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Assessment of the impact of different weave geometries on the crimp factor of woven preforms made from high-performance carbon filaments

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ABSTRACT

Crimp, also known as fabric waviness, is a key factor affecting weaving efficiency and the performance characteristics of woven fabrics, especially high-performance fabrics. Increased crimp typically enhances yarn interlocking, thereby improving the structural stability of the fabric. The added friction between yarns boosts resistance to distortion and slippage, which is crucial for maintaining the fabric's shape during use and subsequent processing. However, excessive crimp can reduce the mechanical symmetry of the fabric and, in demanding applications such as composite materials, compromise its dimensional stability under stress. Producing composite preforms with minimal crimp while ensuring improved structural integrity remains a significant challenge. Crimp levels can be adjusted by employing different weave patterns while keeping the fabric-making parameters constant. In high-performance applications like composites, the reduced crimp is preferred for better load distribution and material strength, making non-crimp woven textiles a favorable option. Advanced automated processes are typically employed to produce non-crimp woven preforms, including three-dimensional (3D) woven preforms with three sets of interlocked yarns or uni-directional woven preforms. This research uses conventional two-dimensional (2D) weaving techniques to fabricate high-performance composite materials. Experimental studies were conducted on various basic weave patterns to produce high-performance carbon woven preforms using advanced 2D weaving machines (Dobby shedding). The findings demonstrate that the weave design significantly influences the crimp in carbon woven preforms. The crimp percentage (C%) was calculated as the ratio of the un-crimped length of the tow to its crimped length. The study revealed that the crimp in both warp and weft tows of the woven preform varies notably based on the weave design.

1. Introduction

Technical textiles have rapidly established a global market over the past few decades, extending their reach across nearly every sector of technology. One such area is textile composite manufacturing. High-performance textile preforms play a dominating role in determining the mechanical stability of composites and highlight the selection criteria for these preforms to enhance the quality and performance of the final products. However, textile preforms typically feature crimped structures, which can degrade the mechanical properties of the composites. As a result, conventional techniques have been modified to develop non-crimp preforms for textile composites [1-5].

Non-crimp, high-performance woven preforms play a leading role in the reinforcement textile industry. Over the years, they have garnered significant interest due to their highly accurate fiber orientation along the full length of the preform and their excellent drape performance [6, 7]. Non-crimp materials offer great potential for use in high-performance composite materials, as they positively impact the final composite's properties. However, a detailed understanding of the behavior of non-crimp preforms is necessary [8, 9]. In variations of non-crimp woven preforms, the woven fabric is stitched to secure multiple fiber layers and prevent misalignment [10].

High-performance carbon fiber is expanding in the textile composite field due to its wide range of applications and low production costs [11]. Due to their lightweight and high-performance functional characteristics, carbon fibers are widely used in aircraft to improve fuel efficiency [12].

Given that 2D weaving is a simple and inexpensive method, it has been around for many years. Since these cloths offer excellent mechanical strength in both the longitudinal and transverse directions, 2D woven carbon-reinforced composites have become increasingly attractive alternatives for use in structural applications [13]. For this dedicated reason, a simple traditional weaving method, in which two sets of yarns, the warp and the weft, interlaced with one another, is employed in the creation of ordinary 2D woven preforms [14]. The type of raw material, yarn structure, particularly yarn diameter, and other related properties, the number of interlacements, and weaving conditions such as temperature, humidity, and yarn tension during weaving and fabric finishing treatments have all been linked to yarn crimp extents, according to research published in the last few years [15].

In our earlier work [16], we developed a warp creel that solves the issues of spool unwinding and excessive friction in creel sections and is used to manufacture textile preforms using high-performance fibers (Carbon, Kevlar, Glass, etc.). Another essential objective and uniqueness of this study is the effortless and gradual removal of high-performance tow under optimal mechanical control. In addition to reducing stress, proper mechanical management of the warp tow ensures a straight and smooth feeding of the tow approaching the weaving process with no folding. Consequently, the newly created and altered weaving machine serves as the foundation for all of the work's outcomes. Previous studies comparing 2D woven preforms to their basic weave patterns have revealed both an increase and a decrease in the C% of those preforms [17].

In addition, it was found by Farhana Afroz et al. [15] and Ayesha Siddika et al. [18] that the C% influences the wefts' size and composition as well. Although a hard weft requires the warp to bend around it forcefully and travel an extended course, a softer weft bends more easily, permitting the warp to remain straight. Elevated warp tensions tend to lessen crimp by compressing the weft more [19], indicating the possible advantages of meticulous preform design that reduces the amount of axial tow crimp. Strength losses in the 2D woven preform samples are most likely caused by the number of filaments in the tow, according to all of the experiments mentioned above.

