CHAPTER 9

GENERAL SUMMARY

This thesis studied the air bending process to investigate how the bend force, springback and bend angle change with forming parameters and material properties in the classical experimental investigation using interstitial free steel sheet. Further, the attention is given to the modeling of springback and bend force by MRA, RSM and ANN. The results obtained in the research work conclude the followings:

- Orientation influences the bend force, bend angle and springback significantly. The bend force was observed higher in 90° orientation than in 45° and 0° orientations. It was found that the bend angle is larger for 45° samples than for 90° and 0°. It was observed that 0° sample experiences larger springback than 45° and 90° samples.

- The experimental springback findings for the IF steel sheet are also compared with that of material model. The standard deviations between the experimental springback and material model springback are noted to be large. The springback variation is a strong function of the process parameters in larger curvature bending.

- Punch travel, punch radius and punch velocity affect the bend force, bend angle and springback. The bend force increases with the increase in punch travel, punch radius, punch velocity
and the width of the sheet, irrespective of material orientations.

- Increasing punch travel, punch radius, punch velocity and decreasing width of the sheet increase bend angle irrespective of material orientations.

- Springback varies inversely with punch radius, width of the sheet and directly with punch travel and punch velocity, irrespective of material orientations.

- Experimental results show that the perforated sheet reduces the bend force compared with plain IF sheet, irrespective of orientations. Bend angle behavior is similar for plain and perforated sheets. But the bend angle for a particular punch travel is more for perforated than plain sheet. The springback value of perforated sheet is greater than the plain IF sheet.

- Effectiveness of lubrication has been experimentally carried out. Lubrication on punch and die effectively reduces bend force. So lubrication method is an influencing parameter to reduce the bend force. The springback value varies significantly with respect to lubrication when compared to those tested under dry conditions and hence it is the most considerable factor governing the magnitude of the springback. Moreover, better surface finish is obtained.

- A greater discrepancy between SAE30 oil lubricant and white grease lubricant on the bending is observed. The lubricant SAE30 oil showed better results than grease in the bend force analysis. For this lubricant, force required to deform is found to be low and this shows that friction between workpiece and tool is less. Lubrication increases the bend angle for all cases.
studied. The application of these lubricants increases the springback significantly. The experimental results show that the lubricant selection is an important issue in developing a successful air bending operation.

- Based on curve fitting techniques, \( S_{r1} = aB^c \) (power law relation) for springback and \( F_{r4} = aB^2 + bB + c \) (polynomial relation) for bend force are proposed for prediction.

- MRA, RSM and ANN can be used in the prediction of bend force and springback. The models are able to provide information necessary for engineers to design the processes and dies, by a more efficient and optimum strategy. The prediction systems minimize the experimental try out and wastage of time, which in turn, improves the production and reduces the lead time.

- Simulation results were compared with measurements. Comparison of MRA, RSM and ANN performances in the prediction problems concludes that the ANN yields better results than MRA and RSM. The overall performance of the ANN approach presented in this research work is found to be superior to that of RSM.

- From RSM analysis, it is revealed that punch travel exerts the strongest influence on springback, whilst punch velocity has a secondary effect.

- From RSM analysis, it is known that the punch travel is the dominant factor determining the bend force followed by punch velocity and punch radius. The interactions effect of punch travel and punch radius are considerably significant.
• It is suggested that the multiobjective simultaneous optimization technique based on desirability function is quite useful for optimizing bend force and springback.

**FUTURE SCOPE**

There are a number of issues needing to be addressed for further investigation. These are suggested as worthy for future research and they are as follows.

• Further research is required to assess the bend allowance, residual stress and punch travel. These issues have not been well addressed and investigated either by industrial practitioners or by research communities. It is hence worthwhile to analyse such responses.

• Bauchinger effect has important consequences in metal forming applications. The Bauchinger effect on springback depends not only on the material type but also on the deformation history in the strain space. To improve the prediction of springback, the Bauchinger effect can be considered.

• Analysis on larger curvature bending can be extended for other materials such as HSLA, TRIP and non-ferrous materials.

• Newer modeling techniques (new design, approach etc.) can be used to predict and analyse the effect of various parameters on the springback/bend force. A hybrid approach can provide
more process information than that provided by a general modeling approach.

- Development of optimization algorithm in order to control springback and bend force by adjusting the weight function in ANN can be implemented for enhancing the predictability. There is a possibility for increasing accuracy of the network by increasing the hidden layer and the number of training data.

- RSM, MRA and ANN are used for prediction of springback and bend force, which have been carried out. Similar studies can be performed for other responses in bending like bend allowance, punch travel and residual stress etc.