Recent developments in small punch testing: tensile and fracture testing

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ABSTRACT

Neutron irradiation in nuclear power plants leads to microstructural changes resulting in the degradation of important properties in structural materials. One of the effects of neutron irradiation is a shift of the ductile to brittle transition temperature (DBTT) towards higher temperatures. The need for characterizing in service materials from nuclear power plants as well as irradiation testing of new materials has led to a need for test techniques using only a small amount of material. The small punch test is one of these techniques: a small hemispherical punch is pushed along its axis of symmetry through a small disc shaped specimen. Normally either the punch is pushed at a fixed displacement rate and the force is measured as a function of displacement (tensile test) or the force is kept constant and the displacement is measured as a function of time (creep test).

This paper lays out the working principle of the small punch tensile/fracture test. Current approaches for determining yield stress, ultimate tensile strength and DBTT from small punch data are reviewed. Based on data from ongoing research projects some new proposals and the application to fuel claddings are presented. Finally an overview over the currently available international standards is given.

KEYWORDS: small punch test, yield stress, ultimate tensile strength, ductile brittle transition temperature (DBTT), standard

1. INTRODUCTION

The development of the small punch (SP) testing technique started at the beginning of the 1980s in Japan and the US. The technique is based on pushing a small spherical tip or ball ("punch") through a disc shaped specimen along its axis of symmetry. The tests are carried out either at constant displacement rate of the punch where the force is measured as function of time (tensile test) or at constant load where the deflection of the specimen is measured as a function of time (creep test).

The initial driver for the development of the SP technique was the need to characterize irradiated materials from nuclear fission and fusion programs using small specimens. These activities aimed at deriving biaxial stress-strain curves [1], determining the Ductile to Brittle Transition Temperature (DBTT) [2],[3],[4], or characterizing the fracture toughness [5] from a small amount of material.

The two specimen thicknesses used in the early development stage were 0.3 mm (derived from TEM specimens) [1],[2] and slightly larger discs with 0.5 mm thickness [3],[4]; the latter is still the most commonly used SP specimen type.

The triaxial, time dependent stress state in the SP tests makes estimating mechanical properties by SP testing a challenge. Although much effort has already been invested in matching the results from SP testing to those from standard tests, this work still continues [6],[7],[8],[9],[10].

This paper describes current developments related to small punch testing with a focus on the determination of tensile properties and the DBTT.

2. OUTLINE OF THE METHOD

2.1 SP test setup

In an SP tensile test, the hemispherical tip of a punch is pushed at a constant displacement rate through the centre of a disc shaped specimen (a tested SP specimen is shown in Figure 1). The punching force in SP tensile testing is typically generated by a universal testing machine with specimen-specific holders. The tests can be conducted within a cryogenic chamber for DBTT testing or fitted with a furnace or induction coil for high temperature tensile properties.

For SP creep testing a range of different test machine designs exist, the most common being the top loaded dead weight machine. The same type of specimen holder is used in the SP creep test as in the SP tensile test.
The specimen is clamped between two dies which hold it in place and prevent it from bending upwards (Figure 2). Typical dimensions according to the European Code of Practice are listed in Table 1.

Table 1 Characteristic dimensions of a typical SP rig according to the European Code of Practice [11].

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch radius $r$</td>
<td>1.25 mm</td>
</tr>
<tr>
<td>Specimen diameter $d$</td>
<td>8 mm</td>
</tr>
<tr>
<td>Specimen thickness $h_0$</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Diameter of receiving hole</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

The lower die has a central receiving hole through which the punch can pass. Below the specimen a hollow ceramic rod is mounted which is used to transfer the specimen deflection to a Linear Variable Displacement Transducer (LVDT). Inside the ceramic rod a thermocouple may be introduced to measure the test temperature in direct contact with the specimen surface.

