Electrochemical Energy Storage
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Module - 07
Introduction to battery pack design
Lecture - 35
Packaging of Battery Pack and Battery Testing: Material Selection, Sealing of Enclosure, Testing including Safety and Abuse Test

Welcome to my course Electrochemical Energy Storage and this is module number 7, where we are talking about Introduction to the battery pack design. And this is lecture number 35, the last lecture of this module, where we will be talking about Packaging of the Battery Pack and Battery Testing, Material Selection, Sealing of Enclosure, Testing including Safety and Abuse Test.

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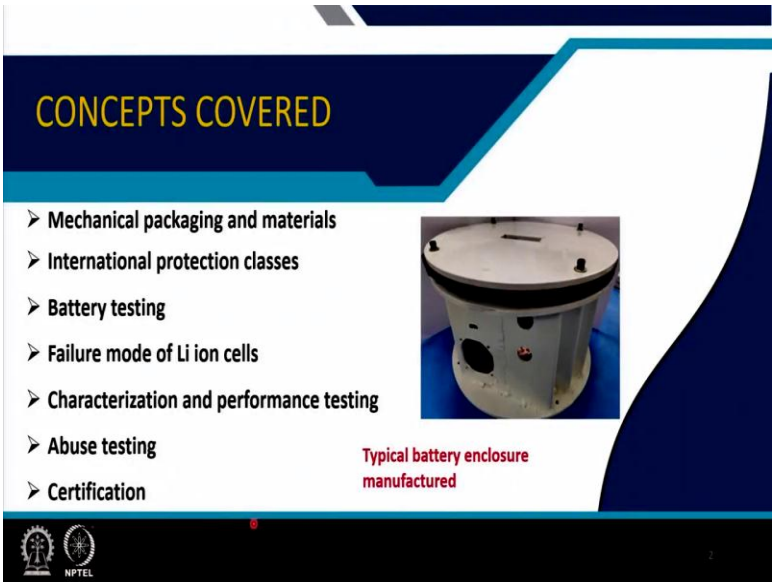

So, in this particular class, we talk about mechanical packaging and materials; what are the materials used; then, what are the international protection classes; then, battery testing, how exactly and what exactly are tested. Then, failure mode of lithium ion cells which is a bit recap from the concepts already I developed earlier. And characterization and performance testing, then abuse testing, and how the certifications that are usually done for the battery pack.

And this is the actual, now the battery pack, in the last lecture also I showed you the same figure. So, this is a typical package that we have done for our battery module which is typically 28 volt 16 ampere hour module.

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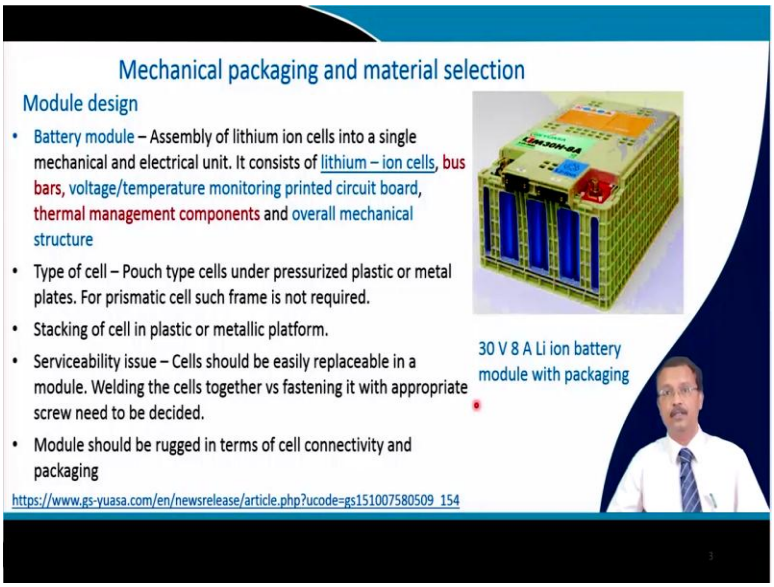

So, the module design, it consists of the battery module, where assembly of lithium ion cells into a single mechanical and electrical unit. So, all the cells are there inside. So, it consists of lithium-ion cells, they are connected with bus bars, then voltage and temperature monitoring PCB; it is a part of your BMS. Then, thermal management components and the overall mechanical structure.

So, this is a typical 30 volt 8 ampere lithium ion battery module that I just I showed as a typical example. Now, the type of cells could be pouch cell; and usually, if you are using a pouch cell, they are always kept under pressurized state. So, you use plastic or metal plates because you know that the pouch cell even after forming cycle, they have a tendency to swell a bit and that will disturb the mechanical integrity inside the battery pack.

