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Effects of exposure time and intensity on the shot peen forming characteristics of Ti/CFRP laminates

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ABSTRACT

Fibre metal laminates (FMLs) have been developed as promising materials in the manufacture of aircrafts. In order to reduce costs during the manufacture process, relatively new forming techniques are required. In this work, shot peen forming process was performed on Ti/CFRP laminates. Additionally, effects of shot peening parameters on the forming characteristic of Ti/CFRP laminates were investigated. The results showed that the peening coverage and the final arc height of the FML strip were increased with the extension of the exposure time. Similarly, the final arc height of the FML strip increased linearly with the augment of the applied Almen intensity. Moreover, FML with different lay-ups showed diverse forming characteristics. It was more difficult to generate the bending deformation in the FML made with unidirectional lay-up prepreg. Finally, an improvement in tensile properties of the FMLs was confirmed after the shot peening treatment.

1. Introduction

Fibre metal laminates (FMLs) are super hybrid materials composed by thin metal layers and fibre reinforced polymer layers. As a family of super hybrid composites, FMLs possess the features that both metal and fibre reinforced composite have, such as high specific strength and stiffness, lightweight, excellent impact resistance and superb fatigue properties [1–5]. With these outstanding characteristics, FMLs have been developed rapidly since they were first introduced by Delft University later in 1970s.

There are several groups of FMLs which are known as Arall (Aramid fibre/Aluminum), Glare (Glass fibre/Aluminum), Carall (Carbon fibre/Aluminum) and TiGr (Graphite fibre/Titanium). At present, Arall has been used as the cargo door of the C-17 and Glare has been successfully utilized in manufacturing the upper fuselage of the Airbus 380 aircraft [6–11]. With the development of the aerospace industry, the aircrafts are being designed to fly faster and to last longer than ever before [12]. Obviously, the skin of the aircrafts will experience a high temperature profile during their service process. Hence, TiGr laminates can be candidate materials for next generation aircrafts owning to their excellent high temperature performance.

During the manufacturing process of the aircraft, there are roughly two steps: the creation of the parts and assembly of the parts into the structure. It is necessary to find effective methods to form the FMLs before assembling. However, compared with sheet metal forming, composite forming is a relatively new area for researchers. Normally, there are two different approaches to obtain a complicated shape of FML parts, as shown in Fig. 1. It can be achieved by deforming the metal layers and thereafter make laminates from the individual plies. However, pre-forming of the thin metal sheets before laminating is not merely difficult but expensive. Hence, it is attractive to reduce the process cycle and labor cost by a forming curved shape of FML plates.

Kalyanasundaram et al. [13] investigated the stamp forming behavior of self reinforced-PP based fibre metal laminates. They studied the effects of temperature, binder force, feed rate and interaction effects on major strain and strain ratios (minor strain/-major strain). However, it was concluded that only the factors such as temperature and binder force affect the major strain and strain ratios significantly. Dou et al. [14,15] simulated the stamping process of fibre metal laminates by using finite element modeling. Two FMLs made with different prepreg types were investigated in their work. It was confirmed that properties of core composite

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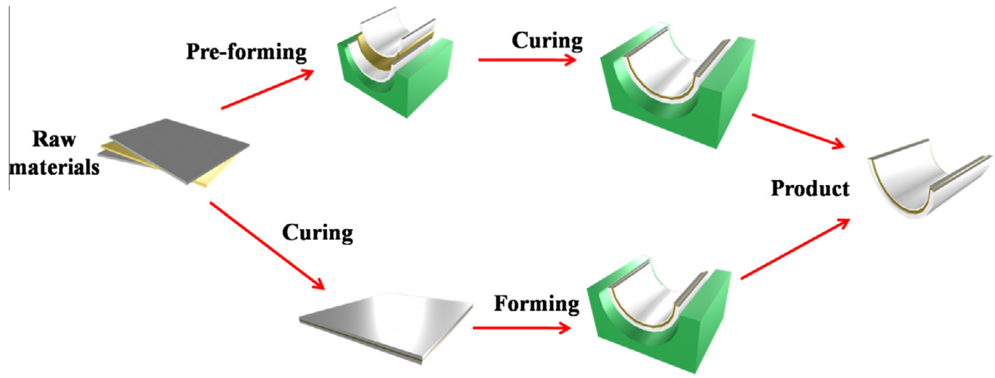

Fig. 1. Two technical routes to create a FMLs product. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