2. Materials and Methods

To fabricate woven preforms with different designs to observe the impact of a weave on fabric crimping. High-performance carbon fiber carbon tow purchased from Technical Textiles Ltd, Sialkot, Pakistan. The mechanical characteristics of carbon tow were provided by the manufacturer and are tabulated in Table 1.

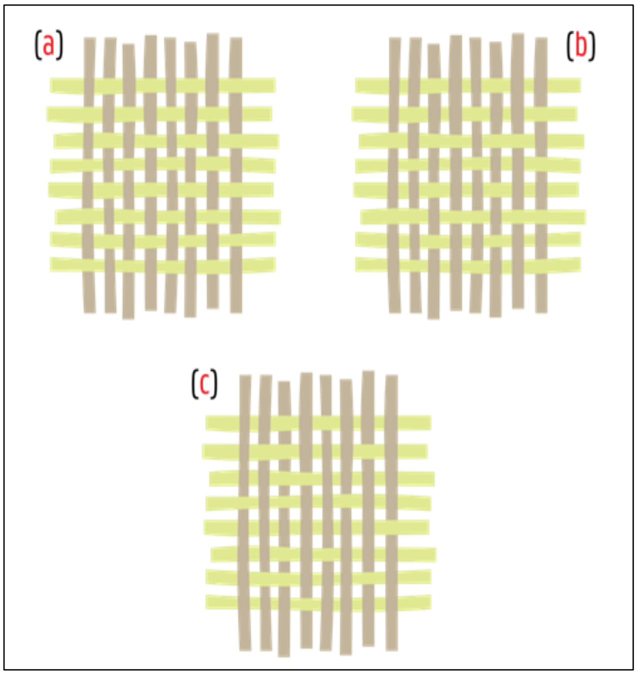

Fig. 1. Schematic Illustration Of Weave Geometries (A) Plain Weave, (B) 2/1 Twill Weave, And (C) 4 To 1 Warp-Faced Satin Weave Of Carbon Tow-Based Woven Preforms

Table 1

Mechanical properties of carbon tow

Density (g/m^3)	1.76
Tensile Strength (MPa)	3.9
Tensile Modulus (GPa)	240
Elongation at Break (%)	1.8

Three basic cloth geometries, plain, twill, and satin, were adopted to fabricate carbon woven preforms. The preforms were manufactured through 2D conventional weaving. The Shirley crimp tester (320A, Italy) was used to measure the C%. Fig. 1 illustrates the schematic illustration for (a) plain, (b) twill, and (c) satin weave geometries, respectively.

3. Experimentation

Three different woven preforms were fabricated through an advanced 2D weaving machine that works on a dobby shedding mechanism. During the weaving process for all preform geometries, both warp and weft were chosen with the same densities. The rest of the machine specifications for the weaving process were kept the same when fabricating carbon tow-based woven preforms.

Fig. 2 depicts the fabricated carbon tow-based woven non-crimp preforms on the Dobby shedding machine. Five preform samples for each woven geometry were fabricated and were tested for their crimping in this research. In total, 15 samples were fabricated and were tested for crimping. Table 2 tabulates the design attributes of woven preforms based on three different aforementioned woven geometries.

