Knit Architecture

Exploration of Hybrid Textile Composites Through the Activation of Integrated Material Behavior

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1 Hybrid Textile Composite with embedded tensile and bending-active behavior through differentiated material properties.

ABSTRACT

The hybrid system in textile composites refers to the structural logic defined by Heino Engel, which describes a system that integrates multiple structural behaviors to achieve an equilibrium state (Engel 2007). This research explores a material system that can demonstrate a hybrid material behavior defined by the differentiated tensile and bending-active forces in a single, seamless knitted composite material. These behaviors were installed during the materialization phase and activated during the composite formation process. Here, the material formation involves two interdependent processes: 1) development of the knitted textile with integrated tensile and reinforced materials and 2) development of the composite by applying pre-stress and vacuuming the localized area with reinforcements in a consistent resin-based matrix. The flat bed industrial weft knitting machine has been utilized to develop the knitted textile component of the system with a controlled knit structure. This enables us to control the material types, densities, and cross sections with integrated multiple layers/ribs and thus, the performance of the textile at the scale of fiber structure. Both of these aspects were researched in parallel, using physical and computational methods informed and shaped by the potentials and constraints of each other. A series of studies has been utilized to develop small-scale prototypes that depict the potential of the hybrid textile composite as the generator of complex form and bending active structures. Ultimately, it indicates the possibilities of hybrid textile composite materials as self-structuring lightweight components that can perform as highly articulated and differentiated seamless architectural elements that are capable of transforming the perception of light, space, and touch.

INTRODUCTION

The material system tries to comprehend architecture as an assembly of different interdependent variables rather than perceiving form, structure, and space as a preconceived idea or definition. The intention is to explore architecture in terms of materiality and materialization. Every element—matter, energy, environment, fabrication process, and human response—participates actively in creating the equilibrium of internal and external forces and thus, generates a dynamic formal and spatial organization.

This research intends to extend the architectural conversation on simultaneously evolving form and material formation processes, as opposed to the typical post-rationalizing process where the forms are defined first and then the materials are engineered (Ahlquist and Menges 2015). The intention is also to test the possibility of developing a lightweight but robust hybrid structural system where both the tensile and bending-active elements can be integrated in a differentiated and seamless piece of textile composite. These material behaviors were activated during and after the material formation process as a means of developing complex 3D forms from a flat initial state, as opposed to the conventional method of laying up fiber components in a three-dimensional formwork as a process of making textile reinforced composite (TRC) materials.

The research builds upon the previous studies on TRC, where knitted textile composites are utilized to produce 3D multilayer spacer fabrics suitable for high-performance composite applications (Abounaim et al. 2010). With the goal of developing 'Textile-reinforced composite components for function-integrating multi-material design in complex lightweight applications,' this particular precedent reinforces the experimentation with the performance of textile composite with varying knit structures. This, along with other precedents on the development of three-dimensional seamless multilayer textile structure generated without the use of any formwork, also defined as near-net shape preforms (Cebulla, Diestel, Offermann 2002), were particularly relevant as a way of understanding the integration of multilayer composite pre-forms. As the advanced composite manufacturing process employed in the industry demands the use of pre-assembled pre-forms, earlier research focused on developing a controlled process of manufacturing complex, lightweight TRC for its potential to achieve high flexibility.

This research also intends to extend the previous exploration of post-forming composite processes, developing a material system that internally houses the hybrid textile form and bending-active behavior (Ahlquist et al. 2014). This demonstrates the potential of hybrid textile composites, where the impact of curing time has

