Analysis on cushion performance of quartz sand in high-g shock

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Abstract

The cushion protection for light mass electronic instruments in projectile is of vital importance to the normal work of an ammunition system. Quasi-static compression tests were conducted on two kinds of quartz sand with different grain diameters and their energy absorption abilities were analyzed. The cushion effect under high g shock was studied by using air gun. The results of experiments show that the quartz sand material takes in energy by grain breakage and the energy absorption ability in unit volume, the energy absorption ability in unit mass and the ideal energy absorption efficiency all improve with the increase of grain diameter. The cushion efficiency of the coarse quartz sand material with grain diameter of 1.0mm to 5.0mm can reach more than 50% under high g shock. This provides a favorable cushion protection for light mass equipment.

Keywords: High g Shock, Quartz Sand, Grain Breakage, Cushion

1 Introduction

When a projectile body attacks a hard object, light mass electronic instruments in projectile like fuse or measuring and control device will bear a more than 50000g's mechanic shock whose pulse width ranges from several hundreds millionth seconds to 10-odd milliseconds. The great shock will defunct electronic measurement and control instruments easily. Non-linear cushion device are used in order to effectively isolate the shock at a limited space [1,2]. Not only can the cushion device decrease the shock and vibration, but also effectively isolate or attenuate the stress wave formed inside the object when the collision occurs.

The American Navy Experiment Center made an experimental study by utilizing hollow glass as a protection layer to dissolve and absorb shock energy. The result shows that the effect of absorbing shock energy is remarkable but the cost is high and the assembly process is demanding. The natural quartz sand grain displays an apparent fragmentation phenomenon when under high pressure stress and the stress usually reaches several tens MPa. The fragmentation of grains produces a plastic strain on sand specimen to reach the goal of consuming energy [3, 4, 5, 6].

The article first conducted quasi-static compression tests on the common quartz sand to analyze its energy absorption ability by using a universal testing machine and then utilized air gun as loading balance to study the cushion energy absorption characteristic of quartz sand in high g shock.

2 Quasi-static compression tests on quartz sand

The compression test selected two kinds of common quartz sand as specimens. One has a diameter of 0.1~1.0mm and the other has a diameter of 1.0~5.0mm. The percentage of SiO2 in sand specimens reaches more than 90%. Detailed parameters can be seen in Table 1. The quasi-static compression test was conducted on WDW--200E universal testing machine. The testing sand specimen was put in a cylindrical mental shell with a parameter of Φ60 (inner diameter)×35 and the acceleration is 2mm/min. The Loading force and the amount of compression were automatically collected by computer through force sensors and displacement sensors. The load-displacement curve is given in Figure 1.

TABLE 1 Basic Physical Parameters of Quartz Sand

Type of specimen	Density of specimen (g/cm^3)	Grain diameter of specimen (mm)
Fine quartz sand	1.623	0.1~1.0
Coarse quartz sand	1.578	1.0~5.0

In Figure 1,if two testing sand specimens have near densities, the average loading force value of the coarse quartz sand with larger grain diameter is 10~20kN higher than that of the fine quartz sand with smaller diameter. The compression curve of the coarse quartz sand with grain diameter of 1.0~5.0mm under quasi-static state can be divided into three stages. They are rearrangement stage, plastic failure stage and compaction and dense stage. When the loading force is weak, quartz sand grains rearrange and only a small portion break. With the increase of loading force, quartz sand grains show a significant fragmentation phenomenon and under the same condition the fragmentation rate of large grains is higher than that of small grains because large grains probably have more cracks and defects. Usually the maximal point on the compression curve is regarded as yield point. The yield point corresponds to the time when the specimen begins to produce a large plastic deformation and a large number of grains begin to break. But the plastic failure stage is not very smooth and there is not a strict boundary to distinguish between plastic area and dense area.

