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FINITE ELEMENT SIMULATION OF DEEP DRAWING OF ALUMINIUM ALLOY SHEETS AT ELEVATED TEMPERATURES

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ABSTRACT

More and more automobile companies are going for weight reduction of their vehicles for fuel economy and pollution control. They have started using tailored blanked bodies with advanced joining techniques. Such material combinations usually are called as "Tailor Welded Blanks-TWB" with better characteristics. However, owing to the presence of different materials their formability is a challenge. The objective of the present study is to determine the effect of blank temperature on forming behaviour of sheets and damage factor of such aluminium sheet alloys of 6061 and 7075 at elevated temperatures. An insight into such a study will throw light on the different temperatures required by the above materials when they are made into TWBs. In the present investigation, a series of simulations were carried out on the formability behaviour of cylindrical deep drawing of aluminium alloys in the temperature range 50-500°C using DEFORM-2D. The damage factor based on Cockcroft Latham algorithm was taken as the constraint for defect free product.

The results show that forming at elevated temperature can yield significant increase in product height, especially for aluminium 7075. The deep drawing of aluminium 6061 alloys show very good formability in a temperature range between 150-250°C and 400-500°C for aluminium 7075. Both the metals gave identical cup heights when drawn at 475°C.

Keywords: model, deep drawing, aluminium alloys, DEFORM 2D, elevated temperature, forming, tailor welded blanks.

1. INTRODUCTION

Now a days, there is a great concern about weight reduction of automobile due to increased production of aluminium alloy with better formability.Aluminium alloy sheets are being widely employed in making components for automobile and ship building due to their excellent properties such as high specific strength, corrosion resistance and weldability. Although cast aluminium alloys are being employed for a considerable number of components, the use of forming products of aluminium alloy sheets is still limited because the formability of aluminium alloy sheet is still poor due to lack of understanding of flow behavior during deformation.

It is well known that the ductility of aluminium alloy sheets can be improved notably with increase in the working temperature. Warm forming is one of the ways to obtain high formability in aluminium sheets. Warm forming is not a new process, Finch *et al*., [1] investigated the potential of warm forming by deep drawing for both rectangular and circular cups of aluminium alloys as early as 1946. The results showed significant improvement in the deformability at relatively moderate temperature of about 150^0C. Fukui [2], Lenz [3], Miyagawa [4] and Tozwa [5] improved the process and enhanced the process usage in industrial application. They examined experimentally the forming limit in cylindrical deep drawing cups under various conditions of temperature and there was improvement in the cup height and the critical punch stroke with increased temperature.

Only a few simulations of aluminium warm forming have been reported so far. Keun *et al*., [6] presented 3D FEM simulations of cylindrical cup deep drawing with AA 5042-H32 alloy. They used Baralat yield function and a double power law work hardening relation. A fifth polynomial was used for the temperature dependant function, in order to obtain an isotropic model at the solution temperature. They presented an accurate thickness prediction and compared it with experiments. Takuda *et al*., [7] used a 2D axisymmetric FEM model for the simulation of cylindrical cup deep drawing with AA5182-O alloy. They concentrated on the calculation of temperature distribution. R. Neugebauer *et al*., [8] investigated the influence of elevated temperatures on the properties and the forming behavior of the materials. Van Den Boogaard *et al*., [9] found that the aluminum which contains 6% magnesium could give a 300% total elongation at about 250^0C.

Although the aluminum alloys have high-strength to weight ratio and good corrosion resistance, the low formability of aluminum sheets limits their use in some products with complex shapes, such as automotive body parts. The elevated forming process is intended to overcome this problem. In order to find out optimal temperature limits of forming of aluminium alloy sheets and its practical implementation, it is necessary to analyze and determine the effect of blank temperature on forming of aluminium deep drawing cups. In this study, the finite element method is applied to find out the formability and damage factor of aluminium alloy sheets at elevated temperatures. In the simulation, formability and damage factor are given as a function of temperature. The forming limits are predicted by simulation under various temperatures and the optimal temperature is found.

2. MATERIALS AND METHODS

2.1 Materials

The work piece materials chosen for this study are aluminium alloys AA6061 and AA7075, the composition and property of whose are given in Table-1.

