

Variables and Methods for Aesthetic Braid Design

Amanda Bicking and William Oxenham

College of Textiles
North Carolina State University
Raleigh, NC 27695-8301
USA

ABSTRACT

The paper describes a study which identified how various yarns, their corresponding spool placement, and interlacements affected the structure, appearance, and shape of a tubular braid. By replacing one certain element or variable of the braid structure with a differing variable, (i.e. color, fiber, spool placement, or interlacement structure), a variance is created, in a similar way to the creation of special effects in a fancy yarn. Though there were several machines available for braid production, the Cobra 450 Maypole braider was chosen to fabricate the experimental products due to its ease of operation, manipulation, and spool replacement. This unit produced hollow braids that allowed the structure to be utilized with or without a core; the machine was also capable of fabricating flat braids through the depression of the tubular structure and stitching the braid flatly in place. By producing a series of braids, an improved comprehension of machine settings, material choice, and placement of yarns was achieved, while simultaneously fabricating a heightened design aesthetic in producing visual effects. Experimental design studies within the preliminary work included color pattern development and structural effects. Imagery of the variety of designs produced is included along with an analysis of all braid designs.

Keywords: Braiding, fancy braids, three-dimensional braiding

Introduction

Historically, the field of textile braiding has had little documentation in comparison to its other textile fabrication counterparts. The rise of composite manufacturing has led to greater interest in research in three-dimensional braiding and mandrel preforms, however the gamut of possibilities offered by more simple industrial braiding machines has been scarce. Specifically, research into the potential of fancy braids and their possible end uses has been limited.

To overcome this void, an investigation was conducted to determine the potentials of fancy tubular braids. The overarching objective was to create an assortment of fancy braids through exploration of diverse desired attributes and testing. The goal of the study was to identify how various yarns, their corresponding spool placement, and interlacements, affects the structural and mechanical properties, appearance, shape, and performance of a tubular braid. By replacing one certain element or variable of the braid structure with a differing variable,

(i.e. color, fiber, spool placement, or interlacement structure), a variance is created, much like that encountered in fancy yarn. Fancy yarns are regarded as any yarn which has deliberate inconsistencies applied during processing, including variation in diameter, character, or color of the yarn (Meadwell, 2004) and the same principal applies to fancy braids.

The research outlined in this article describes the aesthetic design opportunities for fancy braiding. Color and structural designs were developed, recorded, and descriptions of the braid attributes were recorded. Causal relationships could then be determined, such as which fiber attributes are valuable to the structure of the braid and how the pattern and spool placement influences the tubular braid. At the conclusion of the research, one can determine specific relationships between yarns and their spool placement and discover the magnitude of possibilities offered even by a simple braiding machine.

Braiding Overview

Though a variety of different methods may be employed in the production of braids, the fundamentals of the braided structure remain the same. Braiding creates a textile product that involves the interlacement of yarns in a bias, diagonal formation. Ribbonlike or ropelike textures can be formed through the interlacement of one set of threads so that no two adjacent threads twist around each other (Brunnschweiler, 1953). Furthermore, Pal, Thakare, and Kamruddin (2005) define braiding as “a process of interlacing three or more strands of yarn in such a way that each strand passes over and under one or more of the others and are laid together in diagonal formation” (p. 52).

Braiding can be created by hand techniques or through the use of an industrial machine. Though the possibilities of hand braided structures are abundant (hand braiding allows each individual yarn to be controlled, much like a Jacquard loom in weaving), industrial braiding is limited to seven categories of braid design. Braids

within these categories include flat, tubular, square, soutache, fancy, 3-D rectangular, and 3-D tubular.

Tubular braids have two distinct groups of strands in which one group spirals and interlaces in a clockwise direction, while the other travels and interlaces in a counterclockwise direction (Brunnschweiler, 1953). The counterclockwise and clockwise routes cause the sets of yarns to intersect in a full circular path, with each set of yarns moving simultaneously, resulting in a tubular structure. Each set of yarns, traveling either counterclockwise or clockwise, will never intersect with those sequential yarns moving in the same direction. Additionally, the tubular braid may be formed around a solid core of material, pulled around a core, or left hollow. A core can provide a set diameter, assure even tension, and offer rigidity; a core could also be another braid which has been overbraided.

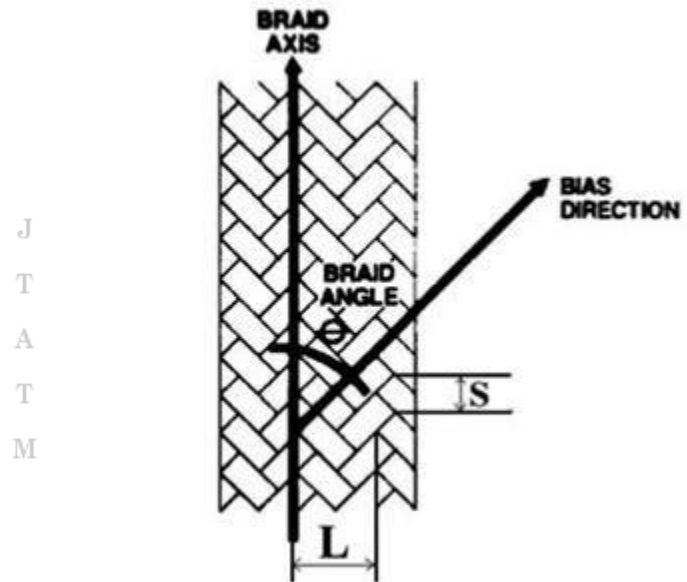


Figure 1. Braiding Geometry (Omerglu, 2006, p.1)

