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Deep Drawing Parameters and Characteristics for the Hot Forming of AA7075

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Abstract. The hot forming of 7000 series aluminum alloys, or die quenching (DQ), consists of solutionizing the blank in a furnace and subsequently stamping it in a chilled die set. Being a relatively new technology, adopting the DQ process into automotive assembly lines involved several challenges. One of these challenges is the constitutive modelling, which is being addressed in literature. Another challenge is determining the proper formability conditions for DQ to work. To this end, the work presented herein investigated different forming parameters required to successfully deep draw AA7075 discs. Two disc sizes were selected: 177.8 and 203.3 mm. Parameters that were investigated were: binder load and lubricant applied. The deep draw experiments were also modelled in the LS-Dyna finite element code, using the constitutive data and a Barlat-2000 yield surface developed in other work by the authors. The predicted deep draw curves were found to match well the experimental data. The earring profiles also matched well.

1. Introduction

In the ongoing effort to lightweight automotive components, several new metal forming techniques are being devised. One such technology is the hot forming, or die quenching (DQ), of high strength 7000-series aluminium alloys [1]. The DQ process is well-established for ultra-high strength steels [2], though its application to 7000-series aluminum alloys introduces a unique set of challenges, from both an experimental and a numerical modelling point of view. From an experimental perspective, the issue of proper lubrication needs to be addressed [3], along with process parameters, such as solutionizing times, acceptable transfer times and quench rates [4,5]. From a numerical perspective, since most aluminum alloys are anisotropic, the temperature and strain rate-dependent anisotropic properties of the blank material need to be accurately captured [6]. Flow stress data [7], coefficient of friction [3] and heat transfer coefficients [8,9] are also needed.

The aim of the current work is to validate the constitutive model developed by Omer *et al.* [6] to simulate the high temperature behaviour of AA7075. Simulations were performed of a DQ deep draw operation in which the blank size, binder load and lubricant were varied. The predicted load-displacement and earring profiles were then compared against the experimental data.

2. Experimental Method

The deep draw operation was performed on a double-action servo-hydraulic press. Figure 1 shows a schematic of the deep draw tooling. The deep draw die was 228.6 mm wide (9”) with an inner radius of 114.3 mm (4.5”). The die entry radius was 12.7 mm (0.5”). The binder dimensions were identical to those of the die. The punch was 101.6 mm wide (4") and had an entry radius of 12.7 mm (0.5"). Two blank sizes were drawn: 177.8 mm (7") and 203.2 mm (8") in diameter. A total of five repeats were conducted per condition. The tooling was not cooled, however, the tooling was allowed to cool for 10 minutes between tests to avoid an increase in tooling temperature prior to forming. The tools were not coated and, as a result, were cleaned between tests to remove aluminum pickup from the blanks.

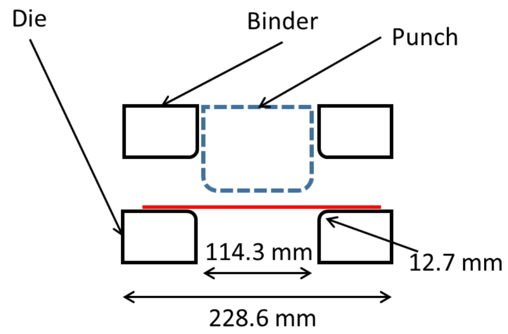

Figure 1. Schematic of the deep draw tool.

The deep draw procedure consisted of heating the AA7075-T6 blanks in a convection furnace at 470°C for 10 minutes. While the blank was heating in the furnace, lubricant was applied onto the surfaces of the die, binder and punch. After 10 minutes, the blank was manually transferred to the die opening. The blank transfer was performed using a pair of tongs to hold the blank and subsequently dropping it onto the die face and took 3-4s.

The drawing operation was performed on a double action hydraulic press. Once in the die cavity, a binder load was applied onto the blank using hydraulic pressure. The speed of the binder was not directly controlled. However, it took the binder 2-3s to fully clamp the blank. Once clamped the punch descended and made contact with the blank in 1s, and formed the blank at a speed of 10 mm/s, and drew the blanks to a depth of 55 mm. The temperature at which the blanks were formed was 405-415°C.

