The Performance Test and Application in Shaped Charge of Heat Resistance Explosive LLM-105

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Abstract—In order to guarantee the safety and reliability on the operation of oil and gas well, tested the thermal stability, mechanical sensitivity, flame sensitivity, electrostatic spark sensitivity and the 5s delay explosion temperature of LLM-105 explosive. And conducted the tests with 4 1/2 " perforating charge loaded mixed LLM-105 under the temperature of normal, 220℃/100h and 220℃/2h/20Mpa conditions. Contrasted with the perforating deep test results of perforating charge loaded S992、Y971 on normal temperature. The test results show that the thermal stability of LLM-105 is stable, DSC maximum exothermic peak up to 360.02 ℃, impact sensitivity is 42%,friction sensitivity is 16%,flame sensitivity is 0%,electrostatic spark sensitivity is low and no obvious ignition, the 5s delay explosion temperature is 387℃, so LLM-105 is an excellent insensitive heat-resistant explosive, the steel target perforating deep results of 4 1/2 " perforating charge loaded LLM-105 show that the average penetration depth are respectively 256.3mm and 254.7mm on normal temperature and 200℃/100h condition. The perforating deep results of API columnar concrete targets show that the average penetration depth of charge loaded LLM-105 is 922.5mm on 220℃/2h/20Mpa condition. the steel target perforating deep of 4 1/2 " charge loaded LLM-105 increased 25.3% than charge loaded S992, increased 36.7% than charge loaded Y791 on normal temperature condition.

Keywords-insensitive;heat-resistance; LLM-105; sensitivity; safety property; shaped charge

I. INTRODUCTION

With the development of oil and gas resources exploration and development unceasingly thorough, the extreme region of deep, ultra deep, deep and ultra-deep sea has become an important field of oil and gas exploration, the formation mainly have high temperature and high pressure, low permeability, high density; therefore put forward higher requirements on the technology of well completion, in order to meet the requirement of safety and reliability in deep oil and gas development, the perforation equipment must have higher perforating deep performance and safety reliability.

The LLM-105 is an excellent energetic materials that has high energy density and low sensitivity, 1993 America Lawrence Livermore National Laboratory (LLNL) the first synthesis [1], the energy is 15% higher than TATB , it is very stable to heat and mechanical effect, the temperature of thermal analysis can reach more than 350℃. It had been concerned and begun to synthesis and characterization research by the international explosives community in 1998 [2-6], various domestic research institutes started synthesis and performance researched of LLM-105 in 2003 [7-9], the LLM-105 is an ultra-high temperature explosive has the prospects for development.

In order to ensure the safety and reliability of operation, this paper studied the related safety of LLM-105 explosive, and tested perforating performance contrast with charge loaded S992, Y971. At the same time, according to the actual situation of the operation of oil and gas wells, have tested heat resistance of perforating charge loaded LLM-105 explosive in different temperature which can provide some reference basis to expand the application of LLM-105 in oil and gas field in future.

II. EXPERIMENTAL MATERIALS

In this paper, the use of materials are: Based on LLM-105 mixed explosives L091, based on HNS mixed explosives S992, based on PYX mixed explosive Y971. The part performance of the L091, S992, Y971 such as shown in Table Ⅰ.

TABLE I. COMPARISON OF THE PROPERTY OF L091、S992 AND Y971

Material	Density/ g • cm^{-3}	Detonation velocity/m • s^{-1}	Formulation/ %
L091	1.726	7680	96.5/3.5
S992	1.607	6879	96.2/3.8
Y971	1.625	6839	95.5/4.5

III. THE PERFORMANCE TEST OF THE EXPLOSIVE

The thermal analysis research has important significance to the production and use of explosive, in this paper, the safety performance of LLM105 has been tested and analyzed by means of differential scanning calorimetry (DSC), impact sensitivity, friction sensitivity, flame sensitivity, electrostatic spark sensitivity and the 5s delay explosion temperature.

A. Thermal stability test of LLM105

Instruments: DSC204F1 differential thermal analyzer made by Netzsch Company in Germany. Its heating rates are: 5℃/min、10℃/min、15℃/min 和 20℃/min.The DSC curves of LLM-105 under different experimental conditions were showed in Fig . 1 – Fig . 4.