Common tubular braided structures involve the interlacing of an even number of yarns, leading to diamond (plain), regular (twill), or Hercules (panama) interlacement

that can either be two or three dimensional (Ratner, 2004). These structures are characterized by their interlacements and are similar to woven fabric constructions of 1/1 plain, 2/2 twill, and 3/3 twill when turned on a 45 degree bias (Pal, 2005). More constructions such as 2/1 and 3/1 interlacements are possible, but have no formal name. As many tubular braiders run a 2x2 interlacement on Maypole machinery, a diamond or basket stitch (1x1 interlacement) can be produced on a tubular braider by removing every alternate carrier or to run the carriers in pairs (Douglass, 1963). A 2x2 Maypole braider may also be modified to produce a 2x1 interlacement; by removing ¼ of the spools, and ensuring that the spools move in the correct 2x1 path, this type of interlacement can be created.

Fancy braids have a less concrete definition in terms of development and braid architecture. The term ‘fancy’, or ‘lace braid’ is assigned to any braid which is not of a uniform flat or tubular construction. The association between regular and fancy braids is equivalent to that between regular and fancy yarns (Brunnschweiler, 1953). Nicolas Reiser (1907) provides a simpler definition, “an irregularly braided fabric” (p.135). Types of fancy braids are numerous and can include variations in structure, color, interlacement type, etc. Yarn tension can additionally be controlled to create tight and loose sections in the braid, resulting in lace or ornamental fabrics (Ko, 1989).

Braiding Geometry

Many attempts at a standard nomenclature such as picks, ends, stitches, lines, etc have been outlined by authors such as Douglas (1963), Rawal (2005), Omerglu (2006), and Brunnschweiller (1953). The simplest approach is that shown by Omerglu (2006) in Figure 1. The diagram displays picks “s”, lines “l”, the braid axis, and the braid angle. In addition, pick count is an important term in reference to braiding. This

refers to the number of picks per unit length in a line parallel to the braid axis and can be used as an identifier of braid size and compaction. Within the study, picks per inch were referred to in identifying constructed braids.

Braid angle is an additional descriptor in identifying braids of the same interlacement type and material. In Figure 1, the symbol θ represents the braid angle in which the braid angle is the area between the vertical braid axis and the bias formation of the yarns from the carriers. As the structure of the braid is extended and contracted along the braid axis, the braid angle as a result, will increase or decrease (Omeroglu, 2006). The take-up rate of the machine furthermore has an important role in the extension and contraction of the braid and braid angle; a slow take-up rate produces a close braid with a high pick count while a rapid take-up rate creates a loose braid with a low pick count.

Industrial Machinery

The braiding apparatus utilized within the research involved a twenty-four spool Maypole braider. With Maypole braiders, a number of carriers move in a predetermined order along continuous serpentine tracks. These carriers contain spools of yarn which are crossed and recrossed as they move over and under each other due to the clockwise and counterclockwise carrier movement. As each set of threads run in opposite directions under and over each other, the yarns are drawn to a central point (known as the braiding point), and the braided structure is then pulled up and wrapped around a roller. An example of a Maypole braider and its components can be referenced in Figure 2. Details of the drive of the carriers and the mechanism for interlacing are described in detail by authors such as Douglas (1963), Ko (1989), Brunnschweiller (1953), and Bicking (2011).

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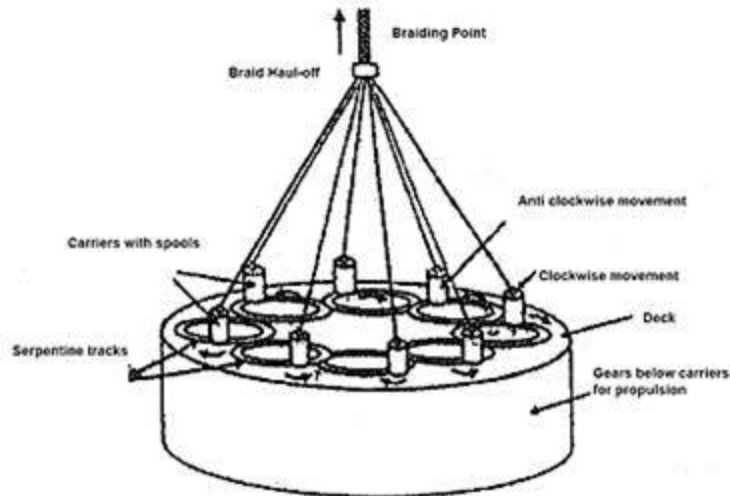


Figure 2. Components of a Maypole Braider (Pal, 2005, p. 53)

As previously stated, the take-up reel has an integral effect on the braid diameter and tightness of interlacement in addition to its purpose of drawing up manufactured braids. To produce a quality braid it is critical to draw the finished product from the machine smoothly and at a uniform rate. A slight jerk will open the braid and the pause will cause crowding and bunching (Douglass, 1963). A slow take-up speed confers a close braid and a high take-up speed a loose braid; gears are used to control the take-up motion and speed of the braid. These can be in the form of interchangeable gears or programmed to be switched in an electronic braider.

