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Batteries & Energy Storage Technology

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Winter 2018



**Will Musk's
battery solve
Oz power
issues?**



How bad formation connections cost you

**The definitive review
of carbon additives**

**Continuus
Properzi's
Open House**



plus all our regulars

Carbon additives— all you ever wanted to know but were afraid to ask



Lead battery technology needs a substantial enhancement to stay competitive. The great grey hope appears to be a steroid boost consisting of a cocktail of carbon-based additives. So why are battery manufacturers not lining up for their shots? Is it the lack of standardisation in tests and procedures making the benefits uncertain? Mike McDonagh investigates.

Carbon, in its many forms, is claimed to provide substantial performance improvements for lead batteries. Improved charge acceptance, energy density and cycle life derived from the electrical and chemical effects of carbon and graphene, incorporated into the active material (AM) of the battery, are the claimed benefits.

With no other chemical benefactor immediately available, carbon seems to be a chance to salvage a role for lead-acid in the future. But are these claims justified? Is carbon the magic bullet that will lift the performance of lead-acid to a level where its advantages would make it the technology of choice for a range of applications? The answer is a resounding: ‘Well maybe, that is if these benefits can actually be realised.’

The effects on cycle life, capacity and water loss, for example, are also changed by factors such as lead and lead alloy impurity levels, the AM balance within a cell, and

processing parameters in paste mixing, curing and formation. With accepted variations of up to 20% in lead oxide quality, and 5% variability in process controls, it is difficult to prove the case for performance enhancements from samples prepared from standard materials and normal processing methods.

The simple truth is that there is so much variation in the materials and processing

methods of lead-acid batteries that it is next to impossible to eliminate all variability in testing to clearly isolate a benefit, let alone the extent of that benefit. This is a vital financial point, as quantifying improvements requires some degree of precision. Particularly where amounts of active material can be reduced by enhancing their utilisation. **Fig 1** from Penox illustrates this point. Critically,

Fig 1: Cost saving estimates based on increasing PAM utilisation

Trial 1 - Standard Battery Design using TBLS+									
Assumption:	Active material was increased to meet the spec. of OEM- batteries								
Model:	75Ah Battery								
	pos. plates per cell	6		PAM (g/plate)	91	changed to	88.5	-2.7%	PAM weight reduction
	neg. plates per cell			NAM (g/plate)					
	TBLS+ quantity (%)	1							
Standard design	Pos. plates/battery	36	91.0	g PAM per plate	total	3276	g		
TBLS+ design	Pos. plates/battery	36	88.5	g PAM per plate	total	3186	g		
						-90	g		-ve= saving/reduction
	Lead content of the paste (90% Pb)			Savings per battery		-81	g		
Prices	TBLS+	3750	€	per mt					
	Lead (LME)	1950	€	per mt					
Savings for 1 million batteries		-81.00	mt	Lead		-157,950.00	€		
		28.67	mt	TBLS+		107,527.50	€		
				NET SAVINGS		-50,422.50	€		
Comment:	Process cost savings have not been taken into account								

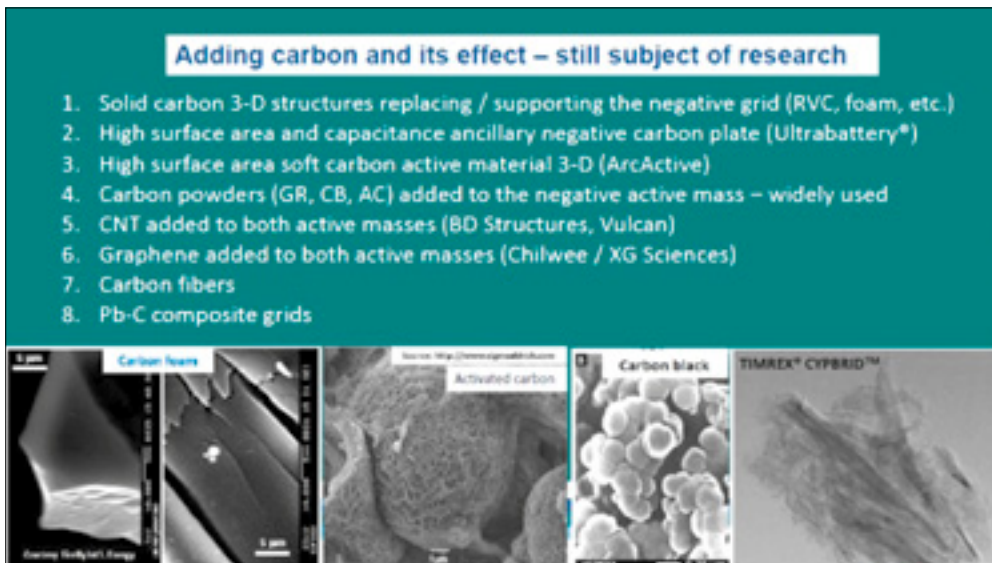


Fig 2: Summary of carbon forms used in advanced lead-acid batteries. Boris Monahov ALABC

the testing procedures used to measure battery performance are a mixture of standard and non-standard tests. Because of this it can be difficult for manufacturing companies to see the benefits for their particular designs, their applications and their materials and processes.

This article examines the more prominent claims made for carbon additives and the major difficulties faced by additive manufacturers in proving these effects. It also

makes some recommendations for standardisation of testing and sample preparation criteria for laboratory tests. There are also contributions from additive companies, which demonstrate their methodologies in ensuring that their products do have a measurable beneficial effect and that they are relevant to the industry's needs.

