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Investigation the effects of mass of active materials of lead-acid battery on active mass utilization coefficient

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ABSTRACT
The lead-acid battery has been widely applied in the fields of electric vehicles, IPS, Solar Power Station etc. due to its advantages of high power, long lifespan, availability of electricity, low cost etc. In this study, 80 pieces lead- acid batteries are adopted to explore the effects of variation of mass of active materials of negative and positive plates on active material utilization co-efficient. Batteries are categorized into four samples according to the mass of active materials of the plates and in every samples has 20 pieces similar batteries of similar plates and active materials. The batteries are charged according to the constant current charging process. After that capacity of the batteries are measured using constant current discharging process. Comparing the capacity found from the research, an optimal combination of plates will be found which will give the best active mass utilization co-efficient.

Keywords: Lead-acid battery, constant current charge, constant current discharge, active material, active mass utilization coefficient, capacity of battery

1. Introduction

From the beginning of the 20th century, the lead-acid battery has been the most widely used power source for some specific applications such as combustion engine starting, small traction, operating easy bikes etc. However, the main disadvantage of lead acid battery is that the energy density and specific capacity is lower compared with other battery systems such lithium ion battery. [1]

The capacity of a battery is the product of the discharge current from a battery with the number of discharge hours. The unit of capacity is measured in ampere-hour. Capacity of Lead-acid battery mainly depends on design and construction of battery and conditions of operation.[2] If conditions of operation remains constant, capacity of battery depends on design and construction of battery.[3] According to design and construction, capacity of the battery will be varied with the change of area of plate surface, quantity of active materials, quantity and strength of electrolyte, circulation of electrolyte.[4] In this study conditions of operation, quantity and strength of electrolyte, circulation of electrolyte are kept constant for all samples but variation is done in area of plate surface and quantity of active materials. The capacity of a battery will be higher if the surface area of its plates is increased. Because larger plate can carry larger amount of active materials. Batteries, containing higher active materials, are suitable for higher discharge. But it is also noticeable that for a decrease in plate size, there will be low internal resistance at the time of discharge which will result in better capacity. [3]

But the actual capacity of battery varies from the theoretical capacity. The ratio of practical capacity to the theoretical capacity is called active mass utilization coefficient. With the variation of active materials and size of the plates, active mass utilization coefficient also varies [1]. So there will be a suitable size of plate which will provide better active mass utilization coefficient and it is the main objective to find out the optimal size of plates in this research which can offer better active mass utilization coefficient. [8]

2. Theory

Active mass utilization coefficient is the ratio of actual capacity found from charge-discharge process to the theoretical capacity of positive or negative material. It is denoted by Ƞ [1].

$$Ƞ = C_{Actual} / C_{Theoretical}$$

Where C_{Actual} is the actual capacity found from charge-discharge process and $C_{Theoretical}$ is the theoretical capacity of positive or negative plate.
Electrochemical equivalent weight, G_{NAM}=3.866 g.Pb/Ah

$$C_{Theoretical(NAM)} = M_{NAM} / G_{NAM}$$

Where M_{NAM} is the Mass of Negative Active Material/Battery [1]
Electrochemical equivalent weight per Ah of PbO_2, G_{PAM}=4.463 g.PbO_2/Ah

$$C_{Theoretical(PAM)} = M_{PAM} / G_{PAM}$$

Where M_{PAM} is the Mass of Positive Active Material/Battery [1]
The Lowest Value of $C_{Theoretical(NAM)}$ and $C_{Theoretical(PAM)}$ is taken as $C_{Theoretical}$

3. Materials

80 pieces Lead-acid batteries are used in this research. 80 pieces batteries are categorized into 4 samples according to plate combination and mass of active materials and each sample contains 20 pieces batteries. A rectifier named jinfan (50A, 400V) is used to charge and discharge the samples. [7]