Color Pattern Design

As there is no formal method of braid color pattern development, experiments were designed to identify how specific spool placements on a Maypole braiding machine could produce certain patterns. As braids were produced, an improved comprehension of machine settings, material choice, and placement of yarns was achieved, while simultaneously fabricating a heightened design aesthetic in producing visual effects. Aesthetic properties were assessed due to the impact of spool placement, materials, and yarn color in the following trials; specific studies in color and structural design were

undertaken to design a diverse analysis of fancy braids.

All braid color studies adopted a series of yarns adhering to the same, unvarying properties aside from color. The yarns chosen for the study were false twist textured Polyester, 650 denier count, 288 filaments. The colors implemented within all studies were orange, brown, white, and blue as these yarns were readily available. Color patterns were developed among the three attainable interlacement paths on the Cobra 450 machine: 1x1, 2x2, and 2x1 structures. To aid in the prediction of braid color patterns, spools were placed in alternate sequences according to strand and spool number; in addition, woven color effects were designed and applied to the braided structure. To produce the desired braid effect, woven color patterns were designed on a grid and then rotated 45 degrees to visually observe the braid pattern; the rotation of the grid was necessary to represent the diagonal helical path that yarns of a braid follow within the tubular structure (figure 3). It should be noted that this rotation was purely for illustrative purposes, the actual braid angle of each braid varies due to the take-up rate, diameter of the yarn, interlacement structure, etc. Though these patterns could be constructed utilizing woven color effect strategy, an important variable lay in the mechanical carrier path;

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spools mounted on carriers followed opposing serpentine routes, differing from the vertical and horizontal layout of a woven product. Due to this factor, color

arrangements had to be carefully considered when translating the point paper design to the actual braided structure.



Figure 3. Woven Color Strategy for the Development of Zig-Zag Stripes



Figure 4. Braid Template

More arduous patterns utilized a braid template (Figure 4) in which all twenty-four spools were prepared with differing colors and labeled with unique numbers; spools following a clockwise path were labeled with even numbers while those moving counterclockwise were assigned an odd number. Each pick could be selected from the braid template to be replaced with a color of the desired pattern. Once the desired pick was selected, it would be referenced to its spool number and replaced with the appropriate color to create the desired pattern (Figure 5).

Two and three-color designs were explored by the careful manipulation of spool placements in each colorway. In order

T to provide instruction on how to achieve the
A color patterns, a diagram was developed in
T which sequential numbers represented
M different colors within each carrier mount
for spools. Diagrams ranged from even,
symmetrical patterns to more complex
patterns with uneven numbers of colors and
placements. Selected patterns from each
interlacement structure are represented,
though a full range of patterns are not
included in order to condense the research
findings. To see all patterns developed,
please refer to the author's previous work
("Explorations in Fancy Braid Creation
Through the Use of Industrial Machinery", a
Master's Thesis (Bicking, 2011).

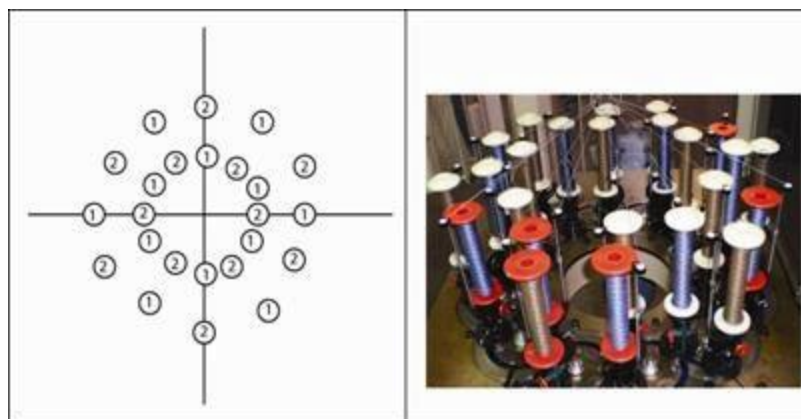


Figure 5. Spool Arrangement Diagram

2x2 Interlacement Patterns

Braids showed in Figure 6 display some of the patterns developed under a 2x2 interlacement structure. In order to achieve this formation, all twenty-four carriers had to be filled with spools. The first series of braid patterns were designed to develop samples derived from an even number of each color. To further illustrate, half of the carriers were mounted with spools wound in

blue, while the other half were filled with spools of brown. Twelve spools of each color were wound on a Herzog spool winder and transferred to the Cobra braiding machine. To produce a braid that was considered the appropriate size in diameter and braid pattern for visual observation, the machine was set up for 12 picks per inch for all 2x2 braids (Bicking, 2011).



