hold together the linear molecules of carbon, hydrogen, and oxygen can be broken by heat and thus shaped in response to heat (Boutrup 2000, Wada 2002). To heat-set shaped fiber, the fabric is heated high enough to soften and change its shape, while avoiding overheating and burning the fiber. The softening, heat-setting, and melting of fibers occurs over a range of temperatures, and the time of setting can vary from less than a second to over 60 minutes (Gupta 2002). Fluctuations are dependent upon fiber, yarn and fabric properties, finishing treatments, and thermal method. The temperature range to heat-set synthetic fibers is 150 °C to 230 °C (Heaton 1971).

Heat-setting has been researched for effects on fiber stress-strain and recovery behavior, dye uptake, optical properties, and thermal properties; as well as for structural and morphological changes in the amorphous and crystalline phases of heat-setting thermoplastic fibers, yarns, carpet yarns, and upholstery fabrics (Gupta 2002). Heating systems in the textile industry and laboratory setting utilize dry air contact, water vapor, and liquid baths. Fabric yardage is typically heat-set with a tenter machine, whereby the fabric is stabilized and moved through a dry heat or steam zone followed by a cooling zone. High temperature steamers dry, cure, and set fabrics by transport through a steam chamber. Liquid bath or hot-water setting is carried out with thermal dyeing machines (Atav *et al.* 2006). Garments stretched over frames or stacked are heat-set in an autoclave, which is a pressure vessel with options for air evacuation, steam, or dry heat. The equipment serves the textile industry needs but is unavailable to the studio artist who is heat-setting three-dimensional forms for aesthetic purposes.

While most information on heat-setting refers to industry applied treatments a few heat-setting recommendations applicable to the studio artist were found. Wada (2002) indicated that

bound or otherwise shaped polyester fabric be heated in a pressure cooker to around 200 °C to 220 °C for 20 to 30 minutes. Wells (1997) noted that fabrics from thermoplastic fibers or blends could be manipulated and heat-set in a baking cabinet or conventional oven at 191 °C for 10 minutes; or small pieces could be set with a pressure cooker. Boutrup (2000) explained that polyester is hot drawn just below its melting point and that other types of shaping are heat-set at lower temperatures using either dry heat or steam. McCarty and McQuaid (1998) used boiling water in combination with a dye bath to heat-set physically resisted fabric.

1.2. Designer applications

The shaping and heating of fabrics as an aesthetic feature has been explored by designers of textiles, fashion, and costume. The Nuno Corporation, established in 1984, was amongst the first Japanese textile companies to combine mechanical, chemical, and thermal technologies with shibori techniques. Nunos' innovative textiles have been exhibited worldwide, are in over 20 museum collections, and are featured in the Nuno Nuno book series (NUNO 2008). One example is *Origami Pleats* created from accordion- or reverse-folded polyester organza, dye transfer printing and heat-setting resulting in sculptural scarves, handbags, and garments (McCarty and McQuaid 1999, Wada 2002, Braddock Clarke and O'Mahony 2005).

Designer Issey Miyake pleated, twisted, and crushed oversized polyester garments and reduced them to size through heat for his *Pleat Please Issey Miyake* collections between 1989 and 1993 (Miyake *et al.* 1999). The fabrics created an interactive environment for the wearer as they collapsed and expanded in response to the wearer's motion. Another expandable garment example is the PockeTee designed by Yoshiko I. Wada for K. Takeda & Co. (Wada 2002, *PockeTee* 2008). Polyester georgette was tied in a loop binding technique, called *miura* shibori, on assembled tops sized three times the normal size. After tying the top, which was reduced to

doll-size, it was heat-set with steam. When the binding was removed the result was a permanently textured and stretchable top.

Designers in theatre and dance have used the extensibility of shaped-and-heated fabrics to reshape how the body looks and moves. Master dyer Joan Morris created the fabrics for Julie Taymor's costume designs for one scene in the Broadway musical production Disney's® *The Lion King*. Morris used stitch- and bound-resist shibori to create textured, three-dimensional cone shapes that emerged from the fabric (Taymor 1998, Wada 2002). Camilla Diedrich, an interior textile designer, has used shaped and heated synthetic fabrics for wall-hangings, pendant lamps and room dividers (Quinn 2009). Further examples of manipulating and heat-setting fabric are presented in Black (2006), Braddock Clarke and O'Mahony (2005), Colchester (1991), McCarty and McQuaid (1998) and Wada (2002).

