Lead-Acid Battery:

Jar-Cover Seals

By D. W. DAHRINGER and J. R. SHROFF

A novel jar-cover seal has been designed and fabricated for the new Bell System battery. The seal consists of a tongue-and-groove seal joint design (jar and cover respectively) with an infrared heat absorbing layer at the joint interface. This heat absorbing layer causes the fusion and sealing of the jar and cover surfaces when exposed to high intensity concentrated infrared energy. The seals prepared in this manner are leak free, acid resistant and have extremely high joint strength. A jar-cover seal life equivalent to the useful life of the polyvinyl chloride in the jar is anticipated.

I. INTRODUCTION

The leakage of electrolyte from lead-acid storage batteries has been a chronic problem to consumers. Industrial and individual consumers share such common seal-related deficiencies as electrolyte leakage, corrosion buildup and premature battery failure. Additionally, telephone companies have experienced high maintenance costs, fire and explosion hazards, and interrupted service.[1] These problems can be related to both the inherent characteristics of the lead-acid system and to inadequate joint design considerations. The limited availability of materials resistant to battery acid and the dimensional changes which occur in electrodes and plates are factors, inherent in lead-acid batteries, which result in poor reliability. Poorly designed cap or plug type jar-cover seals on batteries currently used in telephone plant provide very little effective seal area. In addition, they all use adhesives or sealants with low toughness which further contributes to premature battery failure.

These effects are more obvious in batteries for telephone use because of their large dimensions, type of service and long design life.

Early in the development of the new cylindrical battery, studies were undertaken to provide reliable jar-cover seals. The initial performance requirements for the seal were that:

(i) The seal joint be permanently leakproof—to both electrolyte and internally generated gas.

(ii) The seal material be electrochemically compatible with the lead-acid battery system.

(iii) The seal material be stable to all concentrations of battery acid that it might encounter.

(iv) The seal be strong enough to support safely the weight of a complete battery (approximately 400 lbs.).

(v) The seal be resistant to shock and lateral deformation.

In addition, the seal joint design had to be compatible with an injection-moldable jar and cover and the sealing procedure had to be economical and feasible for production.

II. JAR-COVER SEAL JOINT DESIGN

The circular battery jar geometry and an impact-resistant, unplasticized, polyvinyl chloride (PVC) jar material were selected prior to detailed considerations of the seal design.[2] Both selections ultimately proved to be fortunate in terms of seal joint design and sealing technique.

Initially, consideration was given to the possible use of plug or cap type joints between the jar and cover. These early designs were abandoned in favor of a tongue-and-groove arrangement. Such a design offered advantages of self-alignment with improved shock and static stress resistance.

Figure 1 shows a diagrammatic cutaway view of an assembled jar and cover with a sectional detail of the actual joint area. Incorporated in the design are matching tapers ($4\frac{1}{2}°$) on both the inner and outer surfaces of the jar and corresponding tapers on the cover. This design permits the assembly of the joint with essentially no sliding friction, with a maximum bondline area and with self-adjusting (over a broad range, including zero) bondline thickness.

III. SEALING METHOD

3.1 Early Sealing Method Investigations

Before the ultimate sealing technique was selected, several methods were considered. These include:

(i) Adhesive bonding with:

(a) solvent or bodied solvent* applied by dipping or brushing,

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* The solvent used was cyclohexanone which was bodied or thickened with between 15 and 25 weight percent of the jar and cover plastic. (Airco B983 - Propylene-modified PVC.)
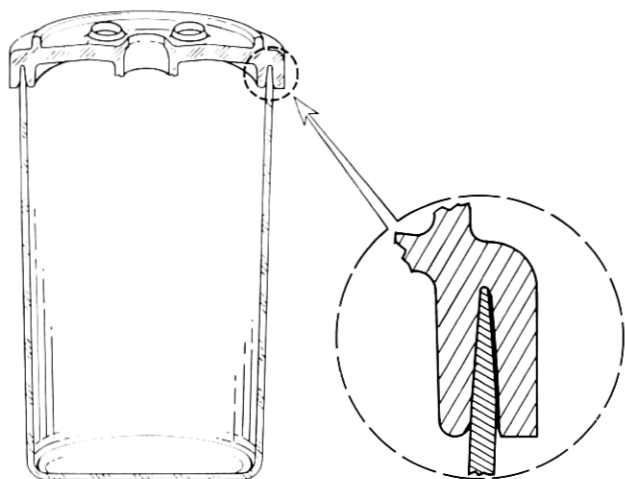
Fig. 1—Jar-cover seal design and assembly.

