Journal of Power Sources, 38 (1992) 123–136

Development of sealed lead/acid battery 'SB60-S4' for automobile use

Takashi Yamada, Yoshio Nakazawa and Naohiro Tsujino
Japan Storage Battery Co., Ltd., 1 Inobabacho, Nishinosho, Kisshoin Minami-ku, Kyoto 601 (Japan)

Abstract

The construction and characteristics of a new sealed, automotive lead/acid battery are discussed and results from two years of field testing are presented. The starved-electrolyte design has virtually the same initial performance as a conventional flooded-electrolyte counterpart of the same size. A longer life is obtained, however, at low temperatures. The sealed batteries have generally exhibited good performance in field tests but there is a small decline in the operational characteristics at high temperatures and/or high voltage charging conditions.

Introduction

At present, sealed lead/acid batteries are widely used in many applications, not only in various industries but also in consumer products. This technology has the advantage of not requiring water makeup nor leaking electrolyte, gas or acid mist. In addition, sealed batteries can be used in any orientation and this allows great flexibility in mounting the units. The sealed lead/acid battery discussed in this paper has a 'retainer' design [1] in which the acid in contained in an absorptive glass-mat separator. Retainer-type batteries have been used in self-powered equipment [2], as well as in compact consumer goods and standby units. In the near future, sealed lead/acid units will increase their share of the industrial battery market. By contrast, only a small number of such batteries have entered the automotive market.

In 1988, the authors' company developed a retainer-type sealed lead/acid battery for automobile use and sold a limited number of the batteries for the purpose of monitoring field performance. To date, no failure claims have been made.

This paper describes the construction and operational characteristics of the new sealed, automotive lead/acid battery and presents the results of the field application tests conducted to date.

Battery construction

General features

The new retainer-type, sealed, lead/acid automotive battery is named 'SB60-S4' and has the size 36B20. Figure 1 gives an external view of the battery. Compared

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Fig. 1. External view and inner structure of the 'SB60-S4' battery.

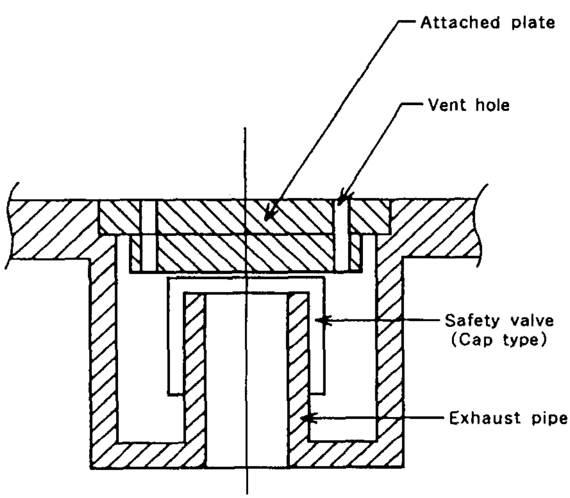

Fig. 2. Construction of gas vent.

with conventional flooded-electrolyte designs, the sealed battery has the following different aspects of construction:

- sealed design using safety valve
- the container, made of re-inforced polypropylene, has thicker walls
- thicker positive grids contain more active material
- separators absorb and fix electrolyte; there is no free electrolyte

Vent plug

Figure 2 shows the structure of the vent plug. The safety valve is made of special rubber and covers the cylindrical exhaust tube. When the internal pressure in the battery increases by more than the set value, the safety valve automatically opens and releases the accumulated gas. As the internal pressure drops below the atmospheric pressure, the valve closes. This valve prevents both excessive deformation of the container and oxidation of the negative plate.

Container and cover

Because of the function of the safety valve, the container is under pressure at all times. If the container is made of polypropylene resin, as conventional containers, it is likely to deform. Therefore, a re-inforced polypropylene resin with a high bending strength has been used for the container. Furthermore, the container has thicker walls and grid-shape ribs on both end-walls. The cover has a safety valve for each cell in order to prevent leakage to adjacent cells.

