

Research on Failure Behavior of 35CrMnSi based on Ballistic Experiment

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Abstract. Failure behavior of metal materials under impact loading has become key research content in industrial manufacturing field. Especially in the field of weapon research, 35CrMnSi dynamic figure behavior in the serving process attracts relevant weapon manufacture researchers' extensive attention. In order to study on failure behavior of 35CrMnSi under shock dynamic loading, obtained the damage mode of 35CrMnSi penetrating steel plate under condition of different impacting velocity by ballistic experiment. Results show that when impacting velocity is lower the 0.469km/s, fragments emerge upsetting deformation only; when impacting velocity is between 0.574km/s and 1.280km/s, fragments emerge fracture failure. Observe fractures of 35CrMnSi fragments using scanning electron microscopy (SEM), results show that when impacting velocity is higher than 0.574km/s, 35CrMnSi fragments present brittle dissociation transgranular fracture and also exist partial melting, adiabatic shear band, molten dimple and irregular particles size of 100 μ m in the fracture surface. The research results provide reference for 35CrMnSi failure behavior related research.

Introduction

Failure behavior of metal materials under strong impact load is the focus that material and weapons researchers pay close attention[1-4]. Some international researchers have been spread out study broadly on dynamic behavior of metal materials under strong impact load[5-9], P.K.Ray、A.G.Odeshi、Rick L.Martineau have studied the dynamic mechanical properties and fracture failure mechanism of High Strength Low Alloy steel (High Strength Low Alloy, HSLA) in different heat treatment states through Hopkinson bar, ballistic rifle, and explosive expansion loop technology. At the same time, some chinese scholars have also studied on metal materials especially the dynamic mechanical properties of high strength low alloy steel step by step[10-12]. X.Zejian studied the fracture toughness of 30CrMnSi steel through experiment under the condition of strain rate 10^2s^{-1} . L.Jinquan discovered 35CrMnSi steel penetrator emerge micro cracks in the head under the condition of 1.200 km/s speed shock impact through experiment. Come so far, dynamic fracture failure research on HSLA steel under the condition of high pressure and high strain rate ($10^4\text{s}^{-1}\sim 10^6\text{s}^{-1}$), experimental tests are mainly considered in the study process. The experiments introduced above are all belong to qualitative experiment, but they do not analysis material fracture failure behavior under different speed testing conditions.

As a kind of widely used high strength low alloy steel at the international level, 35CrMnSi steel not only used in manufactures key components, for example, large aircraft landing gear and wing girder, but also applied to the penetrating warhead shell material in field of weapons industry. Do experiment of 35CrMnSi fragment penetrator impacting steel plate by ballistic rifle, and obtain the damage model of 35CrMnSi fragment under the condition of testing speed range 0.469km/s~0.1280km/s. Microscopic observe and fracture analysis the fracture appearance of 35CrMnSi fragment penetrator under different impacting speed through scanning electron microscopy.

Experimental System

According to reference[13], double quenching and low temperature tempering can improve alloy steel strength, and improving steel toughness. The study experiment adopts 35CrMnSi after double quenching and low temperature tempering, its chemical constituents as shown in Table 1 and mechanical properties as shown in Table 2.

Table 1: Chemical constituents of 35CrMnSi

Material	Chemical component / %				
	C	Mn	Si	Cr	Others
35CrMnSi	0.320~0.390	0.800~1.100	1.100~1.400	1.100~1.400	<0.105

Table 2: Mechanical properties of 35CrMnSi

Density g/cm ³	Elongation %	Hardness HRC	Yield strength MPa	Tensile strength MPa
7.85	10.20~10.80	51.00	1310.00~1400.00	1760.00~1790.00

Considering the speed range of 35CrMnSi fragment penetrator impact on target steel, 14.5mm caliber ballistic rifle was selected in the process experiment[14], according to length-diameter ratio of fragment in typical warheads, design 35CrMnSi cylindrical fragment, size for 11.2 mm×40.0 mm, and mass 30.0g, as shown in Figure 1. Launch method is subcaliber shooting, separation technology of fragment from sabot by aerodynamic principle, test bullet as shown in Figure 2.