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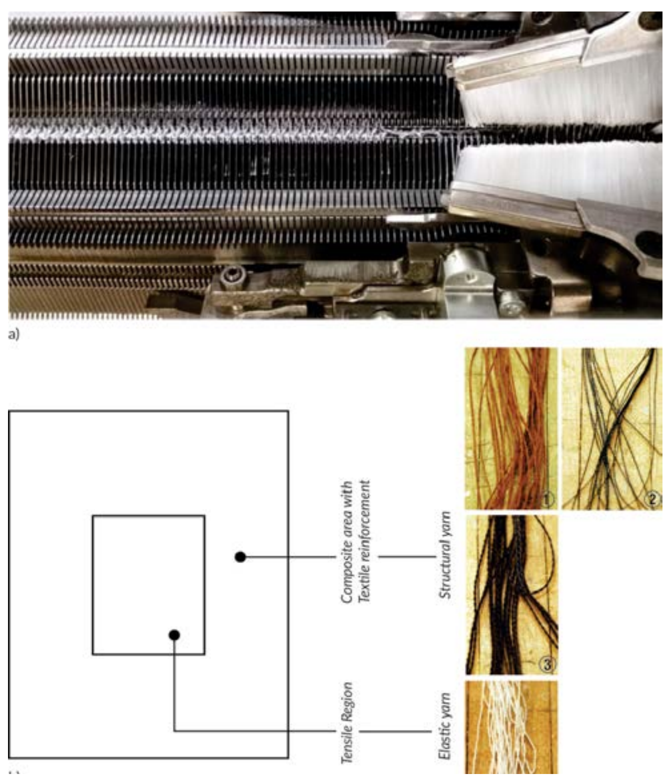

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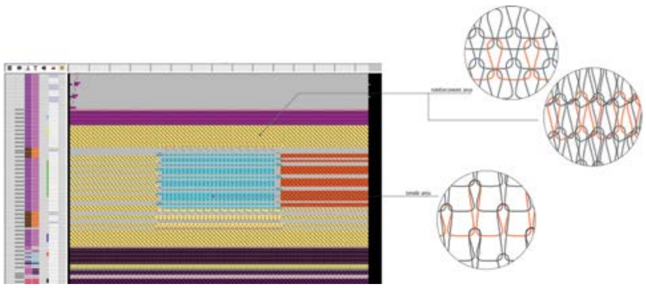
2 Transformation of the knitted sample after the activation of forces through applying prestress and localized composite formation.

3 a) The knitting machined used for tailoring the knit structure of the composites; b) basic material layout.



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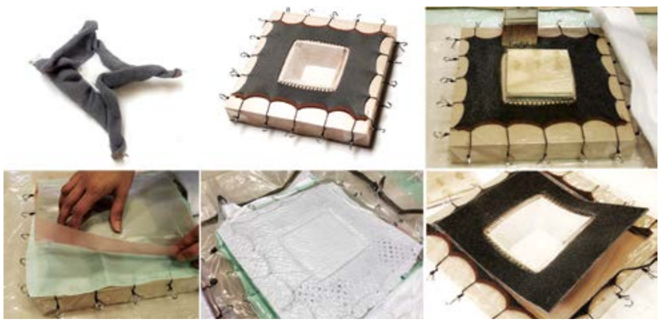

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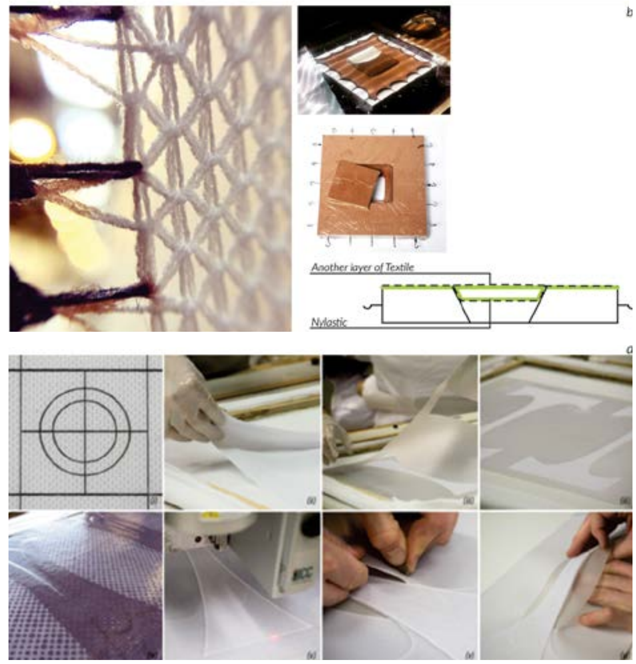

