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Strain rate dependence of impact properties of sintered 316L stainless steel

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Abstract

This paper uses a material testing system (MTS) and a compressive split-Hopkinson bar to investigate the impact behaviour of sintered 316L stainless steel at strain rates ranging from $10^{-3}\ s^{-1}$ to $7.5 \times 10^3\ s^{-1}$. It is found that the true stress, the rate of work hardening and the strain rate sensitivity vary significantly as the strain rate increases. The flow behaviour of the sintered 316L stainless steel can be accurately predicted using a constitutive law based on Gurson's yield criterion and the flow rule proposed by Khan, Huang and Liang (KHL). Microstructural observations reveal that the degree of localized grain deformation increases, but the pore density and the grain size decrease, with increasing strain rate. Adiabatic shear bands associated with cracking are developed at strain rates higher than $5.6 \times 10^3\ s^{-1}$. The fracture surfaces exhibit ductile dimples. The depth and density of these dimples decrease with increasing strain rate.

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1. Introduction

Due to its excellent corrosion and oxidation resistance, good strength and high toughness properties, sintered 316L stainless steel is used to fabricate numerous structural components for applications in the architectural, industrial and nuclear power plant fields [1]. Typical applications in nuclear power plants include filtration, liquid and gas metering, piping flanges and clamps, fasteners, wall/shielding blanket modules, and ball valves. These components can generally be produced most economically by means of powder metallurgy methods. The mechanical properties of sintered compacts are determined principally by their final density and matrix properties and by the loading conditions applied. The effects of porosity, heat treatment, sintering temperature and homogenization on the mechanical and wear properties of sintered alloys have been investigated both experimentally and theoretically [2–6]. However, relatively few studies have investigated the dynamic impact properties of sintered alloys as a function of the strain rate. These properties are

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of fundamental concern when the components are employed in actual service conditions. Therefore, it is necessary to develop a thorough understanding of the effects of strain rate on the impact properties of sintered 316L stainless steel.

Experimental measurements of the plastic deformation behaviour of a wide variety of pure metals and alloys have been carried out in order to study the effects of strain rate. These tests have been performed for various crystal structures, including fcc metals, bcc metals and hcp metals [7–10]. The results of these studies have shown that for a given plastic strain, the flow stress is linearly related to the natural logarithm of the strain rate for strain rates ranging from approximately 10^{-3} to $10^{3}\ s^{-1}$. However, high strain rate tests have demonstrated that many metallic materials show a marked strain rate sensitivity at strain rates in excess of approximately $10^{3}\ s^{-1}$ as a result of a change in the deformation mechanisms [11,12]. The change in the deformation mechanisms at this transition strain rate has been attributed to the increasing prominence of a dislocation drag mechanism or to the enhanced rate of dislocation and twin generation [13]. Furthermore, it has been shown that the flow stress/strain rate dependence has a direct linear relationship in the higher strain rate region [14–16]. Previous experimental measurements have generally been conducted on solid (i.e. fully dense) materials. Accordingly, data relating to the impact behaviour of sintered alloys under high strain rates is sparse, particularly for the case of sintered 316L stainless steel compacts. Hence, the aim of the present study is to investigate the effect of the strain rate on the impact deformation and fracture behaviour of sintered 316 stainless steel. The correlation between the impact response and the fracture evolution of the tested material is also presented.

2. Experimental procedure

The present study used 316L stainless steel powder with the following composition: 16–18 wt% Cr, 10–14 wt% Ni, 2–3 wt% Mo, 2 wt% Mn, 1 wt% Si, 0.03 wt% C, and a balance of Fe, supplied by Novamet Ltd., USA. As shown in Fig. 1, the powder particles were spherical in shape. The mean particle size and apparent density of the powder were 13 μm and 2.75 g/cm^3, respectively. The powder was first mixed with a paraffin wax binder (3 wt% of the powder) in a ball mill for 24 h, and then cold-compacted uniaxially within a 10 mm diameter cylindrical die at a pressure of 500 MPa. The compacts were then sintered in a tube furnace heated at a rate of 10 °C min^{-1} to the specified sintering temperature of 1340 °C. Subsequently, the compacts were soaked for 1 h in a dry hydrogen atmosphere. The sintered compacts with a length of 9.6 mm and a diameter of 9.2 mm were then machined to produce cylindrical specimens measuring 7 mm × 7 mm (length × diameter). The density of the specimens was measured using the water immersion method

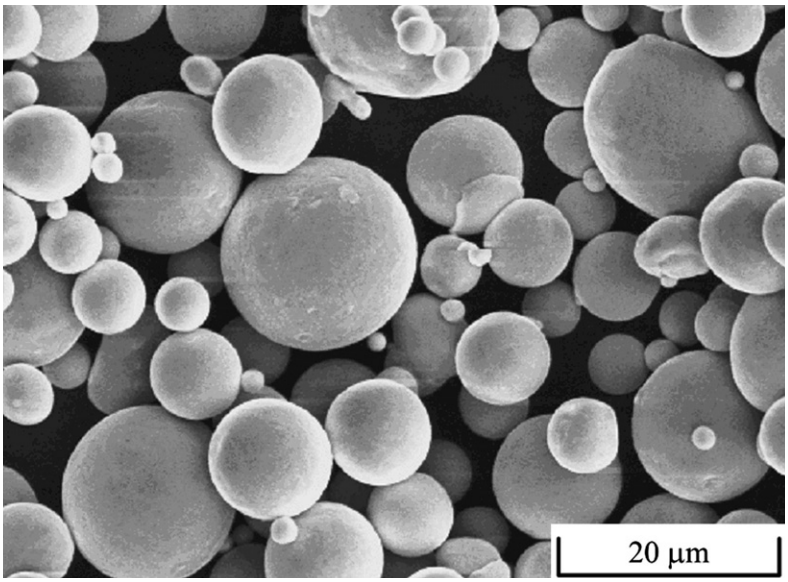

Fig. 1. Scanning electron micrograph of 316L stainless steel powder.