So, they are pressurized and screw tight within two plastic plate or metal plate. And for prismatic cell, it is already there inside a hard plastic cover case. So, it is not required. And you may have to stack the cell. So, stacking of cells in plastic or in a metallic platform is required.

Serviceability issue that is important because the cells should be easily replaceable in a module. So, you can easily detect the faulty cell, because you are using it with a BMS. So, you are monitoring each cell state of health. So, the serviceable; serviceability that is important because you may have to change the cell.

Welding the cells together versus fastening it with the appropriate screw need to be decided. Because if you weld it is relatively difficult for you to take the cell out, but if it is fastening with the screw tight way, then it is a bit easier.

And of course, the module should be rugged in terms of cell connectivity and packaging. So, the lot of wires may be there depending on the type of BMS that you are using. So, specific tests are there to know about how good is the connectivity, cell connectivity and ruggedness of the cell. So that, these are the factors that one should consider when you are designing a module.

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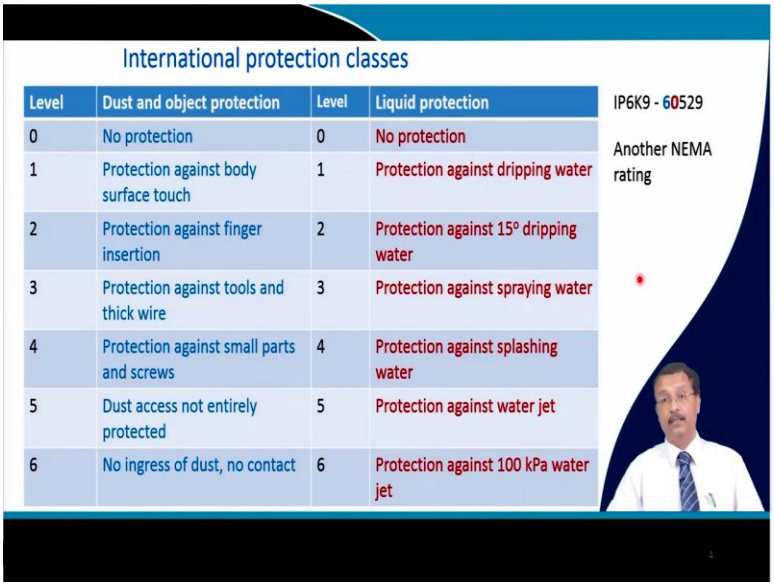

So, there are international protection classes mostly for dust and object protection at one end and another one is the liquid protection. So, 0 always stands for no protection both for dust and liquid. 1, stands for protection against body surface touch protection against dripping water that is for the liquid 1.

Number 2 is protection against finger insertion and here number 2 is protection against 50 degree of dripping of water, very stringent conditions are maintained. Then, class 3 is

protection against tools and thick wire and for liquid, class 3 is protection against spraying water. So, for 3, they should be simultaneously satisfied.

Class 4 is protection against small parts and screws and here, protection against splashing water. Then, 5 is dust access not entirely protected and here, 5 is protection against water jet. Number 6 is no ingress of dust, no contact and 6 is protection against a very pressurized water 100 kilo Pascal of water jet, it is protected.

So, there are many international protection classes. So, one is this IP6K9, where the first two digit this is one for this first one for the dust and the second one for the liquid. So, here you can see it is 60, that means, no ingress or dust or no contact; but this is 0. So, for liquid it does not have any protection.

So, similarly, there are NEMA rating. So usually, internationally, the whole battery pack once you packaged, the module with BMS thermal management system inside a an enclosure, then they are internationally given this number so that you can understand the quality of protection that you will get out of this battery pack.

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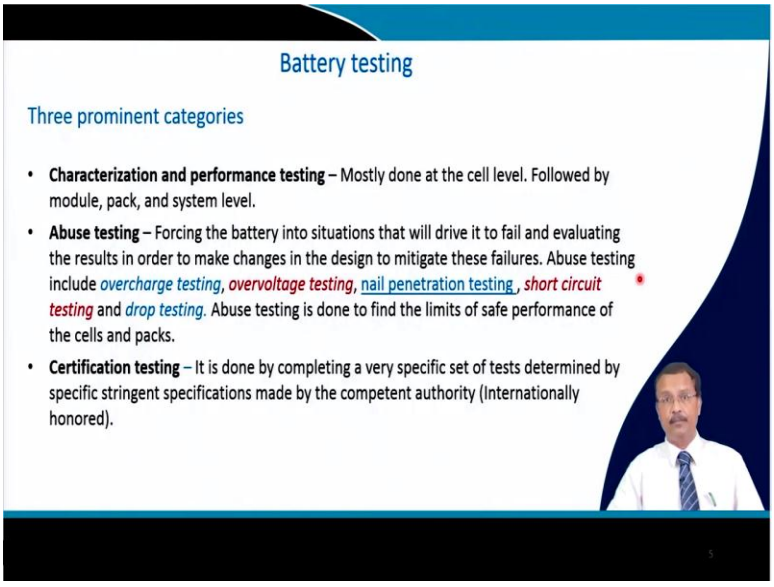

