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Influence of material parameters on Small Punch Test using curved specimens

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ABSTRACT

Remaining life assessment of in-service components is a critical issue in the safety and reliability of power generating industries, because material properties reduce throughout the service life due to order to assess the strength of aged materials during the service life, miniature testing methods especially small punch test (SPT) has become a powerful tool of design engineers. SPT is a promising technique for those circumstances where only a small amount of material is available for characterization. Majority of the literature reported on SPT deals with flat samples. Flat samples are suitable to evaluate material properties of almost planer components only. For curved components, preparation of flat samples is a tedious process. Sometimes, in case of high curvature, it may not be even possible to prepare flat sample. In this regard, SPT using curved samples will be a promising tool for characterizing curved components. In present study, effects of some key material parameters on SPT using curved specimens and their effects are critically examined using simulation technique.

Keywords: Miniature testing methods, Small punch test, material parameters, load –stroke curve

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INTRODUCTION

Obtaining accurate estimate of in-service life is of great importance to the power generating industries especially in nuclear power plants. The life assessment and potential for failure of in service components is a critical issue in the safety and reliability of all such industries. This requires the knowledge of actual mechanical properties of the components material as because of ageing, the material properties could be reduced throughout the service. Thus, in-service evaluation of mechanical properties of power plant component materials especially steels used in reactor pressure vessel, fuel cladding, pressure, boiler, super heater, heat exchanger, condenser, low temperature, low alloy steel and high temperature tubes, carbon steel pipe, turbine blades etc. are very important from the remaining life assessment perspective. The major problems associated with this are the non-availability of sufficient material for ASTM test and need of in-service investigation without affecting the functioning. The need of a large amount of testing material can be eliminated by a new advanced testing method based on “non destructive” sampling of a small amount of testing material from the component surface. The mechanical characteristics are then determined by SPT. SPT is a type of miniature testing methods which has nowadays become a powerful tool to predict mechanical properties of materials under operating conditions of component. Due to small size of specimen used in this method, it may be classified as non- destructive method in power plants. One of the first attempt to use miniaturized testing techniques was the work of Manahan, Argon, and Harling [1] who developed a miniaturized disk bend test for determination of post-irradiation mechanical properties. Baik, Kameda and Buck [2] successfully interpreted the findings from small disc bend tests to fracture appearance transition temperature (FATT) as measured in the standard Charpy V test. In continuation of these research works, Lucas [3] presented a detailed review of the miniature testing techniques and concluded that among all miniature tests, small punch test (SPT) is most popular. SPT was invented in Japan and soon became very popular worldwide [4]. Ha and Fleury [5] reported prediction of fracture toughness using SPT. Mao and Kameda [6] reported measurement of material degradation of Cu alloys. Further, Kameda and Mao [7] determined ductile brittle transition temperature (DBTT) using SPT. Foulds et al. [8] reported calculation of fracture toughness using SPT and finite element method (FEM). Yang and Wang [9] applied SPT to determine creep properties of the of the materials. Lee, Kim and Kimura [10] applied SPT to predict embrittlement of the cladding material of the inner wall of reactor pressure vessel. Husain, Sehgal and Pandey [11] investigated tensile behavior of materials using miniature specimen by an inverse finite elements procedure. Eagan et al. [12] applied SPT as an approach to solve the inverse problem by deformation shape and finite element optimization. Guduru et al. [13] performed FE analysis of a shear punch test for four different materials. Pathak et.al [14] determined the mechanical properties of structural steels using small punch test and neural network. Partheepan et al. [15] presented a method for determining the uniaxial tensile properties such as Young’s modulus and yield strength of a material in a virtually non-destructive manner. Arabshahi and Asmari [16] applied simulation technique to study the influence of temperature in high field electron transport properties in Bulk Wurtzite GaN. Monte Carlo simulation was used to model bulk electron transport at room and higher temperatures as a function of high electric fields. Eskner and Sandstorm [17] developed a Small Punch test setup by which miniature disc specimens 5 mm and 3 mm in diameter and with thickness ranging between 50 to 400 μm could be investigated for determination of yield strength. Ling et al. [18] performed small punch creep tests on type 304 stainless steel at 650 ^{0}C.Recently, Pathak et al. [19] reported the influence of key test parameters on SPT results using flat samples. The aim of present research work is to study the effects of yield stress and strain hardening on peak load and corresponding displacement obtained from SPT using using curved samples and simulation technique. Based on these results, sensitivity of the material parameters may be ascertained.

