# DETERMINATION OF MECHANICAL PROPERTIES OF MATERIALS USING NEWLY DEVELOPED DUMB-BELL SHAPED MINIATURE SPECIMEN AND NUMERICAL TECHNIQUES

by

**G. PARTHEEPAN**

**Department of Applied Mechanics**

Submitted in fulfillment of the
requirements of the degree of

**Doctor of Philosophy**

to the

**Indian Institute of Technology, Delhi**

**Hauz Khas, New Delhi 110 016, India**

**January, 2006**

[illegible]

Machine Components [illegible] Properties

TH
621.7
PAR-D

I. I. T. [illegible]
LIBRARY
Acc. No TH-3297

I.I.T. DELHI
PROCESSED
LIBRARY

# CERTIFICATE

This is to certify that the thesis entitled **Determination of Mechanical Properties of Materials Using Newly Developed Dumb-bell Shaped Miniature Specimen and Numerical Techniques** being submitted by **G. Partheepan** to the **Indian Institute of Technology Delhi, New Delhi (India)** for the award of the degree of Doctor of Philosophy in Applied Mechanics Department is a bonafide research work carried out by him under our supervision and guidance. The research reports and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma.

Dr. D. K. Sehgal
Professor
Department of Applied Mechanics
Indian Institute of Technology Delhi
New Delhi – 110 016

Dr. R. K. Pandey
Professor
Department of Applied Mechanics
Indian Institute of Technology Delhi
New Delhi – 110 016

## ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Prof. D. K. Sehgal for his valuable guidance, interest, constant support, encouragement, and immense patience that inspired me to work smoothly in completion of the thesis. I am very thankful to him for being always available to me for any kind of help in carrying out this research work. His deep knowledge in the field and fruitful discussions brought many ideas in carrying out my research in this very attractive field. He supported me in every possible way without which this thesis could not be in its present form.

I am extremely grateful and indebted to Prof. R. K. Pandey for his valuable guidance, suggestions in successfully carrying out this research work. His expertise in the field and useful practical tips at various stages of the work have helped in completing the thesis timely. His kind cooperation and constant encouragements are the sources of inspiration in doing the work. Without his help the thesis would not be in the present form.

Special thanks are due to Prof. R. K. Mittal and Prof. Suhail Ahmed for being part of my thesis committee. Their questions during my comprehensive and synopsis presentations significantly helped to improve my thought process.

I am deeply indebted to Prof. P. V. Krishnan for his genuine guidance and encouragement. Whenever I met him he asked about my progress in research and welfare, which gave me lot of impetus to do the work. He also encouraged me to be respectful to my supervisors and responsible in my work. I am grateful to both Dr. and Mrs. Krishnan for their loving guidance and support in all walks of my life which made my stay at IIT memorable one. Their personal living example has provided me an unfailing direction to use my education in the service of humanity at large.

Thanks are due to Dr. Shriram Hegde, Mr. Kailash Chand, and Mr. V. S. Rawat for the cooperation extended by them when I was in need.

My special thanks are due to Mr. B. S. Rana, Mr. Rishi P. Dagar, Mr. Prem Chand, Mr. Anil and Mr. Prem Singh for all their help and cooperation during the experimental work in the thesis.

I also wish to thank Mr. D. C. Sharma and Mr. Madan Gopal of Applied Mechanics departmental workshop and the staff of IDDC for the timely help in specimen preparation for the experimental work.

I acknowledge my thanks to Dr. A. Husain, Dr. S. K. Singh, Mr. M. N. Deshmukh, Mr. S. Senthil for their encouragements and discussions in the course of my research work. My special thanks to my friends Dr. R. Kumar, Dr. Ram. Narayan, Dr. Vidyanand, Mr. Ramana Murthy, Mr. Pankaj, Mr. Siddharth Khaitan, Mr. Anurag, Mr. Gauri Shankar, Mr. Ravi Kumar, Mr. K. Satyanarayana, Mr. Naveen Kishore, Mr. Prabhu and many others whose names are not mentioned here but made my stay in IIT very blissful in my heart. I also acknowledge the help and assistance given to me by all others whom I am unable to mention here individually.

I take this opportunity to thank my mother, elder brother and his family, younger brothers and sister for completely relieving me from my responsibilities towards the family. This greatly helped me to concentrate on my research work.

