Journal of Physics: Conference Series

Knowledge Based Cloud FE simulation - data-driven material characterization guidelines for the hot stamping of aluminium alloys

To cite this article: Ailing Wang *et al* 2016 *J. Phys.: Conf. Ser.* **734** 032042

Knowledge Based Cloud FE simulation – data-driven material characterization guidelines for the hot stamping of aluminium alloys

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Abstract. The Knowledge Based Cloud FEA (KBC-FEA) simulation technique allows multi-objective FE simulations to be conducted on a cloud-computing environment, which effectively reduces computation time and expands the capability of FE simulation software. In this paper, a novel functional module was developed for the data mining of experimentally verified FE simulation results for metal forming processes obtained from KBC-FE. Through this functional module, the thermo-mechanical characteristics of a metal forming process were deduced, enabling a systematic and data-driven guideline for mechanical property characterization to be developed, which will directly guide the material tests for a metal forming process towards the most efficient and effective scheme. Successful application of this data-driven guideline would reduce the efforts for material characterization, leading to the development of more accurate material models, which in turn enhance the accuracy of FE simulations.

1. Introduction

Material property characterisation is an essential requirement of FE simulations, as their accuracy is greatly enhanced with a detailed definition of the material's deformation behaviour, input in the form of either discrete data known as 'look-up tables', or a set of constitutive equations describing their flow stresses. Thus, sensible selection of the conditions at which the material properties are characterised, through tensile or formability testing for example, is needed. Currently, tensile testing conditions are usually selected based on experience as opposed to the real requirements of the actual application of the material. Strain rates in the range of 10^{-5} – 10^{-2} s^{-1} are used to study superplastic forming [1, 2], strain rates of 10^{-1} – 1 s^{-1} are used for steel sheet metal forming [3], and strain rates of 10^{-4} –10^{-2} s^{-1} are utilised in the study of low-cycle fatigue [4]. Large variations in temperature ranges also exist across different applications, such as in warm and hot stamping of aluminium alloys, where a range of 150 – 525 °C [5-7] is used. To enhance the utility of the material data input, the selected test matrix must be targeted according to the specific application of the material and its associated conditions of strain rate and temperature. In the present research, an innovative data driven approach was developed by data mining existing experimentally verified FE simulation results obtained from the Knowledge Based Cloud FEA (KBC-FEA) technique. By tracking the deformation history of each element, the real thermo-mechanical conditions in a hot stamping process were identified.

Extraction of the data was achieved through the development of a functional module that operates on the KBC-FEA platform, the structure for which is shown in Figure 1. The module, 'Strategy', would provide analysis of the data collected from the experimentally verified FE simulation results, and output a material and forming technique specific tensile test guide.

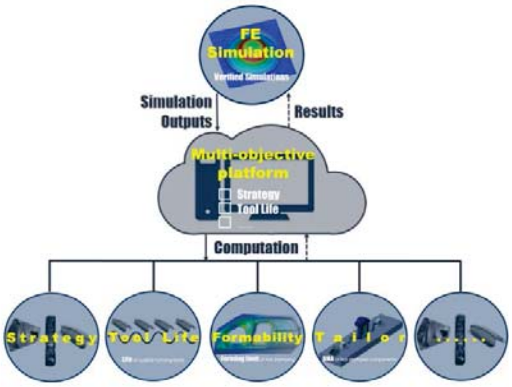

Figure 1. Structure of KBC-FEA system

2. Methodology: Data-driven approach for material characterization

As a FE simulation orientated multi-objective platform, experimentally verified simulations from KBC-FEA can be used to construct a database from historical FE simulations to provide a comprehensive quantification of temperature and strain rate conditions. In this paper, the 'Strategy' module is implemented to study the deformation characteristics of AA6082 under hot stamping conditions.

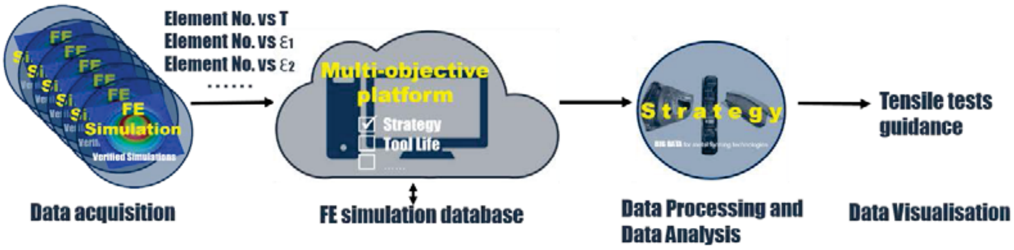

Figure 2. KBC-FE simulation technique – 'Strategy' implementation process

The 'Strategy' module works in three stages: data acquisition, data processing and data analysis, as shown in Fig. 2. Data is acquired through the multi-objective KBC-FEA platform, which can be accessed via www.smartforming.com. This is an online portal system developed at Imperial College enabling engineers to share their knowledge and sophisticated models. The case study in this paper is based on a database for hot stamping simulations of lab scale dome tests. Simulations were conducted at different forming conditions, such as different forming speeds and blank holding forces. The database consists of the thermo-mechanical history of all elements in all stages of each simulation to capture the characteristics of the deformation process. Data from each simulation is stored as a separate entity and managed in the central cloud data system, and is then processed and analysed in the functional module. To establish a uniaxial tensile test guide for the hot stamping technique, evolutions of temperature and strain rate are selected from each simulation file. The first step involves filtering the raw data to distinguish between elements from different regions, *e.g.* the blank holding area, die cavity *etc.* In this study, the elements in the blankholder region are removed since plastic deformation in this region is very low, and does not represent the characteristics of hot stamping. Due to the possibility of each simulation file having different numbers of elements, the data could potentially be distorted, thus a weighting strategy is applied to adjust the proportional relevance of each simulation to generate representative data. Single and bivariate parameter distributions are then generated for data analysis.

