BDX-613-888 (Rev.)

ULTRASONIC WELDING OF
NYLON CELL CASES ON A NICKEL
CADMIUM BATTERY

Topical Report

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MASTER

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Bendix

**Kansas City
Division**

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ULTRASONIC WELDING OF NYLON CELL CASES ON A NICKEL CADMIUM BATTERY

BDX-613-888 (Rev.), UNCLASSIFIED Topical Report, Published August 1973

Prepared by G. W. Bengtson, D/812

A joint design and ultrasonic welding schedule capable of making a leak-tight pressure joint in nylon was developed. This will permit the replacement of polystyrene with nylon for cell cases on a nickel cadmium battery.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission

Contract Number AT(29-1)-613 USAEC

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SUMMARY

The battery under consideration is a special purpose 28-volt battery pack procured by Bendix Kansas City. The cells comprising the battery are vented nickel cadmium using a 35 percent solution of potassium hydroxide as the electrolyte. The assembled cell is 3.70 inches high by 1.10 inches wide by 0.650 inch deep (95.5 by 28 by 16.51 mm) with a wall thickness of 0.060 inch (1.52 mm). The cell, during charging, may develop as much as 30 psig (207 kPa gage) internal pressure. The valve for venting this pressure is designed to release in the range of 7 to 15 psig (48 to 103 kPa gage). The original design specified a polystyrene cell case using a chemical weld as the joining technique. This cell was failure prone because of the brittle polystyrene, nonuniformities in the case, and weak corners. Under pressurization the cells frequently cracked along the 3.70-inch-long corners. A revised design specified a nylon case with a chemical bonding process used as a joining technique. The revised design was later rejected because of bond failures. As a result of this, polystyrene was again specified, using a redesigned mold with stronger corners and improved uniformity in thickness. The new cell also uses an adhesive bond. This design is currently in production but still has the problems inherent with polystyrene even though it is inspected and annealed carefully.

The feasibility of using ultrasonic plastic assembly techniques on a nylon assembly was sufficiently promising to warrant detailed studies of this technique. The application of ultrasonic plastic assembly techniques for nylon offered several advantages over previous assembly techniques. These included a nylon-to-nylon system with a joint strength approaching the strength of the parent material, a leak-tight joint at pressures over four times operational pressures, and a process lending itself to automation. Out of several joint designs considered, a shear joint has been selected. To permit a repeatable and uniform welded joint, the cell was redesigned to incorporate the terminal holes and fill tube into the case as an integral part; the assembly is completed by welding a bottom on the case.

For simplicity, all ultrasonic plastic welding for these investigations was done without the internal portions of the cell being present. It is expected that only a small change in weld parameters will be required when the internal parts are added.

The welded assemblies have been pressure tested for 35 cycles totaling 110 hours of pressurization using a 35 percent solution of potassium hydroxide at 30 psig (207 kPa gage). The assemblies were pretested at 30 psig using water as the pressurizing medium to find early failures. From the 35 samples submitted for testing, there were five samples not usable; only one failure was attributable to leaks at the weld joint. Three more specimens were retained as control samples. The remaining 27 samples survived the pressure cycling test. The 27 assemblies were then tested for electrical leaks and all survived a 3 volt dc potential with maximum allowable current of 100 μ A. Five samples each of the two joint designs then were hydro-tested. The average rupture pressure for the shear joint design was 256 psig (1770 kPa gage), and the average rupture pressure for the altered shear joint was 226 psig (1560 kPa gage), which is 8 and 7 times greater than the required seal pressure. The lowest failure pressure provided a safety factor of 4.

From this work, a joint design has been selected which is compatible with injection molding techniques. The fact that the joint will be molded, as opposed to machined, may also change the welding parameters slightly. It is the intent of Bendix, with the cooperation of the design laboratory, to incorporate the ultrasonically-welded nylon cell into the battery. Weld parameters will be developed at Bendix for the molded cell. Then the technique will be shown to a battery supplier and the supplier will develop equipment and necessary skills required to put the cell into production.