2. Small Punch Test

Small Punch Test popularly known as SPT is one of the most recent miniature testing methods**.** SPT is a tool for measuring mechanical characteristics of material extracted from components during operation. In power plants like hydro, thermal and nuclear the remaining life of the components working in the operation is determined for predicting the reliability of the components. Accurate mechanical properties of the operating components can be obtained only through miniature testing methods like SPT. In SPT, cut samples are metallographically prepared upto 1 μm diamond polish to the appropriate thickness. The samples are given metallographic finish to avoid deformed layer due to the sample preparation techniques. A punching device is used to punch out the prepared curved. Fig. 1 shows the schematic diagram of test configuration for SPT.

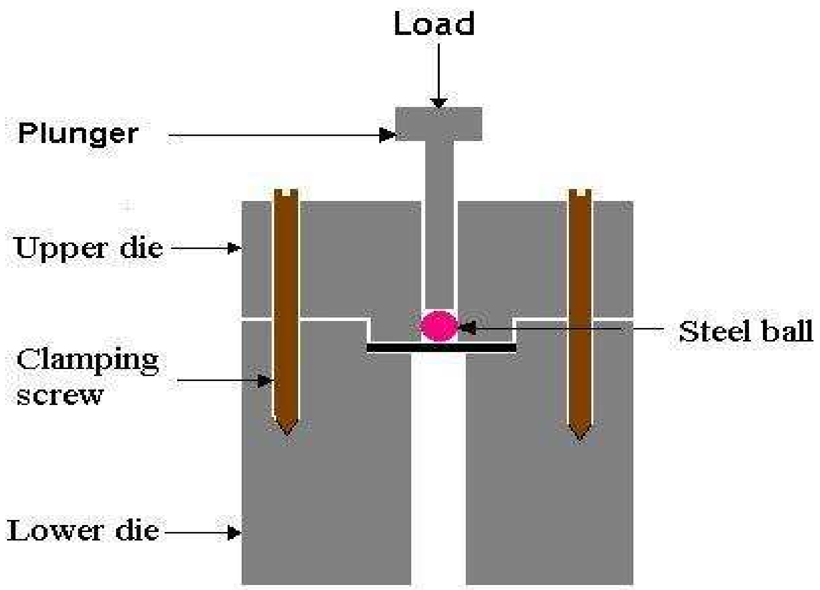

Fig.1: Schematic of SPT Setup

The experimental configuration used in this technique is as per the given specification in Xinayun Mao and Hideaki Takahashi [4] for flat specimens. The load and deflection are continuously recorded during testing. The deflection is measured using a finger gauge with a least count of 0.001 mm. In this study SPT is carried out by using curved specimens.
Following geometrical parameters are adopted:
(a). Sample diameter = 15.2 mm
(b). Sample thickness = 0.42 mm
(c). Ball diameter = 2.40 mm
(d). Die fillet radius = 0.25 mm
The lower and upper dies are suitably curved to hold the sample. A CAD model of the SPT specimen and die punch assembly is shown in Fig.2.