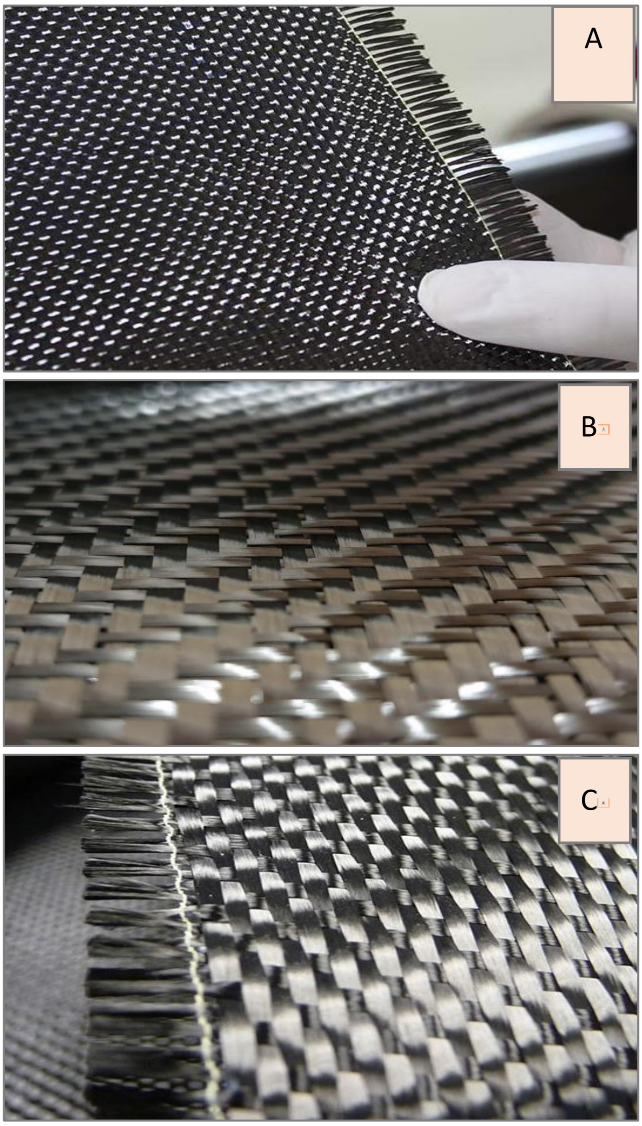

Fig. 2. Carbon Tow-Based Fabricated (A) Plain, (B) 2/1 Twill, And (C) 4 To 1 Warp-Faced Satin Woven Preforms

Table 2

Design specifications of carbon tow-based fabricated woven preforms

	Plain	Twill	Satin
Cloth density (g/m^2)	175	185	195
Ends/inch	2	2	2
Picks/inch	4	4	4
Warp count	12k	12k	12k
Weft count	12k	12k	12k
Warp tow size (mm)	8	8	8
Weft tow size (mm)	8	8	8

First, the warp and weft directions of each woven geometry-based preform sample were determined, and around 100 mm of each warp and weft tow were removed to calculate the C%. The standard operating method, ISO 72113:1984, was followed for crimp measurement. Eq. 1.1 was used to get the C%, and then the average C% was computed.

The C% refers to the mean difference between the straightened thread length and the distance between the ends of the thread while in the fabric, expressed as a percentage of the latter. Eq. 1 is adopted to calculate the C% after obtaining the measured length of a tow in the woven cloth, referred to as p in the Eq., and the length of the same tow after being extracted from the preform and straightened (no-crimp or waviness).

$$C\% = \frac{(1-p)}{p} \times 100 \qquad \text{Eq. (1.1)}$$

where,

C = crimp

l = Straightened length, the length of the yarn or fiber when it's pulled out straight from the fabric without any crimp.

and

p = Crimped length, the length of the yarn or fiber in its natural state as part of the fabric.

4. Results and Discussions

The purpose of this research is to assess the impact of three chosen different weave geometries and to produce woven preforms with minimum crimping. Adopting the aforementioned three different weave geometries helps to observe their impact on the mechanical stability of the woven preforms, ultimately influencing the amount of crimp within the same preform.

For the woven preforms with plain geometry, the C% outcomes are illustrated in Fig. 3. The C% for the plain geometry-based woven preforms was calculated in both the warp and weft directions. As evident from the results, the plain woven preforms show the optimal C% of around 105% in the warp direction. However, the highest C% of around 115% was observed in the weft direction.

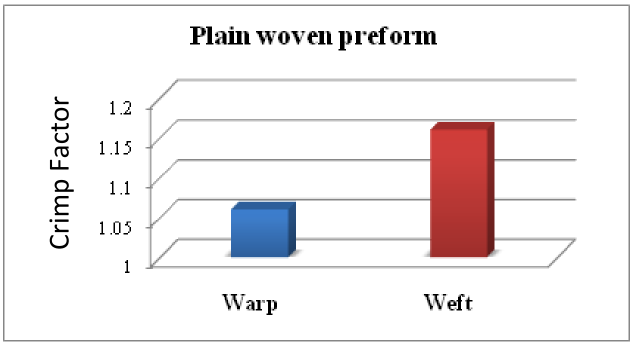

Fig. 3. Crimp Factor Of Woven Preforms Based On Plain Weave Geometry

The plain weave is the simplest of all weave structures, offering the highest mechanical stability. Its geometry creates a compact fabric with maximum interlacement points per unit area, maintaining uniform clearance between each warp and weft thread across all chosen weave patterns. It is observed that due to the highest number of interlacement points, the plain weave structure-based preforms crimp the maximum.

