Evaluation of IoT Applications for UV Curing Temperature Variation of Gel Nails

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Abstract

When gel nails are UV cured, the reaction heat results in a rise in nail temperature, which causes the user to feel pain. In this study, four layers of single-color gel nails were used to measure and analyze the temperature rise of each layer of gel resin during UV curing. The measurement results show that the temperature variations of the base gel and color gel layers were 1.55°C and 1.56°C, respectively, and the temperatures of the builder and sealer rose higher, with an average of 3.96°C and 3.54°C, respectively. The results show that the temperature rise was related to the thickness of the resin applied by the nail technician and varied from time to time, which could be solved by using Internet of Things (IoT) technology. Using a microprocessor and PC to analyze the temperature rise curve in the cloud is conducive to finding how the resin is cured in real-time and adjusting the intensity and duration of the UV light accordingly to keep the temperature variation within the threshold.

Keywords: Gel nails, UV curing, Temperature, IoT

1 Introduction

People have long been concerned with beauty and have invested a lot of time and money in it. The beauty industry is one of the key sectors of the global economy, with the production value reaching hundreds of billions of dollars a year and continuing to grow. The beauty industry covers a wide range of related sectors, including cosmetics, beauty care, hairdressing, make-up, and body care. As the industry has grown, it has gradually become specialized to meet the needs of more customers. Traditionally, the beauty industry required professionals to provide service to customers, mainly in the areas of hairdressing, nail art, eyelash extensions, spas, skincare, and body care. In recent years, the market for hairdressing, eyelash extensions, and body care has reached saturation; however, the market for nail art has continued to expand year after year, gradually becoming a new and booming industry.

In recent years, nail art has become a craze and traditional beauty treatments are no longer enough to satisfy the demand for beauty. As a new trend, nail art has a great development potential ranging from minimalist to creative styles. Nail art can be customized to create unique styles that match people's outfits, making it very popular with women of all ages. Generally, there are three types of nail art, namely, nail polish, crystal nails, and gel nails. Normal nail polish, which can be applied by the user at home, is quick, convenient, and easy to use; however, its disadvantage is that it contains chemical solvents that can be harmful to the human body over time [1-5]. Crystal nails are also a popular nail art style that has a wider range of styles and designs. However, crystal nails are made from acrylics and are not easy to maintain, as the finished product is prone to breakage due to impact. Crystal nails also require the use of organic solvents, which smell unpleasant. Gel nails, which use gel resin as the material, are a new style of nail art that has gained popularity in recent years [6-9]. Compared to crystal nails, gel resin is softer and more flexible, making it less likely to break and allowing it to be more extensively used. Gel nails can be divided into monochromatic gels, marble gels, floral and cartoon gels, material-added gels, and gradient gels according to their appearance. The differences between these gels are mainly dependent on the technique used by the beautician, the complexity of the pattern, and the materials used. Gel nails quickly have become mainstream in the nail industry due to their diversification of styles, which offers customers various patterns to choose from.

The main material of gel nails is gel resin, which needs to be cured by light (usually UV light). The curing reaction of the resin is exothermic, and the heat released during the curing process will heat up the gel nails [10-11]. If the intensity of the light is too strong, a large amount of heat will be released, causing customers to feel discomfort or pain. To solve this problem, devices have been developed to reduce or eliminate the pain and discomfort caused by heat. A common feature of these devices is the ability to reduce the UV intensity to slow down the cure rate of the resin, so as to reduce the amount of heat produced and lessen the discomfort of the customers. However, by slowing down the cure rate, the curing time is extended, which makes it take longer for nail technicians to complete their work and fails to conform to market demand. Therefore, it is important to understand the trend and degree of temperature variation in the nail caused by the reaction heat during the curing of gel nails.

This study explored the relationship between the reaction heat and the temperature variation of gel nails during the curing of different gel resin layers. Artificial nail tips and a temperature sensor were used to find the temperature

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threshold that would cause discomfort and pain in customers. The temperature variation curve was made by using Internet of Things (IoT) technology [12-15], and the temperature data were uploaded to the cloud using microprocessors and personal computers for individualized analysis. The analysis result could help to solve the temperature variation caused by differences in the thickness of the applied resin in real time. Based on the results of the calculations, the intensity and duration of the UV light were adjusted to maintain the temperature rise within an appropriate range.