1.3. Purpose

Inspired by designer applications of shaping and heating fabrics, traditional and non-traditional techniques of shaped-resist and methods for heat-setting polyester and other synthetic fibered fabrics were explored through sample making (Haar and Nguyen 2005) and wearable art (Haar 2004a, b) (Figure 1). Throughout the process several heat sources were used to set the fabric with varying results, which led to the research question: Which heating method available to the studio artist best retains a physical resist in selected polyester fabrics? The purposes of this paper were to overview heat-setting properties and physical resist shaping techniques, and to present the process and findings for the stated research question. The overarching goal was to provide studio artists and textile students a foundation to explore shaping and heat-setting of fabrics.



Figure 1. *Shaped Cloth*, wearable art by Sherry Haar with bound marble heat-set polyester organza sleeves and a variety of shaped-and-heat-set techniques on nylon and polyester throughout skirt. Photo by Daniel Donnert.

2. Heat setting

Heat setting is defined as "a process that uses heat to stabilize the shape and dimensions of yarns or fabrics made of heat-sensitive fibers" (Kadolph 2010, p. 155). The purpose is to set fibers and yarns in various fabric constructions so that the textile will not shrink or alter its dimensions during use. When fabric is manipulated, such as by binding over an object, and heated to the glass transition temperature of the fiber, the molecular orientation and crystalline order in the bound fibers will distort in response to the applied stress and heat, and take up a new arrangement. The new configuration will be retained on cooling, but may be disturbed by subsequent treatments (Hearle 1971). As Denton and Morris (1971) state, "setting does not take place in heating, but in cooling" (p. 124). Therefore, the fabric must be adequately cooled prior to undoing manipulations. Factors influencing cooling time are atmospheric temperature and

humidity, fiber and fabric properties, and type of manipulation. Recommended care for shaped synthetic fabric set by heat is hand-wash in cold water and block dry (Wada 2002).

2.1. Fibre

Most synthetic fibers are thermoplastic and react readily to setting processes of heat, moisture and tension (Statton 1971). For heat-setting physically resisted fabrics, Wells (1997) recommended fabrics that contain high proportions of polyester, polypropylene, or polyamides (nylon). Wada (2002), Boutrop (2000), and Braddock Clarke and O'Mahoney (2005) note polyester's suitability for heat-setting. For this project, sample making was explored on commercially available light- to mid-weight fabrics of polyester and nylon.

Polyester fibers soften at temperatures between 190°C to 250°C, heat-set between 200°C and 220°C, and melt at temperatures above 250°C. Nylon (polyamide) fibers soften between 170°C and 250°C, heat-set between 150°C to 210°C, and melt above 250°C. Mechanisms for obtaining set within fibers during processing include intermolecular bonding and crystallinity (e.g., the relative amount of order and disorder of the chain segment). For nylon, hydrogen bonding between and within fibers influences setting and stabilization (Vigo 1994). In the presence of moisture, there is considerable depression in the melting point of nylon which will result in a higher degree of set because of greater mobility of the molecular chains (Gupta 2002, Hearle 1971). For polyester, the change in crystalline morphology ranges from partial melting and recrystallization at lower temperatures to the growth of larger more perfect crystallites at the upper range of setting temperature (Gupta 2002).

2.2. Fabric

Fabric structure and weight influence the fibers response to shaping and setting. The initial hand of the fabric is an indicator of the way the fabric will hold a set shape. Organza is very efficient

at maintaining tight raised shapes and spires due to its lightweight, open weave, and crisp hand. Lightweight and soft fabrics such as chiffon, georgette, crepe de chine, and knit structures hold shape; however, the released and set texture may be more relaxed than the pre-set shaped resist. Light- to mid-weight stiff fabrics, such as satin lining and taffeta, respond to shaping. Heavyweight fabrics of any structure are more likely to weigh down raised shapes and therefore are recommended for folding, pleating and other such flattened manipulations.

Single layers or multiple layers of fabric can be shaped and heat-set. The advantages of multiple layers are several textured fabrics from one application and the ability to compare how different fabric structures react to a shaping method. When one piece of fabric is folded upon itself and three-dimensionally shaped, heat-set patterns are generated with both concave and convex textures on the fabric face.

