



**Figure 2** Examples of woven fabric patterns: (a) plain weave; (b) twill weave; (c) four-harness satin; (d) eight-harness satin (after Ishikawa and Chou, 1982a).

Woven fabrics provide more balanced properties in the fabric plane than unidirectional laminae: the bidirectional reinforcement in a single layer of a fabric gives rise to enhanced impact resistance. The ease of handling and low fabrication cost have made fabrics attractive for structural applications. On the other hand, the limited conformability, poor in-plane shear resistance, and reduced yarn-to-fabric tensile translation efficiency due to yarn crimp are some of the disadvantages of woven fabrics. Triaxial woven fabrics, made from three sets of yarns which interlace at  $60^\circ$  angles, provide higher isotropy and in-plane shear rigidity than orthogonal weaves.

### 1.23.2.1.2 Braids

Braids are formed by interlacing three or more yarns so that each yarn passes over and under one or more of the others. Braids are divided into two types: (i) flat braids, in the form of narrow flat tapes and (ii) tubular braids, which may be hollow or have a center core. The geometric configurations of some 2-D braids are given in Figure 3. The first one shows the braid with a  $2/2$  repeat of intersecting pattern, and it is known as a regular, plain or standard braid. Figure 3(b) gives a diamond or basket braid, which is characterized by a  $1/1$  repeating pattern. Figure 3(c) is a regular braid with longitudinal in-laid, and it is also

called a triaxial braid because of the three directional fiber orientations.

### 1.23.2.1.3 Knits

A knitted structure is characterized by its interlacing loops. Two basic types of knits can be defined according to the general direction of travel of a looped thread in the fabric. In weft knitting, the thread runs widthwise, and the loops are formed by a single weft thread (Figure 4(a)). In warp knitting, the orientation of a looped thread is warpwise, and all the loops making up a single horizontal row are formed simultaneously (Figure 4(b)). Simple weft and warp knits can provide extensibility in all directions and are thus suitable for deep-draw molding techniques. Directional stability can be established by adding in-laid (nonknitting) yarns in the desired directions as shown in Figure 4(c).

## 1.23.2.2 3-D Textile Preforms

### 1.23.2.2.1 Braids

There are three basic braiding techniques for forming three-dimensional preforms, namely, two-step, four-step, and solid braidings. In the case of two-step braiding, the axial yarns are stationary and the braider yarns move among