

**PREDICTION OF BENDING PROPERTY OF WOVEN FABRICS USING
COMPUTATIONAL MODELLING TECHNIQUES**

by

GURUPRASAD R.

Department of Textile Technology

Submitted in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JUNE, 2011

Dedicated
To
My Parents

CERTIFICATE

This is to certify that the thesis entitled “Prediction of bending property of woven fabrics using computational modelling techniques” being submitted by Mr. R. Guruprasad to the Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy is a record of bona fide research work carried out by him. Mr. R. Guruprasad has worked under my guidance and supervision and fulfilled the requirements for submission of the thesis. The results contained in thesis have not been submitted, in part or full, to any other university for the award of any degree or diploma.

Prof. B. K. Behera

Department of Textile Technology

Indian Institute of Technology Delhi

New Delhi - 110016

ACKNOWLEDGEMENTS

I wish to express my deep regards and profound sense of gratitude to my research supervisor, Prof. B. K. Behera for his inspiring guidance, motivation and support. Without his encouragement and help, it would have been impossible for me to complete this research work in time.

I wish to express my sincere thanks to research committee members, Prof. R. S. Rengasamy, Prof. V. K. Kothari, and Dr. B. P. Patel for their valuable suggestions and constructive criticism at different stages during the course of this research work.

I would like to thank the head of textile department, Prof. Kushal Sen, for providing all necessary facilities to do my research work and also for allowing me to work in the laboratory after official working hours. I also wish to thank ex-Heads of department, Prof. S. M. Ishtiaque and Prof. P. K. Banerjee for their encouragement and support.

I wish to thank lab staff members, Mr. Biswal, Mr. Kundu, Mr. Passi and Mr. Jagdish for their help and guidance in handling laboratory machines & instruments.

I am grateful to M/s Vardhman textiles Ltd., for permitting me to visit their spinning facility and to get yarn samples manufactured in their plant. I wish to thank M/s Sarla fabrics Pvt. Ltd. for their help in procurement of grey cotton fabrics. I owe my thanks to M/s Rossari Biotech for providing the chemicals needed for cotton desizing.

During this work, I have collaborated with many colleagues for whom I have great regard, and I wish to extend my thanks to all those who have helped me with my work. Special thanks are due to my friends Mr. Vijay yadav, Mr. Biswaranjan Das, Dr. Ajit pattanayak, Dr. Kaushik Bal, Dr. Mukesh kumar, Dr. G.V.R. Reddy, Dr. Naveen Padaki, Dr. Brojeswari Das,

Dr. A. Ramesh, Mr. P. Packiam, Mr. B.P. Dash, Mr. J.P. Singh, Mr. Samuel, Mr. Ashwin,
Mr. Harshvardhan, Mr. Vinod, Ms. Renuka and Mr. Vijay sekar.

Last, but not the least, I wish to thank my parents, brother and sister for their understanding,
patience, love and care.

Date:

R. Guruprasad

Place:

Abstract

Bending rigidity is one of the most important properties of fabrics and is a key component in deciding fabric handle and drape. It is an important contributor to fabric's formability, buckling behaviour, wrinkle-resistance and crease resistance. The bending behaviour of woven fabrics has been studied quite extensively over the years, but quantitative prediction of this property is still an issue that needs to be addressed to achieve the goal of design engineering of fabrics. An accurate modelling of the bending behaviour of fabric using the conventional analytical solutions requires rigorous mathematical procedures that are difficult to achieve from the pragmatic view point. Most available methods for prediction incorporate several assumptions to simplify the problem and to make it amenable to solution, which in turn, affects the modelling accuracy. The application of modern approach, therefore, was found necessary to solve this problem. The main objective of this dissertation work was to quantitatively predict the bending property of cotton woven fabrics using various computational modelling techniques. The application of number of soft computing techniques and the computer simulation using finite element method have been explored in this research.

A detailed literature review has been carried out to understand the potential and limitations of various prediction methodologies. Gaps in knowledge have been identified and some of the inconsistencies in application of methodologies have been noted. As a preliminary study, a set of cotton fabrics was manufactured and tested for bending properties. This exercise has been done to understand the nature of relationships that exist between various structural factors and the bending characteristics of woven fabrics. From the review on literature and the preliminary experimentation, input parameters for the prediction models have been selected.