2.2 SP tensile force-deflection curves

A typical SP tensile force-deflection curve is plotted in Figure 3. The data is from a SP test conducted with a ferritic/martensitic steel Gr. 91 specimen (9Cr 1Mo steel) at -100 °C. In this case the hemispherical punch had a tip diameter of 2 mm; the other dimensions were as specified in Table 1 [12]. Punch diameters of 2.4 and 2.5 mm are more frequently found in the literature.

An SP tensile curve is generally divided into four distinct zones as indicated in Figure 3 ([8],[13]), roughly distinguished by the spreading of the deformation through the specimen. Zone I corresponds to indenting of the specimen surface by the punch tip and elastic bending of the specimen. In zone II plastic bending spreads through the entire sample. In zone III the specimen behaviour is dominated by membrane stretching and in zone IV necking and cracking occur which lead to a decreasing force and, finally, to failure.

The evaluation of tensile/fracture SP tests is based on a number of characteristic values that can be derived from the force-deflection curve:

- maximum force $F_m$
- deflection $u_m$ at maximum force
- elastic-plastic transition force $F_e$
- the fracture energy $E_{SP}$ calculated as:

$$ E_{fract} = \int_0^{u_f} F(u) du \quad (1) $$

where the integration is carried out from the start of the test at $u=0$ to $u_f$, the deflection where fracture occurs.

The maximum force $F_m$ and the deflection at maximum force can easily be determined from the force-deflection curve (Figure 3 Force-deflection curve for a tensile SP test on Gr. 91 stainless steel at -100 °C [12]).

Determining the elastic-plastic transition force $F_e$ is less straightforward. $F_e$ is the force at the transition between zone I and zone II (Figure 3). Several proposals for obtaining $F_e$ under discussion are explained in Figure 4 and Figure 5.

Following the two-secants method (also referred to as two-tangents method) the force-deflection curve is...
approximated by a least squares fit of two linear functions in the deflection range \([0; h_0]\), where \(h_0\) is the original specimen thickness (e.g. 0.5 mm; see Figure 4). One of the functions is anchored at the coordinate origin \((F=0, u=0)\). The intersection point of the two linear functions defines \(F_e\) according to the two secants methods.

CWA 16275 [11] recommends using the same bilinear fit but defines \(F_e\) as the projection of the intersection on the force-deflection curve.

\[ \text{BC003} \]

![Figure 4 Determination of \(F_e\) according to CWA 15627 and the two secants methods.](image)

An alternative method is similar to the approach for finding the yield point in uniaxial tensile testing. A parallel to the linear part at the beginning of the force-deflection curve is drawn at a given deflection (see e.g. [13],[14]). The intersection point of this linear function with the curve defines \(F_e\) (Figure 5).

A study comparing different methods for deriving yield strength by evaluating SP tests concludes that the method currently recommended in the European Code of Practice and the \(h_0/10\) offset method work similarly well for a wide range of alloys [8].

\[ \text{BC003} \]

![Figure 5 Determination of \(F_e\) according the offset method with different offsets.](image)

The second point that is not obvious is the upper integration limit used in the calculation of the fracture energy \(E_{frac}\). The European Code of Practice [11] recommends integrating up to the point where the force has dropped to 0.8\(F_m\) after having reached \(F_m\) and some authors use that convention [13],[15],[16]. However, some authors carry out the integration only until \(F_m\) is reached [2],[7],[9] or until the first visible crack occurs [3].

These approaches work well for ductile materials where a smooth, continuous force-deflection curve is obtained as in Figure 3. However, in the case of brittle fracture the situation is less clear as can be seen from the example on Gr. 91 at -196 ºC shown in Figure 6. On several occasions during the test sharp drops of the force occur, indicating partial cracking of the specimen.

\[ \text{Figure 6 Example of brittle failure in a SP specimen [18]. The arrows indicate force drops associated to cracking.} \]

Several approaches have been used for determining the upper integration limit in Equation (1) in such cases of brittle fracture occurring in successive steps:

1) The fracture energy is calculated by integrating the force up to its maximum [2],[9].