Two lubricants were tested for both blank sizes: Fuchs Forge Ease Al278 (diluted in water using a ratio of 1:2 by volume) and a dry Polytetrafluoroethylene (PTFE) spray. The lubricant was cleaned after each drawing operation using soap and acetone. The binder loads that were investigated were: 10, 15, 20 and 30 kN.

The load-displacement data was obtained from a data acquisition system in the hydraulic press. The earring profiles were measured by scanning the formed cups on an optical scanner, using an image resolution of 1500 dots per inch (dpi). The scanned images were then analysed using a Matlab script developed by Noder [3] and an earring profile of the scanned cup was generated.

3. Finite Element Model

The deep draw process was modelled in LS-DYNA, a commercial finite element (FE) code. The deep draw FE model is similar to those documented in [10–12] and used a coupled thermo-mechanical implicit solver. A quarter-symmetry assumption was used for the blank and tooling. An image of the tooling and blank mesh is shown in Figure 3. Four-node shell elements were used in the blank and tooling. The tooling was modelled using a non-deformable rigid material. The blank was modelled with a Barlat-2000 yield surface using the yield surface coefficients and temperature and strain rate dependent flow stress curves obtained by Omer *et al.* [6]. The stress-strain curves are shown in Figure 2 and were obtained by performing elevated temperature tensile tests. The results of the tensile tests were obtained by a technique in which the cross-sectional area of the necking zone of the tensile specimen was calculated. To allow for the flow stress to be dependent on both temperature and strain rate, a user-defined material subroutine was used in LS-DYNA.

The deep draw model was divided into three stages: (1) the transfer stage, (2) the sag stage and (3) the forming stage. In the transfer stage, the heat loss experienced by the blank was modelled, as it was moved from the furnace into the die set. An initial temperature of 470°C was assigned, and a convection boundary condition was assigned using a heat transfer coefficient (HTC) of 21 W/m^2-K [12]. The sag phase modelled the heat loss from the blank as it sits on the tooling surface. Furthermore, the sag phase accounts for the effect of gravity pulling down on the blank through the die cavity (*i.e.,* the blank "sagging"). In this phase of the deep draw model, the convection boundary condition from the transfer phase was retained. In addition, a gravity load was defined onto the blank (in the negative y direction in Figure 1) measuring 9.81 N/kg. A penalty-based contact was defined between the blank and the binder using a coefficient of friction of 0.04 [3]. Thermal contact between the binder and die was also defined and set to activate if the gap between the two parts became less than 0.1 mm. A contact pressure-dependent HTC was prescribed. Figure 4 shows the HTC *vs.* contact pressure curve used in the models, taken from Omer *et al.* [9].

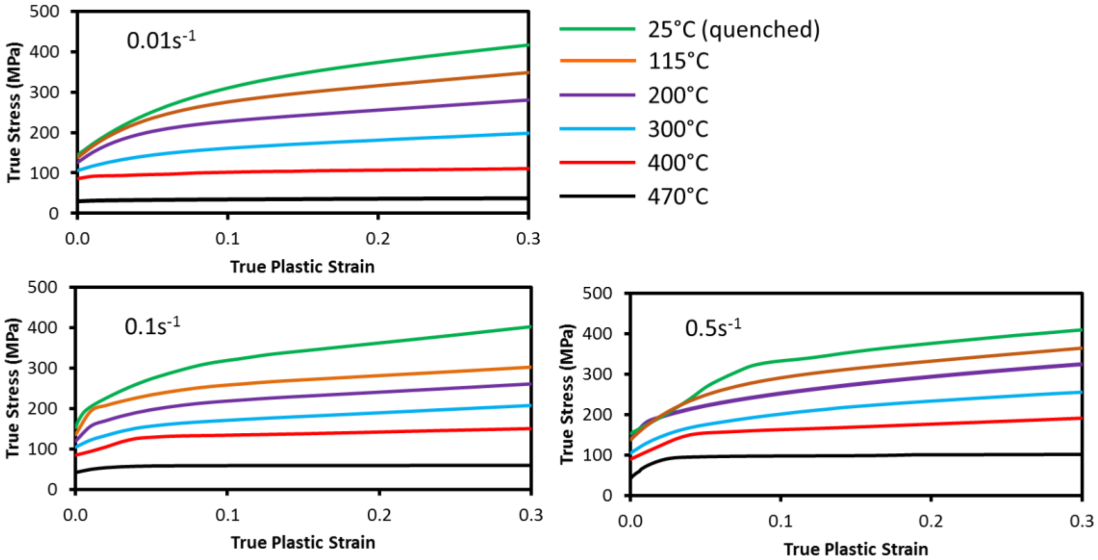

Figure 2. Stress-strain curves used to model the deep draw operations [6].

