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# Comparative study between small punch test and hydraulic bulge test

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**Abstract:** The systematically comparison between small punch test and hydraulic bulge test is carried out, which include specimen geometry, the test device, testing procedure, testing results interpretation. The specimen geometry, test device and testing procedure are three major aspects of the experiments. Both the testing fixtures of SPT and HBT are redesigned to meet the specimen geometry. The testing procedure of SPT is similar to strain-controlled tension test, which control the displacement of the puncher and measure the corresponding reaction load. The testing procedure of HBT is similar to stress-controlled tension test, which control the pressure of the hydraulic oil and measure the displacement of the deformed specimen. The finite element method is used to study the deformation pattern of the specimen. The initial plastic zone distribution is different. The plastic zone of SPT is concentrated in a small area under the puncher and the initial plastic zone is a circle around the corner of the fixture for HBT. The deformation pattern play an important role in the yield stress interpretation, it is suggest that the interpretation method should include the parameters from the testing fixtures for HBT, and radius of the puncher for SPT.

**Keywords:** Small Punch Test; Hydraulic Bulging Test; comparative study; small specimen

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## 1. Introduction

Small specimen testing is a technology to get the mechanical properties from a small volume material. There is big demand in the market and industry for these kinds of methods. Small specimen techniques have been developed for almost 50 years. Lots of testing methods have been invented for small specimen, which include specimen miniaturization, indentation test, small punch test and hydraulic bulge test etc.

Small punch test (short as SPT) is one of the most popular small specimen testing techniques which was developed for nuclear power plant in the 1970s to assessment the safety of critical components [1-2]. After more than 40 years development, there are some codes to instruct to carry out the small punch tests, such as ASTM-F2183, GB/T-29459, and CEN CWA-15627 [3-5].

Hydraulic bulge test (short as HBT) is newly developed small specimen test method. HBT has been used in car industry for plate forming. Recently, HBT is used for small specimen whose width is with 10.0mm and thickness is 0.5mm [6]. HBT use hydraulic oil to make specimen deformation. There is no punch-specimen friction, and there is no puncher related influence, such as the radius of the puncher. The most important advantage is that theoretical derivation could be used to get yield stress and ultimate tensile stress of the specimen. The HBT is sensitive to the environment, for the hydraulic system. High or low temperature will cause the system fail.

Although HBT and SPT are two type of testing method with some similarity, the idea behind the two testing procedure is exactly the same, which is use something to make the specimen deformation, and get the apply force or pressure and the displacement curve. The rigid puncher is used for SPT to make the specimen deformation while high pressure hydraulic oil is used for HBT to make the specimen deformation. So there is no puncher related error factors such as the geometry of the puncher, the puncher axis and friction between the puncher and the specimen in the final testing results. Hydraulic oil which acts same as puncher is used to make the specimen deformation. The puncher related error factors are eliminated due to the fact that there is no puncher in the HBT. The testing device is much more complicated in HBT for the hydraulic system.

Generally, there are four steps in the small specimen testing procedure, which are sampling the specimen from the structure, machining the specimen to specific geometry, testing the specimen and data processing. For HBT and SPT comparison, there is no difference between them in the first step and the second step, and the same sampling machine and sampling procedure could be used. The machining method is slightly different due to the testing specimen geometry. The testing and data processing procedure is different. In this paper, a special design fixture

and a load frames is needed for SPT to get the load force and corresponding displacement, and a high pressure pump and a specimen holdings is used for HBT to get the hydraulic oil pressure-displacement curve.

The testing device, specimen deformation, testing procedure is the major aspect of the comparison. The finite element analysis is used to explain the fundamental difference.

## 2. Materials and Methods

The material used in the testing is P91 and Q420. P91 play a key role in the energy industry for high temperature application, and Q420 is usually in the structure. The chemical composition and mechanical properties are listed in the table blow. The geometry of the specimen is 10mm by 10mm with thickness 0.5mm.

Two testing methods which are HBT and SPT are used to test the specimen. The pressure of the hydraulic oil increase rate is 0.5MPa/s, and the punch speed is 0.2mm/min.