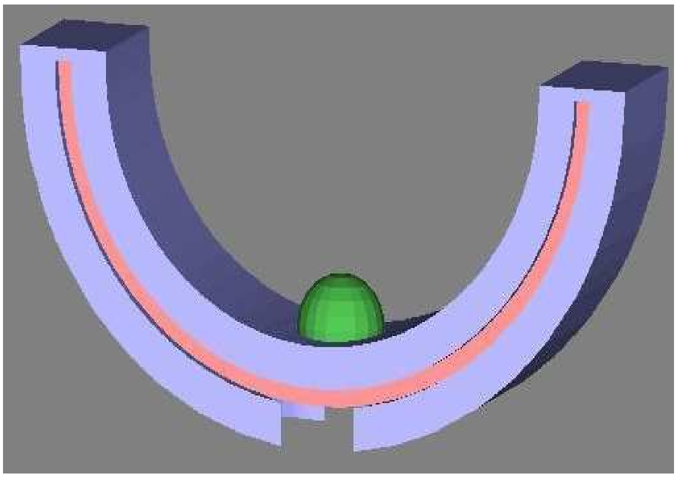

Fig.2: Die punch and specimen

CAD model depicting lower die opening is shown in Fig. 3

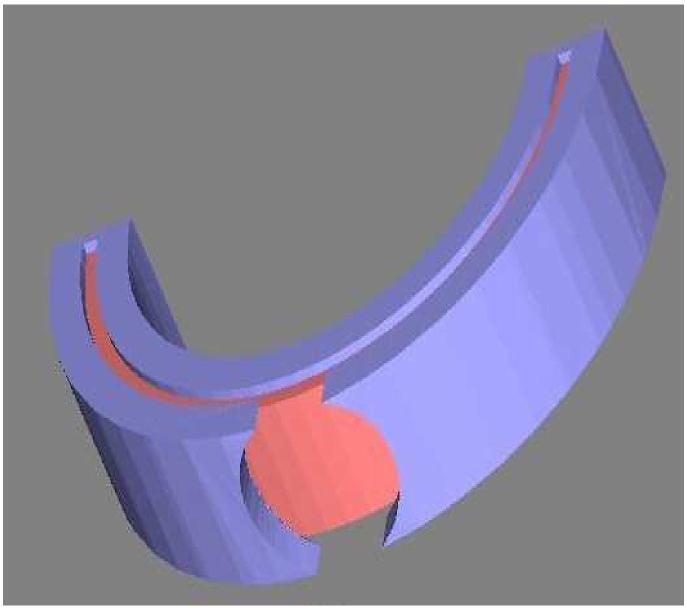

Fig.3: Lower die opening

3. Material parameters

Material modeling is carried out using power law equation: [20]

$$\sigma = k\,\varepsilon^{n}$$

where k is the strength coefficient and n is the hardening exponent Following material parameters are adopted for simulation purposes.

(a). Young's modulus = $2x10^5$ MPa
(b). Poisson's ratio = 0.3
(c). Yield stress = 300, 350, 400 MPa
(d). k = 1275 MPa
(e). n= 0.35, 0.4, 0.45
(f) Friction = 0.2 (Coulomb)

RESULTS AND DISCUSSION

Computer simulation of the SPT using curved samples is carried out using MSC. Superforge software [21]. This software is based on control volume technology and well suited for 3D large deformation problem like this. Displacement boundary condition is applied to the ball. All the cases are identically deformed to a displacement of 1.8 mm. Die and ball is considered as rigid while sample is treated as deformable bodies. Interactions between different bodies are accounted using contact command. A typical deformed sample is shown in Fig.4.