Figure 6. 2x2 Two-Color Braid Patterns: 1. Horizontal Zig-Zag Stripe 2. Pinstripe 3. Argyle 4. Thin Diamond 5. Thick Diamond

In order to develop a “pinstripe” pattern, the pattern was first drawn on point paper and then sequentially placed spools of each color on those carriers advancing in the same direction. For example, all brown spools were placed on carriers moving clockwise, while all blue spools were

assigned to those moving counterclockwise. Alternatively, by interchanging spools containing brown and blue threads in the direction of the carriers, a horizontal zig-zag stripe could be developed; the clockwise spools alternated between blue and brown spools sequentially along the circular path,

while the same sequence occurred in the counterclockwise direction. Figure 6(#1)

displays the zig-zag pattern, while Figure 6 (#2) shows the pinstripe pattern.



Figure 7. Three-color 2x2 Patterns: 1. Three Color Spiral Stripe 2. Three Color Zig-Zag Stripe 3. Checkmarks 4. Racing Stripe

The three other patterns had more intricate spool set-ups for each colored yarn. Instruction for creating these patterns can be found within the spool set-up guides referenced in the author’s previous work (Bicking, 2011). In order to achieve those more randomized patterns, experiments in color effects were constructed through the interchanging of spool location and color. Figure 5 shows an example of the spool diagrams developed in order to document the method of creating color patterns. The diagram represents each of the twenty-four spool carriers and has a number to represent a color. The diagram found in Figure 5 would represent a two color pattern.

Once two-color patterns options were exhausted, experimental trials in three-color patterns were undertaken utilizing the same pattern prediction strategies. Four specific patterns were developed which included a three-color spiral stripe (Figure 7 #1), zig-zag stripe (#2), checkmark pattern (#3), and a racing stripe (#4). In order to achieve a three-color spiral stripe, spools moving clockwise were placed in the

sequence: blue, white, blue, white, blue, white, orange, white, orange, white, orange, white. Those spools traveling counterclockwise followed the same sequence. To further illustrate, all white spools were placed on the outside carriers, while half of the blue and orange spools were placed on each half of the inner carriers.

The third “checkmark” pattern was achieved by placing all clockwise and counterclockwise spools in the order of blue, brown, and white on all carriers residing on the machine. A subtle racing stripe pattern was discovered when an orange, then blue, and another orange spool were placed in sequence on three carriers with the remaining carriers filled with brown spools; this pattern was simple to design and execute from point paper diagram. The three-color zig-zag stripe was considerably more arduous to fabricate with a more complicated spool set-up.

1x1 Interlacement Patterns

To prepare the machine for a 1x1 interlacement, half of the spools were removed from the Cobra 450 in order to leave only twelve spools mounted on the carriers. To ensure that the correct interlacing of threads was accomplished, care was taken to confirm that six of the twelve spools moved in a clockwise direction, while the remaining six circled in a counterclockwise motion. If the spools were not evenly separated to circle in opposing motions, the braid would create areas of twisted yarns, rather than the

interlacing required for braided products. Spools were grouped in twos and were placed at every other grouping. For example, two spools were loaded on the carriers, while two carriers were left vacant. Figure 8 shows this setup; all circles with a bar over them represent those that are empty. To maintain consistency of pattern and braid size, all 1x1 braids were constructed at 16 picks per inch since this produced the most visually pleasing pattern size when observing the braid.

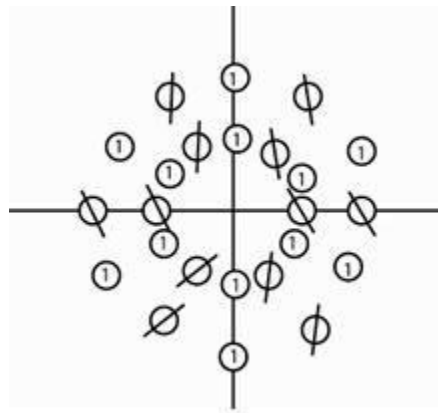


Figure 8. 1x1 Spool/Carrier Arrangement

The first pattern created was a thin diamond pattern in which ten spools were wound in brown yarn and two spools were wound in white; the two white spools traveled in opposing directions to create the intersecting diamond shape. Thicker diamond patterns were created by adding two more white spools in each direction; the first set-up had four white spools and four brown spools, with the white spools moving in adverse directions. The second set-up

J added one more white thread in each
T direction for a total of six white spools and
A four brown spools; three white moved
T counterclockwise, the other three moved
M clockwise. The second set-up not only
created somewhat of a thicker diamond
pattern, but led to areas of color blocks
which created a much different pattern
than the first diamond pattern. The braids
in Figure 9 (#6, #7, and #8) show these
patterns.