Use of carbon

Carbon in the form of lampblack has been used in the negative

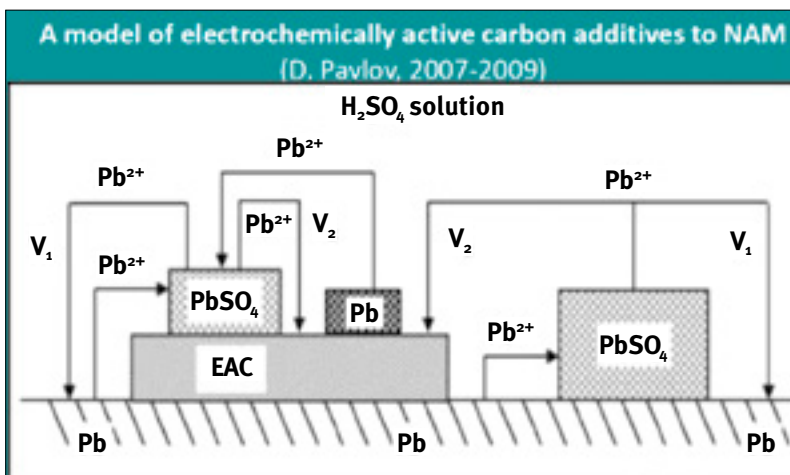
active mass of lead-acid batteries since the earliest days of mass production, and certainly before 1920 (Scarpa Elettrotecnica 1919). In recent years the research into beneficial effects of carbon in various allotropic forms has been prodigious. So too have been the claims made by the companies providing the products. From the two derivatives of lampblack (soot) and graphite, we now have a much wider range of forms to include nano-particles and potentially superconducting graphene structures. Within these broad categories, there are subtle variations that manufacturers use to tease out better performances for different battery properties. **Fig 2** shows the range of carbon forms currently under investigation as battery additives. The current focuses of the carbon additives are broadly:

- CNT carbon nanotubes
- Graphene tubes
- Nanoparticles
- Graphene
- Lampblack

Although there are several carbon structures and many claimed benefits to lead-acid battery performance, most of these are derived from just two effects, namely: the improved electrical conduction at low states of charge and the smaller crystal size of the AM. Clearly better AM utilisation results from a finer grain size whilst the improved charge acceptance and cycle life under PSoC conditions result from better AM conduction.

Without dwelling too much on the theory, **Fig 3** from Pavlov

Fig 3: Interface reactions of carbon on lead according to Pavlov



makes a case for improved interface conduction. The provision of nucleation sites for AM giving a higher surface area and therefore more reaction surface and this is a fairly well-defined mechanism for AM enhancement. **Fig 4** supplied by Cabot shows the well-established effect of increased surface area due to smaller crystal size of AM created by carbon additives.

There is also a third consideration based on so-called fullerene structures. For carbons other than graphene, the outer sp^3 orbitals are involved in the atomic bonding in solid carbon. Graphite is made up of monoatomic layers of sp^2 -bonded atoms, which give the familiar honeycomb structure that results from a four-valent atom having three neighbours.

The single atomic sheet called graphene has a near perfect structure with almost zero defects. **Fig 5** shows an actual TEM picture of a single graphene sheet. This defect-free structure gives rise to enhanced electron mobility and therefore electronic conduction. The

Fig 5: Graphene monolayer

5 (a) TEM image of a single graphene monolayer: Hernandez et al: *Nat Nanotechnol.* 2008. 3. 563
 5 (b) HRTEM image of a single graphene monolayer: Meyer et al: *Nano Lett.*, 2008. 3. 3582

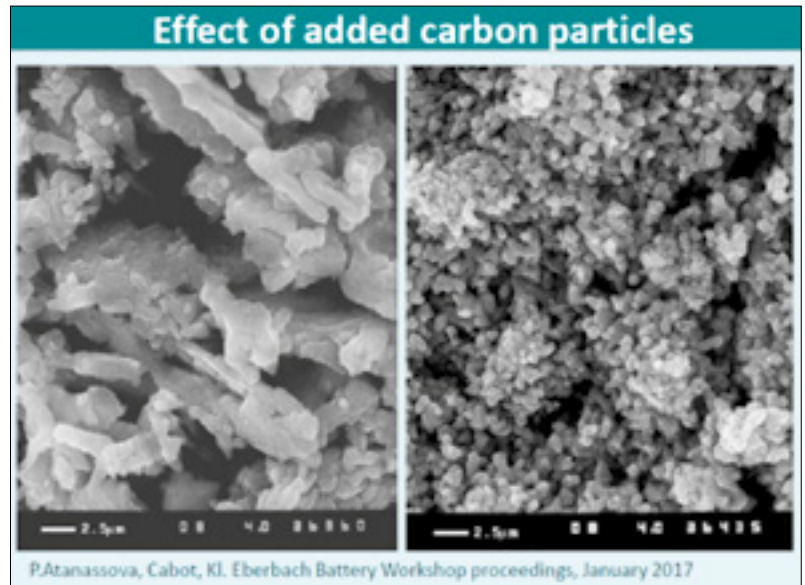
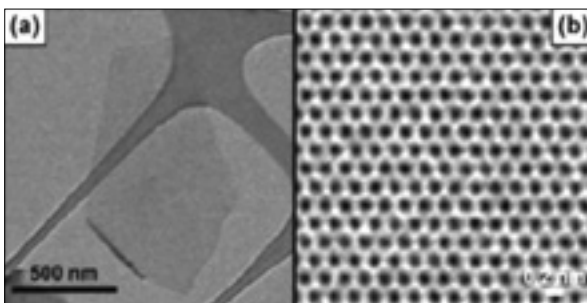


Fig 4: Effect of carbon on NAM microstructure

single graphene sheet can be modified to provide a Buckyball or nanotube structure, the latter being the subject of considerable research for lead-acid applications.

