ABSTRACT

Sheet metal forming process is mostly used in manufacturing industry to produce consumer products in the field of automobile, aerospace, biomedical, architectural and defence sectors etc. In India, sheet metal forming sector has contributed around 15-18% of overall demand for machine tools in the recent years. This indicates the impact of sheet metal forming in the manufacturing domain. Automotive sheet metal forming market was valued at US$ 221.22 billion in 2018 and is projected to grow upto US$ 269.01 billion by 2025, with a compound annual growth rate of 2.83% during the forecast period. The global manufacturing market is literally booming with the rising demand in consumer products. Other sectors that drive demand for sheet metal forming include aerospace, power, construction, steel industry, biomedical implants and aesthetic industry. This brings forth the need to improve sheet metal forming operations in terms of rapid/automated part production.

The incomparable presence of sheet metal forming in the manufacturing industries stimulates significant research interest to explore and improve the process. Sheet metal forming sector witnessed a technology shift in recent years and is moving towards process automation leading to new emerging technologies. One such emerging technique that has a higher degree of process versatility and automation capability is Incremental Sheet Metal Forming which is the subject of study in this research work. This technique does not require any dedicated tool and die setup for forming. In this process, sheet metal blank is subjected to series of localised small incremental deformations in the vicinity of form tool movement leading to enhanced process flexibility, automation capability and reduction in lead time.

Even though Incremental Forming has numerous advantages over conventional sheet metal forming, the process still remains in the evolution phase. There are several unexplored areas that demand clear understanding to

improve the quality of formed part. To address the above issue, this study primarily focuses on improving the geometric accuracy and quality of the formed components. In incremental forming, process variables, part variables and forming methods are the inherent features in part production. Thereby to study the influence of each process determinant, the proposed research methodology is streamlined into six phases as described below.

In Phase 1, study was conducted to understand the impact of process parameters such as tool geometry, feed rate, spindle speed, and incremental depth. In addition to these process parameters five different tool geometry have been used for experiments to test the impact of tool size and tool geometry. The workpiece material used for this study is EN10130 DC01, accounting for its wider application in automotive industry. Finite element analysis was performed to predict the material thinning during deformation. In addition, microstructural study was carried out to understand the deformation phenomenon with respect to form tool geometry.

In Phase 2, study on the effect of friction between tool-sheet interface was tested with roller ball end tool. Response Surface Methodology (RSM) was used as the design of experiments technique to study the interaction between input variables and its effect on output responses to achieve part quality. Results obtained from RSM were statistically analysed to find the influence of roller ball end tool and the optimum parameters for better part quality were predicted using numerical optimization techniques.

In Phase 3, study on tool path was performed, a primary variant that affects the dimensional accuracy and quality of the formed component. Three different tool paths were selected and compared to study its influence on final part accuracy. Experiments were designed using RSM where the tool paths interactions with feed rate and incremental depth were explored. Influence of tool path to achieve better quality products was experimentally studied. In addition, most suitable tool path to achieve better profile accuracy was predicted using numerical optimization technique and the same was experimentally validated. Inconel 718 was used as the workpiece material for this study considering its application in turbojet engine parts.

In Phase 4, effect of lubricant on the tool-sheet interface was studied using three lubricant grades, namely Servo 46 (low viscous), Servo 100 (medium viscous), Servo 150 (high viscous). The friction between tool-sheet interface is a significant factor in achieving defect-free products with improved formability and surface finish characteristics. The work material used for this analysis was Ti6Al4V considering its application in aerospace and biomedical parts. The experiments were formulated with varying feed rate and incremental depth in combination with three lubricant grades. Effect of lubricant on output part quality such as thinning, geometrical accuracy and surface finish were experimentally evaluated and optimum process parameters for better part quality were predicted using numerical optimization technique.

In Phase 5, formability study was conducted to analyse the ability of sheet metal to deform the required shape without failure. Formability of EN10130, Inconel 718 and Ti6Al4V were experimentally studied to find the safe working limit of the material. Formability study also revealed process improvements achieved in first four phases of research work. A conical frustum with four different generatrices namely circular, elliptical, parabolic and exponential were used to study the formability of materials.

In Phase 6, study on forming methods was performed. Based on the forming method, Incremental Sheet Metal Forming (ISMF) is classified into Single Point Incremental Forming (SPIF) and Two Point Incremental Forming (TPIF). To understand the process in a better way, both forming methods were studied experimentally in this research work to achieve better quality products. In TPIF, a modular fixture capable of achieving three variants of material flow phenomenon namely restricted material flow, partially-guided material flow and completely-guided material flow was used for experiments. EN10130 was used

as the workpiece material. Truncated cone and dome profile with 90^o end wall angle was used to determine the best variant to achieve maximum wall angle of 90^o with better profile accuracy. This study leads to development of TPIF fixtures with enhanced material flow capabilities. Initiation of material flow in the deformation region leads to improved formability with reduced thinning and better profile accuracy. It increased the capability of ISMF to a greater extent without compromising the part quality and accuracy.

Thus, systematic study of all the process determinants explored the most suitable combination of process parameters to form the components with enhanced geometrical accuracy and part quality. This study also explored an innovative TPIF modular fixture mechanism which can reframe the process capability of incremental forming, making it applicable for complex part profiles. This research in turn enhances the industrial suitability and commercialization aspects of the process by making rapid sheet metal forming a reality.