EFFECT OF PROCESS TEMPERATURE AND BLANKHOLDER FORCE ON THE FORMING OF FIBRE METAL LAMINATE SYSTEMS

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ABSTRACT

The effect of process variables on the stamp forming of Fibre-Metal-Laminate channel sections has been investigated. The process variables include blankholder force, process temperature and feed-rates. It was found that by judicious choice of the process variables it is possible obtain parts that have better formability characteristics than parts made with monolithic aluminium.

1. INTRODUCTION

Fibre-Metal-Laminates (FML) consists of alternate thin layers of metal and fibre reinforced polymer-matrix composite. The nature of the FML sandwich structure makes it possible to customise the mechanical properties of the system by careful selection of the constituent materials. FML systems have been successfully used in low volume applications such as aerospace. There has been hardly any use of these hybrid material systems in the high volume industries such as automotive due to the need for fast production times to manufacture the components. Stamping is an operation widely used in the production of automotive body panels and has the potential for significantly increasing the production times of FML systems and hence their use in automotive body panels. This in turn can lead to reduction in weight of the automobiles which is one of the priorities of the automobile industries.

Thermoplastic polymer based composites have the advantage that they can be repeatedly formed by heating to soften the matrix. Our Previous work on FML [1] demonstrated the importance of preheating the laminate before stamping for improving springback levels and reducing damage in the laminate. A self-reinforced polypropylene composite based FML exhibited less cracking in the composite while a glass-fibre/polypropylene based FML experienced less inter-facial delamination. It was also shown in [2] that heating of the die and blankholder to 80°C further improves the quality of the formed laminates and that there are detrimental effects associated with stamping at higher and lower temperatures. Several studies have been carried out in past that investigates the effect of spring-in during composite curing. Studies conducted by Darrow [3] on carbon-epoxy composites indicated that the effect of fibre orientation and thickness of specimen have major influence on the spring-in behaviour. Jain and Mai [4] developed a mechanics based model to predict spring-in behaviour for anisotropic cylindrical shells. This model was verified by experimental results and the sping-in behaviour was attributed to moisture gradients and resin shrinkage during cure. These results were then applied in the manufacture of a composite aileron rib [5]. Hou [6] investigated the effect of blankholder forces on the fibre strain and fibre dislocation in the stamp forming of fabric-reinforced thermoplastic composites. It was found that strain distribution was strongly influenced by fibre orientation and that blankholder force is a major factor in the reduction of wrinkling in the formed part. Whilst, springback is a major issue in stamp forming of metallic alloys, spring-in is a common theme during the curing of composite materials. One of the major goals of our research initiative in the stamp forming of FML systems is to understand the synergies between the interaction between metal, composite and the processing parameters to produce defect free components.

The present study investigates the effect of processing temperature, blankholder force and feed-rate on the stamp forming of channels. The material system consists of aluminium and self-reinforced polypropylene (Curv, BP). The effect of the processing conditions on the quality indicators such as springback and delaminations will be presented.

2. EXPERIMENTAL METHOD

Laminate Preparation

Laminates were made in a 2/1, aluminium/Curv configuration. The outer layers were 0.5 mm thick 5005 H34 aluminium. The inner layer of the laminate consisted of one layer of 0.9 mm thick layer of a self-reinforcing polypropylene (Curv, BP). The laminates were produced by arranging the aluminium and Curv layers in a mould, (Fig. 1) A hot-melt polypropylene adhesive (Gluco), recommended for bonding polypropylene and metal, was placed at the bi-material interface. The aluminium surface was prepared by placing the sheet in a 5% solution of sodium hydroxide for 5 minutes. The mould was placed in a hot press and a thermocouple was used to monitor the temperature inside the mould. When the laminate reached 155°C, a pressure of 0.5 MPa was applied and the mould was immediately water-cooled to 50°C. A laminate thickness of 2 mm was achieved. For channel forming, the laminates were sectioned into 20 x 150 mm strips using carbide tipped slitter wheel on a mill. Plain aluminium samples were prepared using 2mm thick 5005 H34 aluminium sheet.

