Industrial application and validation of forming simulation in the flexforming process

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Abstract. The flex-forming process is used extensively in aerospace industry for net shape forming of sheet metal structural components. Common metals used in the manufacture of these components include 7075 and 2024 aluminium alloys; usually in an as quenched condition following solution heat treatment. While the process is commonplace, the level of manual rework remains high, driven by inherent process and material variability and the lack of upfront analysis before the manufacture of tooling. A suitable process modelling method using AutoForm is presented along with an industrial validation study for the manufacture of an aerospace frame component in 7075-W aluminium alloy. The results illustrate the importance of material model accuracy and the inclusion of through thickness compressive stresses in predicting the flange springback of the component.

1. Introduction

Flexforming is a process whereby a rubber membrane, which is pressurized with oil, is used to form a blank onto either a male or female tool, which unlike rubber pad forming applies a hydrostatic pressure. Flexforming is used extensively in the manufacture of complex low volume sheet metal components and is commonplace in aerospace applications. Aluminium aerospace components have the added complexity of requiring additional pre and post heat treatments to provide sufficient formability to form joggles/small radii and subsequently provide in-service characteristics [1].

Asnafi [2] conducted one of the most comprehensive experimental, analytical and numerical studies of the flexforming process. The author examined 2024-O and 6061-O aerospace aluminium alloys looking at both the tension and compression flange behavior, though springback was not considered within the study. Chen [3] also used CAE to model 2024-O and 7075-O straight flanged and joggled aerospace frame components. While pressure and time were shown to have little impact on the process performance, the low pressure of 400 bar and relatively stable, but weak aluminium alloys limit the use of this work for solution heat treated components. The study also illustrated the importance of additional harder 'intensifier' polyurethane pads in forming details at lower pressures of 400 bar. Chen [4] then went on to extend the work of Asnafi [2] using CAE where the primary focus of the work was to examine wrinkling in 2024-O/T3 and 7075-O with no quantifiable analysis of springback in these parts.

While these studies have provided a core fundamental source for analyzing and optimizing the flexforming process, the vast majority of aerospace components are formed in an unstable as quenched condition (W) following solution heat treatment. This paper presents a methodology for modelling the flexforming process for a 7075-W aerospace frame component without the computational cost and complexity of including rubber.

2. Material Data and Modelling Approach

The material used in this study was a 7075-O solution heat treated and naturally aged for 30 minutes before forming. A more detailed study of the post solution heat treatment behaviour of the material can be found elsewhere [5].

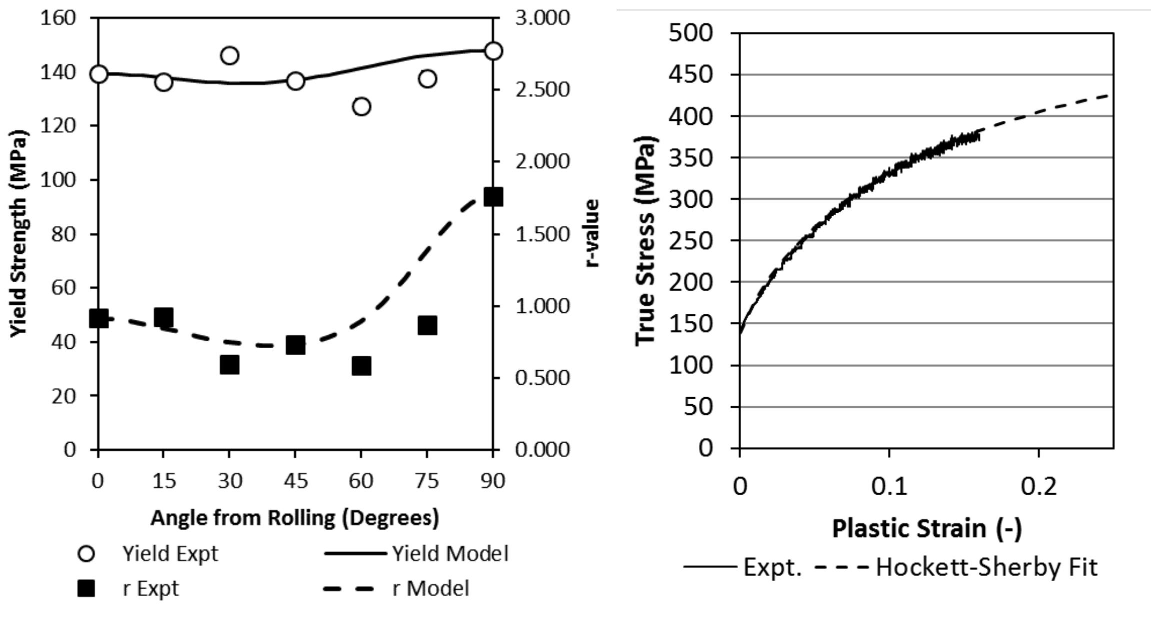
The material yield behaviour was modelled using the BBC2005 yield criterion and Hockett-Sherby isotropic hardening model as implemented in AutoForm. The parameters used in these models are given in Table 1 and 2 respectively