Table-1. Composition and properties of aluminium alloys AA6061 and AA7075.

a) Composition of aluminium alloy AA6061

Element	Al	Mg	Si	Cu	Cr
Amount (wt %)	97.9	1.0	0.6	0.8	0.2

b) Properties of aluminium alloy AA6061

Poisson's ratio	0.33
Elastic modulus (GPa)	70-80
Tensile strength (Mpa)	115
Yield strength (Mpa)	48
Elongation (%)	25
Hardness (HB500)	30
Thermal expansion (10^{-6}/ ºC)	23.4
Thermal conductivity (W/m-K)	180

c) Composition of aluminium alloy AA7075

Element	Al	Cu	Mg	Cr	Zn
Amount (wt %)	90.0	1.6	2.5	0.23	5.6

d) Properties of aluminium alloy AA7075

Poisson's ratio	0.33
Elastic modulus (GPa)	70-80
Tensile strength (Mpa)	220
Yield strength (Mpa)	95
Elongation (%)	17
Hardness (HB500)	60
Thermal expansion (10^{-6}/ºC)	23.2
Thermal conductivity (W/m-K)	130

In this study, cylindrical cup drawing simulations were performed with a toolset given in Figure-1. All the simulations were performed with blank of 102 mm diameter with 3 mm thick sheets of aluminium 6061 and 7075 sheets. The effective punch stroke of 80 mm and punch velocity of 3 mm/sec were used and the motion at both the ends of blank was constrained in both X and Y directions. For each material, a series of cups were deep drawn at temperatures of 50^0C, 100^0C, 150^0C, 200^0C, 250^0C, 300^0C, 350^0C, 400^0C, 450^0C and 500^0C, while punch was kept at 25^0C. The formability of AA6061 and AA7075 sheets under room temperature (RT) condition is required to be the same at the optimum temperature of forming if both the sheets are combined to form a TWB.

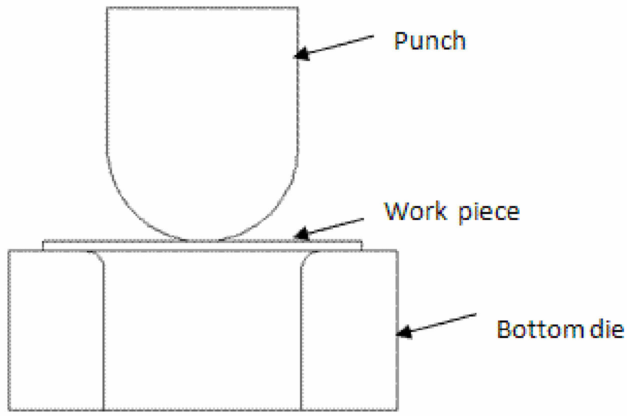

Figure-1. Tool set for deep drawing.

2.2 Methodology

Forming Limit Diagram can be obtained for strain paths ranging from biaxial tension (stretch forming) to equal tension and compression (deep drawing). Some of the tests used for studying formability are Tensile Test, Hydraulic Bulge Test, Cross tensile Test, Erichsen Test, Swift Cup Test etc. In this study, deep drawing study has been performed for determining the drawing limits. The limit of forming has been arrived at the onset of thinning on the walls of the formed tube. The damage factor based on ductile fracture criteria has been studied to arrive at the failure location.

3. RESULTS AND DISCUSSIONS

Now a days, the designers and manufacturers are preferring simulation of process before implementation of the actual process as this provides more information related to the process performance to evaluate the effect of different process variables during process that result in saving of material and manufacturing cost. In this contest, a deep drawing process has been modeled using finite element code. The work piece was meshed with 1500 iso - parametric quadrilateral elements while the tool was modeled as rigid body.

The induction principle was employed to decrease the heat affected zone (HAZ) and improve process performance. Elevated temperatures not only increased the ductility but also decreased the spring back thus improving the quality of the product. The same material, tool and process parameters were used to produce cups under dynamic heating conditions. The two aluminum sheets were heated to different temperatures ranging from RT to 500°C. Under the uniform temperature condition, the cup height increased with increase in temperature. It was found that both the sheets had more or less equal deformation at 400-475°C. The multipurpose code Deform 2D is suitable for doing the finite element simulations of the formability of aluminium sheets at

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various temperatures since it can handle coupled thermo mechanical models.