2 Experimental Setup

In the experimental setup, the specification of the UV source affected the curing speed of the gel resin and the generation rate of the reaction heat. In order to be closer to the actual light curing environment used by nail technicians, this study employed a BQ-3T 36 W UV LED nail lamp, which is a portable light source commonly available on the market. This type of UV source is preferred by most nail technicians due to its portability and energy-saving features. Commercial portable nail machines only have a few fixed modes for lighting. Taking the BQ-3T UV LED light source as an example, the machine only has two modes to choose from (60 sec and 120 sec). In this study, a microprocessor (Arduino Uno) was used to control the time of the UV source in order to observe the curve of the temperature variation for different light times. For the temperature measurement, this study adopted a USB-TC01 temperature sensor with a K-type thermocouple (National Instruments). The experimental setup for the temperature measurement of gel nails is shown in Figure 1.

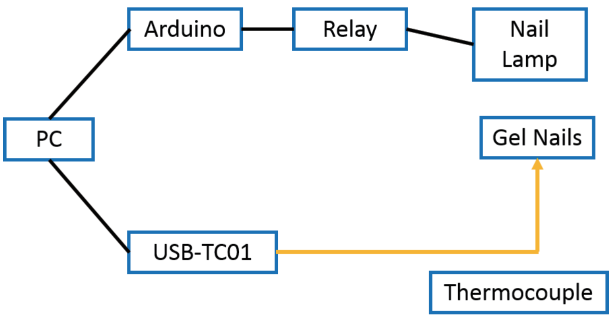


Figure 1. Experimental setup for the temperature measurement of gel nails (This setup uses a personal computer to control the timing of the nail lamp and measure the temperature.)

The experimental framework shown in Figure 1 could be divided into two main parts: UV lamp control and temperature acquisition. A personal computer was used to control the timing of the UV lamp and a temperature sensor was used for temperature acquisition at the same time. The data obtained by the microprocessor and temperature sensor were uploaded from the personal computer to the cloud for analysis. The temperature under a nail cannot be directly measured when gel resin is applied to the fingernail of a person. Therefore, this study employed nail tips made of acrylonitrile butadiene styrene (ABS) for the application of gel resin. The experimental setup showing the nail tips and the thermocouple installed on a base is shown in Figure 2.

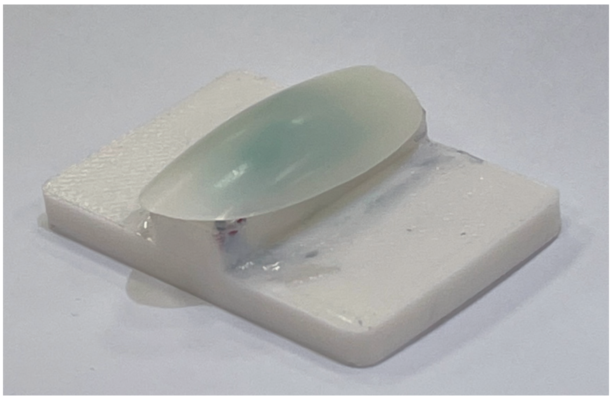
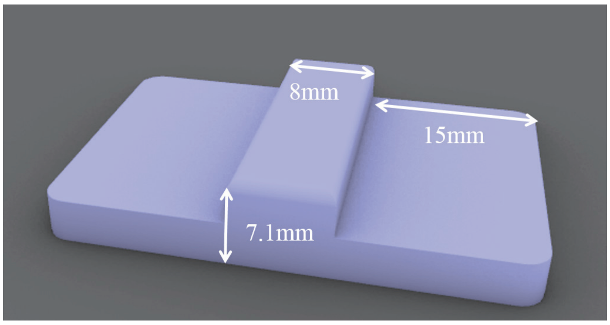


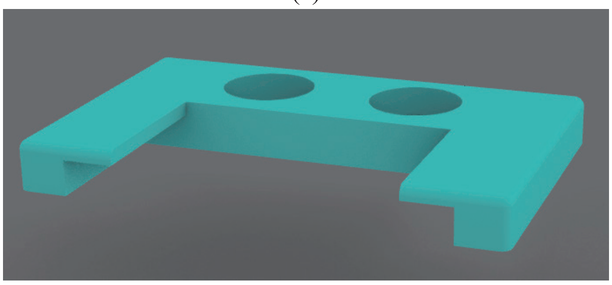
Figure 2. Experimental setup of the actual installation of the nail tips and thermocouple

As shown in Figure 2, the nail was installed on a nail base using clay, and a thermocouple was glued to the back of the nail to measure the change in temperature on the back of the nail. The design drawing of nail base is shown in Figure 3(a), the height of the middle protrusion is 7.1mm, and the width is 8mm. The left and right sides are symmetrical and the width is 15mm. The total height is about 1cm after the nail is installed, which is similar to the height of human fingers. The lower parts on both sides of the nail base can be fitted with the base for positioning purposes. Figure 3(b) shows the fixed component for nail base.

