IOT-POWERED GLOVE FOR ADVANCED CONCRETE TEMPERATURE MONITORING

Kamarul Aini Mohd Sari[1*], A. Darshinii A/P Sivasanmugam[1] and Mohd Syafiq Syazwan bin Mustafa[1]

[1]Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, Pagoh Campus, 84600 Muar, Johor, Malaysia.

*Corresponding Author's Email: aini@uthm.edu.my

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ABSTRACT: Compressive strength is one of the most important characteristics of concrete. The strength of the cement, therefore, has a significant effect on the performance characteristics of the mixture and ensures the overall quality of the finished construction project. Since concrete gains strength through a hydration process between cement and water curing, the temperature has an important effect on the compressive strength of concrete. The aim of the study was achieved by inventing an IoT- based smart concrete temperature monitoring glove for construction workers to record the temperature of fresh concrete at site. The IoT-based smart concrete glove is designed using AutoCAD and C++ coding is used to integrate the NodeMCU microcontroller in the glove to the website where the initial temperature of the fresh concrete will be saved, along with the Blink application. For testing, a total of 18 fresh concrete samples with grade G25 distributed to 3 different construction sites were collected in a 100mm concrete test cube mould and the curing temperature was measured, and compared to ASTM C 1064-86 to not exceed temperature between range of 26.7°C and 35°C. The results of the concrete compressive strength on the 28th day must reach 25 MPa, exceeding grade 25. Meanwhile, the curing temperature of one of the fresh concrete samples collected from the construction sites was 24.82°C and it shows that it does not exceed the ASTM C 1064-86 standard. Therefore, this IoT-based Smart Concrete Temperature Monitoring Glove is very easy to apply at the construction site and the result of curing temperature can be monitored by the management to ensure the quality of the concrete is guaranteed.

KEYWORDS: *initial temperature, fresh concrete, smart glove.*

1.0 INTRODUCTION

Concrete mixed design aids in a foundation's ability to produce sound infrastructure. Concrete mix design is a preparatory technique used to produce the strength and durability required for the concrete structure. Since each ingredient has a unique set of attributes, creating an excellent concrete mix can be challenging. To ascertain the physical properties of each constituent and the project site's carrying capacity, an examination is required. Due to the vastly different qualities of the constituent materials, the site-specific conditions, particularly the exposure conditions, and the requirements for a specific job for which the mix is developed, designing concrete mixes is not an easy operation [1].

The design of the concrete mix is influenced by various elements. Among the factors is compressive strength. Concrete that possesses a particular level of compressive strength is utilized in construction. The compressive strength or characteristic strength of the concrete is often specified by the designer. The site personnel are responsible for verifying that the concrete mix has the required compressive strength. When the contractor provides the concrete mix design, the mix proportions must be verified. In the event that the experimental mixtures are approved, proceed with them. At this time, the concrete's compressive strength needs to be examined. The target strength, which is more than the concrete's compressive strength, is the strength that got measured. Additionally, the concrete mix design specifies the target strength. Compressive strength is one of the key parameters influencing the design of the concrete mix, hence this verification is advised for every new concrete at the start of the project [2]. Standard ACI 301.5, ACI 301, and ASTM C94 set no temperature limit on fresh concrete in hot weather conditions if precautions are considered in proportioning, production, delivery, placing, and curing concrete. Nonetheless, ASTM C 1064-86 set a maximum limit between 26.7°C and 35°C [3].

It has been demonstrated that several impacts that could arise from high concrete temperatures are harmful to the long-term performance of concrete. Elevated temperatures in concrete lead to a rise in the rate of hydration, thermal strains, drying shrinkage cracking tendency, and permeability. These factors ultimately diminish the long-term strengths and durability of the concrete due to cracking [4]. Even though thermocouples are frequently used at construction sites worldwide, there are a number of difficulties and mistakes that could seriously compromise the integrity of your concrete structure. Hard-wired sensors provide several challenges, starting with the wire itself. Second, data is not automatically collected or stored by conventionally wired sensors. The temperature of the concrete during the subsequent hydration phase is influenced by the temperature the concrete displays during placing. This measurement is primarily done to make sure that the temperature of the concrete does not get too high or too low, which would prevent the concrete from developing its strength and durability [5].

