Defence Science Journal, Vol. 65, No. 6, November 2015, pp. 438-443, DOI : 10.14429/dsj.65.9027

Use of BI-Pb-Sn-Cd Alloy in Self-neutralisation Mechanism for Sub-munitions

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ABSTRACT

Unexploded sub munitions for military operations posed economic loss and health hazard. The need for unexploded sub munitons to be rendered safe after a certain period of time was of importance to the militaty. In this work, a self-neutralizing sub-component using soft metal penetration principle was developed and incorporated to the existing sub munitions so as to include a self-neutralizing feature in such sub munitions. This study was also conducted to determine the potential to use a steel wire to cut BI-Pb-Sn-Cd alloy at different temperatures (- 40 °C ~ 40 °C). The effect of temperature on neutralisation time was evaluated in experiments. The experimental results indicated that the neutralisation time was dependent on temperature of soft metal and decreased with increasing temperature. While BI-Pb-Sn-Cd alloy with thickness of 0.75±0.01 mm and height of 2.40 ±0.02 mm was cut by steel wire with a diameter of 0.12 mm, self-neutrlisation of sub munitions was completed ranging from 1 min 5 s to 143 h 2 min. It was concluded that self-neutralisation based on BI-Pb-Sn-Cd alloy could meet its setting requirements in the battlefield, and its failure rate reached less than 10 per cent between - 40 °C and 40 °C, and the self-neutralisation time could be adjusted by the size of soft metal.

Keywords: Self-neutralisation, unexploded sub munitions, BI-Pb-Sn-Cd alloy, soft metal, sub munitions

1. INTRODUCTION

When sub munitions are deployed, fuzes are used to detonate the sub munitions reliably. However, since fuzes are not reliable 100 per cent of the time, it is possible to have a number of unexploded sub munitions littering a battle zone. Incidence of death and injury to innocent victims from such unexploded sub munitions, coupled with an international moratorium on antipersonnel sub munitions, demonstrates a need to find a solution that will minimize undesirable consequences to friendly troops or civilians. The North American Treaty Organisation (NATO) and the U.S. Department of Defences (DoD) have regulations specifying safety criteria for all munition fuzes. For example, the DoD uses Military Standard 1316 which requires all fuzes to provide a sterilisation feature, the primary function of which is to disable the fuzes so that it can no longer detonate the munitions after a specified amount of time[1]. When sub munitions fail to detonate as intended during use, it is important for such sub munitions to neutralise after a certain period of time.

Neutralisation may be realised through detonation, chemical decomposition, bioremediation and disassociation of interactive components, and so on. In recent years, chemical decomposition of deactivating an explosive composition using a chemical have been widely reported, which method comprises exposing the explosive composition to a deactivating agent that renders the explosive composition insensitive to detonation[2-7]. Bioremediation of explosives has been reported to be a potential alternative remediation technology for explosives[8-18]. However, chemical decomposition and bioremediation are still faced with several challenges in practical use. For instance, it may require excessive time to oxidize explosives and degradation time has strongly dependence on temperature. The high cost and complex structure inherently restrict the potential applications of neutralisation mechanism. Several alternative methods[19-23] of fuze neutralisation have been reported. The neutralisation fuze using the above method is complicated structure and costly. Moreover, the time for neutralisation of explosives at different temperatures has not been thoroughly evaluated. These factors have motivated researchers to seek more cost-effective alternatives.

The object of this paper was to develop a self-neutralisation method so as to introduce a new device which is simpler in design with no requirement of power and more economical to manufcture for self-neutralisation. This develpment is intended to have a functioning of the mechanism regardless of ambient temperature of sub munitions and to have an excellent reliability over the entire operational temperature range (-40 °C ~ 40 °C) as well as to have neutralisation time that could also be adjusted by changing the size of soft metal.