Positive plate

The grid uses a Pb–Ca–Sn alloy that has been successfully employed in flooded-electrolyte batteries. The positive grid has a thicker frame in order to provide corrosion resistance, reliability and longer battery life. Because of the limited ('starved') amount of electrolyte, the active materials have a low utilization efficiency. To ensure low-rate discharge, the battery has more active material than conventional units of the same capacity rating. Therefore, the plates are heavier than those of conventional design.

Separator

The separators are made from microfibre glass mat that has been successfully used for many years in industrial sealed lead/acid batteries. This type of separator allows a high absorption of electrolyte and this, in turn, can rapidly diffuse within the separator structure. Only a small amount of the electrolyte exists freely outside the element.

Battery characteristics

Battery specification

Table 1 compares the characteristics of the SB60-S4 battery with those of flooded-electrolyte 'hybrid' (i.e., positive grid: low Sb alloy; negative grid: Ca alloy) and all-calcium (i.e., Ca alloy for both positive and negative grids) designs.

Discharge characteristics

As can be seen from Table 1, the initial performance of the SB60-S4 battery is almost the same as that of the hybrid 'wet' design CX60-S4. To have such equivalent performance, the new battery is slightly heavier than the wet battery. This is because of the increased weight of the plates and the container, although the amount of electrolyte is less.

Gas-recombination efficiency

To determine the gas absorption capability, the gas emitted from an overcharged battery is collected. By determining the percentage of the collected to theoretical gas generation, the gas recombination efficiency can be obtained. As can be seen from Fig. 3, the efficiency is 100% upto 0.05*C* ampere overcharge. There are no gas leaks.

TABLE 1

Weight, dimensions and initial performance of new sealed lead/acid battery

	Sealed battery (SB60-S4)	Flooded battery (CX60-S4)	JIS standard (36B20)
Max. overall dimensions (mm)			
Length	195		≦197
Width	127		≦129
Overall height	227		≦227
Battery weight (kg)	10.2	9.5	10.5
Performance			
5 h capacity (A h)	28.6	31.0	≧28
150 A discharge at −15 °C			
Discharge time (min)	2.9	3.5	≧3.5
5 s voltage (V)	9.75	9.8	≧9.2
Charge acceptance (A)	13.0	11.0	≧3.5

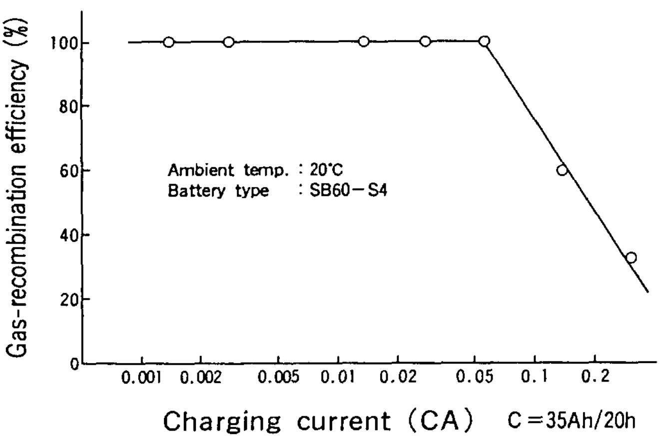

Fig. 3. Gas-recombination efficiency of SB60-S4 battery.

Charging characteristics

Figure 4 shows the relationship between the terminal voltage and the charging current under full-charging conditions. In zone I, the sealed lead/acid battery exhibits a considerably lower terminal voltage than a wet battery. This is due to the high gas-recombination efficiency of the sealed battery which, therefore, emits little gas. In zone III, the rate of gas evolution is greater than the absorption ability of the negative plate. Thus, the hydrogen gas generated at the negative plate increases the terminal voltage. Zone II corresponds to a transient status from zone I to III. To minimize the loss of the electrolyte, the SB60-S4 battery should be operated below 15 V, i.e., under conditions where there is no evolution of hydrogen gas.