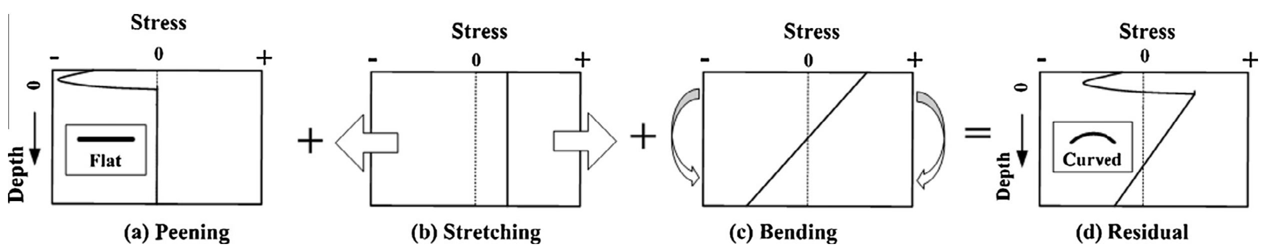

Fig. 2. Balancing of (a) induced stresses through, (b) elongation and (c) bending of the part to reach an equilibrated, (d) residual stress profile.

layers projected strong influences on the forming behavior of the FMLs. Moreover, several manufacture processes and forming methods were reviewed by Sinke [16]. He introduced the roll bending forming process and stretch forming process in the paper. Also, failure modes and forming limit of FMLs were presented. Although traditional methods have been successfully utilized to manufacture FML products, novel forming approaches with advantages of high productivity, low labor cost and dimension stability are still yet to be developed.

Shot peen forming is a manufacturing method which is commonly used in aerospace industry, especially used for forming the contoured integral aircraft skin panels. During the shot peening process, the surface of the metal sheet is mechanically treated by the stream of small hard shot with sufficient kinetic energy. Therefore, the outer layer of the metal sheet surface is plastically deformed, introducing the compressive stresses in the surface through the thickness direction. In order to balance the compressive stresses, the thin outer layer has to be stretched along the surface which produces significant bending, as schematically shown in Fig. 2 [17]. As a promising forming method, shot peen forming has been investigated by numerous researchers. Hong et al. [18] applied a numerical simulation of the shot peening process and successfully obtained the relationships between peening process parameters and peening quality. Quantitative relationships between the saturation, surface coverage and roughness with respect to peening time were established by Miao et al. [19]. Moreover, Russig et al. [20] undertook some pre-study on shot peening forming on FMLs. They investigated the possibilities to form Glare by using shot peen forming. It was proved that Glare possessed a similar deformation behavior with monolithic sheets under quasi-static indentation with single steel balls. Additionally, Glare parts with curvature radius less than 2500 mm could be obtained without damage.

The aim of this work is to experimentally investigate the effects of two important shot peening parameters (exposure time and Almen intensity) on the forming characteristics of Ti/CFRP laminates. Ti/CF/Polyimide FMLs and Ti/CF/PEEK FMLs were prepared and selected as the research objects. Shot peening experiments were carried out on the FML strips under different exposure time durations (0.76, 1, 3, 5 and 7 s) and different Almen intensities (0.097, 0.133, 0.156 and 0.193 mmA). The relationship between the curvature radius and the peening parameters was obtained after experimental and theoretical investigation.

2. Experimental procedure

2.1. Materials

Titanium plates with a thickness of 0.3 mm (BAOJI Titanium Industry Co., Ltd. China), carbon fibre (TR50S 6K, Mitsubishi Rayon Co., Ltd., Japan), PMR polyimide resin (KH-308, Institute of Chemistry, Chinese Academy of Science) and carbon fibre reinforced PEEK prepreg (APC-2, Ten Cate nv.) was used as constituent materials. The PMR polyimide contains 50 wt.% of polymerized reaction mixtures. Carbon fibre reinforced polyimide prepreg was self-prepared by numerically controlled automatic placement machine in a laboratory in Nanjing University of Aeronautics and Astronautics. Two series of FMLs, Ti/CF/Polyimide FMLs and Ti/CF/PEEK FMLs, were prepared according to the consolidating processes reported in [4,21]. The detailed information of the FMLs used in this work is listed in Table 1.

Table 1
Detail information of the FMLs specimens.

Code	Configuration	Thickness (mm)	Tensile strength (MPa)	Modulus (GPa)
PI-U	[Ti/0/0/Ti/0/0/Ti]	1.45 ± 0.12	938 ± 11	105 ± 8
PI-C	[Ti/0/90/Ti/90/0/Ti]	1.46 ± 0.11	633 ± 14	83 ± 7
PEEK-U	[Ti/0/0/Ti/0/0/Ti]	1.49 ± 0.09	935 ± 12	101 ± 10
PEEK-C	[Ti/0/90/Ti/90/0/Ti]	1.48 ± 0.07	621 ± 27	83 ± 6