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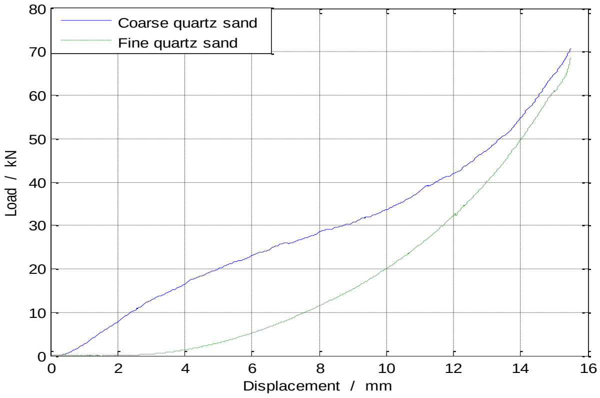

FIGURE 1 The load-displacement curve of quartz sand in quasi-static compression

Three physical parameters to describe the energy absorption ability of cushion materials are as follows [7,8]: W_{total} is the total energy absorbed by cushion during loading process; W is the absorbed energy in unit volume; W_m is a light weight index to represent the absorbed energy in unit mass. According to the law of conservation of energy, the absorbed energy W_{total} during cushion deformation is:

$$W_{total} = \int_0^s F(s)ds \,, \tag{1}$$

$$W = \frac{W_{total}}{V} \,, \tag{2}$$

$$W_m = \frac{W_{total}}{m} \,, \tag{3}$$

where s is compression deformation(m); $F(s)$ is the force on cushion when compression distance is s; V is the volume of cushion; m is the mass of cushion.

I is the ideal energy absorption efficiency of cushion [9]. I is defined as:

$$I = \frac{W}{\sigma_p \varepsilon_m} \,, \tag{4}$$

where σ_p is the peak stress during compression process of cushion. ε_m is the maximal strain of the material allowed to reach. The ideal energy absorption efficiency reflects the energy absorption ratio of the absorbed energy of the quartz sand material under any strain during compression process to the absorbed energy of the ideal energy absorption material under the same strain. The higher the ideal energy absorption efficiency is and the closer the material is to the ideal energy absorption material, the better the cushion performance will be. The calculation results are given in Table 2.

TABLE 2 Cushion Characteristic of Specimen

Specimen symbol	W_{total} **(J)**	W **(J/m3)**	W_m **(J/kg)**	I
c1	447.7	4.524×106	2.888×103	0.422
c2	443.8	4.485×106	2.827×103	0.441
c3	436.9	4.415×106	2.893×103	0.429
c4	412.7	4.170×106	2.715×103	0.445
c5	448.6	4.533×106	2.821×103	0.453
f1	273.3	2.762×106	1.677×103	0.302
f2	251.5	2.541×106	1.497×103	0.306
f3	264.2	2.670×106	1.611×103	0.288
f4	274.9	2.778×106	1.627×103	0.296

Notes: c represents coarse quartz sand with diameter of 1.0~5.0mm;
f represents fine quartz sand with diameter of 0.1~1.0mm

In Table 2, the bearing and energy absorption ability of the coarse quartz sand specimen with diameter of 1.0~5.0mm is better than those of the fine quartz sand specimen with diameter of 0.1~1.0mm. The main reason is that the fine quartz sand contains a large number of micro grains and it is difficult for these grains to make contributions to the increase of breaking ratio. Under the condition of the same deformation in the plastic platform area, the absorbed energy of the coarse quartz sand specimen increases70%～80% more than that of the fine quartz sand specimen. With the increase of grain diameter, the energy absorption ability in unit volume, the energy absorption ability in unit mass and the ideal energy absorption efficiency will all improve.

3 Cushion tests on quartz sand in high g shock

3.1 TEST PLAN

In order to examine the cushion protection performance of the coarse quartz sand with diameter of 1.0~5.0mm for light mass electronic equipment(mass m=300g) during penetration process, air gun were utilized to simulate a high g shock environment. The effect of its cushion was evaluated.