Figure 9. 1x1 Two-color Patterns: 1. Diagonal Stripe 2. Pinstripe 3. Small Chain-like Pattern 4. Large Chain-like Pattern 5. Twisted Pattern 6. Thin Diamond 7. Thicker Diamond 8. Thickest Diamond (Color Block)

A two-color diagonal stripe was created by alternating colors on carriers moving along the same route. The braid created in this experiment switched brown and blue spools on each carrier moving clockwise and then interchanged brown and blue spools on those carriers moving counterclockwise. These spools were grouped by colors, alternating each color

group for each available carrier. The final braid can be found in Figure 9(#1). 1x1 structures created pinstripe patterns as well as the 2x2 braids. The pattern was created by placing six brown spools on those carriers traveling clockwise and placing six white spools on those carriers moving counterclockwise. Figure 9 (#2) shows this pattern.

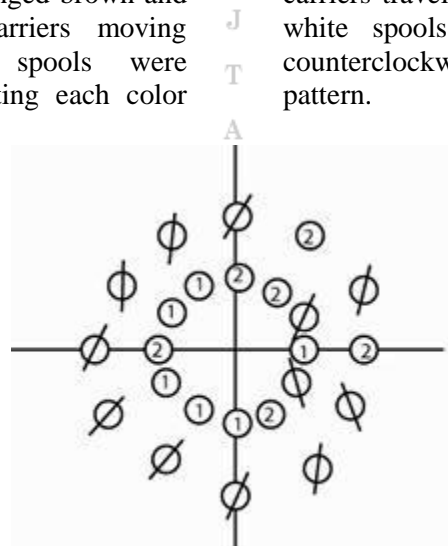


Figure 10. Spool Set-up for Chain-like Pattern

A unique pattern created that was anomalous to the 1x1 interlacement was one that had a chain-like appearance. Two braids exhibited this type of pattern, though one was much larger than the other. The first braid had six white and six brown spools with a specific arrangement shown in Figure 10. Those spools moving clockwise alternated between white and brown, while those moving counterclockwise had three white spools advancing in a row, followed by three brown spools. The second braid with the larger chain pattern was achieved

by adding two more white yarns that were both moving counterclockwise; this pattern utilized the same clockwise arrangement as the first pattern, but the counterclockwise movement had five white spools moving in a row, with only one brown spool following. Both patterns can be found in Figure 9 (#3 and #4). All other braids had more difficult spool set-ups to achieve the resulting patterns. The diagrams for these braids may be referenced in the author's previous publication (Bicking, 2011, p. 116)



**Figure 11. 1x1 Three color patterns: 1. Miscellaneous Pattern #1
2. Three-color Line Pattern 3. Miscellaneous Pattern #2
4. Miscellaneous Pattern #3**

Conforming to the same strategy utilized within 2x2 pattern construction, both two and three-color 1x1 patterns were fabricated. The first pattern achieved (Figure 11 #1) was created by placing four orange spools on those carriers moving clockwise, four white spools placed on those moving counterclockwise, and then placing two blue spools in each direction. When constructing the second 1x1 three-color pattern, orange, blue, and white spools had to be placed in sequence while moving in both directions; the specific arrangement created a pattern of lines in each color. The pattern found in Figure 11 #4 was created by placing two orange, two blue, and then two white colors in sequence moving in both clockwise and counterclockwise directions.

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The third pattern had more random spool arrangements that would need to be represented in a spool diagram.

2x1 Interlacement Patterns

The final interlacement pattern achievable on the Cobra 450 was a 2x1 arrangement. In order to prepare the machine, carriers were modified by removing six of the spools from the twenty-four spool arrangement; eighteen spools remained to form the interlacement. Manual rotation of the carriers was necessary to ensure that each spool revolved in a 2x1 or 1x2 fashion in order to create the proper thread interlacing. Figure 12 displays the setup; all circles with a bar over them represent those that are empty.

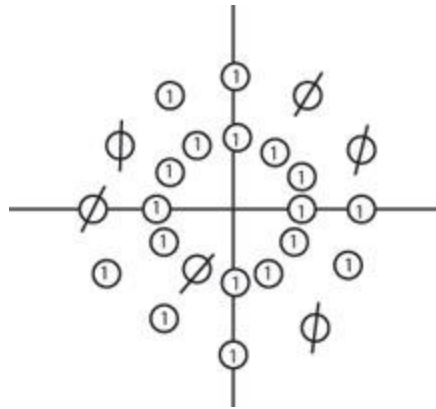


Figure 12. 2x1 Spool/Carrier Arrangement

To develop the second braid shown discovered in Figure 13, all white spools had to be placed one half of the machine, while all blue spools occupied those carriers on the other half; the specific spool arrangement allowed three white and three blue spools to travel clockwise, whereas the other consecutive white and blue spools traveled counterclockwise. The pinstripe pattern (Figure 13 #3) was developed by placing all white spools on those carriers traveling clockwise and all blue spools on carriers traveling counterclockwise. Residual 2x1 two-color braids required more complex spool arrangements; those braids not

described above can be viewed within Figure 13.