**Table 1.** Chemical composition (wt %).

Material	C	Si	Mn	P	S	Cr	Ni	Mo
P91	0.098	0.329	0.499	0.014	0.0041	8.84	0.060	0.94
Q420	0.142	0.235	1.182	0.013	0.0052	0.14	0.036	0.02

**Table 2.** Mechanical properties.

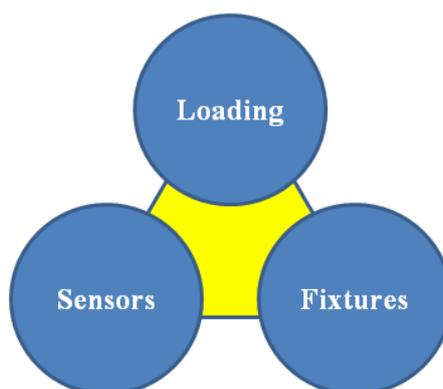
Material	Yield Strength (MPa)	Ultimate tensile strength (MPa)	A (%)	Z (%)
P91	747	877	22.0	70.63
Q420	489	551	26.5	76.48

## 3. Comparison between HBT and SPT

### 3.1. Testing device

For steel properties, small specimen testing method is not a standard testing procedure now, so there is no vendor to supply the testing device to carry out SPT or HBT. Most of the time, we have to design the testing fixture and assemble the testing device. Generally, there are three major parts for the testing device, which are load, fixtures and sensors, as shown in Figure 1, and detail comparison listed in table 1.

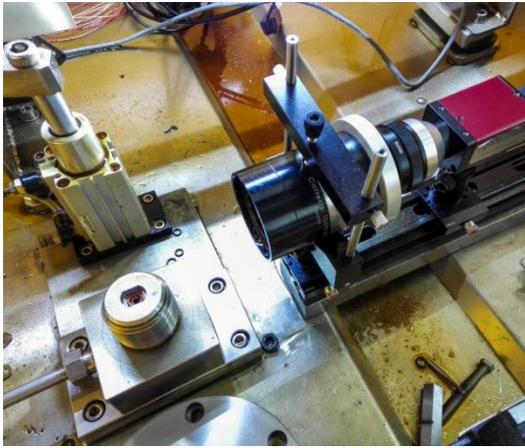
There are many differences in the device. The hydraulic oil pump is used to generate high pressure to make the specimen deform, and the puncher is driven by screw. The displacement of the specimen is measured by no-contact video extensometer for HBT for reliability. The fixture is more complicated for HBT, for the fixture should be designed with seal ring to keep the high pressure oil in the fixture chamber. The testing device are shown in figure 2.



**Figure 1.** The testing system of HBT and SPT.

**Table 3.** The testing system comparison.

Title 1	HBT	SPT
Loading system	Hydraulic pump	Servo Motor
Sensors	Video extensometer Pressure Gauge	Extensometer Force Gauge
Fixtures	Shown in figure 2(a)	Shown in figure 2(b)



(a) The test device for HBT



(b) The test device for SPT

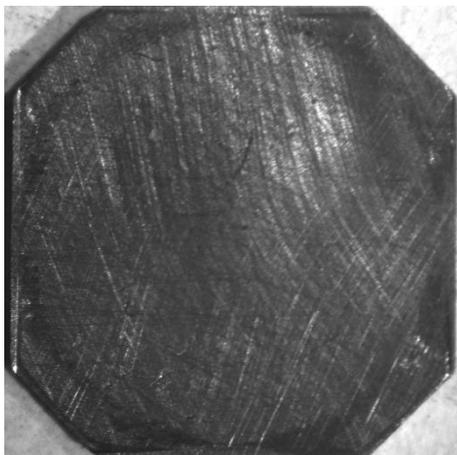
**Figure 2.** Device comparison (a) The test device for HBT; (b) The test device for SPT.

### 3.2. Specimen deformation

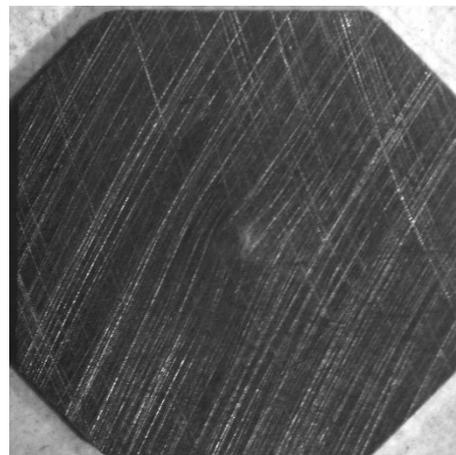
For better comparison between the SPT and HBT, the fixtures of HBT and SPT are redesigned to satisfy the geometry of the specimen.

The geometry of the specimen is shown in the figure 3, which is octagon for HBT and SPT. The width and height of the specimen is 10.0mm, and the thickness is 0.5mm. Four corner of the specimen is removed to make sure that the specimen is perfect contact with the fixtures surface. The specimen is deformed under the load. After the maximum dislocation of the specimen reach 0.1mm, the pressure of the hydraulic oil and the force on the puncher is unload to zero. The deformation of the specimen is shown in Figure 3.