Table 1. Parameters for the BBC2005 yield criterion

Parameter	a	b	L	M	N	P	Q	R
Value	6.823	0.224	0.326	0.233	0.429	0.429	0.600	0.636

Table 2. Parameters for the Hockett-Sherby hardening representation

Parameter	S_{sat}	S_0	m	n
Value	488.780	139.325	5.410	0.827



(a) (b)

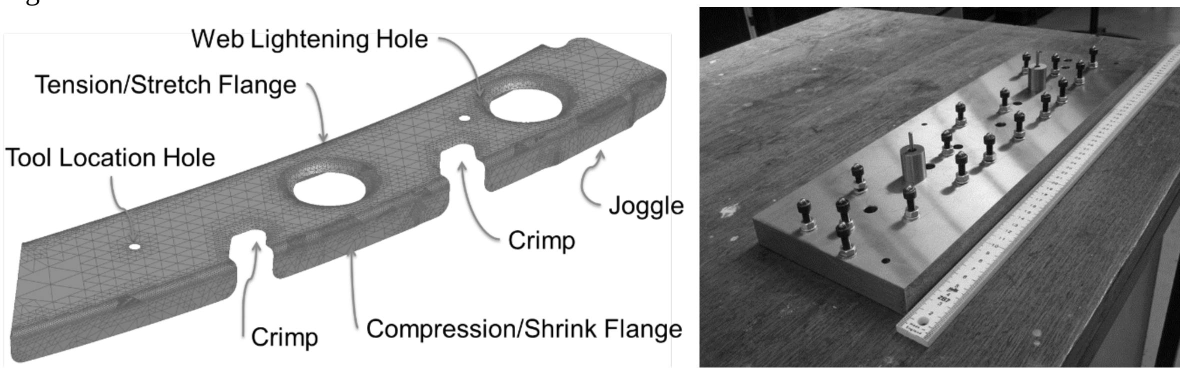
Figure 1. (a) Yield strength and r-value as a function of angle from rolling, (b) Comparison between the uniaxial test data and Hockett Sherby fit in the rolling direction.

The quality of fit obtained in the model is shown graphically in Figure 1 for the uniaxial yield strength, r-values and hardening curve. The propensity for the material to exhibit serrated yielding is clearly visible in the uniaxial hardening curve shown in Figure 1(c).

3. Modelling Approach and Industrial Validation Study

In order to assess the validity of the modelling approach a small aerospace frame component shown in Figure 2 was selected. This small component was selected on the basis of the feature density contained within the form which is representative of the complexity found in the majority of aerospace frame components. There are two location holes on the part to ensure that the part remains stationary during the forming process. The blanks were first removed from the parent material using a router, deburred and subsequently solution heat treated at 465°C for 35 minutes before being stored in a freezer at -18°C until required. During the production trials the blanks were aged for 30 minutes at room temperature before being located on the aluminium tool using two pins. A Quintus Flexforming press was then used to form the components at 1000 bar. Following the forming process, the components were scanned using a Renishaw Cyclone touch-probe scanner while supported on the screw-jack fixture shown in Figure 2 (b)

The process was modelled in AutoForm^{Plus} R6 using a hydro-mechanical process setup and a limit pressure of 1000 bar. The direct pressure application was justified on the basis of the hydrostatic loading characteristic of this forming process when compared to rubber pad forming. The friction coefficient was taken to be a constant value of 0.15. Mesh refinement was controlled using an angle criterion of 22.5 degrees. The time step was set to a value of 0.3 and the convergence tolerance was 0.1. The latter value minimised instabilities in modelling the forming of flanges in net shape components. Two pin holes in the part were used to locate the part during the simulation. A post processing step was used to extract the flange angle as a function of position along the component length.



(a) (b)

Figure 2. (a) Frame component features and (b) support fixture for measurement used in the validation study.

