$$N_l=\begin{cases}\left[\dfrac{d_l}{d}\right]\ldots\ldots\ldots\ldots\ldots\ldots 0\le\dfrac{d_l}{d}-\left[\dfrac{d_l}{d}\right]<f_l\\ \left[\dfrac{d_l}{d}\right]+1\ldots\ldots\ldots\ldots f_l\le\dfrac{d_l}{d}-\left[\dfrac{d_l}{d}\right]<1\end{cases} \tag{4}$$

$$N_r=\begin{cases}\left[\dfrac{d_r}{d}\right]\ldots\ldots\ldots\ldots\ldots\ldots 0\le\dfrac{d_r}{d}-\left[\dfrac{d_r}{d}\right]<f_r\\ \left[\dfrac{d_r}{d}\right]+1\ldots\ldots\ldots\ldots f_r\le\dfrac{d_r}{d}-\left[\dfrac{d_r}{d}\right]<1\end{cases}. \tag{5}$$

Where d is the width of the single tow; d_l, d_r are the width of distance between placement path and the left placement curve, right placement curve respectively; [] is the sigh of round down operation; f_l and f_r are the overlap factor for the left and right respectively, $f_l \in [0, 1]$, $f_r \in [0, 1]$.

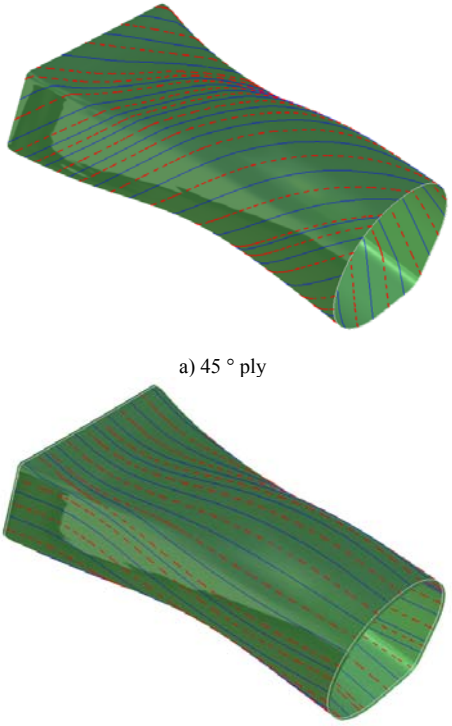
When the maximum fiber number N of tow is odd, the middle tow placed along the path is treated as left. Thus the maximum fiber number on the left is $1+(N-1)/2$, and on the right is $(N-1)/2$. Equations to calculate the tow quantity is shown as (6) and (7).

$$N_l=\begin{cases}\left\{\begin{array}{l}\left[\dfrac{d_l-d/2}{d}\right]+1\ldots\ldots 0\le\dfrac{d_l-d/2}{d}-\left[\dfrac{d_l-d/2}{d}\right]<f_l\\ \left[\dfrac{d_l-d/2}{d}\right]+2\ldots\ldots f_l\le\dfrac{d_l-d/2}{d}-\left[\dfrac{d_l-d/2}{d}\right]<1\end{array}\right\} d_l-\dfrac{d}{2}\ge 0\\ \left\{\begin{array}{l}0\ldots\ldots\ldots\ldots 0\le\left[\dfrac{d_l}{d}\right]<\min(f_l,f_r)\\ 1\ldots\ldots\ldots\ldots \min(f_l,f_r)\le\left[\dfrac{d_l}{d}\right]<1\end{array}\right\} d_l-\dfrac{d}{2}<0\end{cases} \tag{6}$$

$$N_r=\begin{cases}\left\{\begin{array}{l}\left[\dfrac{d_r-d/2}{d}\right]\ldots\ldots 0\le\dfrac{d_r-d/2}{d}-\left[\dfrac{d_r-d/2}{d}\right]<f_r\\ \left[\dfrac{d_r-d/2}{d}\right]+1\ldots\ldots f_r\le\dfrac{d_r-d/2}{d}-\left[\dfrac{d_r-d/2}{d}\right]<1\end{array}\right\} d_r-\dfrac{d}{2}\ge 0\\ 0\ldots\ldots\ldots\ldots d_r-\dfrac{d}{2}<0\end{cases} \tag{7}$$

IV. Simulation of Path Planning

$\pm$ 45 ° and 0 ° plies are the typical plies in the composite lamina design. Based on the proposed algorithms, the CAA application of CATIA is adopted to develop the simulation software. A S-shaped inlet is selected as research subject. The 45° ply and 0 ° ply are illustrated in Fig. 7, where the red dotted line represents the path of the contact point between the compaction roller and the mandrel, and the blue solid line represents the tows' edge. In this case, the maximum tow width is 64mm, consisting of a total of 10 tows. There are 13 paths and 12 edge lines in the 45 ° ply, 20 paths and 19 edge lines in the 0 ° ply. The maximum distance between the neighbor path is less than the maximum tow width, which guarantee the surface of mandrel can be filled.



a) 45 ° ply

b) 0 ° ply

Figure 7. Simulation of placement paths for S-shaped inlet

V. Conclusion

(1) A new path planning method of fiber placement for closed surface is put forward, in which the placement curves are made up of path and tow edge alternately.

(2) The calculation methods of tow number for conditions where the maximum tow number is even and odd, are proposed on the basis of the proposed path planning algorithm.

(3) The fiber placement simulation of S-shaped inlet is performed, which verifies the correctness and feasibility of the algorithms.

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