The application of artificial neural network modelling for the prediction of bending property was first explored. Models were developed using independent and dependent fabric structural variables. In the first model, bending rigidity in warp and weft directions were predicted from the independent fabric construction variables, namely end density, pick density, warp count, weft count, warp twist factor, weft twist factor and weave design. A feedforward neural network architecture with a single hidden layer was formed and trained with backpropagation learning rule. On completion of training, the generalisation performance was tested using an independent test set. A sensitivity analysis was also carried out to investigate the robustness of the developed model. In the second model, three important fabric variables namely, fabric weight, fabric thickness and fabric cover have been used to predict the overall bending rigidity of the fabrics. The prediction performance was ascertained using an independent test set, followed by sensitivity analysis. As the knowledge of the network is contained in the network weights, a connection weight approach was employed to understand and rank the variable contributions in predicting the output.

In an attempt to improve the prediction results of Neural network model (BPNN), a hybrid modelling strategy has been attempted using genetic algorithms. The input-output parameters of second model have been considered for GA modelling. Genetic algorithm was used as a search tool to optimize the neurons and weight values of the backpropagation network. With GA finding the optimum zone in the search space, backpropagation learning was employed as a local search to reach global minimum.

Another hybrid strategy attempted for prediction was Adaptive neuro-fuzzy inference system (ANFIS). ANFIS uses a hybrid learning rule to model the relationships. Gaussian, Trapezoidal, triangular and generalised bell shaped functions have been applied. Neural network tunes the membership functions in such a way that the inputs were mapped to output.

Optimization results showed that G-bell membership function with [2 2 2] combination for each input gives satisfactory results.

The comparison of Backpropagation Neural network model (BPNN), GA based backpropagation model (GANN) and adaptive neuro-fuzzy (ANFIS) models based on their prediction performance showed that the performance of Neuro-Genetic model was better in comparison to other two models. All three models rank the contribution of input variables in the following order: 1. Fabric weight 2. Fabric thickness 3. Fabric cover.

The use of finite element analysis to predict the bending characteristics of woven fabrics has also been explored. The simulation of cantilever bending test has been attempted using nylon and cotton fabrics. Material isotropy was assumed in case of nylon fabric whereas orthotropic behaviour was assumed for a set of cotton fabrics. Geometric nonlinearity was accounted in the analysis. A parametric study was carried out to understand the importance of Poisson's ratio on fabric displacement during bending. The numerical technique of Finite element analysis shows some promising results. Parametric study showed that Poisson's ratio has a significant effect on output.

Contents

	Page no.
Certificate	i
Acknowledgements	ii
Abstract	iv
Table of Contents	vii
List of Figures	xiv
List of Tables	xviii
Chapter 1 Introduction & Objectives	1
1.1 Introduction	1
1.2 Objectives	5
Chapter 2 Literature Review	6
2.1 Introduction	6
2.2 Yarn bending behaviour	7
2.3 Fabric bending behaviour	9
2.3.1 Introduction	9
2.3.2 Measurement of fabric bending	10
2.3.2.1 FAST bending tester	10
2.3.2.2 KES bending tester	10
2.3.2.3 Other methods of testing	11
2.3.3 Moment -Curvature behaviour	13
2.3.4 Effect of fabric set	15
2.4 Modelling the bending behaviour of woven fabrics	15
2.4.1 Geometrical modelling of woven fabrics	15

2.4.2	Models on Bending behaviour of woven fabrics	17
2.4.3	Models for predicting bending anisotropy	19
2.5	Design engineering of fabrics	21
2.6	Low stress mechanical properties	21
2.7	Prediction modelling of woven fabric properties	22
2.7.1	Finite element modelling	22
2.7.2	FEM application to study of woven fabric mechanical properties	24
2.7.3	Soft computing models	25
2.7.4	Neural networks	26
2.7.4.1	Artificial Neuron	27
2.7.4.2	Activation functions	28
2.7.4.3	Network architectures	32
2.7.4.4	Learning in Neural networks	33
2.7.5	Application of ANNs to the study of woven fabrics	34
2.7.6	Fuzzy logic	37
2.7.7	Fuzzy logic application to study of woven fabrics	39
2.7.8	Genetic Algorithms	40
2.7.9	Genetic Algorithm application to the study of woven fabrics	43
2.7.10	Hybrid methods	43
2.7.11	Hybrid Modelling Applications to the study of woven fabrics	45
2.8	Strengths and Limitations of soft computing methods	45
2.8.1	Artificial Neural Networks	45
2.8.2	Fuzzy logic	46
2.8.3	Genetic algorithms	47