Effect of carbon on battery properties

There are many companies offering carbon in several allotropic forms and who have done considerable research into both identifying an effect in lead-acid batteries and then finding a practical application of that effect with the potential benefits on battery performance. Because of the diverse nature of battery performance tests and the applications of batteries, most companies have concentrated on particular test regimes and applications and developed suitable carbon derivatives for these uses.

There are perspectives to consider for the effect of carbon and its different forms:

Physical and chemical effect:

- AM particle size
- Plate resistance
- Conduction of AM
- Grid/AM interface passivation

Battery properties

- IR
- Conductance in sulfated condition
- Power density
- Energy density

Battery performance

- Low sulfation
- PSOC cycle improvement
- Charge acceptance
- Micro Hybrid cycle life
- Deep discharge cycle life
- Higher capacity
- Lower material costs

Prominent in research being carried out by the Advanced Lead Acid Battery Consortium (ALABC) is the study of the effects of carbon on the properties of lead-acid batteries. The claims made for carbon in the active material can be

narrowed down to several of the fundamental properties required of a lead-acid battery:

- **Better AM utilisation for the positive and negative electrodes**

The AM is enhanced by providing a high number of nucleating sites to give finer grained AM with a larger surface area.

- **PSoC cycle improvement**

Standard tests from EN 50342-6 include micro hybrid and 17.5% endurance cycle tests. Some additive companies are making bespoke variations on these tests in collaboration with LAB manufacturers. **Narada** have devised cycle tests aimed at simulating ESS conditions cycling between 30 and 70% SOC whilst C&D use the Erickson test for unstable AC power applications.

- **Deep discharge cycle testing**

Furukawa provide data on a self-made non-standard deep discharge test procedure with results of 4,200 cycles at 70%

“Some additive companies are making bespoke variations on these tests in collaboration with LAB manufacturers.”

DOD. *Little data exists for standard traction 80% DOD discharge cycles*

- **Low temperature cranking**

Tests based on EN 50342-6 are mostly used to show SLI improvements

- **Sulfation prevention**

Most companies claim an anti-sulfating mechanism based on better conduction in the AM when discharged or prevention of build-up of smooth large sulfate crystals during PSoC cycling.

- **Formation energy**

Less energy is used in battery formation due to the lower on-charge voltage during the constant current charging process. This has been known

for some time and the normal carbon addition of lampblack has been used since the end of the 19th century in all lead-acid batteries. This is part of the familiar negative expander formulation used in virtually every paste mix by every company in the world.

In the case of Heraeus, very respectable and cost-effective energy savings in formation of 10% are quoted, **Fig 6**. As can be seen from another article in this edition this could amount to massive cost savings for a battery manufacturer.

- **Water loss**

This is the current bugbear of carbon additives. Standard water loss tests according to EN 50342-6 show that carbon additions increase a battery's water consumption. Field trials however, carried out by ALABC using start-stop taxis, do not show any measurable difference in water consumption compared with control batteries. However, most additive companies recognise the problem and are working towards reducing the hydrogen evolution rate of carbon enhanced batteries.

Minimising variables of test procedures

In all the papers presented at the 17th ABC, in Kuala Lumpur in 2017, neither complete AM balances, nor manufacturing process details for the test samples were shown. This is the heart of the problem: if removing or standardising variables is a challenge for

Fig 6: Summary of benefits from Porocarb carbon

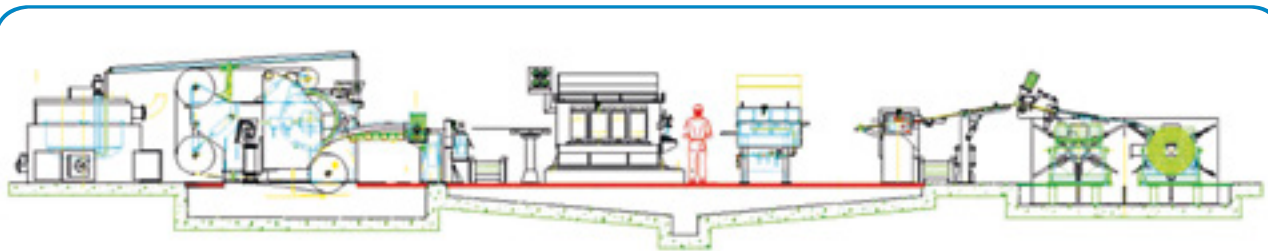


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the additive supplier, then the problem for the manufacturer is greater, as they need to know if a particular additive will work in their product.

This means they need to know if the samples used for testing are limited by positive or negative AM or acid and also if the processes were geared to produce traction or SLI properties.

The variables encountered when producing test samples or batteries can be put into two categories: processes and materials. Although the effect of variables in lead-acid manufacture are near impossible to eliminate, they can be minimised by strict production controls over the processes and materials used. They can also be minimised by using sufficient numbers of samples over a wide enough range of applications and designs to show a statistical significance. Looking at the problems associated with each of these options in the following order:

Process control

- **Oxide production**

This affects the properties of the leady oxide used in the active material. The size distribution and the ratio of alpha to beta lead monoxide are the two main variables that are affected by throughput and temperature.

