FORMING ANALYSIS OF COMPOSITE AND FIBRE-METAL LAMINATE SYSTEMS

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Abstract

This study examines the stamp forming methodology for manufacturing thermoplastic composites and fibre-metal laminates consisting of thermoplastic composites. A finite element model was developed to elucidate the forming of domes. Experimental work was carried out by stamping these domes in an open die configuration. A real time strain measurement system was used to capture the strain evolution during forming. It was found that there is a good correlation between the numerical and experimental values of strain during forming thus validating the finite element simulations. It was found that that stamp forming is indeed a viable technique for mass production of body panels made of composite materials.

1 Introduction

Climate change is a subject of growing global concern. Based on International Energy Agency 2009, research report, about 23% of the CO2 gas emissions from fuel combustion are generated by the transportation sector and its share is likely to grow. Significant increases in the vehicles fleets are expected particularly in China, India, Middle East and Latin America. The Institute for Energy and Environmental Research (IFEU) study analysed the potential energy and greenhouse gas savings from transportation sector shows greenhouse gas emissions contribution are very high from on road vehicles. Moreover the United Nations Framework Convention on Climate Change (UNFCCC) has also emphasized transportation sector in general and on-road vehicles in particular as a major source of greenhouse gas emissions, especially in highly industrialized nations. Furthermore vote by the European parliament on the EU Commission directive proposal concerning reduction of CO2 emissions from light-duty vehicles confirms the overall awareness that fuel consumption in passenger cars and the resulting emissions should be further reduced. The energy required to power motor vehicles is more than four times than required to produce and recycle them. Correspondingly, over 80% of the transport sector’s greenhouse gas emissions are produced during the operating life. A 100 kilogram mass reduction also reduces a standard car’s greenhouse gas emissions by around nine grams of CO2 equivalent per kilometre, proving that mass reduction can significantly contribute to the required reduction of greenhouse gas emissions from cars.

The usage of lightweight materials such as fibre reinforced composite materials and metal-composite structures can significantly reduce the weight of vehicles. The main challenge in using these advanced light weight material systems for automotive usage is a suitable manufacturing technique. Stamp forming is widely used in automotive sector to produce body panels of the automobiles. Our current work will present research outcomes on the suitability of this manufacturing technique for mass producing composite materials.

Fibre reinforced polymers have been used to reduce the weight of aerospace structures for many years. A number of studies have been conducted into forming of thermoplastic polymer-metal laminates which is often used for noise reduction applications. Kim and Thompson [1-2] studied steel and thermoplastics laminates and found forming at elevated temperatures decrease the rigidity during forming and improved the post forming spring back levels. They also found shear failure was the dominant mode near a free edge whereas in regions remote from free edge tensile failure dominated. Our previous studies [3-6] have shown that feed-rate, blank holder force and tool temperatures have important influence in the stamp forming of FML system. Mosse [7] had proposed a basic finite element using coupled structural-thermal model with crystallization behaviour of the interlayer adhesive and its shear stress transfer characteristics using lap shear apparatus.

Bogaerts [8] studied wrinkle formation and the influence of process variables on the formability of glass–fibre reinforced polypropylene composite. They suggested that high temperatures facilitate desirable shearing behaviour. However, this also increases undesirable fibre slipping. Friedrich and Hou [9] drew conclusions in studying the effects of pre-heat temperature and press closing speed on wrinkle formation. Above a certain closing speed, pre-heat temperature has a dominant influence on wrinkle formation.

This study investigates the formability of polypropylene based Fibre-Metal Laminates (FML) and a self-reinforced polypropylene composite (Curv) with stamp forming as the manufacturing process. Laminated sandwich structures consisting of alternating metal and fibre-reinforced composite have excellent impact and fatigue characteristics as well as superior specific strength and stiffness compared to metals. In this study, domes were formed from circular blanks made of Aluminium/composite/Aluminium laminates and Curv. Finite element analysis was carried out using an explicit formulation. The results from the simulations were compared with experiments carried out on an open die stamping press. The experimental values for strain evolution during forming were carried through a real time strain measurement system (ARAMIS).