Chapter 3	Materials and methods	48
3.1	Introduction	48
3.2	Materials	48
3.3	Methods	48
3.3.1	Fabric treatments	48
3.3.2	Testing of fabric properties	50
3.3.3	Prediction methodologies	52
Chapter 4	Studies on the effect of some structural variables on bending behaviour of woven fabrics	53
4.1	Introduction	53
4.2	Materials & Methods	53
4.2.1	Fabric production and treatments	54
4.2.1.1	Fabric production	54
4.2.1.2	Chemical treatments	55
4.2.2	Testing of fabric properties	56
4.2.3	Bending anisotropy	60
4.3	Results and Discussion	61
4.3.1	Effect of Pick density on Bending rigidity	61
4.3.2	Effect of weight, cover and thickness	61
4.3.3	Pure bending test vs. Cantilever test	64
4.3.4	Bending rigidity and Bending hysteresis	64
4.4	Conclusions	65

Chapter 5	ANN modelling for predicting the bending rigidity of woven fabrics	66
5.1	Introduction	66
5.2	Correlation analysis	66
5.3	Modelling using artificial neural networks	68
5.3.1	Introduction	68
5.3.2	Neural network architecture	68
5.3.3	Derivation of Backpropagation algorithm	71
5.3.3.1	Momentum gradient algorithm	74
5.4	Model 1: ANN model using independent fabric structural variables	75
5.4.1	Model Inputs and Outputs	75
5.4.2	Data Division and Preprocessing	75
5.4.3	Feed forward Network	75
5.4.4	Number of Hidden layers	76
5.4.5	Activation functions	76
5.4.6	Learning algorithm	77
5.4.7	Adaptive Learning rate and Momentum	78
5.4.8	Number of hidden nodes	79
5.4.9	Stopping criterion	79
5.4.10	Results and Discussion	80
5.4.10.1	Training Results of Model	80
5.4.10.2	Prediction Performance of Model	81
5.4.10.3	Sensitivity Analysis	83

5.5	Model 2: Neural network model using dependent fabric structural variables	85
5.5.1	Introduction	85
5.5.2	Material selection	85
5.5.3	Model Inputs and Outputs	85
5.5.4	Data Division and Preprocessing	85
5.5.5	Model architecture, optimization and stopping Criterion	86
5.5.6	Results and Discussion	87
	5.5.6.1 Sensitivity analysis	89
	5.5.6.2 Connection weight approach	89
5.6	Conclusions	91
Chapter 6	Neuro-genetic modelling for prediction of bending rigidity	92
6.1	Introduction	92
6.2	Genetic algorithm based solution approach	93
6.2.1	Roulette wheel selection	95
6.2.2	Crossover and Mutation	95
6.2.3	Operational summary of GA	97
6.3	Neuro-Genetic Modelling (GA based backpropagation model)	97
6.3.1	Materials	97
6.3.2	Model inputs and Output	98
6.3.3	Data division and Preprocessing	98
6.3.4	Modelling with Genetic algorithms	98
	6.3.4.1 GA optimization	99
6.3.5	Local search using Backpropagation	102

6.4	Results and Discussion	103
6.4.1	Sensitivity analysis	105
6.4.2	Connection weight approach	107
6.5	Conclusions	107
Chapter 7	Neuro-fuzzy modelling for prediction of bending rigidity and comparison of soft computing models	109
7.1	Introduction	109
7.2	ANFIS	109
7.3	Modelling with ANFIS (Neuro-fuzzy)	112
7.3.1	Structure Identification	112
7.3.1.1.	Selection of inputs, training and testing data	113
7.3.1.2.	Generation of the initial FIS	113
7.3.2	Parameter Identification	115
7.4	Results and Discussion	115
7.4.1	Prediction performance	117
7.4.2	Sensitivity analysis	118
7.5	Conclusions	119
7.6	Comparison of Neural, Neuro-genetic, and Neuro-fuzzy models	120
7.6.1	Introduction	120
7.6.2	Training performance of models	121
7.6.3	Generalisation performance	122
7.6.4	Sensitivity analysis	123
7.6.5	Connection weight approach	124
7.6.6	Conclusions	125

Chapter 8	Finite element modelling of bending characteristics of fabrics	127
8.1	Introduction	127
8.2	Fabric bending	127
8.3	Finite element method	128
8.4	Shell element	130
8.5	Application of FEM analysis to Cantilever fabric bending	131
8.5.1	The Cantilever bending test	131
8.5.2	Case 1: Nylon fabric	132
8.5.2.1	FEM implementation	133
8.5.2.2	Convergence study	136
8.5.3	Case 2: Cotton fabrics	136
8.5.3.1	FEM implementation	137
8.5.4	Results and Discussion	138
8.5.4.1	Effect of Poisson's ratio on fabric displacement	138
8.6	Conclusions	139
Chapter 9	Summary & Conclusions	141
9.1	Scope for future work	145
	References	146
	Appendices	161
	List of publications	166
	Bio-Data	167