IN-SITU MEASUREMENT OF MECHANICAL PROPERTIES USING AUTOMATED BALL INDENTATION TECHNIQUE

G. Das, Paritosh Dubey, Mousumi Das and K.K.Paul
National Metallurgical Laboratory, Jamshedpur 831007
e-mail: : gd@nmlindia.org

INTRODUCTION

To assess the health/integrity of critical engineering component, evaluation of mechanical properties of the material from which the component is made is essential. Estimation of mechanical properties through conventional route is well established and standardized, but in-situ measurement on original structure or by using small amount of materials are in demand and yet to be standardized. As conventional mechanical test requires an adequate amount of test materials and in most of the cases this may not be available from the components that are in service. Therefore, an approach to find the mechanical properties either in-situ or using small amount of test materials got utter importance as an area of research for quite some time.

For in-situ measurement the degradation of an in-service component can be assessed by using portable automated ball indentation (ABI) system and to some extent by a portable hardness test machine. ABI set up is the most desired equipment to meet the requirements of in-situ measurement.

Although the principal of ABI to study deformation behavior of materials is not new, ABI technology has several distinct unique features: Can be used for in-situ application, requires small amount of test materials, avoids fabrication of complicated test specimen as required in conventional test, relatively rapid compared to conventional test, BI test is localized and therefore can be used to characterize weld zone and HAZ, fully automatic, does not require measurement of the indented diameters. Reproducibility and its accuracy are comparables.

It is based on the strain controlled multiple indentations at a single penetration location on a polished surface by a small spherical indenter. The indenter depth is progressively increased to a maximum user specified limit with intermediate partial unloading. The raw data is used to calculate the incremental stress-strain values from a combination of elasticity and plasticity theories and semi-empirical relationships that govern materials behavior under multi-axial indentation loading. By analyzing the flow curves the yield strength (YS), ultimate tensile strength (UTS), strain hardening exponent (n), strength coefficient (K), hardness (BHN) and fracture toughness (K_{JC}) can be determined.

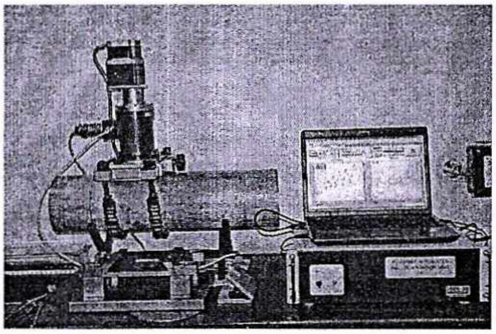
The concept of damage mechanics was used to determine K_{JC}. It is found that the stress tri-axiality beneath the indenter is similar to that ahead of a crack tip in a conventional fracture toughness testing. The indentation energy to fracture (IEF) can be correlated with energy required to fracture in ductile materials. Therefore, it is necessary to determine the indentation depth corresponding to probable fracture. The damage variable due to formation of void surrounding the indentation can be correlated with the elastic modulus and can be used to determine IEF and subsequently the K_{JC}.

The importance of the above development is immense, as the determination of mechanical properties either through small specimen or a portable version plays an important role for estimating the remaining life of the components. The ABI technology will allow: (1) establishing current key mechanical properties which are needed as input for various damage prediction models as well as to re-evaluate the safety factors used for components and (2) periodic monitoring of aging components to develop correlations between the ABI measured mechanical properties and the damage accumulation as a function of service usage of the components.

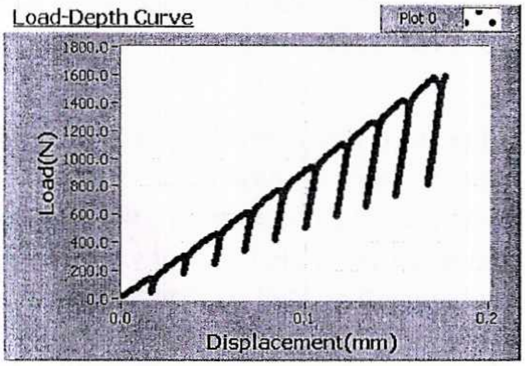
A portable automated ball indentation (PABI) system has been designed and developed at NML, Jamshedpur. Subsequently, a unit has been fabricated, shown below. Comprehensive software was developed for analyzing the ABI data. The operational parameters were optimized for various materials to measure YS, UTS, true-stress vs. true-plastic-strain curve, K, n, hardness and K_{JC}. This unit can be mounted on components with curved or flat surfaces and properties of the material could be evaluated by making a very small indentation. Also it has provision to use small test specimen.

For in-situ application it is nearly non-destructive since no material is removed from the test surface. Only a smooth shallow spherical indentation is left at the end of the test. This spherical impression is harmless for the tested structure because it has no sharp edge and does not introduce any stress concentration site.

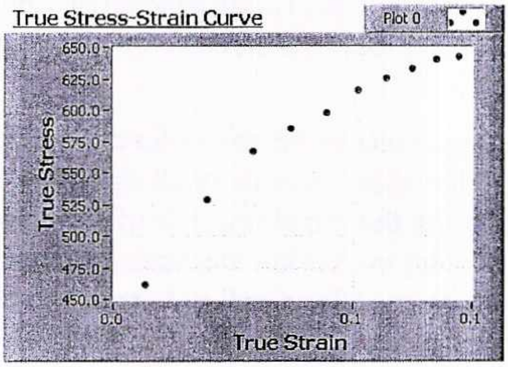
The newly fabricated ABI system was used to evaluate mechanical properties of few pipes as well as some small specimen to validate the unit. For each case the conventional tests were also conducted. The results of SS304LN pipe are given below along with their conventional test results (in the bracket).



The Portable ABI system, developed, designed and fabricated at NML.



Load-deflection plot obta- ined through the ABI.



True stress true strain plot obtained through ABI.

Pipe	YS (MPa)	UTS (MPa)	K (MPa)	n	(BHN)	K_{JC} (KJ/m^2)
SS304LN (Conventional)	295 (252)	641 (643)	1303 (1324)	0.34 (0.391)	194 (190)	185MPam$^{1/2}$ 178 KJ/m^2