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Finite Element Analysis to Study the Effect of Tool Deflection in Incremental Forming Process

Eldho Paul, Hariharan Krishnaswamy, Riby Abraham Boby, Sahil Bharti

Mechanical Engineering
Indian Institute of Technology Madras
Chennai, 600036, India
eldhopaul@mace.ac.in, hariharan@iitm.ac.in, ribyab@gmail.com,
me17d017@smail.iitm.ac.in

Abstract

In the era of immense development in the area of rapid prototyping Incremental Sheet Metal Forming (ISF) boasts of great potential in rapid manufacturing applications with minimum tooling. The flexibility of the process enables the production of complex geometry in a more economical way than the traditional metal forming process. In ISF the desired shape is obtained by forcing a simple hemispherical ball end forming tool against the sheet metal clamped rigidly along its edges with a blank holder [1]. Computer numerical control (CNC) machines can be used to force the tool along the desired trajectory on the blank surface. The sheet plastically deforms by the sum of local deformation induced by the forming tool. Most of the parametric studies [2] regarding ISF involves investigating the effect of sheet thickness, tool path, deformation speed and forming tool radius on formability. However, the forming machine and tools are always assumed to be rigid during the forming process.

Conventional CNC milling machines with single forming tool are usually adopted as a platform for single point incremental forming (SPIF) experiments due to its wide availability and ease of operation. Figure 1 shows a Jyoti Huron KMill CNC machining centre with SPIF toolings. Tool path for SPIF is generated in a way that the milling tool is replaced by a single point tool for forming. But this adoption is limited as these machines are not optimized for high axial force and high dynamic behaviour during SPIF [3]. Though the machine and tool stiffness is high, these factors may influence the accuracy of the formed part. Machine tool compliance is identified as a major factor that can cause premature contact loss between tool and workpiece resulting in the inaccurate prediction of sheet thinning during tool path generation [4]. Recent developments in SPIF is robot-based forming where the major factor that influences the forming accuracy are tool orientation and stiffness. The series of linkages present in the robot exhibits a lower stiffness than conventional machine tools [5].

Figure 1: SPIF process on Jyoti Huron KMill CNC machining centre

This study focuses on investigation of the effect of tool stiffness in the final dimension of formed component. In machine tool there are three aspects that contribute to the deflection of tool point. They are machine frame stiffness, holder stiffness and tool stiffness. Finite element method (FEM) based analysis showed that the stiffness of the machine and tool holder is 15 times higher than that of slender tool [6]. The scope of the study involves modelling tool stiffness and estimating its contribution to the geometrical deviation in the parts formed by SPIF process. It is difficult to make experimental observations due to the practical constraints in making measurements inside the machine tool structure during the incremental forming operation. Especially when equipment like laser tracker requires the mounting of a retroreflector on the machine tool and uninterrupted line of sight for the laser.

Therefore, FEA based analysis is made and the results are presented which shows how important it is to model the stiffness of the system while designing the system for incremental forming.
A production process of a truncated cone using a SPIF process was studied by simulating different models of forming tool using a commercial software code, ABAQUS/Explicit. The material used for this study is Aluminium 1050 sheet of 1.2 mm thickness. A hemispherical ball end tool of 8 mm diameter was used in this simulation. A comparative study was performed using different tool materials considering them as rigid as well as deformable. The deformed profile of the plate after single point incremental forming with M2 high-speed tool steel is shown in figure 2. Here the tool is modelled as a deformable shell structure. The nodal displacement of the deformed profile of the truncated cone was measured and compared with the results from the same experiment set up with a rigid tool. Table 1 shows the results obtained from the simulation study. Even though the range of deviation is small for the above experiment, it will be significant if the tool used is slender and flexible while the sheet metal has a higher stiffness. When considering robot-based forming the above set of results can have a higher deviation resulting in a significant influence on the accuracy of forming due to compliance of the serial linkage in the robot.

Table 1: Comparison of profile displacement

	Maximum Deviation (mm)	Mean Deviation (mm)	Standard Deviation (mm)
X-direction	0.2539	0.0029	0.0324
Y-direction	0.3813	0.1597	0.1799
Z-direction	0.3515	0.0022	0.0355

The influence of different tool path strategies and orientation of the tool on the accuracy of the profile geometry can be compared by measuring the force and deflection in the tool. By knowing the relation between the tool stiffness and the deviation in the profile geometry, the amount of compensation required in the tool path could be estimated for obtaining the required profile with higher accuracy.

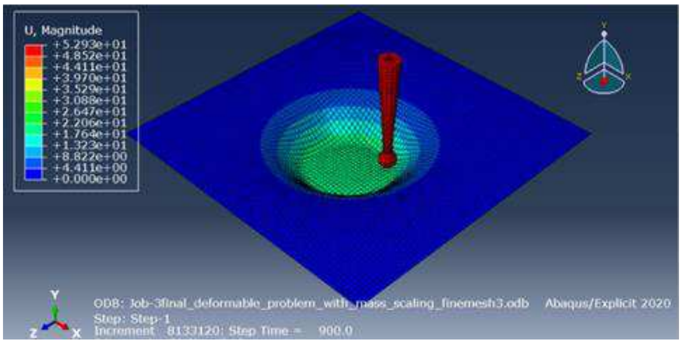

Figure 2: Deformation profile of truncated cone in SPIF process with a deformable tool.

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