The project aimed to create an IoT-based Smart Concrete Temperature Monitoring Glove using AutoCAD. The initial design in AutoCAD was linked to an IoT web server to collect temperature data for fresh concrete. The glove also served as an anti-vibration glove. The second objective involved measuring the initial temperature of fresh concrete from a batching plant supplied to three construction sites. Samples followed ASTM C1064-86 standards, except one from Site C. The third objective included analyzing concrete parameters, comparing initial temperatures with ASTM standards, and assessing the compressive strength of Grade 25 concrete cubes against standard values, specifically evaluating strength at day 7.

2.0 MATERIALS AND METHOD

Firstly, the IoT-based Smart Concrete glove was designed using AutoCAD, before turning it into 3D object. Then, the IoT Smart Glove was developed where GMG anti-vibration gloves were selected in the project. A circuit board was attached to the glove. The circuit board is composed of a Dallas Temperature Sensor DS18B20, a red push button, toggle switch, NodeMCU ESP32 microcontroller, and DHT11 Temperature and Humidity Sensor. Cable tie was used to tight the plastic box to the glove. To continue with that, the IoT- based Smart Glove was developed with IoT, where NodeMCU ESP32 was connected to the laptop using the Arduino IDE. Finally, the temperature of the fresh concrete samples was collected, and then the compression test of the concrete cubes was tested on day 7 and day 28. There are three phases of data collection in this project namely planning, development of glove, and development of IoT.

2.1 Planning Stage

Tool's functionality is determined by the final shape that had been developed. This detection tool was built using tools that are suitable and functional for the project's production operations. Other shields that may be used to design this product include the Sketch-up for circuit diagram. The use of this other shield to come up with ideas for product improvements. Figure 1 shows the front and rear elevation of the IoT Smart Glove in AutoCAD. Meanwhile, Figure 2 shows the circuit diagram of the IoT Smart Glove.

