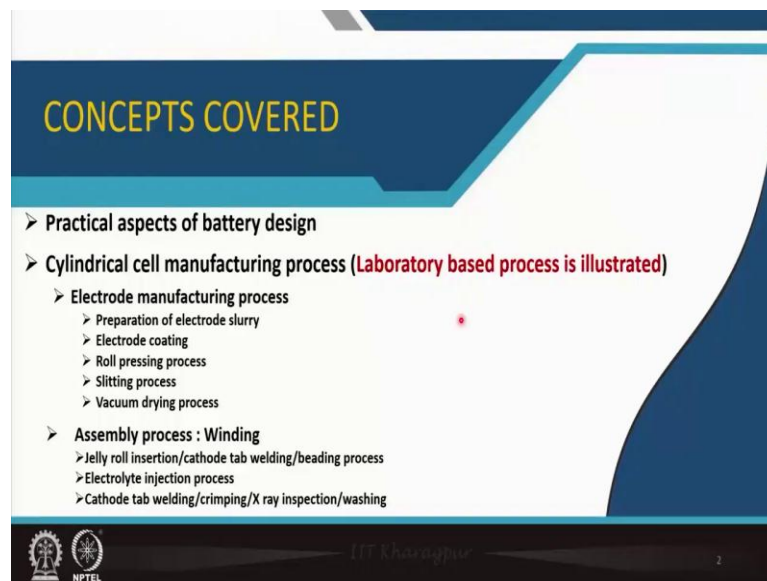


Electrochemical Energy Storage
Prof. Subhasish Basu Majumder
Department of Materials Science Centre
Indian Institute of Technology, Kharagpur

Module - 05
Characteristics of commercial lithium ion cells
Lecture - 24
Fabrication of Li ion Cell: Cylindrical Configuration

Welcome to my course Electrochemical Energy Storage and we are now in module number 5, where we are talking about the Characteristics of commercial lithium ion cells and this is lecture number 24, where I will be describing the Fabrication of lithium ion Cell particularly the laboratory based cell fabrication will be described because it is difficult to get the exact roll to roll processing of commercial lithium ion cell, but this will give you a vivid idea that how the cells are manufactured.

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So, the practical aspects of the battery design that we will we will just talk few words and cylindrical cell manufacturing process this will be mostly be laboratory based process, which usually we do in our laboratory.

Then that includes electrode manufacturing process, then electrode manufacturing included the preparation of the electrode slurry, then how they are coated, then what is

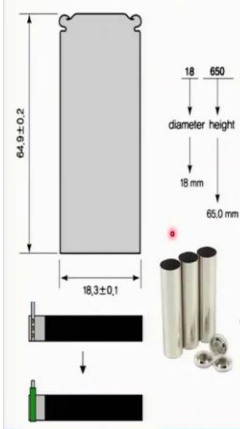
the need of calendaring or roll press, then they are cut according to the size, then there is a vacuum drying process involved and then finally, they are assembled.

So, in terms of winding. So, we call its winding to form a jelly roll to put that insert it after cathode and anode tab welding and the beading process, then how the electrolyte injection process is done and then cathode tab welding, then crimping, inspection, washing this will be covered. So, the manufacturing process in short.

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Practical aspects of cell design

Physical design factors of cylindrical batteries



The diagram shows a cylindrical battery with a diameter of 18 mm and a height of 650 mm. The internal components are shown as a cathode (130 μm thick) and an anode (110 μm thick) separated by a separator. The anode width is 59 mm, which is slightly larger than the cathode width (~58 mm). The separator is wrapped around the cathode and anode to prevent short-circuiting between electrodes. Each electrode has different values of inner and outer coating length. The uncoated collector is located at the outermost cathode (or anode) and sealed with finishing tape.

- Cylindrical battery diameter – 18 mm it consists of a cathode, anode and a separator which are wound in a jelly roll configuration.
- Cathode (130 μm) is generally thicker than anode (110 μm)
- Width of anode (59 mm) is slightly larger than the cathode (~58 mm)
- The separator is wrapped around the cathode and anode to prevent short-circuiting between electrodes.
- Each electrode has different values of inner and outer coating length. The uncoated collector is located at the outermost cathode (or anode) and sealed with finishing tape.

3

So, when we talk about the cylindrical cell the model that is quite important and adopted globally is 18, 650, 18 stands for the diameter of this casing and 650 stands for the height which is 650 millimeter.