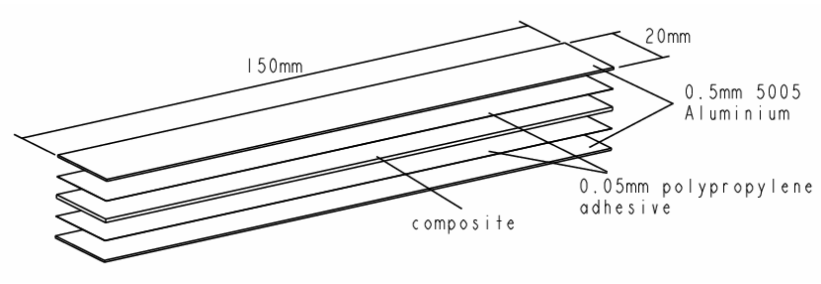

Fig. 1. Laminate construction

In order to prevent asymmetric sliding of the laminate layers over each other during the forming process, the relative inter-facial movement was constrained in the middle of the strip. This was achieved by drilling two holes 10 mm apart and 75mm from the end of the strip and inserting 2 mm lengths of 1.6 mm diameter stainless steel wire. The wire was bonded in place with araldite two-part adhesive (Fig. 2)

Fig. 2. Laminate strip blank

Stamp Forming

The laminated strips were pre-heated to 160°C in the platen press before being transferred to the stamping press. The press (Fig 3.) consists of a custom made custom made die set with PID temperature control for stamping channels forms at elevated temperatures, a pneumatic blankholder and a hydraulic punch feed-rate controller. The punch and die had 5 mm tool radii.

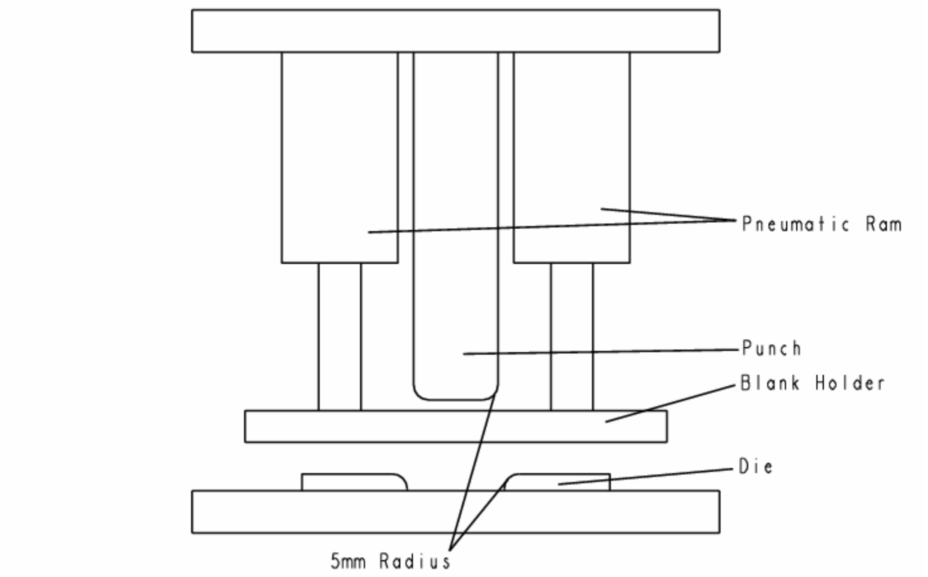

Fig. 3. Press configuration

The die and blankholder were pre-heated to the desired temperature and the punch was at room temperature (25°C). This provided a temperature stamping window between 130°C and 150°C. A heat resistant polymer film was placed on both sides of the laminate to provide lubrication. After applying a preset blankholder force, the channel was formed to a depth of 41 mm at the desired feed-rate. Channels were held in the press for 60 seconds to allow them to reach steady state temperature conditions before being removed. The channels were stamped using blankholder forces of 1, 3.5 and 6kN, three punch feed-rates of 4.4, 28.5 and 53 mm/second and three die and blankholder temperatures of 80, 100 and 120°C. Three measures were used to assess the quality of the stamped laminate (Fig. 4): (i) the deviation in channel wall angle ($\Delta\varnothing$), referred to as springback, (ii) delamination area quantified by measuring side wall crack lengths with a vernier, (iii) channel base curvature.