So, battery testing, it consist of three important categories. The first one is characterization and performance testing which anyway you will have to do, mostly dull done at the cell level followed by module level, then pack level, and then the whole system level. So, at each of this level you will have to test it.

So, if you fabricate the cell, first to do the electrochemical characteristics of the cell, then prepare a module and then connect the module and then make a pack. And then finally, with BMS and all other thermal management system, you do the system level electrochemical test.

The second one is abuse testing. That means, you force the battery into situations that will drive it to fell and evaluating the results in order to make change in the design to mitigate these failures. So, abuse testing include overcharged testing, then over voltage testing, then nail penetration tested.

Basically, it is a short circuiting test; with a nail, you short circuit the anode and cathode. Then, separate short circuiting test; that means, connect the part this anode with cathode the two terminals and drop testing for the impact resistance, you fall the battery from a height.

And usually, abuse testing is done to find the limits of the safe performance of the cells as well as the packs. So, at cell level, you can do the abuse testing; particularly, this nail penetration test, the impact tests or you can do at the pack level. And then, certification testing, this is done by completing a very specific set of tests determined by a stringent specific specification made by the competent authority and which is internationally honored. So, this three level of testing is required when you make the whole battery pack.

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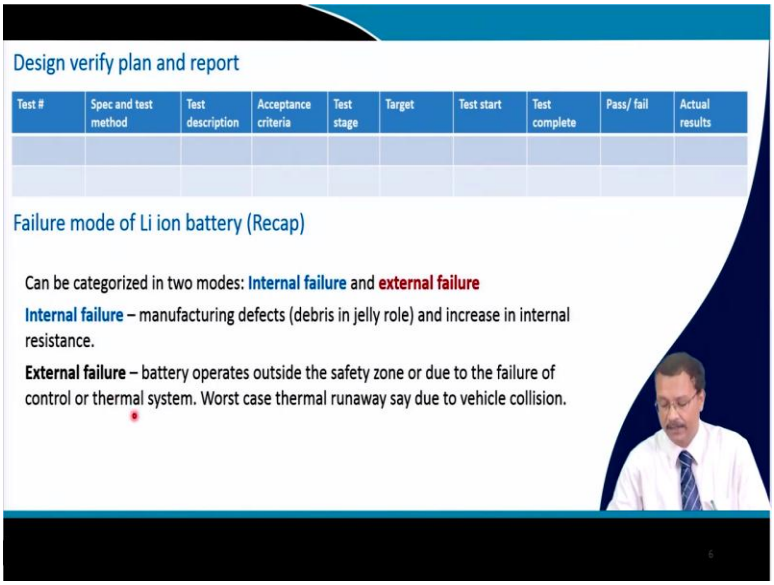

So, then, you will have to make a design verify plan and report- DVPR. So, here you first this is a long table. So, you will have to clarify that what is the test number, then specification and test method, then the description of the test, then what is the acceptance criteria, then what was the test stage, what was your target when test started, when test completed, whether it passed or failed the test and the actual results.

So, this is a DVPR that is actually reported with the battery pack. And the failure mode for lithium battery, this again I am talking about. It can be categorized into two modes; one is the internal failure and another one is external failure. Internal failure is usually manufacturing defect, you remember we talked about the jelly roll formation for the pouch cell and also, the cylindrical cell.

So, if the debris is there accumulated in the jelly roll, so that is one kind of cause of internal failure or increase in internal resistance so that is also another cause of internal failure. Particularly, with the cycling, due to variety of causes including SEI formation and other types of causes that will increase the internal resistance. So, that is the cause of the internal failure.

External failure is the battery operates outside the safety zone or due to the failure of the control of thermal system that leads to a thermal run away. And one example is say vehicle collision. So, that is entirely external failure, the battery was on and then the vehicle collided, so it catches fire. So, this kind of example is the so called external failure.

