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Porosity Analytical Tool Based on Infrared (IR) Images of Concrete

Shera Anak Gilbert[1], Andri Kusbiantoro[1*], Amalina Hanani Ismail[1]

[1]Department of Civil Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, Hub Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, Pagoh, Johor, MALAYSIA

*Corresponding Author

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Abstract: Images analysis techniques are gaining popularity in the studies of civil engineering technology. However, the current image analysis methods often require advanced machinery and strict image acquisition procedures, which may be challenging in actual construction practices. Therefore, this study develops a simplified image analysis technique that uses the FLIR ONE infrared camera to capture the concrete surface compatible with the Infrared (IR) concrete images. The infrared image is then converted into contour plot images using MATLAB software and analysed using AutoCAD to determine the thermal colour's diameter on the infrared images. This study focuses on the white and yellow colours. The yellow thermal colour is the outer of the Thermal Diameter Reduction (TDR) rate of concrete, while the white thermal colour is the inner due to the highest temperature. However, to determine the accuracy of the MATLAB image processing, additional image editing is performed by utilising image exposure editing in conjunction with AutoCAD. The result from MATLAB was then gathered and compared to the image exposure editing to find the correlation between porosity, compressive strength and TDR rate of concrete. Experimental results showed that porosity affected the TDR rate with reliable accuracy of 90.00 %, compressive strength 70.00 %, and concrete density 60.00 %. The result analysis shows that concrete with high characteristic strength is in a less porous state, which means it is denser and transfers heat slowly to the surface, thus making the TDR rate value of the concrete minimum.

Keywords: Infrared (IR) images, Thermal Diameter Reduction (TDR) rate, Porosity, Compressive Strength, MATLAB image processing

1. Introduction

Concrete is an essential material in the construction industry. It is a composite material composed of a binder paste such as Portland cement, aggregates and water [1]. Concrete can be readily blended and moulded to satisfy a range of specific requirements. However, concrete has a significant downside, where pores in concrete can adversely affect its properties in various ways.

As concrete is one of the most widely used building materials, concrete is inevitably affected by various destructive factors, including environmental effects during the production process. For example, a study by [2] found that the mechanical properties of building materials mainly depend on their composite structure. Therefore, the presence of pores will adversely affect the material's mechanical properties, such as failure in strength, elasticity, and creep deformation [3]. Furthermore, porosity has a role in the relationship between the mechanical properties of concrete, such as the elastic modulus of compressive strength relationship [4]. Therefore, when it comes to production topics, the nature of porosity and its influence on the mechanical strength of concrete mixtures is a significant factor for analysis [5].

*Corresponding author: andri@uthm.edu.my

According to [6], porosity measures the volume of the voids in concrete. As a porous material, concrete is permeable to air and water intrusion, significantly influencing strength and durability. However, due to the transportation characteristics of concrete, the permeability in its porous structure is related to many failure cycles. For example, the concrete environment can transport chloride, oxygen, carbon dioxide, and moisture, which cause corrosion in steel reinforcement [7]. Therefore, to accurately analyse concrete buildings' stability and durability, the porosity of concrete must be appropriately quantified.

In recent years, numerous studies have been reported giving application examples of non-destructive testing techniques when detecting and locating anomalies in concrete [8]. Non-destructive testing is the testing of materials, for surface or internal flaws or metallurgical conditions, without interfering in any way with the integrity of the material or its suitability for service [9]. The infrared thermography (IRT) technology is relatively new to civil engineering as a non-destructive evaluation (NDE) technique for identifying damage or defects in concrete structures by giving a visual map of heat dissipation variances to highlight locations where problems may exist [9]. Changes in direct sunlight or ambient temperature cause the surface of concrete structures to cool or heat, thereby emphasising faulty parts of the structure that heat or cool at different rates than non-flawed concrete.

