ELSEVIER

Journal of Power Sources 53 (1995) 283–287

JOURNAL OF POWER SOURCES

Rubber separators for tomorrow: performance characteristics and selection guide

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Received 21 September 1994; accepted 27 October 1994

Abstract

A brief description is given of the basic differences in manufacturing processes and composition of the three types of rubber separator, namely: (i) sulfur-cured, hard rubber, ACE-SIL® separator; (ii) electron-beam crosslinked, FLEX-SIL® rubber separator; (iii) coated glass-mat MICROPOR-SIL® separator containing rubber. The physical, chemical, electrical and electrochemical properties of the three types of rubber separator are considered and the primary differences are explained. The beneficial performance characteristics found with rubber separators are presented, such as on-charge voltage characteristics, electrochemical compatibility for float-charging systems, retardation of antimony transfer, prevention of dendrite growth, and good wettability. Based on analysis of separator properties and battery requirements, a selection guide for rubber separators applicable to various types of lead/acid battery is compiled.

Keywords: Battery separator; Microporous rubber separator; Lead/acid batteries; Electrochemical compatibility; Electron beam crosslinked rubber

1. Introduction

The performance of hard-rubber separators, such as ACE-SIL®, has been well known for many years in the lead/acid battery industry. In recent years, FLEX-SIL® electron-beam crosslinked, flexible, rubber separators have proved very successful in deep-cycling lead/acid batteries. Yet another type of rubber separator, MICROPOR-SIL®, has been introduced recently. Each of these three types of rubber separator has unique physical, chemical and electrochemical properties, as well as distinct performance characteristics [1–3]. The availability of the new types of rubber separator has greatly expanded their range of applications and has enhanced battery performance. Understanding the various properties of these separators has become increasingly important in selecting a suitable type for a given battery design or specific application.

2. Function of separators

The primary function of separators, placed between the positive and negative plates of a battery, is to prevent electrical short-circuiting, while allowing the free transportation of electrolyte and electrical current. In order to accomplish this relatively simple task, a separator must have, among other things: high porosity, small mean pore diameter, mechanical strength, and chemical resistance to corrosive electrolyte. Many types of separators presently used in lead/acid batteries fulfil these functions. A good separator is much more than just a fine insulating mechanical filter. There are other important properties essential to battery performance that are mostly electrochemical in nature and closely related to the material composition of a separator, such as its base polymer or main organic material constituents. For these reasons, rubber separators exhibit different performance characteristics from those of plastic, glass fibre or cellulosic separators.

3. Lead/acid batteries and their separators

For convenience, lead/acid batteries can be classified into two major types, namely, automotive and industrial. In addition, there are many special batteries that cannot be easily categorized as either of the two types. As these types of batteries are constructed with different materials and design to meet the requirements of their intended end-uses, each requires a particular separator with specific material composition, mechanical design,

SSDI 0378-7753(94)02016-V

Table 1
Types of separators classified by the material of construction

Plastic separators	polyethylene–silica PVC (polyvinyl chloride)–silica phenolic resorcinol–silica sintered PVC (polyvinyl chloride)
Paper separators	phenolic resin coated cellulose
Glass separators	glass-fibre mat absorptive microfibre glass mat
Rubber separators	sulfur-cured, hard-rubber separator: ACE-SIL®, Mipor B electron-beam-cured, flexible, rubber separator: FLEX-SIL® coated, glass-mat, rubber separator: MICROPOR-SIL®

and physical, chemical and electrochemical properties that are tailored for the battery. These batteries are available in flooded electrolyte or valve-regulated (sealed) versions.

Separators currently used in lead/acid batteries can be classified by their materials of construction into four major types: plastic separators, cellulosic separators glass separators and rubber separators, as shown in Table 1.

4. Rubber separators

Rubber separators have some intrinsic properties that may not be found in other types of separators. For example, rubber separators have good voltage characteristics, an ability to retard antimony transfer, properties to prevent dendrite growth, and good electrochemical compatibility [4]. All these attributes are very important aspects of lead/acid battery performance and life. Rubber separators do not require additives such as VCA (voltage-control additives) to enhance on-charge voltage characteristics, chemicals to augment retardation of antimony transfer, nor a surface-active agent to improve wettability of separators. Rubber separators impart these properties naturally. Due to the hydrophilic properties of the rubber composition, the separators are highly wettable and rewettable for the dry-charging process. This is in contrast to some separators that have low wettability because of the hydrophobic properties of the plastics that are being used, particularly when they contain mineral oil.