So, as you can see that there is a gasket plus top can the bottom is completely sealed. So, this is hermetically celled once you put the anode cathode etcetera inside it and electrolyte and then there is a vent here. So, if the gas formation is there takes place during the formation cycle or during the cell operation, then this vent valve whenever the pressure is built it goes out.

So, as I told the diameter is 18 millimeter, cathode usually is 130 micron, it is generally thicker than anode which is 110 micro micrometer and you know why it is so because cathode is having the lower capacity. So, it will need to have more material thicker material so, that it matches the capacity of the graphitic base anode in particular.

Width of this strips of electrode, anode is 59 millimeter which we once you wind it; it will go inside this and cathode usually kept at 58, this is also having a reason because cathode contain the lithium part. So, if the anode is slightly larger then it will catch all those lithium.

Separator is wrapped around the cathode and anode to prevent the short circuiting and each electrode has different values of inner and outer coating length. So, both sides of this current collector is coated and the uncoated collector is located at the outermost cathode or anode and that is basically finished with this ceiling cell. So, this is just to take the connection out from the current collector.

So, now you can understand that these are the physical design factor for making cylindrical cells and now we will go step by step how to make these cells.

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Cell manufacturing process

Electrode manufacturing process

1. Mixing
2. Coating
3. Pressing
4. Slitting
5. Vacuum drying

1. Preparation of electrode slurry

- A binder solution is produced by dissolving a PVDF binder in N – methyl pyrrolidone (NMP) solvent.
- Active material and conductive agents are then mixed/dispersed to prepare a homogeneous slurry.
- The process can be divided into binder solution preparation, binder solution transfer, slurry preparation, and slurry transfer.
- During slurry storage process, the prepared slurry is pumped to a storage mixer and stirred to prevent hardening and aggregation.

<https://youtu.be/ffvj919BNik>
Watch how it works

So, the cell manufacturing process this the first step is electrode manufacturing and that constitutes several steps starting with mixing. Mixing the active material with binder and conducting agent to form a slurry, then they are coated mostly by using tape casting, then they are roll pressed so, that the tap density is increased and the electrode is properly adhered on the current collector, then they are slitted in the form of the exact length as well as the width so, that it can be wind properly and fill into the can.

And after slitting they are vacuum dried. So, there is no trace water is absorbed during this fabrication process. So, for preparing this electrode slurry the machineries that is used the typically machinery is shown here. So, MTI is a company US based company, they make all kind of battery manufacturing equipment. So, you can go to their site mtixtl dot com which I have given at the end of the lecture and this is one of the equipment how it functions there is a YouTube link given.

So, if you click on the link you will see that how exactly the mixing is done. So, first a binder solution is produced that is by dissolving PVDF binder in its solvent N - methyl pyrrolidone, then active material and conductive agents they are homogeneously dispersed to prepare a homogeneous slurry.

The process that can be divided into binder solution preparation, then binder solution transfer and slurry preparation and slurry transfer. So, usually the slurry storage process it is prepared this prepared slurry is pumped to the storage mixture and it is continuously stirred so, that it does not get hardened and does not get agglomerated.


So, please watch the video to see that what is the consistency of the slurry because it should wet on the current collector properly. So, the viscosity is one of the major factor and the wettability of this particular ink the slurry onto the current collector that is also important.

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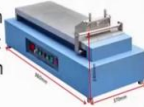
Cell manufacturing process
Electrode manufacturing process

2. Electrode coating

- During coating process, the slurry is passed through the coater head and the metal current collector is coated in a given pattern and thickness followed by drying. Unwinding, coating, drying, density measurement, and winding. Coating is applied to the front and back of the electrodes.
- The coating process is the same for both cathode (on aluminum) and anode (on copper).
- The unwinding process prepares the metal current collector or one side coated electrode for coating
- After the slurry prepared from the mixing process passes through the coater head, the metal current collector is coated at constant thickness. The drying process removes solvent and moisture from within the slurry coated on the metal current collector.
- The density (thickness) measurement process examines the amount of slurry coated on the electrodes.



<https://youtu.be/uiguFkx3Q3w>
Watch how it works



5

Then the next step is electrode coating and this is the machinery that is used and it is semi automatic and the principle is described in this small machine. So, you know that there is a chuck here which is having provision for holding the current collector which is laid on top of this and the vacuum is applied. So, its firmly adhered here and this is a doctor's blade.

