1.1 GENERAL

In various manufacturing processes, sheet metal forming occupies a special place because it produces parts of superior mechanical properties with minimum waste of material in a very short time. High material utilisation, precise manufacture and easy to realise automation are the characteristics of sheet metal forming. The sheet metal products have a very wide range of applications such as aeronautical (panels, nose skins, etc.), automotive (body panels, gasoline tanks, etc.), electrical (casings, switch boxes, etc.), household appliances (kitchenware, washing machines, etc.) and building (roofs, sanitary products, etc.). In the past years, sheet forming engineering has grown with the advent of new materials, processes and control techniques.

The sheet forming behaviour is influenced by material properties, tool and process parameters in a complex fashion. The appropriate knowledge of material behaviour, process parameter design, tool design and specific issues related to advances in material and forming technology is essential for successfully controlling and improving a process to produce a better product. Hence, it becomes essential to study the process scientifically to fulfill this
requirement. Today, in the sheet forming industry, like any other, there is a strong need for reduction in cost, improvement in product quality and shortening of the duration of the development cycle to meet out the competitive market. Consequently, the computer aided design and simulation of sheet forming processes which reduces or eliminates time consuming, resource intensive and costly tryouts becomes a research interest. The researchers employing different methodologies such as experimental work, finite element analysis, analytical modelling and empirical modelling to study the various facets of sheet metal forming processes have been continuing for the past four decades.

Bending is a widely used sheet metal forming process in which a force is applied to a sheet metal blank, causing it to bend at an angle and form the desired shape. During bending, the metal is deformed plastically along a straight line to change its shape. Bending is performed in a press brake by lowering the punch to a required depth on a flat sheet over a die. In small-batch-part sheet metal manufacturing, a bending process that is flexible, effective and efficient is required to meet the higher accuracy demands and shorter lead time. In such an environment, air bending is more flexible (de Vin 2000) than its counterpart, closed die bending. Closed die bending requires a different tool set for every type of bend. Air bending allows forming of sheet metals with a great variety of bending angles by solely adjusting the punch travel into the die without tool changes, as opposed to closed die bending. This makes the air bending process versatile for use in a variety of components, material types and sheet thickness. Since the forces required to form the bends are relatively small, the excessive strain on the press brake is prevented in this process.
In automotive and other fabrication industries, there is a wide use of steel sheets for manufacturing various parts, but the susceptibility to corrosion is a natural weakness of steel products. The necessity to protect the steel products from corrosion has demanded the widespread use of coated steels instead of uncoated ones. The most frequently used coating material is zinc. The zinc coated steels are known as galvanised steels including hot dipped and electrogalvanised (EG) steels. Besides corrosion resistance, the coated sheet steels must also satisfy other requirements such as formability and surface quality. As EG steel sheets have better formability (Jiang et al 2004) and surface finish, they are much preferred as a substitute for uncoated cold rolled steel sheets in automotive and other industries.

During bending, when the bending stress is removed at the end of the deformation process, elastic energy remains in the bent part causing it to partially recover its original shape. This elastic recovery is called springback. Springback can not be completely eliminated but can be minimised using suitable die designs (Garcia-Romeu et al 2007). The information on springback is essentially needed for a designer to provide allowances in die design and for process control to produce accurate bends. Another important factor to be considered in the design of tooling and selection of press brake is bend force. Bend force is the force needed to deform the sheet metal part to the required shape. The material geometry and properties, tooling geometry and process parameters have considerable influence on springback and bend force. For a number of years several researchers have investigated to study the springback and bend force in various bending processes. In the recent years, air bending has received the
research interest as the process has been recognised as a complex one (de Vin 2001) to be studied. Therefore, the features of air bending and the effect of various parameters on springback and bend force must be understood to achieve high quality fabrications. The prediction of springback and bend force is vital for optimal designing of tooling and process design in sheet metal bending. Traditional trial and error methods are time consuming and expensive, while the development of theoretical models for springback/bend force are difficult and cumbersome due to the complexity of sheet bending process. Consequently, the empirical modelling techniques namely, the response surface methodology (RSM) and artificial neural network (ANN) become promising tools for the prediction of springback and bend force because of their robustness and accuracy.