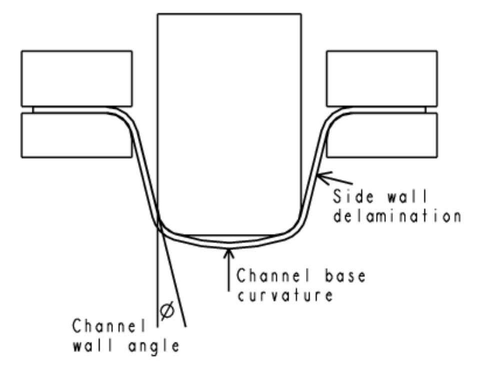

Fig. 4. Laminate channel quality measures

3. RESULTS & DISCUSSION

Fig. 5 illustrates springback behaviour (channel wall angle) as a function blankholder force and feed-rate. For this set of experiments, the temperature of die and blankholder were maintained at a temperature of 80° C. There was a general trend of the springback increasing with increasing blankholder force. However, the feed-rate has a much stronger influence and smallest value of springback was obtained for a feed-rate of 28.5 mm/s. Springback for this setting is nearly 400% less than the spring back of a monolithic aluminium (Fig. 6). Aluminium exhibited no dependence on feed-rate (the experiments were carried out at the room temperature) and showed a steady increase in springback with increased blankholder force. The strong influence of feed-rate on FML samples can be attributed to the rate effects of composite as a function of the cooling rates of the blank material when it is stamped. In addition, for the feed-rate of 28.5 mm/s a spring-in phenomenon can be observed.

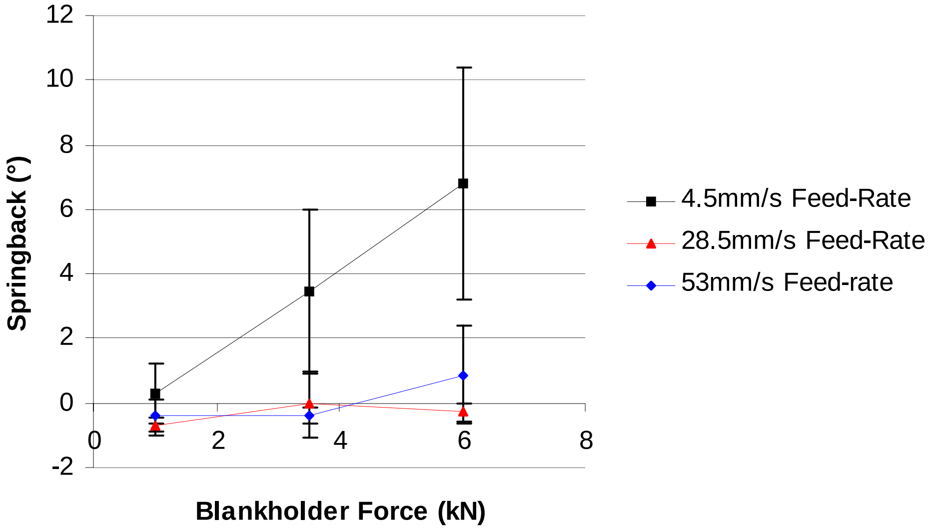

Fig. 5. Effect of blankholder force and feed-rate on the springback behaviour of aluminium-curv laminates stamped at 80°C