Self-discharge characteristics

The terminal voltage and performance of the SB60-S4 battery during standing at room temperature is given in Fig. 5. Since the 5-s voltage is 9 V or more when the

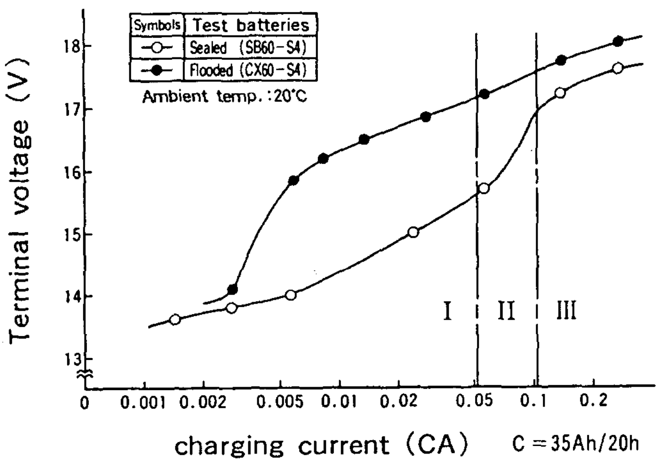

Fig. 4. Terminal voltage at various charging currents for SB60-S4 and CX60-S4 batteries.

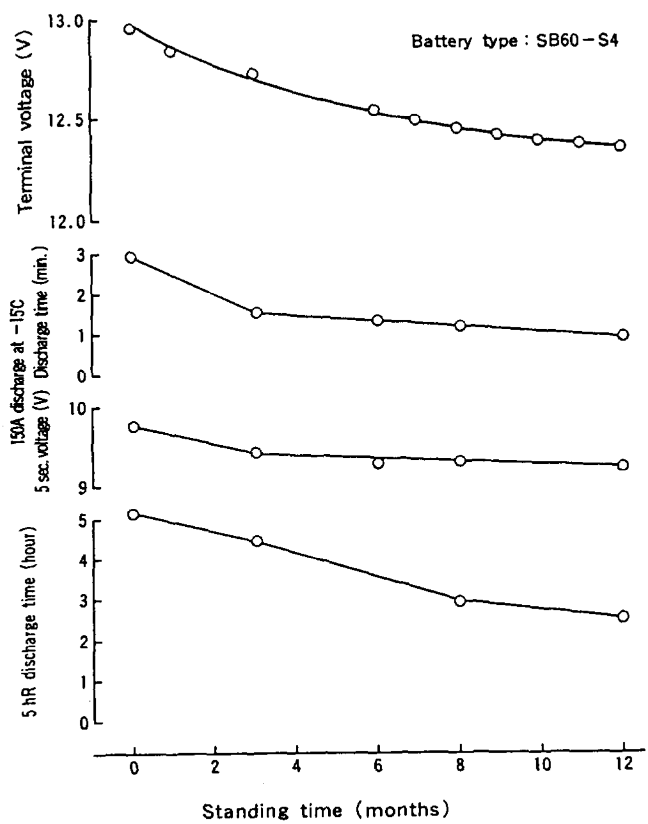

Fig. 5. Terminal voltage and performance of SB60-S4 battery while at room temperature.

discharge rate is 150 A at −15 °C, the battery has the ability to crank an engine, even after standing without maintenance for one year.

Charge-acceptance characteristic after overdischarge

Figure 6 shows the charge-acceptance characteristic when the SB60-S4 battery is fully discharged, (i.e., connected to a 10 W lamp for 12 days) and then left for a further 15 days on open circuit. The initial charging current is smaller than that for a wet hybrid battery. This is due to the fact that the positive grid is made of Pb–Ca–Sn alloy. During subsequent charging, the sealed battery can accept a reasonable amount of charging.

Safety factor

Table 2 presents the results from an explosion-proof test in which sparks are applied over the vent hole while the battery is being overcharged. The findings demonstrate that the SB60-S4 battery has an excellent explosion-proof capability.

