Validating Finite Element Models of Metallic Specimens during V-bending and Relaxation

Q. Lin[1a], Z. Guan[1] and W. J. R. Christian[1]

[1]School of Engineering, University of Liverpool, UK

[a]qiushi.lin@liverpool.ac.uk

Abstract

A technique is demonstrated for validating finite element models of the relaxation behaviour of metallic specimens after V-bending. A digital image correlation (DIC) system was used to measure the evolution of strain fields on the edge of specimens during a V-bending and relaxation process. Finite element models for the specimens were validated based on the variation of strain fields and thus the final shape of the specimen after relaxation can be accurately predicted.

Introduction

Fibre Metal Laminates (FMLs), which are hybrid composites bonding metallic sheets and fiber-reinforced composite matrix together, have had a great impact across many industries due to their high specific strength and stiffness, high fatigue resistance and damage tolerance. Compared to the conventional manufacture method which forms the different layers of FMLs separately, forming the flat metal and thermoplastic composite sheets together within a single step into FML products helps to reduce the manufacture cost [1]. To determine the accurate shape of products after the one-step processing and avoid the potential defects, finite element simulation has been used for a shape change prediction [2]. A drawback of the current finite element analysis lies in the difficulty to validate the finite element model with experimental results, especially for the relaxation stage after the release of the forming load.

The main purpose in the early stage of the study is to obtain good predictions on the behaviour of the metallic part of FMLs. In order for a quantitative comparison between the experiment and finite element simulation, an experiment has been designed that uses a DIC system to record changes in the strain field on the side area of metallic specimens during a V-bending and relaxation process. It has been found in previous studies that the shape change of specimens in the relaxation stage is determined by the final stress distribution along the side area of specimens given in the V-bending stage, and the stress distribution can be affected by the settings of V-bending mould such as tip radius, bending angle and punch depth [3]. As the validation approach in the previous studies was limited to compare the final bending angle between experiment and simulation, a DIC method has been introduced to acquire the value of strain changes along the side area of specimen and to make a more sufficient comparison to the simulation results. Such a method can be used to obtain data for validation and calibration of finite element models so that it can accurately predict the final shape of specimens under various mould settings. Meanwhile, with the combination of numerical and experimental analysis, a comprehensive understanding on the mechanism of the V-bending and relaxation of specimens can be acquired.

Experimental Method

In the experiment, 1.6mm thick 200mm by 50mm monolithic Al2024-O aluminium plates were used as specimens to verify the potential of the validation method. Before the experiment, a pair of moulds were manufactured to bend the specimens into a V-shape with a bending angle of 90° and punch radius of 4mm. One side area of the specimens was painted with a fine speckle pattern for the DIC measurements. The specimens were then V-bended by the mould with a punch speed of 5mm/min. Once the bending angle of the specimen reached 90°, the male mould was released and returned to its initial position. A 3D-DIC system (Q-400, Dantec Dynamics) was used to measure the strain changes around the radius area of the specimen during the V-bending and relaxation process. Because of the small side area of the specimen, DIC was performed with high magnification lenses.

The final bending angle of the specimen was measured on a platform with two laser rangefinders. The strain variation at two significant points on the side of specimen were investigated, which is shown in Fig.1 (A). Point 1 in the figure is near the bottom-radius of the specimen where the maximum deformation occurred. Point 2 is around the transition between the curved and straight section of the mould where stress reversal may occur at the end of V-bending stage due to the interaction between the specimens and mould [3]. The variation of the maximum and minimum principal strain at the two points acquired from the DIC system were compared with the curves acquired from an Abaqus finite element simulation, therefore the effectiveness of the simulation can be determined. In the simulation, the material property of Al2024-O was modelled with a nonlinear isotropic/kinematic combined hardening model because of the cyclic loading in the forming process.

Discussion

As shown in Fig.1 (B), compare to the simulation result, the maximum principal strain over time curve acquired from experiment at point 1 showed a lower strain rate in the first 80 seconds. The experiment and simulation showed similar maximum principal strain at the end of bending process at about 20%, and the strain from experiment after relaxation was slightly lower than simulation at 19.3% and 19.7%. The minimum principal strain over time curve at point 1 showed similar result between experiment and simulation with less difference in strain rate, and at the end of bending the strain acquired from experiment and simulation are at about -10.2%. After relaxation the strain acquired from simulation showed a recovery at -10.1% while the experiment result was almost unchanged. The magnitude of maximum principal strain at point 1 was significantly higher than minimum principal strain, which indicated that the point was dominated by tensile strain during bending and was dominated by compressive strain in relaxation.

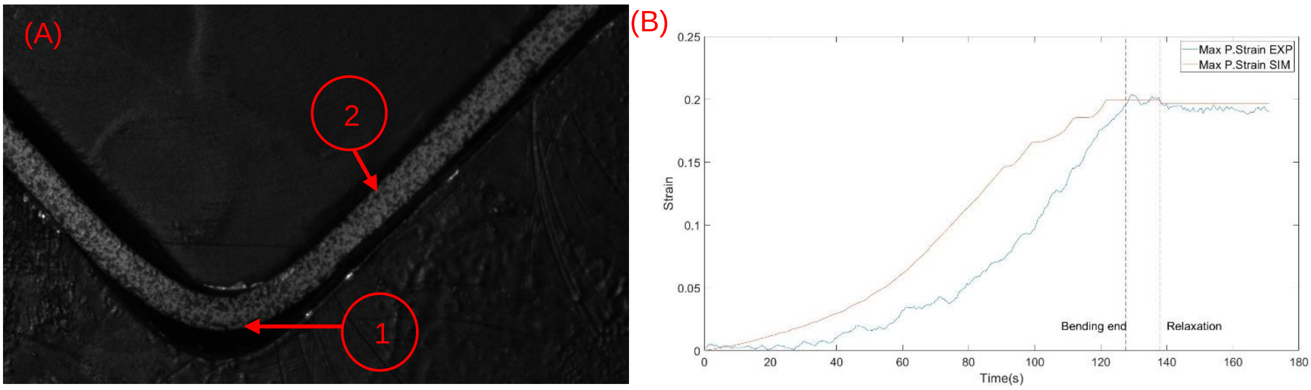

Figure 1, (A) the position of the points of interest, (B) the Maximum Principal Strain over time curve from experiment and simulation.

At point 2, the maximum and minimum principal strain showed similar magnitudes at 4% and -4.2% respectively at the end of bending, and the magnitude of the former is higher than the latter at 2.8% and 1.7% after relaxation. The similar magnitude of maximum and minimum principal strain may be due to the missing of some of the edge area in the strain field acquired by DIC which caused the position of point 2 to be too close to the neutral axis. The strain magnitude acquired at point 2 in experiment was higher than the strain magnitude in simulation, which may result in a larger final angle of 85.7° in experiment compared to the final angle of 86.6° in simulation.

Conclusion

This work demonstrates a technique for validating finite element models of the V-bending and relaxation of monolithic metal plates based on DIC measurements. Current results show that the DIC system is able to quantitatively analyse the strain variation on the side of specimens during forming processes and indicates the potential problems with the model. For the next step, the technique will be used in the study of V-bending and relaxation mechanism of FMLs.

Reference

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