As shown in the actual finished product in Figure 2, the nail base and the fixed component are produced by a 3D printer (D-force v2, material: 1.75mm diameter PLA).



(a)



(b)

Figure 3. (a) Design drawing of nail base (The middle protrusion has a height of 7.1mm and a width of 8mm. The left and right sides are symmetrical and the width is 15mm. The parts on the left and right sides have a positioning function.) (b) The fixed component

In the experiment, in order to fix the relative position of the nail base and the nail lamp, we designed a set of positioning system on the experimental platform to keep the positions of both, as shown in Figure 4.

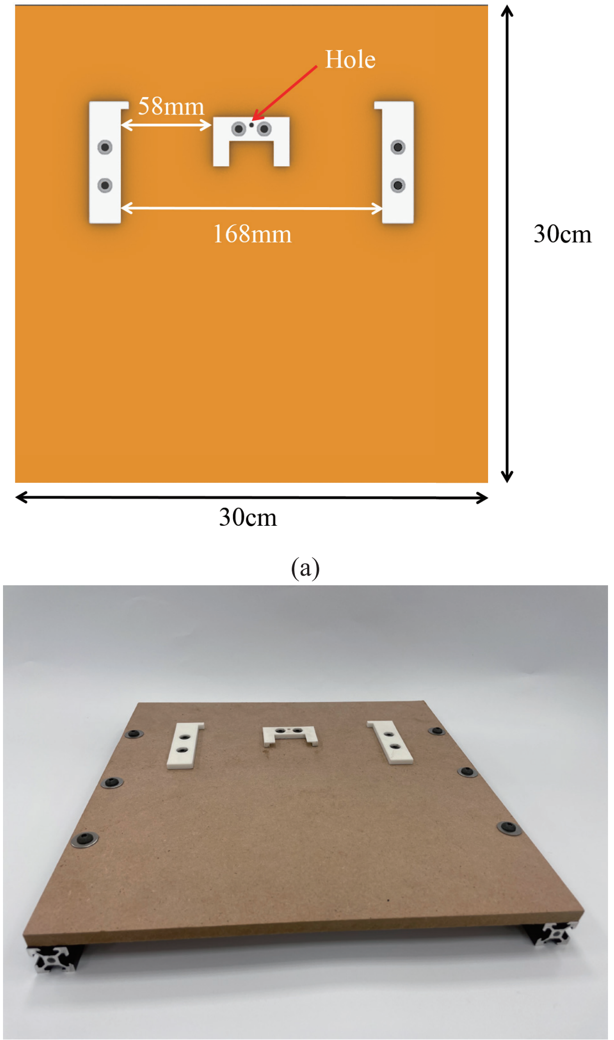


Figure 4. (a) Design drawing of the experimental platform, the size is 30cm*30cm (The platform surface is equipped with the nail base and the positioning point of the nail lamp.) (b) Actual installation drawing of the platform device

Figure 4(a) is the design of the experimental platform, the size is 30cm*30cm. The left and right sides of the platform are the positioning points of the nail lamp, and the middle is the fixture of the nail base. The distance between the nail base and the positioning point of the nail lamp is 58mm. There is a through hole in the middle of the nail base fixture, allowing the thermal couple and control line of nail lamp to pass through, and connect to the temperature measuring device and the computer respectively.

Figure 4(b) shows the actual installation structure of the experimental platform. The positioning bar of the nail lamp is also made with a 3D printer, and the material is PLA. The surface of the platform is made of plywood, and the bottom is supported by extruded aluminum strips.

During the actual measurement, the change in nail temperature was likely to be small. If measurements were made in an air-conditioned room, the effect of ambient airflow on the nail temperature could be significant. Therefore, a transparent acrylic cover was placed outside the overall measurement frame to reduce the ambient effect as shown in Figure 5.

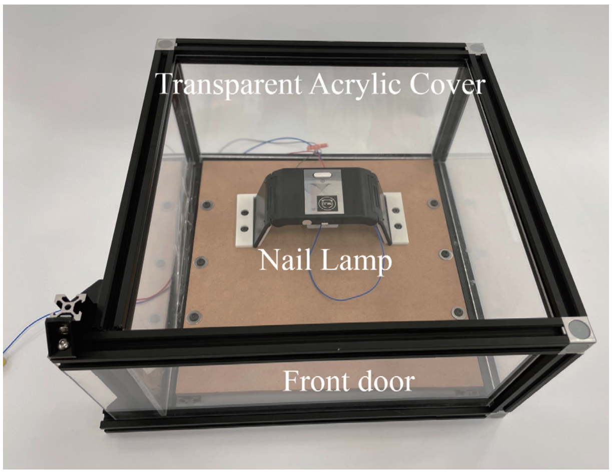


Figure 5. The entire experimental platform with transparent acrylic cover (There is a door in front of the transparent acrylic cover that can be opened laterally, which can reduce air disturbance and make the ambient temperature more stable.)