2. SELF-NEUTRALISATION DELAY METHOD AND MECHANISM BASED ON CUTTING SOFT METAL

2.1 Delay method

Principle of delay method based on cutting soft metal was illustrated in Fig. 1, a steel wire was fixed, and a piece of soft

Received 15 July 2015, revised 15 October 2015, online published 10 November 2015

metal could be movable. When the soft metal came into contact with the steel wire, shown in Fig. 1(a), the steel wire prevented the soft metal from moving forward. Due to the characteristic of low hardness of soft metal, the soft metal was cut by the steel wire under a continuous force exerted by a compression spring. The soft metal moved slowly under the action of spring force, shown in Fig. 1(b), so the time delay method based on cutting soft metal was achieved.

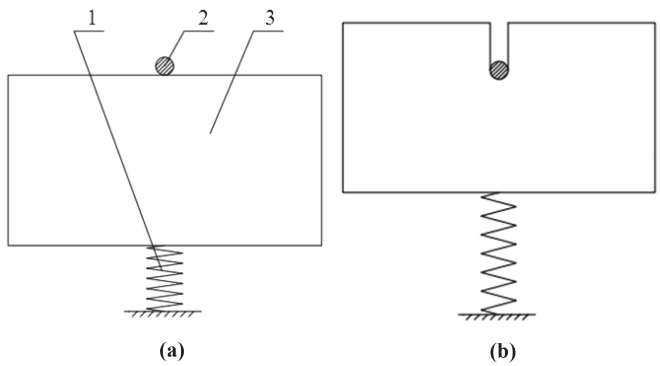


Figure 1. Schematic view for delay method based on cutting soft metal: (1) compression spring, (2) steel wire, and (3) soft metal. (a) Schematic view in a contact position (b) Schematic view in a cutting position.

Figure 2 was a flow diagram of depicting working process for self-neutralisation mechanism and the operation described was as follows. When a safety pin was extracted, sub munitions were brought from a safe operative position to an armed operative position. In the mean time, delay device began to perform time delay function, and compression spring drove soft metal to be cut by steel wire. If sub munitions detected and struck an intended target, a strike member drove into a detonator causing initiation of main charge. If sub munitions did not function normally for various reasons or failed to operate upon striking the ground or target, moreover, soft metal was penetrated after a time delay and the slide was freed, so sub munitions would move from the armed position to a re-safe position.

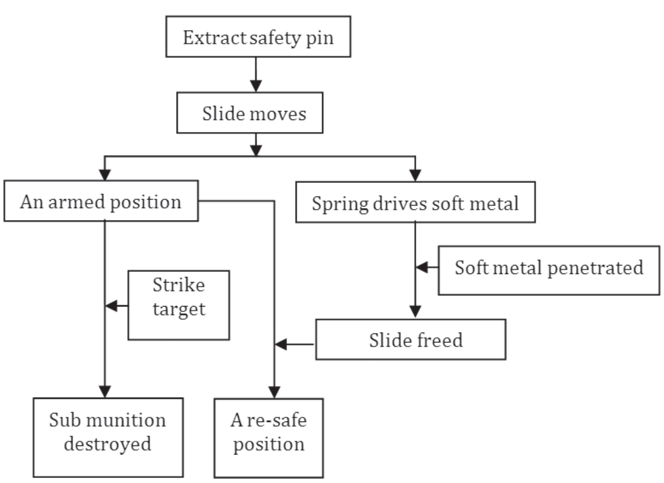


Figure 2. Flow diagram of working process for self-neutralisation mechanism.

2.2 Experimental Mechanism

Principle of the self-neutralisation mechanism was illustrated in Fig. 3(a), which substantially comprised a body, a striker member, a detonator-containing slide and a soft metal delay device. The striker member was movable within the body and able to come into contact with a detonator to cause it to explode. The slide was movable in a direction orthogonal to the striker member. The soft metal delay device included a steel wire and a supporting pin which was disposed a piece of soft metal. This slide could be carried, under the action of a coil spring, from a safe position represented in Fig. 3(a), in which it elastically deformed a spring and was held at a predetermined distance from the striker member, to an armed position represented in Fig. 3(b), in which the detonator was aligned with the striker member, and upon impact, the strike member drove into the detonator causing initiation of main charge. At the moment, the soft metal came into contact with the steel wire, so the movement of the slide was retarded by the steel wire, and the soft metal was cut by the steel wire under a force exerted by the coil spring. The soft metal was penetrated after a predetermined time and eventually freed the slide allowing its movement from the armed position to the re-safe position, as was clearly seen in Fig. 3(c). So the slide from the armed position to the re-safe position could be delayed by the soft metal delay method.