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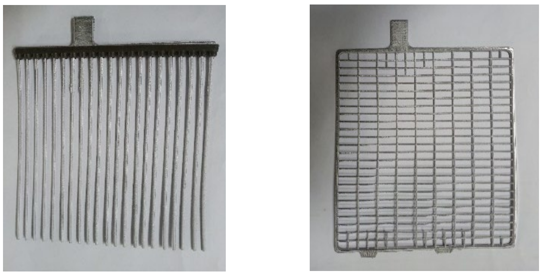

Grid of positive plate　　Grid of negative plate

Fig.1 Grid design of plates

Positive plate　　Negative plate

Fig.2 Sample of plates

Table 1 combination of Plate in samples

Sample no.	Positive plate type	Negative plate type	Posi-tive plate /cell	Nega-tive plate /cell
Sample 1	ET180TP	ET180F	4	5
Sample 2	ET175TP	ET175(2.7), ET175F(1.9)	4	3,2
Sample 3	ET160TP	ET160F(2.7, ET160F(1.9)	3	3,1
Sample 4	ET130TP	ET130F(2.3)	3	4

Table 2 Positive plate dimension and mass of active material

Sample no.	Positive plate type	Plate dimension (mm*mm)	Mass of active material / plate (gm)	Mass of active material /cell (gm)
Sample 1	ET180TP	180*150	365.1	1460.4
Sample 2	ET175TP	175*150	351.8	1407.2
Sample 3	ET160TP	160*150	310	930
Sample 4	ET130TP	130*150	237.8	713.4

Table 3 Negative plate dimension and mass of active material

Sample No	Negative plate type	Plate dimension (mm*mm)	Mass of active materi al /plate(gm)	Mass of active mater ial /cell (gm)
Sample 1	ET180F	180*150	207.6	1038
Sample 2	ET175F(2.7), ET175F(1.9)	175*150	228.4, 155.2	995.6
Sample 3	ET160F(2.7), ET160F(1.9)	160*150	208.4, 141.2	766.4
Sample 4	ET130F(2.3)	130*150	149.5	747

At first grids of plates for the samples are produced using 2.4% antimonial lead. Then grids of positive plates are cover with gauntlet and filled with the appropriate proportion of the active materials and other materials. The grids of negative plates are pasted with the proper chemical mixer. [7] After that positive plates are taken to the sulphation section for sulphation process. Sulphation in lead acid battery refers to the formation of Lead sulphate (PbSO4) on the positive plates of battery. [4] 1.140 gravity acid is used for the sulphation of all the samples. After that positive plates are taken to the drying chamber and dried at 50^0 celsius. After pasting the negative plates, these plates are taken to the curing chamber for curing and drying. For negative plates, curing temperature and relative humidity are set at 45^0 celcius and 95% respectively. [7] After that cured negative plates are dried at the temperature of 65^0 celsius. Finally moister of plates is checked. If the moister content in plates is less than 1%, the plates are ready for making battery. [8]

4. Experimental setup and procedure

After that Plates are brushed in plate brushing section. And then plates are joined according to their combination to form the cells. Positive and negative cells are arranged in the container. [5] The positive and negative cells are inter cell welded using inter cell welding machine. Then the container is sealed with the cover by using heat sealed machine.[6] A terminal burner man joined the terminal post with the main post by burning lead bar. After that leak test is done. Finally the batteries are charged at the charging section. [7]

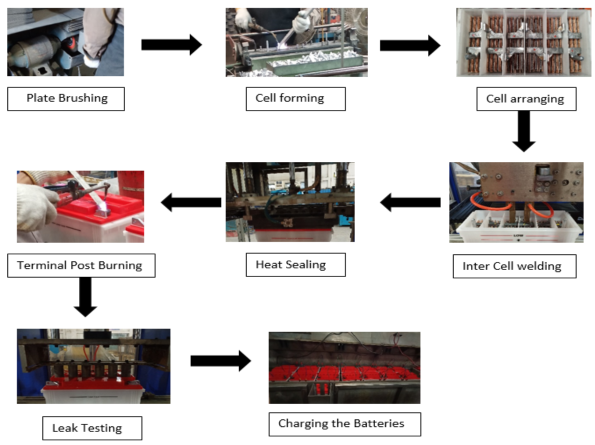

Fig.3 Diagram of experimental process

In charging process, at first every sample was filled with 1.070 gravity acid. After completing the charging processes, every sample was filled with 1.280 gravity acid. The charging process was done according to constant current process. The charging process are discussed in the table 4, 5, 6 and 7.