The transparent acrylic cover completely covers the entire experimental platform. The control line of nail lamp and thermal couple penetrate the bottom of the platform to reduce air disturbance. In front of the transparent acrylic cover, there is a door that can be opened laterally. This lateral open style can reduce the air disturbance caused by placing the experimental samples and make the ambient temperature more stable.

Under this framework, we proceed the ambient temperature stability test. In the experimental environment, we measure the temperature every 300ms for 15 minutes, and observe the temperature change. The results are shown in Figure 6.

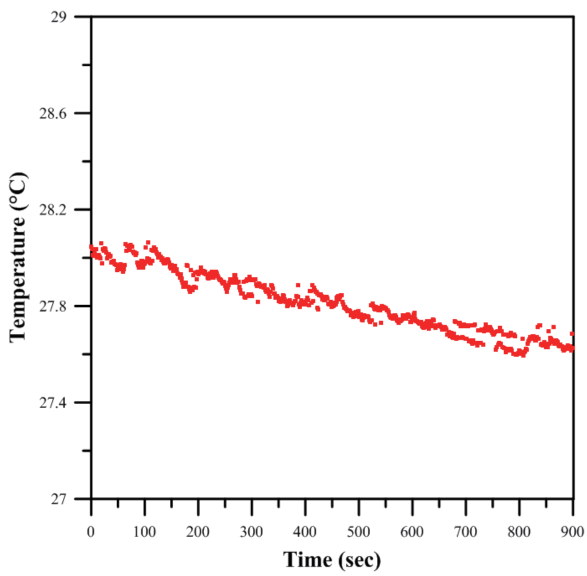


Figure 6. The ambient temperature variation measurement results (The overall temperature range is within 0.2°C.)

The trend of temperature dropped slowly from 28°C to about 27.6°C, mainly because the experimental environment was adjusted by the air condition and not at a constant temperature in certain area. For the overall variation of temperature, the variation is within 0.2°C that is much smaller than the temperature change amount of the gel resin during UV curing. The transparent acrylic cover can improve the reliability of subsequent temperature measurement.

The experimental setup is shown in Figure 7. There is nail lamp, thermocouple, nail and its base placed in the transparent acrylic cover, and the rest are placed outside.

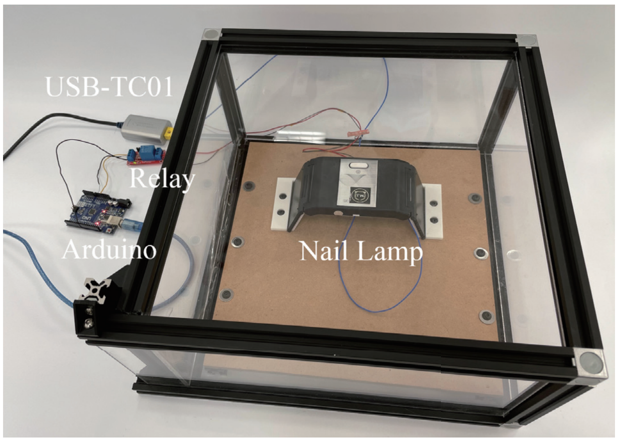


Figure 7. Overall experimental setup, including the temperature measurement and nail lamp control modules

3 Experimental Design

In the mainstream nail art market, the most popular nail styles are simple monochromatic nail designs. Most customers do not choose difficult or complex patterns due to price, and they prefer monochromatic gel nails with simple lines and curves. Therefore, in terms of the experimental design, monochromatic gel nails were selected to study the temperature variation of the nail tips. A basic monochromatic gel nail is made up of four layers, namely, the base layer, the builder, the color layer, and the sealer. In this study, the application of each layer of gel resin was carried out by an experienced professional nail technician to simulate the actual operation.

The illumination times for the four layers of gel resin used in the experiment were: (1) 30 seconds for the base layer (Acrylic (ester) copolymer, Polyacrylate cross-linked polymer-6, Sodium polyacrylate grafted lake, CI10316, CI77947); (2) 30 seconds for the color layer (acrylate copolymer, Cyclohexyl Methacrylate/Ethylhexyl Methacrylate Copolymer, Ethylnonyldimethyl PABA, CI 45430, CI 77266, PIGMENTW-HITE 21, CI 77120, CI 19140); (3) 60 seconds for the builder (Acrylic resin, photoinitiator); and (4) 60 seconds for the sealer (Acrylic acid (ester) copolymer, polyacrylate cross-linked polymer-6, sodium polyacrylate grafted lake, CI10316, CI77947). The illumination times for each layer were set according to the most common times for the commercial production of gel nails at present. Temperature tests were carried out on each layer. As the gel is applied manually by a professional nail technician, each layer was applied five times to prevent significant differences and minimize the effect on the results and analysis of the experiment. The relevant parameters are shown in Table 1.