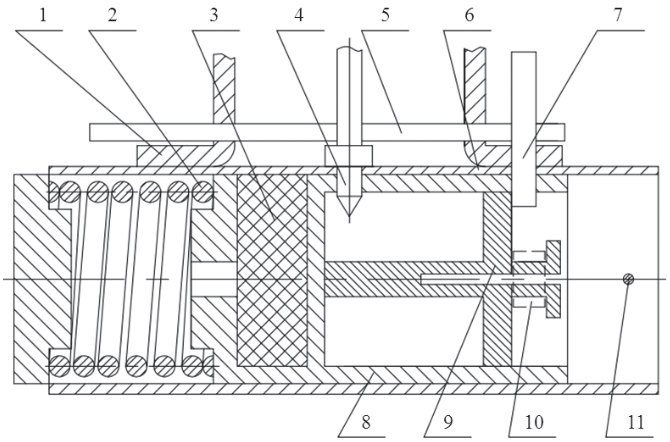
3. MATERIALS AND METHODS

3.1 Materials

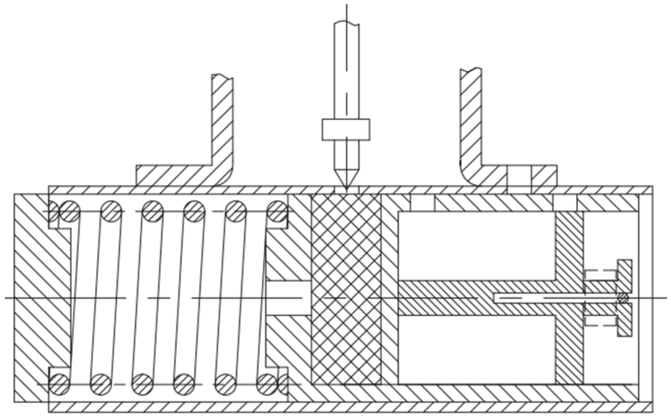
The self-neutralisation mechanism based on cutting soft metal was developed, which was manufactured from Huifeng Machinary Factory, China. The mechanism based on cutting Pb was incorporated to the corresponding sub munitions. The test results showed that the self-neutralisation mechanism could not function at less than - 20 °C. So Pb was removed and replaced by BI-Pb-Sn-Cd alloy. BI-Pb-Sn-Cd alloy was used as a soft metal experimental subject which was composed of 50 % Bi, 25% Pb, 12.5% Sn, and 12.5% Cd. Its melting point and hardness was 71 °C and 1.5 HB, respectively. It had the characteristics of low melting point, low hardness and high ductility, so it could be cut by steel wire because of low hardness of BI-Pb-Sn-Cd alloy. Its thickness and height were 0.75±0.01 mm and 2.40±0.02 mm, respectively. A steel wire with a diameter of 0.12 mm was manufactured from Huifeng Machinary Factory, China, and it had the characteristic with 1410 °C of melting point, and 187 HB of hardness. BI-Pb-Sn-Cd alloy was cut by steel wire under 12.39 N of initial spring force condition.

3.2 Experimental Section

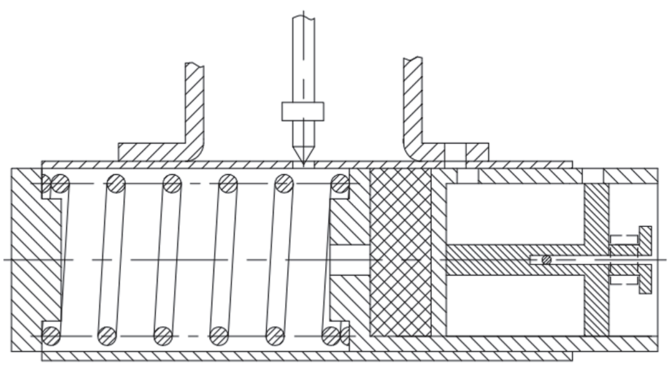
20 experimental mechanism samples were taken, and six samples, involving the minimum and maximum delay time, were selected and analysed at each temperature. The experiments were conducted in thermostat between - 40 °C and 40 °C. The experimental mechanism was partly changed and the striker member was not assembled for safety. Before the experiments, the soft metal was disposed in supporting pin, and then the steel wire was inserted in a corresponding radial hole formed in the body and welded in the body. When