Table 4 Charging program for sample 1

Step	Condition	Current(A)	Duration(H)
1	Charge	5	1
2	Charge	10	1
3	Charge	25	21
4	Charge	22	11
5	Discharge	20	1
6	Interrupt	Change of 1.070 gravity acid and filled with 1.280 gravity acid	
7	Charge	17	8
8	Charge	14	3
9	Discharge	20	4
10	Charge	17	7
11	Charge	14	6

Table 5 Charging program for sample 2

Step	Condition	Current(A)	Duration(H)
1	Charge	5	1
2	Charge	10	1
3	Charge	22	11
4	Charge	20	21
5	Discharge	20	1
6	Interrupt	Change of 1.070 gravity acid and filled with 1.280 gravity acid	
7	Charge	17	8
8	Charge	14	3
9	Discharge	20	4
10	Charge	17	7
11	Charge	14	6

Table 6 Charging program for sample 3

Step	Condition	Current(A)	Duration(Hours)
1	Charge	5	1
2	Charge	10	1
3	Charge	19	11
4	Charge	17.5	21
5	Discharge	17.5	1
6	Interrupt	Change of 1.070 gravity acid and filled with 1.280 gravity acid	
7	Charge	16	8
8	Charge	12	3
9	Discharge	17.5	4
10	Charge	16	7
11	Charge	12	6

Table 7 Charging program for sample 4

Step	Condition	Current(A)	Duration(Hours)
1	Charge	3	1
2	Charge	5	1
3	Charge	13	21
4	Charge	11	11
5	Discharge	10	1
6	Interrupt	Change of 1.070 gravity acid and filled with 1.280 gravity acid	
7	Charge	9	8
8	Charge	7	3
9	Discharge	10	4
10	Charge	9	7
11	Charge	7	6

Then discharge process was done to calculate the capacity of the samples. Discharge process was done according to constant current process and 20A discharged current was fixed for all the samples. Discharge process was continued till the cut-off voltage. The cut-off-voltage was 10.5V for every battery. Every sample has 20 pieces batteries. So cut-off voltage for every sample was fixed at 210V. After fully charged the samples, discharge process was started and continued the process till the reaching of cut-off voltage of the samples. Then the capacity was calculated by multiplying the discharge ampere with the found time from discharge process.

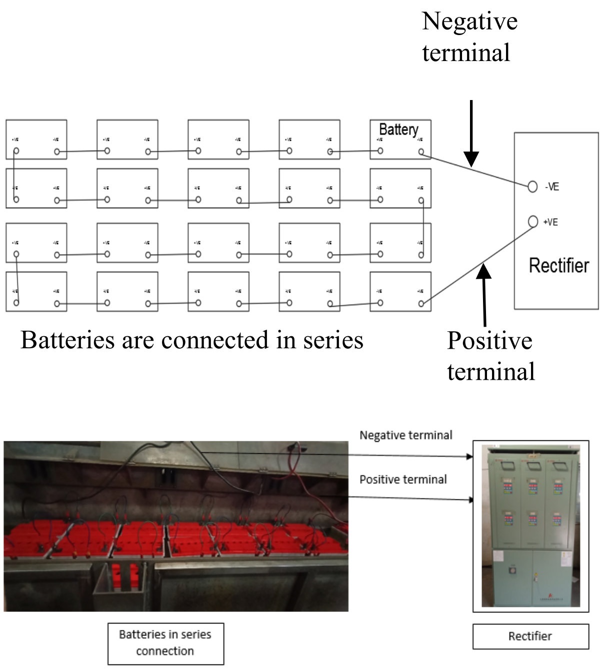

Fig.4 Experimental setup. [7]

5. Experimental result and discussion

In this research, procedure of plate preparation and charging is same for all samples but only change in active materials and the size of plates. As there is a change in active materials of plates, there must be a variation in the capacity of the samples. And the active material utilization co-efficient of the samples also changes with the changes of size and mass of active materials.