So, in the doctor's blade the separation between the blade and this electrode current collector that you can adjust and that will basically fix your coating thickness and you can change the scanning speed. So, it can be very fast it can be slow and also you can heat it so, that the solvent can be evaporated to make it dried right there.

So, these are the things all these things are here also how it works again you can see in this YouTube video. So, the ink is first put here whatever we prepared in the last slide and on top of the current collector, this doctor's blade they scanned here and get a fine coating on the surface and you can control the coating thickness.

So, during coating process the slurry is passed through the coater head and metal current collector is coated in a given pattern here is a flat pattern and thickness is controlled by controlling the blade separation between the doctor's assembly and the current collector and then it is unwinding, coating, drying, density measurement and also winding because it is a roll to roll process it is not a single strip being coated here.

So, for example, your cathode is cathode material is kept here and here somewhere the doctor's blade are there and this is being coated and going to the other side and winding up. So, you get a continuous roll to roll coating process. So, the coating process is same for both cathode usually it is done on aluminum or anode that is copper.

The unwinding process prepares a metal current collector or one side coated electrode for coating and then again it is put back and the other side is also coated so, that you have more active material to increase the capacity of the cylindrical cell. So, after you prepare the slurry from the mixing process passes through the coater head, where from this ink is put on the current collector and it is coated in a constant thickness.

And the drying process that removes the solvent and moisture and density that is the thickness measurement process. So, if you measure the thickness you can have the aerial


density of the slurry that is coated on the electrode. So, that is the coating process that is followed do check this video. So, that you will have a better idea.

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Cell manufacturing process

Electrode manufacturing process
3. Roll pressing process (Laboratory press shown)

- The rolling process increases electrode density after the coating process, improves adhesion between the current collector and active materials, and flattens electrodes between two heated/cold rolls.
- This process is comprised of unwinding, trimming, preheating, cleaning, and winding.
- In **unwinding process**, electrodes in jumbo roll are released for the roll pressing while maintaining tension.
- The **trimming process** trims away the uncoated edge of the electrodes to remove creases arising from thickness differences between the coated and uncoated areas.
- **Preheating** warms up the electrodes before insertion into the roll so as to press electrode well. The cleaning process removes impurities from the electrode surface with a cleaning nonwoven before winding of electrodes.



https://youtu.be/nzadL_qdd00



Then as I said we need to pass it through a roll press. So, that due to this rolling process the dried electrode they are pressed together properly. So, there is no air gap between the current collector and the electrode material. So, they are properly adhered they are not fully dried yet so, that if you roll press it at hot condition then you get a better addition.

And this is also a roll to roll process may be not the same equipment that you can use, but this is for the laboratory equipment only a single strip that you can do, but usually this is also a roll to roll process. So, when one roll getting pressed and this is winded up in the other side then you reverse it and do the same process for the other coated side. So, preheating as I said is important that warms the electrode before insertion to the roll.

So, as to press the electrode well and there is a cleaning process involved that removes the impurity from the electrode surface with a cleaning nonwoven kind of thing before winding this electrode. So, electrode is clean enough. Usually all these operations that is done in a dry room with having a relative humidity as low as 1 percent. So, moisture absorption from the normal ambient is almost very very limited.

On top of that you are vacuum drying it whenever it is required. So, trying to get the moisture absorbed in this electrode they are really marginal. If they do then you will have to pay the price and your electrochemical characteristics will get deteriorated.

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Cell manufacturing process
Electrode manufacturing process

4. Slitting process

- In the slitting process electrodes are cut into uniform widths and prepared for winding in the assembly process. Slitting process can be broken down into unwinding, cleaning, and winding.
- The unwinding process maintains an appropriate tension while feeding electrodes into the cutter.
- The cleaning process removes impurities from the electrode surface with a cleaning nonwoven prior to winding of the electrodes.

4. Vacuum drying process

In the vacuum drying process, the electrode wound on a reel is dried for a given period in a vacuum chamber. Moisture and excess stress from the rolling process are removed through thermal treatment.

<https://youtu.be/RZfZ-lawNWw>

After that this is the slitting process that I was mentioning. So, the electrode is cut here. So, that you can see there are blades here and you have this big electrode coated on aluminum as you can see and here if you can change this separation. This separation you can change and then you pass it here, then the strip will be formed right the strip will be formed and the length and the width is important for winding. So, that you will have to put it inside the case. So, this slitting is important.