(a)



(b)



(c)

Figure 3. Schematic view for working processes of self-neutralisation mechanism: (1) body, (2) coil spring, (3) detonator, (4) striker member, (5) cotter, (6)body, (7) safety pin, (8) slide, (9) supporting pin, (10) soft metal, and (11) steel wire. (a) Schematic view of self-neutralisation mechanism in a safe position, (b) Schematic view of self-neutralisation mechanism in an armed position, and (c) Schematic view of self-neutralisation mechanism in a re-safe position.

the safety pin was inserted in corresponding holes in the body and the slide in order to prevent any axial displacement of the supporting pin, the soft metal was held at 15 mm of a predetermined distance from the steel wire. After preparation, firstly, the experimental temperature was adjusted at constant temperature by thermostat in the laboratory. The mechanism was placed into thermostat for 15min to make sure the even distribution of temperature. Secondly, timing started when the safety pin was extracted, and then the neutralisation phenomena were observed. After a certain period of time, timing ended when the soft metal was penetrated and the slide moved out to the body. Finally, the neutralisation time was obtained, the experimental mechanism was disassembled, and the experiments were performed repeatedly as described above where the experimental temperature was adjusted as variables.

3.3 Experiment Requirements

The experimental mechanism was required to function with no power source at between -40 °C and 40 °C, and its structure was simple in design, and it could easily be incorporated by a modification to the existing sub munitions (e.g. bomblets, grenades, mines). Self-neutralisation was completed with no less than 30 seconds and at most 144 h, and the experimental mechanism could suffer a failure rate of less than 10 per cent between - 40 °C and 40 °C. The delay time could be adjusted in some way.

4. RESULTS AND DISCUSSION

To investigate the effect of temperature on the neutralisation time, a series of experiments was performed using BI-Pb-Sn-Cd alloy as soft metal at temperatures - 40 °C, -20 °C, 0 °C, 20 °C, and 40 °C. Figure 4 showed photographs of the alloy which was partly cut by steel wire in the experiments.

Figure 4. Photographs of BI-Pb-Sn-Cd alloy used in the experiments.

Figure 5 showed the results of the neutralisation time at different temperatures and the results of the test was subject to the samples. For example, at 40 °C, the neutralisation time ranged from 1 min 5 s to 3 min 16 s in comparison to from 18 min 3 s to 27 min 3 s at 20 °C. At 0 °C, self-neutralisation was achieved with the minimum time of 58min and the maximum time of 121 min.

At the lower temperature, especially below 0 °C, reaction time significantly increased. The minimum time and the maximum time were 4 h and 7 h 42 min at -20 °C, and 90 h 15 min and 143 h 2 min at -40 °C, respectively. BI-Pb-Sn-Cd alloy was cut more slowly at -40 °C. It should be reminded that the faster time occurred at the higher temperature.

From the results, the neutralisation time was different at the same temperature for different self-neutralisation mechanisms. Possibly, it might be due to the structure error of the experimental device, additionally, it might also be work hardening effect on the Bi_{50}-Pb_{25}-$Sn_{12.5}$-$Cd_{12.5}$ alloy exerted by harder steel wire, otherwise it might exert different pressures over the soft metal surface by spring. These resulted in irregular cutting time at the same temperature.