2) In analogy to the 20% force drop criterion in the Code of Practice [11] a 20% cumulative force drop criterion was proposed according to which all the force drops are summed until the total drop reaches 20% of the maximum [17].

3) Also integration up to the “first crack” has been proposed [16].

A comparison of these methods in the case of Gr. 91 concluded that there was less scatter when the maximum was used rather than the first crack [19]. However, it remains to be confirmed whether this is generally the case.

3. TENSILE MATERIAL PROPERTIES

SP test data is often used to determine the basic tensile material properties yield stress \(\sigma_y\) and ultimate tensile strength \(\sigma_{UTS}\). For that purpose empirical relationships between \(\sigma_{y,SP}\) and \(F_e\) on one hand and \(\sigma_{UTS,SP}\) and \(F_m\) on the other hand have been established. The most frequently used relations are:
The $\alpha_i$, $\beta_i$ and $\beta'_i$ parameters are test constants. These expressions are used with [8] or without [7],[9] the constant terms $\alpha_2$, $\beta_2$ and $\beta'_2$. In both cases the normalization of $F_m$ with $(h_0 u_m)$ (i.e. Equation (4)) is the preferred relation for describing $\sigma_{UTS}$ [8],[9].

The normalizations with $h_0^2$ for $\sigma_{y-SP}$ and $(h_0 u_m)$ for $\sigma_{UTS-SP}$ are also reasonable from a physical point of view. $F_e$ is determined at a point of the force-deflection curve where the specimen is undergoing elastic-plastic bending. The force needed for bending a plate increases quadratically with its thickness. In contrast the maximum force $F_m$ is reached where necking occurs on a membrane, so the force can be expected to be proportional to the specimen thickness.

A drawback of Equations (2)-(4) for tensile strength ($\sigma_{UTS-SP}$) is that the correlation constants $\alpha_i$, $\beta_i$ and $\beta'_i$ are dependent on the SP test-set-up and different constants have to be found for the TEM specimen and other combinations of specimen thickness, ball diameter and receiving hole diameter. Also the measured displacements at maximum force/fracture are rarely reported in the literature.

In Figure 7 and Figure 8 SP tests conducted on Gr. 91 steel in the MATTER project [20] are plotted against uniaxial test results for ultimate tensile strength [21]. It can be seen that the predefined material constants of [8] for Equation (3) ($\beta_1=0.065$, $\beta_2=268.81$) do not produce satisfactory estimates for $\sigma_{UTS}$, significantly overestimating $\sigma_{UTS}$ severely at high temperature. However for Equation (4) the pre-defined constant ($\beta'_1=0.277$) works well and the estimated $\sigma_{UTS-SP}$ from SP testing is in average less than 7% lower than the value from uniaxial testing over the whole temperature range (RT-650 °C).
Irradiation embrittlement of the structural components Charpy specimens would save precious material for tests conducted on small specimens retrieved from used possibility of replacing a part of the Charpy tests with determining the DBTT with smaller specimens. The there is a strong interest in developing techniques for context of lifetime extension of nuclear power plants as the actual reactor components. Especially in the vessel and thus exposed to the same irradiation history Charpy specimens deposited in the reactor pressure of nuclear power plants is monitored using dedicated higher temperatures. The DBTT is usually determined this embrittlement processes the DBTT shifts towards during the lifetime of a nuclear power plant leads to irradiation induced embrittlement. As a consequence of exposure of structural components to neutron fluxes neutron irradiation on material performance. The technique was to be able to determine the impact of One of the main drivers for the development of the SP specimen has a size of (10×10×55 mm3).

more material than the SP test: the Charpy standard by means of the Charpy test [23] which requires much during the lifetime of a nuclear power plant leads to irradiation induced embrittlement. As a consequence of this embrittlement processes the DBTT shifts towards higher temperatures. The DBTT is usually determined by means of the Charpy test [23] which requires much more material than the SP test: the Charpy standard specimen has a size of (10×10×55 mm3).