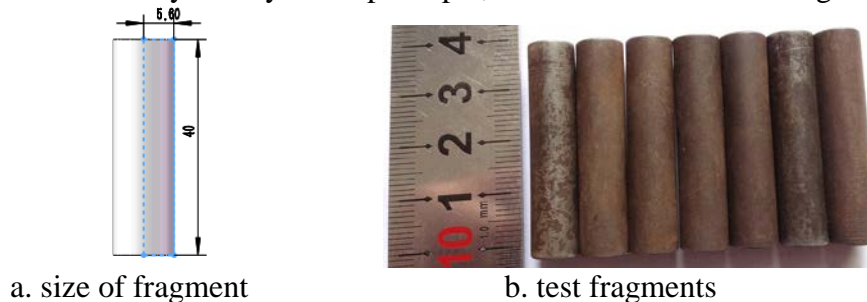


Figure 1: Test fragments

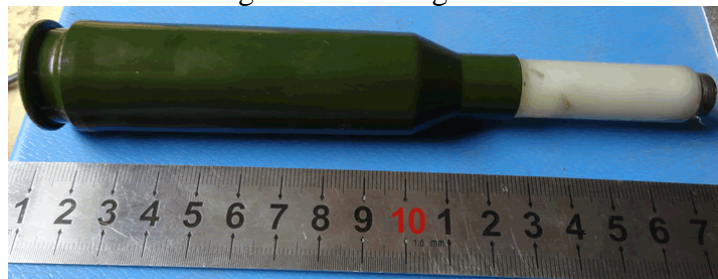


Figure 2: Test bullet

14.5mm caliber ballistic rifle, velocity measuring device, and recycling equipment compose the experimental system[15]. Place the support frame perpendicular to the ground upright in the position away from the muzzle 2.0m, and fix the target plate on the support from in the position as high as muzzle vertical location, put laser target before and after the target plate with distance of 0.5m, put the recycling equipment in 1.0m back of the target plate, specific testing arrangement as shown in Figure 3.

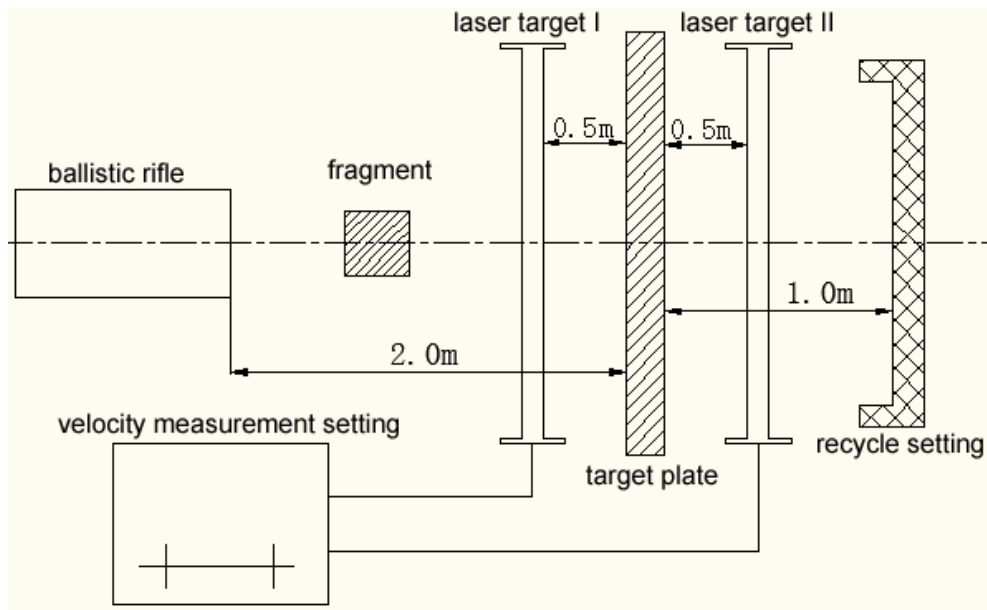





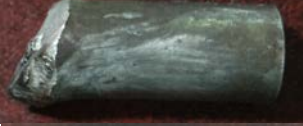


Figure 3: Testing arrangement

Target plate uses the 10.0mm thick low carbon steel plate[16], control fragment speed by changing quantity of gun propellant, and obtain impact speed by laser velocity measurement setting.

Experimental Results and Analysis

Take the experimental data that fragment stable flight before hitting the target plate as effective data. Select 6 testing 35CrMnSi fragments in the effective speed range, recycle and statistics their mass characteristic, the results is shown in Table 3.