2.3. Thread and binding

Considerations for selecting yarn as binding or sewing thread are shape-and-resist technique and fabric weight. The fiber content of the yarn needs to be able to withstand the temperature of the heat treatment. Polyester, cotton, and cotton covered polyester yarns have withstood the heat treatments used. Hand binding and pole wrapping techniques require heavy weight thread, such as upholstery, carpet and button, or topstitching. Pearl cotton, size 3 or 5, and cotton string also work well for bound and wrapped resists.

Thread for hand-stitched resists should be of a weight appropriate to the fabric and of a strength that allows it to be tied without breaking (Wada *et al.* 1999). A single strand of heavyweight thread, such as topstitching weight, can withstand pulling and tying. While doubled all-purpose sewing thread has been noted by artisans for durability and ease of hand-tying, I found the thread breaks when tying. Thread recommended for machine stitched resists is all-

purpose weight through the needle and heavy weight thread in the bobbin (Wolff 1996). As I often stitch multiple layers, I find that a stronger thread, such as hand quilting thread, in the needle and topstitching thread in the bobbin withstand gathering and tying without breaking.

3. Shaping techniques

Shape-and-resist techniques have been used across cultures to create pattern through color by preventing dye from reaching part of the fabric. The Japanese word *shibori* is used to designate a group of resist-dyed textiles (Wada 2002). Tie-and-dye is the term often used in the United States. Amongst the Yoruba of Nigeria the process is called *adire*, meaning "to take, to tie and dye" (Polakoff 1982), and small objects tied into the fabric prior to dyeing is called *onikan* (Wada 2002). The term *amarra*, "to tie," is from Peru (Wada 2002). Tiny bound resists are usually known in India as *bandhani* or *bandhej*, from the verb *bandhna*, "to tie" (Murphy and Crill 1991). In Indonesia, *teritik*, refers to a pattern of small white dots created by stitch resist (Wada 2002).

Traditional and adapted techniques of shape-and-resist are appropriate for shaping and heating thermoplastic fibered fabrics as the three-dimensional shaping inherent of these resist processes can be permanently captured through heat-setting. Shaping techniques can be categorized by the method of resist as binding, stitching, clamping, and pole wrapping.

3.1. Binding

In bound and tied techniques, a portion of fabric is drawn up and bound with heavy duty thread or string. The fabric is picked up from the center position using the fingers, needle, or hook. The fabric is pulled away from the central point creating pleats much like that of a collapsed umbrella (Brito 2002). Thread or string is secured with a knot such as the kamosage or half-hitch which provide a secure hold, yet are easy to undo (Wada 2002, Wada *et al.* 1999). From there another

shape can be bound by moving across the fabric (Figure 2a) or while still on the bound portion the thread can be spiraled up the fabric and back down creating a cone shape (Figure 2b). The height and width of the shape is dependent upon the amount of fabric picked up and bound, ranging from a tiny nub to a cone a couple inches in height. Variations can be created from the number, placement, and spacing of thread wraps. In addition, manipulating the picked up fabric by twisting, folding, and bunching prior to binding provide variation. The range of traditional bound shibori techniques are well described by Wada *et al.* (1999).

Small objects can be tied into the fabric and heat-set. The resulting fabric mimics the shape and dimensions of the objects; thus the surface is often more defined compared to binding only the fabric. Marbles, beads, bobbins, buttons, stones, shells, screws, coins, and corks are some examples of objects to bind with fabric (Figures 3a and b). Objects with a low melting point, such as hard plastic interlocking bricks and plastic beads, warped and melted during the heating process; however the setting effects were interesting (Figures 3c and d). For the bound object technique, items are covered with fabric and bound by tightly wrapping heavyweight thread or string at the base of the object or securing with a kamosage knot. Textural patterns can be created through spacing of the objects or sculptural forms can be developed by binding objects of different sizes into the same piece of fabric (Wells 1997).

Lengths of texture can be created by hand pleating a piece of fabric, then binding the narrow bundle either over itself or around a core, such as a thick cord, rope, or wood dowel. The binding thread secures the pleated length and adds cross-wise creases to the fabric (Figure 2c). Placement, spacing, and direction of the binding create different effects. For more irregular folds, the fabric length can be gathered, twisted, or braided prior to binding. Cross-wise creases can be eliminated by securing the bundle with wide strips of fabric. Another variation, contortion

pleating (Wolff 1996), is to twist the fabric into a rope until it coils upon itself (Figure 2d). The set result is multi-directional wrinkled folds.

