DETERMINATION OF MECHANICAL BEHAVIOR OF MATERIALS USING MINIATURE SPECIMEN TEST TECHNIQUE AND FINITE ELEMENT METHOD

by

ASIF HUSAIN

Department of Applied Mechanics

Submitted in fulfillment of the
requirement of the degree of

Doctor of Philosophy

to the

Indian Institute of Technology, Delhi

Hauz Khas, New Delhi 110 016, India

March, 2003

CERTIFICATE

This is to certify that the thesis entitled '**Determination of Mechanical Behavior of Materials Using Miniature Specimen Test Technique And Finite Element Method**' being submitted *Mr. Asif Husain* to the **Indian Institute of Technology, Delhi** for the award of the Degree of Doctor of Philosophy is a record of bonafide research work carried out by him. *Mr. Asif Husain* has worked under my supervision and guidance and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard for the Doctor of Philosophy Degree.

The results contained in this thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.

D. K. Sehgal

(Dr. D. K. Sehgal)
Professor,
Department of Applied Mechanics,
Indian Institute of Technology, Delhi,
New Delhi - 110 016

ACKNOWLEDGMENTS

I express my deep sense of indebtedness to Prof. D. K. Sehgal for his valuable guidance, keen interest, inspiration, ample support, constant encouragement, and immense patience have inspired me towards the completion of this work. His frankness, simplicity and deep insight into the problem have greatly motivated me to carry out my research in this very fascinating field. He supported me with his marvelous intuitive capabilities without which, this thesis could not be in its present form.

I am extremely grateful to Prof. R. K. Pandey for his valuable suggestions, discussions and guidance. His experimental acumen and useful tips are of constant use throughout the course of this research work. I also wish to thank Prof. S. M. A. Kazimi for his help, constant encouragement and support.

I am thankful to the Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi, for allow me for the higher studies. My sincere thanks to Prof. I. H. Khan, Prof. N. U. Khan and Prof. S. S. Nabi of department of civil engineering, Jamia Millia Islamia, N. Delhi, for their support and cooperation. I am also thankful to other my departmental colleagues for their help and encouragement. I also wish to thank all the faculty members of Applied Mechanics department who helped me at various stages.

I thank Prof. Husain Abbas, Mr. Iqbal Azam, Dr. M. Sharif, Mr.shazad A. Khan for their help, guidance and encouragement. Thanks are due to Dr. Shriram Hegde, Mr. Kailash Chand, and Mr. V. S. Rawat for prompt help, assistance and cooperation rendered by them.

Mr. B. S. Rana, Mr. Rishi P. Dagar, Mr. Prem Chand, and Mr. Prem Singh need special thanks for all their assistance and cooperation during the experimental work in this thesis. I also wish to thank workshop staff of Applied Mechanics Department and IDDC for timely help of specimen preparation. I am thankful to Mr. M. L. Sehgal and Mr. Mahender Choudhry for their help.

I acknowledge my thanks to my friends and fellow research scholars, Dr. Aslam, Dr K. K. Pathak, Mr. Partheepan, Mr. Noor Deshmukh, Mr. Mohd. Ahmed, Mr. Senthil, Mr. Pankaj Kalia, Mr. Abdur Rahim, Mr. M. Ashraf Iqbal and Mr. R. A. Khan for their encouragement and valuable discussion and help.

I also acknowledge the help and assistance given to me by all other persons whom I am unable to mention here individually.

I bow in gratitude to my parents, brothers, sisters and relatives for their blessings and moral support throughout the course of my research. Lastly but not the least, I tender my grateful thanks to my wife Nazneen and my daughters Adeeba and Laiyba for their love, affection and tolerance during this study.

Asif Husain

(Asif Husain)

ABSTRACT

In an increasingly competitive market place, accurate and economical condition assessment of engineering structures and components is imperative. The safe and economic operation of energy producing and process plants equipments is becoming major issue as these equipments age up to and beyond their planned or designed life. The traditional fossil and nuclear fueled electric power, thermal power plants, and the petrochemical plants are examples where the reliability of aging equipment is of much concern. Determination of accurate mechanical properties of operating components is a key element for the enhancement of component reliability, optimization of operating procedures and inspection intervals, and for the definition of a guide to maintenance and repair strategies for extending component life. In most cases, component integrity is hardly evaluated with traditional and well-standardized mechanical test techniques because there is not enough amounts of materials sampled non-invasively from components to allow for the determination of mechanical properties. Small punch specimen test technique provides a way of obtaining mechanical properties of components or structures while consuming an amount of material that is very small relative to that required for full-size conventional specimens.

In the present study, a simple versatile small punch test experimental set up for testing miniature specimen is designed and tested. The detail of such a setup/fixtures for the determination of mechanical behavior of materials is investigated. It incorporates several new features, not generally found in previous designs. Miniature sample holders (i.e. dies) are designed in order to

accommodate different shapes of miniature specimens. Special type of fixture is designed to test miniature sample conveniently in the axial direction. Four different indenters (three hemispherical headed and one cylindrical tip head with line contact) are designed and developed. The displacement under the punch load is measured by various techniques as described. This setup is very versatile for testing either unclamped or completely clamped (rigidly fixed) miniature samples on any modern universal testing machine such as MTS machine, INSTRON machine and Hounsefield Tensometer etc.