- **Grid casting**

This can affect the concentration of minor elements such as tin or calcium that end up in the

“If removing or standardising variables is a challenge for the additive supplier, then the problem for the manufacturer is greater”

cast grid and seriously affect corrosion resistance and/or cycle life.

- **Paste mixing**

There are a number of variables here: the mix temperature affecting the particle morphology and chemistry of the sulfates and oxides, the rate of acid addition, the amount of trim water, the nature and concentration of other additives and the length of time mixing the wet ingredients.

- **Curing**

The temperature and humidity will affect the AM particle morphology to give better cold crank or better cycle life

- **Formation**

Similar to curing, the temperature will determine the cold cranking and cycle life characteristics.

Materials control

- The amount of active materials, the balance of PAM, NAM and acid are critical factors for limiting the performance of the battery. A NAM limited design will have capacity improvements

if the NAM has an improved utilisation. In this case a negative enhancer such as carbon will show a capacity increase. Acid or PAM limited cells would not show an improvement. If the battery were seriously negative limited then the increase would be greater than a slightly limited design. This is critical when analysing cost benefits.

- Pure lead used for oxide contains variable amounts of impurities. The three or four nine impurity limits still allow substantial variation in the concentrations of individual contaminant elements. These elements may have a bigger influence than the proposed carbon additions, in particular, cold crank and water loss on float charge and high rate discharge capability.
- Lead alloy used for grid production. Alloying, secondary and impurity elements can all affect battery performance, in particular, cycle life, hydrogen and oxygen overpotential (gassing rates).

Statistical controls

- Repeat under many different conditions and extract a real, consistent effect outside the limits of the process and materials variability. This is a statistical approach similar to clinical data derived for, say, monitoring diabetes in North America. If the benefits claimed are still evident in all or most of these

cases outside of statistical error then the effect can be classed as genuine. However, the conditions have to be understood and identified to ensure that the relevance to a particular battery design and application is valid.

The process control case is very difficult to achieve due to the interaction of several variables even under laboratory conditions. Most additive companies who make their own samples for testing either have their AM supplied by a battery company or they have a pilot scale paste mixing facility, typically less than 10kg, which is too small to be representative of real paste mixing conditions. Factory-made paste can vary between batches for a variety of reasons with the effects listed above. This can lead to either unrepresentative or variable test results.

Participating companies

There are two valuable contributions to this article from companies who expressed an interest in participating in this review. They have very willingly provided their methodologies and some test results, which illustrate how they are used to ensure the validity of their results.

These methodologies also indicate the relevance of their results to battery manufacturers' applications and standard battery designs. The companies who represent the broad categories outlined in this section are **Cabot**, who place

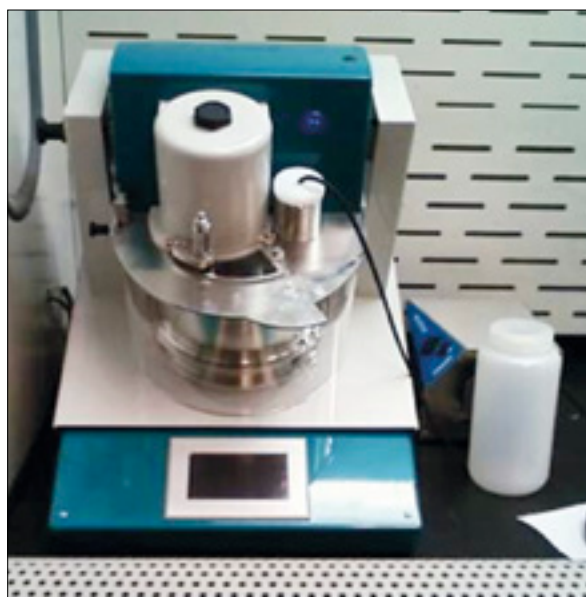


Fig 7: Paste mixer equipment used by Cabot for test sample construction

an emphasis on laboratory trials as a methodology, and **Black Diamond**, who have a predominantly statistical approach to verifying their results. However, it is not an either/or situation. Both companies have pre-screening laboratory tests and both work with battery manufacturers to verify their product effectiveness. It is the emphasis of their approach which is highlighted in this article, rather than a definition of their methods.

Cabot

Cabot has invested in laboratory scale production of lead-acid batteries from the pasting stage. Grids are supplied by participating lead-acid battery companies for pasting and subsequent curing and formation. Cabot's customers also supply the oxide and standard additives for paste mixing. The equipment shown in **Fig 7** is for paste mixing, it is

an Erlich 1kg paste mixer and curing is performed in a T2RC Tenney curing oven (not shown). The process is outlined in **Fig 8** showing the outcome of each process step and the flexibility of deciding on tri or tetrabasic sulfate formation. The materials used are also clearly defined in their document with an intended negative limited design for their test samples.

As an example, the following is an excerpt from their hand pasting procedure: 'The paste is applied to a lead-alloy grid that serves as the current collector for the negative electrode. The negative electrode limits the lead-acid cell by having three positive electrodes providing the excess capacity. Negative plates use lead Pb-0.04 Ca-1.10 Sn alloy, with grid dimensions of 57 mm x 60 mm x 1.5 mm. Pasting is done manually with a PE spatula. Thickness of the coated plates is 2.5 mm.'

