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3D HOLLOW FABRIC PRODUCTION WITH MODIFIED DOBBY SAMPLE WEAVING MACHINE

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Keywords

Sample Weaving Machine,
3D Woven Fabric,
Tubular Fabric,
Honey Comb Fabric,
Mutli Roller Warp System.

Abstract

3D fabrics, also known as three-dimensional textiles are fabrics beyond the flat surface typical of traditional fabrics. A variety of methods, such as knitting, weaving and even braiding, are used to manufacture these textiles. This research aims to present a unique sample weaving machine made especially for creating especially 3D hollow fabric. For this aim, in the study a modified sample dobby weaving machine specifically tailored developed for the production of three-dimensional (3D) fabrics. The sample weaving machine incorporates a multi roller warp let off system designed for the production of 3D woven fabrics. This multi-roller warp-let off system facilitates the production of 3D woven fabrics by letting off and rewinding the warp yarns during the weaving process. Subsequently, this sample weaving machine was utilized to fabricate tubular and honeycomb 3D fabric structures. Consequently, 3D composite materials produced using these structures exhibit remarkable strength, lightness, and energy-absorption properties. In future studies, the aim will be to manufacture three-dimensional woven fabric structures with built-in impact protection features, eliminating the need for sewing.

MODİFİYE EDİLEN NUMUNE DOKUMA MAKİNESİ İLE 3B BOŞLUKLU KUMAŞ ÜRETİMİ

Anahtar Kelimeler

Numune Dokuma Makinesi,
3B Dokuma Kumaş,
Dikdörtgen Boşluklu Kumaş,
Bal Peteği Kumaş,
Çok Leventli Çözgü Sistemi.

Öz

Üç boyutlu tekstiller olarak da bilinen 3B kumaşlar, geleneksel kumaşlara özgü düz yüzeylerin ötesindeki kumaşlardır. Bu tekstillerin üretiminde örgü, dokuma ve hatta halat örgü gibi çeşitli yöntemler kullanılmaktadır. Bu araştırma, özellikle üç boyutlu içi boş kumaşlar üretmek için olmak üzere üç boyutlu (3D) kumaşlar oluşturmak için yapılmış benzersiz bir örnek dokuma makinesi sunmayı amaçlamaktadır. Bu çalışma üç boyutlu (3B) kumaş üretiminde kullanılabilecek armürlü numune dokuma makinesi geliştirilmesini içermektedir. Makine çoklu çözgü leventine sahip olup, her bir çözgü leventinin hızı birbirinden bağımsız olarak ayarlanabilmektedir. Çoklu levent sistemi, kumaşların üretimi sırasında çözgü ipliklerini salma ve sarma işlemleri ile bazı 3B dokuma kumaşların üretimini gerçekleştirmek mümkün olmaktadır. Bu araştırma makalesinde, modifiye edilmiş dokuma makinesi ile dikdörtgen boşluk ve petek yapıdaki 3B dokuma kumaş yapıları üretilmiştir. Bu iki yapı, gelişmiş 3B tekstil yapılarıdır. Sonuç olarak, 3B kompozit malzemeler güçlü, hafif ve enerji emicidir. İleride yapılacak çalışmalarda darbe koruma özelliği ile dikim gerektirmeyen üç boyutlu dokuma kumaş yapılarının üretimi amaçlamaktadır.

Alıntı / Cite

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Highlights

- Introduction of a sample dobby weaving machine with the capability to produce complex 3D woven structures.
- Incorporation of multiple warp beams equipped with rewinding capability and two distinct weft insertion systems, namely shuttle and rapier, enhancing versatility and efficiency in fabric production.
- Successful production of two distinct types of hollow fabrics: tubular 3D fabric and honeycomb fabric, utilizing innovative weaving techniques

Purpose and Scope

The purpose of this study is to introduce a specialized sample weaving machine designed specifically to produce 3D fabrics, particularly 3D hollow fabrics. This machine serves the dual function of testing new designs and identifying production issues, particularly when faced with constraints such as limited availability of raw materials.

Design/methodology/approach

A modified sample dobby machine was developed, equipped with multiple warp beams featuring independent let-off and rewind mechanisms. This machine demonstrated versatility by incorporating two distinct weft insertion systems: shuttle and rapier. To assess its effectiveness, two types of hollow fabrics were produced using a multilayer weaving technique. One fabric exhibited flat top and bottom surfaces (tubular 3D fabric), while the other displayed uneven top and bottom surfaces (honeycomb fabric).