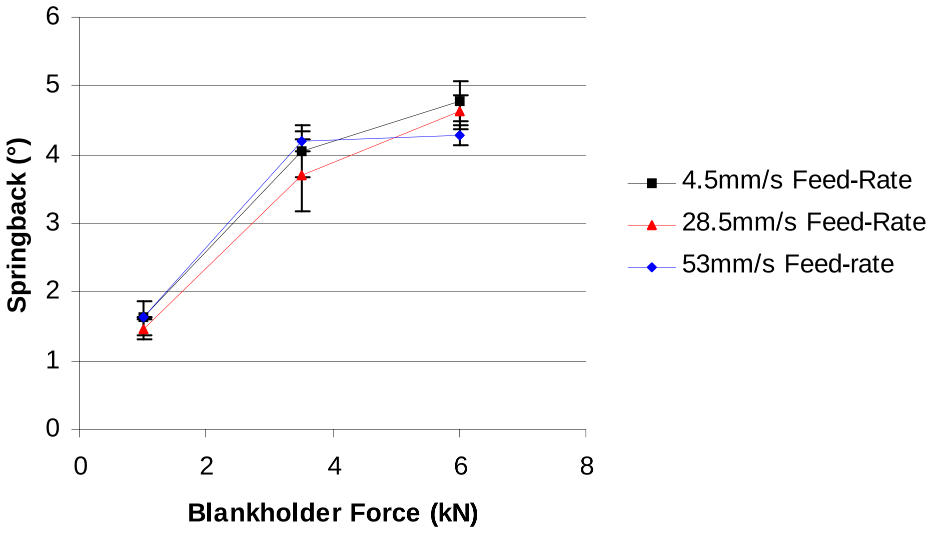

Fig. 6. Effect of blankholder force and feed-rate on the springback behaviour of aluminium

Fig. 7 and Fig. 8 illustrate the effect of feed-rate and blankholder force on the channel base curvature for FML and aluminium samples. FML samples were stamped with the blankholder and die held at 80°C. Aluminium samples were stamped at the room temperature. FML samples exhibited less base curvature than the aluminium samples. Base curvatures for both FML and aluminium samples decreased with increasing blankholder force. and some the behaviour of base curvature decreasing with increasing blankholder force can be attributed to the open die setting used in the experiments.

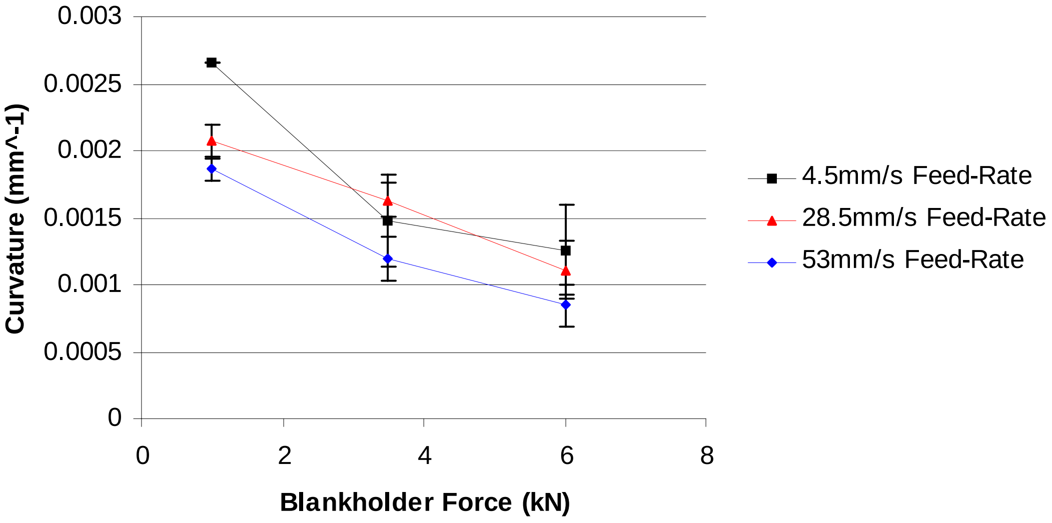

Fig. 7. Effect of blankholder force and feed-rate on the springback behaviour of aluminium-curv laminates stamped at 80°C