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been examined to understand the relationship between geometry and stiffness of the material, along with the application of the pre-stress as a way of driving the three-dimensional formation. This precedent also shifts the concepts of form and bending-active structural logic achieved by deploying separately manufactured bending-active rod and tensile textiles in previous researches (Ahlquist and Menges, 2013). As this behavior is invested during the process of forming, it represents the potential of a fully materialized system embodying the aspects of material behavior.

Looking upon the precedents, this particular research tries to integrate the knowledge of developing differentiated multi-layer knitted textile, where the tensile and bending-active properties are installed during the materialization phase and activated during the composite formation process (Figure 2). The flat-bed industrial weft knitting machine has been utilized to develop the knitted textile component of the system with tailored knit structure. This enables the control of the material density and the material cross section and thus, the performance of the textile in the scale of fiber structure. Basically two types of yarn have been used. The peripheral area consists of structural yarn which, after resin impregnation, works as the bending resistant component for the system. The interior part is knitted with a type of elastic yarn with spandex core and elastic nylon sleeves around, referred to as "nylastic" yarn, which is kept isolated and utilized for providing pre-stress during the composite formation process and later, instigates three-dimensional formations upon releasing the tension. Various yarns have been tested as the reinforcing material (carbon fiber, nylon and polyester). (Figure 3).

METHODS

The series of experiments aims to explore the hybrid behavior of the knitted textile composite through the differentiated knit logics and the process of formation. It focuses mainly on two aspects: 1) development of the knitted textile with differentiated knit structure and material behavior and 2) application of pre-stress and development of the composite with resin impregnation through vacuum bagging process. Both of these aspects were researched in parallel and were informed and shaped by the potentials and constraints of one other. Thus, the research methodology was essentially based on multiple feedback loops and negotiation between several variables, including fabrication process and material behavior.

The research investigated computational and physical methods simultaneously. The computational method was mostly utilized in developing the textile component of the material system, both in design and fabrication. The knit program was developed by utilizing M1 plus software, a tool specifically dedicated for the industrial flat-bed CNC knitting machine (Figure 4). This helped to tailor the properties of the composite at the scale of fiber with a considerable number of variables, such as: 1) variation of stitch structure, 2) material types, 3) density of the material, 4) integration of yarns with different material properties, 5) location and shape of these materials/yarns, and 6) addition of layers and 3D elements in a single assembly. The development of the machine code to produce the knit requires an extensive understanding of the knitting process in the weft knitting machine, which further includes nuanced control of stitch length, machine speed, and

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4 The knit program as viewed in the M1 plus software with blow-up diagrams of knit structures.

5 The fabrication process of the composite through pre-tensioning, localized resin impregnation, and vacuum bagging.

6 The formwork used to separate the integrated nylastic part, as opposed to the precedent method of cutting.

7 The prototypes with 1 x 1 alternating single jersey knit structures, before and after the resin impregnation: a) polyester, b) nylon, c) carbon fiber stretch broken yarn, and d) carbon fiber tow.

fabric take-down values—all of which varied according to the material types and stitch structure.

