Small Punch Test for the Investigation of Mechanical Property Evolutions Due to TRIP at Low Temperatures

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Abstract
Materials' mechanical properties transform at various temperatures. Transformation-induced plasticity (TRIP) makes the material's properties change. The current study aims to investigate how the small punch test (SPT) can reveal the TRIP in steel. To this end, first, two SPT specimens were prepared and tested at ambient temperature and -196 degrees using liquid nitrogen. A considerable difference in force-displacement curves was seen, revealing a great increase in ultimate stress at -196 degrees. This change proves that the TRIP phenomenon is seen in the SPT.

Keywords: Small punch test, Transformation induced plasticity, Mechanical property

Introduction

The SPT is popular due to its small-scale specimen that can be removed from structures surface to determine material properties. It was first introduced for material degradation in irradiated structures [1]. However, it has also been used for other investigations. This test is employed for material characterization from various points of view, namely determination of mechanical properties such as yield stress [2, 3], ultimate stress [4, 5], fracture toughness [6, 7], fatigue [8, 9], and creep [10, 11].

TRIP is introduced as the transformation from austenite to martensite phase where the material experiences plastic deformations. The process leads to a high rate of work-hardening and more strength. The process causes a delay in necking, thereby achieving more resistance to failure. This procedure can be observed as an upshift in the stress-strain curve[12]. There have been lots of studies in the field of material engineering to investigate TRIP phenomenon, aiming to reach better mechanical properties[13].

The current study is to investigate the possibility of the SPT test in TRIP evaluation. For this purpose, some SPT specimens are prepared from TRIP steel and are tested at room temperature and at -196 degrees. The low temperature is achieved by putting the SPT setup in liquid nitrogen. If there is resistance to failure, it should be a sign of TRIP in the SPT test.

Theory and Experiment

The main reason for TRIP is to obtain a required minimum amount of retained austenite in the microstructure. This is possible only if austenite transforms into martensite. The initial temperature of martensite is somehow lowered to a value below room temperature[14]. Hence, testing at low temperatures should be focused on TRIP investigations.

The SPT specimen is a 0.5 mm thickness and 1cm diameter disc that is punched by a rigid ball. Figure 1 shows a schematic of the SPT setup. Figure 2 also shows a typical SPT force-displacement sample curve. Clearly. There are four sections in the curve. Sections 1 and 2 refer to specimen bending during the test. The first relates to elastic bending and the second relates to the plastic. In the third section, a membrane regime starts. The TRIP phenomenon occurs in sections 2 and 3. Using Py and Pmax the yiels stress and ultimate stress are determinable [15]. Finally, Figure 3 shows the test setup.

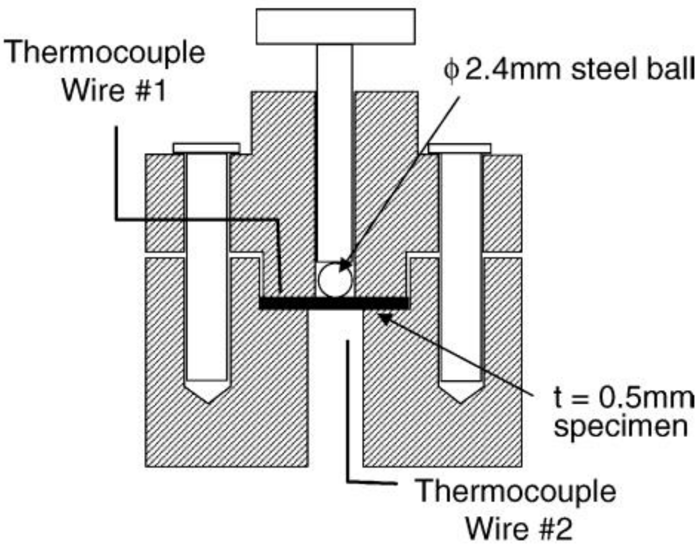

Figure (1) Schematic of a SPT setup [16]

