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The use of the small punch test to solve practical engineering problems

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ABSTRACT

Two examples of the use of the Small Punch Test (SPT) to solve practical engineering problems are studied in this paper. The first is the mechanical characterization of powder metallurgical samples. In this case, the complex geometry of the samples does not allow the use of any other type of mechanical test, while knowledge of the mechanical properties of the sintered product before its use allows the modification of process parameters aimed at optimizing the product easily and economically. The second example is the mechanical characterization of the heat affected zone (HAZ) of a weld joint, which is currently difficult to characterize, except using hardness profiles. Application of the SPT to samples machined from the different HAZ subzones allows a precise description of the characteristic mechanical behavior of the different microstructures produced in the welding thermal cycle.

1. Introduction

The Small Punch Test (SPT) is a miniature test that has found a broad field of application in engineering as it employs quite small samples, it is a very simple and economic test and it allows the evaluation of the characteristic mechanical properties of different types of materials with sufficient precision and reliability. Furthermore, although this test has not yet been internationally standardized, there exists a European Code of Practice [1] specifying the way to perform this test in order to determine the mechanical properties of metallic materials at room and low temperatures (tensile and fracture behavior) as well as at high temperatures (creep tests). Moreover, the SPT has been used to obtain the tensile mechanical properties of many different metallic materials and appropriate correlations have been defined between the parameters derived from this test and tensile mechanical properties, i.e. yield strength, ultimate tensile strength and tensile elongation [2].

The use of the SPT is especially attractive when analyzing the progressive degradation of metallic alloys during their service life, as for example in the case of nuclear components submitted to neutron irradiation or those working during long periods of time at high temperatures [3,4]. In these situations, the SPT can be considered a quasi-non-destructive test, as small SPT samples can be extracted, machined and tested directly from a given component without affecting its mechanical behavior in order to determine the progressive reduction in its main properties in the course of its normal service. The SPT is also especially useful for analyzing the mechanical properties of very small regions, such as the heat affected zone of welded joints or the thickness affected by specific surface treatments and also to characterize small, heterogeneous and anisotropic components [5,6].

This paper describes the use of the Small Punch Test in two different, well-known engineering applications. The first refers to the mechanical characterization of automotive synchronizer hubs made by cold compaction and sintering of steel powders. These components have parts of different thicknesses, with small sizes that do not allow the extraction of standard tensile specimens. Moreover, the directionality of the usual axial compaction gives rise to mechanical heterogeneities which are difficult to evaluate by other testing procedures. In the second application, the SPT was used to characterize very small regions of a heat affected zone of a steel weld, i.e. the region that suffered the characteristic thermal welding cycle that induces significant microstructural modifications and local variation of mechanical properties that can result in premature failure of the weld.

2. Small punch test

The SPT specimens used in throughout this study had the following dimensions: 10×10 mm and 0.5 mm of nominal thickness. Fig. 1 shows the experimental device, custom designed and manufactured in our laboratory, which was mounted on a universal testing machine fitted with a 5 kN load cell. A hemispherical-head punch with a diameter of 2.5 mm and a lower die hole with a diameter of 4 mm provided with a 0.2 mm chamfer edge were employed for this purpose. The SPT specimens were firmly clamped by means of a threaded fixer and were deformed until

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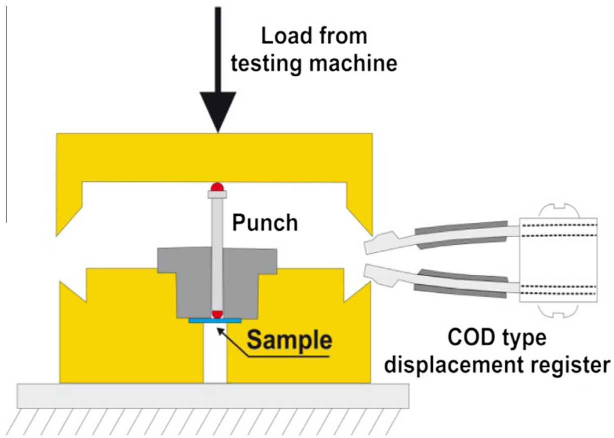

Fig. 1. Schematic representation of the SPT testing device.

failure under a constant displacement rate of 0.2 mm/min. The punch and the specimen were lubricated before testing to minimize the effect of friction. Punch displacement was accurately measured by means of a COD extensometer and was corrected taking into account the compliance of the testing device as a whole. All these SPT variables complied with the European Code of Practice [1].