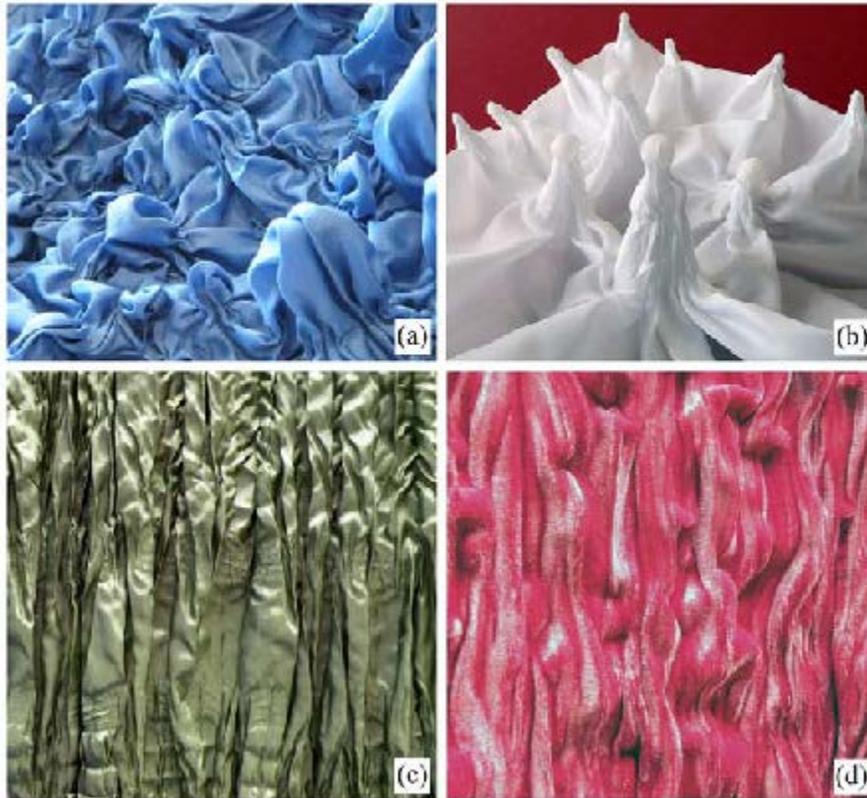


Figure 2. Binding heat-set samples: (a) bound loops (*miura shibori*) of differing sizes in polyester satin lining, (b) bound spires in spiderweb (*kumo shibori*) with wooden beads enclosed, and the small spires were folded 4 times prior to binding (*hon hitta kanoko*); fabric is polyester satin lining, (c) hand pleated and randomly bound polyester satin, and (d) coiled polyester/spandex velour. Photos by Sherry J. Haar.



Figure 3. Binding over objects heat-set samples: (a) glass marbles bound closely in polyester/metallic organza, (b) metal bobbins in polyester satin lining, (c) plastic interlocking bricks in nylon organza, and (d) plastic beads in polyester organza. Photos by David Mayes and Sherry J. Haar.

3.2. Stitching

Stitched shaping resists can be executed by hand or machine stitching. The hand process uses long millinery needles and heavyweight thread. Machine stitched resists can be sewn with sewing, pleating, or smocking machines. In addition, a gathering foot can be attached to conventional sewing machines for controlled gathers. The general process is to mark the lines, patterns, or shapes on the fabric as a guide for stitching, stitch the design, pull the threads to gather the fabric, and secure the threads. The heat-set fabric retains the gathered texture. Textural effects are determined by the stitch type, arrangement of fabric, stitched pattern design, and

stitch length, whereby the longer the stitch length the deeper the fold. Another consideration is compactness of pulled stitches which can range from tightly gathered to loose folds (Figure 4a).

Multiple rows of parallel running or gathering stitches are called shirring (Wolff 1996) or *mokume* (wood grain) shibori (Wada *et al.* 1999). After the stitching is completed the rows are drawn up and knotted. The heat-set result is undulating pleats. Fabric can be fully shirred over the entire piece, partially shirred, or shirred to create shapes or patterns. Stitch length and spacing between rows can be changed to vary the fold depth, and movement or direction of stitched lines (i.e., curved, chevron) provide design variations (Figure 4b).