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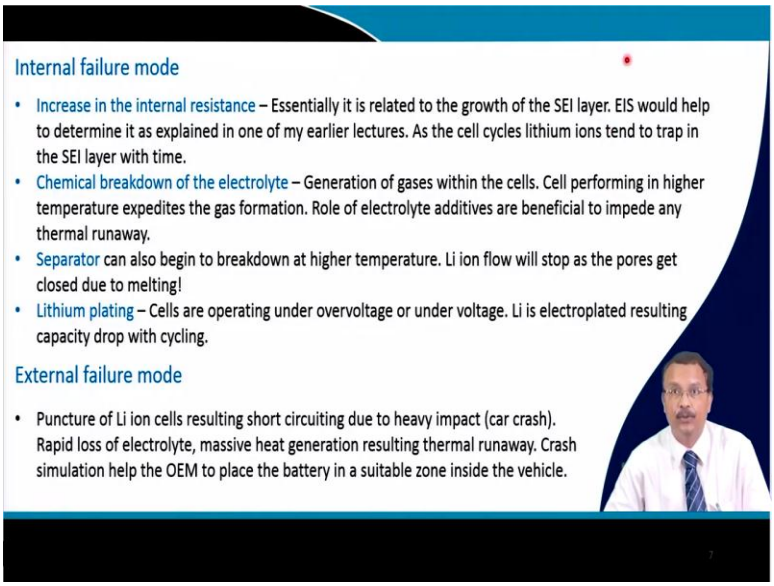

Now, internal failure modes is one is increase the internal resistance. So, that is essentially due to the growth of the SEI layer. So, one can do this electrochemical impedance spectroscopy that will help to determine it. So, that already I explained in one of my earlier lectures. So, as the cell cycles, cell is cycled repeatedly charge and discharge cycle. So, lithium ion tend to trapped in the SEI layer with the time and that causes the charge transfer resistance to increase.

Chemical breakdown of the electrolyte that is another cause. So, that generation that generates gases within the cell. So, the cell performing at higher temperature that usually expedite this kind of gas formation. And as I mentioned earlier that the role of additives are beneficial to impede this any possible thermal runaway due to this.

Separator can also begin to break down, again at high temperature. So, initially the lithium ion flow will stop because it will melt and the pore will get clogged. Then, if it completely melts, then there is there will be short circuit and thermal runway because of the heat generation.

Lithium plating is another cause of internal failure. So, cells are operating under over voltage or under voltage. So, lithium is electroplated resulting the capacity drop with cycling. So, these are the actual causes of internal failure.

External failure mode puncture of the lithium cells that resulting the short circuiting due to heavy impact as I mentioned car crash. Then rapid loss of electrolyte, massive heat generation resulting thermal ran away. Crash simulation is usually done with the Original Equipment Manufacturer to place the battery in a suitable zone inside the vehicle; that is very important. So, that even if the car crashes, it does not have any catastrophic effect due to the battery explosion or the battery total failure thermal runaway.

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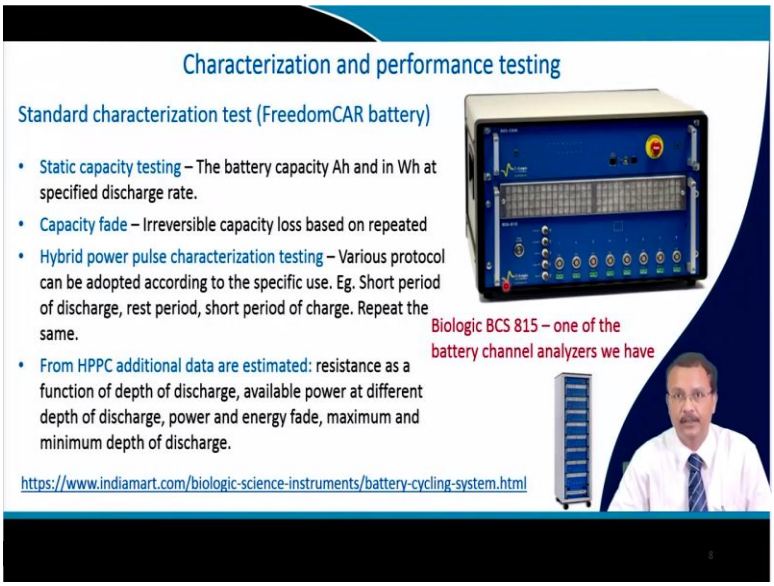

So, the standard characterization test that is usually done is a couple of specific tests. One is static capacity testing. So, the battery capacity in ampere hour and in whatever at specified discharge rate, so this ampere hour, the total charge or the energy that actually we will have to test. Capacity fade is another thing; cyclability, irreversible capacity lost based on repeated cycling that also will have to test.

Hybrid power pulse characterization test depending on the use, various protocol is followed according to the specific use. For example, it could be a short period of discharge, then a rest period, then short period of charge, then repeat the same. So, various types of charge discharge cycle depending on the use of the battery that usually is done. So, this is hybrid power pulse characterization testing is done.