The working theory of air gun：compress air and push simulation projectile. Collide with examined device during the test stage to make the device acquire the needed acceleration. During the experiment, the adjustments of the thick of the felt pad between bullets and testing device and the pressure value in high pressure room can realize the adjustments of the amplitude and the pulse width of collision acceleration. The air gun experiment equipment is shown in Figure 2. A Double channel acceleration testing device was developed to evaluate the cushion effect. The device has two sensors. One is installed on the bottom to test the acceleration A_1 of the testing device before cushion. The other sensor is installed in the storage module to test the acceleration A_2 of the testing device after cushion. Read the record signals of the two sensors after the test and analyze and evaluate the experiment effect and the cushion effect.

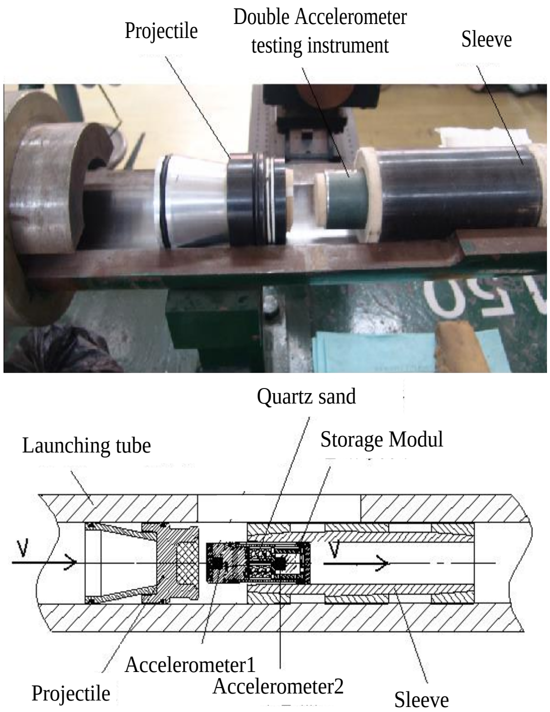

FIGURE 2 Air Gun Testing Device and Its Double Accelerometer Testing Instrument

3.2 ANALYSIS OF THE EXPERIMENT RESULT OF HIGH G SHOCK

From the result of the penetration test, the missile-borne storage record device potted by epoxy resin can at most bear the acceleration a_0 . a_0 is 3.0×10^4 g .In order to verify the cushion performance of the coarse quartz sand with grain diameter of 1.0~5.0mm for electronic device under high g shock, five high g shock experiments were conducted on the double channel accelerometer testing instrument by changing the pressure value of the air gun. The peak value of the loading shock acceleration is more than 30000g. Testing data are given in Table 3. The testing instrument works well after the test. The result of the test shows that the quartz sand material provides a favorable cushion protection for light mass electronic device.

TABLE 3 Data of Cushion Test

Times of shock	Maximal value of acceleration（g）		Pulse width of acceleration(μs)		Cushion efficiency
	Sensor 1	Sensor 2	Sensor 1	Sensor 2	η_a
1	33820	13480	213	412	60.14%
2	36640	14060	181	360	61.63%
3	42280	20160	186	401	52.32%
4	47910	21830	174	364	55.43%
5	50080	24480	190	382	51.12%

Cushion efficiency η_a is defined as

$$\eta_a = \frac{A_1 - A_2}{A_1} \times 100, \tag{5}$$

where A_2 is the maximal recorded value of circuit acceleration response after cushion. A_1 is the maximal value of the acceleration of the testing device after cushion. The contrast before and after the compression of quartz sand in the fifth shock test is shown in Figure 3. The quartz sand grains after shock compression show a fragmentation in large area. The fragmentation rate increases, the fragmentation is much severer and residual grains become less with the increase of shock strength.

