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Study on dynamic mechanical properties of high nitrogen steels

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ABSTRACT

Reliable dynamic mechanical properties of high nitrogen steels are necessary for the design and assessment of armor structures subject to impact and blast. A series of experiments, based on Hopkinson bar techniques, were conducted and described in this study. The dynamic compression, tensile and shear properties of high nitrogen steel had been tested, and the stress-strain curves under high strain rates were obtained. The results have been showed as follows: High nitrogen steel has a remarkable strain rate strengthening effect. Compared to the static curves, the constitutive curves of dynamic tension and compression move upper. The dynamic compressive yield strength of high nitrogen steel increases first and then decreases with the increase of strain rate, and the yield strength varies in the range of 1465−1549 MPa within the range of 1147−2042 s^{-1} strain rate; The tensile strength of high nitrogen steel increases with the increase of strain rate. When the strain rate is greater than 1341 s^{-1}, the tensile strength will not increase and the curve tends to be gentle. The pure shear yield strength of the high nitrogen steel is above 800 MPa.

1. Introduction

Armor steel is the main structural material for the bodywork, turret and additional armor of tanks and armored vehicles, which has good strength, toughness, ballistic performance and good technological performance [1–3]. For a long time, the medium carbon and low alloy series by increasing the carbon content and using the corresponding heat treatment methods to improve the ballistic performance are used in armor steels at home and abroad [4,5]. High nitrogen steels have been studied and applied abroad since 1960s. And in 1990s, further research on high nitrogen steel has added a new way to the development of armor steel [6]. The strength of high nitrogen steel under the impact of high strain rate is obviously improved. When the projectile penetrates, the target of high nitrogen steel has strong impact hardening, which improves the ballistic performance of high nitrogen steel [7,8]. More than ten years of researches have been carried out in the field of high nitrogen steel abroad, which has already been applied in the field of national defense and military industry, especially in armor protective materials [9]. Therefore, it is necessary to study the dynamic mechanical properties of high nitrogen steels. In this paper, a series of experiments, based on Hopkinson bar techniques, were conducted and the dynamic properties of high nitrogen steel had been obtained, which could support the design and assessment of armor structures.

2. Experiment

2.1. Experimental materials

The raw material used in the experiment was 20 mm thickness nitrogen austenitic steel plate. The chemical composition was shown in Table 1. The quasi-static compression and tension stress-strain curves of high nitrogen steel were shown in Figs. 1 and 2. They showed that the compression yield stress and tension yield stress of this material under quasi-static test are about 900 MPa and 1000 MPa respectively.

2.2. Experimental method

Dynamic tests of high nitrogen steel were carried out on the

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Table 1
Chemical composition of high nitrogen steel (ω/%).

Element name	N	C	Mn	Ni	Cr	Mo	Cu	W
Percentage/%	0.88	0.030	19.28	2.01	19.32	0.0001	0.031	0.005

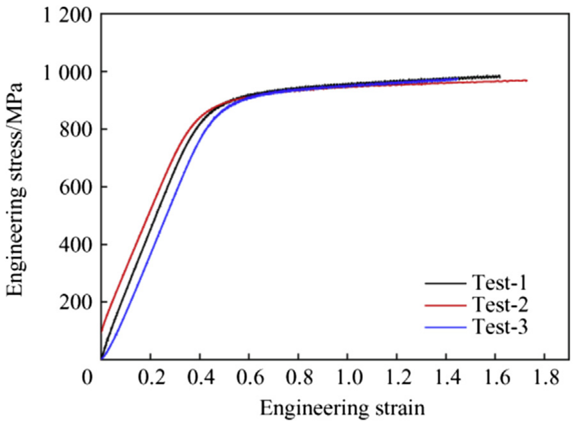

Fig. 1. Quasi-static compression stress-strain curve of high nitrogen steel.

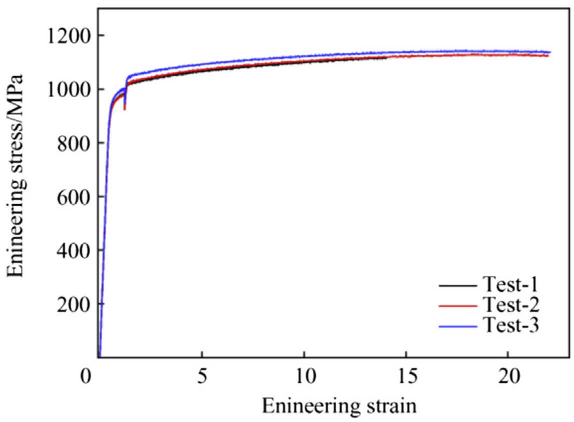

Fig. 2. Quasi-static tension stress-strain curve of high nitrogen steel.