And then, from this HPPC additional data are estimated. For example, resistance as a function of depth of discharge, availability power at different depth of discharge, then

power and energy fade, maximum and minimum depth discharge. So, these are all estimated.

So typically, the battery tester looks like this. In fact, this one is we have it from a company called Biologic, the model is BCS 815. So, it has 8 means 8 channels are there. So, you can connect your battery for charge discharge measurement and 15 ampere each of this channel can give. So, this is a quite useful for ours pouch cell and cylindrical cell of capacity like 1 to 10 ampere hour.

And in fact, we have several other cycler, but this is one of them. So, similar type of cycler, you can stack together like this and you can imagine. So, here 8-9 cyclers are there. So, number of cells you can test at the cell level or you can integrate each of this channel and the whole pack also can be tested.

So, this is very very useful equipment. And this is also powered by a reasonably good software to from the measured data, from the charge discharge data or cyclability data. Even you can do the impedance spectroscopy measurement of each cell using this particular equipment. And then, there is a powerful software to estimate various characteristic electrochemical characteristics using the software tools. So, it is connected with the computer to do this kind of characterizations.

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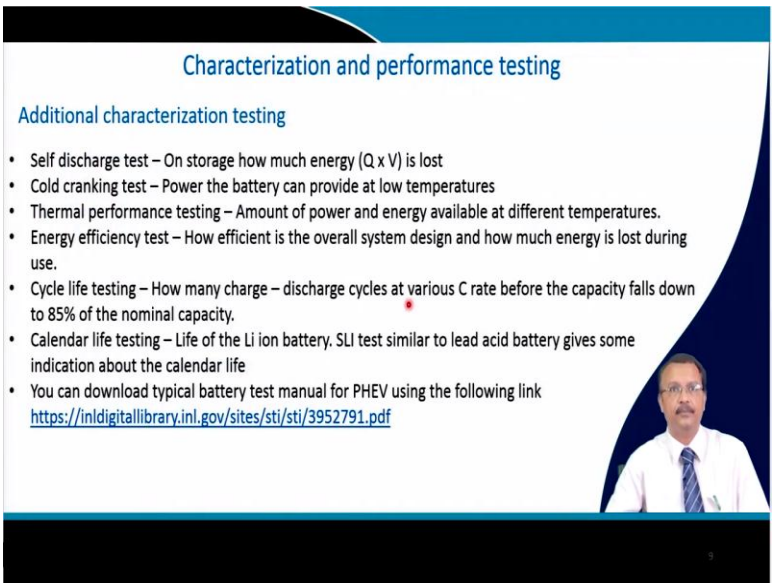

Additional characterization testing that is usually done is self discharge test. So, the battery is stored and how much energy is stored over a period of time; so, you know the energy is Q into V. So, whether capacity or voltage if it reduces, then it will be reflected in the self discharge test at open circuit condition.

Cold cranking test that is the power of the battery can be provided at low temperature. So, how effective is your electrolyte operating at lower temperature. Then, thermal performance testing, amount of power and energy available at different temperatures which is very important for the operations of the developed battery pack.

Then, energy efficiency test, how efficient is overall system design and how much energy is lost during its use, because it can take energy to run its BMS, to run its thermal management system. So, what is the energy efficiency eventually at the end of the for the battery pack that is to be tested.

As I said cycle life testing is important; how many charge discharge cycles at various C rate before the capacity falls down, typically 85 percent from the nominal capacity started. Calendar life testing, life of the lithium ion battery; SLI test that is the start lighting and ignition. So, that test similarly to the lead acid battery gives some indication about the calendar life, how long it will last.

And this is a good link. You can download the typical battery test manual which is basically made for plug in hybrid electric vehicles. And this link is quite good and all this test the exact details, you will find in this manual. So, I suggest you to download it from the link given and read it that how exactly this kind of tests are done.