The deformation character is different for HBT and SPT. There is a plastic circle around the boundary of the specimen for HBT, and there is a plastic deformation point at the centre of the specimen for SPT. The different deformation marks indicate that the initial plastic zone is different for HBT and SPT, which indicates that the initiate test curve of HBT is sensitive to the geometry of the fixtures while the curve of SPT is sensitive to the radius of the puncher. This different indication could be further explained by numeric simulation.

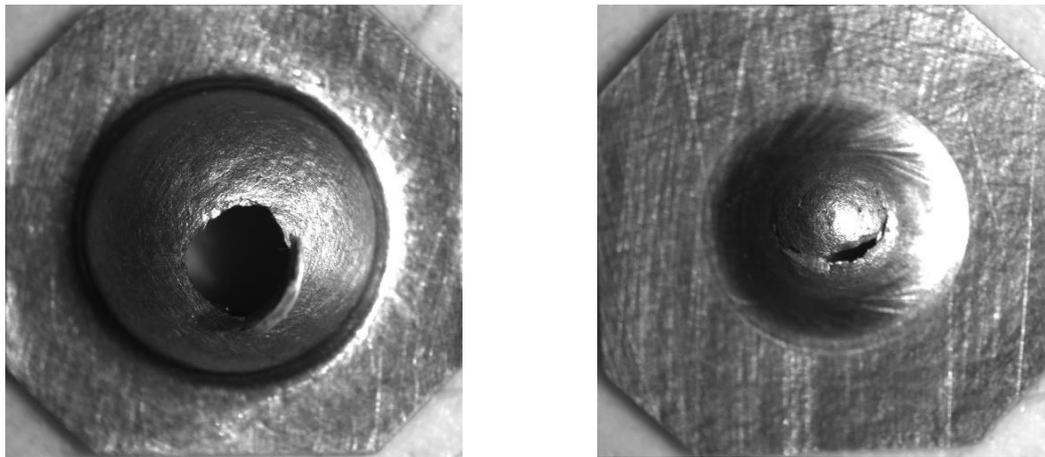


(a) HBT



(b) SPT

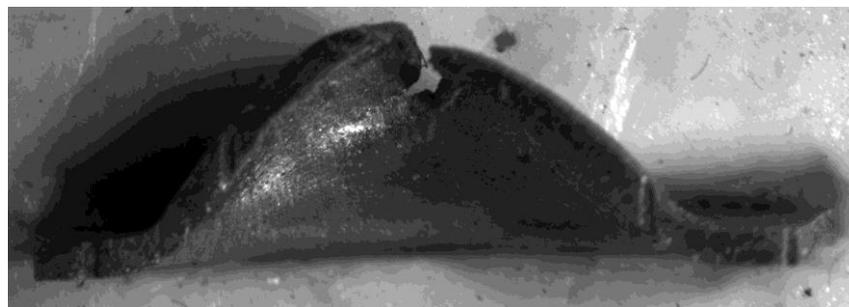
**Figure 3.** The specimen deformation comparison, the maximum displacement is 0.1mm. The surface of the specimen is sanded to make the deformation more obvious.



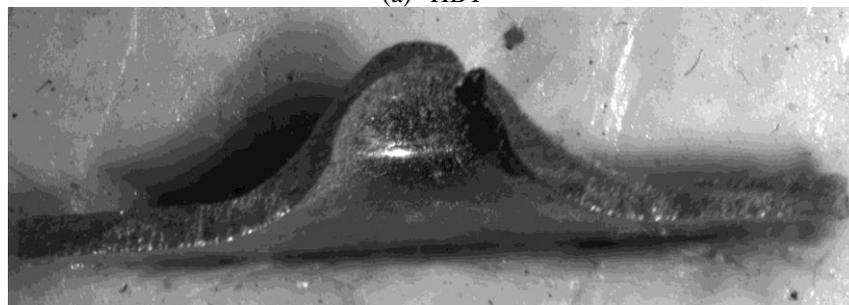
(a) HBT (b) SPT

**Figure 4.** The fractured specimen deformation comparison.

The specimen after break is different, as shown in figure 4. For HBT, the deformation is similar to sphere, and the radius of the sphere is decrease with the increase of the hydraulic pressure. At the final moment, the initial break area is at the top of the sphere. For SPT, the deformation is similar to cone, and the height of the cone is raise with the increase of the load. Not like HBT, the initial break area is at the skirt of the cone, not at the top of the specimen. The friction between the puncher and the specimen play an important role in determining the location of the initial break. The specimen cut into two parts by electron discharge machining. The section of the specimen is illustrated in figure 5.