2 Finite Element Modeling

Finite element analysis (FEA) could be used to understand the deformation behavior of material during the forming process. In our work, different elements of the model will be validated through experimental results. This will allow the finite element model to be used for a wide range of geometries and for designing dies for production parts. In this paper the commercial FE code Ls-Dyna 971 was used to run all simulation on SGI Altix Unix platform. Hypermesh was used to create the model and finite element mesh while LS-PrePost software was used to assign the boundary conditions for the analysis. The punch, die and blank holder were created using rigid materials. A one way coupled thermal-structural analysis was carried out. For the thermal analysis, the aluminium layer of the laminate and composite were treated as thermally isotropic materials. For the mechanical analysis, aluminium layers were modeled as an elastic-plastic material which uses a power law hardening rule. The composite material was modeled as a temperature dependent orthotropic material.

A typical finite element model for the simulation is illustrated in Figure 1(a). Figure 1(b) shows the geometry of the tools used in the simulation.

The FML blank is modeled using three deformable shell bodies to represent the 2/1 aluminium/composite laminate configuration. Interfacial load transfer in between the aluminium and composite layers are modeled using stick release routine to capture the crystallization behavior of the interlayer adhesive. User friction subroutine option in Ls Dyna was used in the model to mimic the stick release behavior of the aluminium and composite layers.

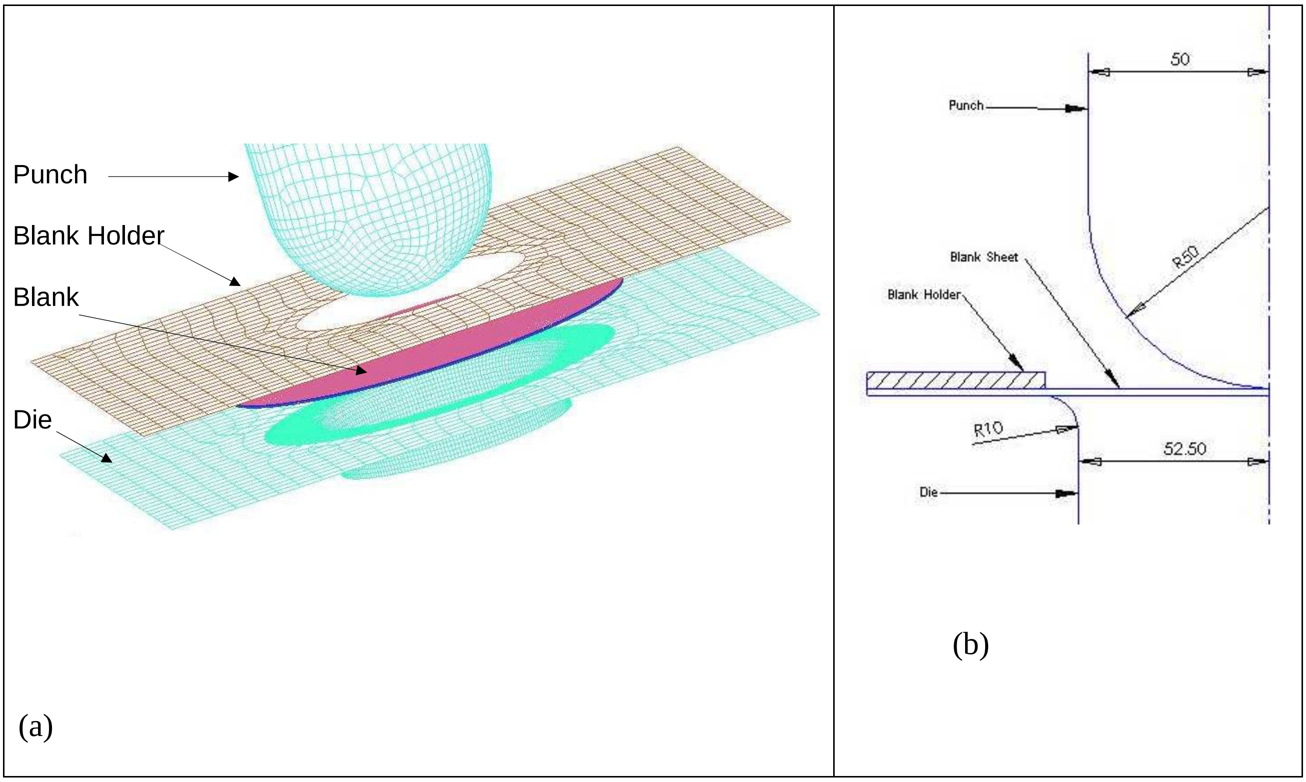

Figure1. Tools used in simulation units in mm.