All subsequent processes are equally well defined and include plate curing, cell assembly and formation. Each stage uses painstaking methods to ensure that process variability is as far as possible eliminated. Analysis at each stage, which includes XRD of the dry cured plates, provides detailed information on the structure and chemistry of the plates. The analysis is always performed on freshly washed plates to prevent increased levels of PbO in the carbon-enhanced samples created by the higher surface area of the smaller particle size. This level of detail in the sample preparation is continued in the subsequent processes. As an example shims

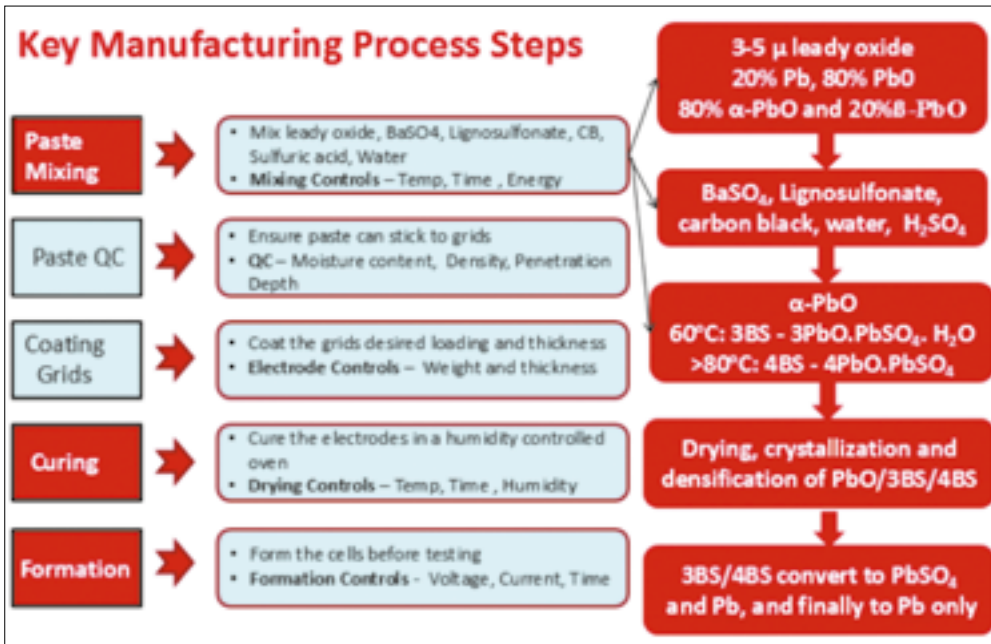


Fig 8: Summary of Cabot's manufacturing process steps for test sample preparation

are used in cell assembly to exactly reproduce cell pressures on every build.

The sample cells are then formed using a two-step formation method on a Maccor 4000 series battery cycler in 1.18g/cc sulfuric acid according to a multistep algorithm. The desired acid density after

“This level of detail is about as far as one can go with standardising LAB manufacture.”

Table 2: Application test procedures

Application	Cycle test	High rate tests	Capacity tests	Water loss	Charge acceptance
SLI	PSoC EN 50342-6:7.4/7.5 Microhybrid EN 50342-8:7.2	EN 50342-1:5.3 and 50342-6:7.9.1	20hr 50342-1:5.1, 50% DoD	50342-6: 7.6 Non standard cyclic simulation	DCA EN 50342-6:7.3
Standby power	50–80% DoD EN62040 – Part 3	N/A	5-10hr	Non-standard cycle water loss	Non standard static C/A
UPS	PSoC non-standard Partial SoC	EN 50342-1:5.3	20hr 50342-6	Standard high temperature	Non-standard partial SoC
Energy Storage	Deep discharge 50–80% DoD PSoC bespoke	PSoC high rate bespoke	5-15hr bespoke	Cycle loss elevated temperature	Non-standard partial SoC
Traction	Deep discharge 50–80% DoD IEC 60254-1:2005 and non- standard	N/A	5-10hr standard and non standard	Cycle loss elevated temp IEC 60254-1:2005	Non-standard partial SoC opportunity charging
Solar	Deep discharge 50–80% DoD IEC 61427 and non-standard	N/A	5-12hr standard and non standard	Cycle loss elevated temp	Non-standard partial SoC

formation is 1.28g/cc. Electrolyte is replaced after formation with 1.28g/cc sulfuric acid. The formed cells are then tested on Maccor 4000 series battery cycler for C20 capacity, cold crank, cycle-life and water loss according to the protocols listed in **Table 2**. Hydrogen and hydrogen sulfide sensors are installed in the test enclosure for safety, and hard wired to the battery tester. Testing is automatically suspended if the sensor alarm is triggered.

This level of detail is about as far as one can go with standardising LAB manufacture. It is of course laboratory scale and meant for comparison of results rather than compatibility with batteries made using industrial scale manufacture. As such it serves as an important process to decide which measured effects are valid and reproducible before moving on to collaboration with battery manufacturers using their equipment and processes.

	Application	NAM Product	PAM Product
Automotive	SLI & Heavy Truck – Conventional Flooded	Pb1100N	Pb1100P
	Start/Stop – Enhanced Flooded	Pb1200N	Pb1200P
	Advanced Auto - VRLA	Pb1300Nx	Pb1300Px
	Motorcycle – VRLA	Pb1400N	Pb1400P
Motive Power	eRickshaw - Flooded (Tubular)	Pb2100N	
	eRickshaw - Flooded (Flat Plate)	Pb2200N	
	eVehicles - VRLA	Pb2300N	Pb2300P
	Lift Trucks – Flooded	Pb4100Nx	Pb4100Px
Stationary	Inverter - Flooded	Pb3100N	
	Solar - Flooded	Pb3200N	
	Solar (PSOC)- VRLA	Pb3300N	Pb3300P
	Advanced Renewables & Utilities - VRLA	Pb3400Nx	Pb3400Px
	Telecom - VRLA	Pb3500Nx	Pb3500Px

Table 1: Black Diamond product types tested in use by application

According to Cabot’s Dr Paolina Atanassova: “We have multiple such cases of collaboration with battery manufacturers, starting with review of our cell level data and deciding on two or three formulas (carbon loading, LS loading) to test in a large-scale manufacturing trial for further fine tuning of the best recipe.”

