5.2.3 Basic Weave Patterns

5.2.3.1 Introduction

The three basic weave patterns are plain weave, twill weave (warp and weft faced twill) and satin weave (warp and weft faced satin). All basic weave patterns are characterized by their repeat unit, which is constituted by the same number of yarns in warp and weft direction. The repeat unit indicates the number of warp and weft yarns necessary to repeat the weave pattern. Each warp yarn (end) interlaces with the weft (pick) in the same manner whereas the next corresponding adjacent warp yarn, starts interlacing by stepping up (or down) by one or more squares in the graph. These basic weave patterns are sufficient for most applications of woven fabrics in lightweight construction. Complex patterns can be derived from the basic weave patterns by means of expanding or derivation for special fields of application.

Plain weave is the simplest form of interlacing and the most common basic weave pattern (Fig. 5.2). It has a repeat unit of two warp and two weft yarns. The first warp yarn is raised over the first weft and then lowered under the second weft

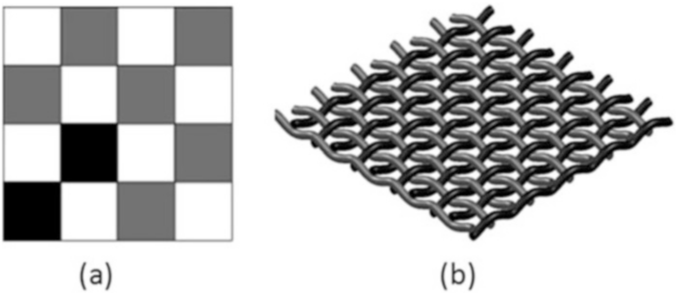

Fig. 5.2 (**a**) Plain weave diagram with 4 repeat units, (**b**) schematic diagram

whereas the second warp yarn is lowered under the first weft and raised over the second weft. The plain weave is the most closely interlaced weave pattern with the highest crimp. This results in a high shear resistance and good handling characteristics, but also causes a loss of strength and stiffness. The high crimp of plain weaves causes a significant difference between fiber orientation and angle of maximum stress and significantly reduces the load-carrying capacity.

5.2.3.2 Twill Weave

The twill weave (Figs. 5.3 and 5.4) is characterized by distinct diagonal lines. Its minimal repeat unit consists of three warp and three weft yarns. The simplest twill weave is the weft faced twill shown in Fig. 5.3a. One warp yarn is raised over one weft and then lowered under two wefts. The diagonal line runs from the bottom left to the top right side. Three additional basic twill weaves can be derived from the first one by negotiation and reflection:

– Weft faced twill with diagonal line going down,
– Warp faced twill with diagonal line going up,
– Warp faced twill with diagonal line going down

Twills with more weft yarns than warp yarns floating on the fabric surface are called weft faced (Fig. 5.3) and twills with more warp yarns than weft yarns floating on the fabric surface are called warp faced (Fig. 5.4), with the fabric back of a weft faced twill looking like a warp faced twill and vice versa.

5.2.3.3 Satin Weave

The third basic weave pattern is the satin weave (Fig. 5.5). Satin weaves are characterized by a smooth surface and a minimum amount of interlacing. Compared to plain weave and twill weave, the satin weaves enable higher warp and weft densities (see Sect. 5.3.1). The smallest repeat unit for satin weaves consists of five warp and five weft yarns. One warp yarn is raised over one weft yarn and lowered under four weft yarns. The interlacing points in satin weaves are scattered as far as

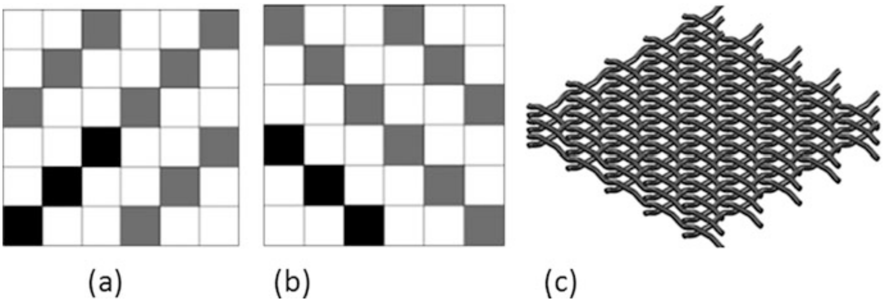

Fig. 5.3 (**a**) Weft faced twill with diagonal line going up, (**b**) weft faced twill with diagonal line going down (4 repeat units), and (**c**) schematic diagram