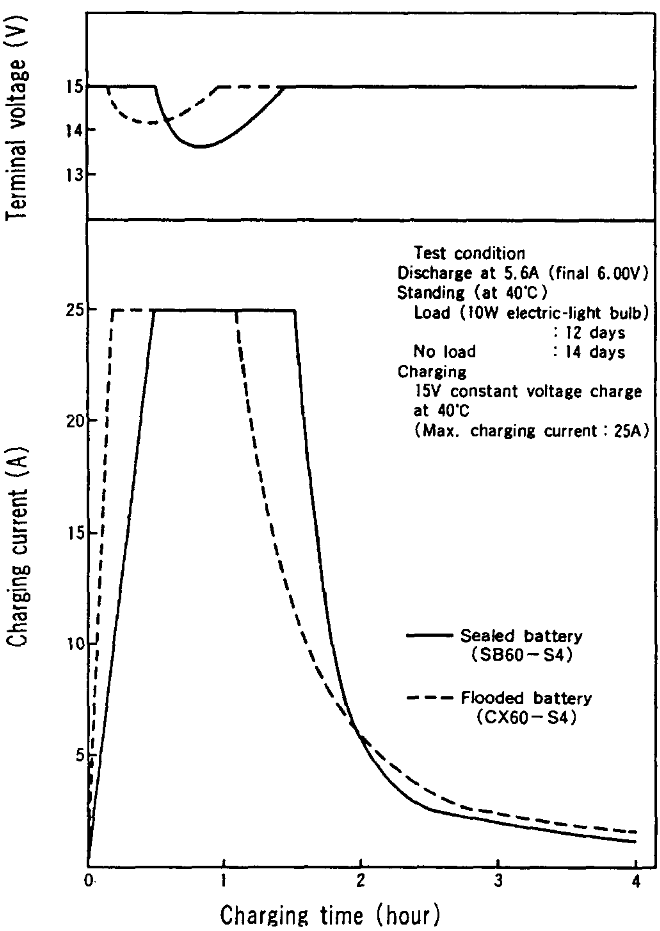

Fig. 6. Charge-acceptance characteristics after overdischarge of SB60-S4 and CX60-S4 batteries.

TABLE 2

Results of explosion-proof test

Test batteries	Overcharge current (A)						
	2	4	6	8	10	15	20
Sealed battery (SB60-S4)	O	O	O	O	O	O	O
Flooded battery (CX60-S4)	O	×	×	×	×	×	×

O: no explosion; ×: explosion.

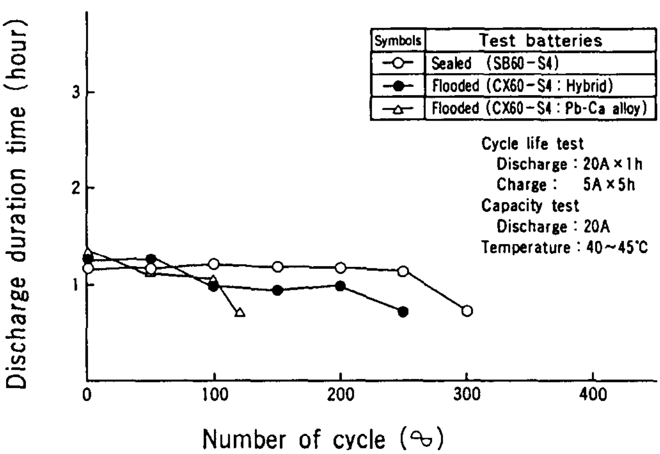

Fig. 7. Results of JIS life test.

To evaluate the extent of leakage-proof ability, the battery was continuously overcharged for 2 h at the 5-h rate in various positions. That is, the battery was placed either in a normal position, on its narrow side, or on its wide side. In all cases, no leakage of electrolyte was observed.

These tests showed that the battery is highly explosion-proof and leakage-proof.

Bench life test

The results from life tests under the JIS standard, while overcharging at a constant current, and the SAE procedure at 75 °C are presented in Figs. 7 to 9, respectively. The data show that the performance of the sealed lead/acid battery is at least equal to that of a wet battery. In particular, the sealed battery provides greater cycle life under the JIS test.