Cross or waffle shirring involves stitching a grid of lines by hand or machine (Wolff 1996) (Figure 4c). The setting effect is an all-over soft looped texture. When stitching within the grid format, ensure the needle passes over previously stitched rows so not to impede the gathering. The fabric is gathered in one direction and then the cross-stitched lines are gathered. Design variations can be achieved by changing the size, spacing, direction, and movement of the grid lines. For example, diamond shapes emerge from unstitched areas between narrow stitched rows at an angle.

A stitching variation which creates a heat-set raised edge is fold-and-edge stitched resist (*orinui* shibori) (Wada *et al.* 1999) or pattern tucking (Wolff 1996). A fold line is marked, the fabric is folded, a running stitch is hand or machine sewn along the edge of the fold, and the thread is gathered tightly and secured. An alternative to the running stitch is to whipstitch or overcast over the folded edge (Figure 4d). The setting results are linear rope-like creases along the raised line. Variations for the fold-and-edge stitched technique are changing the stitch length and angle, the height of the fold, and the number folds stitched through at one time.



Figure 4. Stitched heat-set samples: (a) machine gathers pulled into a raised circle and hand tacked on nylon organza, (b) machine shirring in curvilinear sections on nylon organza, (c) cross shirring by machine on polyester/spandex velour and (d) fold-and-whipstitch multiple folds by hand on polyester satin. Photos by David Mayes and Sherry J. Haar.

3.3. Clamping

With the clamping method, called *itajime*, fabric is folded into deep accordion pleats that extend the length of the fabric (Wada *et al.* 1999). Traditionally, the fabric is narrow, ranging from 36 cm to 42 cm, which accommodates four to five pleats. The pleated fabric strip is then repeatedly reverse folded upon itself, either horizontally or diagonally, into a square (Figure 5a), rectangular or triangular form. The bundle is placed between two pieces of wood, and secured with c-clamps, hand clamps, or string. The heat-set results are alternating crisp folds across and down the length of fabric. When clamping, the fabric can be enclosed or extend beyond the board edges for

pattern effects. The extended fabric can be bound to create set peaks instead of crisp folds. Other variations include pleat width, shape of folded fabric, and shape and placement of the boards.

3.4. Pole wrapping

Wrapping and compressing fabric around a pole (*bomaki*) is another form of resist applicable to heat-setting. *Arashi shibori* (diagonal pole-wrap resist) is a form of pole-wrapping in which long narrow fabric is wrapped diagonally around a pole, wrapped with string, and compressed. The resulting pattern is diagonal folds on the bias. If the fabric is folded into deep pleats prior to wrapping and compressing the resulting heat-set folds will align as a chevron alternating the raised texture between the deep pleats. Heat-set patterns can be created by varying the fabric direction, twist, number and type of folds, and size, spacing and direction of binding; as well as, rewrapping previously heat-set pleats (Figure 5b).

Challenges for heat-setting pole-wrapped fabric are the pole must be able to fit inside the heating unit and tolerate the heat-set temperature. Poles are typically a few feet long. Heat-setting poles are much shorter, especially if using pressure cooker, therefore the processes of wrapping and compressing are done in smaller segments and repeated more often. Traditional poles were made from wood, but polyvinyl chloride (PVC) pipe or plastic drainage pipes are most often noted. As these pipes vary in wall thickness and heat tolerance, they should be tested for stability in heated conditions.

3.5. Other shaping methods

Scanning the environment for shaping possibilities can lead to unique heat-set forms. Fabric sandwiched between a jar and lid create a circular relief (Figure 5c). Interlocking or stackable molds are other options to sandwich fabric to create raised shapes. The grid or hex structure of wire mesh fencing works well to create repeating or all-over texture by pushing fabric through

the openings (Figure 5d). The fabric can be heat-set while in the fencing or the fencing can be used to hold fabric for binding. Aluminum foil also holds fabric in place for heat-setting. The foil can be folded to hold pleats (Wells 1997), slit to pull fabric through (Wada 2002), or crumpled to hold shape.