Lastly, 2x1 three-color pattern studies were undertaken, developing eight patterns that were fabricated through the adoption of orange, white, and blue colors. The first braid constructed (Figure 14 #1) was achieved by placing three orange, three white, and three blue in succession in both the clockwise and counterclockwise directions. The second braid created somewhat of a three color spiral pattern by placing a white, blue, and orange spool in order and repeating around the circular area in both directions of carrier movement.

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Figure 13. 2x1 Two-Color Patterns: 1. Miscellaneous Braid #1
2. Color Blocks 3. Pinstripe 4. Miscellaneous Pattern #2
5. Double Cross Pattern

Figure 14 #4 formed a pattern that had blue and white blocks of color, with orange crosses through the blocks; this design was conceived by placing four blue

threads in a row, then one orange, then four white threads in the clockwise direction. The same sequence was used in the counterclockwise direction; all eight blues

and all eight white threads were grouped together. The fifth braid utilized the spool arrangement of the pinstripe pattern formed within the two-color study; the only exception was that an orange spool was positioned on carriers moving in each direction. The third pattern had a complex arrangement which can be explained by its spool diagram.

Structural Design

Yarns with various extension properties were chosen to integrate within braids to determine their influence on the braided structure. The materials chosen to place within braids included boucle nylon yarns, wire, monofilament nylon, and elastane; these yarns were appointed specific spool placements to influence structural differences between braids. Additional materials were also explored in the author's previous research.

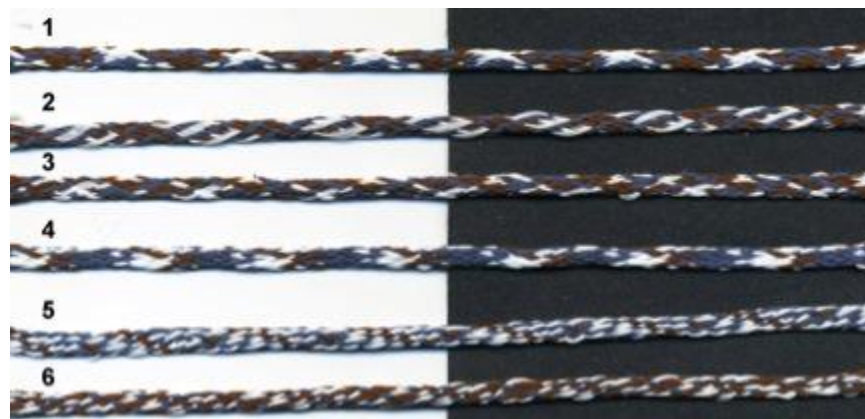


Figure 14. 2x1 Three-Color Pattern: 1. Color Blocks 2. Three-Color Line Pattern 3. Miscellaneous Pattern #1 4. Color Block #2 5. Pinstripe Variation 6. Miscellaneous Pattern #2

Boucle Studies

A study was designed to observe the effects of large diameter yarns paired with their thinner counterparts. Varying the take-up was essential to the process since changing the picks per inch significantly affected the profile of the resulting braid. A boucle yarn and a thicker Antron Lumena

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carpet yarn was integrated into the braids in this part of the study. The boucle yarns were encased in the polyester structures used within the color studies. These boucle studies were carried out on all three interlacement types to detect any distinctiveness within braids.

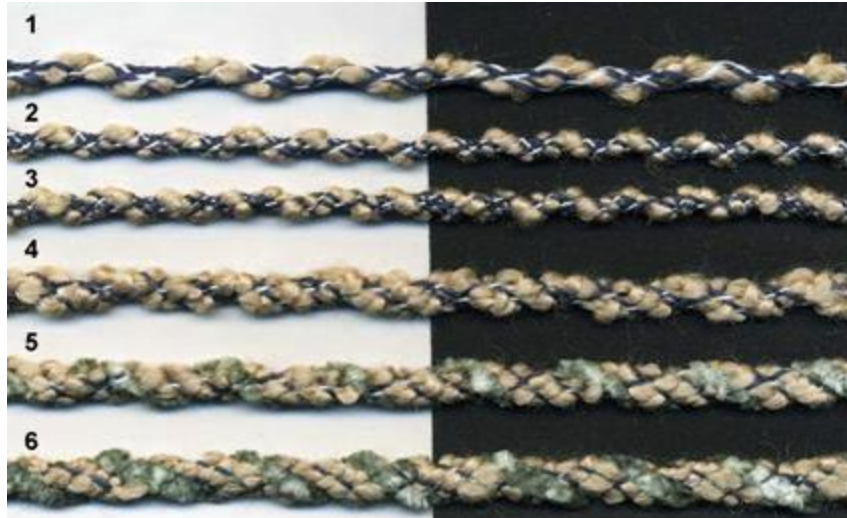


Figure 15. 1x1 Boucle Studies: 1. 16 ppi Opposing Two Boucle 2. 26 ppi Opposing Two Boucle 3. 26 ppi Opposing Four Boucle 4. 16 ppi Opposing Four Boucle 5. 16 ppi Four Opposing Boucle, 1 Pseudo Chenille 6. 16 ppi Four Opposing Boucle, 2 Opposing Pseudo Chenille