4.1. Physical, chemical, and electrochemical properties of rubber separators

All three types of rubber separators have an ultrafine pore structure, with mean pore diameters of less than 0.3 μm. Porosity (determined by the mercury intrusion method) and electrical resistance (determined by the preboil test method) for the latest samples are listed in Table 2. Also shown are electrochemical compatibility (BCI Battery Technical Manual Section 3-044, Test Procedure 12D) and analytical test results including metal and chloride ion contents. A well-established specification for electrochemical compatibility of a separator for a float-charged stationary battery requires that the shift in cathodic polarization in the hydrogen evolution region with separator-leached sulfuric acid compared with pure acid should not exceed ± 50 mV and ± 25 mV in anodic polarization in the oxygen evolution region. Figs. 1–3 show the pore-size distribution of ACE-SIL®, FLEX-SIL® and MICROPOR-SIL®, respectively.

4.2. ACE-SIL® separator (sulfur-cured, microporous, hard-rubber separator)

The ACE-SIL® separator is the longest continuously serving product among the rubber separators. The manufacturing process starts by mixing natural rubber, rehydrated precipitated silica and sulfur in an internal mixer. The rubber compound stock is then extruded and calendered, vulcanized under water, and dried. A flow chart of the manufacturing process for ACE-SIL®, along with that for FLEX-SIL® and MICROPOR-SIL®, is presented in Fig. 4. There has been a continuous effort to refine the manufacturing process and product design; this has resulted in products with finer pore diameter (averaging 0.2 μm), increased mechanical strength, lower electrical resistance (through the reduction of backweb thickness), and reduced acid-displacement volume. The new ACE-SIL® also provides versatility in rib configuration that includes diamond-shaped interrupted alternating diagonal ribs for the positive plate and mini-ribs (cannelure ribs) to be faced against the negative plate.

ACE-SIL® imparts a higher end-of-charge voltage than plastic separators. This prevents overcharging when a voltage-limited charging system is used, and, thereby increases the life of the battery. It exhibits favourable Tafel curves and very good float-charging characteristics for stand-by system. ACE-SIL® has excellent resistance

Table 2
Physical, chemical, and electrochemical test results of rubber separators

	ACE-SIL®	FLEX-SIL®	MICROPOR-SIL®
Mercury intrusion porosimeter test			
Total porosity (ml/g)	0.87	0.47	1.22
Mean pore diameter (μm)	0.25	0.06	0.17
Pore size over 20 μm (%)	4.4	7.0	6.2
Volume porosity (%)	58	49	69
Electrical resistance			
(Ω cm^2 (mΩ in^2)	0.226 (35)	0.258 (40)	0.071 (11)
Backweb thickness (mm (inch))	0.71 (0.028)	0.38 (0.015)	0.28 (0.011)
Electrochemical compatibility			
Cathodic shift (mV)	− 1	+2	+39
Anodic shift (mV)	−12	−20	−7
Chemical analysis (%)			
Ash	28.87	56.63	64.60
Iron, Fe	0.017	0.031	0.016
Sodium, Na	0.021	0.200	0.194
Magnesium, Mg	0.006	0.011	0.006
Manganese, Mn	<0.0001	<0.0001	<0.0001
Aluminum, Al	0.064	0.109	0.046
Calcium, Ca	0.007	0.008	0.010
Copper, Cu	<0.001	<0.0001	<0.0001
Chloride, Cl^-	0.0003	0.0007	0.0004

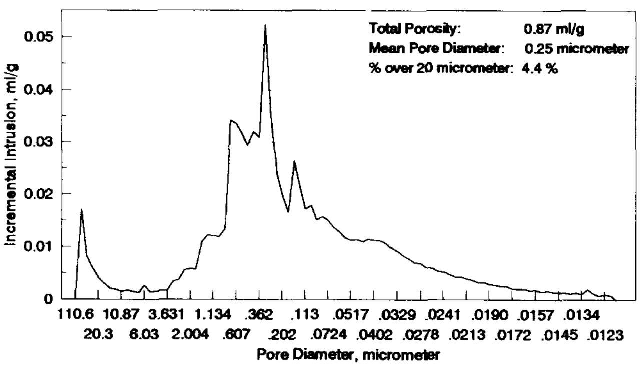

Fig. 1. Pore-size distribution of ACE-SIL® rubber separator.