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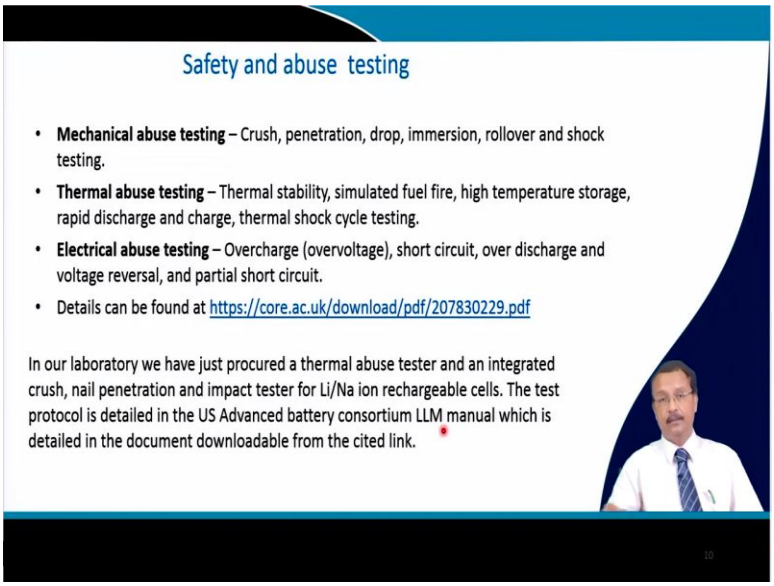

Then, we will have to do the safety and abuse testing. One, the first one is the mechanical abuse testing. So, that includes crushing, the cell at the cell level crushing the battery; then penetration, nail penetration to do a force short circuit slow way; then drop, then immersion inside a liquid, rollover and shock testing.

One should also do thermal abuse testing that to know the thermal stability, simulated fuel power fire, high temperature storage, rapid discharge and charge and thermal shock cycling testing. At different temperature, the battery is exposed and you do the electrochemical charge discharge and see how does it affect the battery performance, I mean the cell performance.

Then, electrical abuse testing is over charge or over discharge, short circuit, over discharge with voltage reversal and partial short circuit. So again, these three types of safety testing that is the mechanical abuse testing, thermal abuse testing and electrical abuse testing. There is a nice document here, which you can download from this link and the details you can go through that how exactly, what are the conditions that is followed to do these tests.

In our laboratory, just we have procured a thermal abuse tester and an integrated crush nail penetration and impact tester for the mechanical abuse testing and thermal abuse testing. The test protocol you can see the this link also talks about it.

So, usually US Advanced battery consortium LLM manual according to that, the test will have to be performed. So, there is a stringent specification and one can find it the test protocol in this particular link. If you click it, then you can get this pdf document.

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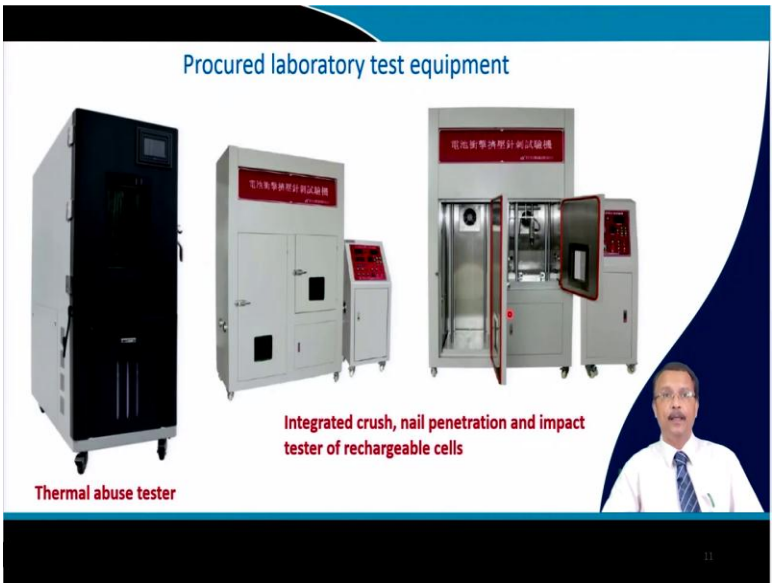

So, this is the typical picture of the thermal abuse tester. So, it is having a thermal chamber, where you can change the temperature and the battery cycler test is kept aside. And you can abuse the battery in the cell level and then, you can test the performance.

And this is a integrated nail penetration and impact tester for rechargeable cell. So, the cells usually drop from a height. So, the height is specified according to the specification and cell can be dropped from different height. And this is the nail penetration and the crush.

So, the battery is crushed within two plates and as you can imagine that these are all smoke free chamber because one once you are abusing the battery, then in most of the instances, it explodes, it catches fire. So, all these chambers are explosion proof and fire proof and they are expensive of course and fortunately, we received all this equipment in our laboratory. But yet to any test, but we will be using it heavily in near future.