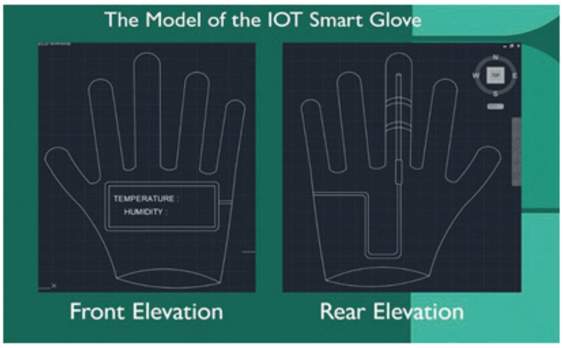

Figure 1: Front and rear elevation of the IoT Smart Glove

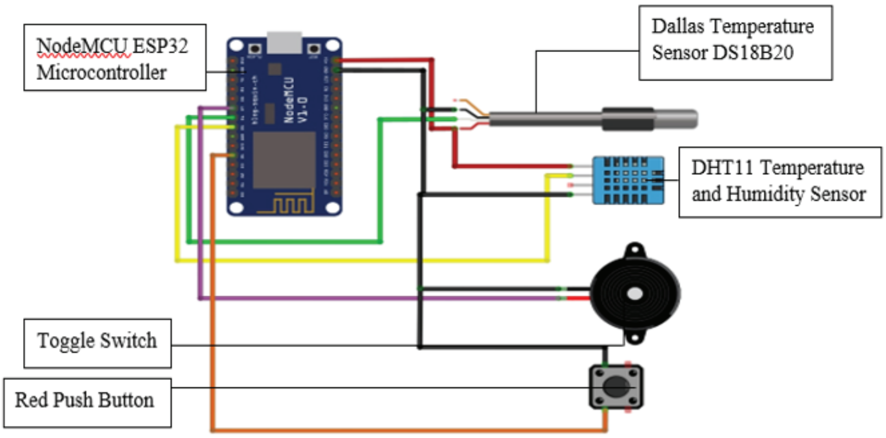

Figure 2: Circuit diagram of IoT Smart Glove

2.2 Development of Glove

The GMG anti-vibration heavy-duty safety work gloves were selected for the project. A circuit board was attached to the glove. The circuit board is composed of a Dallas Temperature Sensor DS18B20, a red push button, toggle switch, NodeMCU ESP32 microcontroller, and DHT11 Temperature and Humidity Sensor. Cable tie was used to tight the plastic box to the glove. Figure 3, and Figure 4 show the front view, and rear view of the IoT Smart Glove.

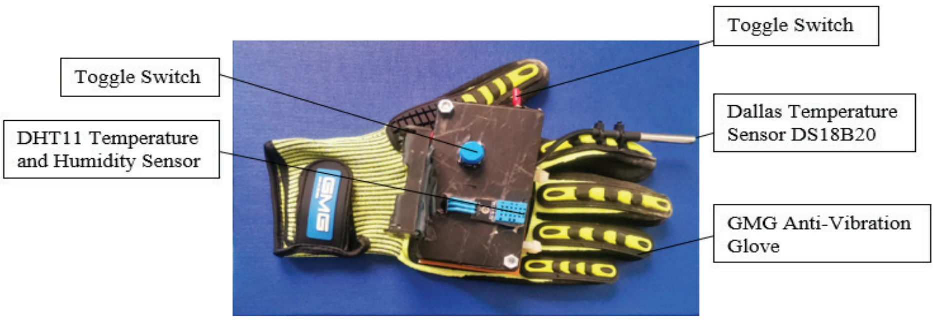

Figure 3: Front view of IoT Smart Glove

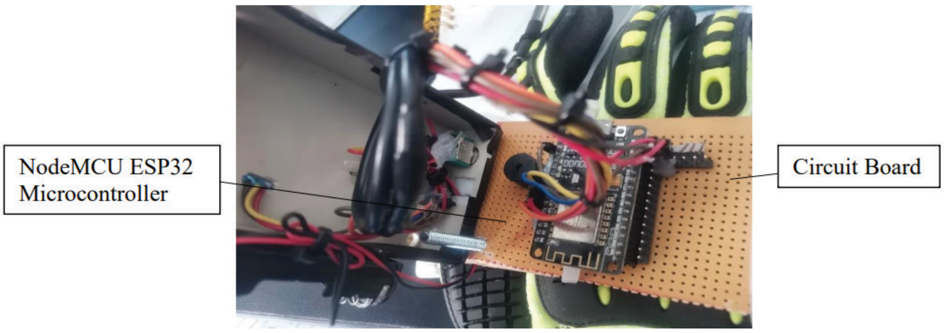

Figure 4: Rear view of IoT Smart Glove

2.3 Development of IoT

NodeMCU ESP32 in the glove was connected to Arduino IDE in the laptop. IP address was obtained from the Blink App in the phone after connecting the phone with the same Wi-Fi as the Arduino IDE. The IP address displayed in the Blink App was copied and pasted into the search bar of your browser. The device that contains the Blink app and the NodeMCU ESP32 are both connected to the same Wi-Fi or mobile hotspot.

All information related to this project has been applied to make coding and directly entered the NodeMCU ESP32 to test the effectiveness of the system NodeMCU before applying to the prototype. The coding that has been used for this project is C++. For the website HDML layout has been used to arrange the web pages in a well-defined manner. CSS font-style has been used in the website. Most importantly, JavaScript (JS) which is a lightweight interpreted programming language used on the web page. Figure 5 below shows that the IP address from Blink app was inserted in Chrome to open the website where the temperature of the fresh concrete was saved.