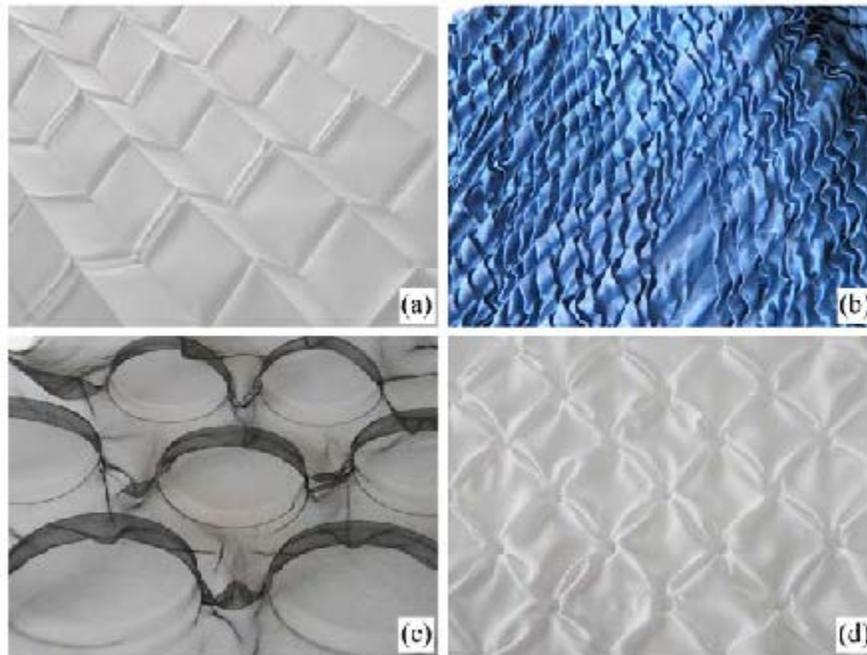


Figure 5. Heat-set samples: (a) clamped squares bound with string on polyester satin lining, (b) double-folded polyester satin lining was pole-wrapped, compressed and heat-set; then removed from the pole, turned at an angle, pole-wrapped, compressed and heat-set again, (c) polyester organza sandwiched between jars and lids, and (d) polyester satin lining pushed through wire mesh fencing in repeating pattern. Photos by Sherry J. Haar.

The possibilities for shaping fabric to create three-dimensional texture are endless. Possibilities abound in established, adapted, and combined techniques of binding, stitching, clamping, and pole-wrapping; as well as in the use of found objects and development of new methods for manipulating fabric. Throughout the exploration process several heat types (dry, liquid, vapor, and microwave) were used to heat-set shaped samples that yielded varying results.

With the goal to inform the studio artist and textile student of practices for heat-setting selected polyester fabric the following experiment was conducted.

4. Heat-setting experiment

The aim of the experiment was to apply a physical resist and heat-setting methods to polyester fabric specimens, and compare pre- and post-heat measurements. The heat sources used in the study were steam from a pressure cooker, dry heat from a conventional oven, boiling water in a pot, and microwave radiation from a microwave oven. A heating method not mentioned in the literature but accessible to the studio artist was a microwave oven and therefore was included in the study. As polyester emits a noxious gas when heated, care should be taken to not overheat or burn the fiber and to work in a ventilated area.

4.1. Specimen preparation

Two commercially available, lightweight 100% polyester fabrics, organza (25 g/m²) and satin lining (48 g/m²), were used for testing. Organza was selected due to its open weave and stiffness which held its shape with prior samples and the satin lining was selected due to its use in commercial heat-set products such as scarves and tops. Three specimens were prepared of each fabric for testing the four heat sources; thus, there were a total of 24 specimens.

Since no test methods were found to guide specimen preparation, binding and stitching techniques were experimented with, but rejected due to inconsistency across samples. The solution was to stitch and gather the fabric over a wood dowel which provided a means to control the fabric but did not interfere with heat transfer as wood is a poor conductor of heat.

Fabric strips were rotary cut 10 cm x 58 cm and a guideline was marked down the center of each strip using a permanent pen. Beginning 2 cm from the top edge of the fabric strip, seven cross marks, spaced 9 cm apart, were marked down the center guideline. To prevent the organza

fabric from shifting during marking and cutting, freezer paper was ironed to the fabric. When the shiny side of freezer paper is ironed to fabric, it serves as a temporary, removable stabilizer.