Figure-2 shows the cup height drawn at room temperature using DEFORM 2 D and Figure-3 is the cup drawn with AA7075. The simulation was stopped at the onset of thinning on the drawn cup. The damage factor based on Cockcroft Latham algorithm was used as a constraint to study the fracture strain and thus the formability. It is found that AA 7075 has shown very little deformation compared to AA6061 at room temperature.

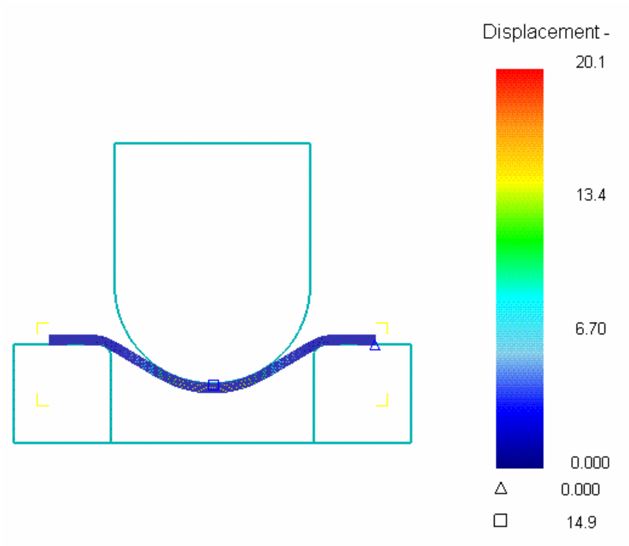

Figure-2. Forming at RT of AA6061.

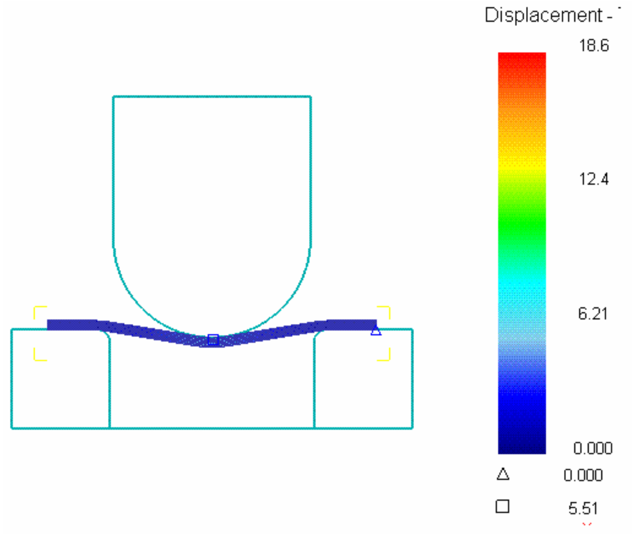

Figure-3. Forming at RT of AA7075.

Figure-4 shows the graph between cup height and temperature. It is found that AA6061 is having good formability compared to AA7075 between room temperature and 200^0 c. However, after 200^0 c, it is found that the drawability of AA 6061 remains almost same and in the case of AA7075 it has stated to improve upto a temperature of 450^0C. At 450^0C, the cup height was almost same for both materials. It is thus infered that, if the temperature is maintained at 450^0C for a blank with material combinations of AA6061 and AA7075, a more or less equal deformation can be achieved.

