Comparative investigations on numerical modeling for warm hydroforming of AA5754-O aluminum sheet alloy

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This study aimed to determine the proper combinations of numerical modeling conditions (e.g. solver, element type, material model) for warm hydroforming of AA5754-O aluminum alloy sheets. Assessment of finite element analyses (FEA) is based on comparison of numerical results and experimental measurements obtained from closed-die forming, hydraulic bulge and tensile tests at different temperature (25–300 °C) and strain rate (0.0013–0.013 1/sec) levels. Thinning (% t) and cavity filling ratios (CFR) on the formed parts were taken as comparison parameters. Several numerical analyses employing different element types, solution methods and material models were performed using the commercially available FEA package LS-Dyna to determine the best combination of modeling options to simulate the actual warm hydroforming operation as accurately as possible. Analyses showed that relatively better predictions were obtained using isotropic material model, shell elements and implicit solution technique when compared with experimental results.

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1. Introduction

Lightweight materials, in particular, aluminum alloys have been widely used in automotive and aircraft industry as the high strength-to-weight ratio of aluminum results in significant weight and fuel savings [1–4]. In addition to weight reduction, utilization of aluminum offers some other advantages such as better corrosion resistance, higher recyclability potential and increased energy absorption during a crash situation. 5XXX alloys, in particular, have the highest formability, and are used in automotive inner panels [5]. Automotive industry has a special interest in AA5754 because of its high ductility, lightweight, strength and weldability properties [6]. However, because of their susceptibility to microstructural damage, aluminum alloy sheets generally exhibit a lower level of formability compared to typical sheet steels [7]. Furthermore, utilization of aluminum alloys in the automotive industry has been far behind of steel because of cost and formability issues at room temperature [8]. On the other hand, this alloy present some problems such as surface roughening during deformation, yield point phenomena, and the Portevin–Le Chatelier (PLC) effect [9]. Therefore, innovations are imposed to achieve higher formability of aluminum including the attempts of increased forming temperature [10–15], heat treating [16,17]

or using new forming technologies such as hydroforming [10]. It was reported that limiting drawing ratio of AA5754 aluminum alloy cup can be increased from 1.9 (at room temperature) to 2.7 when the forming die is heated to 250 °C [5].

Quite a few studies investigating the proposed solutions for improved formability of AA 5754 are available in literature. Multiaxial as well as uniaxial tests were performed with AA5754-O by Iadicola et al. to better predict the AA5754-O deformation behavior [18]. Similarly, Mahabunphachai et al. conducted a series of tensile (at strain rate of 0.0083/s) and hydraulic bulge tests (at strain rates of 0.0013/s and 0.013/s) for AA5754-O sheet blanks at different temperatures ranging from 23 °C to 260 °C [19]. As a general observation, significantly improved formability beyond 200 °C, and at low strain rates were reported [17–19].

Numerical analysis, especially the finite element method (FEM), has been extensively used in automotive design and forming processes to accurately predict deformation mechanics. It is vitally important for understanding, and forecasting the complex deformation behaviors that take place during sheet forming processes. For example, Ahmed and Hashmi modeled the hydraulic bulging process with combined pressure and in-plane compressive loads on the sheet-plate by finite element method. They used elastic, linearly plastic (bi-linear) isotropic material models with 20 4-node quadrilateral elements that allow large-deformation and large-strain analysis [20]. Wowk investigated strain rate sensitivity of AA5754 sheets experimentally employing very wide range of strain rates (0.001/s–1500/s), and then numerically implemented these