Nevertheless, as shown in Fig. 10, the life of the sealed battery decreases sharply as the temperature is raised. Furthermore, the sealed battery will itself increase the temperature due to the generation of heat during the gas-recombination process. One of the key factors in using sealed lead/acid batteries is to prevent excessive rises in temperature.

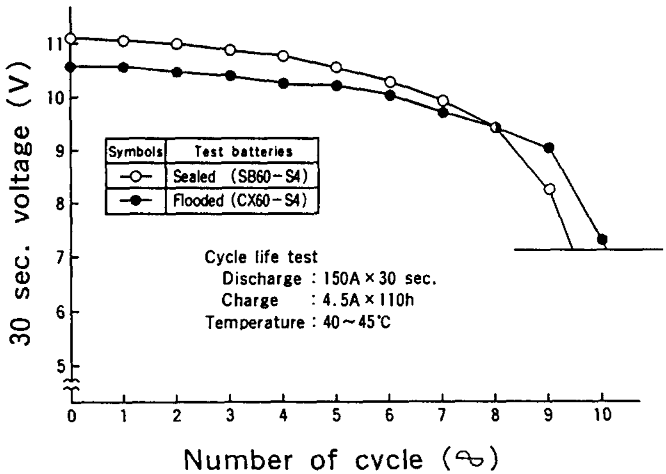

Fig. 8. Results of overcharge life test.

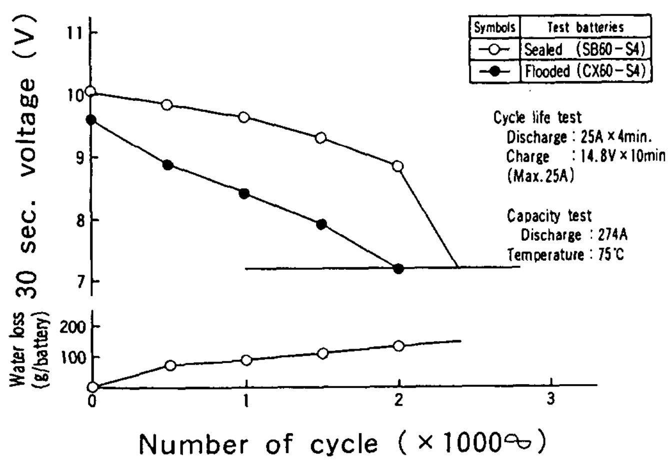

Fig. 9. Results of SAE life test at 75 °C.

Field tests

Results of tests in car

A total of 60 sealed lead/acid batteries were used for two years in automobiles in seven cities throughout Japan, from the northern part of the main island to Kyusyu. The average mileage of these cars during that time was 32 000 km. All the batteries were still usable but were returned to the authors' laboratory for performance evaluation and analysis of plate condition.

The weight loss and *C*/5 capacity of the batteries are given in Fig. 11. It was found that the electrolyte was, on average, reduced by 20 g per unit, i.e., a negligible amount. The reduction in the *C*/5 capacity was also insignificant.

The 150-A discharge characteristics at −15 °C of the batteries are shown in Fig. 12. The degradation in performance is almost equal to that of wet batteries. After