Irradiation embrittlement of the structural components of nuclear power plants is monitored using dedicated Charpy specimens deposited in the reactor pressure vessel and thus exposed to the same irradiation history as the actual reactor components. Especially in the context of lifetime extension of nuclear power plants there is a strong interest in developing techniques for determining the DBTT with smaller specimens. The possibility of replacing a part of the Charpy tests with tests conducted on small specimens retrieved from used Charpy specimens would save precious material for required testing during a prolonged service life. SP testing is still a topic of research for testing of irradiated materials and many studies have been carried out to compare the DBTT determined by SP testing to standard Charpy test results [6],[9],[15],[24]. It has generally been observed that DBTT_{SP} determined from SP testing is significantly lower than the transition temperature from standard Charpy testing. The current code of practice [11] and most authors express this difference via the ratio of the absolute transitions temperatures:

$$\alpha = \frac{DBTT_{SP}}{DBTT} \quad (5)$$

Some authors introduce an additional parameter:

$$DBTT = DBTT_{SP} \times \alpha^* + \beta^* \quad (6)$$

Where $\beta^*$ is either a constant [25] or a geometry or material depended parameter [24].

If a relation according to Equation (5) is used, typical values for $\alpha$ in the range of 0.35–0.5 have been found for a variety of steels [16],[26],[27]. For some materials like Gr. 91 [9],[15] or low alloy Gr. 22 (2.25Cr1Mo) steel [28] the DBTT_{SP} is so low that the lower shelf cannot be reached by SP testing even in liquid nitrogen at -196°C.

For the time being there is no detailed explanation for the gap between DBTT and DBTT_{SP}. However, the main differences between the Charpy and SP tests which might be relevant for explaining why $\alpha<1$ are:

1) strain rate: Charpy tests are carried out at displacement rates that are several orders of magnitudes above those in SP tensile tests. The duration of a Charpy test is in the order of ms whereas the duration of a SP test is a few minutes.

2) size effect: Charpy specimens have characteristic dimensions in the mm-cm range whereas the thickness of a SP specimen is typically 0.5 mm or less. The different specimen sizes are likely also to have an effect as suggested by Charpy impact tests where smaller specimens are known to lead to lower transition temperatures [6].

3) notch (stress concentration): The notch in Charpy specimens acts as a stress concentrator. Standard SP specimens don’t have a notch.

4) notch (loading mode): The stress distribution in SP tests has a higher degree of triaxiality than in Charpy tests.

Experimentally studying which of these effects leads to the observed shift in transition temperature as determined by SP testing is a challenge. With usual SP test rigs, displacement rates can only be varied in a limited range and strain rates similar to those in Charpy tests cannot be achieved. A study with circular notched SP specimens did not provide evidence for the notch having a major influence on the DBTT shift [29].
Numerical studies based on finite element analysis are likely to be more conclusive and to lead to more insights in the future [10]. Experimentally, the DBTTSP is determined by a procedure similar to that used for Charpy tests. SP tests are carried out at a number of temperatures and the fracture energies calculated. A typical result for the fracture energy \( E_{\text{frac}} \) as function of temperature \( T \) is shown in Figure 11. The tests were performed on Gr. 91 martensitic steel. The punch diameter was 2 mm, while the other dimensions complied with the requirements listed in Table 1. The punch displacement rate was 0.5 mm/s. The lower and upper shelves can be well distinguished. However the energy is not constant in the upper shelf but drops continuously with rising temperature. This behaviour is well established in the literature for a number of different steels [5],[15],[24],[29],[30]. When the DBTT is determined, the lower and upper shelf regions are often treated separately as can be seen in the fitted functions in Figure 11. The functions for both regions were of the form used in [9]:

\[
E_{\text{frac}}(T) = A + B \exp(C \cdot T)
\]  

(7)

Where \( A \), \( B \) and \( C \) are different fitting parameters for the lower shelf region (including the transition region) and the upper shelf.