FIGURE 3 before and after the cushion test of quartz sand

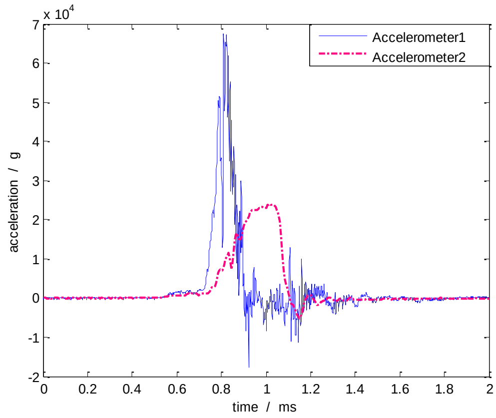

FIGURE 4 Acceleration-time curve in the fifth shock test

The acceleration curve acquired in the fifth shock test is given in Figure 4. The accelerometer$_1$ measures the global acceleration change of the testing instrument and the accelerometer$_2$ measures the acceleration change after the cushion of quartz sand. The spectrogram of accelerometer$_1$ output curve is shown in Figure 5.

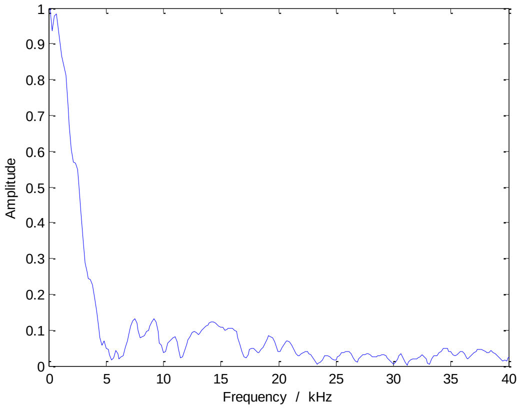

FIGURE 5 Spectrogram of the curve of accelerometer 1

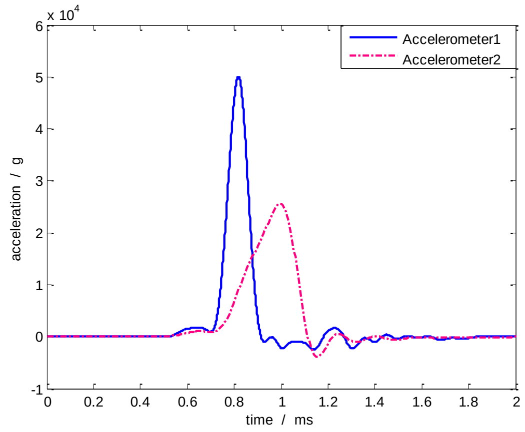

FIGURE 6 Acceleration-time curve-6.5kHz low pass filter in the fifth shock test

The method of low-pass filter was used on the acceleration curve to remove the influence on acceleration signals by installation structure. The frequency of the low-pass filter is 6.5kHz. The acceleration curve acquired after filtering is shown in Figure 6. In Figure 6, the maximal acceleration value measured by accelerometer$_1$ is 50080g and the pulse width is 190μs.The maximal accelerometer value measured by accelerometer$_2$ is 24480g and the pulse value is 382μs.It can be seen that the shock acceleration amplitude bear by circuit module decreases sharply after the cushion of quartz sand. The pulse width becomes wider apparently.

4 Conclusions

The cushion energy absorption ability performance of quartz sand in high g shock was studied on the basis of the quasi-static compression test on the common quartz sand material. The cushion effect of quartz sand material on shock energy is remarkable. The energy absorption ability in unit volume, the energy absorption ability in unit mass and the ideal energy absorption efficiency all improve with the increase of grain diameter. The coarse quartz sand with grain diameter of 1.0~ 5.0mm has a cushion efficiency of more than 50% under high g shock. The coarse quartz sand can be utilized to provide cushion protection for light mass electronic device in the narrow space of projectile body under penetration environment.

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