ABSTRACT

In recent years, the passenger and fighter jet manufactures are configuring the structure of the aircraft with strong lightweight durable materials. The selection of titanium and titanium alloys in the aerospace industry is mainly due to the exceptional properties such as high strength to density ratio and good corrosion resistance. Titanium alloys are categorized into alpha, alpha-beta and beta alloys. The alpha and beta are single phase alloys. The alpha–beta is a dual phase alloy. The addition of beta stabilizers improves the strength of titanium material. The unique property of titanium such as high temperature strength has been identified as a reason for utilization of material in extreme heat applications.

Aircraft manufactures articulated that about two-third of titanium material produced are used in aircraft engines and frames. The structure of SR-71 “Blackbird” aircraft was built with extensive use of titanium. 85% of the aircraft structure was comprised of titanium. American Society for Testing and Materials (ASTM) has recognized 31 grades of titanium and its alloys. Grade 1 to 4 is Commercially Pure (CP) titanium. Titanium grade 2 (Ti-Gr2) is preferred for its combination of properties such as excellent formability; good strength and superior corrosion resistance in industrial applications.Ti-Gr2 sheet is widely used in airframe skins, ductwork, brackets, galley equipment, heat exchangers and medical implants.

The tensile test is a primary test used to determine the mechanical properties of material used in engineering applications. The result of the tensile test is a stress strain curve. The stress strain curve provides the relation between applied stress and the resulting strain. The tensile test has low significance with respect to the point of deformation as the load is applied

relative to a single axis. In practical situations the sheets are subjected to multi-axial stress and strains.

The cupping test is a technology test to access the deformation characteristics of the material in biaxial loading condition. The indentation is produced by pressing a spherical punch against the test piece. The loading is applied until the crack appears on the surface of the test piece. The test helps to determine the maximum depth of penetration that the material can withstand before fracture which is known as Erichsen Cupping Number. Grid marking is the procedure commonly adapted for strain analysis in the sheet metal forming process. The circular patterns marked on the sheet become elliptical after forming. The longest dimension of the ellipse is the major axis and the dimension perpendicular to the major axis is the minor axis dimension. Forming Limit Diagram (FLD) is a graphical plot between major and minor strain at the onset of necking in the forming process.

Spring-back is a problem constantly faced in majority of the bending operations in sheet metal industry. The sheet metal components are bent by trial and error method to obtain the desired angle. The accuracy of the bent parts is influenced by operational parameters and the property of the material. Spring-back is a major defect confronted in the materials with high strength to density ratio like titanium. Spring-back defects are common in both U and V bent components. The factors controlling spring-back are punch radii, punch angle, sheet thickness, blank material, anisotropy, friction conditions, draw bead geometry and constitutive behaviour of the material in plastic field.

Ti-Gr2 sheet was subjected to chemical analysis by Optical Emission Spectroscopy (OES) and the material composition was obtained. The specimens for uniaxial tensile test was prepared in three different grain orientations 0°, 45° and 90° as per ASTM standard. The stress strain graph provided the mechanical properties of the material in three different orientations at 0°, 45° and 90º. The 0° grain orientation exhibited maximum yield strength and the percentage of elongation compared to 45° and 90° test specimens. The ultimate tensile strength of the sheet decreased with increase in grain orientation. It was apparent that the percentage of elongation was maximum in 0° grain orientation and fracture analysis performed by Scanning Electron Microscope (SEM) indicated localized necking and ductile fracture.

The Limiting Dome Height (LDH) test consists of a hemispherical punch used to stretch and fracture a rectangular sheet. The specimens were prepared based on the Hecker’s simplified technique. The screen-printing method was used to mark the circle grid patterns on the test specimens. The entire procedure consists of three steps (i) marking grids on the sheet specimen (ii) punch-stretching of the specimen to failure (iii) measurement of strains. Six specimens prepared as per Hecker’s method was punch-stretched until failure. The circle grid patterns assumed the shape of an ellipse after deformation. A series of five measurements on major strain and minor strain values was done in safe, necking and the fracture region of the specimen. Based on the measured values, a graph was plotted to determine the experimental Forming Limit Diagram (FLD) and Fracture Forming Limit Diagram (FFLD) of Ti-Gr2 sheet.

Bending of Ti-Gr2 sheet at room temperature results in the high spring-back. Bending is one of the plastic deformation processes in which sheet elastically recovers as the load applied on the material is removed. The spring-back behaviour of Ti-Gr2 sheets was studied using finite element method and experimentation. The process parameters considered are punch radius, die opening and sheet thickness. Taguchi (L9) orthogonal array was chosen to conduct trials in finite element method and experimentation.

The parameter levels were arrived based on trial and error experiments. The bending of V parts was performed with respect to different combination of parameters as per (L9) orthogonal array in ANSYS 12.0. The same combination of parameters was repeated to conduct experiments. The results obtained from finite element method and experiments were in good agreement .Analysis of variance was used to study the influence of process parameters on spring-back. Signal to noise ratio was the criteria used to select the best combination of parameters that minimize spring-back.

In the initial work, only minimum process parameters were considered to evaluate spring-back. It has been identified from literature survey, the effect of process parameters such as grain orientation and punch angle is not yet explored in V bending of Ti-Gr2 parts. The best parameter combination present between the optimum levels is not revealed in Taguchi method. Response Surface Methodology (RSM) was preferred in the proposed study to make use of the unique advantages of the method over Taguchi method. The individual, combination and square parameters effect on the response is inferred from the quadratic equation in RSM. Also, optimum parameters for targeted value of response is possible in RSM. Box-Behnken Design (BBD) with four parameters and three levels was planned for V bending experiments. Three parameters and three levels of BBD design was used in U bending experiments. Mathematical model was obtained in RSM based on spring-back & spring-go experimental results in V and U bending process .The predicted and the measured values were found to be in good relationship with each other. The optimum combination of process parameters which results in zero spring-back/spring-go was determined to ensure quality and geometric accuracy of bend parts in V and U bending process.