ABSTRACT

Deep drawing is one of the sheet metal forming processes widely used in automobile, aerospace, electronics and allied industries to produce the hollow parts. Presently, the conventional deep drawing (CDD) operation is carried out at room temperature in industries. Some of the problems encountered during the conventional deep drawing operation are: (1) large deformation during deep drawing at room temperature causing problems in forming high strength/low formability materials like magnesium, aluminium alloys etc. (2) the occurrence of deformation induced transformation of martensite in case of austenitic stainless steel imposes the difficulty in forming operation and (3) the major defects such as wrinkles, tearing likely to occur. Warm deep drawing (WDD), one of the non conventional forming processes, which is performed at the temperatures above the room temperature but below the recrystallization temperature of the material, is gaining importance in recent years because of its effectiveness in overcoming the above mentioned problems.

In this research work, the investigations are carried out by conducting experiments using AISI 304 austenitic stainless steel blank of thickness 1.0 mm and at temperatures ranging from room temperature to $300^0\text{C}$ at an increment of $100^0\text{C}$. The effects of temperature rise on maximum drawing load, changes in the thickness, radial and hoop strains are analyzed.
The stainless steel components are successfully deep drawn without any defects at all forming temperatures considered for investigation. The experimental results have shown that there is a substantial decrease in the maximum drawing load of 37\% due to warming of the blank without appreciable change in the strains when compared with the conventional deep drawn components.

The investigations are carried out to evaluate the changes in microstructure, micro-hardness and grain size of the deformed components at different forming temperatures and also to determine their influence on the forming characteristics of the material. The investigations reveal that the microstructure, grain size and micro hardness of the material do not have significant effect on the warm formed components. Further, by warming the blank, no strain induced martensitic transformation in microstructure is observed in the drawn components.

The experiments are conducted at different processing temperatures using different blank diameters to find out the limiting draw ratio (LDR) and to study the formability of the material. Formability limit diagrams (FLD) are drawn to find out whether any region on the surface of the drawn cup is in the vicinity of fracture. This helps to realize the failure of the deep drawn component. The experimental results have shown that there is a significant improvement of approximately 23.8\% in LDR and 63\% increase in the maximum height of the deep drawn cup is observed at 300°C. These results indicate that the formability of the stainless steel material is improved
due to the warm forming. Also, the forming limit diagrams drawn for warm deep drawn components have shown moderate severity of deformation and margin of safety and thus the material is not wasted.

Also, the finite element method based simulations using ABAQUS/standard software are performed to evaluate the maximum drawing load, true strains such as thickness strain, radial strain and hoop strain and the results are compared with the experimental values for validation. The results of finite element simulations have shown a good correlation with the experimental results. The finite element simulation may be used effectively to analyse the deep drawing operation by changing the process parameters, material parameters and tool parameters without conducting the actual experiments. This reduces the tryout time and cost considerably. The thinning and thickening regions shown by the finite element simulations agrees well with the experimental results at all warming temperatures considered for investigation.

A new approach is proposed to calculate the thickness distribution theoretically in a warm deep drawn circular cup. Also, the limiting draw ratio values, the height of the deep drawn cup and the punch force are predicted theoretically. The results of theoretical predictions are compared with those of the experimental results in order to ascertain the accuracy of prediction. The results of theoretically predicted values correlate reasonably well with the finite element method and experimental results at all warm forming temperatures.
The investigations reveal that the warm deep drawing has more advantages than the room temperature deep drawing. The influence of temperature helps in overcoming the problems encountered during conventional deep drawing operation. The various advantages of warm deep drawing make it to become one of the widely used sheet metal forming operations in industries in future.