All braids developed similar structural trends with little variance among interlacement types. Most braids integrated boucle yarns following in the same direction as the previous boucle yarn before it to create helical structures. Some braids placed boucle yarns in opposite directions of each other, creating a more wavy path rather than a helical one. As the take-up rate decreases (and picks per inch increase), the helical structure becomes more defined due to the compression of the braid and its picks. Figure 15 shows an example of braids created under a 1x1 interlacement structure. A difference in size and compaction can be viewed between braids one and two and four and three. The third braid displays a looser, large diameter braid, whereas the fourth shows a more compacted braid.

Wire Studies

It was hypothesized that placing wire yarns in both directions of the tubular structure would open up the braid and keep it from collapsing into a flat tubular formation. To provide adequate volume to visually note the braid expansion, the machine was set at 12 picks per inch. The first sample (Figure 16) used four wire spools moving in adverse routes. The second braid (Figure 16) used six wire spools with half moving clockwise while the other half traveled counterclockwise. The final braid of the series (Figure 16.3) utilized eight wire spools and sixteen polyester spools; in this set-up, four traveled clockwise and the remaining spools followed the counterclockwise path.

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Figure 16. 2x2 Wire Studies: 1. 12 ppi Four Wires, Opposing Directions 2. 12 ppi Six Wires, Opposing Directions 3. 12 ppi Eight Wires, Opposing Directions

Nylon Monofilament Studies

A nylon monofilament was interspersed within 2x1 braids made from polyester yarns. Due to its high rigidity, the monofilament was chosen to integrate into braid structures to assess any effects it would have on the braid's construction.

The braid was fabricated by placing one monofilament spool among seventeen polyester spools. Due to the monofilament's rigidity, the material did not conform very easily to the spool and proved difficult to control and wind; it was found that only one monofilament could be integrated within the braid without causing severe complications during processing. Since more than one monofilament spool was placed on the machine, the uncontrollable unwinding of the yarn would catch onto to other spools and monofilaments, causing tangling and producing knots. Each time these faults occurred, the machine would have to be stopped and shut down. Though one spool was difficult to control, it could be kept from causing problems if the machine was run at a slow speed (Figure 17).

Results and Discussion

Patterns created from the three interlacement types were assessed for differences and similarities. Though a few

similar patterns were developed between interlacement structures, the patterns could never be exact due to the differences in thread density and interlacement path. In addition, the diameter between braids of different interlacement structures would grow as each braid required more or less yarns within its structure.

The image in Figure 18 shows an example of a pinstripe pattern that can be identified among all three interlacement patterns. One can notice the similarity of the pattern itself, but each braid varies with interlacement type. Figure 18 shows a 1x1 structure in which white picks are evenly distributed among brown picks. The formation of this pinstripe pattern can be easily understood; as all brown spools moved clockwise and all white spools moved counterclockwise, the over-one-under-one nature of the 1x1 interlacement pattern would allow for one brown and then one white pick to form continuously along the braid helical path.

The more randomized pinstripe pattern of the second braid (Figure 18.2) was created through a 2x1 interlacement pattern. Just as the 1x1 pattern was constructed by mounting all of one color moving clockwise and the other color moving counterclockwise, the 2x1 and 2x2 pinstripe

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patterns were also constructed through this arrangement. The differing interlacement constructions had an effect on the layout of the pattern. With the 2x1 pattern, the more randomized layout of picks was achieved due to the uneven architecture of the interlacement. The 2x2 pattern had a more defined line down the vertical axis of the braid, rather than the more “dotted” line of the 1x1 structure. The nature of the 2x2 interlacement path allowed for the spools to pass over a color of its own and an opposing color at the same time, leading to the line pattern.

Figure 19 displays the thin diamond pattern achieved among the three types of interlacements. As more yarns were added, the length of the diamond grew due to the additional picks. The spacing between picks can be varied between interlacements; for example, the 1x1 pattern had less distance between white picks, forming a more defined solid line at the diamond intersection points. All thin diamond patterns were created with the same spool set-up strategy; one of the spools filled with the diamond color moved clockwise while the other spool moved counterclockwise.

A reoccurring pattern discovered among interlacements was a “color block” pattern (Figure 20). In the 1x1 and 2x1 patterns, the yarns formed more star-shaped blocks of color, whereas the 2x2 interlacement created actual solid areas of color with pinstripe patterns in between. The 2x2 braids developed a more argyle-like pattern rather than just color blocks. As the 1x1 and 2x1 did not have as many yarns within their carrier set-ups, the more complex argyle pattern could not be completed. These interlacements additionally could not complete a pinstripe pattern between color blocks due to their lack of yarns; rather, more helical dots occurred between color blocks. Larger braiders holding significantly more spools with complex interlacements have the capability to produce more defined argyle patterns; these braiders additionally can produce the argyles in a multitude of colors. The argyle pattern formed in Figure 20 was

the limited pattern achievable on the Cobra 450.