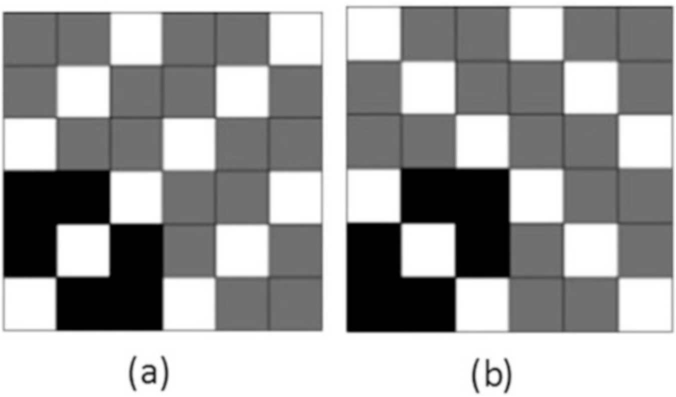

Fig. 5.4 (**a**) Warp faced twill with diagonal line going up and (**b**) warp faced with diagonal line going down (4 repeat units)

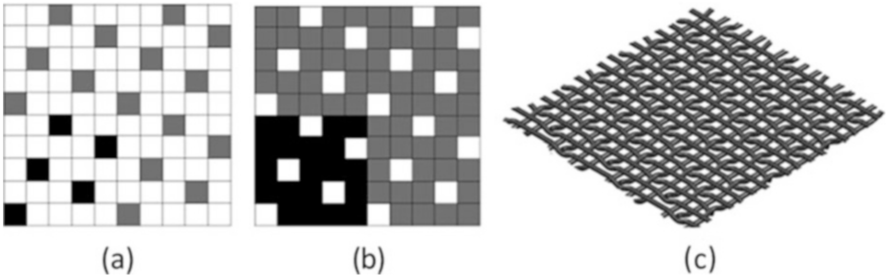

Fig. 5.5 (**a**) Weft faced satin, (**b**) warp faced satin (4 repeat units), and (**c**) schematic diagram

possible, e.g. the points of interlacing must touch neither side by side nor diagonal. Satins with more weft yarns than warp yarns floating on the fabric surface are called weft faced and satins with more warp yarns than weft yarns floating on the fabric surface are called warp faced, where the fabric back of a weft faced satin looks like a warp faced satin and vice versa. The relatively small number of interlacing points results in a lower crimp and causes a lower shear resistance, in comparison to plain weave (assuming same material and warp and weft density). This results in an outstanding draping behavior but also creates poor handling characteristics.

5.2.4 Extended and Derived Basic Weave Patterns

5.2.4.1 Extended Basic Weave Patterns

The three basic weave patterns can be extended into a multitude of other weave pattern as desired and required. *Extended basic weave patterns* are created by inserting or removing warp lifts in any direction. However, within each weave pattern, only one variant may be applied. For the plain weave, no extension exists. In contrast to the basic satin weave, an extended satin weave allows direct contact between the interlacing points. Examples for extended twill and satin weaves are given in Figs. 5.6 and 5.7.

5.2.4.2 Derived Basic Weave Patterns

Derived basic weave patterns are created by the enhancement of basic weave patterns or extended basic weave patterns. This can be achieved by orienting additional warp lifting and/or warp lowering, or by using offset numbers, which are not valid in basic weave patterns or extended basic weave patterns. Derived