3. Results and discussion: thermo-mechanical characteristics of the hot aluminium stamping technology

Hot stamping of the dome shapes exhibits complicated temperature, strain rate and strain path histories. Figure 3 shows the temperature and strain rate distributions for AA6082 dome shaped parts formed under hot stamping conditions. The temperature distribution is found to be negatively skewed as the majority of elements undergoing hot stamping tend to have higher temperatures. 66% of the elements were formed in the 400-450 °C temperature range. The peak of the distribution indicates the most frequent occurrence, and corresponds to the initial forming temperature of 450 °C used in the lab scale dome tests. The minimum temperature was found to be around 210 °C, while the maximum was 455°C, which may have been caused by frictional heat. The strain rate distribution resembles a normal distribution, and although the peak region of strain rates of 0.1-1 s^{-1} are commonly tested, strain rates higher than 1 s^{-1} are also encountered during hot stamping, occupying 29% of the distribution, where the maximum strain rate was around 30 s^{-1}. Single parameter distributions provide valuable insights into the lower and upper limits, as well as the variation of the conditions encountered in hot stamping processes.

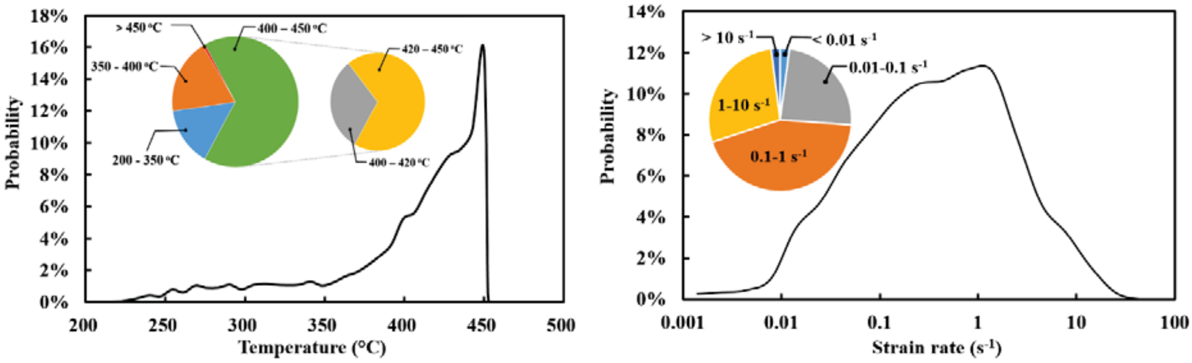

Figure 3. Temperature and strain rate distribution for AA6082 formed under hot stamping conditions

To facilitate the design of tensile test guidelines, a bivariate distribution incorporating the relationship between temperature and strain rate was investigated. This offers greater benefits as tensile tests are conducted at conditions based on both parameters. The relationship between temperature and strain rate obtained from the dome shape forming simulations is visualised in Figure 4, and provides the tensile test boundaries for the hot stamping of dome shapes from AA6082. The maximum and minimum values are the same as those identified in the single parameter distribution. However, higher strain rates (> 5 s^{-1}) were found to be only associated with high temperatures between 350 – 450 °C; this phenomenon is expected as at higher temperatures, the material is softer and hence more plastic deformation occurs leading to higher strain rates. 71.5 % of the elements deformed in the temperature and strain rate range of 400 – 455 °C and 0.01 – 10 s^{-1} respectively. For all temperatures below 350 °C, a maximum strain rate of 5 s^{-1} would be sufficient, which occurred for 13.5% of the elements. It is therefore critical to conduct tensile tests that cover the lower and upper limits, as well as to focus on specific combinations of conditions with the greatest probabilities.

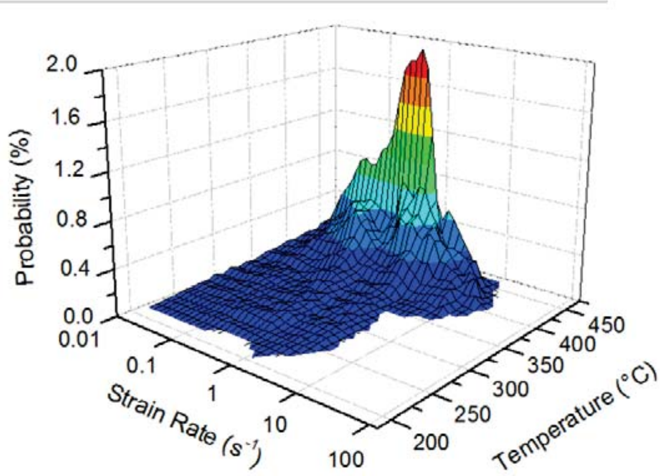

Figure 4. Temperature and strain rate distribution for AA6082 formed under hot stamping conditions

4. Conclusion

The parametric study utilised in the 'Strategy' functional module provides a viable approach for determining test matrices for tensile tests and the conditions to be investigated. The module integrates data from different simulation parts used in the KBC-FEA technique, and numerically analyses the temperature and strain rate distributions to reduce uncertainties in the critical input used in simulating the mechanical behaviour. It has captured dominant temperature and strain rate conditions the blank undergoes during a hot stamping process and detected the trends in the hot stamping of AA6082. The boundaries and trends identified will allow researchers to conduct more focused and targeted tensile tests, reducing the efforts of experiments, and improving efficiency and productivity. As the KBC-FEA database expands, more material and forming technique specific tensile test guides could be generated, with opportunities to develop more strategic analyses to gain insights into various forming techniques.

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