Though following the same spool set-up configuration, different interlacements could produce completely different patterns. An example of this occurrence can be found in Figure 21. This arrangement grouped spools in colors (one blue in front and one blue in back, then one white in front, one white in back). Between the 2x2 and 1x1 interlacements, the resulting patterns were very different. The 1x1 braid could not achieve the zig-zag pattern of the 2x2 braid due to the lack of the appropriate number of yarns. Alternatively, the 2x2 braid was unable to mimic the alternating spiral of the 1x1 structure; the only way to create a similar pattern within the 2x2 braid was to use three colors, as the braid had too many yarns to create the simple spiral of the 1x1 braid. A 2x1 pattern with the above spool set-ups was not attainable as the 2x1 was an uneven interlacement structure.

Braids produced with yarns of varying diameters created many braids that were similar in appearance. A general observation was that slower take-up rates produced tighter helical structures among boucle yarn studies. The more yarns added side by side in the helical sequence created a thicker knotted structure, though the entire braid was much smaller in diameter. Those braids constructed with boucle spools traveling in opposing directions created structures with a somewhat wavy path.

Between interlacements, boucle structures did not vary much other than in diameter size. Each interlacement was capable of producing a helical or wavy structure through various gear arrangements due to the simple spool arrangement. As these structures were not dependent on the amount of yarns available to the interlacement, each structure was attainable between interlacements. Lastly, those structures created from boucle and Antron Lumena yarns resulted in straight, bulky braids. As the thick Antron Lumena yarns were implemented between boucle knots, the structure did not maintain the helical

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shape, rather the braid become more uniform.

Structures formed after the introduction of rigid monofilament yarns were found to cause the resultant braid structure to straighten and follow the rigid path of the monofilament. Close observation noted the parallel alignment of braid picks to the monofilament yarn; when these yarns were integrated within the braid structure, it was as if the monofilament acted as the vertical braid axis for picks to align with.

Those braids fabricated with metal wires had the opposite effect on the final structure; the metal remained bent and conformed to the spool and helix of the braid. Therefore, the wire maintained a bent structure and caused the braid to expand, whereas the monofilament pulled the braided structure in. These properties of the differing materials could be explained by their different elastic recovery; the metal structure was malleable and conformed to its surroundings, while the monofilament preserved its shape and sprung back. These differences in materials can be viewed in Figures 22. Expansion properties of wire can be dramatically seen in the hollow structures wires created.

Monofilament yarns proved extremely difficult to work with on the Cobra 450 braider. The unwinding of the yarn from the spool would cause tangling between spools, which in turn would cause the machine to stop and shut down. Though one spool was successfully integrated within this study, this type of yarn would be greatly advised against for use on the Cobra 450 as it would cause great problems of inefficiency and slow production.

Conclusions

The main objective of this experiment was to discover the multitude of possibilities in fancy braid creation through spool manipulation, variances in materials, and varying interlacement types when utilizing a simple Maypole braider. The Cobra 450 braider was chosen for the

creation of all fancy braids and through material selection, placement, and processing parameter control, the apparatus was manipulated in order to produce an assortment of braids that delved into a variety of the machine's capabilities.

Even though the study explored many potential avenues for fancy braid creation, a wider variety of materials and spool arrangements could allow for many possibilities that exceed those trials undergone within the present study. Those braids fabricated within the preliminary studies have much potential for design applications. In the case of pattern development, a variety of braid manufacturers could allow the client to choose from an offering of available patterns for many applications, even industrial products. Braids fashioned for trimmings, shoelaces, curtain ties, etc would greatly benefit from pattern choices; choosing the suitable interlacement type and spool number has proven to be of great importance and would apply to all desired patterns.

Certain conclusions were drawn at the end of the experimental research. Replacing yarns with those of differing colors led to a diverse range of patterns. With each movement or replacement of spools, a variety of patterns were created. Additionally, the alternation of interlacement structures allowed for a greater assortment of patterns.

Material selection was found to have a great impact on the structure of the braid. It was found that those braids constructed with thicker fancy yarns created a helical structure as the thicker yarn travelled around its circular path. When braids included a rigid monofilament, the braided structure became more "pulled in" with straighter pick alignment (low braid angle), whereas wire yarns caused the braid to expand with higher braid angles.

Structural effects could have diverse applications with many different products. By integrating thicker yarns with thin yarns or applying rigid structures, the braid's architecture could be proven useful for structures that need more abrasion, strength,

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etc. Additionally, structural effects could produce some interesting aesthetics for design applications. The integration of thicker yarns with thin yarns or fancy yarns within the structure create many interesting and aesthetically pleasing forms.

An array of color patterns in multiple colorways could further be explored in addition to more structural effects. The experimental research presented provides a stepping stone for advanced studies in the potential of fancy braids through industrial machinery. The potential for these structures and would be a benefit to the braiding industry in providing an assortment of design options.

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