DISCUSSION

SCOPE AND PURPOSE

The current production cell case for a nickel cadmium battery is a solvent bonded polystyrene design; however, field failures are occurring from the cell case cracking along the corners of the long dimension of the case. Nylon is desirable because of its high strength and relative chemical inertness, but chemical bonding attempted to date has been unsatisfactory. The purpose of this study was to develop a joint design and ultrasonic weld schedules which would make nylon a viable cell case material.

PRIOR WORK

Although development of ultrasonic assembly techniques has only been underway at Bendix since August 1971, several applications, including early work on the part under consideration have been reported. Several papers have been published by DuPont regarding application of ultrasonic welding of nylon and similar materials.

ACTIVITY

Equipment

A model 460 Branson Sonic Welder, modified to accommodate a pretrigger switch, was used. This welder is rated at 5900 inch-pound/second (667 watts) mechanical power. The basic unit (Figure 1) consists of a power supply, a converter, a booster, a horn, and an equipment programmer.

The power supply, operating from 110 volt, 60 Hz line voltage, provides 700 watts at 20 kHz to drive the converter, which transforms electrical power to a 20 kHz axial mechanical vibration. The converter is a piezo-electric device using a lead zirconate titanate transducer.

Figure 1. Branson Model 460 Welder

Boosters are mechanical impedance transformers used to modify the amplitude of the output signal from the converter by a specific ratio. The booster used for this work was Branson's 101-149-012, which increases the amplitude by a ratio of 2.5 to 1.

Horns are also mechanical impedance transformers; their function is to direct the mechanical energy with the proper amplitude to the correct location on the part being fabricated. In general, special horns are required for each application. Two horns were used for this work. The first horn was a solid rectangular/cylindrical solid horn (Branson No. 304-035-020) 1-1/8 by 1-3/8 inches (28.6 by 34.9 mm) modified by Branson to provide a recess for the terminals and fill tube of the case. This horn had a gain of 2:1. The second horn was a solid cylindrical high-gain, Branson No. 308-014-020, which has a gain of 2:5.

The programmer provides the adjustment controls and monitoring circuits required for controlled, repetitive welding cycles. The basic parameters controlled are weld pressure, weld time, and pressure dwell time.

Materials

Commercially available molded cell cases of DuPont's Zytel 31 that approximate the Bendix part were used for these investigations. The molded pieces had not been protected from moisture and initial work was done without attempting to dry the nylon. It was apparent that moisture was presenting problems (when the wet nylon reached its melting temperature, the material produced a froth). Initial attempts to dry the nylon in a vacuum oven at 150°F (65°C) and 180°F (82°C) were only partially successful; Figure 2 shows that, even at the end of the 7.5 hours, volatiles are still being driven off at a nearly constant rate. In an attempt to ensure the nylon was reasonably dry, the parts were dried in a vacuum oven at a temperature of 180°F for 24 hours; as a result, the froth was minimized.

In early work the parts, after being dried at 180°F for 24 hours, were removed from the drying oven as a group. It was noticed that those parts that were still hot from the oven seemed to weld easier in a shorter time, and exhibited a more consistent weld. Therefore, in the bulk of the work the assemblies were dried at 180°F for 24 hours and removed from the oven in pairs for welding.

The use of preheating is supported by the combination of specific heat and melt temperature of nylon. It can be shown, when comparing equal masses of nylon and polystyrene (an excellent ultrasonic welding material), that nylon will take approximately three times the energy required for polystyrene if both materials are initially at room temperature. Nylon is very crystalline and must have more energy to approach a melt level. Polystyrene is more nearly amorphous

Figure 2. Volatile Loss of Nylon Cell Assembly Versus Time

and energy input requirements are less. Conversations with DuPont indicate that DuPont does not feel preheating is necessary as long as energy input capability is available in the ultrasonic unit. Preheating the material therefore may not be needed for production if nylon assemblies are procured with moisture protection or if some defacing of the bottom of the cell is considered permissible.