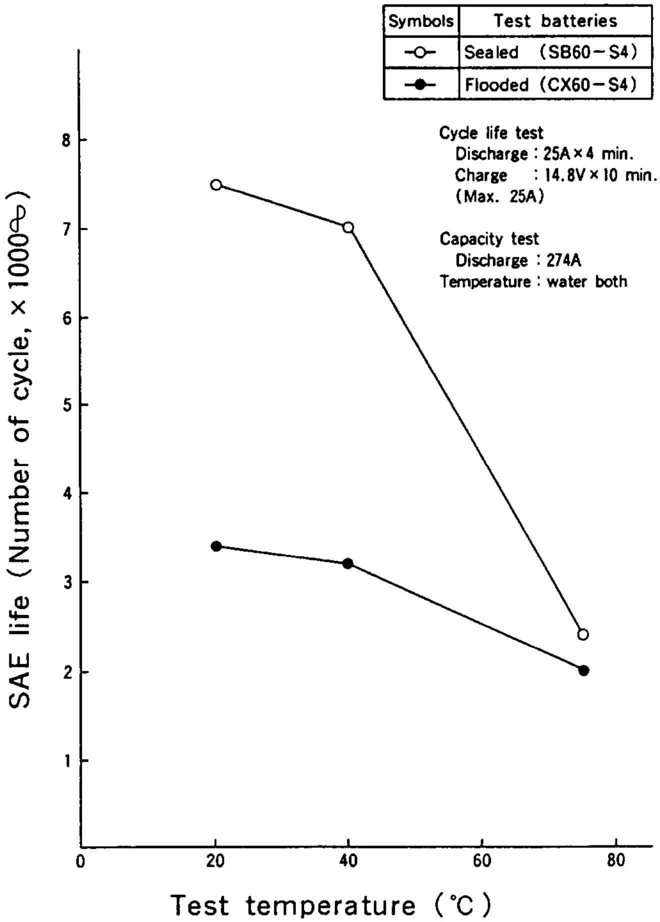

Fig. 10. Temperature dependence of SAE life test.

performance tests, the batteries were disassembled for internal examination. Slight corrosion of the positive grids was observed, but no significant abnormality was found. The batteries had remained in good condition.

Degradation factors

Attempts were made to correlate the life performance of the batteries with the location of the test cars, the mileage and the charging voltage (set voltage of the regulator).

Figure 13 shows the average values. Batteries used in both Tokyo and the northern regions retained a larger amount of electrolyte. The high-rate performance decreased as the regulator was set to higher voltages. The mileage difference did not show significant change in battery performance.

These observations suggest that the sealed battery is likely to decline in performance as its temperature increases and as it is charged at a higher voltage.

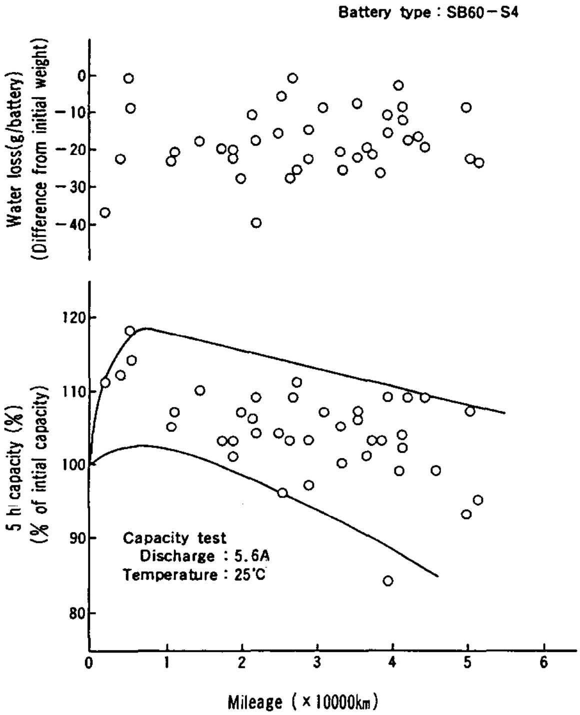

Fig. 11. Water loss and *C*/5 capacity after field test.

Influence of plate type

The sealed lead/acid battery uses a grid cast from Pb–Ca–Sn alloy in both the positive and negative plates (C-C type). For the purposes of comparison, sealed batteries were produced with different plate types but all the remaining components were kept the same (see Table 3).

The resulting JIS and SAE/75 °C life-test data are presented in Figs. 14 and 15, respectively. Although the A-C and A-X types (using 1.7 wt.% Sb alloy) exhibit the best performance under JIS test conditions, the life is reduced under the SAE procedure (constant-voltage charging). In the latter test, the electrolyte decreases at a fast rate.

Batteries using expanded Pb–Ca–Sn grids of the X-X type yielded the shortest life. This was due to positive-grid growth. No problems were encountered when the expanded grid was used for negative plates (i.e., A-X, A-C).