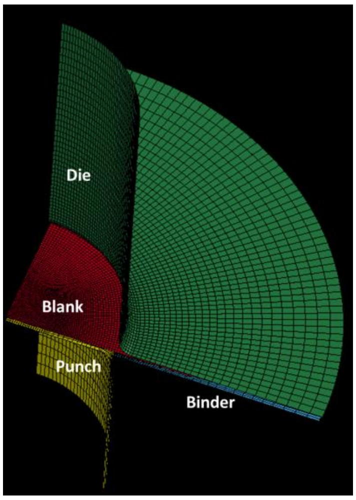

Figure 3. Mesh of the deep draw FE model, using quarter symmetry.

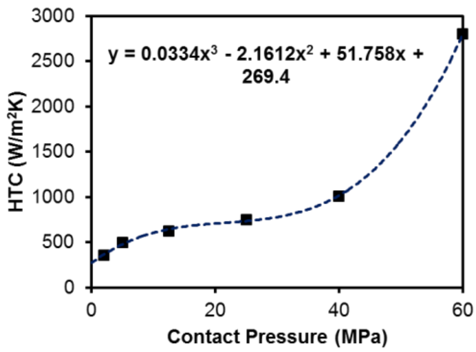

Figure 4. HTC *vs.* contact pressure, in MPa, for AA7075 [9].

During the forming stage, a prescribed force boundary condition was imposed onto the binder, which corresponded to one quarter of the binder load used in the experiments (owing to the quarter symmetry used in the models). Once the binder engaged with the blank, a velocity boundary condition of 10 mm/s was imposed onto the punch. A penalty-based surface-to-surface contact algorithm was defined between the blank and punch, blank and die, and blank and binder. A coefficient of friction of 0.04 was used to replicate the effect of the PTFE spray. Thermal contact was defined in a manner similar to the sag stage, between the blank and tooling.

4. Experimental and Numerical Results

Figure 5 shows the deep drawn cups under the four binder loads tested. All of the cups in the figure were lubricated with PTFE spray. The 177.8 mm diameter cups formed under all binder loads. However, for loads below 15 kN, wrinkling was observed in the flanges. The 203.2 diameter mm cups formed under all binder loads except 30 kN. At loads below 20 kN, wrinkling was observed in the flanges. Based on the results of Figure 5, a binder load of 20 kN was selected for both blank sizes to compare the two lubricants and for the simulations. Figure 6 shows a comparison of cups formed using PTFE spray as a lubricant and cups using Fuchs AL278. All cups in Figure 6 used a binder load of 20 kN. As shown in the figure, the 203.2 mm diameter cups lubricated with Fuchs AL278 exhibited lower formability.

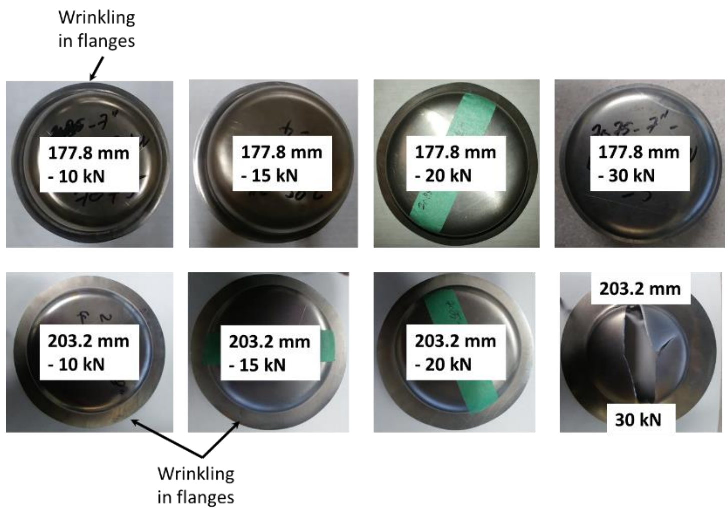

Figure 5. Deep drawn cups under five binder loads (indicated under each up) and lubricated using PTFE spray.

Figure 6. Deep drawn cups drawn under a binder load of 20 kN, and lubricated using either Fuchs AL278 or PTFE spray.