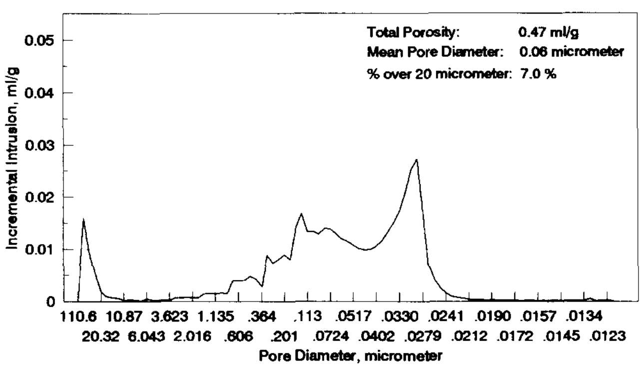

Fig. 2. Pore-size distribution of FLEX-SIL® rubber separator.

against oxidation from both the battery acid and the lead oxide of the plate. It retards antimony transfer and, thus, reduces self-discharge and gas evolution.

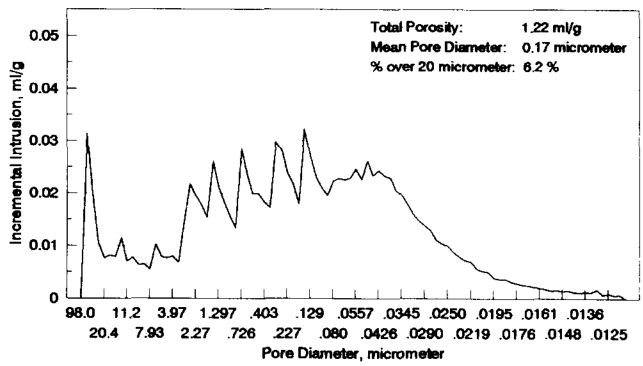

Fig. 3. Pore-size distribution of MICROPOR-SIL® rubber separator.

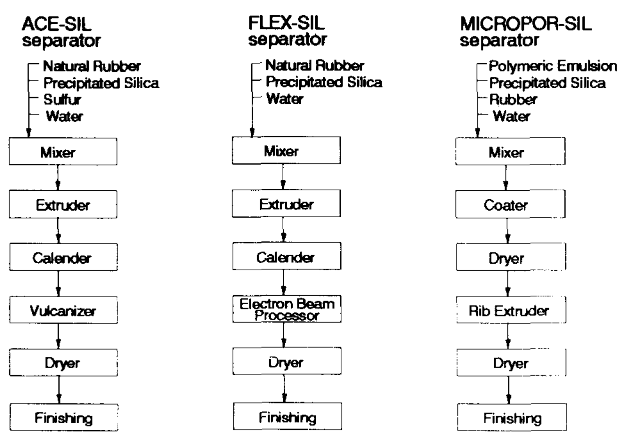

Fig. 4. Flow charts for the ACE-SIL®, FLEX-SIL® and MICROPOR-SIL® separator manufacturing process.

Table 3
Rubber separator selection guide

		ACE-SIL®	FLEX-SIL®	MICROPOR-SIL®
Industrial stationary batteries	telecommunications	XXX		XX
	UPS	XX		XXX
	load levelling	XXX		XX
Industrial traction batteries	forklift truck	XXX	XX	XXX
	mining equipment	XXX	XX	XXX
	automatic guided vehicle	XXX	XX	XXX
Automative batteries	SLI	X		XXX
Other batteries	submarine	XXX		XX
	golf-cart	X	XXX	XX
	marine	X	XXX	XXX
	electric vehicle	XX	XXX	XXX
	diesel starting	XX	X	XX
Gel batteries of all types		XX	XX	XXX

[a] XXX: highly recommended; XX: recommended; X: conditionally recommended.

For these reasons, ACE-SIL® separators are recommended for stationary batteries for telecommunications, UPS (uninterruptible power supply), motive power, submarine, locomotive duties, as well as for batteries to be used in load-levelling/peak-shaving applications.