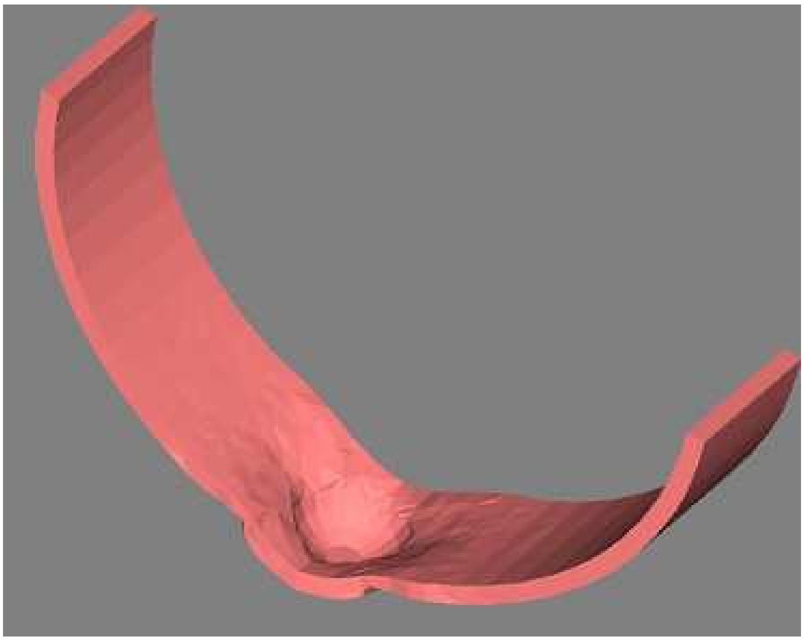

Fig.4: Deformed sample

Effects of strain hardening and yield stress on the peak load and corresponding displacement are given in Table 1 and Table 2.

Table 1: Effect of Strain Hardening Exponent (k = 1275 MPa, σ = 300 MPa)

S.No	Strain Hardening Exponent	Peak Load (ton f)	Peak Displacement (mm)
1.	0.35	0.134	1.6518
2.	0.40	0.127	1.6518
3.	0.45	0.121	1.6557

Table 2: Effect of Yield Stress (k = 1275 MPa, n = 0.45)

S.No	Yield Stress (MPa)	Peak Load (tonf)	Peak Displacement (mm)
1.	300	0.121	1.6557
2.	350	0.120	1.6557
3.	400	0.118	1.6636

Load stroke curves considering different strain hardening exponents are shown in Fig. 5 to 7.