The measured and predicted force-displacement curves are shown in Figure 7. The FE scenario modelled was the binder load equalling 20 kN and lubricant being PTFE spray. Both blank sizes were modelled. The measured and predicted earring profiles of the formed cups are shown in Figure 8. The FE model was able to predict the force-displacement accurately, as well as the earring profiles for the two blank sizes.

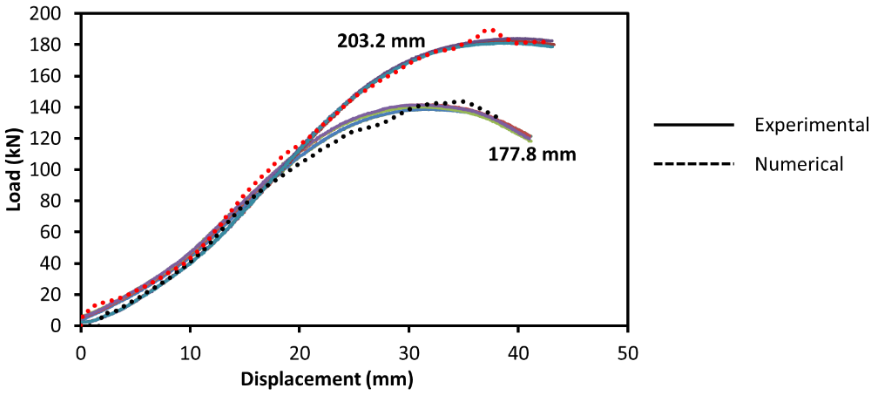

Figure 7. Experimental and numerical force-displacement curves from the deep draw operation.

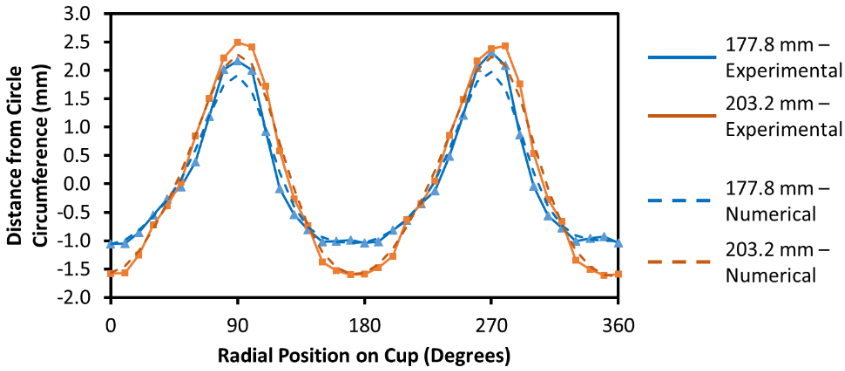

Figure 8. Measured and predicted earring profiles from the deep draw operation. The radial position of 0 corresponds to the rolling direction of the sheet and a position of 90 corresponds to the transverse direction.

5. Discussion and Conclusions

The formed cups indicate that PTFE spray performance during die quenching was superior to the Fuchs AL278 lubricant (when mixed with water), which is not designed for temperatures above 230°C [13]. The PTFE spray used in this work is designed only for use up to 270°C; however, the PTFE spray did serve as an effective lubricant for the DQ deep draw operation, although it's commercial application is questionable.

The appropriate binder load for the DQ operation was found to be 20 kN. This load is noticeably lower than what is used typically in warm forming operations. For example, Noder [3] used a load of 100 kN for the warm forming of AA7075-T6 in the same tooling and blank geometry. Abedrabbo *et al.* [14] used a load of 60 kN for warm forming of similar-sized AA5182-O blanks, which is a much softer alloy than AA7075-T6. The low binder load of 20 kN, however, is reasonable since at 470°C, the aluminum alloy is expected to be softer than at warm forming temperatures, particularly in a solutionized condition. Noder [3] and Abedrabbo *et al.* [14] have confirmed that the strengths of aluminum alloys at warm forming temperatures (approximately 250°C) are higher than at 470°C. The softness, or low strength, of the material means that a lesser binder force is sufficient to prevent sliding during the drawing operation.

The modelling conducted in this work affirms that the constitutive model developed by Omer *et al.*[15] for DQ of AA7075 is reliable and can produce accurate force-displacement and earring profile predictions.

Acknowledgements

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