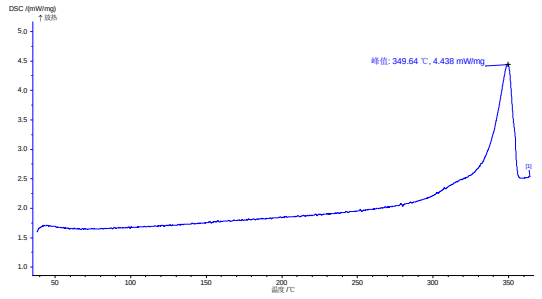


Figure 1. DSC curve by 5℃/min

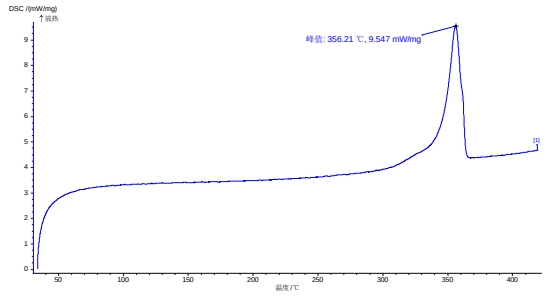


Figure 2. DSC curve by 10℃/min

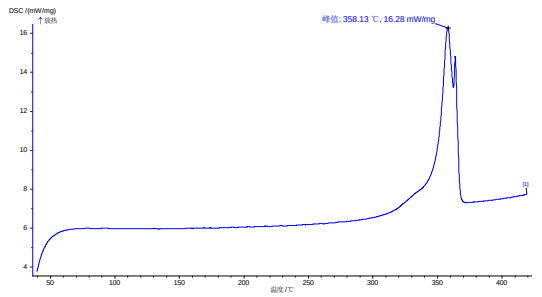


Figure 3. DSC curve by 15℃/min

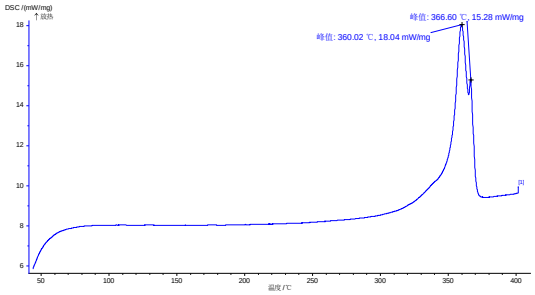


Figure 4. DSC curve by 20℃/min

According to figure from figure 1 to 4, by different heating rates, onset temperatures for decomposition of LLM-105 are 349.64 ℃、356.21 ℃、358.13 ℃ and 360.02 ℃.It showed that LLM-105 has excellent heat resistance.

B. Impact sensitivity of LLM-105

Measured by Custer impact sensitivity apparatus, with GJB772A-97 testing method: 50 mg dose, 10 kg hammer, 25 cm drop height, testing number 50. The result is shown in Table Ⅱ.

TABLE II. IMPACT SENSITIVITY OF LLM-105

Material	LLM-105
Probability of explosive (P %)	42

C. Friction sensitivity of LLM-105

Using the friction pendulum to measure its friction sensitivity, with GJB772A-97 testing method: 80 ° swing angle, 3.43 Mpa pressure, 20 mg dose, testing number 50. The result is shown in Table Ⅲ.

TABLE III. FRICTION SENSITIVITY OF LLM-105

Material	LLM-105
Probability of explosive (P %)	16

D. Flame sensitivity of LLM-105

Using the flame sensitivity instrument to measure its flame sensitivity, with GJB772A-97 testing method: testing number 25, 20mm ignition distance. The result is shown in Table Ⅳ.

TABLE IV. FLAME SENSITIVITY OF LLM-105

Material	LLM-105
Probability of explosive (P %)	0

E. Electrostatic spark sensitivity of LLM-105

With GJB5891.27-2006 static spark sensitivity testing method: 25mg dose, test number 30, 3.0 ~ 7.0kV charging voltage, 0.22μF electric capacity, 1000Ω series resistor.

The result pointed out that although charging to 0.22μF capacitor by 7.0kV, there was no obvious ignition phenomenon.

F. The 5s delay explosion temperature of LLM-105

Using BDF-1 flash point tester, with GJB5891.20-2006 Pyrotechnics pharmaceutical test methods, the 5s delay explosion temperature of LLM-105 was tested. Table Ⅴ is flashpoint test data.