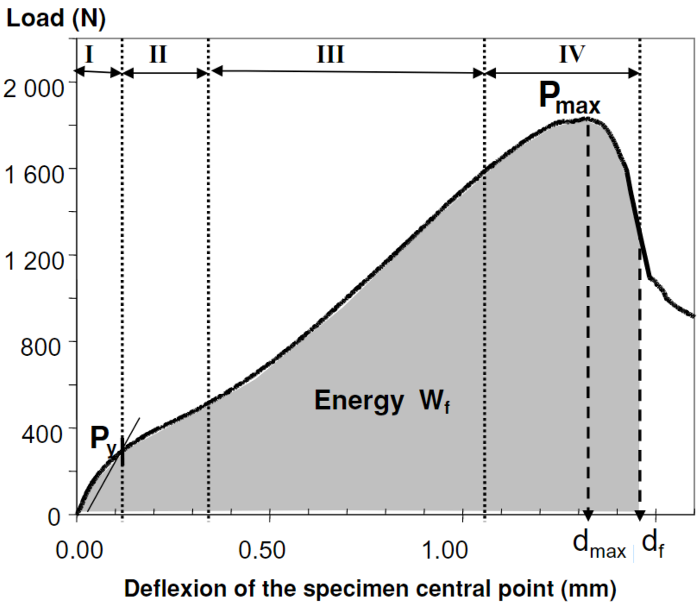

Figure (2) Typical SPT force-displacement curve [17]

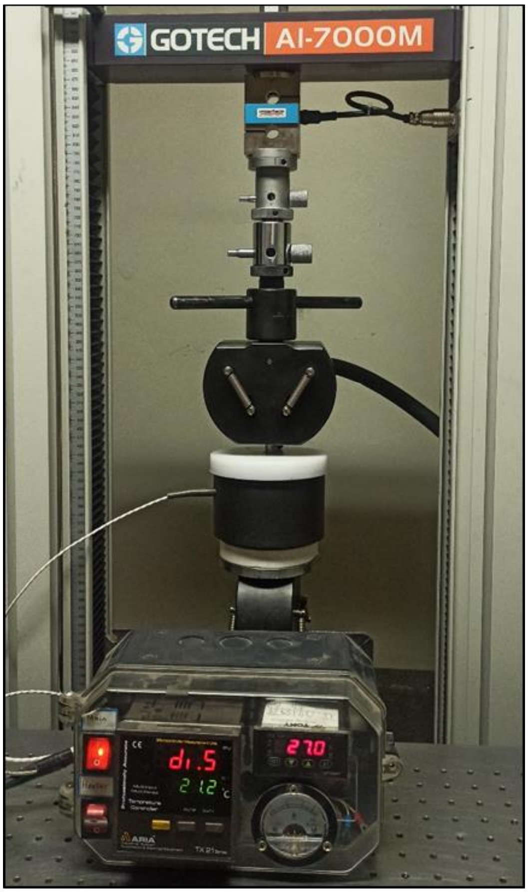

Figure (3) Test Setup

Results Discussion

After specimen preparation, various tests were done at room and -196 degrees. Figure 4 shows the curves resulting from the tests at two temperatures. The red line demonstrating the ambient test result is more deflected. Nevertheless, the maximum force in the purple curve representing the tests done at -196, is approximately 2.5 times more than the red curve. This reveals a considerable strengthening due to low temperatures. Table 1 shows results. Here, it can result that the SPT test is able to report TRIP, and could be employed for future studies. The final figure shows the SEM images from specimen fracture surfaces. In the Figure, the left image with the red frame shows the fracture surface of the specimen tested at room temperature, and the right one with the purple frame shows the fracture surface of the specimen tested at -196 degrees.

