EVALUATION OF MECHANICAL PROPERTIES OF HEATER TUBE MATERIALS OF REFINERIES AT VARIOUS TEMPERATURES USING MINIATURE SAMPLE TESTING APPROACH

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by

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CERTIFICATE

This is to certify that the thesis entitled “Evaluation of Mechanical Properties of Heater Tube Materials of Refineries at Various Temperatures Using Miniature Sample Testing Approach” being submitted by Mr Satya Pal Singh to the Indian Institute of Technology Delhi, India for the award of the degree of Doctor of Philosophy in the Department of Applied Mechanics is a bonafide research work carried out by him under our supervision and guidance.

The research reports and the result 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.

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ABSTRACT

The mechanical properties (such as YS , UTS, DBTT, creep , toughness etc) of service-exposed components alter with the cumulative time & temperature of exposure and environment and therefore safe and economic operation of the process plants needs the quantitative assessment of mechanical properties at regular intervals. The conventional methods of determination of mechanical properties of metals require bulk metal removal leading to process shutdown and post repair. There has been constant emphasis for many years now on quantitative assessment of current mechanical properties of the components for reliable health assessment and Remaining Life assessment (RLA). To achieve such an objective, small punch test (SPT) / Miniature sample test technology (MSTT) has emerged as one of the promising techniques.

SPT requires a very small quantity of metal which can be removed almost non-destructively from component surface to form a miniature sample and performing a destructive test on the miniature sample using specialized miniature sample testing facility to assess mechanical properties of parent metal. Such techniques being almost nondestructive in nature requires no post sampling treatment, leading to no process time loss. However, significant part of such studies has revolved around irradiated materials of nuclear industry and those used in refining and other process industries have been studied only to a limited extent. Moreover such studies have been revolving around the estimation of room temperature (RT) properties of materials with the help of empirical correlations. Estimation of high temperature mechanical properties has been attempted but no empirical relations are available in literature.

Heater tube is one such critical application in petroleum and many other process industries wherein the tubes of various grades of CrMo steels are operated even beyond 700 °C skin temperature and are subjected to high temperature damages like creep, carburization, microstructural degradation etc and hence calls for their periodic health assessment. Under the present work, two most widely used grades of heater tube steel namely 5Cr0.5Mo and 9Cr1Mo having service life of nearly 23 years and 10 years respectively have been selected for study at room temperature and elevated temperature ranging from 400 °C to 700 °C through small punch test.

Initially the selected materials have been thoroughly analyzed and evaluated for their mechanical properties including yield strength (YS), ultimate tensile strength (UTS) and ductile brittle transition temperature (DBTT) using standard test methods. These parameters are set as bench mark parameter for their comparison with SPT parameters.

A small punch test set up has been in-house designed and developed. Innovatively designed SPT set up consist of less than 1 cm^3 of inert gas charged space to avoid oxidation of sample and punch during its prolonged use and can be suitable for small punch creep tests also.

Subsequently, small punch test method, suitable for elevated temperature, has been developed and tests carried on two service exposed heater tube grade materials namely 5Cr0.5Mo and 9Cr1Mo. The load displacement data recorded during SPT tests has been analyzed and relationship developed between SPT parameters and standard mechanical properties for estimation of YS and UTS. Two different approaches, namely energy and load based have been adopted for such relation development and both of the two found equally capable. In the present research, both the materials have been found to correlate well with common relationships for each of the property (i.e. YS and UTS) in the entire range of test temperature.

Significant light has been thrown on the parameters affecting the results of small punch test, particularly carried out at elevated temperatures. Many aspects related to deformation mechanism of SPT have also been discussed. Inter relationships among the various SPT parameters have also been explored.

Low temperature studies have been carried out using liquid nitrogen cooled environmental chamber and an in-house developed testing set up. The standard DBTT obtained with Charpy V Notch tests have been compared with the results of small punch low temperature and relationship developed for estimation of DBTT of heater tube grade steels by SPT. Both the materials have been found to correlate well with a common relationship.

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