And once you slit it, again you will have to clean it at every stage because although it is kept in a clean environment, but some material can get stuck onto it and that will deteriorate the battery I mean battery performance so, that you will have to do that cleaning is very important.

And then it is vacuum dried. So, in vacuum drying process the electrode is wound on a reel and put in a vacuum chamber. So, moisture and excess stress that is involved due to this rolling that are removed to through this thermal treatment.

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Assembly

1. Winding
2. Jelly roll press & insert
3. Tap welding
4. Can - cap welding
5. Electrolyte injection
6. Ball welding
7. Bottom plate welding

Cell manufacturing process

1. Winding

- The winding process produces a jelly roll by attaching a tab to the electrode and placing the separator between cathode and anode followed by cylindrical winding. (see the video link)
- At this point the jelly roll is completely wound and ready for insertion into the can.
- Tab ultrasonic welding process uses ultrasonic welding to attach an aluminum tab to cathode and nickel tab to anode.
- The center reforming process removes creases at the center of the jelly roll and creates space to insert the welding tip.
- The internal short circuit inspection ensures resistance more than tens of $M\Omega$.

<https://youtu.be/nhPiYuDoo>

Now you are in a stage to assemble the cell. So, what you have done? You have done something like this an electrode which is coated and then you have slit it, then you have roll pressed it so, that the tap density is increased.

And then also you have connected a small tab because you will have to connect it with the casing, the battery casing right positive and negative and that eventually you will have to mark. So, a small tab is there and that tab is basically connected with this with the can. So, that you will have to do.

And this is the machine that is winding machine, a semi automatic one where you can see the separator is connected here and the electrode is put from this side and it will just wind. It will just wind like this and then it will form something like this. You can see this tab is connected here, this tab is connected here ultimately it is coming out and one tab is here and another tab is here. So, accordingly you will have to wind it and this is called the jelly roll.

So, this jelly roll you can insert into this can right and then eventually you will have to tap weld this to the bottom side and the top one is to the top side. So, the process of the remaining part which we call assemble is winding, then jelly roll press and insert, then tap welding then can cap welding. So, on top of that this can cap is also there then we will have to do electrolyte injection and then there is something called ball welding here and finally, the bottom plate welding.

So, the description is given there I am not going line by line you will have to see this video and the process the individual process whatever I explained that is all written there. So, go through it and along with the video you will be able to understand the operation of this winding process which is very important.

You remember that the diameter of the jelly roll should be exactly fitted into the can. So, otherwise if the rolling diameter is more, then it will not be going inside the can and if it is less, then the battery if you shake it will have some kind of sound and you will not like it.

(Refer Slide Time: 17:33)

Cell manufacturing process
2. - 4 Jelly roll insertion/anode tab welding/beading process

- The jelly roll insertion process inserts the jelly roll in the can.
- The anode tab welding process bends the anode tab for welding to the floor of the can.
- Beading (grooving) process creates a bent groove for the gasket to reach the top of the can containing the jelly roll.
- See the cited video link to get clear idea about these processes.

<https://youtu.be/TL0dJlqx98>
Tab spot welding machine

<https://youtu.be/cKMacC4HNBI>
Grooving machine

So, after the jelly roll you have inserted there is a process called tab welding or this is sometimes called beading process also. So, what is done here that the jelly roll is inserted in the can, then the anode part the tab it is coming from the anode that welding process bends the anode tab for the welding to the floor of the can. So, usually the positive is the top part and negative is the bottom part.

So, this tab which is connected is slightly bent and then it goes to the floor of the can, then beading or sometimes we call it grooving process that is done by this machine again you see the this thing this link. So, in a cylindrical can on the top surface you have put the jelly roll inside it. So, if you just reverse it, the jelly roll will come out. So, in order to avoid it you have a grooving. So, you slightly reduce the diameter at the neck.


So, the jelly roll is stick there and inside there is a gap. So, through this gap you can weld it through the bottom can and also the top can in a subsequent process. So, you will have to see the video as I said step by step so, that you can understand the actual process. It is difficult to explain it unless if I can show it; it is much better, but at least in the video we will get some idea out of it.

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Cell manufacturing process


5. Electrolyte injection process

During electrolyte injection, the internal pressure after injecting the electrolyte should be kept lower than atmospheric pressure and the electrolyte is allowed to be impregnated into the jelly roll by introducing air into the can. After electrolyte injection, electrolyte surrounding the cathode tab and the grooving area is wiped with a cleaning nonwoven. The gasket is inserted to complete the process.