4.3. *FLEX-SIL® separator (electron-beam-cured, microporous, flexible rubber separator)*

Even though FLEX-SIL® is a relatively new product that has been marketed since 1982, it is currently supplied to more than 90% of the golf-cart battery market in the United States. The manufacturing process consists of mixing natural rubber and rehydrated precipitated silica in the internal mixer, and then extruding and calendering the compound. The calendered sheet is irradiated with an ionizing electron beam and dried (see Fig. 4). As a result of a state-of-the-art, electron beam crosslinking process, the separator is flexible and has the finest pore structure, with a mere 0.06 μm mean pore diameter. Its ultra-fine pore structure and ability to retard the transfer of antimony from the positive plate to the surface of the negative plate makes the FLEX-SIL® separator perform best in deep-cycling applications by reducing overcharging, gassing, water addition, and charge-current demand.

FLEX-SIL separators are recommended for golf-cart, floor-sweeper/scrubber, marine, wheelchair, electric-vehicle, and other traction batteries.

4.4. *MICROPOR-SIL® separator (coated, glass mat, microporous, rubber separator)*

The MICROPOR-SIL® separator is the latest development by Amerace, Microporous Products Inc. The leaf separator is produced by mixing polymeric emulsion, precipitated silica, and rubber in a mixer; this compound is then coated on a fibreglass mat and finally cured and dried (see Fig. 4). The average pore diameter is less than 0.2 μm and the material has a very high total porosity. Because of its thin backweb design and high porosity, it has a very low electrical resistance and a low electrolyte-displacement volume. This makes the separator suitable for high-rate discharging and cold-cranking applications. Since MICROPOR-SIL® is made with a rigid and chemically-inert glass-mat substrate, it shows excellent thermal dimensional stability under unusual conditions. It is therefore appropriate for the dry-charging process. The separator, which has a physical affinity to silica gel, is well suited for gelled-electrolyte battery applications. Because MICROPOR-SIL® contains rubber, it imparts many of the characteristics unique to rubber separators.

MICROPOR-SIL® is recommended for UPS, starting/trolling marine, motive power (traction), automotive SLI (starting, lighting and ignition), miner's cap-lamp, and various types of gelled-electrolyte batteries.

5. Rubber separator selection guide

There are several factors that link the design and properties of separators to the performances requirements of batteries for specific applications. The art of choosing the correct separator for a given battery begins with understanding various features and properties of separators. Table 3 is provided to help select the proper rubber separator for a particular battery type.

6. Conclusions

The three types of rubber separators, ACE-SIL®, FLEX-SIL® and MICROPOR-SIL®, have unique electrochemical properties that may not be found in other types of separator. They show high on-charge voltage, which prevents overcharging of cells under a voltage-limited charging system, desirable Tafel behavior, and electrochemical compatibility for float-charging systems. They also retard the transfer of antimony and prevent dendrite growth. All of these features given rise to a long battery life with reduced battery maintenance. These separators are available with mini-ribs (cannelure) to be faced against the negative plates, or glass retainer mats attached to regular ribs to prevent the shedding of active material from the positive plate. The rubber separators are highly wettable and do not contain mineral oil, residual organic solvent or voltage-control additives (organic surface active compound) that can leach out to the electrolyte.

ACE-SIL® separators perform best in industrial stationary or traction batteries, FLEX-SIL® separators are ideally suited for deep-cycling batteries, and MICROPOR-SIL® separators are an excellent choice for high-rate discharging or cranking applications and all types of gel cells. The battery separators for tomorrow will demand more than just good insulators and mechanical filters; they will require unique electrochemical properties already found in rubber separators today.

References

[1] S.L. Paik and G. Terzaghi, *Batteries Int.*, (Apr.) (1993).
[2] S.L. Paik, *2nd Int. Symp. Mechanization and Automation of Battery Production, Warsaw, Poland, Sept. 17–19, 1991.*
[3] S.L. Paik, *Int. Conf. Lead-Acid Batteries, Varna, Bulgaria, June 7–11, 1993.*
[4] A.D. Butherus, W.S. Lindenberger and F.J. Vaccaro, *The Bell System Tech. J.*, (Sept.) (1970) 1377–1392.