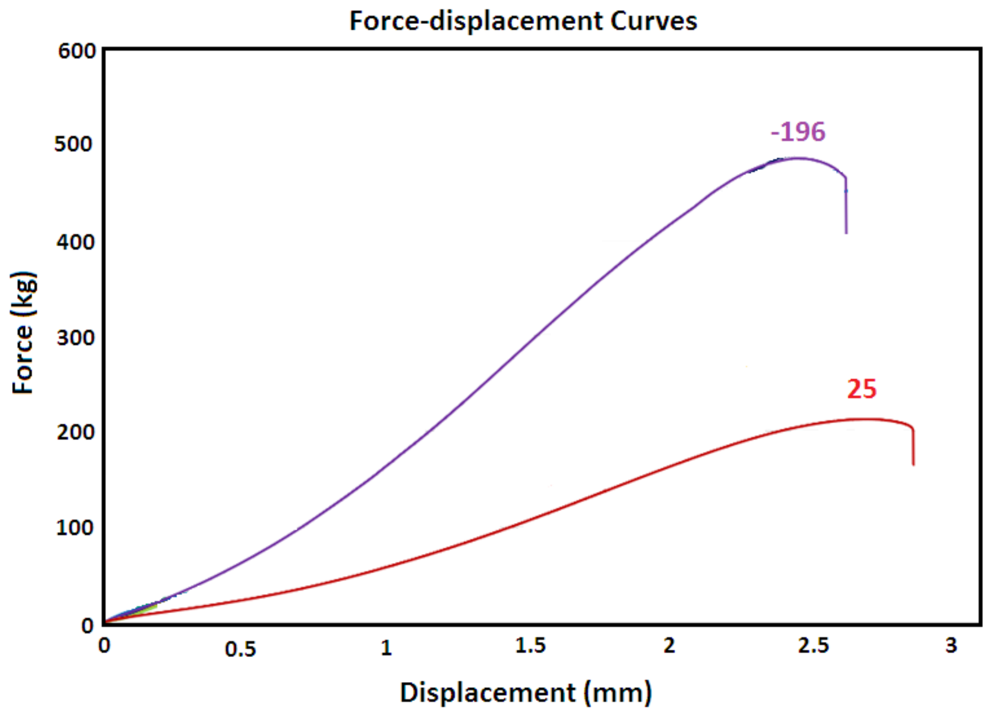

Figure (4) SPT Force-displacement curves at ambient and cold temperatures

Table 1-Test Results

Specimen	Temperature (°C)	Maximum Force (kg)	Fracture Energy (J)	Ultimate stress (MPa)
1	25	214.4	1.57	~500
2	-196	472.5	5.2	~1250

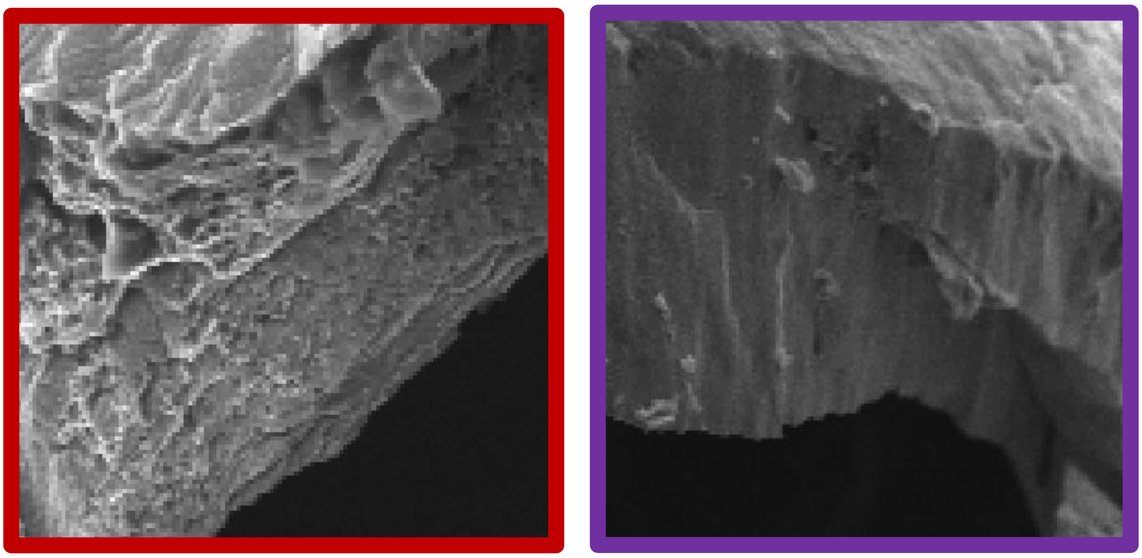

Figure (5) SEM images from the specimen surface of SPT specimens

Conclusions

The applicability of the SPT in the investigation of TRIP was studied. Two SPT specimens were tested and a remarkable enhancement was observed in resulted curves, showing that the ultimate stress reaches to around 1250 Mpa at -196 degrees. This can show the effect of TRIP in the material. Hence, the SPT test is a useful technique to study the TRIP phenomenon.