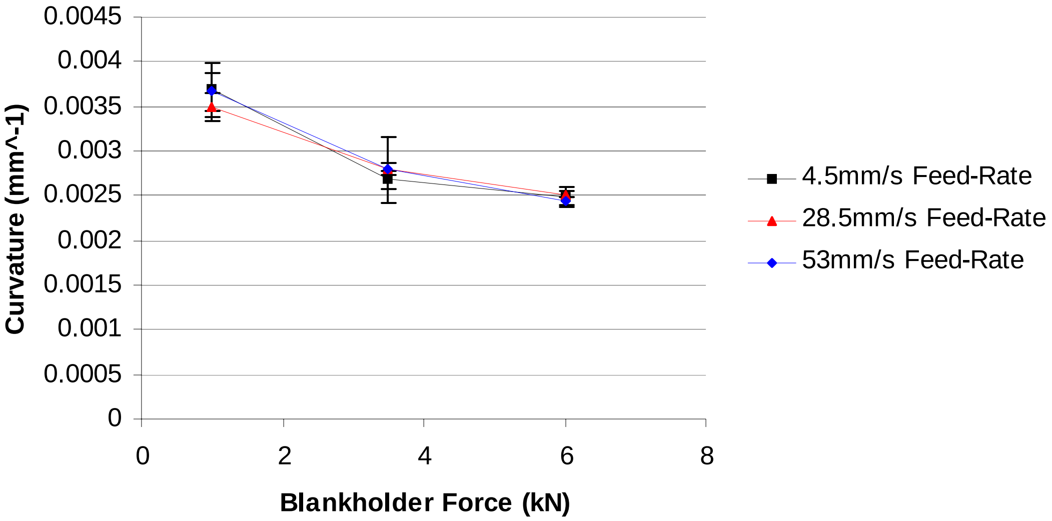

Fig. 8. Effect of blankholder force and feed-rate on the springback behaviour of aluminium

Fig. 9 illustrates the effect of temperature (die and blankholder) and feed-rate on channel wall angle. The feed-rate was held at 28.5 mm/s for all the experiments. By maintaining tools at a temperature of 80°C smallest value for springback/spring-in can be obtained. For temperatures of 100°C and 120°C, there is a tendency for the wall angle to increase with the blankholder force.

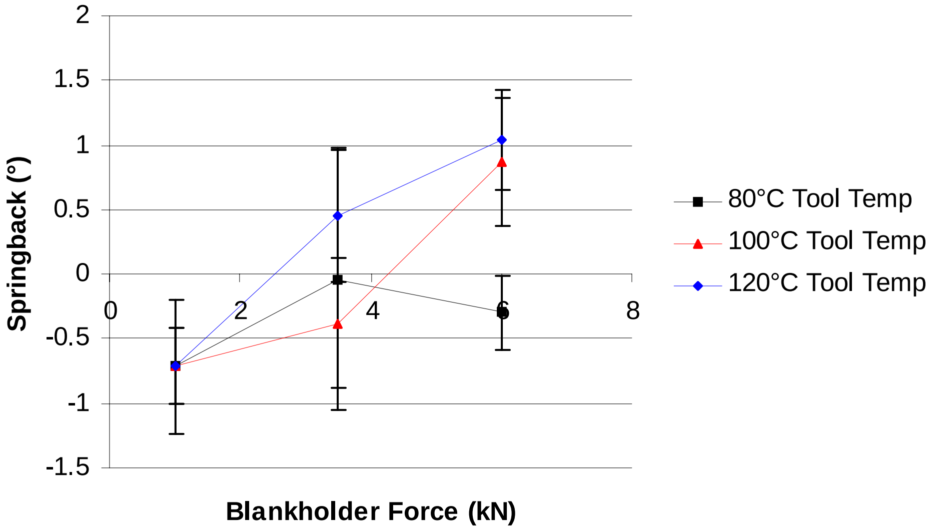

Fig. 9. Effect of temperature on the springback behaviour of aluminium-curv laminates

Fig. 10 illustrates the effect of temperature (die and blankholder) and feed-rate on base curvature. The feed-rate was held at 28.5 mm/s for all the experiments. The base curvatures decreased with increasing blankholder force.