DuPont is closing out their Zytel 31 line of molding compound, and Zytel 151 has been chosen as a replacement material. From DuPont's literature³ and conversations with DuPont representatives, Zytel 151 appears to be more conducive to ultrasonic welding, perhaps because this material will pick up less moisture and is slightly less crystalline. This, however, remains to be demonstrated at this facility.

It was also demonstrated that the nylon assemblies should be of the same type nylon. Through a material mix-up, lids of Zytel 101 were "welded" to the Zytel 31 case. Cross sections of the completed assembly revealed that the Zytel 31 had melted but the Zytel 101 had not. The melt temperature of Zytel 101 is 70°F (39°C) higher than that of Zytel 31, and, therefore, the Zytel 101 never reached its melt temperature. These differences are caused by the chemical structure changes which give an energy absorption change.

Initial Assembly Concepts

Initial planning was to use the assembly concept presently being used for the battery, with the joint interface of the lid and case altered to a design which would be conducive to ultrasonic welding. The cell case was to be loaded with the components, with the lid placed over the terminal studs, and with the washers and nuts in place as in Figure 3. The assembly was then located in a fixture which provided location and supported the assembly at the weld interface in such a way that the case would not flex under welding pressure and yet not dampen the ultrasonic vibration at the weld interface. Much emphasis is placed on the above conditions.^{1,2}

The assembly was then welded with a high-gain system using Branson's Black booster (gain of 2.5:1) and a solid rectangular/cylindrical horn (Branson No. 304-035-020, gain 2:1) modified by Branson to provide a recess for the fill tube and terminal studs.

Five joint designs using this assembly concept were investigated initially (Figure 4). A minimum of 25 each of these joint designs were used, with the joint design machined into the as-molded assembly.

Figure 3. Case Initial Assembly Concept

Figure 4. Joint Designs Initially Attempted

The ultrasonic weld shear joint, as developed by DuPont,¹ is a joint in which at least one component has a narrow step. The components to be welded are initially in contact only at this step. As ultrasonic energy and pressure are applied, the contact surfaces melt and the step no longer supports the load; the components shear past each other and melt together along the vertical wall. This shear joint has several advantages. Nylon has little shear resistance once the crystalline melt temperature is exceeded. Because nylon changes rapidly from a solid to a low viscosity liquid during melting, conventional joints are not satisfactory. If molten nylon is exposed to air (oxygen), oxidative degradation of the nylon will occur. The shear joint also has the distinct advantage that it traps a large percentage of the flash within the joint and little deburring is required. Figure 3 indicates the shear joint action.

Prior to August 1972, Bendix did not have a pretrigger switch for the welder. It was found that, if ultrasonics are not started before the horn contacts the material, a partial weld will be made across the initial interface and additional pressure will shear the joint (Figure 5).

Using the assembly concept previously described presented many problems, and these were not necessarily the fault of the joint design, although joint designs certainly made their contributions. It is desirable to have as much horn surface used as practical and therefore little clearance was left for the superstructure present on the lid. This condition made location and orientation of the assembly with the horn a larger problem than was justifiable. Also, the horn left an imprint on the lid and marred the surface that it contacted.

Figure 5. Weld of Shear Joint Without Pretrigger Switch

The fill tube, inside lip, and support ribs on the lid tended to resonate to destruction because of their length to thickness ratio. The fill tube problem was solved, but only in a laboratory mode. The lip and ribs continued to present problems and all three components were necessary for the cell assembly.

The welded joint also exhibited problems. The welded joint did not, in general, go completely around the seam and at best only a mechanical seal could be guaranteed. Also, the lid did not always seat on the case, presumably because the inside lip of the lid was too long and the lip, when resonating, made a series of spot welds to the case before the lid seated. Even with the addition of the pretrigger switch, weld times were higher (2 to 4 seconds) than were expected. If nylon is subjected to ultrasonic vibration of this duration it may froth in a manner similar to welding "wet" nylon.