References

[1] M.P. Manahan, A.S. Argon, O.K. Harling,, "The development of a miniaturized disk bend test for the determination of postirradiation mechanical properties," Journal of Nuclear Material, vol. 104, pp. 1545-50, 1981.
[2] J. Kameda, X. Mao, "Small-punch and TEM-disc testing techniques and their application to characterization of radiation damage," Journal of Material Science, vol. 27, pp. 983-9, 1992.
[3] P. Hähner, C. Soyarslan, B.G Çakan, S. Bargmann, "Determining tensile yield stresses from Small Punch tests: A numerical-based scheme," Materials & Design, vol. 182, 2019.
[4] E. Altstadt, M. Houska, I. Simonovski, M. Bruchhausen, S. Holmstr, "On the estimation of ultimate tensile stress from small punch testing," International Journal of Mechanical Sciences, vol. 136, pp. 85-93, 2018.
[5] J. Calaf Chica, P. Bravo Díez, M. Preciado Calzada, "A new prediction method for the ultimate tensile strength of steel alloys with small punch test," Materials, vol. 11, no. 9, pp. 1-16, 2018.
[6] R. Lacalle, D. Andres, J.A. Alvarez, F. Guti, "Transition Region of Nuclear Vessel Steels: Master Curve Approach Using Small Punch Notched Specimens," Key Engineering Materials, vol. 734, pp. 77-86, 2017.
[7] M. Abendroth, M. Kuna,, " Identification of ductile damage and fracture parameters from the small punch test using neural networks," Engineering Fractuire Mechanics, vol. 73, pp. 710-25, 2006.
[8] R.J. Lancaster, S.P. Jeffs, H.W. Illsley, C. Argyrakis, R.C. Hurst, G.J. Baxter, "Development of a novel methodology to study fatigue properties using the small punch test," Materials Science and Engineering: A, vol. 748, pp. 21-9, 2019.
[9] D.T.S. Lewis, R.J. Lancaster, S.P. Jeffs, H.W. Illsley, S.J. Davies, G.J. Baxter, "Characterising the fatigue performance of additive materials using the small punch test," Matewrial Science and Engineering: A, vol. 754, pp. 719-27, 2019.
[10] A. Moradi, N. Soltanui, H. Nobakhti, "Experimental study of remaining creep life of SA-304L stainless steel using small punch creep test," Materials at High Temperatures, vol. 35, no. 4, pp. 1-8, 2017.
[11] H. Nobakhti, N. Soltani, "Evaluating Small Punch Test as Accelerated Creep Test Using Larson–Miller Parameter," Experimental Technique, vol. 40, pp. 645-50, 2016.

[12] F.D. Fischer, G. Reisner, E. Werner, K. Tanaka, G. Cailletaud, T. Antretter, “A new view on transformation induced plasticity (TRIP)”. International Journal of Plasticity, Vol 16, pp 723-748, 2000.
[13] M. Soleimani , A. Kalhor, H. Mirzadeh, “Transformation-induced plasticity (TRIP) in advanced steels: A review”, Materials Science & Engineering A, 2020.
[14] V.A. Alza, V.P. Chavez, “TRIP Steels: Factors influencing their formation, Mechanical Properties and Microstructure- A Review”. Journal of Mechanical and Civil Engineering, Vol 19, 2022.
[15] “European standard on small punch testing of metalic material”, 2017.
[16] M. Kim, Y.J. Oh, B.S. Lee, “Evaluation of ductile–brittle transition temperature before and after neutron irradiation for RPV steels using small punch tests”, Nuclear Engineering and Design 235, 2005.
[17] M. A. Contereras, C. Rodriquez, F. J. Belzunce and C. Betegon, “Use of the small punch test to determine the ductile-to-brittletransition temperature of structural steels”, Fatique and Fracture Engineering Material Structures, 2008.