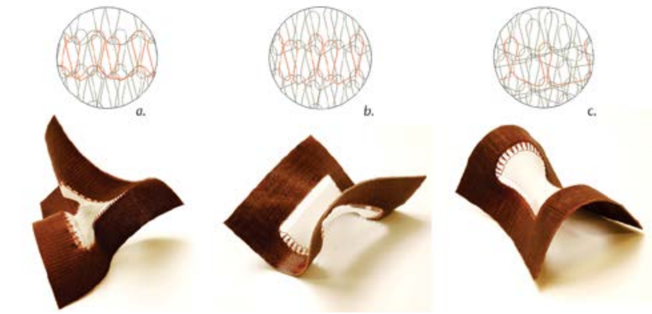
The other facet of the research regarding the development of the composite mostly involves the application of physical methods. Pre-stress was applied the textile component utilizing the integrated tensile behavior of the elastic yarns, fixing the whole piece in a flat, two-dimensional formwork. The tensile area was carefully isolated and the peripheral reinforced areas were fused in a consistently distributed resin matrix. Formworks, as well as the consolidation process, were developed to facilitate the segregation of the tensile part during the impregnation of resin without extensive post-processing or post-cutting of the masking layer, as opposed to previous studies (Figure 6). Though the different curing time in some of the initial studies showed differentiated material behavior in the cured composites, it was kept constant for most of this research to reduce the number of variables and have a better understanding of the impact of material properties. Thus, the variation in the three-dimensional outcome was essentially a result of the knit structure and the interconnection of differentiated material properties.

EXPERIMENTS

The initial experiments focused on developing a basic knit structure, integrating elastic and reinforcement yarns in the same knitted sample, where the elastic region was connected with the peripheral reinforcement areas by spaced connections. Simultaneously, different iterations were performed to develop the workable mechanism in the formwork, which can easily segregate the elastic region from the composite to prevent the bleeding of resin during the impregnation process and finally, produce a cleaner composite and allow consolidation of multiple layers in a faster and controlled way. (Figure 5).

The next iterations for the knitted samples investigated the variations in knit structure to understand and tailor the equilibrium of forces after releasing pre-tension in the cured composite. The first array of tests employed the alternating 1 x 1 knit structure, which utilized all needles in only one bed, essentially known as single jersey knit. This specific knit structure increased the amount of yarn in the sample and produced a denser knit than the regular single jersey structures. This first iteration was done using four types of yarn as reinforcement materials: polyester, unbonded soft nylon, carbon fiber stretch broken yarn, and 1.5k carbon fiber tow (Figure 7). The outcome demonstrated that heavier yarn or denser material in the reinforced area produces more bending-resistant behavior after releasing the pre-stress. This led to the next array of tests, where polyester was continued to be used as the reinforcement yarn, and the knit structure was explored as a means to tailor the material's density.

The next steps included the development of knit samples with heavier knit structures like interlock, tubular, and spacer fabric, which engaged both beds to produce the knit, known as double jersey. The 1 x 1 alternating knit structure was carried on to ensure more density in the double jersey. Simultaneously, the central elastic region was developed to achieve maximum tension during the pre-tensioning process. As the yarn at the



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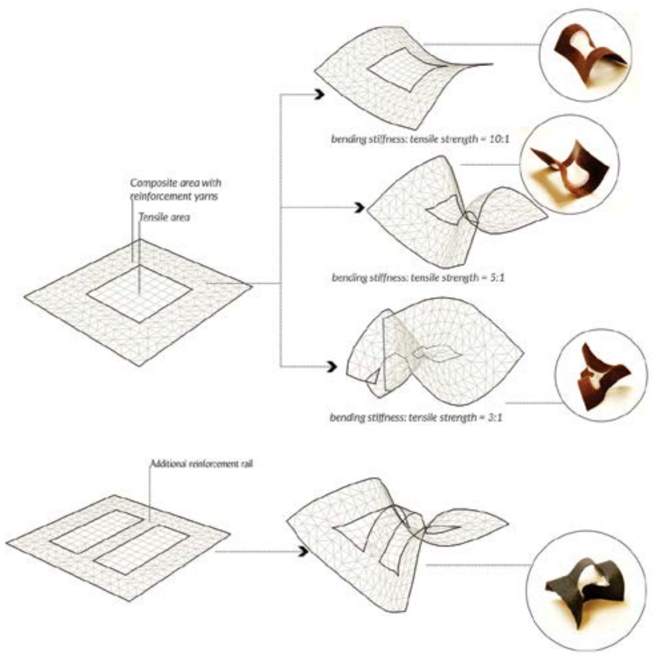

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8 The prototypes with double single jersey knit structures after the composite formation process with different knit structures: a) interlock, b) tubular, and c) spacer.