<https://youtu.be/g2yf5EVxAiA>

The shown equipment works both for pouch and cylindrical cell. The accompanied video shows the filling in pouch cell. Adopting the same procedure one can fill electrolyte in the cylindrical cell as well.



10

Then we will go for the electrolyte injection process because we will have to fill electrolyte inside. So, this machine is used again the operation is there in this link. So, electrolyte injection, the internal pressure after injecting the electrolyte should be kept lower than the atmospheric pressure. So, the electrolyte will be sucked in and this will be properly waiting the electrode material separator inside the can.

After the electrolyte injection, electrolytes surround the cathode tab and the groove area is wiped off that is very important because electrolyte can corrode because outside is in air ambient, after vacuum if it spills off and you will be using this battery. So, it can rust the stainless steel shell. So, it is very important to properly wash the electrolyte that is coming out of the system and a specified amount of electrolyte that is put inside the groove.

This type of equipment that actually works both in case of pouch cell and cylindrical cell because this is just used to put the electrolyte inside the can or inside the pouch.

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Cell manufacturing process

6. Cathode tab welding/crimping and washing process

The cathode tab welding process includes welding of the cathode tab. The crimping process applies pressure to the top part of the battery. X ray inspection examines the internal electrode arrangement after assembly and checks for any defects. The washing process is to remove electrolyte and other impurities from the battery surface. The battery is then dried to eliminate moisture. Finally the battery is imprinted with the manufacturing factory, line number, and date before entering to the formation process.

<https://youtu.be/TvEhbeob2n8>
The cylindrical cell manufacturing process can be found here. Shown equipment might have different model number. Hence the process may look a bit different than that has been individually described.

<https://youtu.be/ligoP9Ob8iU>



So, no separate equipment is required for doing this. Then we are in a process to do the cathode tab welding and then crimping and followed by the washing process. So, the cathode tab welding process includes the welding of the cathode tab and the crimping process that applies pressure to the top part of the battery. Then they are inspected by the X ray inspection that basically examines the internal electrode arrangement after assembly and checks for any kind of defect that may have.

The washing process is followed by that it is to remove the electrolyte and other impurities from the battery surface.

The battery is then dried to eliminate any kind of moisture in it and finally, the battery is imprinted you need to have the name of the manufacturer the batch number and what kind of voltage. For example, here the capacity we will get 2600 milliampere hour, the voltage is 3.7 volt nominal, you can charge it up to 4.2 volt, this is the batch number and it is 18650 kind of cell and finally, a plastic sleeve is there.

You see that this plastic sleeve is printed and then there is a separate machine I did not include it here so, that this stainless steel can the whole assembly you can put there in. So, this kind of cell you can see in Amazon if you give the search 18650 lithium ion battery cell in Amazon you will see that this is available a different source you will get this kind of battery. So, they are manufactured in this way.

Now, this cylindrical cell manufacturing process separately I will ask you to go through this video to know the function of each individual equipment be that crimping tool, tab welding and grooving machine, electrolyte filling machine, coating machine, winding machine and this is the link for the video where the cylindrical cell manufacturing process can be found and this shown equipment here in this video, that may not be exactly identical what you see here individual one may be some other model has been used.

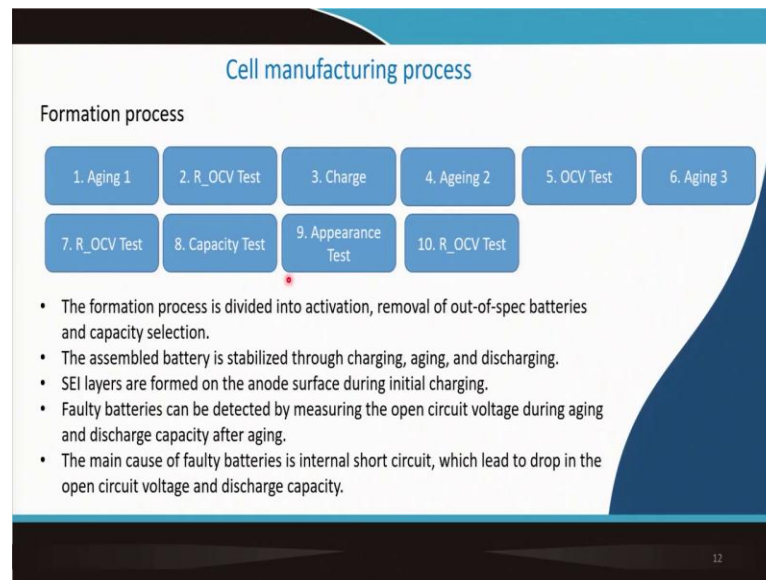
So, do not get confused about it that I do not see that this particular model, but its function wise it is operating this is having the same function. So, it may have a different model, the process may look little bit different, but you will get a vivid idea that how the cell is manufactured in the prototype condition.