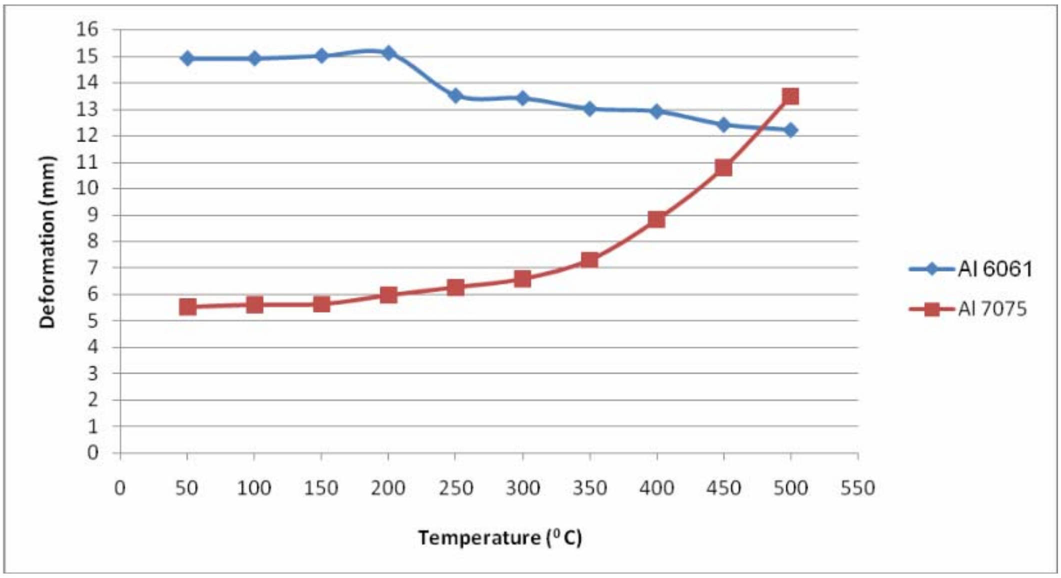

Figure-4. Graph between cup height and temperature.

Figure-5 shows the relation between temperature and damage factor. It was observed that the damage factor of AA 6061 increases with increasing of blank temperature (up to 250^0 C) and falls on further increasing of temperature. In case of AA 7075, the damage factor is gradually increasing with increase of blank temperature. It was found that both materials have a unique damage factor at 475^0C (2.12) which have almost same deformation.

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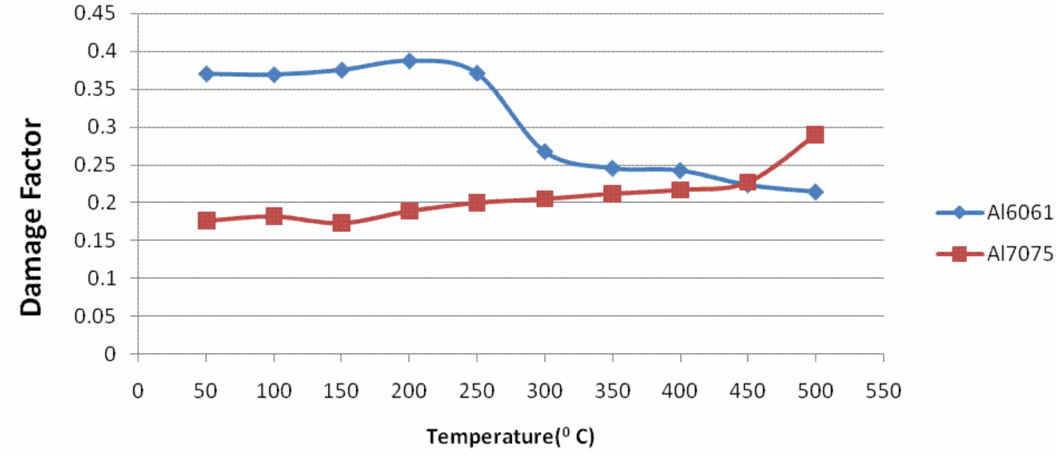

Figure-5. Graph between cup height and damage factor.

Figure-6 shows the maximum height of the cup that was deep drawn with different blank temperatures ranging from room temperature to 500^0 c. At 200 C the cup was drawn without failure to a height of 15.1 mm, which is 9 % larger than when it is drawn at room temperature for AA6061, whereas in the case of AA7071 even though it showed an increase in cup height of 8 % compared to room temperature, the max cup height achieved was far less than that of AA6061. Moreover, it is clearly found that the thinning starts at a very small cup height level itself for AA6061 and as the temperature is increased AA 7075 shown some enhanced formability and at 450°C it has reached the drawability level of AA 6061. As the draw ability of AA6061 is found to stabilize after 200°C.

The punch forces obtained from simulations for forming temperatures from 50^0C to 500^0C are shown in Figure-7. High punch force required for deformation at room temperature was observed due high shear stresses due to interface friction coefficient.

