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Round robin exercise on ball indentation technique in India: Indian nuclear reactor materials☆

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ABSTRACT

This paper presents outcome of round robin exercise on usage of ball indentation technique to predict strength properties of three different materials which are used in Indian nuclear reactors. The main objectives were to evolve a standardized procedure of determining the mechanical properties by the Ball Indentation technique and quantification of the variation in strength and fracture properties due to ageing through such tests. Standard uniaxial tensile tests were also carried out to quantify the differences between strength properties predicted by ball indentation and those determined using conventional tests. Three different materials studied were, carbon-manganese steel (Grade: SA 333Gr.6), stainless steel (SA312 Type 304LN) and zirconium alloy (Zr-2.5Nb). The carbon-manganese steel and stainless steel materials were drawn from extruded pipes while Zr-2.5Nb was drawn from pressure tubes, used in Indian Pressurized Heavy Water Reactors. Ball indentation tests were carried out on materials in as received and in aged conditions. The ageing was simulated artificially. The carbon-manganese steel and stainless steels were subjected to cold work while Zr-2.5Nb alloy was subjected to heat treatment at different temperatures with varying hold times and in some cases with charged hydrogen. The round robin exercise was conducted within different research centers of Department of Atomic Energy (DAE), India. This was a blind exercise in which all the conventional tests were carried out by a group (who was not involved in Ball Indentation tests) after the completion of ball indentation tests by participants.

The paper presents the prediction of strength properties, using ball indentation, by different participants. The reasons of scatter in the results among the various participants and differences with respect to conventional test results are discussed in the paper.

1. Introduction

The assurance of integrity of primary pressure boundary components, in nuclear power plants, is one of the important requirements for their continued operation or life extension. Assessment of changes in material properties, during periodic inspection, plays key role in assessment of ageing. Ball indentation technique is capable of in-situ assessment of properties. It is well known that the ball indentation technique has been successfully applied for estimation of mechanical properties like yield strength (YS), ultimate tensile strength (UTS), strain hardening exponent (n) and strength coefficient (K), (Haggag, 1993; Byan et al., 1997), through (Sharma et al., 2011). Several researchers have also made attempts for approximate assessment of fracture properties, (Byan et al., 1998; Haggag and Byun, 1998; Mathew et al., 1999), through (Haggag and Nanstad, 1989).

Round robin exercise coordinated by ASTM E28.06.14 task group on ABI test methods was conducted on two aluminum alloys and two steel alloys (Haggag, 2003). Six laboratories were involved to predict the YS, UTS, K, n and uniform ductility. They have demonstrated that ABI test methods provide excellent repeatability within laboratory and between laboratories for the ABI determined YS, UTS and K. The repeatability coefficients of variation for the strain-hardening and uniform ductility are slightly higher because it depends on the shape of true stress-true plastic strain curve.

It was planned to use this technique on materials of primary pressure boundary components of Indian Pressurized Heavy Water Reactors

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Table 1
Details of material and simulated ageing treatment.

Material	Conditions of materials	Material constants related to BI*		Chemical composition (% weight)
		α	β_m	
Carbon-Manganese Steel (SA-333 Gr.6) Production form: Seamless Pipe 8″ NB Sch 120	As received Cold work: 10% and 20%	0.2285	1.0	C – 0.14, Mn – 0.9, Si – 0.25, P – 0.016, Cr – 0.08, Ni – 0.05, V - < 0.01, N – 0.01
Stainless Steel (SA-312 Type 304LN) Production form: Seamless Pipe 6″ NB Sch 120	As received Cold work: 10%	0.165	1.0	C –0.013, Mn – 1.57, Si – 0.36, P – 0.025, Cr – 18.6, Ni – 8.46, S - 0.001, N – 0.11
Zirconium alloy (Zr-2.5Nb) Heat treatment series- 1 Product form: Pressure tube OD: 90 mm, thickness 3.3 mm	A- As received Zr-2.5 Nb pressure tube material (AR) B- AR + 550 °C for 6 h and furnace cooled C- AR + 700 °C for 2 h and furnace cooled D- AR + 800 °C for 0.5 h and furnace cooled E- AR + 850 °C for 0.5 h and furnace cooled F- AR + 900 °C for 0.5 h and furnace cooled	0.28	1.0	Nb – 2.53, O – 0.12, H – 0.001, Sn – 0.018, Cr – 0.02, Fe – 0.13 Ni - < 0.007, Zr - Balance
Zirconium alloy (Zr-2.5Nb) Heat treatment series- 2	G- As Received (AR) + 20PPM (H_2) H- AR + 843 °C + 20PPM (H_2) + 30 min hold + He Quenching I- AR + 873 °C + 20PPM (H_2) + 30 min hold + He Quenching J- AR + 903 °C + 20PPM (H_2) + 30 min hold + He Quenching			

* α is constraint factor and β_m is material type constant (see Section 4).