The maximum and minimum neutralisation time was obtained at different temperatures and the results were

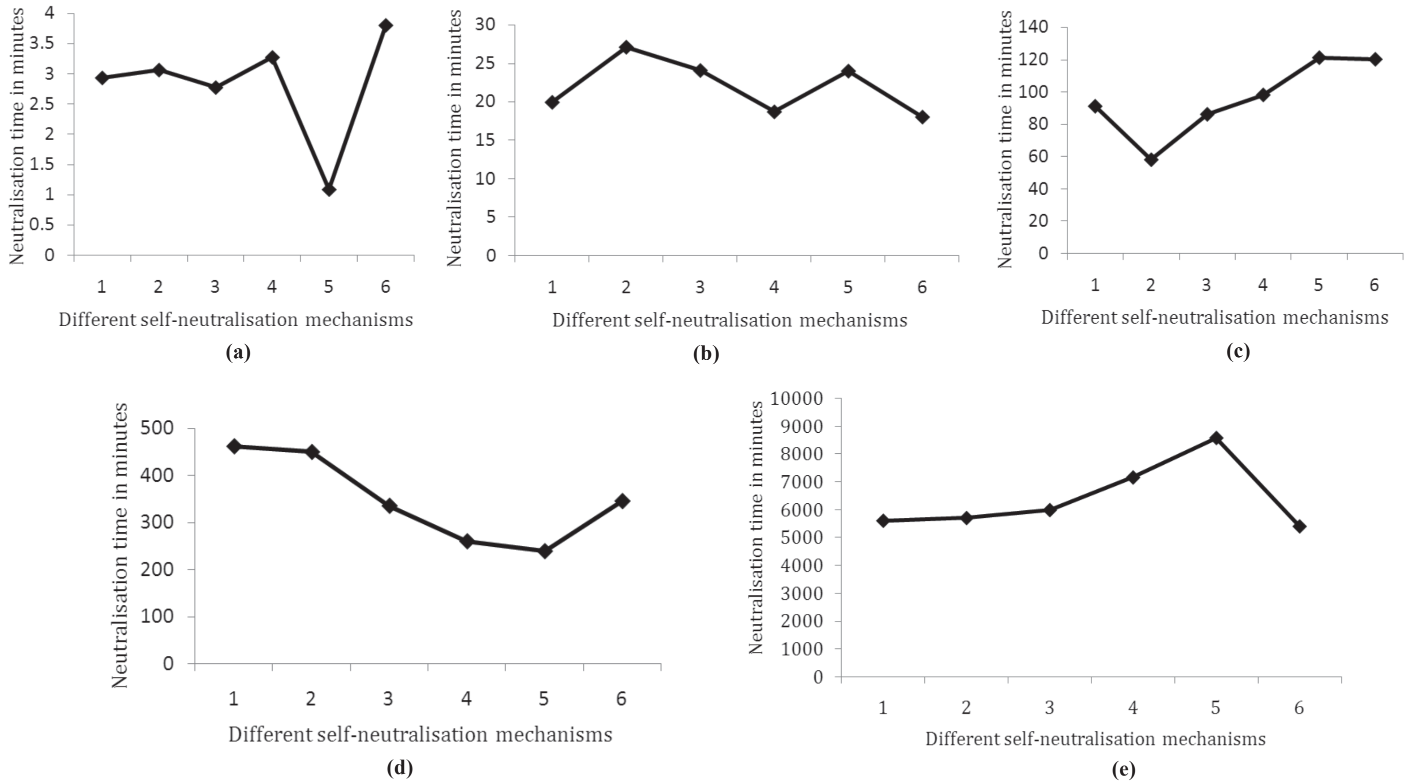


Figure 5. Neutralisation time at different temperatures: (a) Neutralisation time at 40 °C, (b) Neutralisation time at 20 °C, (c) Neutralisation time at 0 °C, (d) Neutralisation time at -20 °C, and (e) Neutralisation time at -4 °C.

presented in Fig. 6. Under the same conditions, the order from fastest to slowest Neutralisation time was 40 °C, 20 °C, 0 °C, -20° C, and -40 °C. The experiments showed that the maximum and minimum neutralisation time were different at different temperatures. From this result, it was evident that self-neutralisation was faster at 40 °C.