A different approach which is based on normalizing the fracture energy \( E_{\text{frac}} \) by the maximum force \( F_m \) [19] is shown in the plot in Figure 12. This method has the advantage that a single function can be used to describe the data over the entire range:

\[
\dot{\psi} = \ln\left(\frac{h_0}{h_f}\right)
\]

(9)

Where \( h_0 \) is the initial specimen thickness and \( h_f \) the thickness adjacent to the area where failure occurred. A further possibility for determining the DBTT is based on the fracture strain which is defined as:

\[
E_{\text{frac}} = \frac{E_{\text{US}} + E_{L\text{US}}}{2} + \frac{E_{\text{US}} - E_{L\text{US}}}{2} \tanh\left(\frac{T - \text{DBTT}_{\text{SP}}}{2\Delta T}\right)
\]

(8)

Compared to the approach depicted in Figure 11 this reduces the number of fitting parameters from 6 to 4 and omits the (potentially subjective) explicit attribution of data points to the fitting functions.

Figure 11 DBTTSP derived from the fracture energy \( E_{\text{frac}} \) with two fits for the lower and upper shelf.

Figure 12 DBTTSP derived from the fracture energy \( E_{\text{frac}} \) normalized by the maximum force \( F_m \) using a tanh fit function.

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(9)

Where \( h_0 \) is the initial specimen thickness and \( h_f \) the thickness adjacent to the area where failure occurred. For a number of specimens \( h_f \) has been determined by computed X-ray tomography (CT). The example of a full CT reconstruction is shown in Figure 13 and a diametrical cut in Figure 14.

Figure 13 CT reconstruction of a Gr. 91 SP specimen [18]. The colours indicate the specimen thickness.
Figure 14 Cut through the CT reconstruction of a Gr. 91 SP specimen [18]. The colours indicate the specimen thickness.

The fracture strains as a function of temperature are displayed in Figure 15 for the same tests as in Figure 11 and Figure 12. The data can be fitted with a tanh function of the same form as in Equation (8).

![Figure 15 DBTT\textsubscript{SP} derived from the fracture strain $\varepsilon_f$.](image)

The values DBTT\textsubscript{SP} determined from the fracture energies $E_{\text{frac}}$ using the fitting methods "two fits" (Figure 11: -120.9 °C), and "tanh" (Figure 12: -125 °C) on one hand and from the fracture strains $\varepsilon_f$ (Figure 15: -123 °C) lie very close together. That is impressive given that the results based on $E_{\text{frac}}$ and $\varepsilon_f$ are derived completely independently from each other from different data (on the same specimens). This speaks for the robustness of the method.

APPLICATION TO FUEL CLADDINGS

In a nuclear power plant the fuel is supplied as UO\textsubscript{2} in form of small cylindrical pellets. These pellets are stacked one atop the other and contained in a tube. This cladding tube has typically a length of 3-4 m, a diameter of 10 mm and a wall thickness of 0.6 mm [31]. It separates the nuclear fuel from the coolant and is the first containment barrier.

In the framwork of the EERA-JPNM pilot project TASTE, several experimental methods for the mechanical characterization of fuel cladding tubes are compared. The SP test is one of these techniques. The dimensions of the fuel cladding tubes are too small to allow extracting the usual 8 mm × 0.5 mm SP specimens. The two approaches to address this problem are using very small flat specimens that can be cut from the tubes or to use curved specimens. Both solutions are investigated in TASTE. Here the use of curved specimens is discussed.

Figure 16 shows the geometry of the setup used for tubular SP specimens. The upper and lower dies have been modified to receive the specimen directly cut from the cladding tube.

![Figure 16 Scheme of the holder for tubular SP specimens (blue) clamped between the upper (red) and lower dies (grey). The punch is the hemisphere in the centre (green).](image)

For the results presented here tubular specimens from Gr. 91 have been used; the tensile curve is presented in Figure 17. The specimens had a thickness of 0.45 mm, an internal radius of 2.825 mm, and a length of 11 mm.