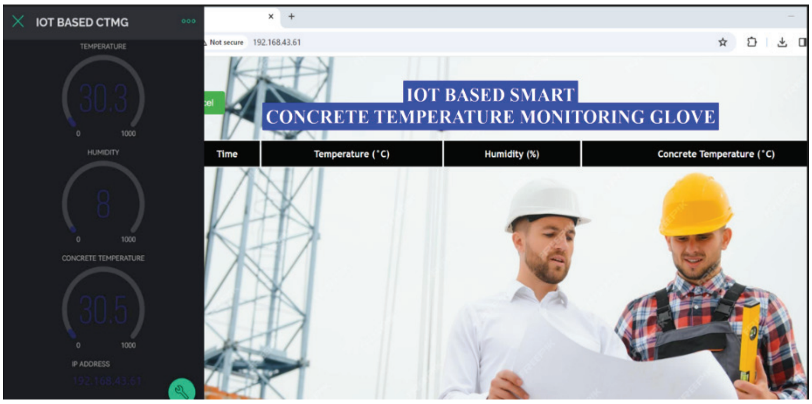

Figure 5: IP address from the BLYNK app is inserted in the chrome to open the website for data monitoring

3.0 RESULT AND DISCUSSION

The results and discussion section provided the results of the initial temperature of the fresh concrete samples from three different Construction Site A, B and C along with the compression strength of the concrete cubes on day 7 and also day 28.

3.1 Temperature of Fresh Concrete

The IoT Based Smart Concrete Temperature Monitoring Glove and the traditional method, which involved using an infrared thermometer for this project, were both applied to measure the initial temperature of the fresh concrete that was supplied to three separate construction sites. Apart from the temperature of the fresh concrete, the ambient temperature and the ambient humidity were recorded. Fresh concrete temperatures were measured on the site and compared to the ASTM C 1064-86 concrete temperature maximum limit, which is 26.7°C to 35°C.

3.1.1 Result Site A

On September 18, 2023, fresh concrete was delivered to site A. Site A was to be the location of a new homestay at Bakri, Muar which is in construction process. The batching facility is about 18 km away from this building location. For the construction's ground slab, concrete of Grade 25 was provided. Table 1 shows the temperature reading of the fresh concrete that collected from Site A by using both infrared thermometers, and IoT Based Smart Concrete Temperature Monitoring Glove. Apart from that, the table also contain the reading of the ambient temperature, surrounding humidity, and the difference in fresh concrete temperature utilizing the IoT-based smart concrete temperature monitoring glove and infrared thermometer that were developed for this project. Then Figure 6 shows the time vs temperature of IoT Smart Glove, infrared thermometer, and humidity of Site A.

Table 1: Fresh concrete temperature reading from Site A

Sample	Time	Ambient Temperature (°C)	Surrounding Humidity (%)	Concrete Temperature using Glove (°C)	Concrete Temperature using Infrared Thermometer (°C)	Difference between temperature reading of infrared thermometer and IoT Smart Glove (Δ°C)
1	11:39:42	34.80	65	29.07	29.66	0.59
2	11:40:12	34.70	65	29.92	30.45	0.53
3	11:40:37	34.80	65	30.12	31.74	1.62
4	11:40:57	34.90	65	29.44	30.27	0.83
5	11:41:17	34.90	65	29.37	29.54	0.17
6	11:41:32	35.10	65	32.06	31.86	0.2

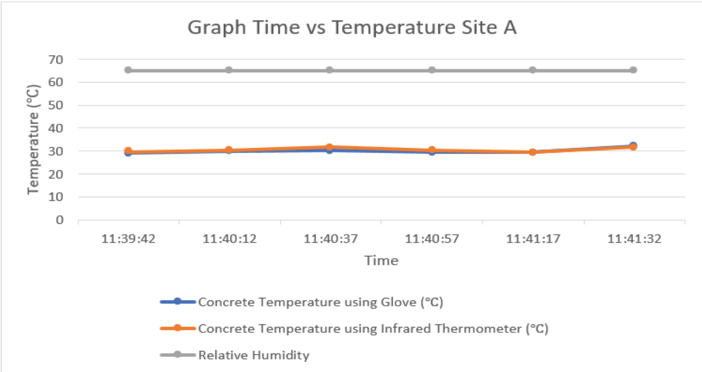

Figure 6: Time vs temperature of IoT Smart Glove, infrared thermometer, and humidity of Site A

