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SIMULATION OF SMALL PUNCH TEST FOR MATERIAL CHARACTERIZATION TO ENHANCE FLEXIBILITY IN MANUFACTURING SYSTEM

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ABSTRACT

A flexible manufacturing assures the benefits of highly automated and controlled systems like; mass production, flexibility, versatility, adjustable system, individuality of product. To convert production system into versatile and flexible manufacturing system simulation; has a vital role at every step. This research paper, focuses the role of simulation in characterization of irradiated materials by using Small Punch Test (SPT) through miniature samples. Determination of mechanical properties of material when component is in functioning is a great challenge in front of present researchers. To make a manufacturing system flexible and reliable, the remaining life of component must be evaluated during functioning. The SPT is most successful tool for the same. It is a suitable miniaturized test method to determine the actual and local material states in structural components under operating conditions. A combined experimental – numerical simulation approach is presented, to identify material parameters of plastic deformation and ductile damage behavior by SPT. Evaluation of mechanical properties of irradiated nuclear reactor structural materials, such as, reactor pressure vessel steels, fuel cladding and pressure tubes, involves testing of highly radioactive materials

involving personnel exposure to radiation. This minimizes the data generation capability; to overcome this limitation one of the routes followed is testing of miniature specimens by specially developed techniques such as SPT. In this work, an inverse approach is adopted to predict the material properties using experimental and simulation techniques. The measurable output is, load -displacement curve of the punch. The load - displacement curve, obtained by testing miniaturized samples through SPT is matched with that obtained by computer simulation using finite element analysis. This way, the material parameters could be successfully predicted. These findings substantiate the feasibility to gain comprehensive material characteristics from the SPT and their transferability; to quantify the ductile failure of structural components. As SPT uses miniature samples instead of using large size samples for testing as in case of universal testing machine, Brinell hardness tester etc.; it is strongly recommended for the organization working for flexible manufacturing system.

Keywords: *Small punch, Flexibility, stress, strain, miniaturized sample, finite element, load stroke.*

Introduction

The small punch test (SPT) is a testing technique in which a small amount of material can be used. This is an important advantage for evaluating the mechanical properties of a material

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when its availability is limited. The data obtained from an SPT can be used to predict the tensile, yield and ultimate strengths. A linear correlation between tensile and SPT shear strengths has been reported by several researchers [3], [8]. The SPT has been used for testing nuclear irradiated materials, biomaterials and composites. The SPT was first introduced in the nuclear industries to monitor the degradation of material properties due to irradiation [1], [9]

Mostly, empirical correlations were established between results from SPT and conventional specimen data to find out the shift of the ductile to brittle transition temperature. The test is similar to a blanking process in which a solid flat cylindrical punch shears a disc specimen through a die at constant speed. The thickness of the discs used are usually in the range of a few hundred microns and the diameters are in the range of 5 to 10 mm. The SPT generates a non uniform state of stress in which bending, shearing and compression stresses can occur as the material deforms. Studying the deformation response in SPT is important for better understanding of the testing and correlation procedure[5]. Finite element simulations of deformation process have gained wide popularity in recent years due to its various advantages. Finite element studies of the SPT are required to establish the material deformation details during the test and to correlate the measurements made on the disc to the uni-axial tensile properties and fracture toughness[7]. In this study an inverse approach is adopted to predict the material properties using experimental and simulation techniques. It can be observed that proposed technique is very powerful especially for nuclear materials where only a small amount is available at the disposal. Practicality of this technique is described based on the experimental and simulation result. It can be observed, this technique will be a very handy tool for design engineers in material characterization.[2]

SPT Technique

In SPT, cut samples are metallographically prepared up to 1mm diamond polish to a thickness of 0.25 mm. 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 samples to a disc of 3 mm diameter. Fig. 1 shows the schematic diagram of test configuration for testing of disc sample of 3 mm diameter and 0.25 mm thickness. The experimental configuration used in this technique is as per the given specification in Xinayun Mao and Hideaki Takahashi [11]. It consists of a clamped center-loaded specimen disc of 3 mm f and 0.25 mm thick, an upper and a lower die, four clamping screws, a hardened steel ball punch of 1mm f and a plunger to drive the ball. Small punch tests are carried out using a computer controlled universal testing machine with 500 kg load-cell and a constant crosshead speed of 0.2 mm / min. The tests can be carried out at room temperature and elevated temperatures up to 350°C. 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. Figure 2 shows original and tested samples [4].