As a result of these studies, the C-C type of grid was adopted for automotive batteries.

Future sealed battery products

Commercial units of the sealed automotive battery are presently in the size B20. To meet future market demands, however, prototype batteries have been produced in sizes D26 and D31. Table 4 compares the initial performance of these batteries

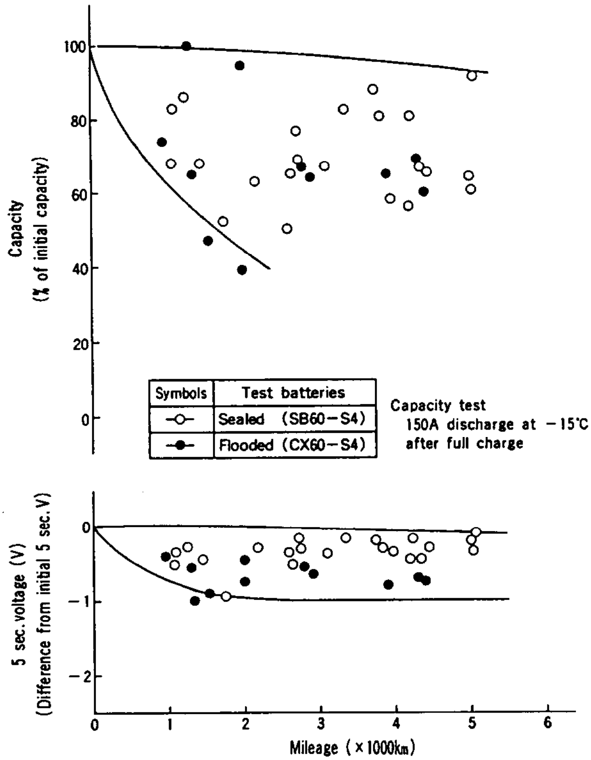

Fig. 12. Results of 150 A discharge at −15 °C after field test.

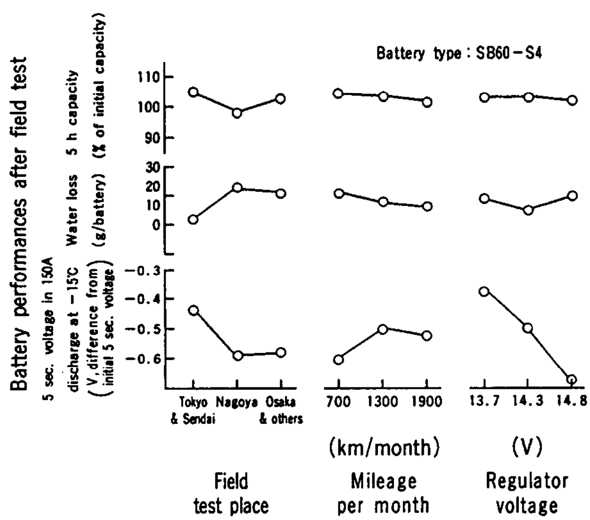

Fig. 13. Relation between battery performance and field test conditions.

TABLE 3

Grid compositions of sealed batteries

Battery	SB60-S4	Trial sealed batteries (SB60-S4)		
Grid type	C-C	A-C	A-X	X-X
⊕ Grid (alloy)	cast (Pb–Ca–Sn alloy)	cast (Pb–1.7wt.%Sb alloy)		expanded (Pb–Ca–Sn alloy)
⊖ Grid (alloy)	cast ⟵ (Pb–Ca–Sn alloy) ⟶		expanded ⟵ (Pb–Ca–Sn alloy) ⟶	

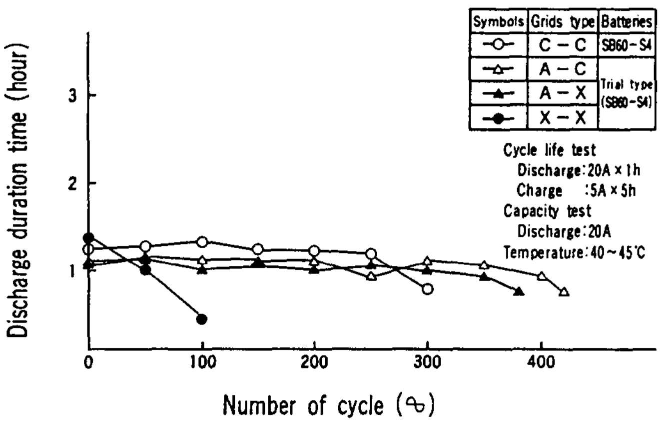

Fig. 14. Results of JIS life test.