Table 1. UV illumination time for different gel resins

Gel resin	Illumination time
Base	30 sce
Color	30 sec
Builder	60 sec
Sealer	60sec

4 Discussion

In the basic curing temperature test for the four layers of gel resin, the gel resin applied at the beginning was the base layer. The temperature rise curve of this layer from its own curing and due to the application of the other four layers is shown in Figure 8. The measurement result shows that the temperature rise curves of three groups were close to each other, while the other two groups tended to be higher or lower. The temperature variations may have been due to differences in the thickness of the gel resin applied by the nail technician. Of the five sets of curves, the maximum temperature rise was 2.30°C and the minimum was 0.76°C. The average of the three sets with similar trends was 1.56°C, and the average of all five sets was 1.55°C.

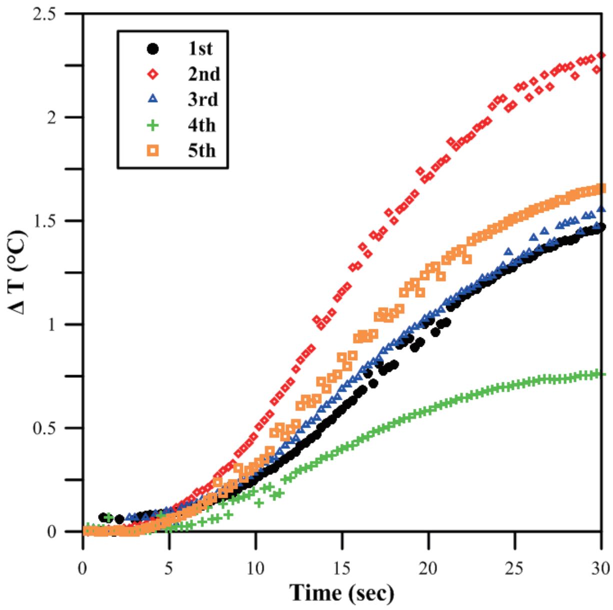


Figure 8. Temperature rise curve for the light curing of the base layer with an average rise in temperature of 1.55°C

Figure 9 is the statistical diagram of the maximum temperature rise of the five curves, and the median temperature change falls around 1.50°C. In the base layer, the temperature rise can reach a maximum of 2.30°C, which may cause finger discomfort. In commercial practice, this situation rarely occurs. According to the data, there is only a 20% probability that the temperature rise will exceed 2°C. This probability is expected to decrease with the increase in the number of groups. This is why base layer rarely cause discomfort to customers' fingers during optical curing.

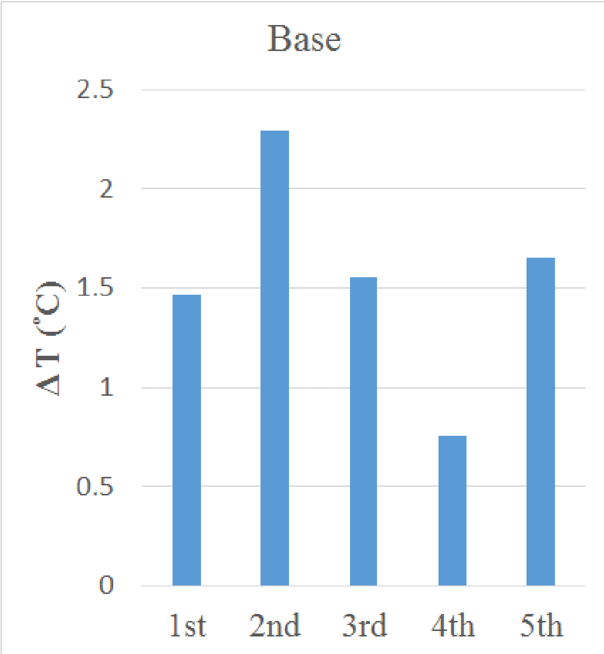


Figure 9. The statistical diagram of the maximum temperature rise of the five curves, and the median temperature change falls around 1.50°C

The temperature rise curve for the curing of the color layer is shown in Figure 10. The result indicates that similar to the base layer, the color layer also had a significant temperature difference due to the uneven gel thickness during application. The data showed a maximum temperature rise of 2.19°C and a minimum of 0.67°C. The average maximum temperature rise for the five sets of data was 1.56°C.