The results in Figures 8 and 9 confirm a general trend of the temperature and strain rate effects on the flow stress of aluminum alloys. It is found that the flow stress decreases with increasing temperature and/ or with decreasing strain rate thereby, improving the formability. However, in the case of bulging of AA6061 tube at low temperature level, the flow stress was observed to be more compared to at high temperature and found to increase with increasing strain rate. With a higher percentage of Mg content in AA 7075 than in AA 6061, the ductility of AA 7075 at elevated temperatures is found to be higher than that of AA 6061 (after 250^0C) which was caused by the increasing number of the slip planes in the hexagonal structure of Mg at elevated temperatures. The effect of Mg content on the ductility of aluminum alloys at elevated temperatures is reported elsewhere [10-11] and a similar behavior is reported.

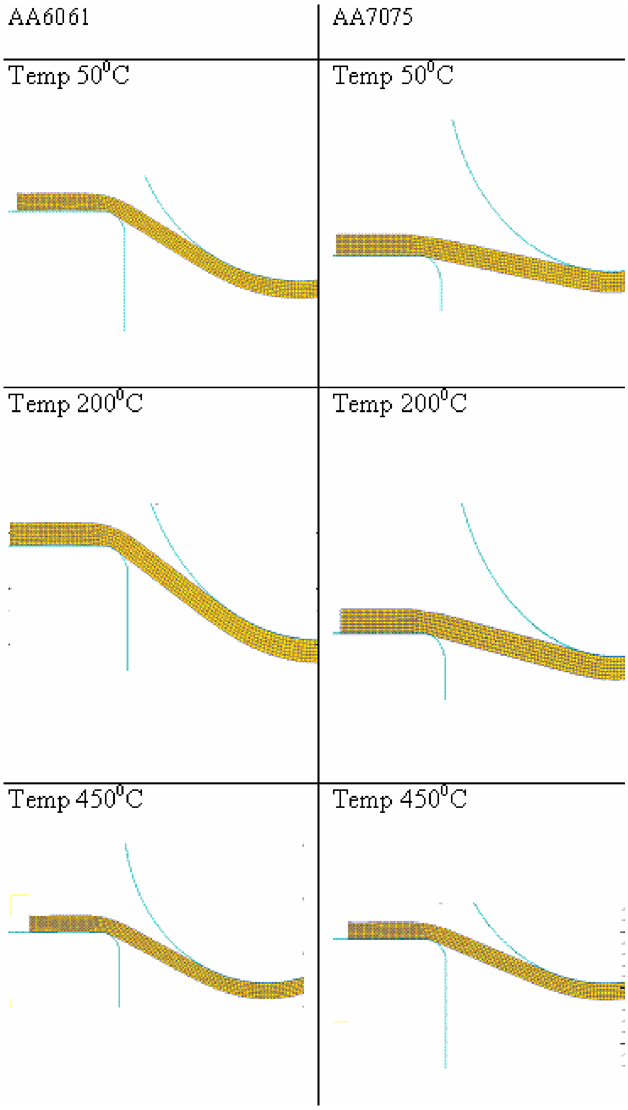

Figure-6. Failure locations at different temperatures.

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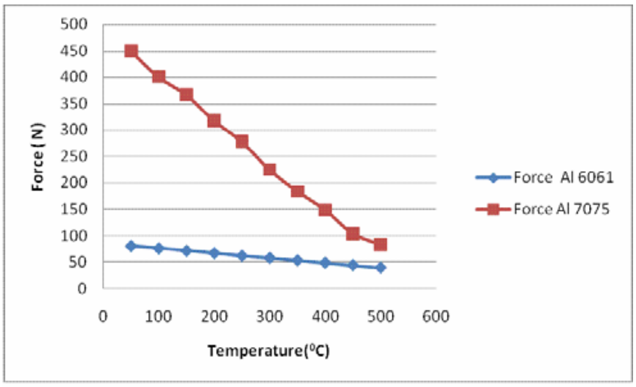

Figure-7. Punch force obtained from the FE at different temperatures at punch velocity of 3mm/sec.

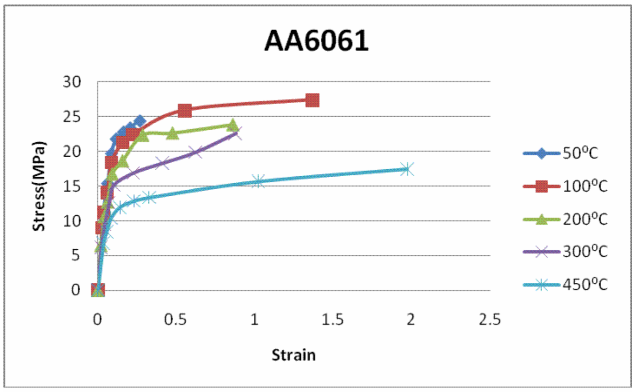

Figure-8. stress –strain curve for AA 6061.