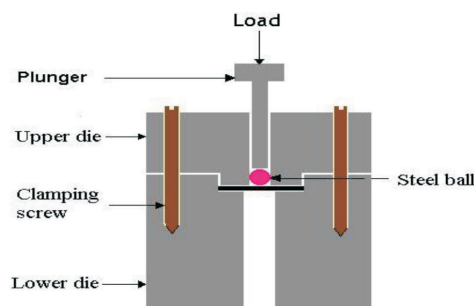


Figure 1: Schematic of SPT setup

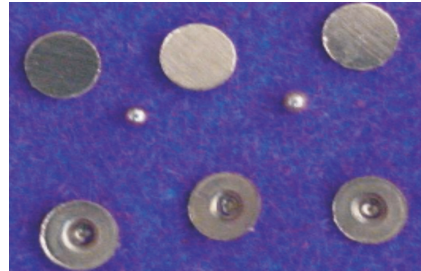


Figure 2: SPT specimens

Material Characterization Using SPT

Small punch test can be used for material characterization. The basic output of the test is load stroke curve. In Figure 3, a typical load stroke curve is shown. The curve can be divided into 6 zones. Zone I is the elastic response, zone II represent transition between elastic and plastic behavior. Zone III is related to hardening. In zone IV, geometrical softening and damage occurs and zone V is related to failure and crack growth. Our goal is to obtain material model corresponding to this curve. For this an inverse engineering approach is employed [6]. In this, finite element analyses, considering various material models are carried out. In Figure 4, stress strain curves corresponding to various hardening exponents (n_1 , n_2 , n_3) are shown. When experimental and simulated load stroke curves are in close match we get the true material model. Following steps are taken up for material characterization.[6]

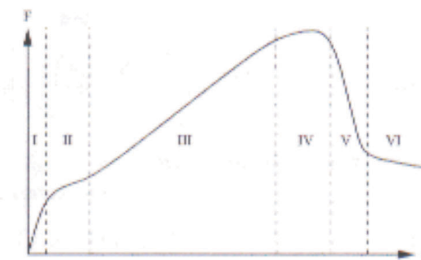


Figure 3: Typical Load Stroke Curve

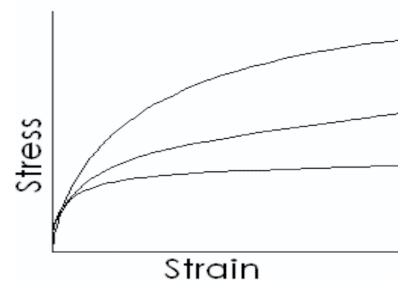


Figure 4: Stress Strain Plots

1. Carry out small punch test in order to obtain experimental load stroke curve.
2. Carry out finite element analysis of small punch test using assumed material model and obtain simulated load stroke curve.

3. Compare experimental and simulated load stroke curve.
4. If they are not close, change the material model and repeat step 2 and 3.
5. Otherwise desired material model is achieved.

Role of Computer Simulation

FEM study need to be done to understand the deformation behavior of the sample during SPT. Further, FEM Studies need to be done on SPT of flat specimen. The design features of the die and punch assembly of the flat samples shall be made based on these studies[10] . Finite element simulation are needed for the following studies.

- i. Predicting deformation behavior of the SPT for varying geometrical material and process parameters.
- ii. Optimization of die design profile in order to achieve streamline flow.
- iii. Reverse engineering. calculation of flow curve based on load deflection graph and prediction of frictional parameters.
- iv. Study of edge effect in the test, which can not be accounted accurately by analytical approach.

This simulation based prediction of life of the component is very promising tool. It can even be extended to irradiated materials whose experimentation is risky and may not be possible. Clubbing of experimental and numerical tools to stand arise STP is an ideal goal and the demand of the day[4].