Dr Atanassova adds: “We believe that the research we are doing is quite relevant to the industry and have received feedback from many customers that supports this belief. Our philosophy has always been to share openly how our cell level test results are derived and incorporate feedback on how to improve them further.”


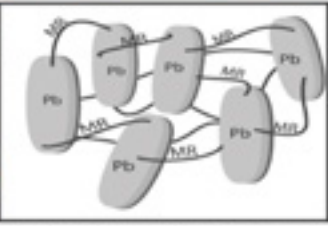
Black Diamond
This is an example of a company emphasising the customer trial approach. Even with extensive laboratory facilities the primary focus is to ensure

“This molecular rebar effect is thought to be responsible for increased mechanical properties in AM making both positive and negative AM stronger, resulting in an increased cycle life.”


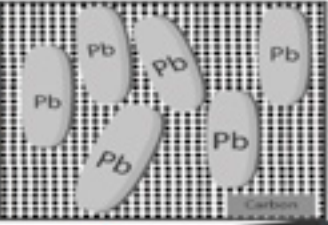
that lab results are translated into an effective benefit. Their molecular rebar (MR) technology is different from other carbon additives as it has an additional function of increasing the AM mechanical strength. It consists of carbon nanotubes that not only provide the improved conductance and finer grained AM structure associated with

Fig 9: Strengthening of AM for improved cycle life using Molecular Rebar carbon nanotubes

Not Another Carbon: Unique Form & Function

- MR acts as a physical and rheological modifying agent, its form and function are unique from Carbon; “Rebar Effect”
- Benefits of MR are not derived primarily from surface area, hence addition rates at 10% or less of Carbon

- Carbon has an important role in conductivity and is necessary in a lead acid battery
- Its interactions and purpose are different than MR

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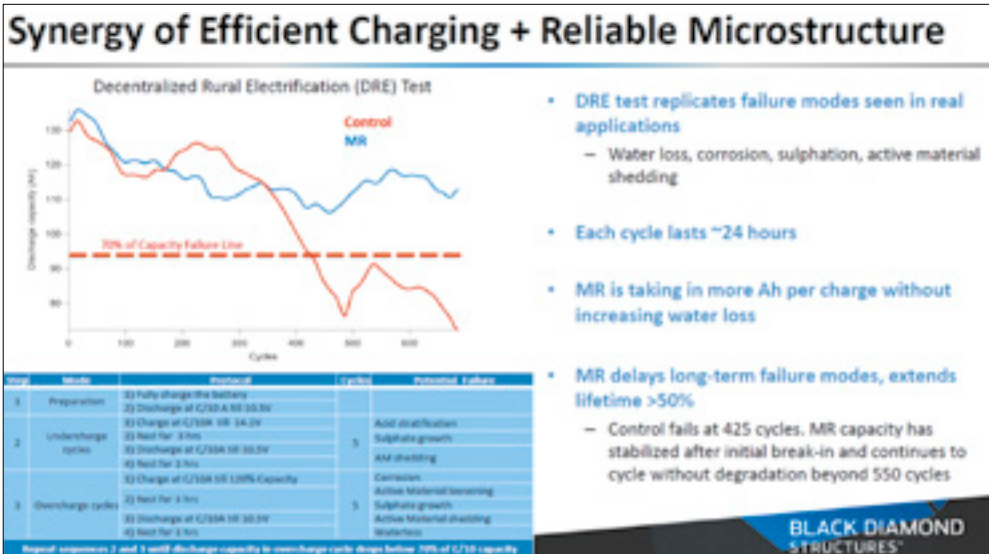


Fig 10: Improvement in cycle life and charge acceptance without additional water loss using Molecular Rebar carbon nanotubes

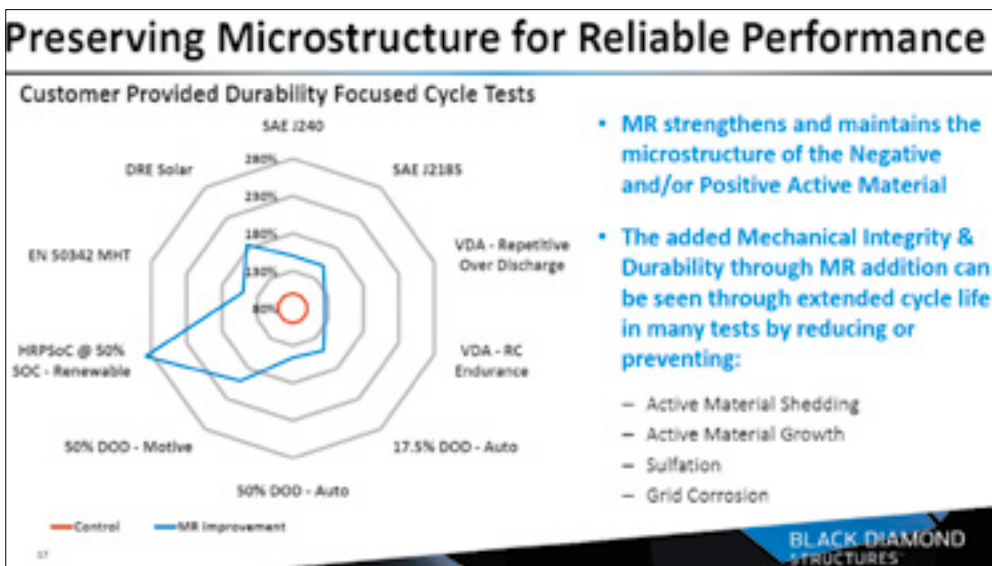
carbon additions but also act as a sort of binder holding the AM particles together (Fig 9).

