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Influence of Case Materials on Smartphone Temperatures in Multitasking Operation Modes

Chibuzor Ndubisi[1], Howard O. Njoku[2]

[1,2]Sustainable Energy Engineering Research Group, Department of Mechanical Engineering, University of Nigeria, Nsukka 410001, Nigeria, chibuzor.ndubisi.197845@unn.edu.ng[1]

[2]Department of Mechanical Engineering Science, FEBE, University of Johannesburg, Johannesburg 2006, South Africa, howard.njoku@unn.edu.ng

Abstract—**The capacity of smartphones to execute demanding tasks has improved with advancements in electronic technology, and their user experience has increasingly been shaped by the development of new materials and designs. Moreover, as smartphone prowess and adoption increases, users are more likely to protect their devices from damage using smartphone cases. But smartphones still face the challenge of optimal thermal management. To provide more insight into the problem, then, this work examines the effects of various case materials on smartphones performing multiple tasks simultaneously. The experiments were conducted on two identical smartphones, with one encased (test phone) and the other not encased (control phone). Three sets of tasks—single task set, double task set, and triple task set—were run in order to investigate the impact of the number of tasks on smartphone temperature. The case materials utilized for the study were carbon fiber, silicone, and plastic. The phones' surface temperatures were obtained using an infrared camera, and their battery and processor temperatures were retrieved through their inbuilt thermal sensors. The experiments revealed a significant difference between the use of smartphones with and without cases, and the differences in thermal profiles based on the smartphone case material. The test phones recorded higher temperatures than the control phones, and the plastic case was found to cause the highest smartphone internal temperatures of all three cases. Also, the results indicated a positive correlation between the increase in phone temperatures and the number of tasks being run at the same time.**

Keywords – casings, materials, multitasking, smartphone, temperature.

I. Introduction

Today, smartphones are more versatile than ever before in history. They have become a significant dimension of human life and a mark of 21st century existence. Among other things, the increased attention to the smartphone industry has resulted in rapid innovations in smartphone technology—including and especially in the areas of processing power, materials engineering, and software. Simultaneously, smartphones have become more compact and portable, and they have enjoyed enhancements in design for optimum user experience.

However, these improvements have been sustained at the cost of other smartphone engineering considerations, resulting in challenges that must be addressed. Among these considerations is the issue of heat generation and transfer in smartphones. This thermal challenge has two major negative effects: first, smartphone internal components deteriorate as they experience repeated fluctuations in temperature; second, the high temperatures diminish the user comfort. Reference [1] notes that heat generation and dissipation are the cause of a significant fraction of smartphone failures.

As smartphone thermal management becomes a major subject of scientific inquiry, it must also be noted that phones generate heat, in the first place, due to the tasks run by their users. Because smartphones are now able to run

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multiple applications at once, and because different applications impact phone processors at different levels, it is necessary to provide research results on this area of heat generation that is user-based. In addition, as smartphone cases have become a notable accessory, and since these cases are produced with materials of varying thermal properties, their influence on smartphone thermal behavior is also worth investigating.

This work thus aims to evaluate the impact of certain case materials on smartphone temperatures while running more than one task simultaneously. The work entails an analysis of smartphone surface temperatures based on infrared thermal images, a comparison of the processor and battery temperatures of encased and non-encased smartphones, and a comparison of the effects of smartphone case materials on the internal temperatures of encased smartphones.

II. Thermal Behaviour in Mobile Phones

A. *Smartphone Heat Generation and Transfer*

Within a conventional mobile phone, the major sources of heat are the electronic chips mounted on the printed circuit boards—including transistors, integrated circuits, and resistors—and the phone's battery [2]. Each of these internal components possesses its own thermal conductivity, electrical resistivity, and specific heat capacity among other properties. The electric current flowing through the components when a smartphone is in use is met with resistance, which results in the most basic form of smartphone heat generation as given by (1):

$$P = I^2 R \ , \tag{1}$$

where P is the heat generated, I is the electric current, and R is the resistance to the flow of current. As (2) shows, this generated heat is proportional to the temperature increase in the components:

$$P = mc\Delta t \ , \tag{2}$$

where m is the mass of the component, c is the specific heat capacity, and Δt is the magnitude of temperature increase.

