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Experimental and simulation research on thermal stamping of carbon fiber composite sheet

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Abstract: To improve the manufacture efficiency and promote the application of composites in the automobile industry, a new composite forming method, thermal stamping, was discussed to form composite parts directly. Experiments on two typical stamping processes, thermal bending and thermal deep drawing, were conducted to investigate the forming behavior of composite sheets and analyze the influence of forming temperature on the formed composite part. Experimental results show that the locking angle for woven composite is about 30°. The bending load is smaller than 5 N in the stamping process and decreases with the increase of temperature. The optimal temperature to form the carbon fiber composite is 170 °C. The die temperature distribution and the deformation of composite sheet were simulated by FEA software ABAQUS. To investigate the fiber movement of carbon woven fabric during stamping, the two-node three-dimension linear Truss unit T2D3 was chosen as the fiber element. The simulation results have a good agreement to the experimental results.

Key words: thermal stamping; carbon fiber composite sheet; shear angle; bending; deep drawing

1 Introduction

Compared with other commonly used materials such as metals and alloys, fiber composites possess excellent features such as low weight, high specific strength, high modulus, high stiffness and outstanding designability. Therefore, they have been widely used in the fields such as aerospace, automobile manufacture, shipping, building reinforcing, sports, energy development [1,2]. But the commonly used composites forming technologies, such as hand lay-up, spray-up, resin transfer molding, filament winding and autoclave molding, cannot overcome problems, such as high operation complexity, low efficiency and high cost. As composite parts are widely used in manufacturing fields, especially in automobile manufacturing, a high-efficiency, low-cost, mass-production forming method for composite parts is in urgent need [3−5].

Thermal stamping was one of the most effective ways to fabricate composite sheets. This method was proposed to form composite parts directly by the isothermal die set. As shown in Fig. 1, the forming process is composed of three stages. First, die set is heated up, and the punch moves downward until it contacts with the blank. Second, the resin in the blank becomes soft because it is heated by contact heat transfer with the heated punch and die, then the composite blank is stamped as the punch moves downward. Finally, the resin in the composite resolidifies in the cooling die set, and the part is obtained.

Since thermal stamping has great advantages over traditional forming method, a lot of studies have been conducted to investigate the forming property and deformation mechanism of thermal stamping [6−8]. HOU and FRIEDRICH [9,10] heated the composites to 180 °C by contact heat transfer, then put the sample in the die set to stamp and resolidify to get orthopaedic part. ZHU et al [11] measured the strain of the workpiece in the thermal stamping process. The results show the shape of the die set and the initial distribution of the fiber may affect the forming property. CABRERA et al [12] studied the thermal stamping process of polypropylene self-reinforcement composites. The results show that shear deformation is the dominant mechanism of deformation for composites thermal forming and thermal stamping is

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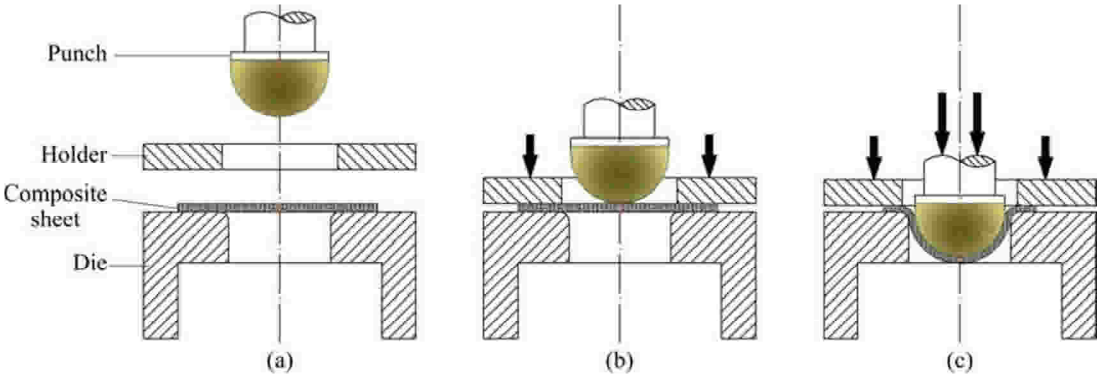

Fig. 1 Illustration of thermal stamping process: (a) Heating die set and punch; (b) Heating specimen through heat transfer; (c) Thermal stamping

an efficient way to form complex parts.

In this study, we investigated the deformation mechanism of thermal stamping by bias extension test and picture frame test, and also obtained the reasonable temperature range. In order to obtain the load−displacement curve of the stamping process, thermal bending and thermal deep drawing experiments were conducted, the temperature distribution and fiber movement was simulated by ABAQUS software.

2 Shear properties of reinforcement

2.1 Shear angle

Carbon fiber reinforced polymer matrix composites consist of woven fiber reinforcement and polymer matrix. Woven fabric plays a vital role in composites forming. In thermal forming process, resin matrix turns into the viscous state, so the constraint between fiber reinforcement and polymer matrix reduces greatly. The specific mechanical properties and deformation mechanisms of fiber-reinforced polymer matrix composites are influenced by the characteristic of fiber reinforcement.

Shear deformation is the dominant mechanism of deformation for composites thermal forming. A 3D deformation of fabric is required at corners or over spherical regions [13]. When textile composites are subjected to deep drawing, in-plane shear will occur. This primarily corresponds to the relative sliding of parallel tows with fabric layer or composite ply, and to rotation of tows at their crossovers. The change of angle between the warp and weft yarns is defined as shear angle, and it is equal to the difference of the enclosed angle between the two yarn directions before and after deformation. Since the warp and weft yarns are perpendicular to each other before deformation, so shear angle can be defined as follows:

$$\gamma = \frac{\pi}{2} - 2\theta \tag{1}$$

In thermal forming process, fiber bundles are extruded and twisted, and when the angle between two crossover fiber bundles comes to its crucial value ‘locking angle’, wrinkle will occur gradually. To investigate the forming properties of carbon fiber reinforced matrix composites, picture-frame test and bias extension test are often used to study the forming phenomenon of carbon fiber.

2.2 Testing methods

Experimental equipments for picture frame test and bias extension test are shown in Fig. 2. Carbon woven fabric specimens are clamped by testing device. With moving up of the testing machine slide, the displacement and force of the woven fabric are measured.

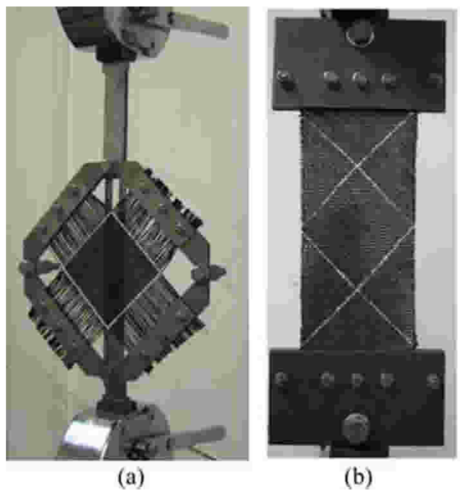

Fig. 2 Experimental set-ups for picture frame test (a) and bias extension test (b)

Experimental principles for picture frame test and bias extension test are shown in Fig. 3, from which the equations to measure the shear angle for the two tests can be deducted as Eqs. (2) and (3).

$$\gamma = \frac{\pi}{2} - 2\theta = \frac{\pi}{2} - 2\arccos\left(\frac{\sqrt{2}L + \delta}{2L}\right) \tag{2}$$