Table 3: Mass characteristic of recycled fragments

Number	Impact speed /km ^{s-1}	Recycled fragment	Residual mass /g	Residual length /mm	Macroscopic morphology
#1	0.469		30.10	36.70	upsetting deformation
#2	0.574		24.60	34.30	shear fracture, fracture smooth and no obvious plastic deformation
#3	0.656		22.10	30.90	preventatives white fracture, brittle fracture, appear local oxidation zone
#4	0.673		21.80	31.40	the upper part is white surface, the lower part is obvious ablated
#5	0.722		23.40	33.00	fracture is roughly 45 °shear stress direction, preventatives light plastic deformation, and fracture surface is uneven
#6	1.280		19.60	28.60	fracture is roughly 45 °shear stress direction, and fracture surface oxy-generated seriously

The final analysis conclusion can be concluded as follow:

1) Impact stress increases with the increase of impact speed, less than 0.469 km/s, 35CrMnSi fragment only emerges upsetting deformation, above 0.574 km/s, 35CrMnSi fragment emerges fracture failure.

2) By comparing the mass and length of the recycling 35CrMnSi fragment, mass and length reduce sharply along with impact speed increase.

3) It can be concluded from macroscopic morphology that 35CrMnSi fragment emerges shear brittle fracture accompanied by local high temperature oxidation under testing condition more than 0.574 km/s impact speed.

Fracture Microstructure Analysis

Heat treated 35CrMnSi steel has features of high strength and high hardness[17]. Therefore the 35CrMnSi fragment is not easy to break but emerges upsetting deformation on a macro-scale under testing conditions of low speed and low impact load. When the impact speed is higher than 0.574km/s, high temperature, high pressure and high strain areas form in the penetrator-target interface under strong impact load, then it leads to fracture damage. In order to study failure mechanism of 35CrMnSi steel under the condition of strong dynamic impact load, observe and analysis fracture of 35CrMnSi fragment using scanning electron microscopy, the result is shown in Figure 4.