Wood dowels, 0.3 cm diameter x 61 cm, were marked with seven cross marks spaced 3 cm apart. As with marking the fabric, the first dowel mark was 2 cm from the top edge. The shorter distance between the markings on the dowel, 3 cm, compared with the markings on the fabric, 9 cm, provided guides for the fabric to be gathered to one-third of the original length.

A marked dowel was placed on a fabric strip along the center guideline and stitched down the length of the fabric with a sewing machine zigzag stitch. A beading foot was used to align the dowel and accommodate its diameter. The fabric was evenly gathered up the dowel, aligning coordinating cross marks between the fabric and dowel. Hence, the fabric was gathered to one-third its original length, from 54 cm to 18 cm between end markings. Each end was secured with stitching. The excess dowel length was snipped off using needle nose pliers.

4.2. Heat treatments

Three test specimens of each fabric, measuring 18 cm of gathered length, were heated for 30 minutes using heat options readily available to the studio artist. The heat types and sources included steam from a pressure cooker, boiling water in a stock pot, microwave radiation from a microwave oven, and dry heat from a conventional electric oven. After 18 h the fabric specimens were removed from the dowel and post-treatment measurements were recorded.

The procedures for steaming in a pressure cooker included a 20.9 L pressure cooker with 6.8 kg (15 psi) of pressure that was filled with water to one inch below the cooker's wire rack. A specimen was placed on the rack, dowel side up. The cooker was heated on high using an electric stove top range. Once the cooker's valve began to rattle, indicating that 6.8 kg (15 pounds) of pressure was achieved, the sample steamed for 30 minutes. At this pressure the temperature is

approximately 122°C. When the cooker cooled down enough to remove the lid, the specimen was removed and placed on a towel to dry. The procedure was repeated for the remaining specimens.

The boiling method used a 20 l stock pot filled with enough water to cover the specimen, which was placed under a wire rack to ensure immersion yet prevent the sample from touching the bottom of the pot. The pot was covered with its lid and heated to boiling using an electric range. The boiling temperature was 98°C in accordance with the location elevation. After 30 minutes at boiling the pot was removed from the heat source, the specimen removed and placed on a towel to dry.

Radiation was conducted with an 1100 W microwave oven with a turntable system. A specimen was placed dowel side up on the turntable and heated for 30 minutes at 80% power. The time and power were determined through experimentation as the highest power that did not burn the fabric.

The dry heat source came from an electric conventional oven heated to 202°C. The specimen was placed dowel side up on a piece of aluminum foil on an aluminum baking sheet and heated in the oven for 30 minutes. As with the microwave oven, pre-trials were run to determine which temperature softened, but did not burn the fabric.

4.3. Statistical analysis

Data were analyzed using the General Linear Model (GLM) procedure of SAS 9.2 for two-way analysis of variance (ANOVA), with heating method and fabric type as treatment and length as the dependent variable. A two-way ANOVA is appropriate to use when determining how a response is affected by two factors. Post hoc test of Least Significant Difference (LSD) was

conducted to compare cell means. As the overall number of pairs was small, Tukey’s Honestly Significant Difference (HSD) test was also conducted to address overall experiment error rate.

5. Results and discussion

The GLM ANOVA with heat source (pressure cooker, boil, microwave, or oven) and fabric type (organza, lining) as independent variables and length as the dependent variable yielded a significant interaction between fabric type and heating method (Table 1). Thus, indicating that the type of heating method used and fabric selection did have an effect on length. The variation in length was $r^2=.938$, suggesting the model fit well.

Table 1
Analysis of Variance for Length

Source	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Pr>F</i>
HEAT	3	28344.50	9448.16	70.38	<.0001*
FABRIC	1	150.00	150.00	1.12	0.3062
HEAT × FABRIC	3	3861.33	1287.11	9.59	0.0007*
Error	16	2148.00	134.25		

* $p<.05$

Post hoc LSD and HSD were conducted to compare means in order to examine the nature of the significant interaction between heating method and fabric type. Table 2 presents the interaction means. Significant differences between mean interactions are indicated in Table 3. The length means for interaction between each fabric heated in the oven compared to the pressure cooker were not significantly different from one another when examined with the HSD test; however, the lining and pressure cooker mean did obtain significance from these pairs using the LSD test (Table 3). These findings suggest that the oven is an effective method to heat-set shaped polyester fabric similar in structure and weight to organza and lining, while the pressure cooker is recommended for fabrics such as organza, but may not be as effective heat-setting a slightly heavier lining weight.

