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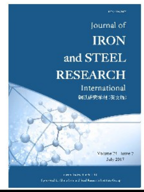

Dynamic mechanical behavior of ultra-high strength steel 30CrMnSiNi2A at high strain rates and elevated temperatures

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ABSTRACT

During high speed machining in the field of manufacture, chip formation is a severe plastic deformation process including large strain, high strain rate and high temperature. And the strain rate in high speed cutting process can be achieved to $10^5\ s^{-1}$. 30CrMnSiNi2A steel is a kind of important high-strength low-alloy structural steel with wide application range. Obtaining the dynamic mechanical properties of 30CrMnSiNi2A under the conditions of high strain rate and high temperature is necessary to construct the constitutive relation model for high speed machining. The dynamic compressive mechanical properties of 30CrMnSiNi2A steel were studied using split Hopkinson pressure bar (SHPB) tests at 30—700 ℃ and 3000—10000 s^{-1}. The stress-strain curves of 30CrMnSiNi2A steel at different temperatures and strain rates were investigated, and the strain hardening effect and temperature effect were discussed. Experimental results show that 30CrMnSiNi2A has obvious temperature sensitivity at 300 ℃. Moreover, the flow stress decreased significantly with the increase of temperature. The strain hardening effect of the material at high strain rate is not significant with the increase of strain. The strain rate hardening effect is obvious with increasing the temperature. According to the experimental results, the established Johnson-Cook (J-C) constitutive model of 30CrMnSiNi2A steel could be used at high strain rate and high temperature.

1. Introduction

30CrMnSiNi2A steel is a kind of high-strength low-alloy steel which is widely used in the manufacture of aircraft landing gear, wing, engine shell and other aviation structural parts[1,2]. However, it is difficult to machine because of its high strength, high hardness and poor plasticity[3]. As an important product of the cutting process, the formation of chip contains the dynamic mechanical characteristics of large strain, high strain rate, and high temperature, and so on. Thus, it is helpful to study the mechanism of chip formation for investigating the dynamic mechanical behavior.

In recent years, studies have mainly focused on the tensile properties of high-strength steel. Qin et al.[4] investigated the effects of strain rate on the tensile properties of two high-strength steel, and the results showed that DP700 and DP500 steels had significant strain rate sensitivity. Liu et al.[5] studied the effects of strain rate on the tensile properties, deformation and fracture behavior of the laser welded DP780 steel joint by quasi-static and dynamic tensile tests. Yan et al.[6] introduced the tensile behavior of the high-strength S690 steel at low temperatures encountered in the arctic region. In Ref. [7], the effects of strain rate on the necking and fracture behavior of high-strength steels were investigated using quasi-static and dynamic tensile tests. Trajkovski et al.[8] studied the flow and fracture properties of high-strength armor steel PROTAC 500 at 20—400 ℃ and various strain rates (0.001—1 s^{-1}). On the other hand, some researches have been done focusing on the dynamic compressive properties of high-strength steel. The mechanical properties of direct metal deposition (DMD) generated high-strength steel alloy parts with prismatic cavities under quasi-static and dynamic compressive loading were investigated in Ref. [9]. Qi et al.[10] gave the results about the compressive deformation behaviors of 300M high-

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strength steel at the temperatures of 850−1 200 ℃ and strain rates of 0.001−10 s^{-1}.

However, there were few studies about the dynamic mechanical behavior of 30CrMnSiNi2A steel, and the existing researches mainly aimed at the dynamic tensile or compressive behavior of 30CrMnSiNi2A steel at low strain rates and low experimental temperatures. Chen et al. [11] studied the effects of electron beam local post-weld heat-treatment on the properties of 30CrMnSiNi2A steel, and the new heat-treatment procedure was an effective method. Wu et al. [1] analyzed the dynamic compressive deformation behavior of 30CrMnSiNi2A at the strain rates of 500−5 000 s^{-1} and obtained the material parameters of its Johnson-Cook model. The dynamic mechanical properties of the 30CrMnSiNi2A steels heat treated by different processes were studied at different strain rates and room temperature in Ref. [12,13].