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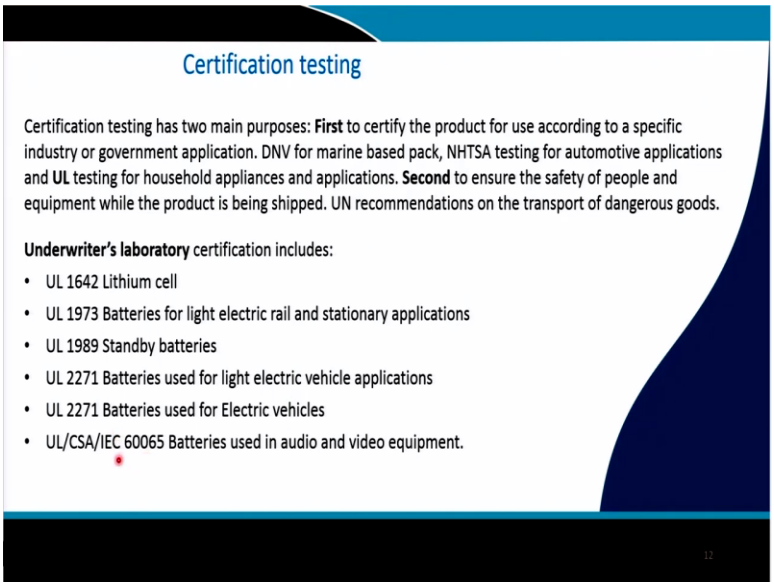

Finally, there is a certification test. So, certification test, it has two main purposes. The first one is to certify that the product for use according to a specific industry or government application. So, then there is a authoritative body to certify this. And usually DNV, they give marine based pack. NHTSA, they test for automotive applications and this Underwriters Laboratory, UL, testing for household appliances and applications. So, these are the certification authority.

So, they can certify the battery pack that is developed. And second one is to ensure the safety of people and equipment, while product is being shipped that is also equally important that when you get lithium ion battery from abroad. Then during transport, it should satisfy certain criteria. So, basically UN recommendations are followed for transport of dangerous goods and it falls under this dangerous good category.

So, this underwriter's laboratory, they have various types of certifications depending on this number. So, UL 1642 for example, is to test certification for lithium cells. UL 1973 that is batteries for light electric rail and stationary applications. UL 1989 is for standby batteries for the storage of renewable energies and UPS. UL 2271 that is batteries used for light electric vehicle applications. UL 2271 is batteries used for electric vehicles and UL CSA oblique IEC 60065 batteries used in audio and video equipments.

So, this certifications are important, when you purchase a battery pack or cell, then whether it is certified or not that is important and one should only use those cells which

are certified by the competent authority. There are many cell makers; not in India, but in abroad and faulty cells if you make a battery pack out of it, certainly that will be very detrimental and price also varies. You can get cells from different vendors, but whether they are really certified by the competent authority or not that is important.

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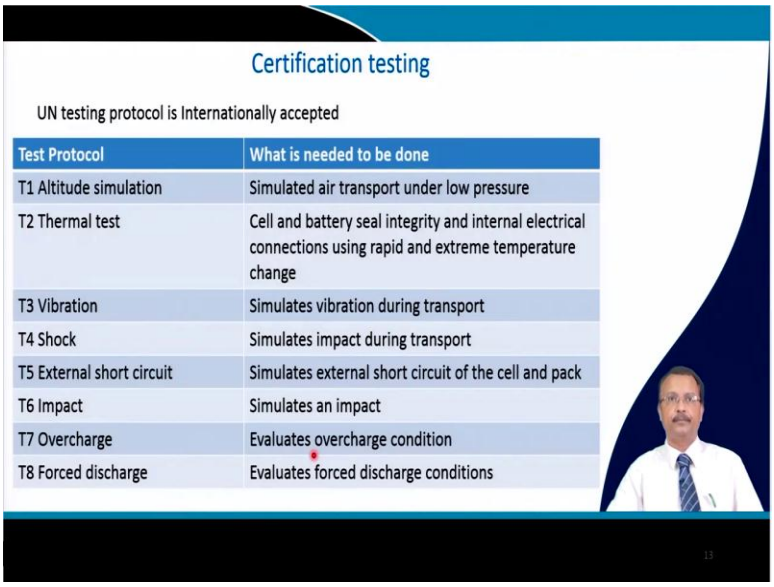

So, this UN test protocol, they are internationally accepted and there are 8 specific test protocol. The first one is the altitude simulation T1. So, simulated air transport under low pressure, so assuming that it is being transported by air. So, there are test protocols that is followed and certified that the lithium cell, you can that is useful for you for the air transport.

T2 is the thermal test, cell and battery seal integrity and internal electrical connections using rapid and extreme temperature change. So, one of this kind of chambers are used following certain protocol before they give the certification.

This is important; the T3 one, the vibration for our battery pack, we also in a process of doing all these things. So, vibration was important that simulates the vibration during transport. So, in a specific frequency range, a platform vibrates and your battery is clamped on the platform.