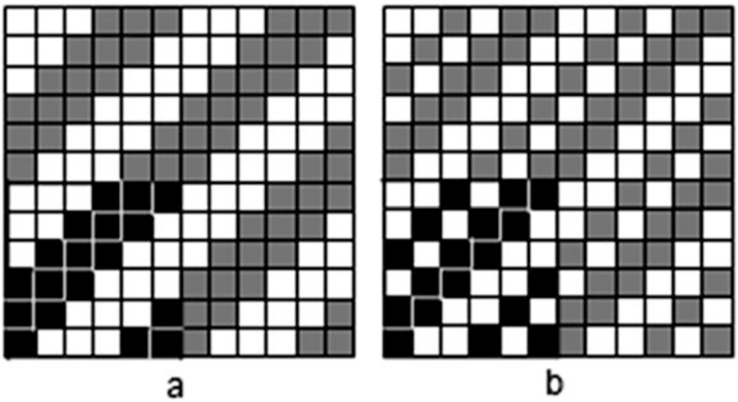

Fig. 5.6 Extended twill weaves—4/2 twill weave and equilateral stitched twill (4 repeats)

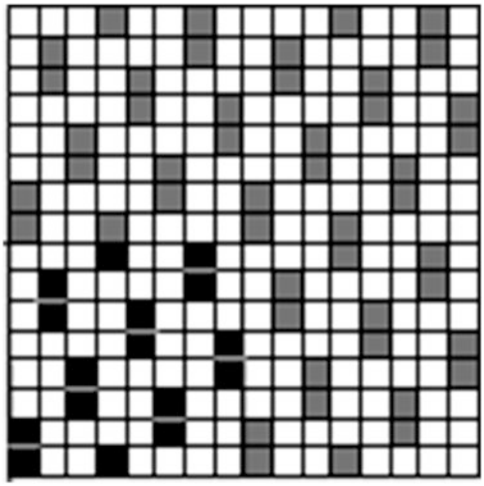

Fig. 5.7 Extended satin weave (4 repeats)

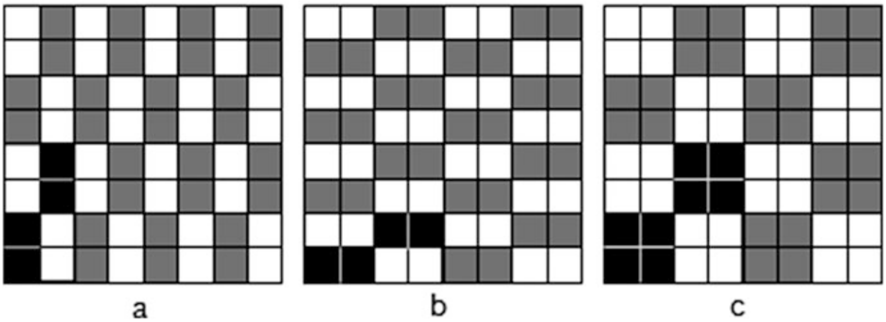

Fig. 5.8 Derivations of the plain weave—(**a**) warp rib weave pattern, (**b**) weft rib (8 repeats each), and (**c**) panama weave pattern (4 repeats)

basic weave patterns are also created by the joining, doubling, omission, mirroring or turning of weave patterns and parts of weave patterns. In derived basic weave patterns, the repeat size can be changed, and the weave pattern characteristics of the initial weave pattern can be lost.

- Derived plain weave patterns
  Derived plain weave patterns originate from the addition of extra warp lifts. The principal set-up of the weave pattern structure remains, while the repeat of the weave diagram is enlarged. If the existing interlacing points are extended by a warp lift in warp direction, a warp rib (Fig. 5.8a) is created. Extending the existing interlacing points by a warp lift in weft direction results in a weft rib (Fig. 5.8b). A panama weave pattern (Fig. 5.8c) is the result of adding a warp lift at existing interlacing points in both warp and weft direction.