TABLE V. THE 5S DELAY EXPLOSION TEMPERATURE OF LLM-105

Material	Temperature(K)	Delay time(s)
LLM-105	655	6.01
	661	5.04
	664	4.31
	668	3.44
	671	2.89

The delay explosion τ and temperature of explosion T uses the following equations of state, in the form:

$$\tau = ce^{\frac{E}{RT}} \quad (1)$$

$$\ln \tau = \frac{E}{RT} + \ln c \quad (2)$$

where τ is the value of delay explosion in s, c is a constant related the tested material component, E is the values of apparent activation energy of the tested material in J/mol, R is gas constant of molar(8.314/(mol • K)), T is values about temperature of explosion in K.

Fig .5 showed the analysis of the data in Table Ⅴ.

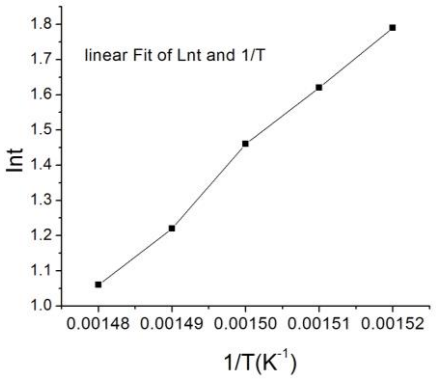


Figure 5. Relations of lnt versus 1/T

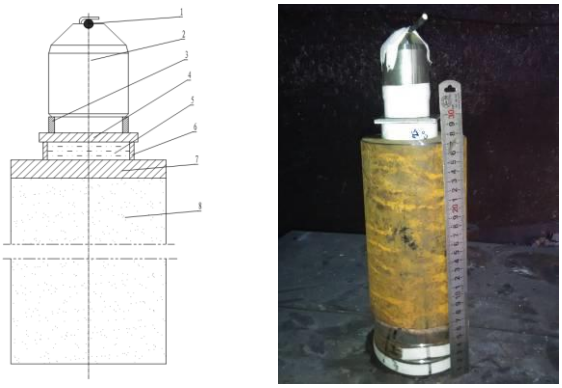
After the linear regression processing to data in Table. Ⅴ, the 5s delay explosion temperature of LLM-105 is 660K or 387℃.

IV. APPLICATION AND RESULTS OF THE ANALYSIS OF LLM-105

After a series of tests about the safety of LLM-105, in this paper, the explosive mixture L091 which is based on LLM-105 was used for the main charge of shaped charge. Then researched the performance varieties of penetrating on steel target by simulated ground guns under different conditions of normal temperature, 220℃/100h and also under the conditions of 220℃/2h/20MPa to penetrate API cylindrical concrete target. At the same time, carried out contrast tests by using explosive mixtures S992 which is based on HNS and PYX based on Y971 as the main charge of shaped charges penetrating on steel targets under normal temperature. The diameter of the guns is 4 1/2 "

A. Penetrating tergat in condition of normal temperature

Under normal conditions the LLM-105 mixed explosives packed in 4 1/2" type perforated shells, the loading dose 38g, conduct ground simulation equipment 4 1/2" steel target type guns wear test, the test assembly drawing as Fig .6, the test results are shown in Table Ⅵ.



1—blasting fuse 2—perforating charge 3—High-burst inside gun 4—gun 5—water 6—High-burst outside gun 7—casing pipe 8—target

Figure 6. Schematic diagrams of penetrating tergat in condition of normal temperature

TABLE VI. PENETRATING TERGAT USING 4 1/2 " GUN IN CONDITION OF NORMAL TEMPERATURE

Sample	Power	casing pipe	Penetrating/ mm	Pore size of casing pipe/mm
1	L091	7 "	256.0	12.0×13.0
2			257.0	12.0×12.0
3			256.0	11.0×12.0
Average			256.3	12.0
4	S992		193	12.0×12.0
5			197	12.0×12.0
6			222	12.0×12.0
Average			204.0	12.0
7	Y971		184	11.0×11.0
8			192	11.0×11.0
9			195	11.0×11.0
Average			190.3	11.0

Table Ⅵ shows that, under normal conditions L091 loading explosives 4 1/2 "type perforating gun shells terrestrial analog equipment wear steel target average penetration depth of 256.3mm, the average pore diameter of the sleeve 12.0mm, compared to the S992-based perforation steel Target wearing dark charge 25.3% performance increase, perforated shells steel target compared to Y971-based charge to wear dark performance increase 36.7%.