  (b) bodied solvent applied by injection,
  (c) frozen solvent gasket, and
  (d) solventless adhesive;
 (ii) Welding with embedded, heated resistance wire;
(iii) Preheating with hot matching dies;
 (iv) Spin welding; and
  (v) Ultrasonic welding.

Of these early methods, the solvent-related sealing techniques offered the best combination of production feasibility, low cost and acceptable seal strength. After extensive mechanical testing, several field trial cells were prepared using the solvent-dip technique. Although the mechanical characteristics of these seals were satisfactory, electrode polarization was encountered. Investigations confirmed that contamination of the electrolyte by cyclohexanone from the sealant was responsible for the polarization.[3] Investigation of all of the above sealing methods was superceded by the investigation of the infrared sealing technique described below.

3.2 Infrared Sealing Technique

An infrared sealing technique was devised as a practical, production-oriented method for making the jar-cover seal. The method involves concentrating sufficient thermal energy at the jar-cover interface to

permit welding to occur. Specifically, a focused source of high-intensity infrared energy is directed through the outer cover skirt to the interface between the cover and the jar. At this interface, a thin layer of infrared-absorbing material becomes hot, melts, and causes the melting and fusion of the adjacent jar and cover surfaces. The fused layers solidify upon cooling to form the seal.

A quartz line heater* was used in the initial experiments to provide a focal line energy of approximately 125 watts per inch when operated at 110 volts ac. Later, other operating conditions were found to be better (see Section 3.4). The absorbing layer was a 0.0015 to 0.002 inch thick black coating of the same plastic used for the jar and cover molding and containing a small quantity of a carbon black dispersion. With the cover in place, the infrared source was focused on the coated surface at the jar cover interface and the battery rotated with respect to the infrared source until the entire seal was formed. The assembly and sealing steps are shown schematically in Fig. 2.

Times ranging from $\frac{1}{2}$ minute to 2 minutes were necessary, depending on the experimental conditions employed, to achieve complete 40-inch circumferential seals. Shorter sealing times are possible with variations in the infrared source parameters. This will be discussed in a later section.

Of particular importance in the successful use of this technique is the alignment of mating surfaces and the availability of contact pressure at the interface during sealing. An attempt to seal a joint with either a misalignment or a lack of follow-up contact pressure would result in only a one-sided melt and a low strength, potentially leaky, seal. The jar-cover seal design incorporated features to achieve alignment and contact pressure within the range of molding tolerances on the jar and cover diameters, provided the original tapers are accurate.

During the sealing operation, we can observe the point at which a seal forms. As the absorbing layer melts and fuses at the jar-cover interface, the air layer disappears, providing a visible "wetting" of the cover and blackening of the absorbing layer. This characteristic is extremely helpful in quality control evaluation of the seal.

If heating is continued for a period of time beyond that necessary for the seal to form, blistering, burning and charring can result on the outer surface of the cover. This causes an unsightly appearance and degradation of the materials involved. Experiments designed to minimize this problem are discussed in Section 3.4.