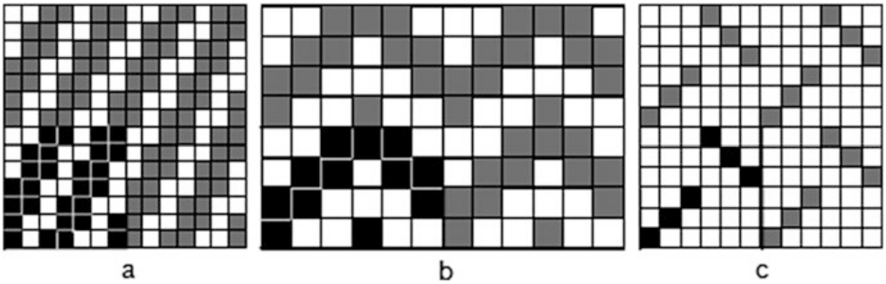

Fig. 5.9 Derivations of the twill weave—(**a**) steep twill, (**b**) transverse pointed twill, and (**c**) cross twill

- Derived twill weaves
  Derived twill weaves are realized by inserting additional warp lifts or changes in offset or ridge direction by turning or mirroring the weave diagram. Steep twill and reclining twill (Fig. 5.9a) are examples for changes in offset, in which the typical angle of inclination of the twill ridge is altered. Pointed and zigzag twill weaves (Fig. 5.9b) are the result of an alternating use of Z ridge and S ridge. Here, the twill ridges are converging at the reversal points. One example for a mirroring of the one repeat half is the cross twill (Fig. 5.9c).
- Derived satin weaves
  Derived satin weaves result from the application of a steadily changing offset. This aims to prevent false twill lines. The number of possible derivations of the satin weave is much smaller than for the twill weaves. Detailed descriptions can be found in [2].
- Special forms
  In addition to the derived basic weave patterns, weave patterns beyond the named classifications can be developed. These weave patterns, referred to as special forms, allow the realization of design or functional effects.

  By means of this large number of weave pattern possibilities, a practicable woven fabric with locally adjustable mechanical properties and drapability characteristics can be constructed. Since these weave patterns are usually created on dobbies (with a maximum of 28 heald frames), the pattern possibilities are limited to a weft repeat corresponding to the maximum number of heald frames.

5.2.5 *Jacquard Weave Patterns*

As opposed to the basic weave patterns, in which several warp yarns are lifted and lowered simultaneously in groups, jacquard-patterned woven fabrics allow the lifting and lowering of each individual warp yarn. The result is an unlimited variety of pattern possibilities with infinite repeat size. A repeat can therefore cross the entire width of the woven fabric. The use of various weave pattern variations on the same fabric and/or the patterned change from single-layer to multilayer woven fabrics enable the production of semi-finished stringer rib-reinforced shells, branched hollow profiles, and preforms with different properties within the woven fabric.

5.3 Woven Fabric Parameters and Properties

5.3.1 Woven Fabric Parameters

The following parameters have significant influence on the properties of the woven fabric:

5.3.1.1 Yarn Material

The properties of the yarn used for the woven fabric influence the properties of the woven fabric, according to the type of material, fineness, inner or outer yarn structure, and additional finishing. A more detailed explanation of the individual yarn parameters is given in Chap. 4.

5.3.1.2 Crimp

Crimp refers to the relation of the length of a representative strip of a woven fabric and the length of the yarn used to weave this strip. The crimp exists both in warp and weft direction, and they influence one another (Fig. 5.10). In general, crimp is a gage of how the yarn deviates from the straight orientation within the woven fabric. The smaller the crimp, the more stretched the yarns of the woven fabric are. By using the adjustment possibilities (warp and weft yarn tension) offered by the weaving machine, the crimp can be varied depending on the direction. Generally, the relation of warp yarn and weft yarn crimp is balanced (Fig. 5.10b).

5.3.1.3 Weave Pattern

The realized weave pattern of the woven fabric crucially influences crimp, making it a factor in the orientation of the individual yarns within the woven fabric. A higher interlacing point density generally means a higher crimp of the individual yarn systems. Woven fabrics with high crimp (e.g. plain-woven fabrics), display a much higher structural elongation than woven fabrics with low interlacing point density (e.g. satin-woven fabrics) (Fig. 5.11) [3]. Woven fabrics with a high

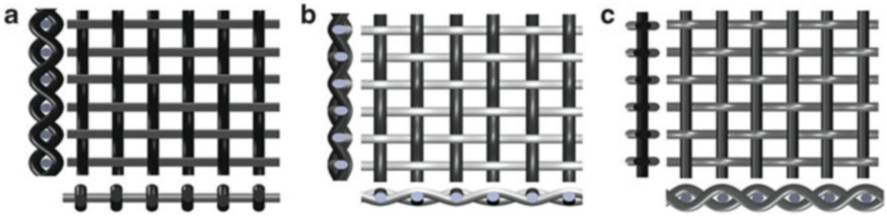

Fig. 5.10 Sectional views of plain-woven fabrics with (**a**) low crimp, (**b**) balanced crimp relation, and (**c**) high crimp