![Figure 17 Tensile curve for P91.](image)

The test rigs used for these tests do not allow measuring the specimen deflection (from below the specimen) but instead measure the displacement of the punch head.
In order to study the influence of the geometry on the force-displacement curves, finite element analysis (FEA) models of flat and tubular small punch specimen were created [32]. Besides the curves themselves, damage initialization is modelled by means of the ductility exhaustion parameter $\Lambda$ [33] based on the Rice-Tracey [34] rigid plastic deformation model for growth of voids under a triaxial field of stress. Two variations of $\Lambda$ parameter are used, $\Lambda_M$ and $\Lambda_{Eq}$. The former is based on maximal principal strain (Equation (10)), whereas the latter refers to the equivalent strain (Equations (11) and (12)).

$$\Lambda_M = \frac{\varepsilon_{\text{Max.principal}}}{1.65 \cdot e^{1.5 \frac{\sigma_{11} + \sigma_{22} + \sigma_{33}}{\sqrt[3]{3\sigma_{\text{Mises}}}}}}$$

$$\Lambda_{Eq} = \frac{\varepsilon_{\text{Eq}}}{1.65 \cdot e^{1.5 \frac{\sigma_{11} + \sigma_{22} + \sigma_{33}}{\sqrt[3]{3\sigma_{\text{Mises}}}}}}$$

$$\varepsilon_{\text{Eq}} = \sqrt[3]{3} \left[ (\varepsilon_{11} - \varepsilon_{22})^2 + (\varepsilon_{22} - \varepsilon_{33})^2 + (\varepsilon_{33} - \varepsilon_{11})^2 \right]^{1/2}$$

(12)

Preliminary results for flat and tubular specimens respectively are presented in Figure 18 and Figure 19.

![Figure 18](image_url)  
**Figure 18** Force-displacement curves of a flat specimen: FEM and experimental results. Markers indicate where $\Lambda_M = 1.0$ (star markers) and $\Lambda_{Eq} = 1.0$ (circular markers).

The overall shapes of the experimental and numerical force-displacement curves match very well for both types of specimens. However, the simulation underestimates the maximal force and deflection at maximal force for both cases.

The markers in Figure 18 and Figure 19 indicate at which load/displacement the ductility exhaustion parameter $\Lambda$ reaches a value of 1.0 at which point damage should initialize. It was observed experimentally that significant damage occurs already before the maximum force has been reached. For the flat specimens this is quite well predicted by the $\Lambda_{Eq}$ parameter. However, in the case of the tubular specimen both $\Lambda$ parameters reach the critical value of 1.0 only after the maximum for had been reached. Further work is needed to improve the model performance in this case.

### Standards

SP testing has been used since more than 30 years to obtain fundamental material characteristics from very small specimens. The limited amount of material required is particularly useful when irradiated or new experimental materials are investigated of which only small quantities are available.

However, it is not obvious how to obtain bulk material properties from small specimens and there is still no unified approach for determining fundamental material characteristics such as the ultimate tensile strength or the yield strength from SP tests. Currently there is no international standard covering the most widely used applications of SP testing.

A Japanese standard document exists but it seems to be limited to creep testing and only a small part is available in English [37].

In the U.S. SP standards exist for characterizing materials used in surgical implants by tensile SP tests at room temperature [38],[39]. For material characterization they recommend using quantities...
derived from the force-displacement curves (i.e. peak force, ultimate force, work to failure) that are also used within the structural engineering community. However, they focus on assuring reproducibility and ranking but do not provide tools to compare the results from SP testing to properties obtained from standard specimens. Other topics relevant for e.g. the power industry like DBTT or creep testing are not covered at all. Current activities under the auspices of ASTM Subcommittee E10.02 (Behavior and Use of Nuclear Structural Materials) may go in that direction [40].