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* Research, Incorporated, Model 5215-5, "Quartz Line Heater" with water-cooled elliptical reflector, and 1200 T3/CL/HT lamp.
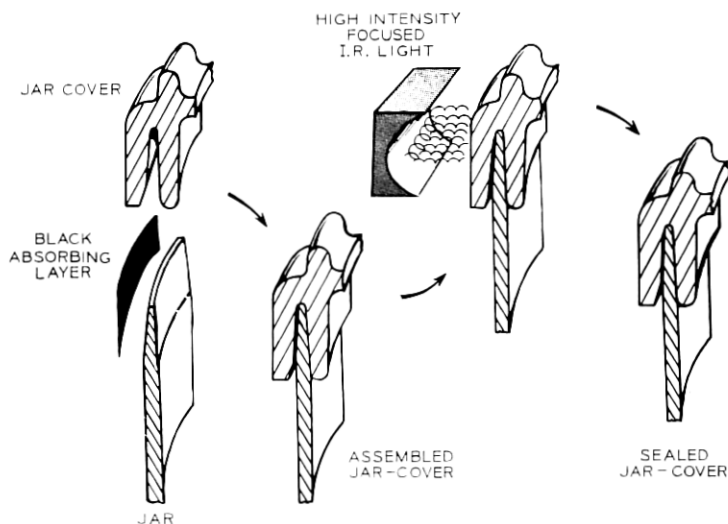
Fig. 2—Jar-cover seal assembly and sealing sequence (schematic).

3.3 *Infrared Absorbing Medium*

The infrared sealing technique was originally evaluated using a black film made from a solution of the jar cover material in cyclohexanone to which a carbon black dispersion was added. Sections 1 and 2 of Table I give the formulation data. Because of handling difficulties with the film, a direct coating technique of the jar lip was devised. Cyclohexanone was originally selected as a solvent because of its solution capacity and relatively low hazard potential. However, this solvent was ultimately replaced by more volatile methyl ethyl ketone (MEK) to reduce possible cell contamination due to residual solvent and to accelerate solvent evaporation. The coating formulation with MEK is shown in Section 3 of Table I. The solids content of this formulation was changed since the MEK is capable of dissolving only up to 15 percent of the PVC.

The present technique does not form a seal at the inner jar-cover interface because little or no energy passes through the absorbing layer at the outer jar-cover interface. Should it prove desirable to seal the inner jar-cover interface, this can be accomplished by applying the absorbing layer to the entire inner jar surface and only the upper half of the outer jar surface. When exposed to the radiation, such an arrangement leads to a two-sided seal.

TABLE I—INFRARED ABSORBING MATERIALS

1. Coating Solution	
25% Airco B983 in Cyclohexanone	— 95.0
Carbon Black dispersion*	— 5.0
Total	100.0

2. Dry Film Components	
Airco B983	— 92.7
Carbon Black	— 2.9
Vinyl resin VYHH	— 4.4
Total	100.0

3. Methyl Ethyl Ketone Based Coating Solution	
15% Airco B-983 in MEK	— 95.0
RBH #5404	— 5.0
Total	100.0

* RBH #5404, Inmont Corp.
  Carbon Black   — 15.0
  Vinyl resin VYHH   — 22.5
  Methyl Ethyl Ketone   — 62.5
  Total   100.0

3.4 Operating Parameters of Infrared Heat Seal Technique

As explained in Section 3.2, most of our initial experiments were carried out with the lamp operated at 110 volts and the seal in the focal plane. During the course of these experiments it became clear, however, that the margin between seal formation and the onset of blistering and charring was not as wide as one might wish. We have therefore investigated the effects of running the lamp hotter and of moving it further away.

In order to determine which ranges of wavelength are effective for forming the seal and which for causing blistering and charring, the infrared transmission characteristics of the jar or cover material were

obtained, using a Beckman IR-9 spectrophotometer. The infrared transmission spectrum of the PVC (Fig. 3) shows a small absorption peak around 1.2 μ and a region of strong absorption beyond 1.7 μ. The blackened film used for sealing, on the other hand, may be presumed to be strongly absorbing throughout this region. Ideally, therefore, a light source with its emission restricted to the range 0.17 μ to 0.6 μ would be preferred. Since optical filtration is not practical in view of the high radiant flux, some control of the emission spectrum can be achieved by adjusting the temperature of the source. Figure 3 shows computed values for the spectral distribution of the light emitted by the lamp at three different voltages, based on measurements of the color temperature of the filament made with an optical pyrometer. It will be seen that, other things being equal, higher voltage operation should be preferable because a larger fraction of the emitted energy lies in the range of wavelength below 1.7 μ, where it is effective for sealing.

