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Skin burns and safety events for wearable electronics batteries

Introduction

One of the key technical challenges for consumer acceptance of wearable electronics such as the Apple Watch, Samsung Gear S, and Google Glass is single charge battery life [1]. Much like modern jets use their wings as space-saving fuel tanks, one widely explored way of extending the battery life of smart watches is to insert a battery or batteries as an integral part of the band [2,3]; two such designs are highlighted in figure 1. Given the checkered safety history of Li-ion batteries, the use of Li-ion batteries in direct contact with human skin raises potential safety concerns, namely the potential for 2nd and 3rd degree burns upon battery or device (e.g. smart watch) malfunction. In this case study, using AutoLion™ software, we explore the potential for 2nd and 3rd degree burns upon the external and internal shorting of a wristwatch auxiliary battery.

Technology Used

- AutoLion-ST^{TM}

Setup

- A 1 Ah LCO/Graphite Li-ion cell integrated into a smart wristwatch band is simulated using AutoLion-ST™. This battery is 185mm long, 22mm in wide, 3mm thick, and is 20g in mass. Assuming a standard smartwatch battery of 400mAh, this battery, integrated seamlessly into the band, can extend the single charge life of the smartwatch 3.5x.
- Table 1 gives the widely published hot water burn chart [4]. This table has been formulated to give the time required at a given water temperature to cause 2nd and 3rd degree burns. In this case study we use this chart as a guide to battery temperature in the embedded smartwatch band that will cause 2nd and 3rd degree burns.
- In this case study, two scenarios of battery heating upon malfunction are investigated:
    - Shorting of the battery due to malfunction of the watch (not the battery itself). One very plausible scenario for this to occur is if the electronics of the watch are exposed to salt water, possibly due to a cracked watch casing if the owner swims in the ocean. Watch electronics malfunction can easily cause ***external shorting of the battery***.
    - Shorting of the battery internal to the battery itself. A wristband battery may be flexible in order to facilitate bending of the band. A flexible battery will undergo frequent flexing, which can lead to wear out of the battery separator causing a short inside of the battery. This is one of many likely scenarios of ***internal shorting*** of a wristwatch battery.
- We use a shorting resistance of 200 mΩ for all simulations herein.

Results

Table 1: Hot water exposure burn chart [4].

Temp (°C)	Temp (°F)	Time at Temp to Get 2nd Degree Burn (s)	Time at Temp to Get 3rd Degree Burn (s)
45	113	7200	10800
47	116.6	1200	2700
48	118.4	900	1200
49	120	480	600
51	124	120	252
55	131	17	30
60	140	3	5

Figure 1: Two example designs of smart watch wristband auxiliary batteris to extend single charge life of the smartwatch.

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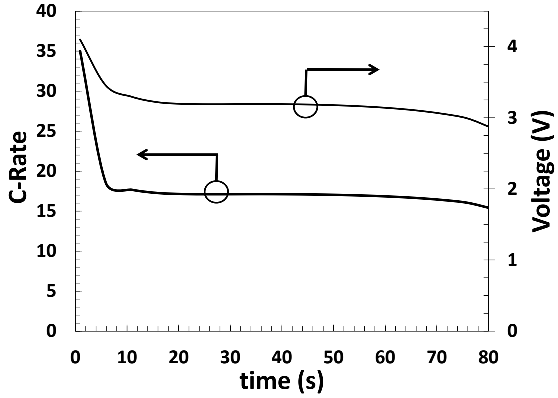

Figure 2: Battery C-rate and voltage during external shorting at 200 mΩ.

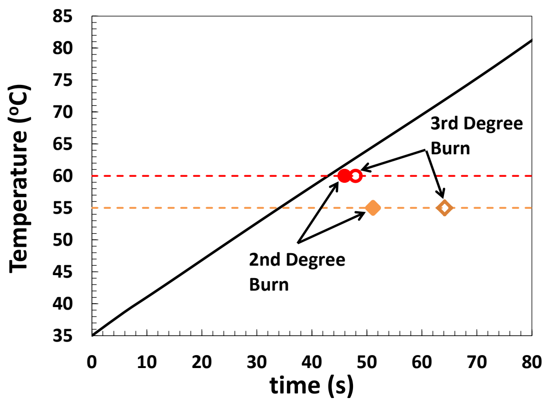

Figure 3: Average battery temperature during external shorting event, and approximate time to reach 2nd and 3rd degree burns.