1.2 NEED FOR THE RESEARCH

Air bending is a commonly used sheet metal bending process in automotive and fabrication industries. Many researchers have attempted to study the bending behaviour of various sheet metals in air bending process. This research work aims at studying the effect of various processing parameters on bending behaviour of the EG steel sheets formed in air bending process. The two important technical problems in the bending process are prediction of springback and bend force (Farsi et al 2011). Insufficient allowance for springback often causes tolerance error in the formed component and this may generate problems during assembling or installation. Springback prediction is essential for proper tool design to produce sheet metal parts within acceptable tolerance limits. The prediction of bend force is needed to select the press for a given bending operation. This research work has been extended to develop effective and precise
prediction models for springback and bend force in air bending of electrogalvanised steel sheets. The present work is motivated as (a) the effect of processing parameters on springback and bend force and (b) the prediction models for springback and bend force of the EG steel sheet in the air bending process have not been satisfactorily attempted by the previous researchers.

1.3 OBJECTIVE AND SCHEME OF THE RESEARCH

The main objective of the present study is to evaluate the effect of the material, tooling and process parameters on springback and bend force of EG steel sheets during forming using an air bending process. This would be essential for understanding and controlling the process in a better fashion. The work also deals with the development of models to predict the springback and bend force. These prediction models can be easily implemented in a real manufacturing environment for improving the productivity and quality of the product.

The present research comprises the following specific objectives:

i. To analyse the effect of parameters on springback and bend force of EG steel sheets in an air bending process. The parameters considered in the study are coating thickness, orientation of the sheet, die opening, die radius, punch radius and punch velocity.
ii. To examine the effect of lubrication on springback and bend force. The parameters considered in the investigation are type of lubricant, surface roughness of the sheet, die radius and punch velocity.

iii. To develop response surface models and an artificial neural network model for the prediction of springback and bend force.

iv. To assess the accuracy of the models by comparing the responses of the predictive models with experimental results.

v. To compare the predictive models and identify a better model.

The scheme adopted to accomplish the objectives is presented in an itinerary diagram shown in Figure 1.1.

1.4 ORGANISATION OF THE THESIS

This thesis comprises of eight chapters. Chapter 1 introduces the background of the thesis and provides the motivation and objectives of the thesis. In Chapter 2, a detailed literature review relevant to the field of air bending and springback/bend force is presented. The contributions of various researchers on experimental methods and modelling techniques and the limitations of their research works are discussed. In Chapter 3, the theme of the research, the methodology adopted in the research and scope of this research are described. Chapter 4 deals with the fundamentals of a bending process which gives a basic idea about press brake forming, mechanism of springback and bend force for understanding the thesis. Chapter 5 details the experimental work comprising the material study, material preparation, experimental setup, measuring techniques
EXPERIMENTAL STUDIES AND MODELLING OF AIR BENDING PROCESS OF ELECTROGALVANISED STEEL SHEETS

Literature Review

Springback / Bend force

Experimental Analysis

Development of Prediction Models

Material Properties
Coating Thickness
Orientation
Tooling Parameters
Punch Radius
Die Opening
Die Radius
Process Parameters
Punch Travel
Punch Velocity
Lubrication

RSM
Validation
Comparison

ANN
Validation

Conclusions

Figure 1.1 Research Scheme
and discusses the effect of various parameters on springback and bend force from the results obtained. Chapter 6 describes the development and analysis of models on springback and bend force using the response surface methodology. These models are validated with experimental results. In Chapter 7, the development of an artificial neural network model is narrated and the accuracy of the model is evaluated by comparing its results with experimental results. A comparison is made between the ANN and RSM models for their prediction accuracy. Chapter 8 provides the conclusions of the research and recommendations for future work.

1.5 CONCLUSION

In this chapter, the need for this research was discussed in detail and the objectives of this research were provided. The overview of the research work was briefly explained. The detailed literature survey was presented in the next chapter.