Findings

The successful production of two types of hollow fabric structures, namely tubular 3D fabric and honeycomb fabric, was achieved without encountering any challenges. This success can be attributed to the incorporation of multiple warp beams with independent let-off and rewind mechanisms in the modified sample dobby machine.

Research limitations/implications

This study is limited by the production of only two types of 3D hollow structures, namely tubular 3D fabric and honeycomb fabric. Additionally, mechanical testing of the fabricated structures was not conducted. Future studies should aim to explore a broader range of fabric structures and incorporate mechanical testing to provide comprehensive insights into the performance and properties of the produced fabrics.

Practical implications

The development of this modified sample dobby weaving machine holds significant practical implications for the future production of technical fabrics. Its versatility and capability to produce 3D woven fabric structures holds potentials for various studies and projects. Specifically, it could facilitate the development of three-dimensional woven fabric structures integrated with impact protection features, which could revolutionize the manufacturing process by eliminating the need for sewing.

Originality

Conventional weaving machines can make 3D woven fabrics, but setup is labor-intensive. This study presents a sample machine with a multi-roller warp system for 3D fabric production. It's ideal for research, education, and small-scale fabric creation.

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1. Introduction

The use of 3D fabrics has grown significantly in recent years since 3D fabrics find novel applications in various industries such as aviation, transportation, constructions and sports. These fabrics are distinguished by their remarkable strength, low density, and lightweight properties, making them highly desirable for technical applications (Tripathi et al., 2020). A defining characteristic of 3D fabrics is their substantial thickness in the Z-direction, in contrast to the two-dimensional structure of conventional fabrics. In other words, unlike flat 2D fabrics, 3D fabrics exhibit noticeable depth and volume (Hearle et al., 2009).

3D fabrics can be manufactured through various techniques including weaving, knitting, braiding, and nonwoven fabrication. Among these methods, 3D woven fabrics stand out as particularly desirable for technical applications (Mountasir et al., 2021) especially in composite applications. These fabrics can be categorized into four main groups: solid, hollow, shell, and nodal. Hollow woven fabrics, also known as spacer fabrics, feature a porous cross-section with empty or void spaces within the structure (Chen et al., 2011). These void spaces create a tubular or hollow structure within the fabric, offering advantages such as improved insulation, energy absorption, lightweight properties, and enhanced breathability. For instance, 3D woven spacer composites, produced utilizing woven spacer or hollow fabrics, demonstrate superior compression and shear characteristics compared to traditional counterparts. They are highly valued in industries such as automotive manufacturing, particularly in the production of electric vehicles, where reduced weight contributes to lower energy consumption and sustainable practices (Tripathi et al., 2020). Additionally, they find applications in construction industry as a light weight construction material (Grossmann et al. 2010), and superior thermal insulation material (Unal, 2012).

One commonly employed technique for producing 3D hollow fabrics is the multilayer weaving method (Chen and Wang 2006). This method allows for the creation of hollow fabrics with either flat top and bottom surfaces or uneven top and bottom surfaces. In the case of hollow fabrics with flat surfaces, three or more fabric layers are typically employed. For example, in a three-layer fabric, the middle layer, which acts as a connector between the top and bottom layers, is longer in length compared to the top and bottom layers. The length of this middle layer is determined by various factors such as the fabric thickness and the configuration of the fabric cross-section. Another method for producing hollow fabrics with flat surfaces involves utilizing the face-to-face weaving technique. In case of hollow fabrics with uneven surfaces neighboring layers of fabric are stitched together and then separated at arranged intervals, in accordance with the designated cross-sectional shape (Mancași et al., 2021). One example for hollow fabrics with uneven surfaces is honeycomb fabric structure. Chen et al. (2008) worked on honeycomb fabrics. They stated that a honeycomb fabric structure consists of the free and bonded cell walls. While a single layer of fabric forms a free cell wall, a bonded cell wall is formed by the combination of two adjacent fabric layers. The cell size can be adjusted by varying the length of the free and bonded cell walls. In other studies by Chen et al. (2004) and Chen and Wang (2006), the computerized design and manufacturing of honeycomb fabric structures were investigated. Başal Bayraktar et al. (2018) produced a four-layer honeycomb fabric structure using polyester filament yarns and an automatic sample loom. After weaving, they opened cells within the fabric structure using PTFE rods and subsequently transformed the fabric into a composite by saturating it with epoxy resin. They compared this fabric structure with one featuring unopened cells and demonstrated that the hollow structure absorbs more impact energy.