As a result, this assembly concept gave welds that were mechanically strong but with poor sealing characteristics.

Present Assembly Concept

Although many problems existed using the current piece part assembly concept, ultrasonics still showed promise. It was, therefore, decided to simplify the problem by redesigning the case to incorporate the original lid features into the end of the case and using a plain smooth lid. This would mean that assembly problems for the internal parts of the cell would become more complex since the plates, terminals, and spacer would have to be slid into the case using guide pins to lead the terminals to their holes and the spacer to its location. Although the assembly technique would be more complicated, this would be more than offset by the improved weldability of the new lid by permitting use of a solid horn.

Rather than building a new mold immediately, as-molded cases were used. The lid had the desired joint design machined in, with the inside lip shortened and the fill tube machined off to approximate the desired lid. This still left some undesirable discontinuities in the model: a molded-in nut for the vent valve was still present; the terminal holes were still present; the recess for the terminals on the bottom were still present to some extent; and voids in the material, apparently from the complex geometry of the original lid, were now close to the horn/lid interface. These discontinuities caused some cosmetic and real defects in the welded samples which will disappear when the desired lid is used.

Two joint designs were investigated (Figure 6). The first was a shear joint of the type previously used by DuPont. Because welding time had been longer than desirable in previous attempts, an altered shear joint was also tried. It was thought that by combining a shear joint and energy director into a single entity it might be possible to shorten weld times to a maximum of 1 second and thus eliminate "overweld." There was some concern that the altered shear joint might entrap oxygen in the melt and thus defeat the purpose of the shear joint.

A high-gain system was used to weld both types of shear joints. A Branson 308-014-020 1-1/2-inch-diameter (38 mm) solid cylindrical horn was used with a Branson Black 101-149-012 booster. Travel speed was medium, and weld pressure was 20 psig (138 kPa gage) on the welder gage. Hold time was 3.0 seconds.

Before welding the normal shear joints, the parts were dried in a vacuum oven at 180°F (82°C) for 24 hours, and the first four specimens were removed at the same time. Weld time for the first two specimens was 2.0 and 1.0 seconds, respectively; both attempts resulted in too much weld. The third specimen was welded for 0.5 second, resulting in too little weld. A weld time of 0.8 second was used for the fourth specimen, which resulted in considerable flashing around the weld. The remaining specimens, removed from the oven in pairs, were welded for 0.8 seconds, and the flash was reduced.

Figure 6. Present Nylon Assembly Concept

Because of a delay in the welding schedule, the altered shear joint specimens were dried for 29 hours at 180°F, left in the oven for 17 hours at 100°F (38°C), and returned to 180°F for 6 hours before removal in pairs. At a weld time of 1.0 second, the first specimen showed too much weld. Specimens 2 and 3 were welded for 0.4 second, but the energy director was not melted. Weld time for specimens 4 through 15 was 0.6 second; weld time for specimens 16 through 20 was raised to 0.8 second to compensate for the change in pre-heat temperature caused by opening of the oven door. The lid was askew with the case in all specimens welded.

The altered shear joint's acceptable weld time was 0.2 second less than the apparent corresponding weld time for the normal shear joint. It may be possible to reduce the weld time to 0.6 second for the normal shear joint; however, this was not done because subsequent testing (discussed in the next section) indicated the normal shear joint as-welded was superior to the altered shear joint samples.

The change in assembly concept offers several advantages: the weld time required is less than 1 second (the time range associated with good nylon welding practice); welds are more consistent; simpler tooling is required; and in addition, by turning the cell upside down, the probability of the cell plates and S-wrap resonating to destruction has been diminished.

Testing

In general each cell was tested to 30 psig (207 kPa gage) in an unrestrained state with water as the pressurizing medium to find early failures.