This MR effect is thought to be responsible for increased mechanical properties in AM making both positive and negative AM stronger, resulting in an increased cycle life. There is also some good news on the water loss problem associated with carbon additives: Decentralised rural

electrification (DER) tests do show an increased charge acceptance and cycle life with no increase in water loss compared with a standard battery Fig 10.

Black Diamond has substantial laboratory facilities and are able to manufacture and test samples against customers' and national standards. Working in close collaboration with more than 100 battery manufacturers, they have tested a range of

Fig 11: Summary of beneficial effects proven to have occurred over a large number of customer tests



MR additives in both NAM and PAM of multiple battery types in multiple applications Table 1.

The total number of validation tests Black Diamond has conducted externally is in the hundreds and covers a very broad range of battery types/sizes. The battery manufacturers typically produce a minimum of three batteries per variant for testing, and always include a control variant. Identical control batteries are always tested along with the battery variants containing the MR solutions.

As a result of these trials, Black Diamond have been able to identify the effects of MR on battery performance in a range of applications. Fig 11 is a spider diagram showing the extent of the measured benefits. As can be seen from this chart, there are a number of cycle tests undertaken. These are a mixture of familiar national standards and customers' own product and application-focussed tests.

Black Diamond also focuses on the manufacturers' production requirements and has developed a liquid form of MR, which is easily added at the paste mixing stage. The amount and process details have been established by both collaboration and laboratory trials for all the applications and battery types encountered in their industrial collaboration.

Standardisation of tests and methods for sample preparation

It is fairly obvious that there are many different tests across a wide range of applications and battery designs that are

being unilaterally followed by additive manufacturers, usually in collaboration with LAB manufacturers.

The benefits of having standards for test sample manufacture, the testing procedures and the reporting protocols are clear. The main problems are: what standards, what procedures, what protocols and who will set them?

Within many conference presentations and papers there is a diverse range of battery properties that are tested for a variety of applications. A substantial number of testing procedures are non-standard and are derived by collaboration between battery and additive manufacturers.

This occurs because the existing formal national standards are not able to fully satisfy the requirements of lead-acid battery and additive manufacturers, so some sort of bespoke testing procedures are required. This is particularly true in the energy storage arena where higher cycle life and more efficient charging are key parameters for economic operation. **Table 2** gives suggestions for which types of tests and properties would be beneficial to standardise.

This table is neither definitive nor exhaustive and is only a suggestion for a base to build on with collaboration between battery manufacturers, additive manufacturers and organisations such as ALABC. It is not intended to replace national standards which are already in existence it should be additional to them.

“This table is neither definitive nor exhaustive and is only a suggestion for a base to build on with collaboration between battery manufacturers, additive manufacturers and organisations.”

Testing methodologies

In order to prepare samples of cells or batteries, either in the laboratory or in a battery factory, there are fundamental factors that affect the outcome of any battery testing procedure. These are consequences of the materials and the processes used to manufacture test samples from those materials. The purity and quantity of materials used, particularly the AM and the grid alloys, has significant impact on several battery properties.

Likewise, the quantity and balance of active materials is a crucial factor in understanding the extent of capacity or cycle life improvement shown in performance testing.

The process parameters used in the manufacture of the samples are also critical as they can influence AM material structure to the extent that it may override any effects of carbon, particularly with cycle life and high rate discharge testing.

With this in mind the following are suggested material and process criteria to measure and record:

• Materials

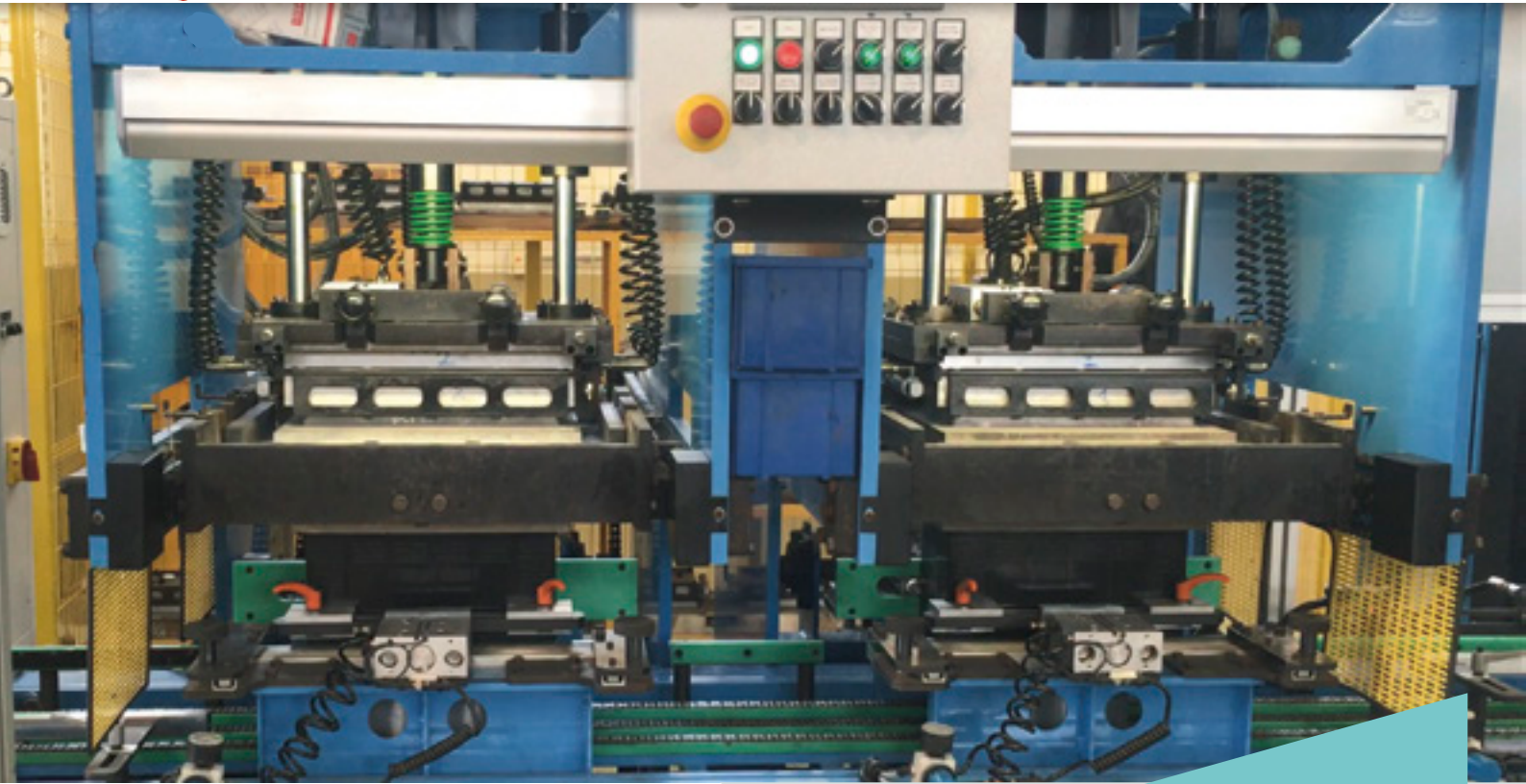
- › AM balance: weight of dry cured NAM, PAM, acid and grids per plate and per cell
- › Paste formulation and density for NAM and PAM
- › Grid alloy composition including measured impurity levels on batch assay
- › Lead oxide analysis on quality certificate plus the impurity levels from the delivered pure lead assay
- › Acid density and impurity levels
- › Separator material and properties such as porosity, resistance, ash content, g/cc etc.

• Test sample/battery design

- › Dimensions and number of plates per cell and per battery
- › Cell structure: plate pitch separator thickness, compression of pack
- › Acid volume per packed cell

• Processes used to manufacture samples, paste mix, curing, formation etc. (AM crystal forms)

- › Paste mixing: maximum temperature, rate of acid addition, density test results
- › Curing: complete profile including results for maximum temperature and humidity, free lead and moisture
- › Formation: complete programme with results for maximum temperature, final SG and final sulfate



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level. Acid filling method and initial filling gravity with maximum-recorded temperature

- **Manufacturing and test equipment used to prepare samples**

- › Paste mixing equipment: manufacturer and batch size.
- › Pasting method including manual or machine application with details including temperature settings.
- › Formation equipment: manufacturer, output capability, voltage and current, programmable or not, programming software used

- **Conclusions:**

- It is next to impossible to provide definitive test results free of variability in test samples.
- With laboratory testing used as a screening process to select the products most likely to be effective in field trials, it is possible to isolate reproducible benefits from various carbon additions.
- The testing procedures to demonstrate the effect on battery properties need to be defined to ensure that manufacturers can compare the results with their existing battery testing. This applies particularly to life cycle or endurance tests, which currently have several variations.

- Standard tests should be selected from national standards organisations such as IEC, SAE and JIS, which are considered representative for the applications listed.
- An independent organisation such as the ALABC should conduct a survey to decide which standard and non-standard testing procedures should be adopted.
- If necessary the ALABC might suggest suitable testing procedures to standardise on for additives.
- ALABC could also make recommendations for standard laboratory sample preparations for materials and processes.
- For material control, as a minimum, active material balances should be declared in all testing. The details of non-active components such as separators, bus bars and packing pieces should also be included.
- Process controls should also be declared. As a minimum, the paste mixing, curing and formation parameters

used should be declared and the actual measured values should be recorded for comparison.

- Details of test samples and battery constructions should be recorded and include plate dimensions, cell dimensions, separator and compression ratios where applicable.

- **Summary**

There are measurable benefits associated with carbon-enhanced batteries which could help lead-acid be more competitive in existing and emerging markets such as energy storage. It is still has further research needed to maximise the benefits and address issues such as increased water loss. The rate of progress could be significantly increased by streamlining and standardisation of procedures and testing allowing easier collaboration between battery and additive manufacturers, as outlined in this article.

“Carbon additives are not a problem, they are an opportunity for lead-acid batteries— it depends on all of us how well we will use this opportunity”. +

Can you write compelling copy about the design and manufacture of batteries?

Can you explain complicated processes with an economy of words?

If so, BEST magazine wants to hear from you.

Contact Gery Woolf in the first instance:

gerry@bestmag.co.uk with a feature subject outline.

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