Table 2
Length Means (mm) for Fabric Type and Heating Method

	Fabric Type	
	Organza	Lining
Pressure Cook	181.667	213.333
Boil	291.667	240.667
Microwave	291.000	256.000
Oven	183.333	185.667

Each cell $n=3$.

Table 3
Significant Differences between Interaction Mean Comparisons

Fabric \times Heat	Comparison to	<i>M</i> Difference
Org \times Micro	Lin \times Micro	35*,**
Lin \times Micro	Lin \times Boil	15.33
	Org \times Boil	36.33*,**
Lin \times Boil	Org \times Boil	21*
	Lin \times PC	27.33*
	Lin \times Oven	55*,**
Org \times Boil	Lin \times PC	6.33
	Lin \times Oven	34*,**
Lin \times PC	Lin \times Oven	27.67*
	Org \times Oven	30*
	Org \times PC	31.67*
Lin \times Oven	Org \times Oven	2.33
	Org \times PC	4
Org \times Oven	Org \times PC	1.67

*= $LSD > 20.06$; **= $HSD > 32.8$

The difference in temperature between the oven and pressure cooker (202°C and 122°C) may explain why lining heat-set in the pressure cooker did not retain its set shape as well as lining in the oven. The pressure cooker temperature of 122°C is lower than the 190°C softening temperature for polyester. However, the melting curve could be lowered due to the presence of

moisture (Hearle 1971). An explanation for the set differences between lining and organza in the pressure cooker is that the open weave and lightweight of the organza may have responded to the moisture in the cooker. It is interesting to note that polyester does not necessarily need to be heated to the recommended 200°C for a good set. This supports the finding that polyester crystallizes through temperature ranges. At lower temperatures molecules are organized into new bonds, while at higher temperatures ideal crystallites are grown (Gupta 2002).

The average set length difference for satin lining between the oven and pressure cooker treatments was 3 cm. In practice this difference may not impact the aesthetic intent of the design. Of consideration though is the limited space of the pressure cooker (29 cm diameter × 26 cm) compared to the conventional oven (58 cm × 48 cm × 48 cm). A longer (23 cm × 137 cm), but more expensive option for pressurized steam setting is a professional vertical textile steamer.

Even though the dry-heat method of the oven closely retained the manipulated lengths of fabric, the appearance and hand of the organza fabric changed. The pre-treatment organza was white, while the post-treatment fabric yellowed and stiffened. Further testing at lower oven temperatures may prevent the discoloration and hand change, while still maintaining the set. Another consideration is to introduce moisture to the oven by placing a tray of water on the lowest rack and the fabric on a higher rack.

The remaining significant mean differences with HSD (Table 3) occurred between boiling and oven treatments, microwave lining and boiling organza, and fabric type with microwave treatment. These findings suggest that boiling performs better than the microwave as a heat-setting method; however, both are inferior to heat-setting in the oven or pressure cooker. An explanation for the poor performance of boiling is that the 98°C temperature was lower than the pressure cooker and oven temperature treatments. A reason for the microwave's poor ability

to reshape the polyester could be that microwaves randomly bounce through the oven and thus would not evenly nor consistently provide heat to the fabric.

6. Conclusions

Based on the results of the study, use of an electric oven to heat-set gathered lightweight organza and lining is effective in shaping the fabric to nearly retain the resisted size, while the pressure cooker is most effective for sheer lightweight fabrics such as organza. Both boiling and use of a microwave did not retain the resisted shape of either fabric as well as the other two methods.

Even though the oven best retained the resisted shape, the hand of the organza became stiff and the color darkened. Therefore, based on the data and visual evaluation of the specimens, steam is recommended for sheer fabrics such as organza and dry heat from the oven is effective for heat-setting lining weight fabrics.

7. Future direction

A challenge noted was working within the confines of the pressure cooker. The oven does provide an overall larger space; however, the dry heat can burn and discolor lighter weight fabrics. A future direction is to establish a method that incorporates steam while heat-setting in the oven.

The application of dyes with shape-and-heat-setting processes is another research direction of interest to the studio artist. Considerations are the lower temperature at which the dyes are set compared to the temperature at which the fabric is set; as well as the presence of moisture which can aid in dye uptake.

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