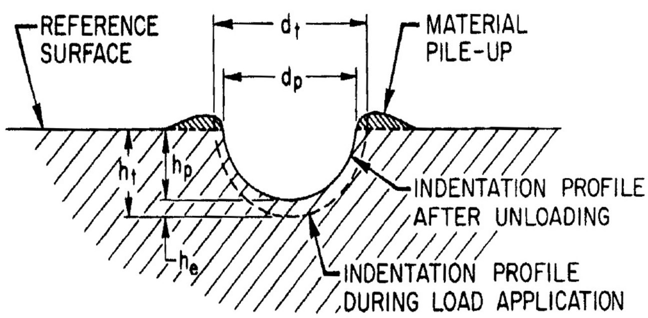

Fig. 1. Schematic of Ball Indentation Process (Haggag, 1993).

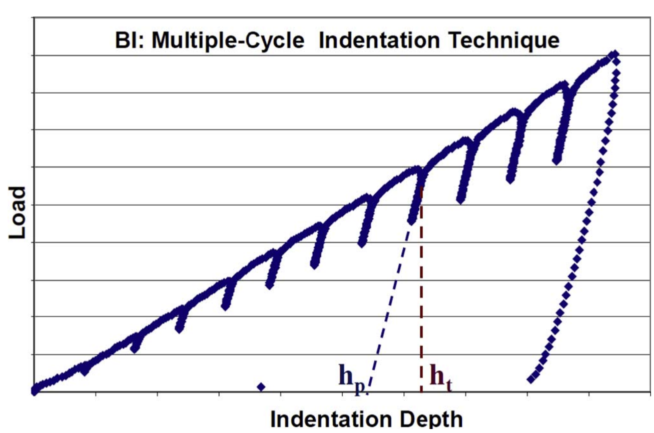

Fig. 2. Typical load indentation depth curve.

(PHWRs). The main aim is to assess changes in material properties during operation of nuclear power plants. The salient primary pressure boundary materials in PHWRs are Zr-2.5Nb (pressure tubes), carbon-manganese steel (primary coolant piping) and low alloy steel (primary head of steam generator). In view of this a round robin exercise on ball indentation technique was initiated within different research groups of Department of Atomic Energy (DAE), India. The materials included in of this exercise were carbon-manganese steel (SA-333 Gr.6), Zr-2.5Nb and stainless steel (SA312 Type 304LN). The carbon-manganese steel

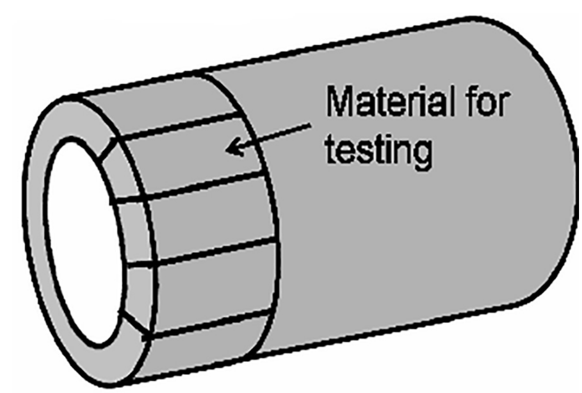

Fig. 3. Schematic of Specimen Sample Extraction from pipe or tube.

and Zr-2.5Nb were included from the point of applicability at PHWRs whereas stainless steel grade was included for its applicability to Advanced Heavy Water Reactor, which is at design stage. The main objectives of this round robin exercise were:

(i) Quantification of variation in prediction of strength properties by participants.
(ii) Assessment of extent to which effects of ageing on strength properties can be predicted.

Ball indentation tests were carried out on materials in as received and in aged conditions. The ageing was simulated artificially. The carbon-manganese steel and stainless steels were subjected to cold work while Zr-2.5Nb alloy was subjected to different temperatures with varying hold times and in some cases with charged hydrogen.

The paper presents the strength properties predicted by different participants and their comparison with conventional test results. The inter-participant variation is also presented and discussed.

2. Participants of the round robin exercise and its scope

Different research groups, with DAE, India participated in this round robin exercise. Ball indentation technique is being used by these groups for various applications like assessment of material ageing,