ABSTRACT

In the manufacturing sector, especially in the automobile and the aerospace industries, there is a perpetual demand for producing complex shapes on various materials. Steel alloys are commonly used in automobile industries to manufacture body panels, decorative panels, wipers, mufflers and trims, other components such as batteries, lighting and braking and structural applications.

Incremental forming is an ideal technique to obtain customized products accurately with complex shapes. It is a flexible and innovative die-less sheet metal forming process, which allows the production of various shapes by progressively applying a series of localized deformations using conventional tool in a CNC Machine.

Incremental forming has been successfully applied to aluminum alloys, magnesium alloys and pure titanium sheets to form a variety of simple shapes, though some unresolved issues still exist. The process requires precise digital computer aided design that represents the part to be manufactured involving low manual work. Thus the repeatability of the process is very good. However the surface properties of formed sheet need to be evaluated, optimized and modeled to obtain high quality prototypes.

In this study, steel alloys IS: 513 CR3 deep drawing quality steel, IS: 277 galvanized steel and AISI 304 stainless steel sheets were used in
incremental forming with an aim to investigate the influences of process parameters on forming of these alloys. Optimization of incremental process parameters has also been carried out to identify the combinations of the parameters that yield better surface characteristics on the formed sheets. In addition a finite element analysis has been done for the optimized variables to predict the incremental forming characteristics.

Incremental forming was carried out under different process parameters such as tool rotational speed, table feed and step depth on a constant thick steel sheets in a CNC vertical milling machine. The process was done using two different hemispherical shaped forming tools, such as high speed steel and silicon carbide. The surface and formability characteristics such as surface roughness, Vickers microhardness, forming limit, thickness distribution and microstructure were evaluated for the processed materials.

The results indicated that the tool rotational speed, table feed and step depth have a major influence in determining the surface and formability characteristics of the formed material, which is attributed to the cold working and plastic deformation during incremental forming. It was also observed that the surface roughness and Vickers microhardness invariably increases with all the process variables. The thickness of the formed components was found to be non uniform. Forming limit diagrams (FLD) are remarkably useful in identifying the critical combinations of major strain and minor strain on the sheet surface at the start of necking failure. They are constructed by
identifying and plotting the major and minor strains. The forming limit curve in SPIF appears as a straight line with negative slope in the stretching region of the forming limit diagram, so that the formability in this process can be expressed as the combination of major and minor strains. In the forming limit diagram, the position of the straight line forming limit curve is higher than that of the conventional one, enabling this innovative process to produce larger deformations.

The microstructure of the incrementally formed cone and pyramid shapes were studied at various locations under different process variables. Most of the photo-micrographs showed near identical grain formation due to the plastic deformation of the incremental forming process. The zone near to the apex of cone and pyramid showed more thinning as compared to the other areas. However no visible change in the grain size was observed between various locations.

Parametric optimization is one of the key issues influencing manufacturing industries for achievement of higher productivity and better quality. Optimization of incremental forming process is a difficult task owing to many regulating variables. The selection of the combination of influencing factors for an optimal forming involves a reasonable estimate of a precise output. In order to optimize the process parameters in incremental forming (performance characteristics) concurrently Response surface methodology (RSM) was used in the present work. Central composite design (CCD), one of the most popular types of second order model was used to fit the data.
The F-values obtained from ANOVA tables implied that the model terms were significant. There is only a negligible chance that a large F-value could occur due to noise. The predicted R-Squares were in reasonable agreement with the adjusted R-Square. A measure of signal to noise ratio called as adequate precision was higher for all the models. The final equations for optimum final thickness in terms of coded and actual factors are also provided.

Confirmation experiments were conducted to validate the optimum process parameters obtained through optimization techniques. Optimum process variables were used as input conditions. Surface roughness and final thickness were evaluated for the sheets incrementally formed cone and pyramid shapes under optimum parametric values using the same experimental setup. The measured surface roughness was the lowest for all the cases as compared with originally conducted experiments. The deviation between predicted and experimental results was less than 10% for surface roughness and 8% for final thickness.

Finite element analysis was carried out for optimized variables using Abaqus v 6.4.8 software. A circular sheet and a square sheet were analyzed for FEM analysis over the end of rotating hemispherical tool. The results of the thickness and forming time of finite element analysis correlate closely to experimental results with the variation less than ±10%.