The most recent European standardization document on SP testing is the CEN workshop agreement (CWA) from 2007 [11]. A CWA is a pre-normative document agreed upon by the participants in a CEN workshop. It is not voted by the CEN members and is not a standard but meant to prepare the future development of a standard.

A proposal for developing an SP standard within CEN has recently been accepted and introduced in the working programme as work item (WI) EC101162. A new working group (WG) will be installed within ECISS/TC 101 (Test methods for steel (other than chemical analysis)) to draft an EN standard on SP testing [41].

An informal group has already started a round robin testing campaign as well as underpinning modelling activities to agree on best practices. The standard is expected to cover tensile/fracture as well as creep testing and to include TEM specimens (0.3 mm thickness) as well as the more commonly used specimens with 0.5 mm thickness. Data will be exchanged between the participating organisations using the MatDB materials database hosted at https://odin.jrc.ec.europa.eu. To ease the collection and exchange of data, the new standard will include a section dedicated to data formats. This part of the activity will build on a series of CEN Workshops on formats for engineering materials data. Given the lack of any widely adopted technology for exchanging engineering materials data, the CEN Workshops rely on existing documentary testing and product standards from which to derive data models and accompanying formats. To date, the CEN Workshops have delivered data formats for ambient temperature tensile testing (based on ISO 6892 Part 1) and materials pedigree data [35]. Ongoing [36] and future CEN Workshops will extend the test type coverage to fatigue (ISO 12106), uniaxial creep (ISO 204), creep crack growth (ASTM E1457), creep-fatigue (ASTM E2714-13), and creep-fatigue crack growth (ASTM E2760-10). Whereas the CEN Workshops are focusing on existing testing and product standards, the development of the small punch data formats will be integral to the development of the testing standard. At a time when all aspects of engineering materials manufacture and qualification rely on digital systems, the parallel development of the standard testing procedure and accompanying data formats will set a precedent for the way in which mechanical testing standards could (and perhaps should) be developed.

5. SUMMARY AND OUTLOOK

The SP testing technique was introduced in order to characterize irradiated materials with regard to their mechanical properties and in particular the DBTT using small specimens. The triaxial, time-dependent stress state in an SP test makes correlating the results from SP tests to those of classical uniaxial of Charpy tests a challenge.

Nevertheless significant progress has been made in recent years and some properties such as the ultimate tensile strength can now be determined quite reliably from SP tensile data. For other information like the DBTT the transfer from SP data to results from standard tests is still difficult and further research is necessary. Numerical analysis and in particular finite element calculations have the potential to give a much more detailed insight into the test method than the experiment and will certainly be helpful in that regard.

The SP technique is influenced significantly by the test geometry (e.g. specimen size, diameter of the hole in the lower die) compared to standard techniques using larger specimens. Establishing international standards will ensure the comparability of the test data while standardized data formats will foster the exchange of data.

REFERENCES


J.-M. Lapetite, M. Bruchhausen, Small punch tensile/fracture test data for Gr. 91 material at -100 °C and a displacement rate of 0.005 mm/s, version 1.0, European Commission JRC Institute for Energy and Transport, [Dataset], http://dx.doi.org/10.5290/1900105, 2015


J.-M. Lapetite, M. Bruchhausen, Small punch tensile/fracture test data for Gr. 91 material at -196 °C and a displacement rate of 0.5 mm/s, version 1.0, European Commission JRC Institute for Energy and Transport, [Dataset], http://dx.doi.org/10.5290/1900103, 2015


Frits de Haan, Test data for uniaxial tensile on material P91 ar, version 1.1. European Commission JRC Institute for Energy and Transport, [Dataset], http://dx.doi.org/10.5290/2500004 to http://dx.doi.org/10.5290/2500015 (inclusive), 2014


S.-H. Song, R. Faulkner, P. Flewitt, R. Smith, P. Marmy, Temper embrittlement of a CrMo