(a) HBT



(b) SPT

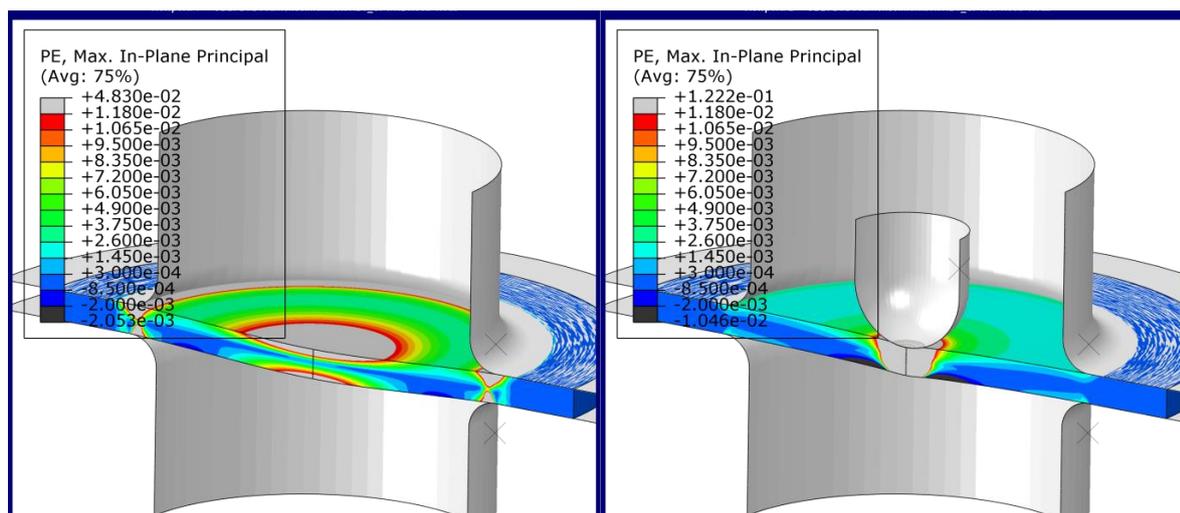
**Figure 5.** The cross sections of the broken specimens.

### 3.3. Loading and deformation

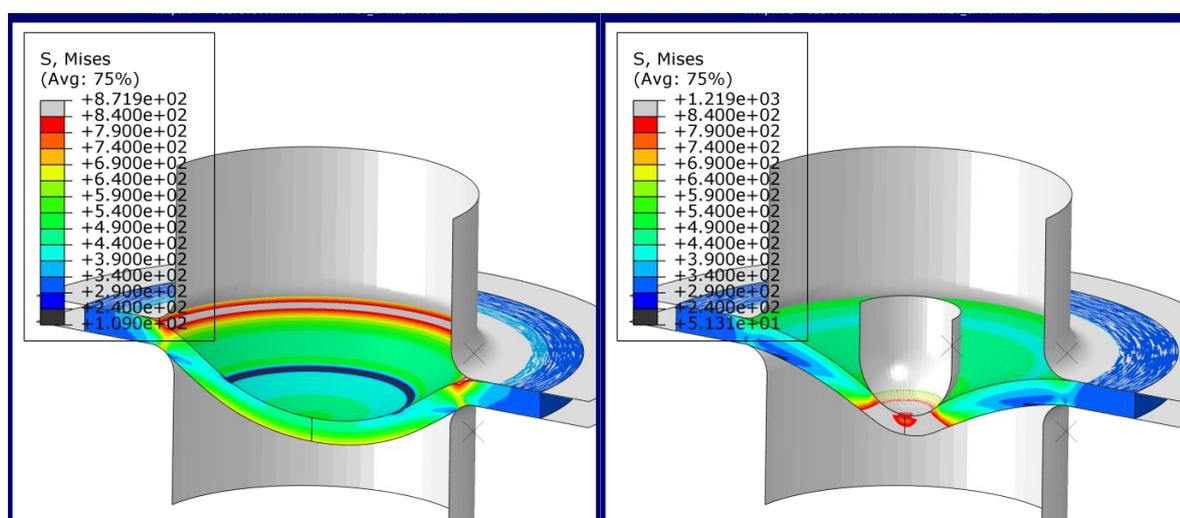
At one level, SPT is a strain-controlled testing method, while HBT is a stress controlled testing method. For SPT, the puncher move to the specimen with a constant speed and a load sensor connected the puncher measures the load to get the displacement-load curve of the test. For HBT, the pressure of the hydraulic oil increase with a constant rate, the displacement of the specimen is transmitted outside of the fixtures and measured by a digital camera. The data for the pressure-displacement curve is from the hydraulic system pressure sensor and the computer digital camera. After the break of the specimen, the pressure of the hydraulic oil decrease to zero immediately and hydraulic oil pour out from the broken specimen, while the load on the puncher will decrease but not to zero. The

SPT and HBT are similar to the two kinds of testing procedure to the uniaxial tension test, which are strain-controlled tension test and stress-controlled test. Usually, the tension test machine drive by servo motor use strain-controlled testing procedure and electro-hydraulic servo use stress-controlled testing procedure.