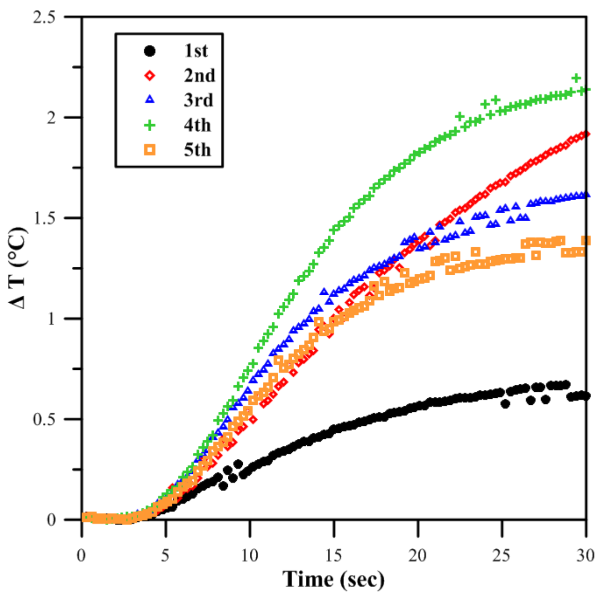


Figure 10. Temperature rise curve for the light curing of the color layer (With an average rise in temperature of 1.56°C.)

The difference in temperature rise of the color layer is larger than that of the base layer, and the temperature rise statistical diagram is shown in Figure 11. In the five tests, only one had a larger temperature deviation of 0.67°C only. The results show that the optical curing temperature change of the color layer is higher than that of the base layer.

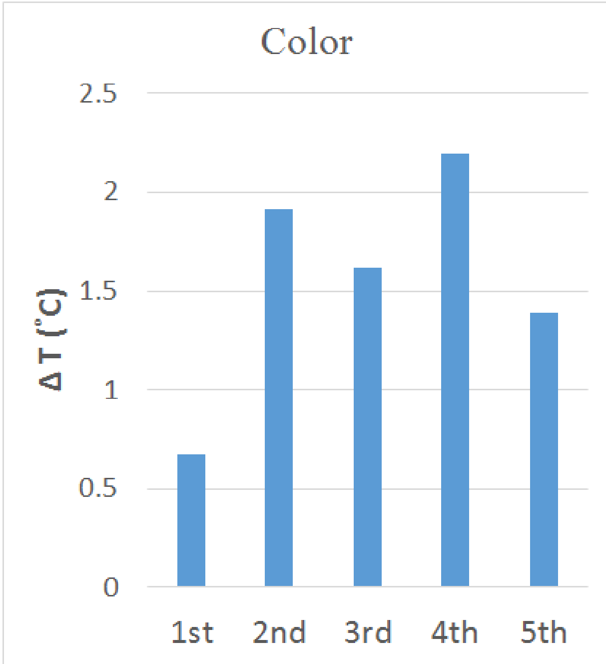


Figure 11. The statistical diagram of the maximum rise in temperature of color layer (In the data, only one set has a larger temperature deviation.)

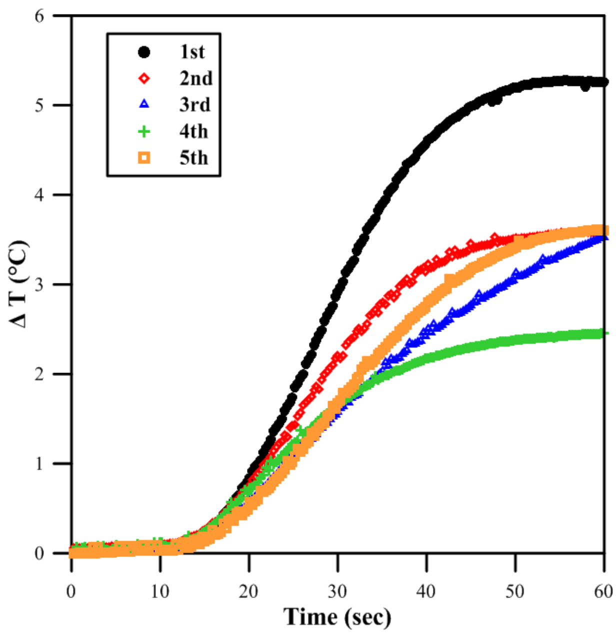


Figure 12. Temperature rise curve for the light curing of the builder layer, with an average rise in temperature of 3.96°C (The temperature rise for light curing of the builder is the highest of the four layers. The temperature curve also shows that 60 seconds of exposure to UV light was just enough to cure the resin.)

