CHAPTER 1
INTRODUCTION

1.1 GENERAL

The sheet metal industry, a part of the metal forming industry, involves processes for producing small sheet metal covers up to aeronautical application (panels, wingtip, nose skins, etc.) through automobile bodybuilding (body panels, gasoline tank, etc.). Many articles are made from metal sheets which fulfill our household needs, decoration work and indispensable engineering articles whose production through other methods will be either uneconomical or involve too many complications. As a consequence, both the scientific insight and manufacturing procedures of various sheet metal forming processes have been rapidly developing. The technical-economic advantage of sheet metal forming is that it is a highly efficient process that can be used to produce complex parts with high degree of dimensional accuracy, increased mechanical properties and a good surface finish. But the limitation is that the deformation imposed on sheet metal forming process is complicated.

During the last several decades, sheet forming engineering has been developed in two directions, namely the improvement of sheet materials and reliable process design and control. Concerning materials, research has aimed at understanding the effect of material composition and behavior on the sheet formability. The design and control of sheet forming processes consist of the design of tooling (punch, die, etc.), process sequence, selection of the
proper forming process parameters (punch velocity, punch travel, lubricant, etc.) and control of the process performance. Today’s highly competitive market mandates the sheet forming industry to make major changes in its traditional product development cycle from conceptual design to production. There is a strong need to reduce the cost, shorten the development cycle and improve product quality. Therefore, the design and simulation of sheet forming processes to reduce and finally eliminate costly die tryouts are of significant economic interest.

In press-brake bending, a flat sheet is placed over a die and a punch is lowered onto the sheet to form the bend. In air bending, the required angle is produced on the workpiece by adjusting the depth to which the punch enters the die opening. This permits the punch to over bend the metal sufficiently to produce the required angle after springback. The main advantage of the air bending process is the variety of forming that can be done with a minimum number of punches and dies. It also requires less force for a given bend, thus preventing excessive strain on the press brake.

In the recent years, the trend of applying materials such as Aluminum, Interstitial Free (IF) steel, brass to automobile components has emerged due to their lightweight to strength ratio. The sheet material used in this investigation is Indian interstitial free steel owing to its excellent formability. Vacuum degassed steels containing very small amounts of titanium and niobium are known as interstitial free steels. Since these additions combine with interstitially dissolved atoms of carbon and nitrogen and form separate precipitates of TiC, TiN and NbCN, no carbon or nitrogen remains in ferrite solid solution.

In a bending process, springback is often of great concern due to its impact on the accuracy of the product. The springback is an inherent additional deformation of the material during the unloading. It is necessary to
compensate for springback by over-crowning, under-crowning, over-bending and under-bending techniques on the die surface. Numerous fundamental studies have been made over the years in an attempt to obtain a basic understanding of sheet metal bending and its springback behavior. Various investigations of springback prediction show that process parameters such as bend radius, die gap, punch velocity and material properties such as thickness, flow stress, texture and grain size have considerable influence on springback. Accurate prediction of bend force for the forming operation is vital for the design of dies and selection of appropriate bending press. Conventional predictions of springback/bend force are by trial and error method and it is expensive and laborious. The modeling of springback and bend force in bending is often needed for automation.

Several researchers have investigated the relationships between bending parameters and the developed springback/bend force. An empirical approach is more powerful for industrial applications. Consequently, multiple regression analysis (MRA), response surface methodology (RSM) and artificial neural network (ANN) approaches become attractive as they are fairly robust and in most cases rapidly converge on the target solution.

1.2 MOTIVATION

The study of bending has a wide engineering science background and a broad field of applications. In order to increase the efficiency of production and to improve the quality of product, researchers work in the field of bending such as analysis of bending process, calculation of forming load and prediction of springback. The practical aspect of this research is to provide a scientific approach to analyze the bending behaviour of sheet parts formed in air bending process. Bend force prediction is required in bending process, so as to provide a base for choosing appropriate press machines and designing dies. The springback effect is one of the major problems for
engineers to design appropriate tooling and selection of forming machine. The designing process also is complicated and die tryouts are costly. There have been diverse efforts to evaluate springback in the sheet metal forming industry for a long time. This has not been previously attempted for an IF steel sheet. Hence, the research aims at studying the bending behavior of IF steel sheet and to formulate reliable models for predicting the springback effects and bend force. Furthermore, IF steel is an emerging material that has many potential applications. The study also provides the information necessary to design the parts, processes and finally it eliminates costly tryouts. The present work is motivated by a lack of literature available on (a) effect of process parameters on the bending behavior, (b) prediction models for bend force/springback of Indian IF steel sheet and (c) simultaneous optimization.

1.3 SCOPE AND OBJECTIVE OF THIS RESEARCH

This study focuses to evaluate the effect of material orientation, tooling geometries and process parameters on the bending behavior. This would help in the design of tools/press selection in the metal forming Industry. The models could be easily implemented in the real production environment to resolve the uncertainty of springback due to variation in material and process parameters, thereby large volume of experimentation is reduced. The prediction methods require short computation time and are useful to simulate the process. The objective of this research is to conduct classical experimental study, prediction and simultaneous optimization of air bending process using IF steel sheet.