To investigate the effect of varying the voltage applied to the lamp (and its temperature), test specimens were assembled from small squares of jar. These were clamped together with a film of the absorbing material between them. A recording thermocouple was placed immediately behind and in direct contact with the film. The infrared source was then focused on the area of the seal at the thermocouple and temperature
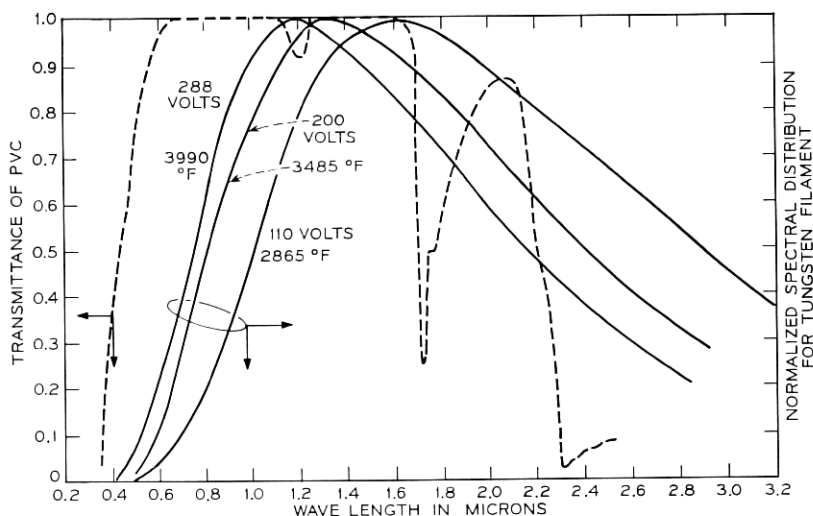

Fig. 3—Infrared transmittance of PVC and emission spectra of tungsten filament lamp.

recorded as a function of time. The instants at which the seal was formed and at which charring became evident were recorded by visual observation. Results are shown in Fig. 4 for three different voltages applied to the lamp. It will be seen that, while there is some decrease with increasing voltage in the time to formation of seal, there is also a substantial decrease in the time to onset of charring. This is to be expected since, even though the *relative* amount of radiation at wavelengths beyond 1.7 μ decreases with increasing filament temperature (Fig. 3), the absolute amount does not. It is possible to compensate for the increase in overall intensity by moving the lamp further away from the seal. Figure 5 shows what happens when the lamp is run at 150 volts and moved progressively further away from the seal. It can be seen that the increase in distance is accompanied by a considerable increase in char time, with only a slight increase in seal time, and that, somewhere between one and two inches, charring no longer occurs. The increased sealing time at the 2-inch distance is compensated by the broader section of seal which can be made with the out-of-focus beam.

IV. MECHANICAL STRENGTH TESTS

Several tests were used to evaluate the breaking strength of jar-cover seals. Shear separation tests were conducted on specimens cut from a
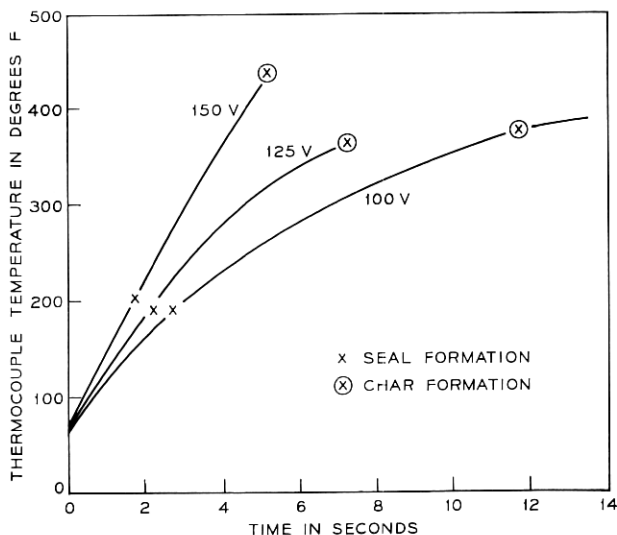

