ABSTRACT

Warm Incremental Sheet Forming (ISF) is an innovative manufacturing technique for producing prototypes and sheet metal parts with complex geometry. Manufacturing of sheet metal products for aerospace, automobile and biomedical applications is a challenging task, because it demands the fabrication of complex intricate structures. For products with complex part geometries the manufacturing cost of dies and punches increases, since its fabrication becomes complicated because of intricate shapes involved in it and also time taken for design and fabrication is too high. This is highly undesirable for Research and Development (R&D) and for low volume production environment. This provide the research scope for warm ISF process, where complex part geometries could be formed without use of any dies at high temperature with enhanced characteristics. Warm ISF process could be considered as a viable replacement, since it form the components by making use of single generic tool for infinite variety of shapes with great potential for short production runs of new and replacement parts. To implement the warm ISF process for manufacturing of aerospace, automobile and biomedical parts, better understanding of formability limit, geometrical accuracy, sheet thinning and forming behaviour of materials is important. The complex geometry produced by conventional manufacturing process may fail to achieve desired surface finish, geometrical accuracy and formability due to process incapabilities. Maximum achievement of geometrical accuracy and formability is possible with warm ISF process due to localized heating associated with incremental deformation technique.

Aerospace, automobile and biomedical sector focuses on innovative rapid manufacturing processes, which can enable product customization, reduction in cost and manufacturing lead time. Aerospace, automobile and biomedical industries mostly uses Titanium grade 2, Magnesium AZ31 and Aluminium 6061 alloy materials for manufacturing of products because of their lower elastic

modulus, excellent corrosion and fatigue resistance. Parts produced by conventional manufacturing processes like deep drawing, grinding, bending and forging process shows poor surface finish, geometrical accuracy and formability. These conventional processes often require additional tools like punch and die, and would not be economically viable to produce the customized structure for applications. An emerging forming technique known as warm ISF process is evolved, which is capable of forming intricate, asymmetrical components at elevated temperature with localized deformation method. As it is well known from the past research articles review, design of aerospace, automobile and biomedical components requires strong decisions about tolerances and the product has to be manufactured with careful definition of the process parameters. Hard to form materials such as Titanium grade 2, Magnesium AZ31 and Aluminium 6061 alloy used in aerospace, automobile and biomedical applications are limited to simple shapes due to manufacturing capabilities in conventional deep drawing, grinding, bending and other forming methods.

Very few research works are addressed about the mechanical forming of materials such as Titanium grade 2, Magnesium AZ31 and Aluminium 6061 alloy to produce complex profile geometry for industrial applications. Most of the researchers conducted experiments without inclusion of temperature parameter in the process, which resulted in low formability of materials, poor profile accuracy and high thickness reduction. Warm ISF is an advanced sheet metal forming technology which incorporates the effect of temperature phenomena to produce parts with desired profile geometry by increasing the formability of materials. This phenomenon suggests the need for the further investigation on warm ISF process for Titanium grade 2, Magnesium AZ31 and Aluminium 6061 alloy materials.

Few challenges are still exist in warm ISF process including the formability of materials, geometric accuracy and final thickness of parts produced. These challenges need to be further investigated for potential practical applications. In order to overcome these challenges in warm ISF process, a novel theoretical thermal model is developed and experimental investigations are performed to analyze the thermo-mechanical behavior of the materials during warm ISF process. Based on the literature review, it was concluded that conventional sheet metal forming processes are strongly controlled, new processes like warm ISF is to be improved further. Because of these reasons, it becomes important to study the influence of warm ISF process parameters and forming characteristics on Titanium grade 2, Magnesium AZ31 and Aluminium 6061 alloy materials for application in aerospace, automobile and biomedical industry which emphasizes the necessity to control process parameters for improving the accuracy and formability of materials.

This work has been divided into two important phases. In Phase I, thermal modeling and experimental investigation on the influence of process parameters on warm incremental sheet metal forming of Titanium grade 2, Magnesium AZ31 and Aluminium 6061 alloy materials using electric heating technique was studied. In Phase II, conventional ISF and warm ISF process of Ti-6Al-4V Titanium alloy for aerospace application was attempted and compared.

In Phase I, theoretical thermal model to predict the effect of temperature, material property and process parameter of warm ISF on formability was developed. Experimental investigations were carried out to compare and validate the proposed thermal model. Forming tool was designed and fabricated to incorporate electrical coils for the purpose of conducting experiments at warm temperature with the help of electric resistance heating technique. Influence of process parameters namely incremental depth, wall angle and temperature on the formability, geometrical accuracy and sheet thinning in warm ISF process were studied by forming Constant Wall Angle Conical Frustum (CWACF) component. Analysis of Variance (ANOVA) was used to identify the percentage contribution of each process parameters on the response parameters. The optimum combinations of process parameters for maximizing output responses were obtained by Taguchi method and confirmation experiments was carried out. Fractography study has been performed to analyze the fracture behavior of formed components.

In Phase II, an attempt has been made to study the feasibility of manufacturing customized Ti-6Al-4V Titanium alloy sheet using conventional ISF and warm ISF process. Aerospace component with asymmetrical curvilinear part geometry was considered and tool path for the hemispherical forming tool was generated using Mastercam software. Finite Element (FE) simulations for conventional ISF and warm ISF process were carried out using ANSYS workbench to analyze the geometric accuracy and thickness distribution of asymmetrical curvilinear part. Experimental work was carried out on a three axis Computer Numerical Control (CNC) machine to investigate the profile accuracy with consideration of thickness distribution.

Based on results obtained from Phase I, it has been found that experimental results are in good agreement with the developed theoretical thermal model. From ANOVA, it was observed that forming temperature played a significant role in formability of materials and also found that wall angle and temperature influenced geometrical accuracy. Sheet thickness reduction of the component was influenced by wall angle and incremental depth. Fractography study explained the fracture behavior of the formed components. Results of Phase II were useful for understanding the geometric accuracy and thinning effects on the parts manufactured by conventional ISF and warm ISF process. It was found that results obtained from finite element analysis and experimental works are in good agreement. It clearly shows that proposed warm ISF technique produces component with improved quality compared to conventional ISF process.

Results of proposed study provides better knowledge on the effect of process parameters on materials manufactured by warm ISF to improve the formability, geometrical accuracy and to control the sheet thinning. Outcome of this research work suggests the new forming method to produce complex structural parts with desired formability and geometrical accuracy at low cost and minimum lead time.