And if you have faulty bus bar connection or the wiring etcetera from BMS to the slave board, if they are not they are disconnected, then this vibration test the battery will fail.

So, that is very important. Then, T4 is the shock simulates the impact during the transport as if the car crashes; so, what will happen to the battery.

T5 is the external short circuit, extremely important that simulates the short circuit of the cell and the pack as if two cells, they are short circuited, they are kept in close proximity. So, what if they are short circuited, then that is also tested and the certification is given. T6 is the impact simulates the impact of the cell and battery level.

T7 is over charge evaluates the overcharge condition and T8 is a forced discharge, so evaluates the forced discharge condition, we call it a deep discharge. So, this 8 test protocols, they are first tested before the certification is given.

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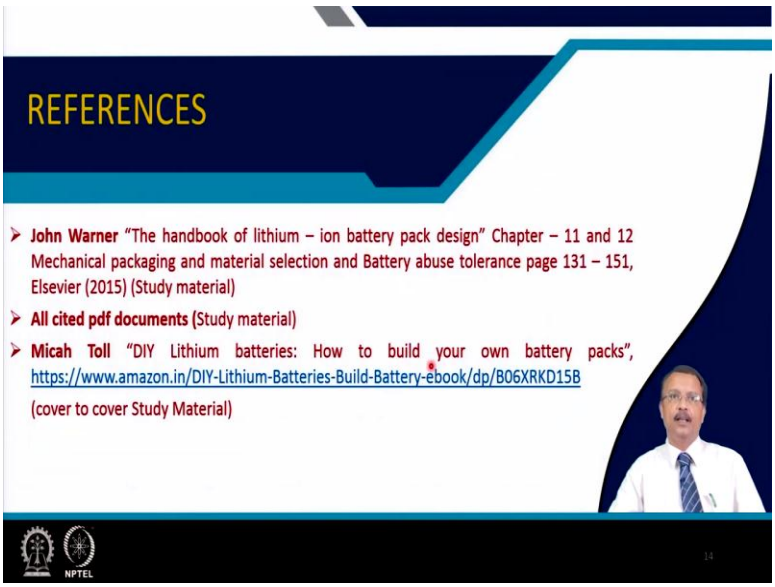

So, again the book by John Warner chapter 11, 12 that is Mechanical packaging and material selection and Battery abuse tolerance pages which is 131 to 151 of this book. That is your study material and all cited documents, the I mentioned about the testing protocol, so that must be downloaded and read it. And again, this the book by Micah Toll for the battery manufacturing that is also important for you to read the relevant part.

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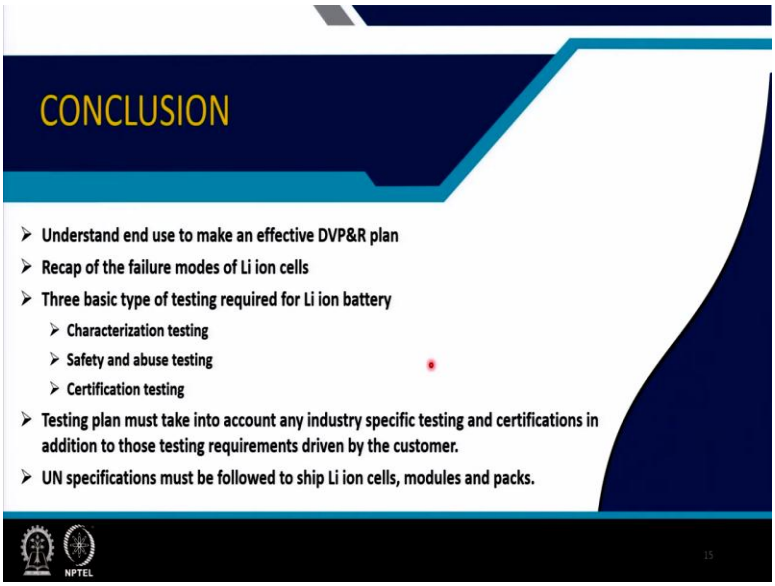

So, in this particular lecture, we talked about the understand the end use to make an effective DVP and R plan, the table that I showed. Then, recap the failure mode of the lithium ion cells, and three basic type of testing that is required for the lithium ion battery which starts from characterization testing, then safety and abuse testing, and then finally certification testing.

Testing plan must take into account any industry specific testing and certifications in addition to those testing requirements driven by the customer. So, both are important, whether for your purpose the battery will serve it or not that should also be tested and the vendor should also specify that this particular application, this battery module will be useful. And UN specification must be followed this 8, T1 to T8 to shift lithium ion cells, modules and pack.

Thank you for your attention.