The research carried out encompasses the following objectives:

- To analyze the bending behavior of Interstitial Free (IF) steel sheet in plain and perforated conditions with respect to
orientations. This work attempts a comparative study of the several combinations of process parameters with plain and perforated sheets of different sized holes (5mm and 10mm).

- To examine the relation between springback and bend angle and bend force and bend angle of IF sheet during air bending process.

- To analyze the effect of lubrication on the air bending of interstitial free steel sheet with two different lubricants namely SAE30 oil and white grease.

- To develop a multiple regression model, response surface model and artificial neural network model for the prediction of springback and bend force.

- To compare the responses of multiple regression analysis (MRA), response surface methodology (RSM) and artificial neural network (ANN) with experimental results to prove the reliability of the models. By comparing the prediction techniques, the best model is identified.

- To carry out the simultaneous optimization with an objective of minimizing the bend force and springback effect.

1.4 ORGANIZATION OF THE THESIS

The method of approach adopted to achieve the aforementioned objectives is presented in an itinerary depicted in Figure 1.1. This dissertation consists of nine chapters. The present thesis is composed of an introduction section and four subsequent sections. The introduction section consists of literature review, fundamentals of bending and a summary of modeling techniques. All the details of research methods, results and corresponding discussions are described in the first four chapters.
STUDIES ON AIR BENDING PROCESS USING INDIAN INTERSTITIAL FREE STEEL SHEET
AIR BENDING - IF STEEL SHEET

- Classical Experimental Analysis
  - Bend force / Bend Angle / Springback
    - Plain Sheet
    - Perforated Sheet
    - Effect of Lubrication
      - Correlations with Bend Angle
        - Springback
        - Bend Force
  - Multiple Regression Analysis
  - Artificial Neural Network
    - Artifical Regression Methodology
    - Comparison / Selection
      - Analysis Effect of Parameters
    - Summary

- Prediction Systems (Springback / Bend Force)
  - Plain sheets
  - Bend Force / Springback

- Simultaneous Optimization Using Harrington’s Desirability Function

Figure 1.1 Research Scheme
The second section, comprising chapter 5, focuses on experiment works for investigating the effect of parameters in air bending of Indian interstitial free steel sheets for plain, perforated sheet, the effect of lubrication and correlation analysis. The third section, consisting of two main chapters (6 and 7), contains the prediction systems for springback and bend force through multiple regressions based on Taguchi design of experiments, response surface methodology based on central composite design and artificial neural network based on back propagation algorithm for plain sheets. The simultaneous optimization approach is addressed in the fourth section to identify the appropriate model of the process variables on response and it is concerned with chapter 8. Finally, the findings of investigation are summarized in the chapter 9.

Chapter 1 is the introduction which provides an overall view on the motivation and objectives of the thesis. Chapter 2 provides a literature review of sheet bending operations and facilitates the reading and understanding of the thesis. It contains the pertinent work on the subject, the techniques adapted in treating the different classes of problems and the limitations and difficulties encountered. Chapter 3 presents the fundamentals of air bending, springback effect, bend force and anisotropy. It serves as a base to perform the experimental investigations. Chapter 4 deals with summary of modeling techniques and it provides mathematical description to assist prediction of responses.

Chapter 5 is meant for classical experimental investigations. Chapter section 5.2 deals with the effect of material orientation of IF sheets during the process. Chapter section 5.3 emphasizes the effects of process variables on bending with plain sheets. Chapter section 5.4 is devoted to the study of perforated sheets. Chapter section 5.5 is concerned with the effect of lubrication on bending. Chapter section 5.6 examines the relationship between
springback and bend angle, bend force and bend angle and comparison with general equations.

Chapter 6 is devoted for modeling and analysis. In this chapter, springback prediction resulting from using modeling technique is investigated. The prediction starts in Chapter section 6.3 with MRA approach of the models. Chapter section 6.4 describes response surface methodology. The ANN models are described in Chapter section 6.5. Chapter section 6.6 addresses the comparison and selection of models. Within the context of this study, MRA, RSM and ANN models are considered and compared with each other for accuracy and efficiency.

The modeling and analysis of bend force are presented in Chapter 7. In Chapter section 7.3 the models for bend force are analysed. Chapter section 7.4 deals with the RSM.

Chapter 8 is dedicated to simultaneous optimization approach of process variables. The optimization approach and the contribution of variables to response of bending are treated in Chapter section 8.2. Chapter section 8.4 deals with the analysis of the simultaneous optimization that is very useful for parameter selection purpose. Process parameter optimization using RSM is elaborated upon in Chapter section 8.5. Finally, Chapter 9 provides a summary of the research and recommendations for future work.