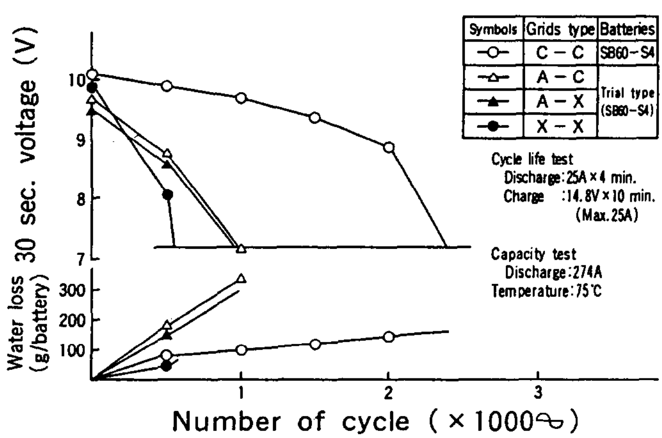

Fig. 15. Results of SAE life test at 75 °C.

TABLE 4

Results of trials on size D26 and D31 sealed batteries

	Battery size			
	D26		D31	
Test batteries (type)	sealed battery (trial type)	flooded battery (65D26)	sealed battery (trial type)	flooded battery (75D31)
No. plates/cell	⊕ 6/⊖ 7		⊕ 7/⊖ 8	
⊕ Grid (alloy)	cast (Pb–Ca–Sn alloy)	cast (Pb–low Sb alloy)	cast (Pb–Ca–Sn alloy)	cast (Pb–low Sb alloy)
⊖ Grid (alloy)	cast (Pb–Ca–Sn alloy)	expanded (Pb–Ca–Sn alloy)	cast (Pb–Ca–Sn alloy)	expanded (Pb–Ca–Sn alloy)
Battery weight (kg)	18	16.8	21	19.5
Performance				
5 h capacity (A h)	50	55	61	67
300 A discharge at −15 °C (30-s V)	2.9 min (9.3 V)	3.0 min (8.8 V)	3.7 min (9.6 V)	4.1 min (9.0 V)

with that of wet hybrid batteries (65D26, 75D31). The batteries will be put on the market as the need arises.

Conclusions

The advantages of the sealed automotive battery are:

(i) completely maintenance-free design (low self-discharge rate, no need for water addition);

(ii) position-free (gives more freedom to automobile designers);

(iii) can be made compact (minimum space under cover and element rest).

By contrast, the disadvantages of the battery are:

(i) heavier and slightly inferior initial performance (low active-material utilization);

(ii) inherently susceptible to high temperature, overcharge and overdischarge (small quantity of electrolyte);

(iii) increased cost (both in materials and production).

It is obvious that direct replacement of wet batteries by sealed units will not take full advantage of the new technology. One possibility is to integrate the sealed battery into the assembly of the automobile body. The adoption of such a proposal will rapidly increase the demand for the new battery technology. Furthermore, since the battery is maintenance free, it can be fitted anywhere, e.g., in inaccessible parts within the vehicle body rather than in the engine compartment itself. Another possible application is to use the battery in conjunction with a high-voltage line and thus avoid water-maintenance and electrolyte-leakage problems.

References

1 M. Iwata, Y. Kawanami, K. Yonezu and H. Tanaka, *GS News Tech. Rep., 40*(1) (1981) 13.
2 M. Iwata, *GS News Tech. Rep., 42*(2) (1983) 22.