TEMPERATURE EFFECT ON FORMING OF SELF-REINFORCED POLYPROPYLENE BASED LIGHTWEIGHT METAL COMPOSITE STRUCTURE

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ABSTRACT

This study investigates the effects of blank temperature on the strain of self-reinforced polypropylene based lightweigh Metal Composite Structure(MCS). Comparisons between MCS and monolithic aluminium revealed that MCS shows a more uniform strain distribution over the punch face of the laminate and reduction in the required work to form stamping operation. Moreover MCS gives a 30% weight reduction compared to monolithic aluminium. The experimental results obtained in the present study shows MCS systems have the potential to be adapted to high volume production technique of stamp forming. A significant finding from this work is that these material systems exhibit forming characteristics that are comparable and sometimes superior to metal forming.

KEYWORDS: *Lightweight, Metal composite structure, Strain, Forming*

1.0 INTRODUCTION

International agreements, such as the Kyoto Protocol, have forced Governments around the world to ensure that their greenhouse emissions are capped within reasonable limits. Combustion of fossil fuels is one of the contributors to greenhouse emission. Vehicle-weight reduction has been identified as a means by which fuel consumption can be reduced (Das, 2000; Green & DeCicco, 2000; Schmidt et al., 2004). Fuel-economy improvement for passenger vehicles is projected to increase by 6% to 7% for every 10% of weight reduction (Casadei & Broda, April 2008), with lower fuel consumption implying reduced combustion of fuel per distance traveled hence reducing green house-

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gases emissions, which consequently leads to reduced air pollution. Furthermore, lighter vehicular weights should not compromise passenger safety and needs to be sustainable. In view of environmental benefits brought about by widespread usage of lightweight vehicles, it is therefore ethically justified to mass produce environmentally friendly vehicles.

Fiber metal laminate (FML) is a grade of MCS that has been used to reduce the weight of aerospace structures for many years. Numerous studies have demonstrated that MCSs combine the superior fatigue and fracture characteristics associated with fiber-reinforced composite materials, with the durability offered by many metals (Krishnakumar, 1994; Vlot, Kroon, & La Rocca, 1998; Vogelesang & Vlot, 2000). Reyes and Kang (Reyes & Kang, 2007) formability tests using a sphere punch at room temperature on MCS showed similar deformation behavior with plain aluminium and 25% lower forming load. Compston et al. (Compston, Cantwell, Cardew-Hall, Kalyanasundaram, & Mosse, 2004) investigation showed surface strain in the bend regions from channel forming of preheated MCS is much less than plain aluminium. Mosse et al. (L. Mosse, Cantwell, Cardew-Hall, Compston, & Kalyanasundaram, 2005; Luke Mosse, Compston, Cantwell, Cardew-Hall, & Kalyanasundaram, 2005, 2006) recognised temperature as the primary process condition followed by feed-rate and blank-holder force in achieving good formability for rectangular cups and channel section of MCS. It was also found mechanical properties of the constituents have a major influence on the forming characteristics of these material systems. Studies of channel section shows 75% less shape error compared to aluminium. Gresham et al. (J. Gresham, Cantwell, Cardew-Hall, Compston, & Kalyanasundaram, 2006) identified blank-holder force has a significant effect on the failure mode of the metal composite system with lower forces resulting in wrinkling and higher forces resulting in splitting and fracture during draw forming of MCS. Sexton et al. (Sexton, Cantwell, & Kalyanasundaram, 2012) investigated stretch forming of MCS at room and found MCS to exhibit superior formability to aluminium. Crystallisation behaviour of the interlayer adhesive in MCS is identified as significant in changing the stamp forming behavior of MCS systems (Kalyanasundaram, DharMalingam, Venkatesan, & Sexton, 2013).

The objective of the present work was to investigate the effect of temperature on the formability of MCS through the experimental investigation on open die dome stamp forming processes on self-reinforced polypropylene. Real time strain evolution on the MCS surface will be captured during forming using a photogrametry method.

2.0 EXPERIMENTAL PROCEDURE

The following sections elobrates on the experimental procedures.

2.1 Experimental setup

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. Details of both presses were elaborated by Kalyanasundaram et al (Kalyanasundaram, et al., 2013). This study employs biaxial forming to investigate two of the main forming modes that commonly occur, namely stretching and drawing. Hemispherical-shaped punch with a diameter of 100 mm and an open die with a diameter of 105 mm were used to produce the necessary forming modes.