3 Experimental Set Up

The apparatus configuration included a stamping press and a heating press. The heating press consisted of a manually actuated hydraulic cylinder press and two heating elements in each of the contact faces. The press could be safely operated to a temperature of 250 C. The stamping press was a 300kN double action mechanical press used to form the FML sheet to the dome geometry. Forming action was performed using a hydraulic ram with a stroke length of 200mm. A blank holder was coupled with the press to hold down the composite sheet during the forming process and had a maximum holding force of 14kN. To record the punch force, a 150kN compression load cell was mounted in line with the punch and a potentiometer was used to measure the displacement.

An open die configuration was chosen to provide for the coupling of 3D strain measurement system (ARAMIS) manufactured by GOM, mbH, Germany, which provides deformation and strain analysis using 3D image correlation. The system provides a full field strain measurement using photogrammetric method as the samples are being tested. Each sample was sprayed with a contrasting stochastic pattern which deformed with the sample during the test. Two high speed, high resolution, digital CCD cameras recorded the images of the sample during the test and the deformation was calculated from these images using an area based matching algorithm. The two dimensional displacements recorded by each of the cameras are then correlated to a three dimensional measurement using intersection of the two dimensional measurements. The result is a three dimensional point distribution for each of the stages and the strain values are calculated from this point. This digital image provides a full-field contour of the sample and the strain distribution throughout the test. The image sampling frequency was maintained at 20Hz.

3 Results and Discussion

3.1 Validation of Finite element model

The finite element model was validated by studying the strain evolution at the pole of the dome during forming.

