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The use of Fused Deposition Modelled Tooling in Low Volume Production of Stretch Formed Double Curvature Components

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Abstract

Stretch forming is commonly used for low volume production of double curvature panels; primarily in the architectural cladding and aerospace sectors. The lower volume production requires a low cost tooling solution that minimizes the non-recurrent cost. Tools are currently manufactured from a range of different materials including cast iron, plastic and wood, utilizing a range of production and finishing processes. More recently the use of additive manufacturing technologies implemented in low cost 3D printing devices provides a compelling alternative that offers a fast and cost-effective tool fabrication methodology. This paper illustrates the use of desktop 3D printing technology in the production of a large tool through assembly of smaller printed hollow sections. The low cost and production time for the additive manufacturing tool solution is noted. In addition, two profiles illustrate the viability of FDM tools for an anticlastic component. The forming process is modelled in PAMSTAMP and comparisons made between the springback and surface strains in the experimental trials. It is interesting to note that the anticlastic tooling solution has significantly lower springback due to the interaction of the longitudinal and transverse residual stresses.

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Keywords: Stretch Forming, Tooling, Modelling, FDM

1. Introduction

Aerospace, medical and architectural applications of sheet metal forming are often small batch/single component manufacturing that typifies mass customization production methods. As a result, minimizing the non-recurrent tooling

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costs becomes an economic imperative [1]. While reconfigurable tooling systems and incremental forming methods are gaining ground, the surface finish and residual stresses created by these processes limit their wider application.

Standard machining of complex tool surfaces requires a CNC milling machine and extensive programming knowledge. This paper examines the possibility of producing tooling without the need for large capital equipment or specialist machining knowledge in the mass customization sheet metal forming environment through the application of Fused Deposition Modelling (FDM)[2].

2. Material Testing and Modelling

2.1. Mechanical Characterization

The material used throughout this study was a 3 mm thickness commercial grade 5083 aluminium alloy typically found in architectural applications. A series of tensile tests were conducted on an Instron 5500R as per ASTM E8M at 15° intervals between 0° and 90° from the rolling direction. Three repeats at each orientation assured repeatability in the results. Each test was conducted at a constant crosshead speed of 1.27 mm/min. The strain was monitored throughout the test using longitudinal (2620-600 dynamic (25 mm gauge length)) and transverse (2640-010) extensometers. All results were recorded using BlueHill 2 software.

Normally an hydraulic bulge test would be used to determine the biaxial yield point, however the higher blank thickness is outside the range necessary for the assumption of thin shell theory. The biaxial yield point was therefore determined using a 12.7 mm diameter disc compression test. Before each test the specimen faces were lubricated using a two-parts Molybdenum Disulphide powder mixed with one-part petroleum jelly. The test was conducted at 1.27 mm/min.

2.2. Material Model Calibration

PAMPSTAMP 2G was chosen as a flexible Finite Element Analysis (FEA) system suitable for modelling the stretch forming process. The main material model available for capturing the yield behavior of aluminium alloys is the Hill-1990 yield criterion [3]. The yield criterion is given by

$$(2\sigma)^m = \left|\sigma_1 + \sigma_2\right|^m + A^m\left|\sigma_1 - \sigma_2\right|^m + \left|\sigma_1^{\ 2} + \sigma_2^{\ 2}\right|^{(m/2)-1}\left\{B\left(\sigma_1^{\ 2} - \sigma_2^{\ 2}\right) + C\left(\sigma_1 - \sigma_2\right)^2 \cos 2\alpha\right\}\cos 2\alpha \quad (1)$$

Where m, A, B and C are material constants and α is the angle measured from the rolling direction. Three calibrations using the yield strengths (Hill 90 Yield), r-values (Hill 90 r) and both the yield strengths and r-values from 0° to 45° (Hill 90 0-45) were used to determine the model parameters for use in PAMSTAMP 2G. A more detailed explanation of these calibrations can be found elsewhere [4]. The Hill 1990 yield criterion is also compared with the Hill 1948 for a baseline comparison.

It is clear from Fig. 1 (a, b and c) that the effectiveness of the yield criterion is dependent upon the data used in the calibration. The Hill 90 Yield tends to fit the yield strengths well, but not the r-values; while the Hill 90 r method tends to fit the r-values well, but not the yield strengths. The Hill 90 0-45 method tends to fit both the yield strengths and r-values well in the range 0° to 45° from the rolling direction. Since this angle range is typical of the loading orientation found in a stretch forming process the Hill 90 0-45 method was selected for the modelling work presented here.

Fig. 1 (c) shows the yield locus plot in principal stress space. While there are only minor differences in the loci; the inability of the Hill 1948 criterion to capture the biaxial yielding is clearly evident. Accurately representing the yielding behavior both in uniaxial tension and plane strain is a key element of modelling the stretch forming process. With all these criteria, the plane strain yield point is influenced by the r-values and the biaxial yield point, so accurate representation of these experimental results is crucial.

The material work hardening was captured using the Voce representation as described by Lademo [5]. The form of this equation is