Finite Element Modeling and Failure Analysis of Roll Bending Forming of GLARE Laminates

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Abstract:

In this paper, a three-dimensional finite element model of three-roller bending forming process was built under the ABAQUS/Explicit environment based on the solutions of several key techniques, consisting of material property definition, diverse failure criterions, contact boundary condition treatment and meshing technique. Failure characteristics of GLARE in this process were also investigated. Then numerical modeling was used to analyze stress-strain, failure modes and damage characteristics of different laminates. It was found that the failure of epoxy resin matrix occurred with the increase of the displacement of top roller, followed by fiber breakage. Comparison between numerical simulation and experimental tests was provided.

Keywords: Hybrid; Laminates; Roll bending forming; Finite element modeling (FEM); Failure

1. Introduction

Roll bending forming of GLARE laminates is the most appropriate option for single curved skins [1]. It should be noted that roll bending forming is an efficient technique for forming metal plates into cylindrical or conical shapes due to its simple configuration. Over the years, an extensive investigation was carried out on modeling and simulation for roll bending forming of metal sheets [2-5]. However, published data related with roll bending forming of GLARE laminates are still rather meagre.

Therefore, it is of great worth to investigate roll bending forming of GLARE with FEM simulation to obtain optimized finite element model of roll bending forming of GLARE laminates.

Finite element modeling and analysis for roll bending forming of GLARE laminates were primarily indagated in order to make a study of stress and strain, failure of different laminates during roll bending forming. The three-dimensional finite element model was established in this paper with the help of ABAQUS/Explicit & Standard solvers through which the position of the top roller can be predicted accurately. The stress and strain of different GLARE laminates were also investigated. Finally, the results of numerical modeling were compared with experiments.

2. Finite Element Modeling

Many key techniques were taken into account including geometry modeling, definition of material properties, contact boundary conditions, mesh and element type to model the roll bending forming of GLARE laminates using ABAQUS/Explicit &Standard solvers [6]. Thus it is necessary to establish constitutive relation and failure model of different GLARE laminates.

The finite element model of GLARE laminates employed an independent mesh technique for each layer. Aluminum layers were meshed by three-dimensional eight-node linear brick solid elements, meanwhile, eight-node quadrilateral continuum shell elements were applied for glass/epoxy composite layers. Particularly, a cohesive element was selected to analyze the delamination initiation and propagation of the adhesive layers. The finite element model of roll bending forming of GLARE laminate was built as illustrated in Fig. 1.

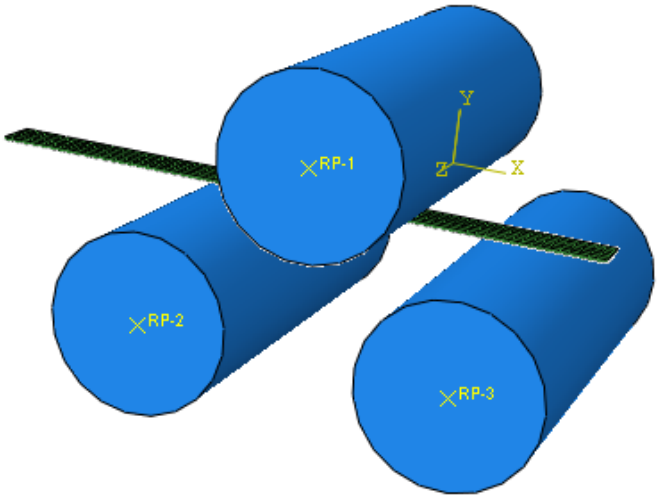

Fig. 1The finite element model of roll bending forming of GLARE

3. Results and Discussion

The bending strength of GLARE-3/2 laminates after roll bending is shown in Fig. 2(a). Bending strength of finite element simulation is all slightly higher than the experimental value and the error is 3.24%, 4.23% and 4.21%, respectively, totally in the range of 5% allowed by the specification. Thus, the accuracy and reliability of the finite element results are certified. Furthermore, GLARE with 0°/0° configuration show the highest bending modulus after roll bending while GLARE with +45°/-45° configuration show the lowest bending modulus, as shown in Fig. 2(b). It suggests that the ability of bearing bending deformation in the elastic bending deformation stage decreases with the reduction of the content of 0° fiber.