G. Partheepan.

# ABSTRACT

With rapid industrialization in the last century, a significant number of plants and structures in the present day industries have already served or are nearing their designed lifetime. The cost of replacing them with a new infrastructure would require prohibitively large sums of capital investment. However if by suitable assessment, their life could be extended without sacrificing safety and without additional huge capital investments, it will be of great importance. Determination of mechanical properties of operating components is a key element in defining the strategies for maintenance and repair for extending component life. The assessment of the present health and an estimate of the remaining life have to be done without disturbing the structural integrity and functional capabilities of the plant components. In most cases, components integrity is hardly evaluated with traditional and standard mechanical testing methods because the amount of materials required for standard size test specimens cannot be taken without destroying the components. The miniature specimen test technology provides a way of obtaining mechanical properties of the components present in aged structures while consuming a very small amount of material as compared to that required for standard size test specimens.

In the present work, a simple miniature specimen test setup is designed and used for the prediction of material properties with the help of a newly designed and prepared miniature dumb-bell shaped specimen. A

special type of miniature specimen holder is designed to hold the miniature test specimen. It can accommodate different thicknesses of specimens. The loading in miniature testing is of tensile nature. The miniature specimen experiences tensile load through the loading pin which holds the specimen in a specimen holder. The extension of the specimen upon tensile load is measured by an extensometer. This complete setup can conveniently be used in any universal testing machine.

Experimental study of miniature tension test on dumb-bell shaped miniature specimen is carried out using the setup described above. The experimental study also covers the details of (i) selection of test materials (ii) design and fabrication of the miniature specimen (iii) testing machine (iv) procedure for carrying out the miniature specimen test and (v) data acquisition. The designed miniature dumb-bell shaped specimen is of 0.50 mm in thickness. All the tests are conducted on Zwick universal testing machine at room temperature. The output from the miniature test in the form of load – elongation diagram is recorded. A new empirical correlation for the estimation of yield strength has been proposed from the present work Experimental determination of uniaxial tensile properties as well as fracture toughness values for all the selected materials using the ASTM standards are also reported. These standard tests are used as a "bench mark" or a "reference test".

The finite element simulation of miniature test is conducted to obtain the mechanical behaviour of materials. The miniature specimen geometry along with the loading pins are modeled using the commercially available finite element based software "ABAQUS". The simulation is carried out using implicit code. The study also contains the detailed description of steps involved in modeling and analysis of the results. The miniature specimen is modeled in two dimensional space as a deformable body and the loading pins are modeled as rigid bodies. The miniature specimen is modeled using quadrilateral plane stress elements. Simulation of miniature test is carried out in such a way that it represents the experimental situation as closely as possible by prescribing the appropriate boundary conditions. The load – elongation diagrams from finite element simulation for different materials are obtained and compared with the experimental results. A wide spectrum of information can be collected from the finite element simulation of miniature specimen test. This includes the deformation behaviour of miniature specimen, load – elongation curve, von-Mises stress contour, equivalent plastic strain etc.

An inverse finite element study has been conducted using the experimental output from the miniature test on the designed miniature specimen. The developed inverse finite element procedure helps in finding the constitutive behaviour of the unknown material in combination with miniature specimen test. The initial slope of the experimental load – elongation curve from the miniature test is used to predict the Young's modulus of the material. The entire load – elongation curve is discretized into a number of linear parts. The details of finding the true stress – true plastic strain behaviour of the material using inverse finite element procedure and the load – elongation curve are presented. The results from the inverse finite element procedure are compared with the results obtained from uniaxial tensile test. This inverse finite element procedure is applied to all the selected materials. The empirical correlations for the prediction of fracture strain and fracture toughness are also included. The proposed empirical correlation for the determination of fracture toughness is compared with the existing empirical correlations from the literature as well as the standard fracture toughness test results.

Presently the Artificial Neural Network (ANN) technique is being applied to an increasing number of real-world problems of considerable complexity. It offers reliable solutions to a variety of problems (viz. prediction and modeling), where the physical processes are not understood or are highly complex. A comparison is made between several training algorithms in an attempt to find an ideal artificial neural network-training algorithm to predict the material properties from the miniature test. This model uses a feed forward back prorogation neural network. After using the experimental results to train and test the network, the model is applied to new data for prediction of material properties. The values of fracture toughness obtained by ANN technique are compared against the standard values and the results are found to be promising.

# TABLE OF CONTENTS