The coupling of 3D strain measurement system (ARAMIS) with the open die configuration is elucidated in Figure 1. The system provides a full field strain measurement using photogrammetric method as the samples are being tested. The image sampling frequency was maintained at 20 Hz.

Dome was formed at following parameter: feedrate 20 mm/s, blank holder force 14 kN and forming temperature varied from 25°C to 150°C. Meridian strain and work required to form the dome were recorded.

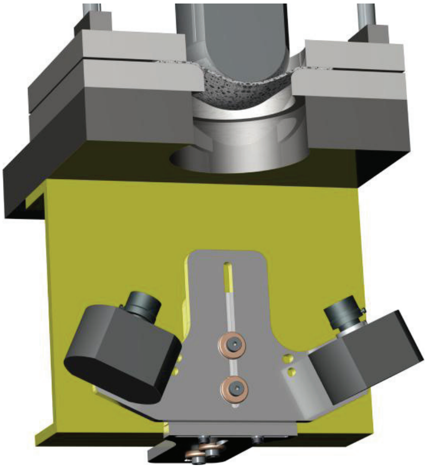

Figure 1. Schematic of ARAMIS setup with stamp press (Joel Gresham, 2006)

2.2 Materials and laminate preparation

A 2/1-aluminium/composite MCS was used for the experimental work in this study. The inner layer of laminate consisted of 1 mm thick self-reinforced polypropylene, CurvTM, produced by Propex Fabrics, Germany. The MCS structures were made by placing a single ply of the composite in between aluminium sheets. Two layers of hot-melt Gluco film were applied to each bi-material interface. The laminate structure is shown in Figure 2. The manufacturing of the MCS circular blank with a diameter of 180 mm is detailed in (DharMalingam, Nov 2011). This MCS system gives a weight reduction of almost 30% compared to 2 mm thick 5005 H34 monolithic aluminium.

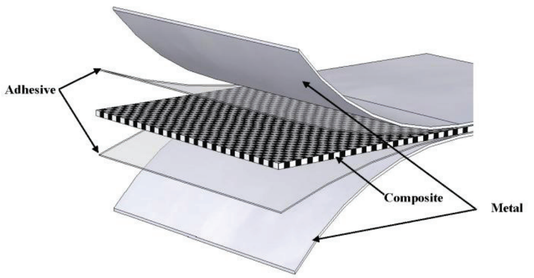

Figure 2. MCS structure

3.0 RESULTS AND DISCUSSION

3.1. Meridian strain

In hemispherical punch forming the major strain or 1st principal strain direction is in line with the meridian and as such is called the meridian strain. Plotting of the meridian strain along the fiber direction and at 45° to fiber direction was used to illustrate the influence of forming temperature and fiber direction on meridian strain. Evolution of surface meridian strain was taken along the fiber direction and 45° to fiber direction as illustrated in Figure 3.

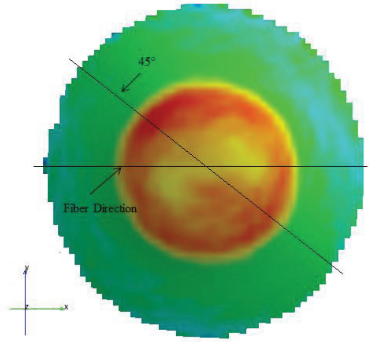

Figure 3. Strain contour and meridian lines for fiber metal laminate

Figure 4 shows measurement of the meridian strain along fiber direction while Figure 5 shows measurements of the meridian strain at 45° to fiber direction where both are plotted at an increment of 5 mm. Two extreme temperatures, 25°C (room temperature) and 150°C, for MCS are investigated. The monolithic aluminium formed at 25°C fails at the depth of 36 mm.

Meridian-strain curve along fiber direction for both 25°C and 150°C is observed to show similar trends. The major strain values for 25°C are slightly higher than for 150°C on the punch face up to the depth of 30 mm. Matrix cracking contributes to higher strain values at these points for low-temperature forming. The reduction of strain increment for 25°C on the punch face can also be attributed to the drawing of material into the die cavity as the forming depth increases and, as a result, stretching would have decreased.

In high-temperature forming the melting of the adhesive layer (glue melting point is approximately 140°C) will result in loss of bond strength between the aluminium and composite layers. This loss of bond strength will allow the outer layer to move over the composite core and vice-versa with less restriction, which increases draw in and as a result reduces material deformation over the punch face for MCSs at the early forming stage. But with solidification of the glue and a softer composite core the MCS is able to stretch more than at 25°C with increase in forming depth. Laminates formed at 150°C exhibit continuous strain increment up to the depth of 40 mm. When observing the meridian strain on the side wall it can be seen that up to 30 mm depth the 25°C forming has higher meridian strain than the 150°C forming after which the 150°C forming meridian strain increases more than the 25°C forming at the punch-face edge. This is attributed to softening of the composite so enabling it to stretch more than the room-temperature forming. The lower major strain at the edge of the side wall for 150°C forming is attributed to the effect of the initial draw in during the initial melt state of glue.