Although there are specialized weaving machines designed specifically for producing 3D woven fabrics, conventional weaving machines, with or without modifications, are often adequate for their production. Several studies have demonstrated successful production of 3D fabrics using conventional weaving machines (Ala et al., 2015, Ala et al., 2016a, Ala et al., 2016b). For instance, Badawi (2007) employed face-to-face weaving on a narrow weaving machine equipped with two warp beams and a specialized take-up mechanism comprising rows of rollers. After fabric production, auxiliary rods were utilized to fill spaces in the sandwich fabric. Similarly, Dash and Behera (2015) created three distinct 3D solid fabric structures using the 2D weaving process, utilizing E-glass fiber on a rapier loom. In this case, an additional warp beam was integrated into the 2D weaving system to facilitate 3D fabric production.

While conventional weaving machines are capable of producing 3D woven fabrics, it's important to note that preparing a weaving machine for fabric production can be a labor-intensive task, requiring substantial time and manual effort. This process involves configuring approximately 200 machine parameters after each fabric change, and extensive weaving trials may be necessary to ascertain the optimal machine setup. To overcome these challenges, this study introduced a sample weaving machine designed specifically for testing new designs and identifying potential production issues with limited raw materials. Subsequently, 3D hollow structures were successfully produced to demonstrate the machine's capability.

2. Material and Method

2.1. Modified Sample Dobby Weaving Machine

This study involves the production of 3D fabric using a modified sample dobby weaving machine. The machine comprises two main parts: machine body, which consists of fabric roller, take up rollers, reed, shedding mechanism, frames, compressor, electrical-electronic control panel, and computer. The machine frame is constructed using ST37 quality sheet metal, with dimensions of 89.6*209*107.5 (cm) and is protected with electrostatic powder paint. It includes 24 heald frames, and the electrical and electronic control elements, along with the compressor, are housed in a removable unit on the right side of the machine. The machine's total size is 89.6*389*145.2 cm^2. For ease of mobility, the machine is equipped with wheels, and self-vacuum feet are used to prevent machine vibration during weaving.

Various methods can be employed to transform two-dimensional fabrics into three-dimensional ones, but these materials tend to be less resistant to mechanical forces when compared to directly woven three-dimensional fabrics. In applications where the composite structure experiences out-of-plane loading, 3D woven fabrics prove especially advantageous due to the added strength imparted by the z-thread in the thickness-length dimension, resulting in better tolerance to delamination, which is the separation of layers caused by out-of-plane forces. The weaving machine, designed for this purpose, employs a pneumatic system consisting of pneumatic pen pistons, electro pneumatic valves, and connecting components in the shedding mechanism required for weft insertion. Each frame is equipped with one of the 24 (16 mm-diameter) pneumatic pen pistons for up and down motions. The motion of the pneumatic pen pistons is controlled by transmitting pattern-specific commands from a computer to the electric-electronic control card and transferring compressed air from a compressor to the electro-pneumatic valves under the control of the electric-electronic control card, in accordance with the pattern. The electronic control of the weaving machine is managed through an electronic control card and a tablet computer. The fabric take up system is comprised of two stepper motor-controlled take-up rollers and one fabric roller, with the rollers coated in polyurethane to prevent static electricity. The front view of the sample weaving machine is given in Figure 1.