An experimental study of small punch test on circular shaped miniature specimens is carried out, using the experimental setup described above. Study contains the description of the selection of (i) different materials (ii) specimen holders (iii) punch geometry (iv) testing machine and (v) procedure for carrying out experiments using small punch test setup. The small punch test experiments are conducted on circular disk (10mm diameter and 0.5mm thick) miniature samples of different materials in phased manner according to hemispherical headed indenters. The quasi-static loading is applied on circular shaped miniature samples by three different diameters of rigid indenters. The small punch specimen experiments are conducted on MTS testing machine in air at room temperature. Experimental results of small punch specimen, in the form of load vs. displacement curve are presented and discussed. The influence of tip diameter of rigid hemispherical headed punches on the deformation of circular shaped miniature sample is investigated. A new empirical correlation for the estimation of yield strength is proposed for circular shape miniature specimen. Experimental determination of material properties as well as fracture toughness parameters based on standard conventional specimen tests are also reported. These conventional standard tests are used as a “bench mark” or a “Reference test”.

An experimental study is also carried out on the non-circular (square and rectangular) shape of miniature specimen. The square (10mm x 10mm x 0.5mm) and rectangular (10mm x 2.5mm x 0.5mm) shape miniature samples are prepared from four different materials and small punch test have been conducted using specially designed die. Hemispherical headed punches of three different tip diameters are used for the quasi-static loading on square shaped miniature specimen. The small punch test for both non-circular specimen is carried out on INSTRON testing machine at room temperature, with cross head speed of 0.2mm/min. The load vs. displacement curves are obtained and recorded. The deformation behavior of these diminutive samples during quasi-static loading under the tip of rigid penetrator is closely monitored. The influence of tip diameter of (rigid hemispherical headed) punches on square shaped miniature sample is investigated. A new empirical correlation for the estimation of yield strength for square shape miniature sample is established. The last experimental portion is devoted to the study of small punch test technique on rectangular (fixed beam) shape miniature specimen. The quasi-static load is applied along the width at the center of rectangular specimen using specially designed cylindrical headed punch. An empirical correlation for the prediction of yield strength for rectangular shape miniature samples is also proposed. The estimated values of yield strength using proposed correlation is compared with the values obtained from existing (in literature) relations and as well as from standard tensile test.

The simulation of small punch test for three different shape miniature specimens using finite element method, for obtaining the mechanical behavior is studied. The circular and non-circular miniature samples with different punch geometries are simulated using finite element method. Direct finite element analysis on different shape (circular, square and rectangular) miniature specimens of different materials is carried out using FE ABAQUS code. For the circular disk and non-circular (square and rectangular) shape miniature specimens, three dimensional finite element models comprising different number of elements are developed, and validated through comparisons with small punch experiments on four different type of steels. The four different types of rigid punches (three hemispherical headed and one cylindrical headed tip specially for rectangular specimen) have been simulated for quasi-static loading. The solid iso-parametric elements of 20 noded brick (hexahedral) are used in the present study. Simulation of the small punch test for different shape miniature samples follows the experimental (physical) procedure as closely as possible using the same prescribed boundary conditions. For the modeling of the circular, square and rectangular shape miniature specimens, the dimensions considered are 10mm diameter, 4mm x 4mm x 0.5mm and 4mm x 2.5mm x 0.5mm respectively. A special contact algorithm represented the contact between the tip of hemispherical headed punch and the miniature sample is defined through ABAQUS code. The load vs. displacement curves are compared with small punch test experimental curves and wide spectrum of information is collected. This includes the deformation behavior of miniature specimens, load vs. displacement curves, von-Mises stress, equivalent plastic strain, logarithmic strain components and contact pressure etc. for different types of punches, miniature shapes and materials.

A computational study of miniature specimens through inverse finite element procedure using the results of small punch experiments has been conducted. An inverse finite element procedure for the determination of constitutive behavior of any unknown materials is developed. The initial slope of the small punch load vs. displacement curve is used to predict the actual value of elastic modulus of materials in conjunction with the inverse finite element method. The inverse FE analysis provides the small punch test based prediction of true stress-strain behavior and this is compared against the conventionally measured (standard tensile test) behavior for three different steels. This technique is based upon optimal matching of the experimental and simulated SP load vs. displacement curves for miniature specimens. This inverse FEM technique is tested and validated on three different miniature shapes (circle, square and rectangular) for four different materials. The empirical power correlations for the prediction of fracture strain and fracture toughness for different shape miniature specimens are established. The fracture strain and fracture toughness determined by proposed empirical correlations and existing empirical relations are compared. The computed SPSTT based fracture toughness values are also compared with the values obtained from standard three-point bend specimen test for four different materials and results are quite encouraging.

TABLE OF CONTENTS