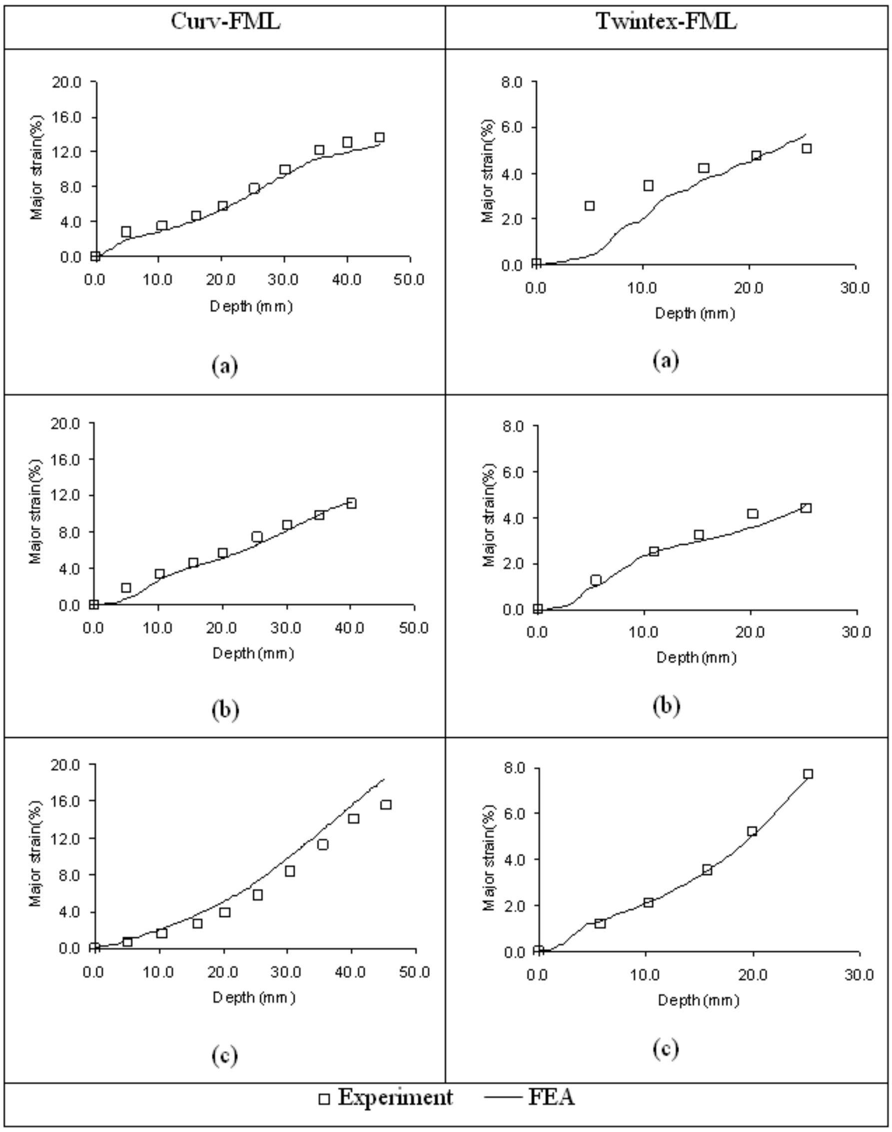

Figure2. Strain evolution at the pole for FML-Curv and FML-Twintex, (a0 Room temperature, (b) 100^{o} C and (c) 150^{o}C

The feed rate of 20 mm/s and a binder force of 14kN were used in the simulation and experimental work. These studies were conducted at three temperature settings of room temperature, 100^{o}C and 150^{o}C. Two material systems were used in these validation studies.

The first system consisted of Aluminium/Glass-Fibre reinforced composite/Aluminium configuration (FML-Twintex). The second system consisted of Aluminium/Self-reinforce polypropylene/Aluminium configuration (FML-Curv). FEA results show good strain evolution trends with the experimental results for both FML-Curv and FML-Twintex. The small discrepancy between the FEA and experiments can be attributed to the values used in the tangential modulus in the user defined material properties and the conditions existing between the tooling and blank.

3.2 Meridian Strain distribution

Figure 3 elucidates meridian strain for experimental results of 0.5 mm thick monolithic aluminium, FML-Curv and plain Curv composites along the fibre direction at the depth of 30 mm, while Figure 4 shows meridian strain for experimental results of 0.5 mm thick monolithic aluminium and for FML-Twintex and plain Twintex composite along their fibre direction at the depth of 25 mm.

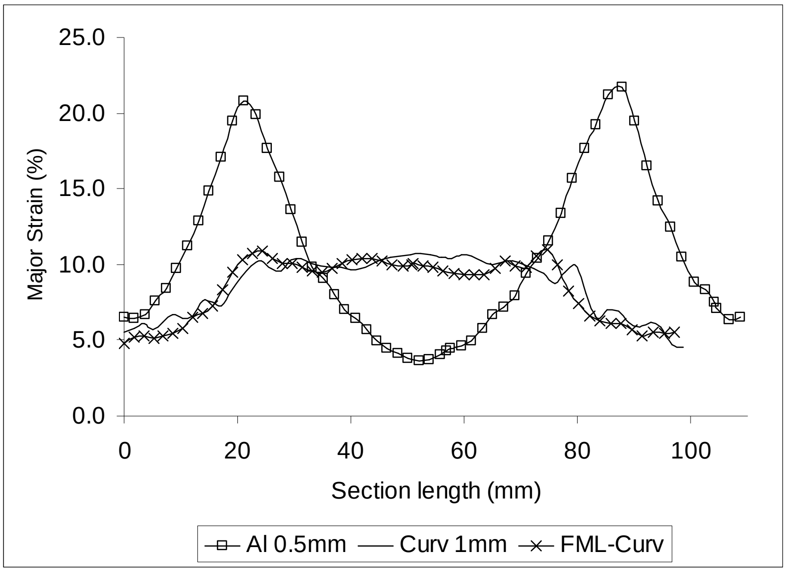

Figure3. Experimental results on meridian strains formed at room temperature to a depth of 30 mm