Furthermore, the battery emits its own heat as it discharges during use. Reference [3] carried out experiments on lithium-ion batteries and found that they generate heat due to battery resistance—known as "ohmic heat"—and due to entropy change. Mathematically, this heat generation is represented in (3):

$$P_{bat} = P_{bat,r} + P_{bat,s} = \\ = I_{bat}(t)^2 \cdot r_{int} - T_{bat} I_{bat}(t) \frac{\partial V^{OC}}{\partial T} \ , \tag{3}$$

where $P\text{-}_{bat}$ is the heat generated by the battery, $P_{bat,r}$ is the ohmic heat, $P_{bat,s}$ is the heat due to entropy change, $I_{bat}(t)$ is the battery discharge current at time t, r_{int} is the internal resistance of the battery, T_{bat} is battery temperature at t, and V^{OC} is the battery open-circuit voltage. The temperature increase due to this heat generation makes it more difficult to maintain a safe operational temperature range for the smartphone internal components, causing them to deteriorate faster. Also, the heat generated might increase the smartphone surface temperature above the healthy threshold of 45°C [4], reducing user comfort in the process, and exposing the user to harmful infrared radiation [5].

In considering the mode of heat transfer from the internal components out of the phone, [2] developed a model based on the electrical analogy of heat transfer. This model specifies a bidirectional pattern of heat transfer, one through the back cover of the smartphone to the surroundings, and another through the smartphone display. Heat travels by conduction within the smartphone and by natural convection from the smartphone surface to the surroundings.

B. *Smartphone Thermal Management and Multitasking*

Numerous attempts have been made to deepen the understanding of and improve smartphone thermal management. With a focus on determining the relationship between device sizes and heat dissipation, [6] developed a parametric model for heat transfer in handheld electronic devices and applied finite element analysis in understanding heat transfer by conduction, convection, and radiation. Reference [7] analyzed the energy usage and power consumption in a smartphone and developed a model to estimate the battery life span for varying usage patterns. In addition, [8] performed a detailed thermal analysis for smartphone and tablet systems.

In an attempt to improve heat transfer, [9] integrated a cooling fan into a mobile phone and reported a 60% increase in heat dissipation at a fixed surface temperature. Despite this success, the use of active fans has not been adopted for smartphones, as it would eliminate the advantage of portability. Also, [10] experimented with phase change materials—materials that change phase at constant temperature while absorbing heat—and noted that they would be highly instrumental in thermal management by creating a delay in temperature rise.

A discussion on thermal management would be incomplete without pointing to the effects of multitasking on smartphone performance. When apps are run on a smartphone, more space is occupied in the phone's Random-Access Memory (RAM). This increases the heat generation, as the phone's internal components struggle to maintain high performance. It should be noted that this effect is dependent on the demands of the application itself; for instance, large online games that utilize the phone's Graphic Processing Unit (GPU) in addition to other components would cause more heat generation than a calculator app.

III. Methodology

As shown in Fig. 1, the experiments were conducted in a wooden test chamber, having a glass door and laced internally with aluminum foil to prevent thermal interaction with the surroundings. Placed in the chamber were two identical smartphones, with one encased (test phone) and the other not encased (control phone). An infrared thermal imaging camera was placed at a distance from the smartphones and captured the images through a peephole.

Figure 1. Experimental setup.

Three smartphone cases of different materials—carbon fiber, silicone, and plastic—were used in the experiments. To investigate the effect of the number of running tasks on smartphone temperature, the study involved three sets of tasks: the single task set, the double task set, and the triple task set. Each test was run for 30 minutes, and the infrared camera was utilized in capturing thermal images at the start and end of each test. Also, by connecting with their inbuilt thermal sensors, the CPU Monitor application was used to record the phones' battery and processor temperature variations. To improve the accuracy of the study, the phones' batteries were charged before the experiments and all other background tasks were disabled.

The apps to be run were determined through a survey on the most frequently used apps by people in the local community, and the possibility of using these apps at the same time. The experiments were thus based on the following tasks: the single task set involved **offline music playing** (Muzio Player); the double task set involved **social media** (Instagram) and **video calls** (Google Duo); and the triple task set involved **social media** (Instagram), **internet browsing** (Google Chrome), and **video streaming** (YouTube).

IV. Results and Discussions

A. *Smartphone Infrared Thermal Images*

The thermograms obtained from the tests are shown in Figs. 2-10. Figs. 2-4 illustrate the smartphone surface thermal profiles for the single task set while switching between the case materials. Figs. 5-7 show the same for the double task set, and Figs 8-10 are the images obtained during the triple task sets.