In the same site the website which I will be giving you will find that the roll to roll process machinery is also there. So, spend some time to look through those videos, look through those machineries which is not the laboratory based prototype, but it is for a mass manufacturing. So, you will get a reasonable good idea.

So, there are few companies, MTI is one of them Gelon g e l o n that is another one Hussain a Japanese company one of the oldest one that is one and there is one Korean company called Semyung.

So, these are the companies who do this type of equipment and roll to roll process, they will come and install the whole battery manufacturing unit if you wish to very very expensive they charge lot of us and we need that our country should have this kind of manufacturing process. So, that in future we are really honor this Make in India initiative.

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So, after you do the forming process, then you need to sorry after you do the assembly process then you have a formation process and this formation process you remember that we do because the testing of the battery this is divided into activation, removal of out of spec batteries and capacity selection.

So, you will have to see that based on your calculation of irreversible capacity, length of the anode and length of the cathode whether you have really getting the capacity. So, this is the steps that are involved you see that 10 steps are involved.

Aging, then open circuit voltage test, then you have to charge it and then again you will have to age it, then again you do the OCV test, then again you age it, then again you test the OCV, then you test the capacity, then appearance of the battery whether it is swollen or something has happened that you will have to test. So, there are 8 to 10 processes that will be this formation process.

Then the assembled battery is stabilized through charging, aging and discharging. Then SEI layers are formed on the anode surface during initial charging as you know, the faulty batteries can be detected by measuring the open circuit voltage. So, open circuit voltage usually is in the range of 2.5 to 3 volt. So, if it is bad, then you can throw it out and the main cause of faulty batteries is internal short circuit, the tab that you are putting it with the can.

So, if there that is malfunctioning your equipment is malfunctioned then anode and cathode will be short circuited, the copper and aluminum they are in close proximity not like the bigger photograph what I have shown that this is anode, this is cathode, this is separator they are all now in the form of a jelly roll.

There is every possibility if your separator is little bit away and your cathode is touching anode part, then it is gone this is internal short circuit. So, this kind of precautionary measure you will have to take.

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So, this is in a very short I tried to explain the cylindrical cell manufacturing process and you are supposed to see this website for cylindrical cell preparation and that this is part of your study material and along with that I named couple of companies like Hussain, like Gelon, Semyung. So, you can go to their site as well to check the equivalent things equivalent equipment.

And in this book there is a good description of cylindrical cell preparation by Park, this book also you can consider and this is a very good handbook I am telling several times for lithium ion pack battery pack design very easy to read book and you will get a vivid idea how to make it.

There is another book which is a do it yourself type for the battery that is still better that is for the novice who does not know anything about it, they also can prepare the cell,

actually they are purchasing the cell and making the battery module for different purpose. So, I will introduce that book as well in the future classes.

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CONCLUSION

- Cylindrical cell manufacturing process (Watch the cited videos for better understanding)
 - Electrode manufacturing process
 - Preparation of electrode slurry
 - Electrode coating
 - Roll pressing process
 - Slitting process
 - Vacuum drying process
 - Assembly process : Winding
 - Jelly roll insertion/cathode tab welding/beading process
 - Electrolyte injection process
 - Cathode tab welding/crimping/X ray inspection/washing
 - Forming process

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14

So, in this particular lecture we talked about cylindrical cell manufacturing process and I will tell you to go through this videos and it consists of electrode manufacturing process which contains preparation of electrode slurry, electrode coating, then roll processing process, roll pressing process, then slitting process then finally, vacuum drying process.

Then after that, there is a assembly process which includes winding, then jelly roll is inserted inside, then electrolyte is injected, then cathode tab welding takes place, crimping takes place to make the battery. So, during crimping, it is hermetically sealed and finally, there is a forming process to check the individual battery using a multi-channel battery analyzer.

And thank you for your interest.