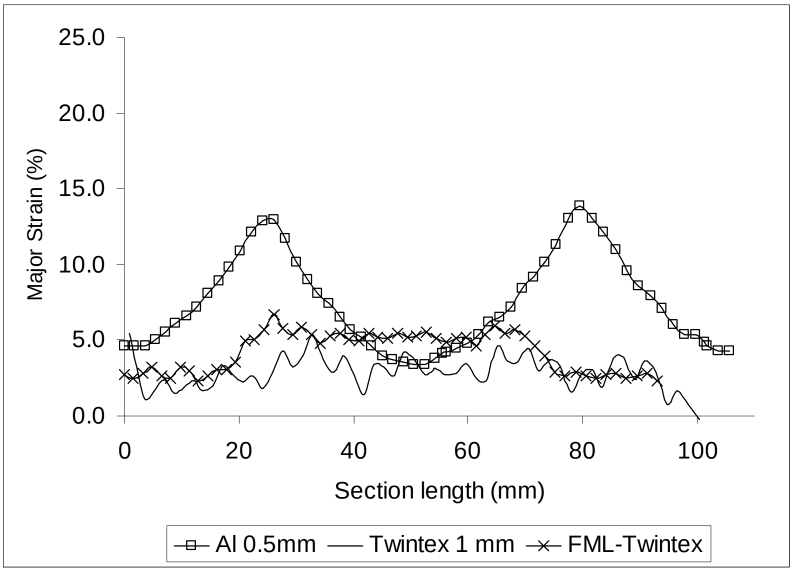

Figure4. Experimental results on meridian strains formed at room temperature to a depth of 25 mm

The monolithic aluminium layers in both figures show two sharp peaks and this effect is also exhibited for thicker aluminium samples. Both composite layers show negligible sharp peaks and the strain distribution shows uniform magnitude throughout the deformed part of the blank over the punch face. This peak is also observed in FML but there is a very large difference in the strain magnitude between FML and aluminium. This can be attributed to the presence of composite layer and the metal/composite interface. It is very beneficial to have this uniform distribution since this can lead to better dimensional tolerances in the formed part.

3.3 Surface strain distribution

Figure 5 and Figure 6 elucidate strain distribution on the bottom aluminium surface produced by FEA for FML-Curv and FML-Twintex at a depth of 35 mm.

