Research on the Dynamic Mechanical Properties of 22SiMn2TiB-(616) Armored Steel

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Abstract

22SiMn2TiB-(616) armored steel is a kind of high-strength alloy steel. Considering its bullet-proof performance, the study of its dynamic mechanical properties is quite important. Thus, on the basis of SHPB experiment (hopkinson pressure bar), tests were conducted on the armored steel 616 specimen with different strain rates when it was impacted at different temperature and it is concluded from the experiment that temperature and strain rates influence the dynamic compression of the material to a greater degree. Higher strain rates can produce more dynamic yielding. Lastly, microstructure changes of the impacted material were observed. After comparison of the material before and after being impacted, bright ASB (adiabatic shear band) and tempered structure were discovered in the microstructure. This research will provide findings and references for the improvement of the properties of the armored steel material.

Keywords

22SiMn2TiB-(616) armored steel; Dynamic mechanical properties; SHPB experiment; Strain rate; Adiabatic shear band.

1. Introduction

22SiMn2TiB-(616) armored steel is a kind of alloy manufactured in special equipment with added material of manganese, nickel, molybdenum and vanadium. It is a low-content alloy but with great strength. Its final heat-treatment is tempering or quenching at low tempering. Up to now, research on 22SiMn2TiB-(616) armored steel is focused more on its welding techniques. For instance, Mr. Wang Qingneng studied welding stress and deformation of 22SiMn2TiB-(616) armored steel door with the finite element method; Mr. Li Xin did research on laser hybrid welding of the material; Mr. Yang Chao and others focused on bullet proof and dynamic mechanical properties of the materials 603, 675, 685 and the different effects of different components on their dynamic mechanical properties; Mr. Magudeeswaran and others' studies show that volume expansion can effectively prevent cold crack from widening and that austenite weld microstructure can dissolve much hydrogen, but to a lower degree of hydrogen dissolved; Mr. Zenitani and others devoted to high-strength cold crack sensitivity of the material and found that the stick with more Ni-Cr was better after comparison of four different sticks.

To sum up, more researches are focused on welding but not on dynamic mechanical properties of the material. Obviously, studies on this steel's dynamic mechanical properties and its relations to working conditions can benefit accurate selection of material and therefore improve economic profit and use ratio. Armored cars' working condition is mostly harsh and complicated----bullet and shell may collide the cars at high velocity in a much complicated mechanical way, which has great difference from that under quasi-static strain, response, strain rate, stress and shearing force of the material. More researches have been made on common mechanical properties, such as Yang modulus (E), ultimate strength（σ_b), yielding limit（σ_s), poisson ratio（μ), proportional limit（σ_p), hardness and stillness, etc. These data are important for judging material quality. But in reality, armored cars work often in dynamic loads, so their properties are different from those in quasi-static condition, and their failure mechanism is also different. Therefore, research on 22SiMn2TiB-(616) armored steel's mechanical properties under dynamic impact is near to understand its response in working condition and provide judgment for material quality and improvement of material properties with accurate references.

2. Test on 22SiMn2TiB-(616) armored steel's Dynamic Mechanism

Put the specimen between the incident bar and reflecting bar, as showed in Figure 1. Considering the high hardness of the specimen, put two spacers of the same material and diameter as the specimen, each between the specimen and the bar in order to protect the bars. When the specimen is placed smoothly and steadily, impact can be conducted. In high-temperature impact test, the specimen should be heated first and impacted when the temperature reaches the preset point, and its record and original oscillogram be recorded and kept. Then repeat the test on another specimen. See Figure 2 for impacted specimen.

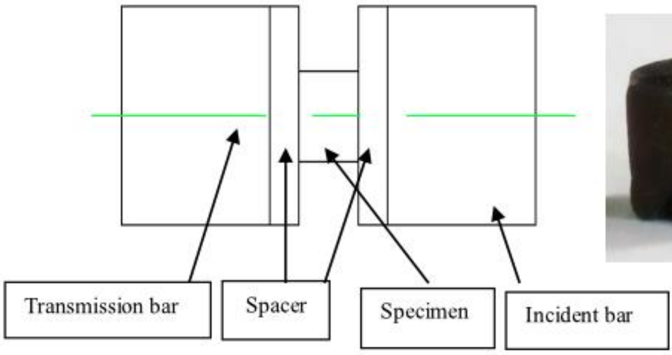


Fig.1 The installation of the specimen

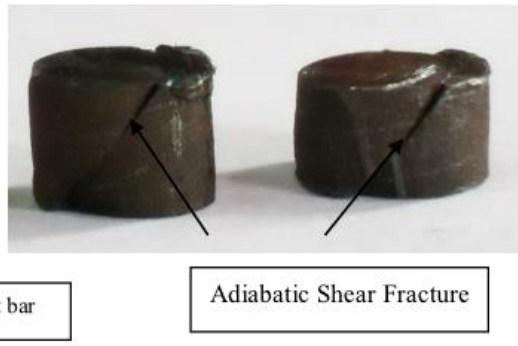


Fig.2 The macroscopic figure after the shock

The Following Tables 1 and 2 show the record of the test on 22SiMn2TiB-(616) armored steel. Before the test, the thickness and diameter of the specimen should be recorded. Table 1 is the test at normal temperature, with different air pressure, that is, with different impact speed. More air pressure produces faster speed. Different speeds produce different strain rates. Table 2 is the test under high temperature. Heat the specimen first, and then impact at the preset temperature. Most specimen did not have offside shear, apart from decreased thickness and bigger diameter. The shear appears at the slope of 45 ° angle to the horizontal line.