The curing time for the builder was longer than that for the previous two layers, with a UV illumination time of 60 seconds. The temperature rise curve for curing the color layer is shown in Figure 12. Similar to the results for the base layer, two of the five sets of tests showed a significant variation in temperature, with a maximum of 5.28°C and a minimum of 2.46°C. The average rise in temperature for all five sets of data was 3.96°C. When only the three sets of data with similar rise trends were averaged, the average became 3.57°C. The rise in temperature caused by the light curing of the builder was greater than 3.5°C, much higher than that of the base and color layers. Figure 6 also shows that the temperature curve tended to level off as the UV illumination time approached 60 seconds, and no more reaction heat was generated. The results show that the curing of the resin should have been completed near this time point.

According to the trends of curves in Figure 6, four sets have finished the reaction and only one set has not yet. The statistical diagram of the maximum rise in temperature of builder layer is shown in Figure 13. Of the five sets of data, only one had a temperature below 3.00°C, and the median temperature was around 3.50°C. The rising temperature of the builder layer is much higher than that of the base layer and the color layer, and the maximum value exceeds 5.00°C.

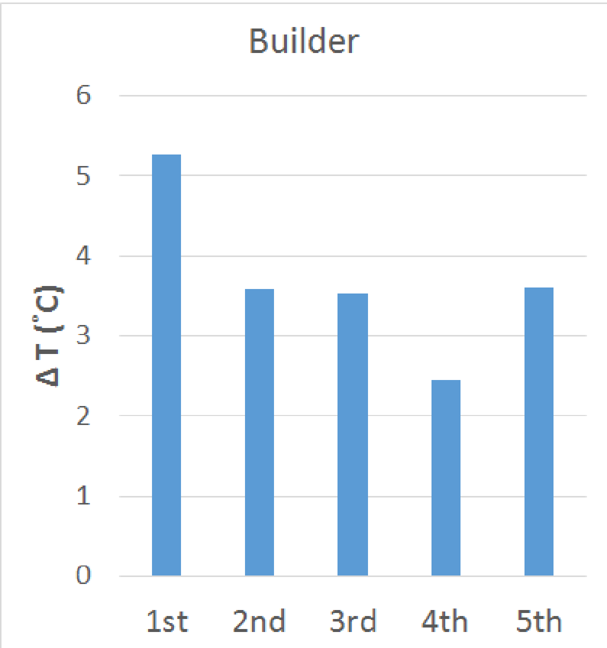


Figure 13. The statistical temperature rise diagram of builder layer (The overall temperature rise is above 3°C.)

The sealer was the outermost protective layer of the gel nail and was exposed to UV light for 60 seconds, similar to the builder. The temperature rise curve for the light curing of the sealer is shown in Figure 14. It could be seen that the maximum temperature rise in two groups was 4.87°C and 4.01°C, respectively, higher than that of the other three groups. The average temperature rise in the other three groups was 2.93°C, and that for all five groups was 3.54°C. The experimental results show that the temperature rise trend reached its maximum after approximately 20 seconds of exposure to light, after which the temperature trended downward. It was assumed that the reaction heat generated by light curing would not continue to increase after 20 seconds, and that the temperature of the nail surface would continue to decrease.

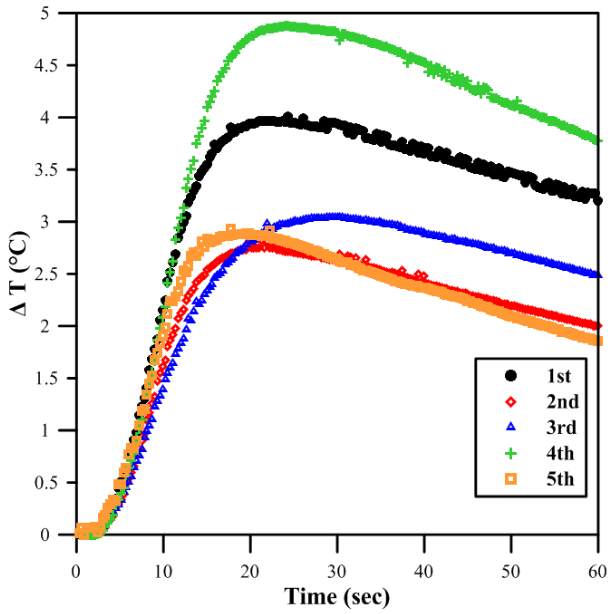


Figure 14. Temperature rise curve for the light curing of the sealer, with an average rise in temperature of 3.54°C (Approximately 20 seconds of exposure to light could cure the sealer.)