Fig. 2 shows the typical SPT load-displacement records obtained in tests performed on ductile and brittle samples, respectively. Their respective characteristic regions are also given, along with images corresponding to the typical failure observed in both specimens (a circumferential crack in the case of the ductile specimen and star-shaped cracks in the brittle specimen). The same figure also shows the P_y and P_m loads, respectively used to estimate the yield strength and the ultimate tensile strength, and the displacement under maximum load, d_m, used to evaluate the tensile elongation. P_y was always calculated at the crossing point between the SPT curve and a straight line parallel to the initial slope of the graph, with an offset displacement of t/10, $P_{y(t/10)}$, t being the specimen thickness.

Using many different steels as well as aluminum alloys, Garcia et al. [2] found the best expressions to estimate the yield strength and the ultimate tensile strength of ductile metallic alloys by means of the aforementioned SPT parameters:

$$\sigma_{ys}\ [\mathrm{MPa}] = 0.346\ (P_y/t^2) \quad (1)$$

$$\sigma_{ut}\ [\mathrm{MPa}] = 0.277\ (P_m/d_m t) \quad (2)$$

It has also been demonstrated that the SPT parameter that best characterizes the ultimate tensile strength in the case of brittle materials is P_m/t^2 [6,7]. However, the different proposed correlations between tensile elongation and displacement at the SPT maximum, d_m, are generally poor and do not afford sufficiently reliable results. This is because tensile elongation is not a material property, but is dependent on the geometry and dimensions of the tested specimens.

3. Sintered synchronizer hubs

Sintered processes are especially useful in the manufacture of large series of small components with a complex geometry. These components show interesting mechanical properties, but are highly dependent on the different parameters used in the manufacturing process. One of the most important factors is the final porosity, which depends on the type of powder used and the compacting and sintering phases of the process [8,9]. For example, a pre-diffusion alloyed iron powder will have a higher compressibility and will give rise to a component with a lower porosity than a pre-alloyed powder when the rest of manufacturing factors remain unmodified. Moreover, the geometry of the component (volume differences among its constitutive parts) also affects its porosity [10]. The type of furnace and the atmosphere are also important manufacturing parameters to take into account. Although different atmospheres can be used (N_2/H_2, endogas, exogas, etc.) to maintain the chemical composition of the product, it is not easy in practice to avoid phenomena such as de-carburation, carburation, oxidation, reduction, etc. Furthermore, the size of the component is another important parameter to take into account. For a similar sintering time, the diffusion process will be less effective in a larger component and, moreover, the cooling rate after sintering will be

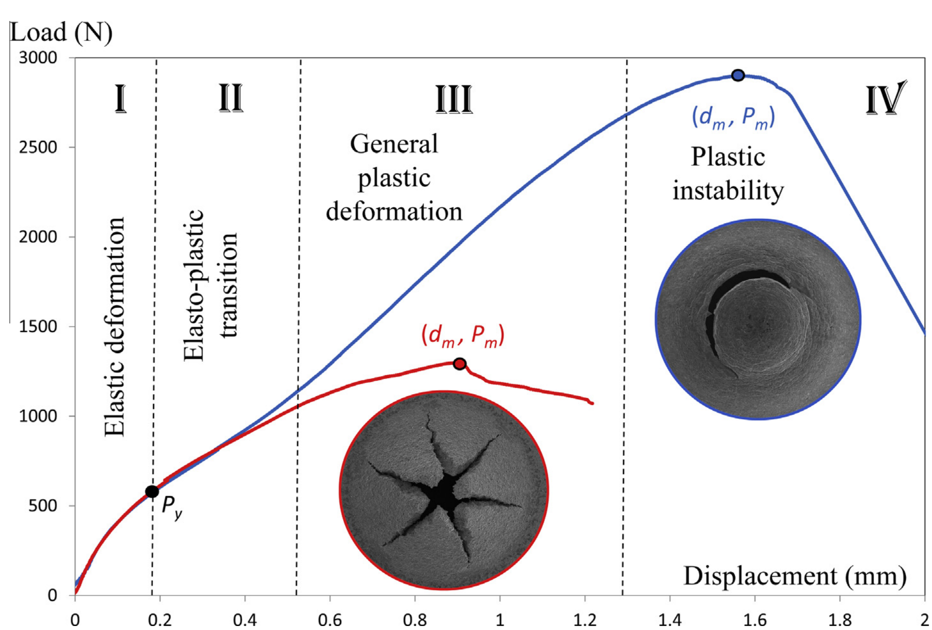

Fig. 2. Characteristic SPT curves. Ductile and brittle samples showing their typical failure morphology.