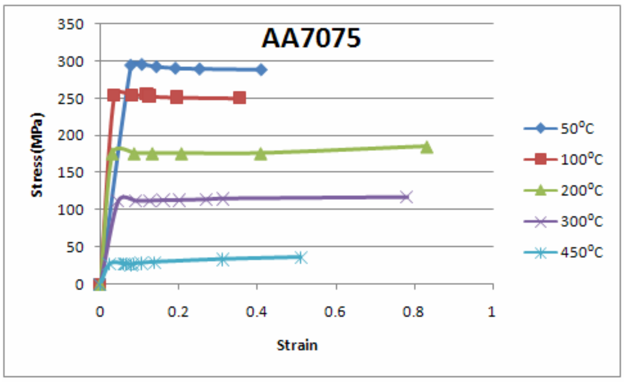

Figure-9. Stress-strain curve for AA 7075.

When AA 6061 blanks were bulged at the lower strain (0.0013) at 300^0C, the maximum strain value is shown to be as high as 0.9. Therefore, at a low strain, the formability of AA6061 was high but it almost remained same at temperatures above 200^0C. In case of AA 7075 the minimum strain (0.00107) was experienced at 450^0 C, the formability was very high at this temperature. However the strength of AA6061 blank has to be improved through aging treatment before putting the product in to service.

3.1 Effect of punch velocity on deformation at higher temperature

Simulations were carried out at higher temperatures ranging from 400^0 C to 500^0 C with various punch velocities of 1 to3 mm/sec to find out the effect of punch velocity on deformation of AA6061 and 7075 blanks. Figures 10 and 11 show the results of the deformation at higher temperatures and at different punch velocities. It was observed that both materials had been deformed more when they were carried at a velocity of 1mm/sec. The deformation load at low velocity was lesser that that of higher velocity.

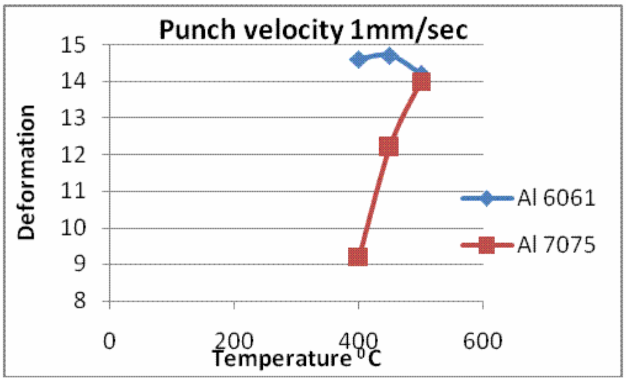

Figure-10. Puncch velocity 1mm/sec.

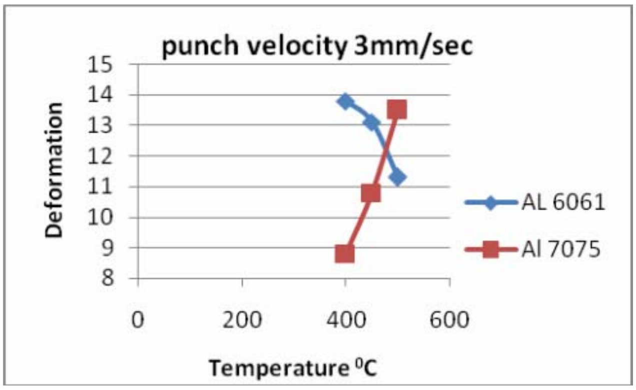

Figure-11. Punch velocity 3mm/sec.

4. CONCLUSIONS

In this study, forming of two different aluminum alloys has been simulated for circular cup drawing using DEFORM 2D. It has been confirmed that higher cup depth is possible at elevated temperatures. Forming limit and necking location has been successfully predicted in the simulation. The optimum temperature at which both the blanks will have identical maximum uniform cup depths has been found during deep drawing. Such a result will help to understand the behavior of tailored welded blanks made of two or more materials such as tailor welded blanks.

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