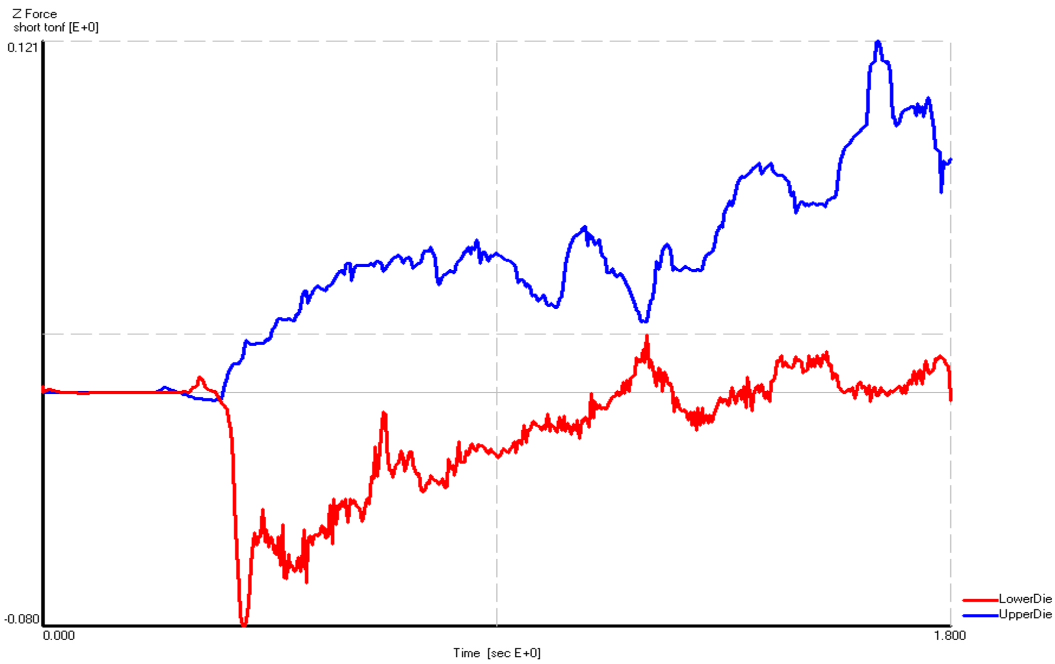

Fig.5: Load stroke curves for yield stress =300 MPa, n =0.3

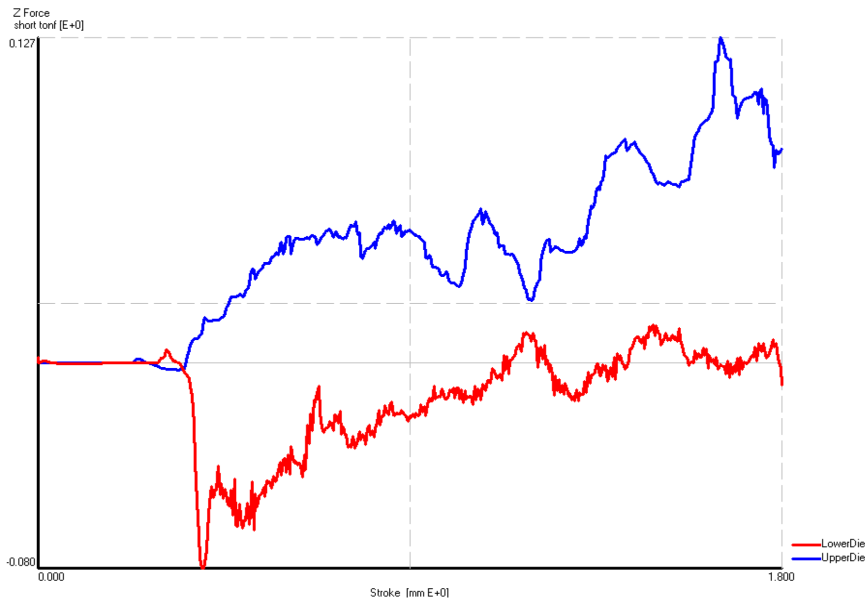

Fig.6: Load stroke curves for yield stress =300 MPa, n=0.35

From these results, following observations can be readily made.

1. With increase in yield stress, the peak load value decreases.
2. With increase in strain hardening exponent, the peak load value decreases. The rate of change of peak load with respect to hardening exponent is greater than that of yield stress.
3. Displacement corresponding to the peak load is independent of the yield stress and strain hardening.

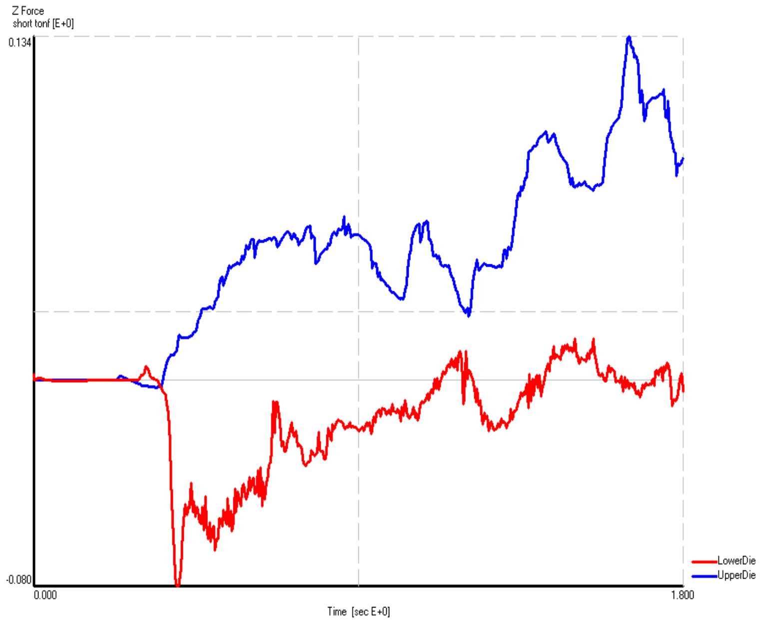

Fig.7: Load stroke curves for yield stress =300 MPa, n=0.45

CONCLUSION

In this study, effects of materials parameters on SPT output using curved samples are studies using simulation technique. It is assumed that these parameters has considerable influence on peak load and displacement. The analyses indicates that yield is less sensitive parameter as it does not affect peak load and corresponding displacement but strain hardening considerably affect the value of peak load and corresponding displacement. So, the value of strain hardening must be precisely and carefully measured during small punch tests. Based on these findings, experimental load - stroke data, obtained due to faulty test parameters, may be corrected rather than going for a new test with correct parameters.

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