Table 1 Impact data under the normal temperature

		Before impact		After impact		Remarks	
Sequence	Pressure	Diameter	Thickness	Diameter	Thickness	Dynamic limit of yielding	Strain rate/s^{-1}
1	0.32	4.66	5.26	4.82	4.68	1425MPa	500
2	0.32	4.61	5.25	5.2	4.22	1430MPa	512
3	0.42	4.71	5.35	5.1	4.62	1508MPa	1021
4	0.52	4.57	5.25	5.06	3.1	1520MPa	1532
5	0.35	4.55	5.23	5	4.5	1365MPa	2120
6	0.45	4.58	5.24	5.3	3.9	1380MPa	4120
7	0.55	4.62	5.32	5.1	3.04	1420MPa	3510
9	0.35	3.75	3.34	5.5	1.68	1590MP	4510
10	0.45	3.54	3.45	6.2	1.38	1530MPa	5500
11	0.55	3.59	3.42	6.58	1.2	1550MPa	6100

Table 2 Impact data under the high temperature

			Before impact		After impact		Remarks	
Sequence	Temperature	Pressure	Diameter	Thickness	Diameter	Thickness	Dynamic limit of yielding	Strain rate/s^{-1}
1	100	0.32	4.7	5.3	4.8	4.8	1380MPa	600
2	100	0.52	4.67	5.26	5	4.3	1420MPa	1300
3	100	0.35	4.62	5.2	4.92	4.44	1350MPa	2012
4	100	0.55	4.61	5.24	5.2	4.24	1450MPa	3500
5	200	0.32	4.64	5.3	4.84	4.68	1210MPa	700
6	200	0.52	4.83	5.27	5	4.34	1320MPa	1520
8	200	0.35	4.57	5.27	4.92	4.64	1300MPa	2541
9	200	0.55	4.63	5.24	5.3	4.22	1330MPa	3510
10	300	0.32	4.61	5.2	4.92	4.02	1220MPa	1320
11	300	0.52	4.83	5.27	5	3.7	1310MPa	3010
12	300	0.35	4.59	5.24	5.1	4.32	1250MPa	2140
13	300	0.55	4.71	5.23	5	4.6	1320MPa	3640
14	300	0.55	4.57	5.26	5.1	3.6	1310MPa	3521
15	400	0.35	4.71	5.25	5.88	3.94	980MPa	2510
16	400	0.55	4.56	5.23	5.64	3.24	1020MPa	4120

3. The Adiabatic Shear and Microscopic Structure of 22SiMn2TiB-(616) Armored Steel

3.1 The Adiabatic Shear of 22SiMn2TiB-(616) armored steel

Figure 3 is the lateral shear stress-strain curve of the specimen. At common temperature, occurrence of shear failure to the specimen needs great stress; at 400℃, it needs the least stress. So the conclusion is, from common temperature to 400℃, stress to produce strain decreases gradually. It is evident that temperature is the main factor in the process. According the test data, the test condition for the specimen to have lateral shear is the temperature at more than 300℃, or more stress on the impacting bar, or both factors. Under such conditions, most specimen is certain to have shear failure. More stress on the bar accompanies with greater speed and longer time of impact, therefore, the time for formation of cavities and microcracks, or the formation of kernels is longer with the result of easier shear and fracture. Figure 4, 5 is the macrograph of the fracture in the specimen. The surface of the fracture is 45 °to the horizontal line.

3.2 The Microstructure of the Specimen's Adiabatic Shear Band

Adiabatic shear band (ASB) is a narrow crack of shear deformation. it is seen that during adiabatic shear process, there is higher stress and greater strain rate. In this process, more energy is accumulated to cause hardness of the material, and also to soften the material under high temperature. To the armored steel, adiabatic shear is one of the main forms of failure. Adiabatic shear failure appears from gradual formation, increase and accumulation of microcracks, with the result of the final macrocracks. The temperature around the shear band may keep increasing and decrease the strength of the specimen. During this process, cavities grow bigger and more cavities assembles to form crack. So adiabatic shear does not form in an action. Figure 8 shows the micrograph of the shear.

In Figure 6(a) and (b), there are some fractured lath-shaped martensites around the shear band. In Figure 6(a), a bright band is clearly seen, which is the phase change structure in the area of adiabatic shear. In Figure 6 (b), a black crack is seen, which is obviously the macrocrack caused by the stress. Armored steel 616 has lath-shaped martensites and few bainites in its microstructure. The bright band is about 25μm in width. Compared with the original specimen, the impacted one has bigger crystalline grains, as if being tempered again. The test obviously shows that bright band (ASB) appears in the impacted specimen, and around it there are tempered sorbites; farther from the shear band.