The most import difference between HBT and SPT is the loading and its distribution on the specimen. The hydraulic pressure distribute on the specimen evenly for HBT, while the puncher is only contact with the specimen within a small area for SPT. With increase the pressure of the hydraulic oil, the contact geometry of the hydraulic oil and specimen changes from plate to spherical cap, and the radius of the spherical cap decrease with the increase of the pressure. During the testing, the contact area is always one side of the surface, and the pressure is distributed evenly on the contact area. For SPT, the contact geometry of the puncher and specimen is just a point at the beginning, and with the increase of the loading force, the contact geometry transform from a point to a spherical cap, and the radius of the spherical cap is a constant which is determined by the radius of the puncher. The intact force distribute on the specimen is not evenly and the will change with the deformation of the specimen. The plastic strain and stress distribution could be simulated by finite element method, and the simulation results are show in figure 6 and figure 7.

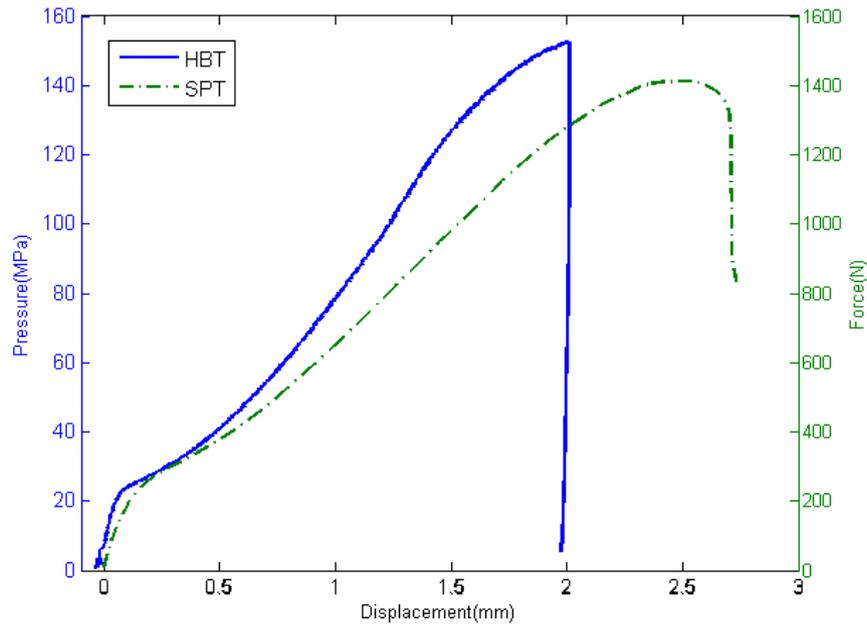


**Figure 6.** The initial plastic zone(the maximum displacement is 0.1mm.Left:HBT, right:SPT).



**Figure 7.** The stress distribution(the maximum displacement is 1.2mm.Left:HBT, right:SPT).

From a general point of view, if we regardless of the friction between the puncher and the specimen, HBT could be seen as a special kind of SPT whose puncher radius decrease with the deformation of the specimen. SPT could also be seen as a special case of HBT whose hydraulic pressure is limited to a small area with unevenly distribution.



**Figure 8.** The testing curve of Q420.

The pressure-displacement curve from HBT and the load-displacement curve from SPT is drawn in figure 8. Both curves have turning points at low pressure or load, but the mechanism of the turning point is different. It is related to the initial plastic zone, as shown in figure 6.

#### 4. Conclusion

Due to the similarity between HBT and SPT, these two methods could be seen as one type of testing method. Those two testing methods could learn from each other in all aspects.

The test devices, test procedure and the results are systematically compared. All of them will greatly influence the test results. A universal test platform is designed for the comparison result. Two kinds of materials P91, Q420 are tested for comparison. The fracture location of small punch test and hydraulic bulge test is compared based on the profile of ruptured specimens, and the fracture mechanism of them is analyzed. The testing data interpretation methods should be further optimized to get a uniform formation.

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