Table 8 Theoretical capacity of the samples

Sample no.	Active material weight /Cell(g)	Theoretical capacity (Ah)
Sample 1	1038	268.49
Sample 2	995.6	257.52
Sample 3	766.4	198.24
Sample 4	713.4	159.50

Table 9 Actual capacity of the samples

Sample no.	Discha-rging hour	Discharg-ing ampere (A)	Cut off voltage/ sample (V)	Actual capacity (Ah)
Sample 1	6.5	20	210	129.9
Sample 2	6.183	20	210	123.8
Sample 3	4.95	20	210	102.9
Sample 4	3.475	20	210	69.5

In this research, actual capacity is 40-50% lower the theoretical capacity. In figure 3, variation between actual and theoretical capacity is shown.

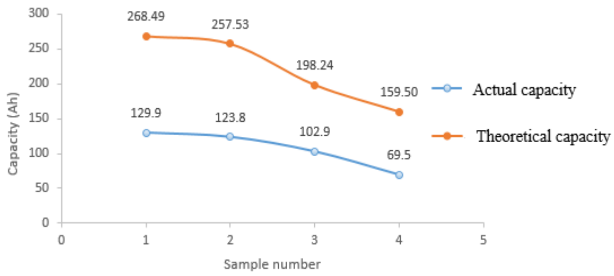

Fig.5 Active mass utilization co-efficient vs sample number graph showing theoretical capacity and actual capacity

Table 6 Active Material Utilization co-efficient of the samples

Sample no.	Actual Capacity (Ah)	Theoretical Capacity (Ah)	Active Material Utilization co-efficient
Sample 1	129.9	268.49	0.484
Sample 2	123.8	257.52	0.481
Sample 3	102.9	198.24	0.519
Sample 4	69.5	159.5	0.436

In this research, it is found that highest active mass utilization coefficient is found for sample 3. And lowest active mass utilization coefficient is found for sample 4. In figure 4, the result is shown graphically. The batteries containing higher active materials can provide higher capacity but due to larger grid size, there is more internal resistance which decreases the capacity. On contrast, battery with lower active materials such as sample 4, can't cope up with higher discharge which results lower capacity as well as lower efficiency. [8]

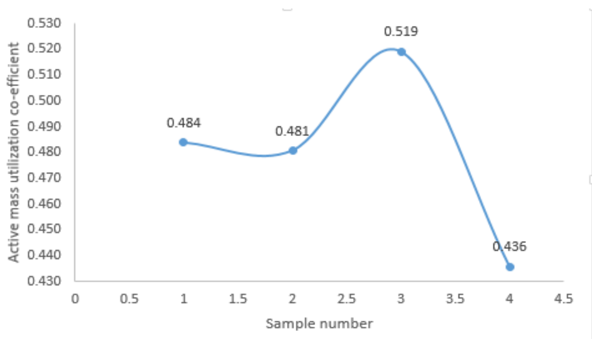

Fig.6 Active mass utilization co-efficient vs sample number graph

6. Conclusions

It is clear that if all other variable regarding capacity variation are constant, Active mass utilization coefficient of lead acid battery depends on the size and mass of active materials. In this research, among plates of different size and mass, batteries of sample 3 gives the highest active mass utilization coefficient. So to get the better active mass utilization co-efficient from lead acid battery, it is recommended to use the combination of active materials of sample 3.

7. References

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NOMENCLATURE

C_{Actual} : Actual capacity
$C_{Theoretical}$: Theoretical capacity
M_{NAM} : Mass of Negative Active Material/Battery
M_{PAM} : Mass of Positive Active Material/Battery