B. Pendtrating target in condition of 220 ℃/100h

On the 220℃/100h high temperature of conditions, it is done that the simulation assembly gun will penetrate steel target. The heating and temperature measurement test device shown in Fig .7, Figure 8 shows the results of the effect of the test chart, the test results shown in Table Ⅵ.

Figure 7. Devices of testing

Figure 8. Testing results of penetrating target

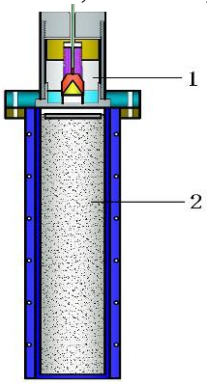
TABLE VII. RESULTS OF PENDTRATING TARGET IN CONDITION OF 220℃/100H

Sample	Powder	casing pipe	Penetrating/ mm	Pore size of casing pipe/mm
1	L091	7 "	254.0	12.0×13.0
2			255.0	12.0×12.0
3			255.0	11.0×12.0
Average			254.7	12.0

Obtained from Table Ⅶ, on 220℃/100h of condition, the average penetration depth of steel target is 254.7mm by shaped charge of assembly 4 1/2 "type perforating gun, the average pore diameter of casing pipe 12.0mm.

C. Penetrating API targets in condition of 220 ℃ /2h/20Mpa

In the high-temperature performance of the laboratory temperature 220℃/2h, under pressure 20Mpa conditions to simulate loaded gun through API cylindrical concrete target test, the test assembly shown in Fig .9, the test results are shown in Table Ⅷ, test results, see Fig .10.



1--Perforator；2—Target of API beton

Figure 9. Schematic diagtams of testing device

Figure 10. results of testing

TABLE VIII. RESULTS OF PENETRATING API TARGETS IN CONDITION OF 220℃/2H/20MPA

Sample	Powder	casing pipe	Penetrating/ mm	Pore size of casing pipe/mm
1	L091	7 "	920	13.4×13.6
2			925	13.3×13.5
Average			922.5	13.6

Obtained from Table Ⅷ, on 220 ℃ /2h/20Mpa of condition, the average penetration depth of API concrete target is 922.5mm by shaped charge of assembly 4 1/2 "type perforating gun, the average pore diameter of casing pipe 13.6mm.

D. Results and Discussion

Compared the data in Table Ⅵ with in Table Ⅶ, the depths of holes shaped in the steel targets by shaped charges under normal temperature and 220℃ /100h were 256.3mm and 254.7mm.Thus after high-temperature environments, the penetrating depth of steel target fell by 0.62 percent, a small decline, indicating the good heat resistance of the mixing explosives L091.

V. CONCLUSION

Through the safety testing of LLM-105 explosive performance related and the performance testing of mixed explosive LLM-105 with 4 1/2 "type of perforating charge, the following conclusions can be obtained.

(1) The thermal performance of LLM-105 is better, the highest exothermic decomposition temperature can reach 360.02℃; flame sensitivity is 0%. The result shows that LLM-105 has excellent heat resistance.

(2) LLM-105 explosive with low mechanical sensitivity, impact sensitivity is 42%, the friction sensitivity is 16%,LLM-105 had no obvious ignition phenomenon when the capacitor of 0.22μF is charged to 7.0kV, electrostatic spark sensitivity is low, the 5s delay explosion temperature of LLM-105 is 387℃. Visiblely LLM-105 is an insensitive, high safety explosive.

(3)Compared to L091, S992, Y971 as the main charge perforator ground simulation load 4 1/2 "gun performance testing, test results show that: the steel target average penetration depth of the 4 1/2" charge loaded L091 improved 25.3% than the charge loaded S992, and 36.7% than the charge loaded Y971 under the normal temperature condition. Visiblely, LLM-105 is a high-energy and heat resistant explosive.

(4)The steel target average penetration depth of the 4 1/2" charge loaded mixed LLM105 is 256.3mm in normal temperature environment, 254.7mm in the temperature of 220℃/100h. The API columnar concrete targets average penetration depth is 922.5mm under220 ℃ /2h/20MPa conditions, that LLM-105 explosive has high energy, obvious effect of perforating charges application, it can use in the ultra-high temperature wells, and has safe , reliable, stable performance.

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