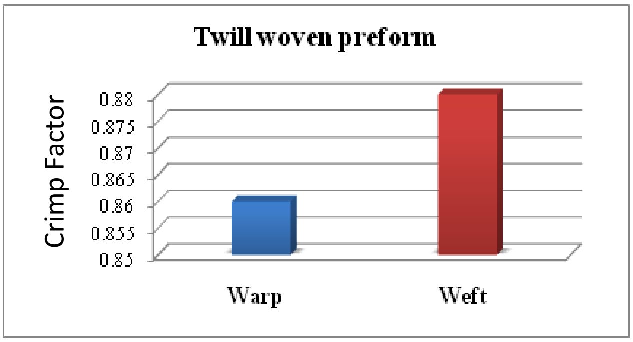

Fig. 4. Crimp Factor Of Woven Preforms Based On Twill Weave Geometry

Fig. 4 highlights the effect of the twill weave structure on the Crimp Factor of twill woven preforms in both the warp and weft directions. As illustrated in the figure, twill woven preforms exhibit a lower C% of about 85 % in the warp direction, while a higher C% of around 88% is observed in the weft direction. This result indicates that the twill weave structure produces approximately 3% more crimp along the weft direction than along the warp direction of twill weave-based woven preforms. Moreover, the twill weave has a lesser number of interlacement points compared to the plain weave, making it more flexible than the plain weave and resulting in a lower overall C% [20].

The effect of weave structure on the C% of satin woven preforms in warp and weft direction is depicted in Fig. 5. Observing the results in the figure, the satin weave-based woven preforms give a lower C% of about 6% in the weft direction compared to the 30% in the warp direction. This result shows that the satin weave structure dramatically decreases the C% compared to the other two weave geometries employed in this research work. This is because the satin weave has the least number of interlacement points compared to other weave geometries.

However, less or negligible C% can increase the strength and stiffness of woven preforms [21]. Less or no C% value can increase mechanical properties, which can affect the performance of the final composite preform [22].

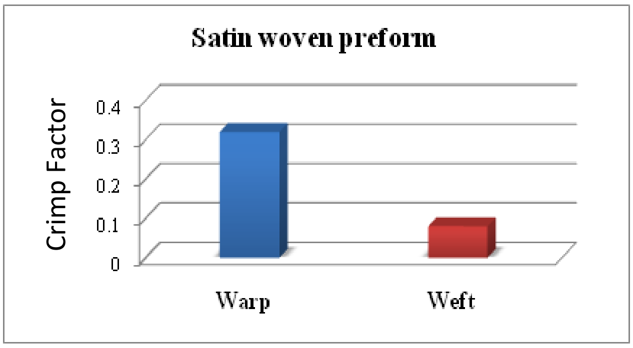

Fig. 5. Crimp Factor Of Woven Preforms Based On Satin Weave Geometry

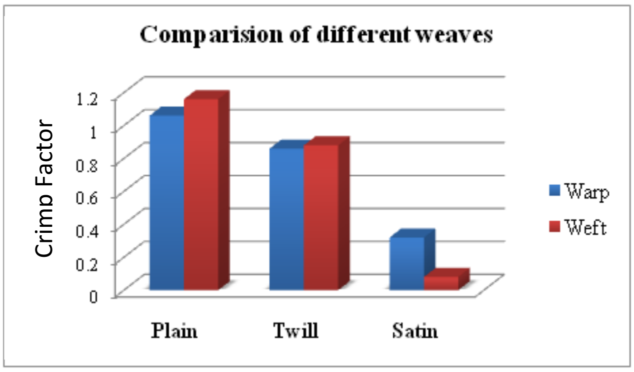

Fig. 6. Comparison Of Crimp Factor Of Various Woven Preforms At Warp And Weft Direction.

Fig. 6 illustrates the comparative results of Crimp Factor in woven preforms based on plain, twill, and satin weave geometries. Among these three basic weave structures, satin weave-based carbon preforms exhibit the least crimping compared to those based on twill and plain weaves. This is primarily due to the number of interlacement points in each weave geometry, with satin having the fewest and plain weave the most. Consequently, the effect of these interlacement points is reflected in the C% achieved. Therefore, the satin weave, with its looser structure and minimal interlacement points, has the lowest C% compared to plain and twill weaves [23].

Less C% decreases fiber friction and tends to increase tensile strength [24]. This is because the carbon filaments are more aligned to the direction of applied force, allowing them to sustain applied loads more effectively. It is also seen that carbon preform doesn't produce enough crimp, which can affect the mechanical properties of that preform [25].

The high C% in high-performance preforms can have negative effects on its mechanical properties, including reduced tensile strength, decreased stiffness, increased risk of fiber breakage, and reduced ballistic performance [26].

5. Conclusions

This study investigated the effect of three basic weave designs, plain, twill, and satin, on the C% of high-performance carbon tow woven preforms. The results revealed that weave geometry influences the overall crimping of the fabric and may affect the mechanical properties of the final product. It was observed that both warp and weft C% decrease with changes in weave type due to the varying number of interlacement points in different weave patterns. Additionally, the number of interlacement points differs between the warp and weft directions within a single weave pattern. In conclusion, the C% of the tow in the woven preform is directly related to the weave structure. Satin weave-based carbon preforms showed the least crimping, around 5%, in the weft direction, while plain weave-based carbon preforms exhibited the highest crimping, approximately 115%, in the weft direction.

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