In this paper, the dynamic mechanical behavior of 30CrMnSiNi2A steel at high strain rates and high temperatures was investigated using the split Hopkinson pressure bar (SHPB) tests. The effects of temperature, strain rate and strain on the stress of 30CrMnSiNi2A steel were analyzed in the dynamic compression process, and the strain rate sensitivity, temperature sensitivity and strain hardening effect of the material were also discussed. Moreover, the Johnson-Cook (J-C) constitutive model of 30CrMnSiNi2A steel was established.

2. Experimental

2.1. Material

The ultra-high strength steel 30CrMnSiNi2A, which was quenched by oil at the temperature of 900 ℃, was employed in this study. Its chemical composition is shown in Table 1[11], and the hardness and tensile strength are 48 HRC and 1570 MPa, respectively.

The cylindrical specimens for dynamic compression tests were machined into dimensions of ϕ2 mm×2 mm by wire-cutting, and the surfaces of samples were polished using sandpaper and coated with the butter. The specimens used in quasi-static tests were the cylinders with dimensions of ϕ5 mm×5 mm considering the accuracy of the experimental data.

Table 1
Chemical composition of experimental material (wt.%)

Mn	Cr	Si	Ni	C	P	S	Fe
1.14	0.92	1.19	1.71	0.30	≤0.0015	≤0.025	Balance

2.2. Experimental procedures

Dynamic compression tests were conducted on a micro Hopkinson pressure bar experimental apparatus, which was self-designed by an impact dynamics research group of Prof. Li Yulong of Northwestern Polytechnical University. Schematic diagram of the SHPB experimental apparatus is illustrated in Fig. 1. All dynamic compression tests were completed at temperatures of 30, 150, 300, 500, and 700 ℃. Moreover, considering the difference of dynamic mechanical behavior of the test material under different strain rates, four strain rates of 3000, 5000, 8000, and 10000 s^{-1} were adopted in the SHPB tests. The method of single factor experiment was used in this paper. Then, according to the results of three experiments under each set of parameters, the average values for each group were obtained with good repeatability. The quasi-static tests were carried out at temperature of 30 ℃ and strain rate of 0.001 s^{-1} by using a universal testing machine WDW-100D.

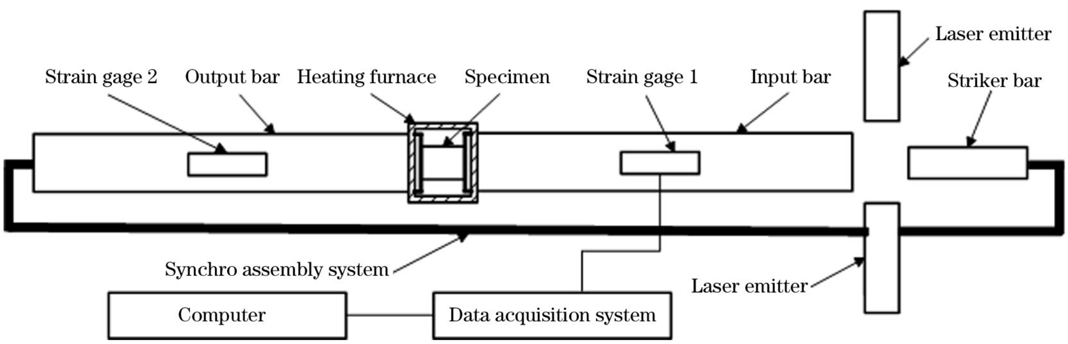

Fig. 1. Schematic diagram of SHPB experimental apparatus.

3. Results and Discussion

3.1. Thermal softening effects

The dynamic stress-strain curves of 30CrMnSiNi2A steel at different temperatures and strain rates are presented in Fig. 2. It can be seen that the flow stress decreases with increasing the temperature at a similar strain rate. Especially, the flow stress decreases significantly with increasing the temperature from 500 to 700 ℃, but it decreases slowly at temperatures of 30 and 150 ℃ with the decrease of temperature. Moreover, it can be seen from Fig. 2 that at strain rates of