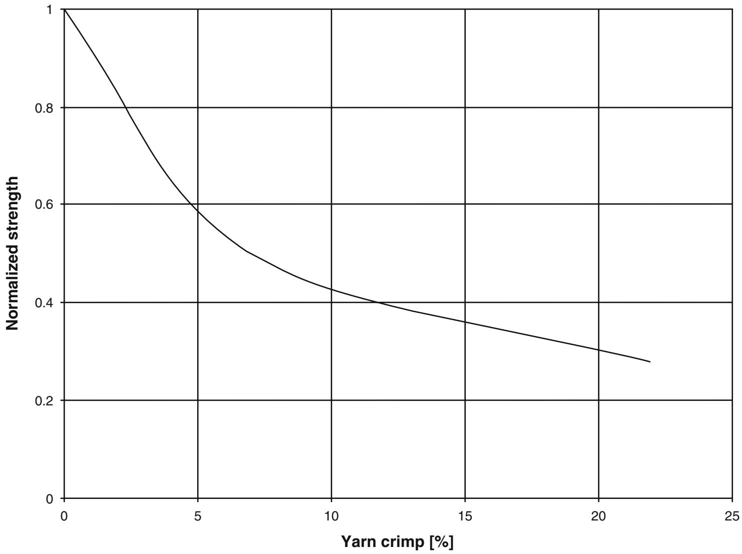

Fig. 5.11 Qualitative relation of achievable maximum breaking strength and crimp

interlacing point density (e.g. plain weaves) have a high slippage resistance, but the high crimp detrimentally affects mechanical parameters in the composite.

5.3.1.4 Woven Fabric Density

Generally, both warp and weft yarn density is given in yarns per centimeter. The higher these values are, the higher the slippage resistance of the woven fabric will be. The relative woven fabric density can be calculated with Eq. 5.1 by Walz and Luibrand [4, 5].

$$DG = \frac{1}{nkns}(ds + dk)\,2\,p \cdot 100\,\% \tag{5.1}$$

In which,

DG (%)	Woven fabric density
n (mm)	Yarn distance (k . . . warp, s . . . weft)
d (mm)	Diameter (k . . . warp, s . . . weft)
p (−)	Weave factor (weave pattern-dependent, tabled in [4])

The weave factor p denotes the number of warp and weft changes in relation to the plain weave. For the plain weave, the weave factor is $p = 1$. For basic twill weaves, it is 0.67, and 0.33 for satin weaves.

5.3.2 Woven Fabric Properties

Chapter 14 details the determination of the properties of textile materials. In the following, woven fabric properties relevant for composite materials and technical textiles will be considered in particular.

Table 5.1 compares the relationships of woven fabric weave patterns and properties at identical warp and weft density and identical yarn material. Depending on the realized weave pattern, the maximum achievable mass per unit area increases from plain to twill to satin weave patterns.

5.3.2.5 Mass per Unit Area

The mass per unit area of any textile fabric is stated in grams per square meter (see Sect. 14.5.2). The mass per unit area of a woven fabric can be increased by using coarser yarns, selecting a weave pattern with a small weave factor, increasing the warp and weft densities, and producing multilayered fabrics. An increasing mass per unit area usually results in increased thickness of the woven fabric, as the yarns generally evade in thickness direction during fabric formation. This can be prevented by means of the weave pattern, but will cause a greater limitation of the thickness of the woven fabric.

5.3.2.6 Woven Fabric Thickness

The thickness refers to the vertical distance between the top and bottom sides of a fabric. Any fabric usually has a distinctive surface profile, which makes normative definitions necessary for an accurate determination of the thickness of a woven fabric (see Sect. 14.5.1). The thickness of the woven fabric is significantly influenced by the respective fiber material and the construction of the woven fabric, and it is closely connected with the areic mass. Special woven fabrics, such as pile and spacer fabrics, can be used to increase the thickness of woven structures while decreasing the density.