Figure 5 shows the effect of 45° fiber direction on meridian strain. The meridian strain value is higher at the side wall and edge of the punch face compared with fiber direction after the forming depth of 25mm. This increase in meridian strain can be attributed to the effects of intraply shear on the composite core. The effect is seen as very dominant at 25°C as the composite is still attached to and therefore able to show the trellis effect on the aluminium skin. The same cannot be said at 150°C, for the trellis effect cannot be fully transferred to the aluminium skin since the glue is in melt condition. Overall the strain is higher in the 45° fiber direction. An indication this direction goes through more stretch compared to the fiber direction.

A comparison between the incremental meridian strains of MCS and aluminium was used to investigate the fundamental differences between the forming of these two materials systems. MCS exhibits a more consistent distribution of strain as depth is increased, while aluminium progressively develops a sharp peak at the edge of the punch face with little change in strain values at the pole after forming to a depth of 5mm. The position of the peak at the edge of the punch face would be the area of expected fracture failure for the aluminium sample.

Strain development on the MCS is more desirable. The maximum value of the strain has been reduced as compared to the aluminium sample, with the strain distributed more uniformly over the punch face of the laminate. The reduction in maximum value of strain for the MCS system and a more uniform distribution of strain is an important finding as it indicates that MCS systems have the potential of superior forming characteristics compared with monolithic aluminium alloys.

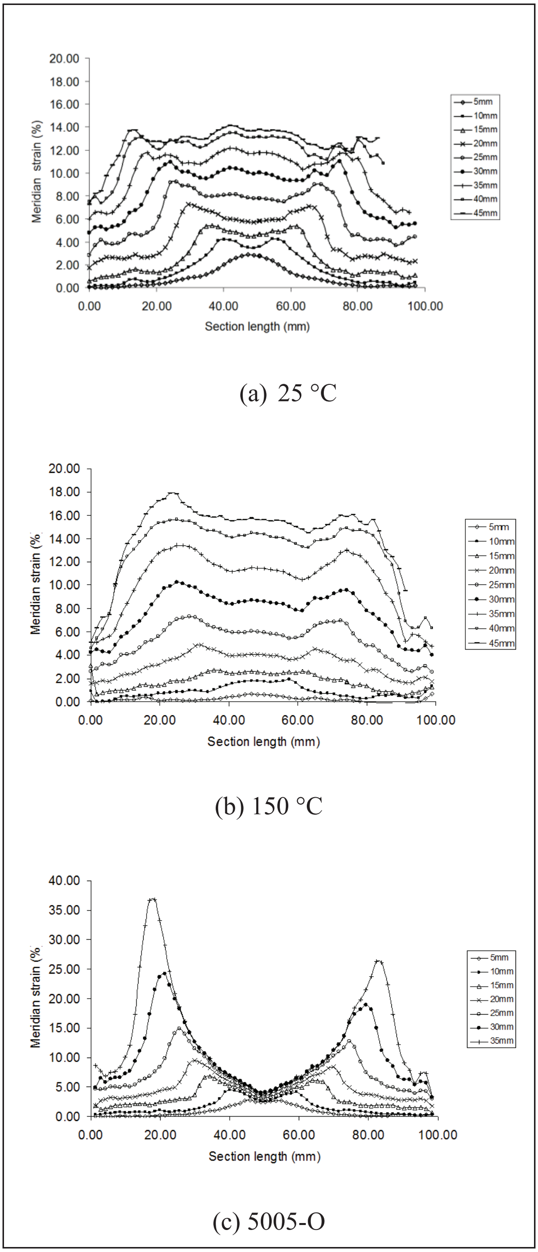

Figure 4. Meridian strains for MCS samples along the fiber direction taken at 5mm increment. Formed at (a) 25°C, (b) 150°C, (c) 5005- O samples formed at 25°C

