The Organic Radical Battery (ORB) utilizes charge storable plastics as an electrode active material, and charges and discharges by redox of those plastics. It has several advantages, i.e. very high power density, relatively high energy density, fast charge time, good charge-discharge cycleability and flexibility. Fuse Impact Simulator (FIS) with Firing Acceleration Simulator (FAS) can simulate variety of high-impact condition by launching the object inside the launcher using high pressure. The impact resistance of ORB is tested by using FIS and FAS. The ORB shows no degradation by the impact of 14,000–16,000 G in vertical direction when the sample is flat or the low impact of 7,000–8,000 G in horizontal direction when the sample is curved tightly. By sandwiching or bending the sample to support the structure, and improving the welded bond between the lead and the current collector, the ORB has potential to be used for ammunition.

INTRODUCTION

Battery is one of the most important components of warheads and fuses, and its capacity, volume, location, etc. should be considered carefully in the development of ammunition. Lithium ion secondary battery is widely used; it has relatively high energy density, but its charge is very slow. Super Capacitor can be another option, but its energy density is very limited.

Organic radical battery (ORB) is a new class of rechargeable battery which utilizes organic stable radicals as electrode active materials. The redox reactions of organic compounds are generally irreversible because the ionic radical compounds, which are produced by the redox reaction, are immediately decomposed. However, some of stable organic radicals show good reversibility in the redox reaction because they change into stable ions by the redox. ORB is charged and discharged by the redox of organic stable radicals.

The concept of the ORB was proposed in 2001 [1] and the fundamental performance of the ORB with nitroxyl radical polymers have been reported. [2]-[4] Nitroxy radicals have fast reaction rate in the electrode reaction [5] and this property means that the ORB with nitroxyl radical has potential to be used for high power battery. Previous papers describe that poly (2,2,6,6-tetramethyl-1-piperidinyloxy-4-ylmethacrylate) (PTMA) can be used as a cathode active material for ORB. This material delivers over 100 mAh g−1 of specific capacity with good cycle life. Its
discharge-rate capability is much better than that of transition metal oxides used for conventional lithium-ion batteries. PTMA is a gel state polymer in the battery and this leads to flexibility for thin type ORB.

The properties above are attractive from the viewpoint of usage for not only digital devices and personal equipment but also ammunition. The thin flexible structure, especially, is effective for design flexibility, but is accompanied with low level of impact resistance. In this research, ORB test samples with several level of curvature were given impact to test its impact resistance at ammunition firing.

EXPERIMENTAL

Fuse Impact Simulator and Firing Acceleration Simulator

Fuse Impact Simulator (FIS), shown in Figure 1, of Technical Research and Development Institute, Japanese Ministry of Defense is a large gas gun. Test projectile of 250 mm in diameter is inserted at the lauder, and can be launched up to 500 m/s by compressed gas in the high pressure chamber through 12.5 m launcher into the test chamber. When Firing Acceleration Simulator (FAS) of Figure 2 is attached at the end of the launcher inside the test chamber as shown in Figure 3, the test projectile is decelerated by the compression of the gas inside the FAS so that shock impact is loaded on the test projectile similar to firing acceleration shock backward. The speed at the muzzle is measured with a pair of optical sensors. The deceleration is both calculated using the pressure inside the FAS and recorded in the acceleration sensor inside the pod of the test projectile explained below.
ORBIT Test Sample and Impact Test

The ORB test sample used in the experiment is shown in Figure 4. The size is 35 mm x 35 mm (except electrodes) and about 1 mm in thickness and the weight is about 1 g. The battery capacity is 5 mAh. The simplified schematic diagram of the sample cross-section is shown in Figure 5.

Each ORB test sample is attached on a sample holder of one of four curvature radii, flat, 40 mm, 25 mm and 15 mm (see Figure 6). Two sample holders are installed in one cylinder-shaped test chassis, as is shown in Figure 7; one perpendicular to and the other parallel to the chassis central axis, i.e. impact direction. It is also possible to attach ORB test sample between a flat sample holder and the test chassis as is shown in Figure 8.

The test chassis is installed in the pod, and the pod united with the flange (Figure 9) is inserted into the sabot of Figure 10 upside down. This FAS test projectile is loaded horizontally at the loader of Figure 3 and is shot into the FAS through the launcher.

Each ORB test sample on a sample holder was provided high impact of 14,000 G to 16,000 G or low impact of 7,000 G to 8,000 G, in one of the two directions.
Figure 6. ORB Test Samples on Sample Holders.

Figure 7. Test Chassis with two Sample Holders (One on the top and the other on the side).

Figure 8. ORB Test Sample is fixed between Flat Sample Holder and Test Chassis.

Figure 9. Flange (lower part) and Pod (upper part).

Figure 10: Sabot.
Charge-Discharge Property

The charge-discharge property of the ORB Test Samples is measured at 20 degrees Celsius in thermostatic chamber before and after the impact test. First, the sample is charged at constant 5 mA until the voltage reaches 4 V, and then is charged at 4 V until the current becomes as low as 0.5 mA. Next, the sample is discharged at constant 5 mA and the time to reach 3 V is measured to be used as the index of the capability. The ratio of the discharge time after the impact to that before is exactly how well the battery can withstand the impact.

RESULTS AND DISCUSSION

The two graphs of Figure 11 show the results of the test. The discharging time of y-axis is the ratio introduced above. Figure 11 (1) shows the data of the samples attached on the top of the test chassis, i.e. the shock direction is perpendicular to the sample surface, and the samples of Figure 11 (2) are attached on the side of the test chassis, i.e. the shock direction is parallel to the sample surface.

In the case of vertical impact to the sample surface, there is no degradation for flat sample, but the batteries deteriorate as the curvature becomes tight for both levels of impact. On the other hand, when the impact direction is in the horizontal direction of the sample surface, the samples cannot withstand the high impact at all, and flat samples neither for even low impact.

The partial deterioration is caused by compression of carbon anode, which consists of carbon and copper foil, inside the package, and failure is due to disconnection between aluminum lead and aluminum foil. In the case of Figure 11 (1), the discharging rate decreases as the curvature becomes tight because the edge part of the sample is pulled by the impact. However, in Figure 11 (2), the samples can withstand the low impact when the curvature is tight because the bent figure supports the inner structure and prevents the carbon anode and copper foil compressions.

The sandwiched sample of Figure 8 still had 50% of discharging time after the high impact, owing to the structure support. The disconnection of the lead should be improved by making the connection robust.

There was no difference between the discharge time ratios of vertical impact on ORB test samples of flat sample holders after either -20 degrees Celsius or 60 degrees Celsius for three days, and those of the same impact without temperature load shown in Figure 11 (1).
CONCLUSION

The impact resistance of ORB was tested by using FIS and FAS. The ORB showed no degradation by the high impact in vertical direction when the sample was flat or the low impact in horizontal direction when the sample was curved tightly. By sandwiching or bending the sample to support the structure, and improving the lead connection, the ORB has potential to be used for ammunition.
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