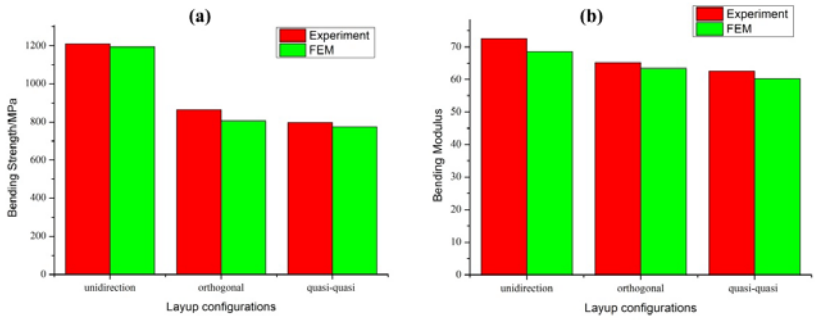

Fig. 2 FEM predicted bending strength and bending modulus compared with experiments.

(a) bending strength; (b) bending modulus

The main failure mode of the samples after roll bending is matrix fracture and debonding between fibers and matrix, as shown in Fig. 3.

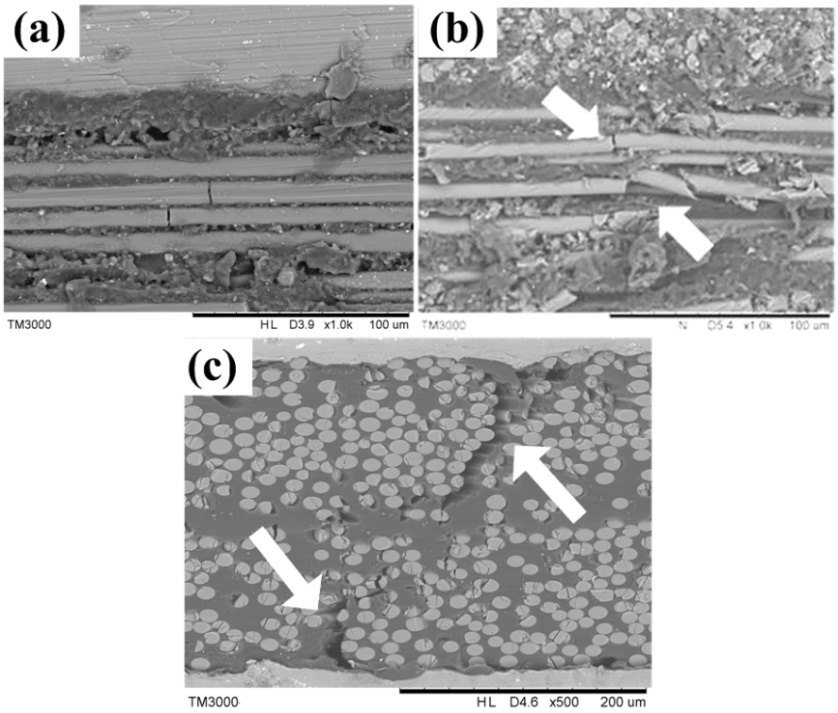

Fig. 3 SEM images of cross section for the GLARE samples after roll bending
(a) GLARE 2A (b) GLARE 3 (c) GLARE 6A

Owing to the existence of 0° fibers in the process of roll bending, GLARE 2A and GLARE 3 possess stronger bending resistance than GLARE 6A. In other words, GLARE 2A and GLARE 3 can bear larger bending deformation during the roll bending process.

4. Conclusions

a) An application of finite element model of roll bending forming of GLARE laminates was presented. The ability of bearing bending deformation in the elastic bending deformation stage decreased with the reduction of the content of 0° fiber. And the accuracy and reliability of finite element results were certified.

b) SEM results showed that the failure of epoxy resin matrix occurred with the increase of the displacement of top roller, followed by fiber breakage. GLARE 2A and GLARE 3 possessed stronger bending resistance than GLARE 6A.

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