Case Study

Material characterization of SS304 steel is carried out using SPT and FEM. The load stroke curve obtained from the experiment is shown in Figure 5. Axisymmetry finite element modeling of the test, using 4 noded elements, is carried out using MSC.Superform software. The FE mesh is shown in Figure 6. There are 150 elements and 186 nodes in the model. Material modeling is done using power law equation.

$$\sigma = K\varepsilon^m$$

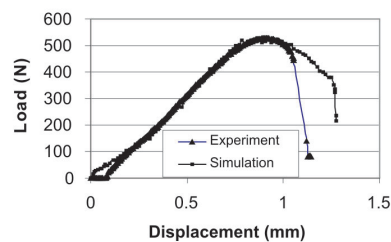


Figure 5: Load Stroke Curve

Where K is strength coefficient and m is hardening exponent. The values of K are taken as 900,950,1000,1050,1100,1150,1200,1250 MPa, whereas m values are taken as 0.3,0.4,0.5. Coulomb friction of 0.2 is accounted. The simulated load stroke curves were compared with the experimental counterpart in terms of peak load and corresponding displacement, which are 527MPa. And 0 .9 mm Based on this matching range on K and m values were further narrowed down. The best matching was achieved when simulated K and m were 526.4 N and 0. 93mm.

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respectively. Both curves are shown in Figure 5. It can be observed that drifting of curves occur after the peak load because of the damage in the material. It indicates the need of damage mechanics modeling after post yielding scenario. Stress and strain contour in the deform specimen is shown in Figure 7 and 8. It can be observed that maximum stress and strain are around 1430 M Pa and 2.517 which are quite high.

Flow Chart of Methodology Used for Material Characterization of SS304

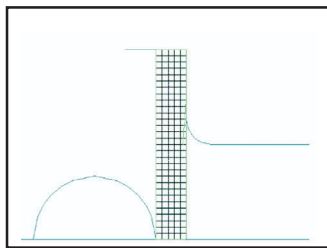
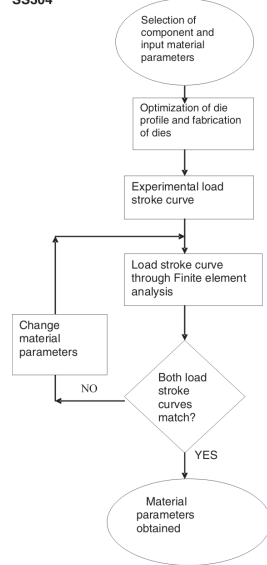


Figure 6: FE Model

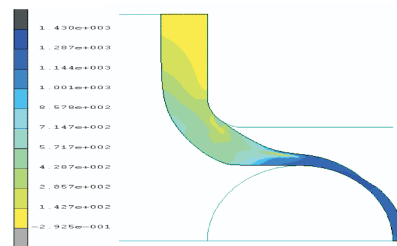


Figure 7: Effective Stress Contour(Mpa)

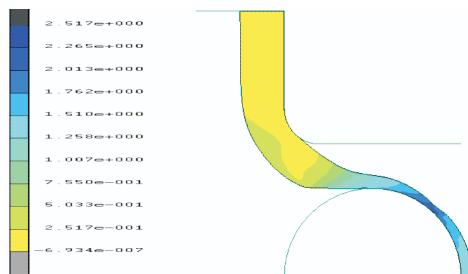


Figure 8: Plastic Strain Contour

Conclusion

In this study, role of computer simulation in material characterization is emphasized which automatically leads to improve flexibility of organization. Inexpensive hardware and software provides inverse engineering solutions of material characterization. A case study using finite element analysis as simulation tool to characterize SS 304 steel is successfully carried out. It is felt that, this type of powerful approach would be getting wide popularity in online monitoring of the functions of components in nuclear and other energy power plants. Load stroke curve obtained from SPT experiment is used as benchmark for FE simulation. Inverse engineering approach in which material parameters are varied to result in desired load – displacement curve is used. Due to extremely small volume, the SPT is qualified to examine local and current material properties. It can be observed that this technique is very powerful where not much material quantity is available for experimental characterization through tensile test. Also material characterization using SPT can be successfully carried out without affecting the functioning of the plant thus making the system more flexible.

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