In each thermal image, the test phone is seen on the left and the control phone on the right. Heat is represented by a spectrum of colors from black to white, with black being the coolest and white the hottest. The thermal images indicate a slight increase in surface temperature after each experiment, with the major heat zones located at the top and bottom of the smartphone. These focal areas of heat generation indicate the

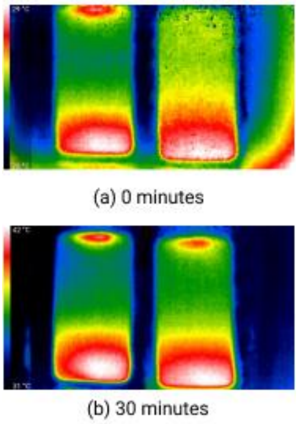

Figure 2. Single task set – thermograms with silicone case.

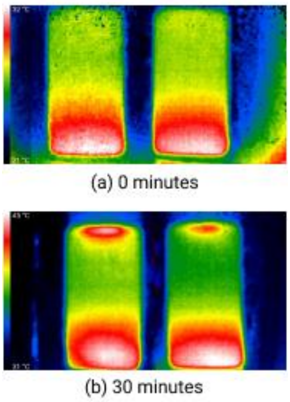

Figure 3. Single task set – thermograms with plastic case.

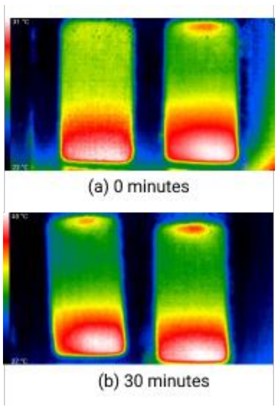

Figure 4. Single task set – thermograms with carbon fiber -case.

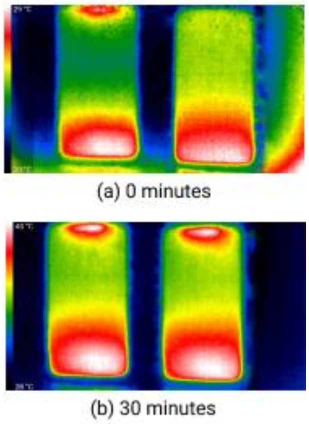

Figure 5. Double task set – thermograms with plastic case.

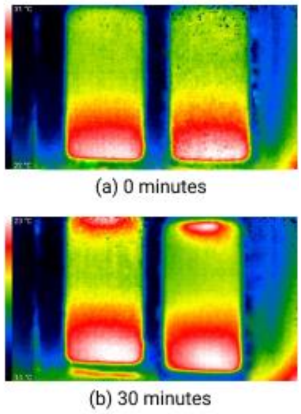

Figure 6. Double task set – thermograms with silicone case.

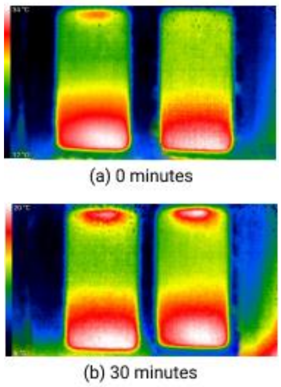

Figure 7. Double task set – thermograms with silicone case.

location of the internal components responsible for generating the most heat.

B. *Smartphone Internal Temperatures*

Figs 11-13 plot the temperature variations in the batteries and processors of the test and control phones for each set of tasks. In all cases, the test processor recorded the highest temperatures, and the plastic case resulted in the peak test processor temperatures. For the single task set (Fig. 11), the test processor reached a maximum of 38°C in 12 minutes of running the task, after which it fluctuated between 37°C and 38°C. In the double task set (Fig. 12), a maximum temperature of 41°C was recorded from the test processor, and the test phone

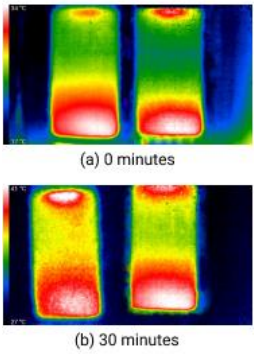

Figure 8. Triple task set – thermograms with plastic case.