4. Discussion

The overall shape of the component and model output results are illustrated in Figure 3 (a) and (b). The x axis represents the distance along the length of the frame component while the zero point is referenced to the first pin hole used to locate the part during forming. There is a good correlation in the overall prediction of springback in the compression flange results, while the tension flange results tend to underestimate the degree of springback. There is also a clear influence of buckling in the compression flange that occurs during the initial pressurization that results in a variable flange angle along the part.

Following the production validation study the internal surface of the components were examined and clearly showed compression on the internal surface of the radius between the flange and the web. Localised through thickness compression in these regions is likely to influence the overall springback. The models were then re-analysed with the addition of through thickness stresses. The results of this analysis are shown in Figure 3 (b) and (c) for the compression and tension flange respectively. In both cases the inclusion of these stresses are noted to increase the simulated springback by almost 1°, improving the overall accuracy of the results.

5. Conclusions

It is possible to accurately model the flex forming process without including the rubber provided an accurate materials characterisation underpins the model, in this case through the use of the BBC 2005 material model. The interaction of the material, process and tooling must be considered, especially in the case of through thickness stresses at the bend radius.

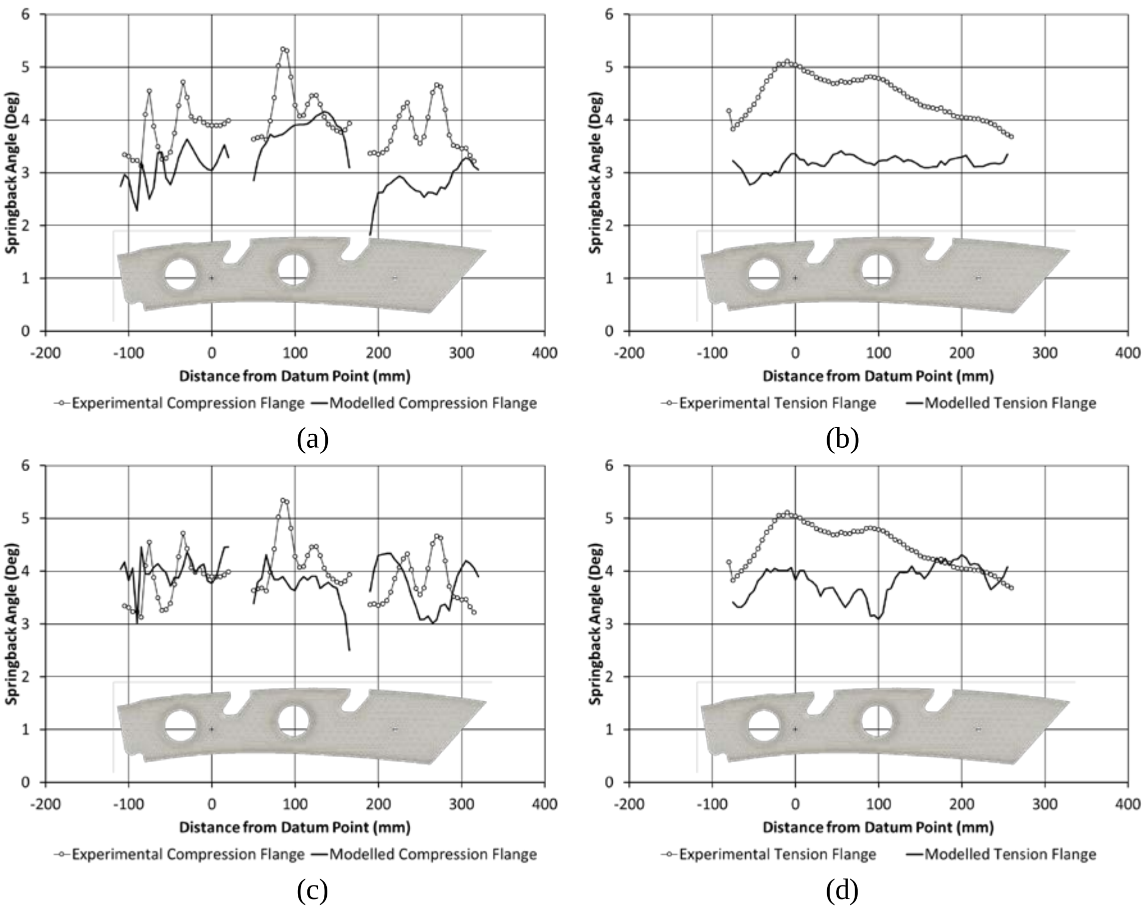


Figure 3. Springback angle for the compression flange (a), tension flange (b) and for through thickness stresses included in the compression flange (c) and tension flange (d)

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