9 Computational studies to simulate the hybrid nature of the composite through varying stiffness and mesh topology, comparing them with the physical prototypes.

reinforcement area is non-stretchable, this required a careful determination of the ratio in terms of the number of courses being knitted for each type of yarn (1 course nylastic = 3 courses of reinforcement yarn). These experiments show how material density and behavior can be tailored through differentiated knit structures (Figure 8).

RESULT AND DISCUSSION

This research challenges the anticipated result of digitally fabricated objects as perceived while designing on a computer, since the ultimate form and structural behavior changes by the influence of material properties and how they are fabricated. Different prototypes shows the effect of material properties in terms of yarn types, fiber density, fiber orientation, and relative position with each other in generating variation in final outcomes from a similar initial geometric configuration. Parallel to the rigorous physical methods that have been tested, investigation has been done to simulate the interaction between the tensile and bending-active components of the hybrid composite using the particle-spring method in Grasshopper's Kangaroo physics. Since it is quite difficult to translate the knit structures accurately in terms of mesh topology in the digital model, triangulated mesh has been used in these studies to mimic the multi-directionality of the fiber connections. As the material performance is mostly dependent on the knit structure and it is still very challenging to combine the exact fiber structure in digital models, these digital studies were mainly utilized as a way of simulating differentiated surface stiffness. Here, the purpose of the computational studies is not to design any predefined form, but rather to generate a system driven by material behaviors as a way to understand the inherent interaction and simulate the formal outcome from it. This establishes the future potential for designing more complex arrangements of materials and forces, simulating the possible 3D outcome generated by the material behavior, though as basic precedents the physical models were mostly relied upon. The digital models also demonstrate the deviation from the physical models that happens because of the influence of material behavior and the fabrication process (Figure 9).

Simultaneously, other small-scale studies were done to explore the possibilities of the knitted hybrid textile composite through the insertion of additional rails above the elastic region as a separate layer to achieve topological variation. These studies demonstrate increased stiffness of the composites in the locations where multiple layers of the composites connect with each other (Figure 10a). Also, further studies demonstrate the possibilities of integrating multiple elastic regions in a single material assembly (Figure 10b). Due to the limited number of feeders in the machine, these studies focused on developing the knit structure and the knitting method using only one feeder with reinforcement yarns. The results generate a more complex interaction of forces and material behavior, altogether revealing the future potential of developing hybrid composites with complex topological variation. (Figure 10c)

CONCLUSION

Integrating differentiated material behavior in the textile composites establishes the potential of hybrid structures with controlled and tailored spatial and structural performance. Since the form and bending-active behavior is installed during the materialization phase, it compresses the involvement of separately manufactured material assembly to achieve the similar hybrid structural actions. Based on the parameters established in this research, similar results can be achieved by repeating the

10 Studies showing the possible future trajectories of the research: a) textile hybrid prototypes with multiple reinforcement layers, b) prototypes with shaped and multiple elastic regions, and c) digital model for aggregation of multiple meso-system into one macrosystem.

experiments, as long as someone has access to a CNC knitting machine. This research also indicates the need for further studies on how different parameters (knit structures, different yarn types, composite formation process and the application of pre-stress during resin impregnation) can influence the formation of hybrid TRC in cases of more complex geometric configuration with multiple tensile regions. There were few attempts to introduce that aspect in some experiments at a very preliminary stage, but that could be researched more rigorously to explore larger systems. This ultimately can lead into developing highly articulated and differentiated full-scale architectural façade elements, designed and fabricated by inherent material logic. Additional research can also investigate the potential for a macro-system through the aggregation of mesosystems.

ACKNOWLEDGEMENTS

The research was developed as part of the capstone project under the MS in Architecture (Material Systems) program at the University of Michigan Taubman College of Architecture and Urban Planning. The authors are also thankful to the Rackham Grant for supporting the research work.

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IMAGE CREDITS

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