Modelling Aspects in Forming and Welding of Nickel-Base Superalloys

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The reduction of fuel consumption and carbon dioxide emissions are currently a key factor for the aviation industry because of major concerns about climate change and more restrictive environmental laws. One way to reduce both fuel consumption and CO2 emissions is by significantly decreasing the weight of vehicles while increasing the efficiency of the engine. To meet these requirements, the European aero-engine industry is continuously focusing on improved engine designs and alternative manufacturing methods for load-carrying structures in advanced materials, such as titanium and nickel-base superalloys. These new manufacturing methods involve sheet-metal parts, small castings, and forgings assembled using welding, enabling flexible designs where each part is made of the most suitable materials and states, with advantages such as reduced product cost, lower weight, and increased engine efficiency.

In this thesis, a manufacturing process chain including forming and welding in two nickel-base superalloys, alloy 718 and Haynes® 282®, is studied. The aim of this work is to determine which aspects within the material and process are the most relevant to accurately predict the amount of shape distortions that occur along the manufacturing chain. The effect of the forming temperature on the predicted springback is included. The results are compared with experimental cold and hot forming tests with a subsequent welding procedure. During forming of a double-curved component in alloy 718 at room temperature, open fractures are observed in the drawbead regions, which could not be predicted while evaluating the formability of the material based on Nakazima tests and forming limit curves (FLC). The generalised incremental stress-state dependent damage model (GISSMO) is calibrated and coupled with the anisotropic Barlat Yld2000-2D material model to accurately predict material failure during forming using LS-DYNA. The mechanical properties of alloy 718 are determined via uniaxial tensile, plane strain, shear, and biaxial tests at 20 °C. The deformations are continuously evaluated using the digital image correlation (DIC) system ARAMIS™. Numerical predictions are able to accurately predict failure on the same regions as observed during the experimental forming tests. Comparisons of the distribution of damage on one of the drawbeads, between simulations and damage measurements by acoustic emission, indicate that higher damage values correspond to bigger micro cracks. The history from the sheet-metal forming procedure, i.e. residual stresses, strains, element thickness, and geometry, is used as the input for the FE analysis of a subsequent welding procedure of a strip geometry in alloy 718 and Haynes® 282®. A comprehensive characterization of the elasto-plastic properties of both alloys between 20 and 1000 °C is included. Other temperature-dependent properties are extracted from JMatPro-v9 for the corresponding specific batches. The results from the simulations show that the welding procedure further increases the shape distortions over the part. Encouraging agreement was found between the model predictions and the results of forming and welding tests in alloy 718. The findings underscore the importance of including the material history and accurate process conditions along the manufacturing chain to both the prediction accuracy of accumulated shape distortions, and to the potential for the industry.

The work also comprises hot forming of the double-curved component in alloy 718 and Haynes® 282®. The presence and nature of serrations due to the dynamic strain aging (DSA) phenomenon between 300 and 800 °C is studied. Microstructural observations are consistent with the behaviour of the material at the different temperatures tested. The residual stresses obtained from the hot forming simulations are transformed based on the stress-relaxation tests performed at high temperatures ranging from 700 to 1000 °C. The results show the importance of using the novel modelling approach combining the anisotropic Barlat Yld2000-2D material model with the thermo-mechanical properties and stress-relaxation behaviour of the material to predict the final geometry of the component with high accuracy. A welding simulation of a bi-metallic strip geometry obtained from the hot formed double-curved component is performed numerically. The effect of the two superalloys on the shape distortions over the part is discussed.