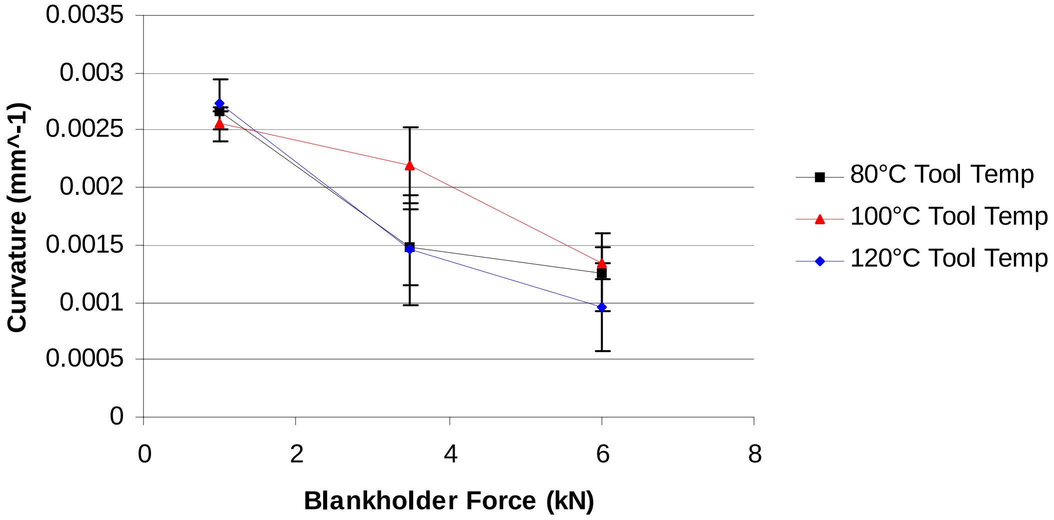

Fig. 10. Effect of temperature on the springback behaviour of aluminium-curv laminates

Fig. 11 illustrates the effect of feed-rate and blankholder force on the delamination damage of FML samples. Increasing the feed-rate leads to reduction in delamination for all the blankholder forces. The temperature for the die and blankholder were held at 80°C, as this temperature setting was found to be the optimum setting.

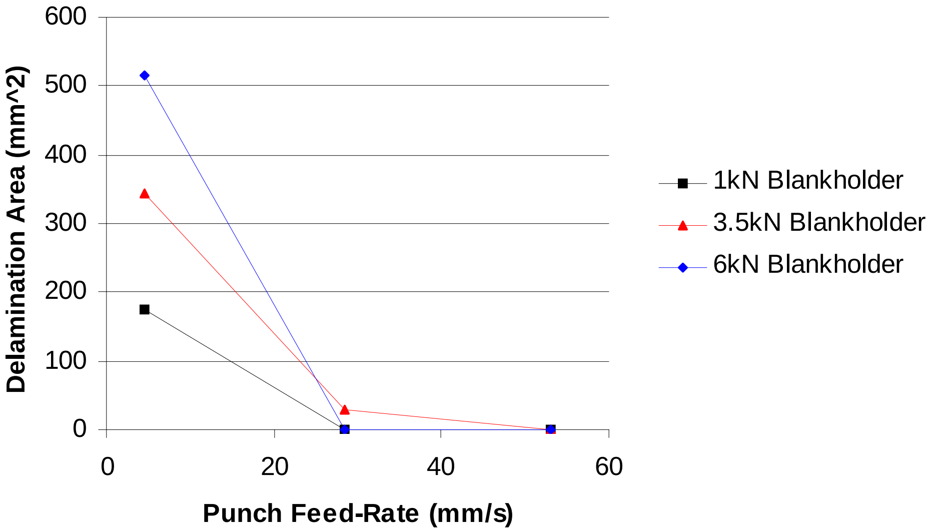

Fig. 11. Effect of blankholder force and feed-rate on the delamination behaviour of aluminium-curv laminates stamped at 80°C

4. CONCLUSIONS

It has been shown that feed-rate, blankholder force and tool temperatures can have important influence in the stamp forming of FML systems. Good formability of stamped channels can be achieved through a judicious choice of these process variables. It is possible to have stamped FML forms exhibiting considerably less springback than monolithic aluminium materials. This result can be of immense benefit in the manufacturing of automotive body panels because significant time is spent in die try-out stage on springback compensation for metallic alloys. Future work will focus on developing constitutive models that can be incorporated into finite element simulation models. These simulation models will have damage criterion built in them and can be used to asses formability characteristics of complicated geometries.

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