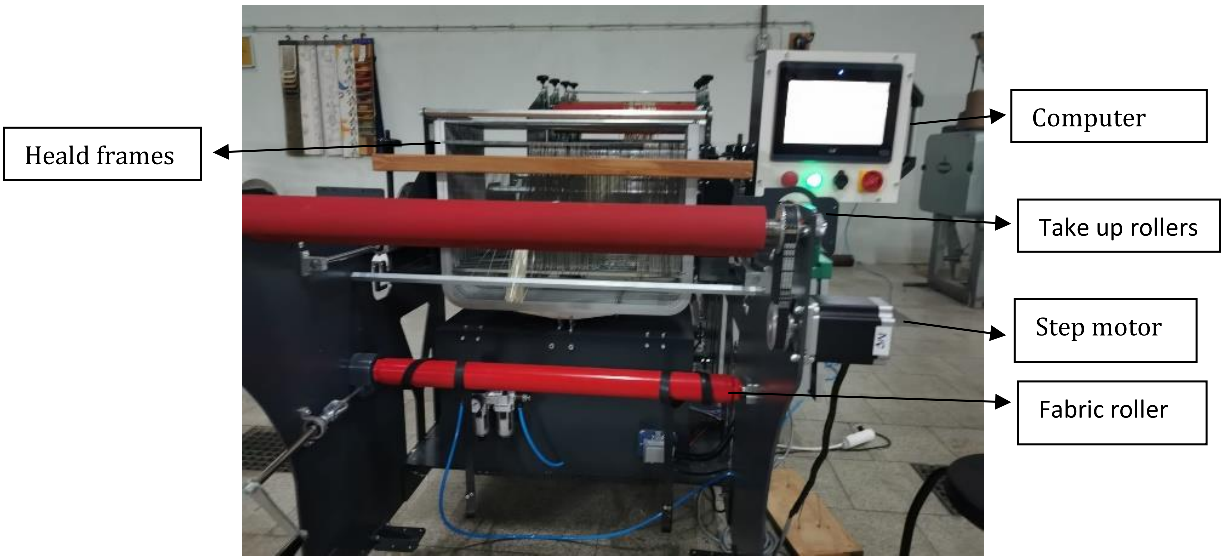

Figure 1. Front view of the sample dobby weaving machine

The weaving machine's warp let off system comprises one warp beam and two warp let off rollers operating under the precise control of a stepper motor, with set values entered on the machine's screen. The warp beams are made from high quality, completely dry beech wood, featuring protective covers on their upper portions to shield against external elements. The warp let off rollers are coated with a 1.5 cm thick, 62-hardness polyurethane and are capable of both forward and backward movements. These coated rollers are equipped with clamping systems at their tops to secure the warp threads between them, and in total, there are eight warp rollers. To ensure uniform tension for each bundle of warp threads coming from these eight rollers, a warp tension is controlled via warp let off rollers. Additionally, materials that prevent static electricity are carefully selected based on the specific characteristics of the warp threads used, with wood chosen for warp beam, polyurethane for warp let off and polyethylene for the bedding of the warp let off rollers. Importantly, none of the warp yarns coming from these eight different warp beams come into contact with each other until they reach the harness frames. Figure 2 shows both front and side views of the warp let off system.