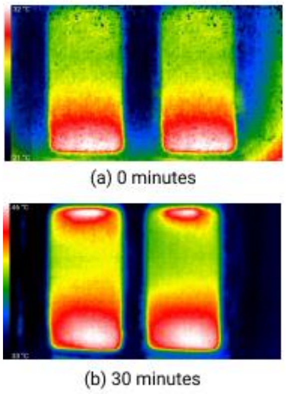

Figure 9. Triple task set – thermograms with silicone case.

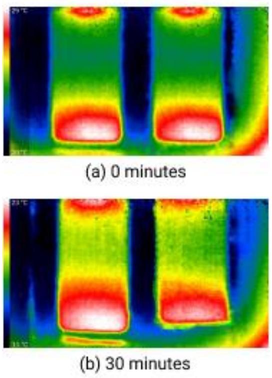

Figure 10. Triple task set – thermograms with carbon fiber case.

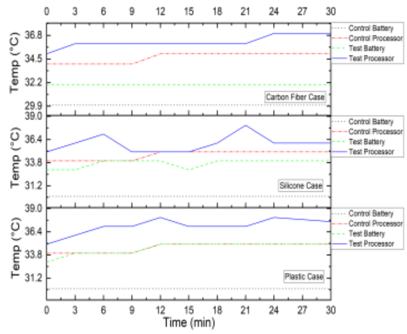

Figure 11. Single task set – internal temperature variations.

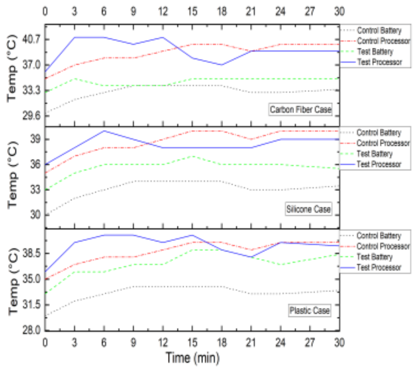

Figure 12. Double task set – internal temperature variations.

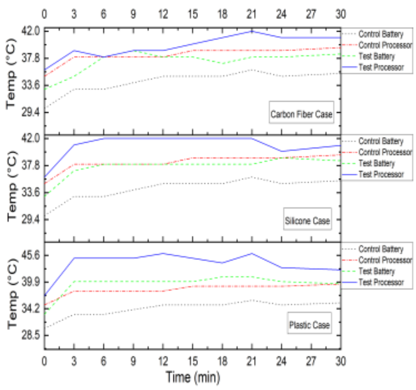

Figure 13. Triple task set – internal temperature variations.

reached this temperature while using both the plastic and carbon fiber case. In the triple task set (Fig. 13), the test processor reached the peak temperature of 46°C while encased in a plastic case; both the carbon fiber and silicone cases gave a maximum temperature of 42°C.

The graphs of temperature variation also point to the significant differences in temperature between the encased and non-encased phones. In the single task set of experiments, the control battery remained at 30°C while the test battery increased to 34°C with the silicone case and 35°C with the plastic case. In the double task set, the control battery reached a maximum temperature of 34°C, while the test battery increased to 35°C for the carbon fiber case, 37°C for the silicone case, and 40°C for the plastic case. And in the triple task set, the control battery recorded a maximum temperature of 36°C while the test battery reached 39°C for the carbon fiber and silicone cases, and 41°C for the plastic case.

V. Conclusion

This study has analyzed the influence of case materials on smartphones performing multiple tasks. It obtained the smartphones' thermal images, identified their major heat zones, and monitored their battery and processor temperatures, while observing the differences in thermal behavior between the test and control phones. The study confirmed the positive relationship between the increase in smartphone temperature and the number of tasks being executed. It also revealed that though the battery and processor both increase in temperature and generate heat in the process, the processor reaches higher temperature levels than the battery and thus generates more heat. In comparing the impact of case materials, it was found that the plastic case caused the highest recorded temperatures—a pointer to the fact that due to its nature as a good thermal insulator, the plastic case inhibits the transfer of heat out of the phone.

It can be inferred from this work that the three focal points of improving smartphone thermal management are materials, design, and usage. Hence, future research should focus on optimizing these areas. Researchers could experiment with new materials for building smartphone components and cases that allow for optimum heat transfer while ensuring smartphone protection. New and improved smartphone internal and external designs should be suggested and studied, so as to strike the right balance between prevention of component damage and a great user experience. And smartphone users could be aided with research-based tips and updates on using their smartphones, to ensure durability and longevity. With all these in place, the landscape of smartphone-user interaction will continue to improve into the future.

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