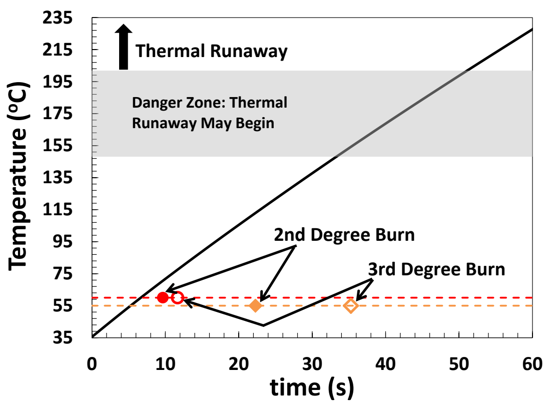

Figure 4: Average battery temperature during internal shorting event, and approximate time to reach 2nd and 3rd degree burns.

Analysis, Conclusions, and Benefits

- Figure 2 gives the battery C-rate and voltage upon 200mΩ external short. There is an initial in-rush current for 5-10s, caused by the short resistance. At t >~ 10s, the internal battery resistance begins to limit the current of the battery, leading to a C-rate of ~ 17 for the majority of the battery discharge during short. The "plateau" current is a direct function of the battery internal resistance and battery design, and directly controls the heating rate of the battery.
- Figure 3 gives the average battery temperature under external short. Using the table 1 as a guide, we also plot the time to reach 2nd and 3rd degree burns along the orange (55^{o}C) and red (60^{o}C) isotherms.
  - The battery takes approximately 34s to reach 55^{o}C. Given that it takes 17s to get a 2nd degree burn when the skin temp is held at 55^{o}C, if the battery temperature stopped rising when it reached 55^{o}C, a second degree burn would occur after 34 + 17 = 51s. This is highlighted by the solid orange diamond in figure 3. Similarly, if the battery stopped rising at 55^{o}C, it would take 34 + 30 = 64s to receive a 3rd degree burn (open orange diamond).
  - The battery takes approximately 43s to reach 60^{o}C. Given that it takes 3s to get a 2nd degree burn when the skin temp is held at 60^{o}C, if the battery temperature stopped rising when it reached 60^{o}C, a second degree burn would occur after 43 + 3 = 46s. This is highlighted by the solid red circle in figure 3. Similarly, if the battery stopped rising at 60^{o}C, it would take 43 + 5 = 48s to receive a 3rd degree burn (open red circle).
  - Given that temperature the real cell undergoing shorting rises continuously, we can conclude from the above that ***for an external short, a second degree burn will occur in ~ 40s, and a 3rd degree burn will occur in ~ 45s***. This time scale is of particular concern, e.g. if somebody is sleeping and does not sense the watchband heating up.
- Figure 4 gives the average battery temperature for internal short due to repeated flexing of the battery. Again, using the times to reach 2nd and 3rd degree burns from table 1, the orange and red lines and symbol are plotted. Using the same logic as described for figure 3, we gather ***that for***

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an internal short a 2^nd^ degree burn will occur in ~10s and a 3^rd^ degree burn in ~ 12s. ***By the time the owner of the watch senses the band heating up, it is likely that 2^nd^ or 3^rd^ degree burning of the skin will have occured.***

- Skin burn is not the only concern for internal shorting of the battery. As highlighted in figure 4, when the battery reaches ~150^{o}C, it reaches the danger zone for thermal runaway; thermal runaway will definitely occur when 200^{o}C is reached. Therefore, in only ~ 35-50s, thermal runaway of the battery may occur, causing a substantial safety event, as the battery is likely to explode.
- We should note that an internal short often has a localized hot spot at the location of the short, and therefore the average battery temperature plotted in figure 4 is most likely a conservative estimate as to both time to skin burn and time to thermal runaway. More rigorous assessment using AutoLion-3D™ is warranted, and can give a more accurate prediction of the time to reach burn and battery safety conditions.

- A Li-ion battery in direct proximity to the skin, e.g. as an integrated component of a smart wristwatch band, poses great safety concerns upon battery or device malfunction. Battery design software, such as AutoLion™ can be used to assess the safety risk and optimize the battery design for safety.

References

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