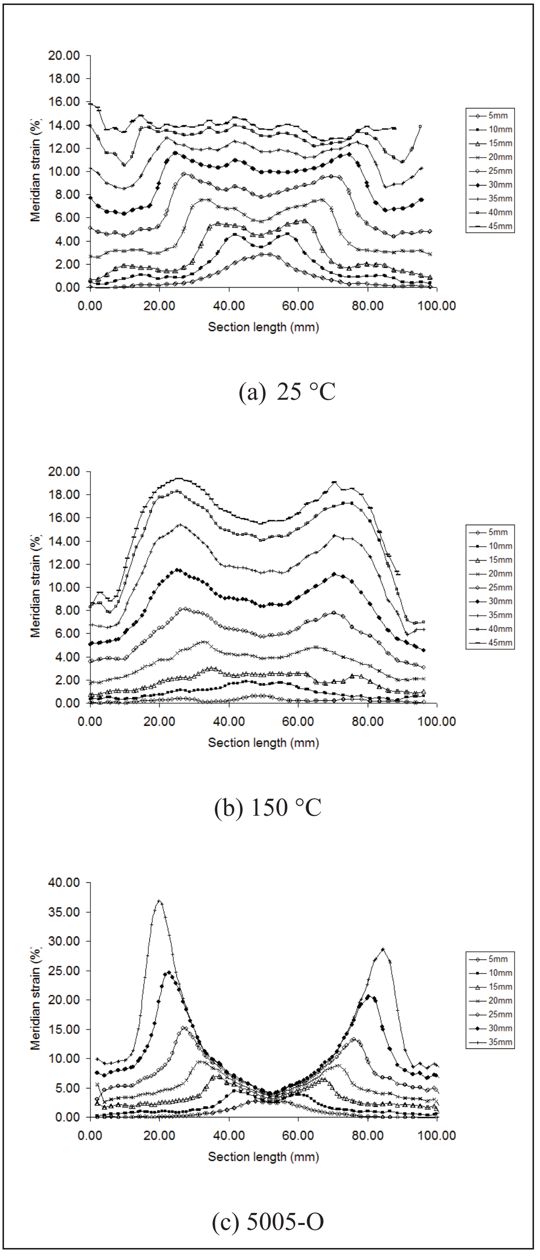

Figure 5. Meridian strains for MCS samples at 45° to fiber direction taken at 5mm increment. Formed at (a) 25°C, (b) 150°C, (c) 5005-O samples formed at 25°C

3.2. Work done during forming

The load-displacement curve for each sample was taken to calculate the work done on the MCS to form to the depth of 30 mm. The work done on MCS is compared with that done on 2.0 mm thick monolithic aluminium at room temperature and is calculated by integrating the load-displacement curve. The work as a function of temperature for MCS is presented in Figure 6. The MCS sample shows a decrease of 0.845 J/°C in the magnitude of work required to form over the temperature range, with the decrease in the work to form MCSs is attributed to softening of the composite and adhesive layers. The work required to form MCS samples was approximately 10-61% lower over the investigated temperature range, 25°C to 150°C. A reduction in the required work to form is desirable for stamping operations as it will reduce wear and tear on the punch and die surfaces, which can prolong the life of the tool, therefore reducing tooling costs.

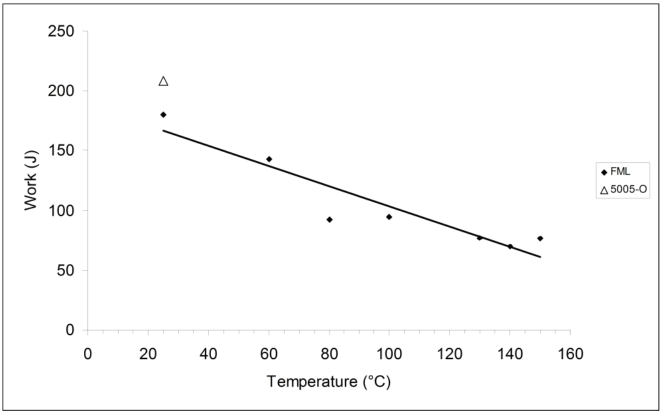

Figure 6. Work done during forming to the depth of 30 mm

4.0 CONCLUSIONS

The meridian-strain development of the MCS is more desirable where the maximum value of the strain has been reduced as compared with the aluminium sample, with strain distributed more uniformly over the punch face of the laminate. Reduction in the maximum value of strain for the MCS system is an important finding as it indicates that MCS systems have the potential for superior forming characteristics compared with monolithic aluminium alloys.

Punch work required to form MCS samples was approximately 10-61% lower than for monolithic aluminium over the investigated temperature range (25°C to 150°C). A reduction in the required work to form is desirable for stamping operations as it will reduce wear and tear on the punch and die surfaces, which can prolong the life of the tool, therefore reducing tooling costs.

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