Split- Hopkinson bar at room temperature. It consists of gas gun, incident bar, transmitted bar, striker, buffer bar, shock absorber, and strain gage circuits to measure strain signal in the bars. Figs. 3 and 4 show the Schematic of SHPB and SHTB device.

In this paper, the compression and tension tests were conducted on Hopkison bar which diameter is 16 mm and material is high carbon chromium alloy steel, the shearing tests were conducted on Hopkison bar which diameter is 20 mm and material is LY12 super-hard aluminum alloy. The test specimens were shown in Fig. 5, in which the compression specimens were measured diameter 8 mm × 4 mm, the tension specimens were measured diameter 4 mm-gage length 10 mm, the thickness of shearing specimens were 2 mm.

In tension tests, the gas gun launches the tubular striker to impact the incident bar. The transfer flange transfers the incoming elastic compressive stress wave into the elastic tensile stress which travels through the incident bar toward the specimen. When the tensile stress wave propagates into the specimen, it reverberates within the specimen until a nominally homogeneous stress state is achieved. And part of the wave is transmitted through the transmitted bar as a tensile wave, the rest is reflected back to the incident bar as a compressive wave. The strain signals were transferred into electrical signals by high dynamic strain indicator, and were recorded by the Multi-channel transient digital recorder. Analogously, in compression and shearing tests, through recorder the stress wave travels in the bar to acquire test result.

The test technology of Hopkinson bar is based on two hypothesis [10]: the one dimensional stress hypothesis and the stress uniformity hypothesis. The stress and strain relationship is derived according to the one-dimensional stress wave theory.

The end surface of specimen connected with incident bar is set 1, and the other end surface connected to the transmission bar is set 2. The displacements of interface 1 and 2 are $U_1(t)$ and $U_2(t)$ respectively. It is assumed that the strain signal of tension is negative and compression is positive. So:

$$U_1(t) = -c_0 \int_0^t (\varepsilon_{\mathrm{i}}(\tau) - \varepsilon_{\mathrm{r}}(\tau))\mathrm{d}\tau \tag{1}$$

$$U_2(t) = -c_0 \int_0^t \varepsilon_{\mathrm{t}}(\tau)\mathrm{d}\tau \tag{2}$$

Where:

c_0 Elastic wave velocity;
$\varepsilon_{\mathrm{i}}(\tau)$, $\varepsilon_{\mathrm{r}}(\tau)$, $\varepsilon_{\mathrm{t}}(\tau)$ Strain signal of incident wave, reflected wave, transmission wave.

It is assumed that the original length and cross section area of the specimen are l_s and A_s respectively, so the average strain in the

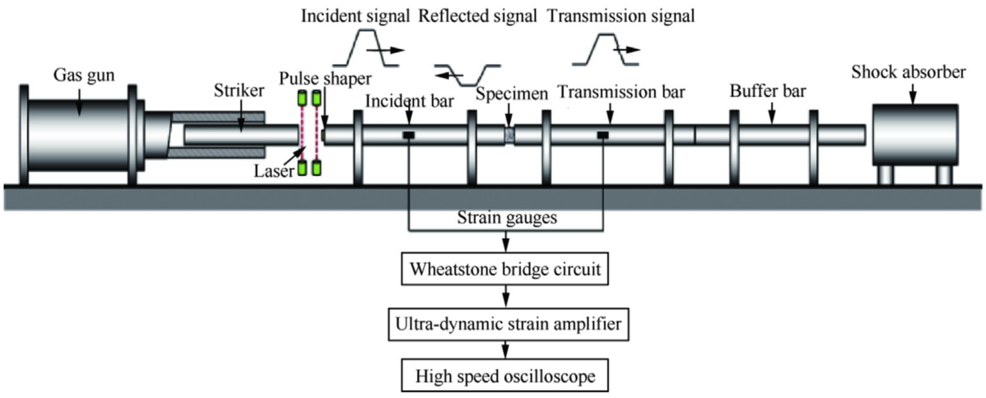

Fig. 3. Schematic diagram of SHPB device.

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