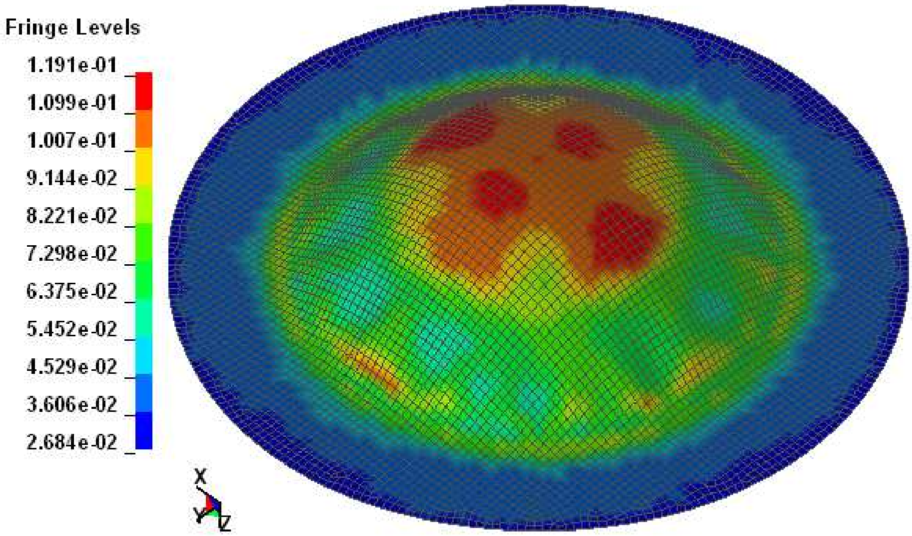

Figure5. Finite element results of FML-Curv of the major strain contours

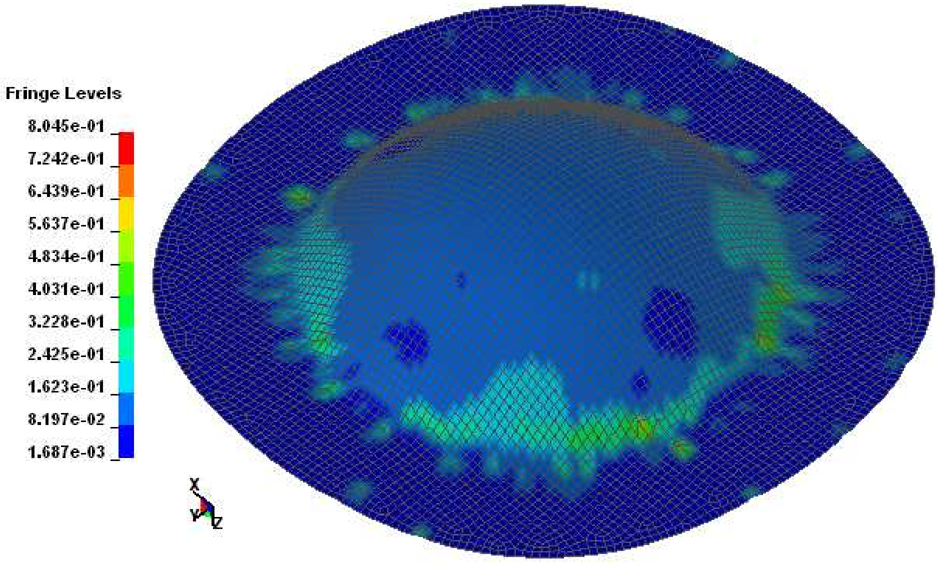

Figure6. Finite element results of FML-Twintex of the major strain contours

These samples were formed at room temperature. It is interesting to note that FML-Twintex exhibits more draw along its fibre direction and similar results were also observed in the experiments. The difference between FML-Curv and FML-Twintex is the higher stiffness of glass fibres in FML-Twintex compared stiffness of the self-reinforced fibres in Curv. This is an important observation in the formability of composites since these results seem to indicate increasing the stiffness of the fibres in composites can lead to changes in the forming behaviour of composite materials from a stretch forming to a draw forming.

7 Conclusions

This study has examined the stamp forming methodology for manufacturing thermoplastic composites and fibre-metal laminates consisting of thermoplastic composites. A finite element model was developed to elucidate the forming of domes. A real time strain measurement system was used to capture the strain evolution during forming. It was found that there is a good correlation between the numerical and experimental values of strain during forming thus validating the finite element simulations. Results on meridian strain distribution indicate that the FML and composite materials have the potential to exhibit more uniform thickness distribution than the monolithic aluminium alloy. Increasing the stiffness of fibres led to change in the forming mode from stretch to draw forming. It was found that that stamp forming is indeed a viable technique for mass production of body panels made of composite materials

References

[1] Kim J.K., Thomson P.F.: Forming behaviour of steel laminate. *Material Processing Technology,* **22**, 44–64 (1990).

[2] Kim J.K., Thomson P.F.: *Separation behaviour of steel laminate during forming. Materials Processing Technology,* **22**, 147–161 (1990).

[3] Mosse L., Cantwell W., Cardew-Hall M.J., Compston P., Kalyanasundaram S.: Effect of process temperature on the formability of fibre-metal laminates. *Composite Part A*, **36**, 1158-66 (2005).

[4] Gresham J., Cantwell W., Cardew-Hall M.J., Compston P., Kalyanasundaram S.: Drawing Behaviour of Metal-Composite Sandwich Structures. *Composite Structures,* **75**, 305-312 (2006).

[5] Mosse L., Cantwell W., Cardew-Hall M.J., Compston P., Kalyanasundaram S.: The influence of process variables on the formability of fibre-metal laminates. *Material Processing Technology*, **172**, 163-168 (2006).

[6] Sexton A., Cantwell, W., Kalyanasundaram S. Stretch forming studies on fibre metal laminate based on a self-reinforcing polypropylene composite. *Composite Structures*, 94, pp. 431-437 (2012).

[7] Mosse L., Ph.D. Thesis, The Australian National University, Australia, 2006.

[8] Bogaerts L., Lossie M., Vandepitte D.: Deep drawing of composite sheet materials. in '*Proceedings of the 9th international conference on sheet metal. Leuven*', 127–34 (2001).

[9] Friedrich K, Hou M.: On stamp forming of curved and flexible geometry components from continuous glass fiber/polypropylene composites. *Composites Part A*, **29**, 217–226 (1998).