Of the 35 samples submitted, four were unusable and one was inadvertently destroyed. Of the four unusable samples, one failed at the weld joint, two could not provide an "O" ring seat at the pressure entrance and one had a through-hole in the lid. Three more specimens were retained as control samples. Each of the remaining samples were then placed in individual plastic bags and subsequently mounted in a test fixture that approximated the mounting conditions in the battery assembly. Each bag was filled with de-ionized water and each cell was filled with a 35 percent by weight solution of potassium hydroxide. The 27 parts were then pressure cycled as a group. The first five cycles were 30 psig (207 kPa gage) for 16 hours, followed by 8 hours at one atmosphere. The last 30 cycles were 30 psig for 2 hours and off for 1 hour for three cycles per day. After each cycle the water in the bags was checked for potassium hydroxide contamination using phenolphthalein paper as the indicator. All 27 samples survived these tests without leaking at the weld joint.

The samples were then subjected to an electrical leak test. Each cell (filled with potassium hydroxide) was lowered into tap water in such a way that the weld joint was covered but the terminals were not. A 3 volt dc potential was put across the cell wall by attaching one lead to the terminal with the other lead, a probe, in the tap water. The weld joint was then traced with the probe. If a current of 100 μ A was detected, the joint was considered to leak. All 27 samples passed this test.

Five assemblies of each joint were then hydro-tested (Table 1). The test was aborted whenever the pressure reached 300 psig (2070 kPa gage); this happened in three of 10 attempts. Also, two of the samples reached 285 psig (1960 kPa gage) without leaking before the test was aborted at that point. The tests were done at several different rates. The failure pressure seemed to be a function of pressure rate. The parts seemed to survive best when the pressure was applied at approximately 5 psig/second (34 kPa gage/second) continuously or stopped at every 50 psig (345 kPa gage) interval for 1 minute. The above rates are quite severe compared to the approximate 1 psig/minute (7 kPa gage/minute) rate during the electrical charging of the cell. The cell walls were not supported and at 250 psig (1720 kPa gage) and above the cells were near 1.5 to 2.0 times their normal volume. The cells, when ruptured, tended to tear along the long seam of the weld down the case and then around one of the corners to the short side.

At the present time it cannot be stated positively where the tear began. Although perturbations in the weld zone are likely, it was indicated by the tear of the parent material, as opposed to the seam releasing, that the weld does approach the strength of the parent material. The lowest rupture was 130 psig (896 kPa gage) which is factor of approximately four times the pressure required. Based on favorable destructive test results obtained thus far, a 5-year maintenance free sealed cell appears to be a reasonable objective for nylon cases assembled in this manner.

ACCOMPLISHMENTS

A joint design and ultrasonic welding procedures were developed which permit the use of nylon as the cell case material for application on a nickel cadmium cell case. The techniques developed are directly translatable to a production process, more economical than the present solvent bonding, which will result in a more reliable battery.

Table 1. Hydro-Test of Nylon Ultrasonically-Assembled Cell Case

Test Sample*	Approximate Pressurization Rate		Fail Pressure		Notes
	(psig/sec)	(kPa/sec)	(psig)	(kPa)	
Normal Shear Joint					
4	5	34	300	2068	No leak****
8	5	34	130	896	Split along wide side and down corner of cell
10	5**	34	285	1961	No leak****
13	5***	34	285	1961	No leak****
15	5***	34	<u>278</u>	<u>1961</u>	Wide-side seam leak
Average			255	1760	
Altered Shear Joint					
1	5	34	300	2068	Leak at welded corner
2	5	34	205	1413	Leak at center of wide side
3	5	34	300	2068	No leak****
6	10	69	162	1117	Split down corner of case
7	10	69	<u>165</u>	<u>1137</u>	Split down corner of case
Average			226	1561	
<p>*Cell walls were unrestrained; tests were performed on a Brock Engineering Pressure Tester</p> <p>**Stopped at 155 psig for one minute</p> <p>***Stopped for one minute at 50 psi increments</p> <p>****Maximum pressure available did not result in part failure</p>					

FUTURE WORK

As the basic techniques required to ultrasonically weld the cell case have been successfully developed and demonstrated, no additional efforts are anticipated.

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