Fig. 4—Thermocouple temperature vs time for various IR source voltages (absorption layer at source focus).
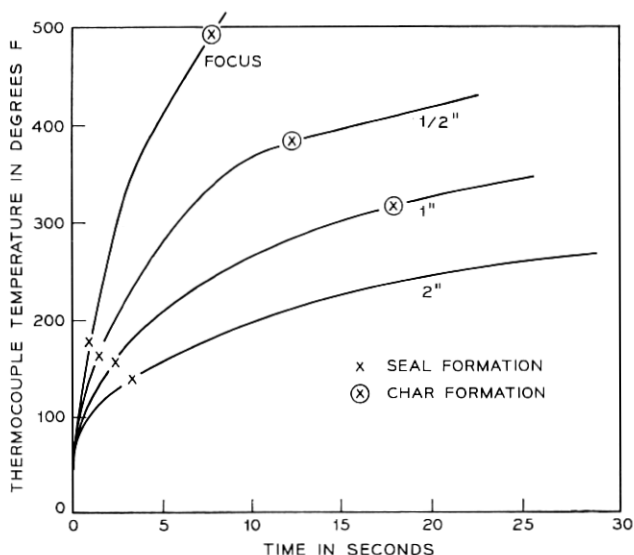
Fig. 5—Thermocouple temperature vs time at various distances from focus at 150 V.

jar-cover seal in the form of a wedge segment of the cover with a one-inch arc. The specimens were placed in a testing fixture and stressed at a rate of 0.1 inch per minute using a Tinius–Olsen "Universal Testing Machine." The force required to separate the seal joint segment was determined and recorded as pounds per circumferential inch of seal joint. The testing fixture with a specimen is illustrated in Fig. 6.

Initial joint strength test results for the infrared sealed jar-cover assembly exceeded the tensile strength of the jar wall using the shear strength fixture and method described above. The actual failing loads averaged about 1500 pounds per inch of seal and generally the failures occurred in the jar wall immediately below the bond area. A few specimens fractured in several places, that is, the top and middle of the outer cover skirt, and a few failed by yielding of the jar wall below the bond area. However, none of these specimens showed any sign of bond area damage or failure. With a total of 40 inches of circumferential seal and each inch capable of supporting three or more times the weight of the battery, there can be little doubt as to the adequacy of the seal strength.

Several jar-cover assemblies, containing 700 pounds of lead weights, were suspended by a ring support under the outer cover skirt. After
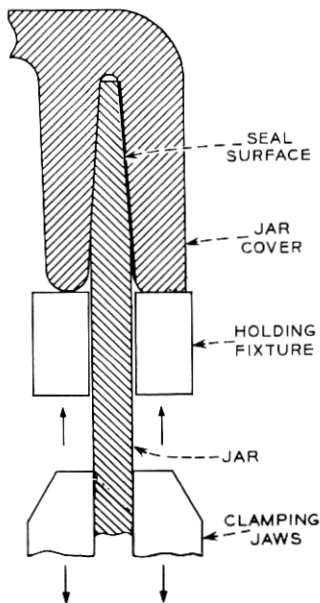
Fig. 6—Jar-cover shear strength test.

three weeks suspension and several deliberate 6″ drops to a concrete surface, no evidence of joint failure could be found.

Additional tests were conducted on sealed empty jars by pressurizing to 5 psi with air and inspecting for leaks. These tests were continued for many months without loss in pressure. Commercial practice for cells currently delivered to the Bell System calls for leak testing at a pressure of only $\frac{1}{2}$ psi for 30 seconds.

V. CONCLUSION

It is demonstrated that reliable, jar-cover seals can be prepared for the new lead-acid battery. Of the variety of sealing techniques investigated, heat sealing by an infrared heat source focused on an absorbing medium placed at the seal interface was found to be economically attractive and production oriented. Seals obtained by this technique are reliable and provide high seal strength. An added advantage of this sealing technique is the ability to determine quality of the seal by simple visual inspection during or after the operation.

VI. ACKNOWLEDGMENTS

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