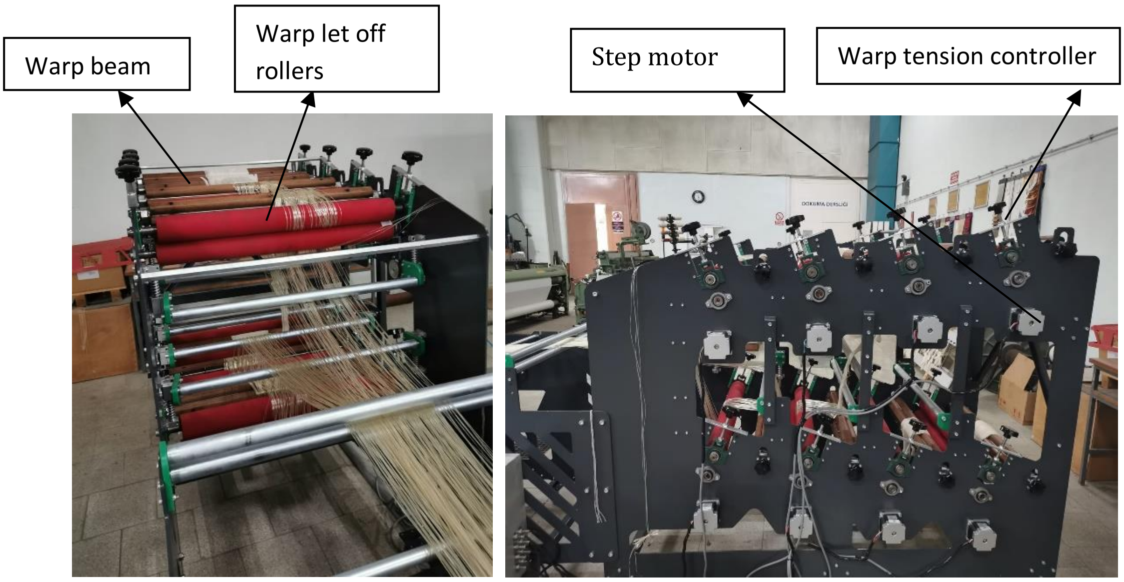

Figure 2. Front and side views of the warp let off system

2.2 Three Dimensional (3D) Woven Fabric Production

The multi-layer fabric structures, which can be called as simple 3D fabrics can be produced with an ordinary weaving machines. However, in this study we aimed to develop a sample weaving machine that allows the production of many different types of 3D shaped fabric structures. For this purpose, in the design of the machine, a special warp let off system is used. With this system, it is possible to control the warp tensions during the weaving process. The developed machine could be not only used to produce 3D fabrics preforms to be used in composite production, but also to it is possible to produce fabric samples for different textile designs for the fashion industry. In the study, the modified weaving machine was used to produce; tubular and honeycomb 3D fabric structures.

The machine's design encompasses all essential components, including 8 warp beams, 8 flexible warp let off mechanisms for adjusting weft density, fabric take up mechanism, dobby cabinet (comprising electronic control cards, modules, and pattern driver), and a touch electronic board monitor for controlling warp let off and fabric take up systems. The machine is dimensioned to operate effectively within limited space, measuring 135*280*300 cm. The shedding system facilitates the opening of the shed by executing commands received from the dobby mechanism. Both rapier and shuttle weft insertion mechanisms are integrated into the machine’s weft insertion system. Warp let off and rewinding, and fabric take up mechanisms are controlled through electronic PLC and a touch monitor. The weft density can be adjusted and monitored via the touch screen. The machine is compatible with pattern design programs commonly used in the industry.

Warp let off is executed in alignment with the weaving design’s warp report. After positioning the warp rollers according to the warp report, the warp let off process begins, followed by warp binding. The pre-established peg plan is displayed on the monitor, and a command is transmitted to the machine via an electronic pedal, initiating the shedding process. Weft insertion is manually performed using the shuttle through the shed, followed by beating up to csrry the weft yarn into the fabric to ensure desired weft density. The motor-driven fabric take up roller is synchronized with the weft density, which is adjustable from the monitor. Simultaneously, the warp let off rollers maintain warp alignment at the specified distance. This process continues until the weaving is completed.

Two different type hollow fabric structures were produced utilizing this sample weaving machine in order to reveal its capabilities. The first one was a hollow fabric with flat top and bottom surfaces. This hollow or tubular fabric consists of four layers, with adjacent layers periodically combined and separated. The top view and cross-sectional pattern of the weave illustrate vertical lines representing warp yarns and horizontal lines representing wefts. The technical drawing and pattern report of the cross-sectional view of the 3D hollow fabric are presented in Figure 3 (Turgut, (2020). The cross-sectional view of the tubular 3D fabric was shown in Figure 4.