5.3.2.7 Resistance to Tear Propagation and Cut Resistance

The resistance to tear propagation and cut resistance quantifies the resilience and damage tolerance of woven fabrics to random and directed damages of membrane materials. In woven fabrics, initial tears continue to grow rapidly. Using specific materials, modified weave patterns and special coatings can significantly increase the resistance of woven fabrics to tear propagation. To increase the cut resistance, which denotes the resilience of a woven fabric to damages caused by sharp-edged objects, special high-strength fiber materials have to be integrated into the structure of the woven fabric in a suitable manner.

6.2 Knitted fabrics

6.2.1 General Remarks

Weft knitting is a fabric formation method in which the yarn material is fed transversely on the needles and formed into stitches by the needles. The textile fabric is created by connecting the stitches. In general, the same work cycle on the needles across the working width is performed consecutively.

The difference between weft *knitting, cotton-type knitting,* and *warp knitting*, apart from the direction of yarn feeding, is in the process step of stitch *forming*. While stitch forming is part of the *knockover* work step of weft knitting, the stitch is formed in a separate step in Cotton-type knitting. In warp knitting, the steps of stitch forming and *yarn guiding* are performed simultaneously (Fig. 6.2). In addition, the same work step is performed on all needles across the working width at the same time in warp knitting (compare Chap. 7).

In the following sections of the chapter, the binding elements of weft knitting will be introduced, basic bindings will be shown, and the main parameters to influence and describe the properties of weft knitted fabrics during manufacturing will be derived from the previous information. Emphasis will be placed on those properties crucial for the manufacture of textile reinforcement semi-finished products by weft knitting.

The terminology for the binding elements is based on the specifications laid out in standards EN ISO 4921 and EN ISO 8388.

6.2.2 Binding Elements

6.2.2.1 Stitch

The basic binding element of weft knitting is the *stitch* (Fig. 6.3). It consists of the head, two legs and two feet. *Stitches* always contain head and foot intermeshing points. The geometry of the stitch can be described with regards to the width (b_M) and height (h_M). The length of the yarn material contained in a stitch is referred to as stitch length (l_M). Deformations of the weft knitted fabrics, e.g. by application of force, result in changes of stitch width and stitch height, but do not in any way influence the stitch length.

Depending on the manufacturer and type of machine, latch needles or compound needles are used in weft knitting machines (Fig. 6.4), with latch needles being more popular at the time of publication.

For the stitch formation, a yarn presentation in the opened needle hook is required. In latch needles, the opening and closing of the needle hook is performed by a motion of the needle tongue, usually initiated by the head of a previous stitch carried on the needle. Brushes at the carriage in the area of the stitch-forming

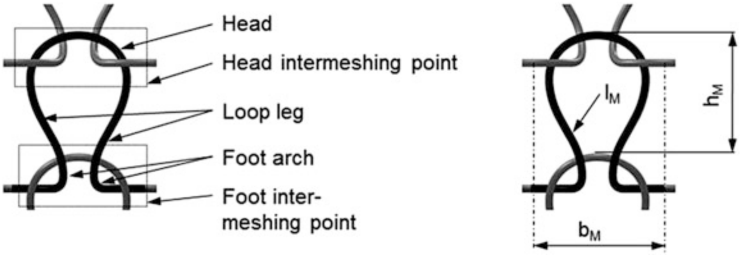

Fig. 6.3 Components of a stitch and stitch geometry

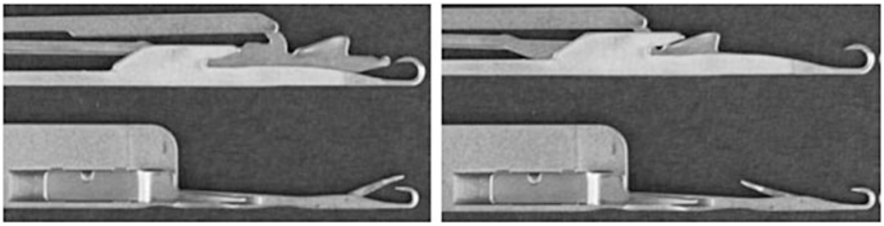

Fig. 6.4 Compound and latch needles in the basic position (*left*), and with opened needle hook (*right*)

elements support the opening and closing of the needle hook especially during the initial insertion of the yarn into empty needles or in critical knitting situation. For the stitch formation, only the motion of the needle needs to be controlled.