The statistical diagram of the maximum temperature rise of the sealer layer is shown in Figure 15, and the median of the data is about 3.00°C. There are two sets of data greater than 4.00°C. This result shows that applying too thick sealer layer may cause discomfort to fingers.

Of the four layers of gel resin, the temperature rise of the builder and the sealer was higher than the other two, with an average of more than 3.5°C. The temperature rise of the builder was higher than that of the sealer. The results of the experiments are consistent with the fact that the light curing of the builder was more likely to cause discomfort and pain to customers during actual operation.

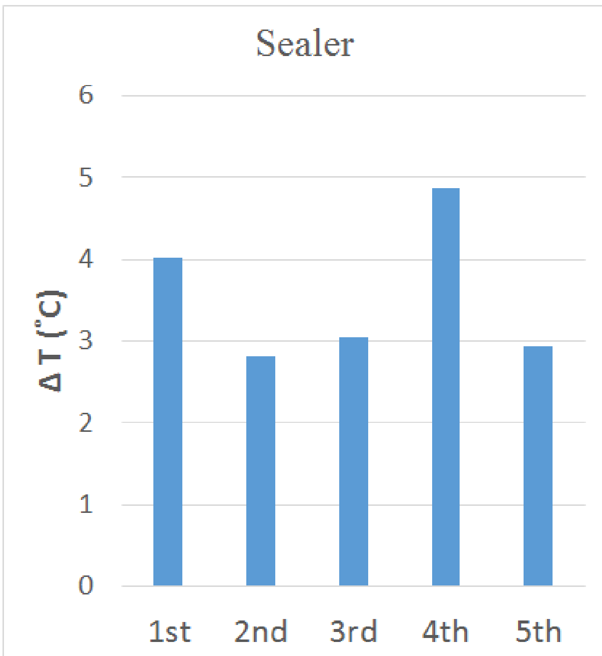


Figure 15. The statistical diagram of the maximum rise in temperature of sealer layer

5 Conclusion

The reaction heat generated by resin light curing is a cause of customer discomfort. In this study, the temperature rise trend during UV light curing was measured for each of the four layers of monochromatic gel nails. The results show that the average rise in temperature of the base and color layers was around 1.5°C and would not induce thermal pain. The temperature of the builder was the highest of the four layers; customers would feel most uncomfortable during the curing of this layer based on the actual operation of gel nails. The experimental results show that 60 seconds of exposure was just enough to completely cure the layer. Therefore, if the light intensity could be reduced, the reaction heat would not build up as quickly and the temperature would not rise so fast. However, reducing the light intensity also required extending the exposure time to provide the same amount of energy needed to fully cure the builder. The temperature curve of the sealer showed that the curing reaction was complete after approximately 20 seconds. Therefore, 60 seconds of exposure might not be necessary and could be reduced. Additionally, to keep the temperature from rising too quickly, an alternative intensity of UV light may be used.

In gel nails, manicurists do not know the actual resin curing time and the amount of reaction heat generated during curing. The number of seconds of light exposure is usually increased to ensure that the resin has been cured. This way increases the illumination time for each layer. In business operation, manicurists need to make 10 fingers once, and each finger has at least four layers or more. The illumination time of the resin takes up too much, which is a big problem for this industry. According to results, these empirical parameters can be further improved. The optical curing reactions of the base layer and the color layer has not been completed, and the temperature rise curve has not yet reached the equilibrium point. In the builder layer, it is close to the temperature equilibrium point. The sealing layer has already completed the optical curing process. By this method, it is possible to clearly understand the change of curing time and rise temperature of each resin. It can make the gel nails industry more efficient in practice, and at the same time solve the problem of making customers uncomfortable due to temperature rise.

In practice, gel nail art varies in thickness due to different designs, resulting in differences in the maximum rise in temperature. The use of IoT technology could solve the problem of differences in different designs. After finding the temperature rise trend of the gel resin and the time required for light curing, the parameters obtained could be calculated in the cloud using a microprocessor and a personal computer. The results of the calculations in this study show that the intensity and time of UV illumination could be adjusted in real time to maintain the temperature rise within the required range. The experimental results of this study could provide a reference for the trend of temperature rise due to reaction heat during the resin light curing of gel nails and are conducive to the development of nail machines which can connect to the Internet.

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Biography

Shu-Ting Chen received her M.S. degree in Arts Design from MingDao University, ChangHua, Taiwan, in 2015. Her research focuses on nail art, gel nails, sensors, beauty care, fashion makeup design, and body painting.