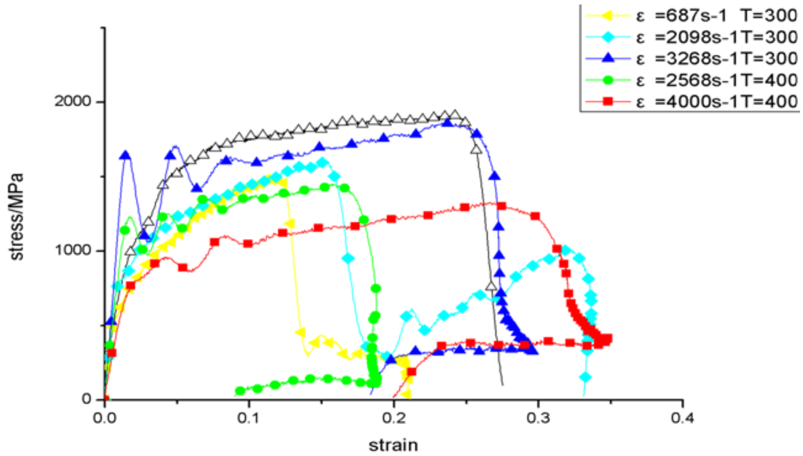


Fig.3 Occurrence of lateral shear stress-strain curve of specimen

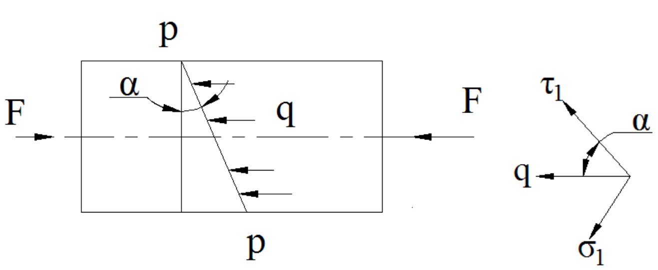
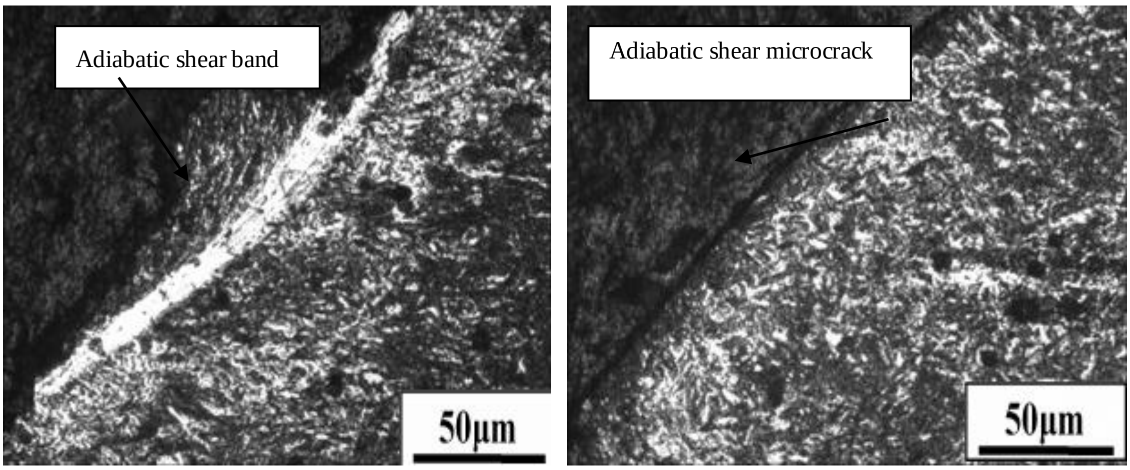


Fig.4 The shear stress analysis

Fig.5 The sample adiabatic shear failure



（a) Adiabatic shear band （b) Adiabatic shear microcrack

Fig.6 Microscopic picture of adiabatic shear band

4. Conclusion

This research shows that 22SiMn2TiB-(616) armored steel's dynamic mechanical properties relate to speed, temperature and strain rate of the impact. With the SHP device, dynamic yielding limit of the specimen is tested under different conditions, the data of which can be used on various similar occasions, and also in finite element dynamic impact simulations.

Armored steel 616 is sensitive to stress at 200℃ and 300℃, but not sensitive at 100℃. When the strain rate remains in a certain scope, the dynamic yielding increases with the increase of the strain rate, but bigger strain rate may cause shear to the specimen.

The difference between dynamic and static mechanical properties of the steel is great. At common temperature, its dynamic yielding limit is mainly related to impact speed, and increases with the increase of speed in a certain scope. During the test, the specimen's dynamic yielding stress varies from 1300Mpa to 1600Mpa.

Armored steel 616's microstructure is of lath-shaped martensites and few bainites. There is a bright band with the width of 25μm after impact, and the internal structure has changed. Compared with the original material, there are bigger crystalline grains, as if the specimen is tempered again to have bigger tempered structure.

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