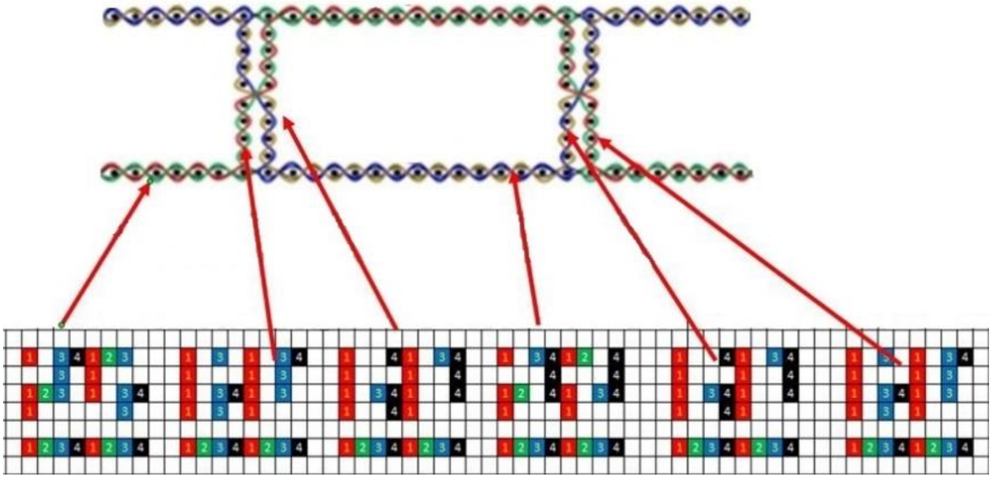

Figure 3. Cross-sectional view and the peg plan of the tubular 3D fabric

Figure 4. Tubular 3D fabric

Another 3D fabric structure produced with the developed sample weaving machine is the honeycomb structure. Three-dimensional honeycomb structures mimic the geometry of natural honeycomb structures to achieve minimal weight and maximum strength by minimizing material usage during production. Composites reinforced with honeycomb structures exhibit lightweight properties, excellent impact absorption, and high strength (Başal et al., 2018). The presence of open spaces between layers results in a 3D structure with honeycomb-shaped cells in the cross-section, featuring non-flat top and bottom surfaces. The technical drawing and pattern report of the cross-sectional view of the honeycomb 3D fabric is provided in Figure 5, while Figure 6 shows honeycomb hollow fabric in its original form and composite form.

(a) (b)

Figure 5. Honeycomb fabric; a) Original form b) Composite form

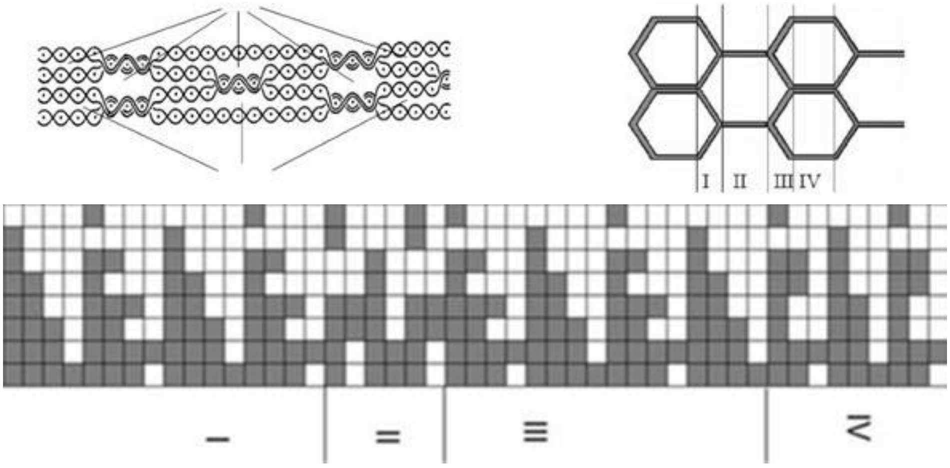

Figure 6. Cross-sectional view of honeycomb fabric and the peg plan

3. Result and Discussion

This study introduced a sample woven fabric machine with a multi-roller warp system, which was utilized for the production of three-dimensional woven fabrics. The developed sample-weaving machine holds potential for application in research and development activities within textile enterprises, educational institutions offering textile programs, research centres and composite material manufacturers. This machine, capable of producing fabrics in small sizes for research purposes. It features a multi-roller warp let off system, which offers a great potential to produce specific type 3D woven fabrics by letting off and rewinding warp yarns during the weaving process which is not possible with conventional weaving machines. The inclusion of both rapier and shuttle weft insertion mechanisms in this shuttle system facilitates the continuous release of the weft yarns from the shuttle bobbin, ensuring a smooth fabric edge. Additionally, by eliminating the need for cutting, this system addresses the cutting challenges associated with high strength technical yarns. The machine requires minimum space and allows for the creation of simple, medium, and complex weaving patterns with reduced time consumption and simplify process requirements. In addition, the low production cost of this machine, compared to similar sample weaving machines produced abroad, eliminates the high costs associated with machine spare parts and long lead times for overseas procurement.

Following the development of the sample weaving machine, its capability for 3D fabric production was verified by creating two distinct hollow fabric structures: tubular 3D fabric and honeycomb fabric. The results demonstrated that the developed machine successfully produced these structures without encountering any difficulties.

In conclusion, this sample weaving machine is expected to support various studies for producing technical fabrics in the future, potentially leading to new projects, including the development of three-dimensional woven fabric structures with impact protection features that eliminate the need for sewing.

Conflict of Interest

No conflict of interest was declared by the authors.

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