3.1.2 Result Site B

On September 21, 2023, fresh concrete was delivered to site B. Site B was a housing project which was located at Pagoh Jaya, Muar which is under construction. The batching facility is about 9 km away from this building location. For the construction's ground slab, concrete of Grade 25 was provided. Table 2 below shows the temperature reading of the fresh concrete that collected from Site B by using both infrared thermometers, and IoT Based Smart Concrete Temperature Monitoring Glove. In addition, Table 2 includes readings for the surrounding humidity, ambient temperature, and the differential in fresh concrete temperature using an infrared thermometer and an Internet of Things-based Smart Glove that were created in this project. Figure 7 shows the time vs temperature of IoT Smart Glove, infrared thermometer, and humidity of Site B.

Table 2: Fresh concrete temperature reading from Site B

Sample	Time	Ambient Temperature (°C)	Surrounding Humidity (%)	Concrete Temperature using Glove (°C)	Concrete Temperature using Infrared Thermometer (°C)	Difference between temperature reading of infrared thermometer and IoT Smart Glove (Δ°C)
1	12:11:17	34.70	65	32.19	31.87	0.32
2	12:11:42	34.60	65	30.94	30.14	0.80
3	12:12:12	34.60	65	32.75	32.00	0.75
4	12:12:32	34.60	65	30.62	30.41	0.21
5	12:12:47	34.70	65	32.25	32.20	0.05
6	12:12:57	34.60	65	31.81	31.53	0.28

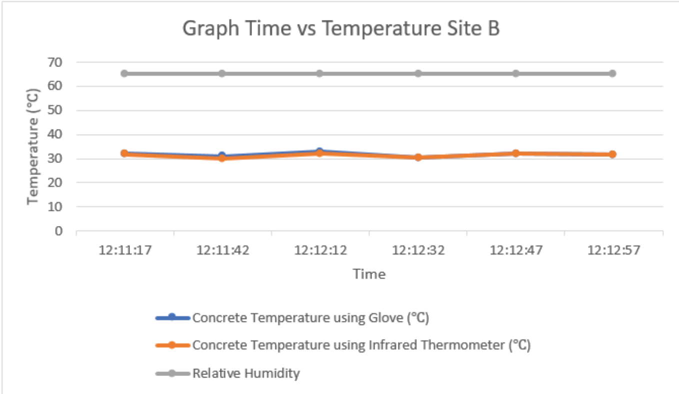

Figure 7: Time vs temperature of IoT Smart Glove, infrared thermometer, and humidity of Site B

3.1.3 Result Site C

On September 27, 2023, fresh concrete was delivered to site C. Site C was a factory construction project by Golden Comet Sdn. Bhd which is at Muar. The batching facility is about 16 km away from this factory construction site. For the construction's ground slab, concrete of Grade 25 was provided. Table 3 below shows the temperature reading of the fresh concrete that collected from Site C, using both infrared thermometers, and IoT Based Smart Concrete Temperature Monitoring Glove. Furthermore, using an infrared thermometer and an Internet of Things-based Smart Glove developed for this project, the table presents values for ambient temperature, surrounding humidity, and the difference in fresh concrete temperature. Figure 8 shows the time vs temperature of IoT Smart Glove, infrared thermometer, and humidity of Site C.