From Fig. 6, it could be seen that the neutralisation time was closely related to ambient temperature of the experimental mechanism, and the neutralisation time showed increasing trend with temperature decreasing. The results indicated that the neutralisation time slowly increased from 40 °C to 0 °C, and then significantly increased from 0 °C to - 40 °C. This was due to the fact that there were no significant changes in hardness of BI-Pb-Sn-Cd alloy at between 0 °C and 40 °C, however, the hardness of the alloy obviously increased with decrease of temperature from 0 °C to - 40 °C. Therefore, based on the principle of cutting BI-Pb-Sn-Cd alloy, the neutralisation time was different at different temperatures. However, the time divergence was allowed in the actual use and could meet the experimental requirements. Based on the relation between the neutralisation time and ambient temperature of the experiments, the neutralisation time could be predicted and obtained by ambient temperature.

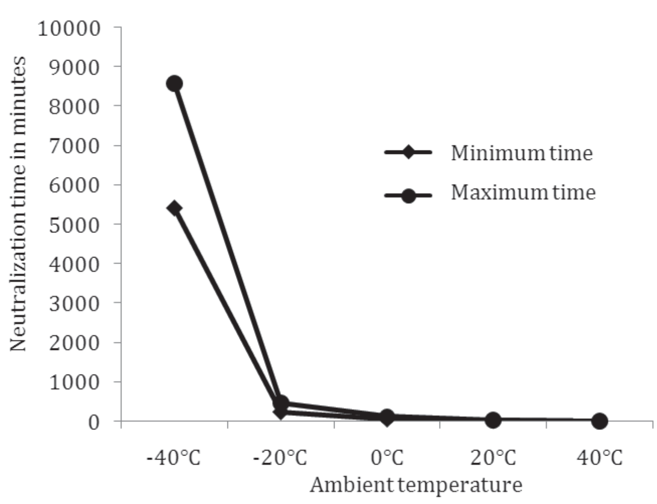


Figure 6. Neutralisation time based on soft metal at different temperatures.

5. CONCLUSIONS

The objective of this work was to develop a self-neutralisation technology of unexploded sub munitions based on cutting soft metal. With BI-Pb-Sn-Cd alloy as a kind of soft metal material, neutralisation time tests were conducted. Based on the above data, the following conclusions were made.

(i) The experimental results indicated that the neutralisation time based on BI-Pb-Sn-Cd alloy could meet its setting requirements. while the alloy with the thickness of 0.75 mm ± 0.01mm and the height of 2.40 mm ± 0.02 mm was cut by steel wire with a diameter of 0.12 mm, its failure rate reached less than 10 per cent at between -40 °C and 40 °C. Self-neutralisation was achieved ranging from 1 min 5 s to 143 h 2 min.

(ii) Self-neutralisation was faster ranging between 0 °C and 40 °C and that was slower below 0 °C. Self-neutralisation was achieved more easily at 40 °C and also retained its ability to disarm sub munitions even at the lower temperature of -40 °C. The neutralisation time had a strong dependence on temperature and decreased rapidly as temperature increased. This was due to the fact that the hardness of soft metal increased with decrease of temperature.

(iii) The current study showed self-neutralisation of sub munitions at constant temperature under laboratory conditions. Neutralisation time was different at the same temperature. In the situation of no high need on time accuracy, this was allowed in battlefield. Further research was needed to improve the reliability of neutralisation time. Moreover, the time at varying temperature was studied by subsequent experiments.

(iv) On account of the close relation between the size of soft metal and neutralisation time, this paper carried out preliminary experiments to verify the relation. The results showed that neutralisation time was closely connected with the size, indicating feasibility of this material. The time could be adjusted by size of BI-Pb-Sn-Cd alloy.

(v) It was concluded that the technology was simple and feasible and one of the advantages of the proposed method was that it could easily be incorporated by a modification to the existing sub munitions with no power source. This paper provided a powerful new technique to solve dangers of unexploded sub munitions.

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ACKNOWLEDGEMENTS

This study was funded by the China Provincial-level Department, through Fund project. Special thanks are expressed to Xiaojie He and Yong Zhang for the experimental work.

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