Compound needles are equipped with an independently controllable slider to open and close the needle hook. For stitch formation, both the needle and the slider have to be moved. In comparison to latch needles, this manner of stitch formation requires a much smaller maximum clearing path. The resulting smaller relative motion between needle and yarn material can positively affect the friction stresses exerted on the yarn material. Therefore, compound needles are tools with a high potential for the processing of more sensitive yarn materials or for increasing machine speed during knitting.

Figure 6.5 shows the schematics of a cam box driving latch needles in a flat knitting machine with one needle bed. The numbers signify the individual needle positions (compare Fig. 6.6).

The needle positions traversed by the needles during stitch formation are given with their designations in Fig. 6.6.

At the beginning of the stitch formation, the needle is in its basic position (1). A yarn stitch with foot intermeshing point, but without head intermeshing point (half stitch) is positioned in the needle hook. In a first step, the needle is cleared into the tuck position (2). The half stitch slips across the needle shaft onto the needle tongue, which is opened by the motion. After that, the needle is moved into the clearing position, the highest position during stitch formation.

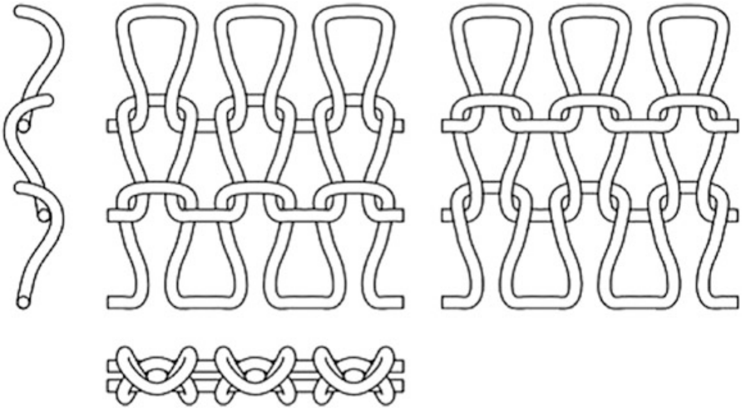

Fig. 6.14 Purl stitch basic binding: *right* and *left* side of the knitted fabric

(BWK), multiaxial weft knitted fabrics (MWK), Multi-layered knitted fabrics (MLKF) or non crimp knit (NCK)]—the single jersey MLG, or interlock-MLG binding, can properly be introduced in this context. These bindings are based on the single jersey or interlock basic binding, in each case extended with stretched weft and warp yarns integrated into the stitch structure (Fig. 6.10). Depending on stitch configuration, different numbers of warp yarn layers and/or weft yarn layers can be integrated in the stitch structure [8].

6.2.4 Knitted Fabric Properties and Knitting Parameters

The binding describes the arrangement of the binding elements for the formation of a knitted textile surface. The selection of the binding, therefore, fundamentally defines the structure of the weft knitted fabric. Apart from this, the yarn material and chosen knitting parameters, such as machine gauge, stitch cam adjustment, take-down settings or yarn tension, exert considerable influence on the structure and characteristics of the knitted fabric.

The m*achine gauge* describes the number of needles per reference length, which is usually given in inches. The higher the machine gauge, the higher the *stitch density* of the knitted fabrics. The take-down settings have to be selected in a manner that ensures the knockover of the stitches off the needles as well as the removal of the weft knitted fabric from the stitch forming area. A suitable yarn tension during yarn feeding to the knitting area, which is also constant on all needles, is the most important prerequisite for the realization of an equal *stitch length* in all sections of the knitted fabric.

The characterization and description of weft knitted fabrics also rely on textile-physical properties like stitch density in course and wale direction, stitch length, fabric thickness, or areic mass.