Table 3: Fresh concrete temperature reading from Site C

Sample	Time	Ambient Temperature (°C)	Surrounding Humidity (%)	Concrete Temperature using Glove (°C)	Concrete Temperature using Infrared Thermometer (°C)	Difference between temperature reading of infrared thermometer and IoT Smart Glove (Δ°C)
1	13:27:57	34.60	61	27.75	27.72	0.03
2	13:28:42	34.60	61	28.31	28.30	0.01
3	13:29:25	34.70	61	24.82	23.85	0.97
4	13:30:07	34.60	61	29.42	29.81	0.39
5	13:30:47	34.60	61	26.70	26.43	0.27
6	13:31:22	34.40	61	33.06	32.80	0.26

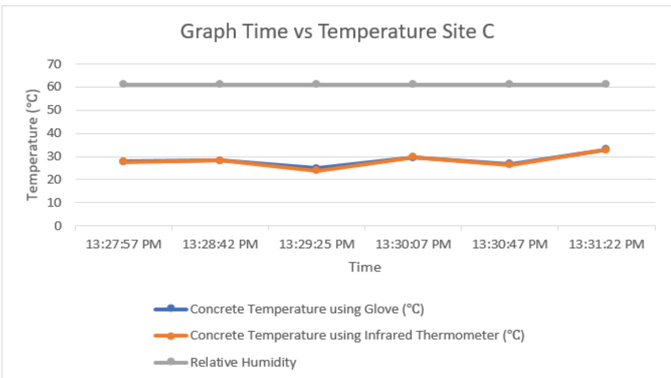

Figure 8: Time vs temperature of IoT Smart Glove, infrared thermometer, and humidity of Site C

3.2 Compressive Strength Result for Hardened Concrete

The data analysis and discussion section of the study provides the data collected from Mersing Concrete Sdn. Bhd which is located at Bukit Pasir, Muar. Fresh concrete samples of Grade 25 from 3 construction sites were placed in 100mm plastic concrete cube molds. A total of 6 samples were collected for each site, with 3 samples for compression testing on both day 7 and day 28. The samples were collected on 18th, 21st, and 27th September 2023 for Site A, B, and C, respectively. Table 4 shows the compressive strength of concrete cubes from three sites.

Table 4: Compressive strength of concrete cubes from Site A, B, and C

Site	Average Initial temperature using smart glove (°C)	Average Compressive Strength (MPa)			Distance from Mersing Batching Plant (km)
		Day 7	Day 28	Design Strength G25	
A	29.9	21.7	28.1	25	18
B	31.7	27.9	36.3	25	9
C	28.3	19.8	26.8	25	16

3.3 Discussion

Table 4 shows summary at 28 days concrete samples from Site B has the highest compressive strength value compared to concrete samples from Site A and Site C. While concrete cube samples from Site C has the lowest compressive strength and the initial temperature of one of the samples from Site C was 24.8°C (refer Table 3) which had not followed the ASTM C 1064-86 standard where the temperature should be within 26.7°C to 35°C. Only one sample from Site C on 27th September 2023 didn't fulfil the standard where the initial fresh concrete temperature was 24.8°C which is below the limit. Site C was the construction site which had the longest distance from the Mersing Concrete batching plant compared to the other sites which is 16km. Meanwhile, Site B had the highest compressive strength due to the shortest distance from the batching plant. It shows that, compressive strength of the sample which had the standard initial temperature had good compressive strength. According to Mersing Batching Plant the average distance a batching plant could supply fresh concrete to construction sites depended on various factors such as the transportation infrastructure, type of concrete mixer trucks used, and local regulations.

4.0 CONCLUSION

In conclusion, this research successfully developed a monitoring glove to measure the initial temperature of fresh concrete at batching plants. The initial temperature readings of collected concrete samples were compared against the ASTM C 1064-86 standard range (26.7°C to 35°C). Additionally, the compressive strength of Grade 25 concrete cubes was evaluated against standard values, specifically assessing whether the strength reached 65% of the overall grade strength by day 7. Through integration with IoT, this smart glove allows top management to remotely monitor data via office or mobile applications and estimate the compressive strength of hardened concrete.

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