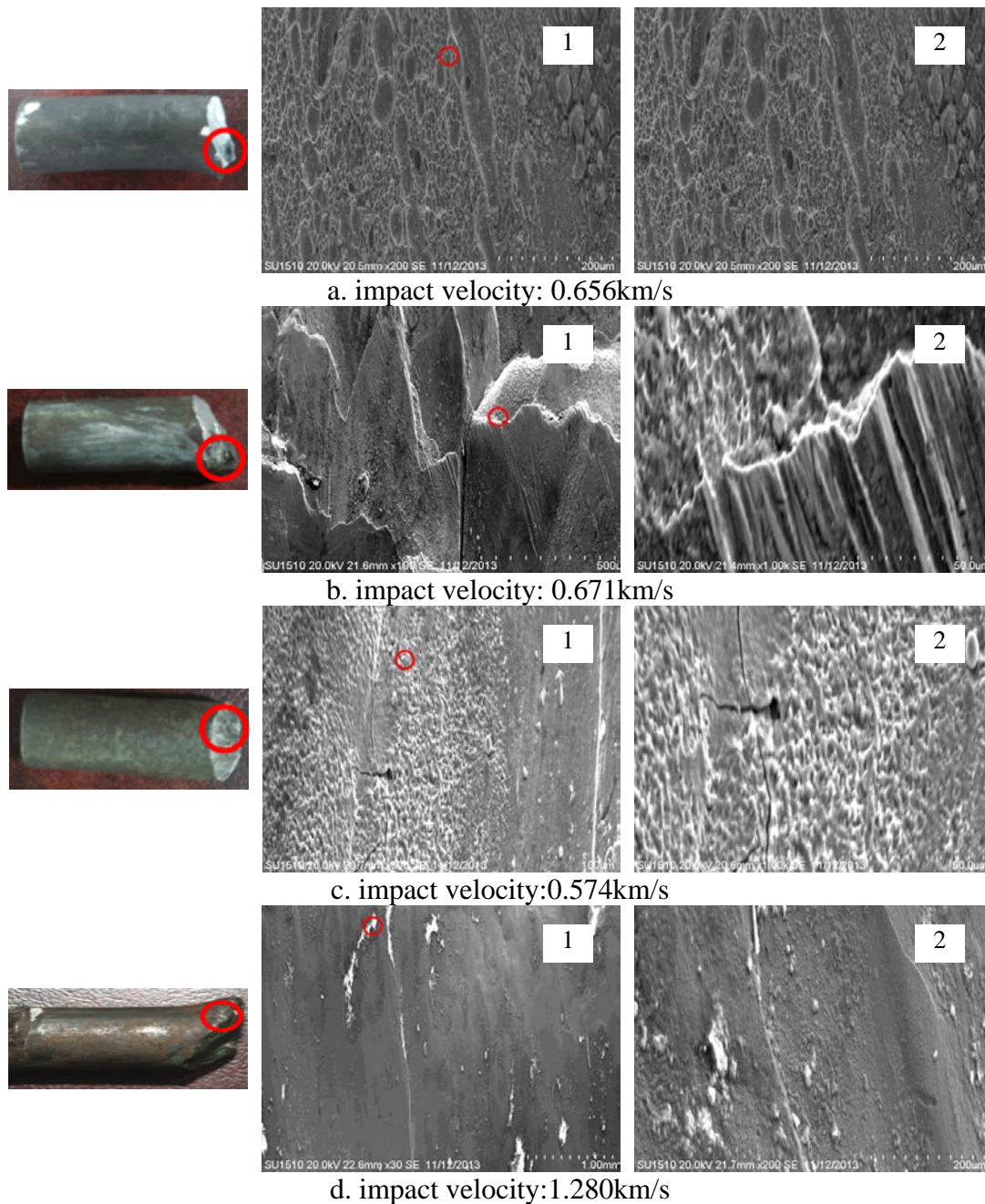


Figure 4: SEM photographs of recycled fragments

Fracture Model under Strong Impact Load

In Figure 4-a1, dimple fracture is small size and shallow depth. According to reference[18], dimple fracture large size and deep depth fully shows good toughness and plastic deformation, on the contrary, the material toughness is poor. Small size and shallow depth dimple fracture declare heat treated 35CrMnSi steel shows poor toughness under high speed impact. Also observe the dimple fracture shape in Figure 4-a2, it is elongated type shear caused by shear plastic deformation.

Observe fracture microstructure in Figure 4-b1, it is typical dissociation fracture, main microscopic characteristics is a flat mirror. The cracks cross parallel each other and different height dissociation surfaces and from dissociation steps, the Figure 4-b2 shows typical dissociation steps. The characteristics of dissociation fracture illustrate 35CrMnSi fragment emerges brittle transgranular fracture.

According to the analysis typical morphology and macrostructure in Figure 4-a and Figure 4-b, 35CrMnSi fracture mode is dissociation transgranular fracture and show poor toughness under testing condition of strong dynamic impact load.

Analyses of Adiabatic Shear Band and Melting Phenomenon

Heat treated 35CrMnSi has characteristics of high hardness, poor toughness and poor

deformation ability, according to analysis above that 35CrMnSi fracture mode is shear fracture.

The white long-thin ribbons in Figure 4-c1 inner the red circle, combination material high temperature and high pressure status under strong dynamic impact load, and severe shear plastic deformation impedes thermal dissipation then cause material softening in the slip line, the process can be considered as adiabatic, thus the adiabatic shear band formed.

The emergence of adiabatic shear band led to materials bearing capacity decrease and even lost, so crack extension along with the direction of adiabatic shear band, as shown in Figure 4-c2, the secondary cracks emerge along with the direction of the adiabatic shear band. In addition, there are molten dimple components in both sides of adiabatic shear band, and direction of dimple is consistent with adiabatic shear band.

Strong impact load leads high temperature environment formation in the fracture, causes molten dimple in the fracture surface, and causes irregular coagulation particle size of 100 microns after melted, as shown in Figure 4-d1 and Figure 4-d2.

Conclusions

From the experiments and analysis on failure behavior of 35CrMnSi, the following conclusions can be obtained.

(1) 14.5mm caliber ballistic rifle used for the ballistics experiment, it can provide effective shooting speed, and satisfy the requirements of the material performance test, and the velocity data laser velocimeter provided is real, effective and high reliability.

(2) Accelerate the 35CrMnSi fragment penetrator by ballistic rifle, when impact speed higher than 0.574km/s, the fragment emerges fracture failure, fracture macroscopic morphology characterized by shear brittle fracture, and accompanied by local high temperature oxidation.

(3) The 35CrMnSi fragment's fracture microstructure was observed through scanning electron microscope and find that the brittle type fracture mode mainly is dissociation fracture. Strong dynamic impact load causes lots of heat thus lead formation of high temperature product such as adiabatic shear band, molten particulate matter and molten dimple.

(4) Comparing the scanning electron microscope photographs, it can be seen that degree of fracture surface oxidation when the impact speed is 1.280 km/s is higher than other three groups. That is, with the increase of impact speed, the more serious degree of oxidation in fracture.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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