In the past two decades, the application of digital image analysis in civil construction has expanded significantly. Quantitative image analysis is used to digital images to provide data and information and can be done using computer technology for pattern recognition. The quantification includes determining the layer thickness distribution, Porosity and pore size distribution, which can be quantified using the imaging toolkit provided in MATLAB R2007a, which the human eye cannot do due to the large amount of information generated and collected [10].

The main objective of this study is to develop an image processing technique that will be compatible with the infrared images of concrete. Meanwhile, the sub-objective of this study is divided into two: to quantify the porosity of concrete based on the infrared images and to correlate the porosity of concrete with their characteristic strength. A strength test determined the compressive strength of various concrete strengths 20, 30 and 40 MPa, and the porosity analysis was conducted using a FLIR ONE infrared camera. The detailed analysis was performed using MATLAB image processing and AutoCAD software.

2. Materials and Methods

All methods and flow of overall research methodology used to achieve the objectives of this study are discussed. It also included the explanation of specimen preparation, the material used and the testing method. All the methods and procedures discussed used standards from the American Society for Testing and Material (ASTM) and British Standard (BS) as a guideline.

2.1 Materials

The concrete used in this study is made of OPC type of cement, tap water, crushed stone as coarse aggregate and sand as fine aggregate. Six samples of concrete with various strength characteristics were prepared, i.e., M20, M30 and M40. Every grade of samples is prepared using the DOE form, respectively, as shown in Table 1 below.

Table 1- Concrete mix design

Mix no.	Cement: kg/m^3	Water: kg/m^3	w/c ratio	Coarse aggregate: kg/m^3	Fine aggregate: kg/m^3	Processing Tool
M20a	305	190	0.62	1142	765	MATLAB
M20b	305	190	0.62	1142	765	Image Exposure Editing
M30a	352	190	0.54	1115	743	MATLAB
M30b	352	190	0.54	1115	743	Image Exposure Editing
M40a	404	190	0.47	1084	722	MATLAB
M40b	404	190	0.47	1084	722	Image Exposure Editing

2.2 Sample Preparation

Six cube specimens were prepared for each group mentioned above for different curing ages. Ordinary concrete samples are formed by cement, water, coarse aggregate and fine aggregate material. The preparation of the concrete mixture is shown in Table 1 above. First, the freshly mixed concrete was poured into the moulds with the size 100 mm

× 100 mm ×100 mm in three layers, with each layer tamped 25 times. Afterwards, the cube specimens were left for 24 hours. Finally, all cube specimens are submerged in a curing tank for seven days and 28 days.

2.2.1 Compressive Strength Test

This test was conducted to determine the compressive strength of concrete specimens with cube size 100 mm × 100 mm × 100 mm A compressive strength test was done for the cured concrete specimens of 7 and 28 days. The test was conducted according to BS EN 123903:2009. The compressive strength of each cube is obtained using the equation below:

$$Compressive\ Strength, F = \frac{P}{A} \qquad Eq.1$$

Where,
P = Maximum Compressive Load, (kN)
A = Surface area and contact with the platens (mm^3)
2.2.2 Porosity Test

After seven and 28-days of curing, one concrete cube specimen for seven days and two concrete cube specimens for 28 days were taken out from storage for a porosity test according to ASTM C 642 for testing on a particular day. First, these specimens were turned to SSD (Saturated Surface Dry) condition by removing water from the surfaces. Then SSD weight of samples in the air (B) was measured. Next, the specimens were placed underwater in a bucket, and weight underwater (A) was obtained. After that, the specimens were placed in the oven at a temperature of 105 ºC for 24 h. Then, the weight of the specimen was measured as the oven-dry weight of samples in the air (C). Finally, from "Equation 1", the porosity of concrete was calculated.

$$Porosity, P = \frac{(B - C)}{(B - A)} \times 100\ \% \qquad Eq.2$$

Where,
A = Mass of the sample submerged in water, (gram)
B = Mass of saturated surface-dry sample in air, (gram)
C = Mass of oven-dried sample in air, (gram)

2.2.2 Infrared (IR) Images Sampling

In infrared thermal images, the concrete cube surface was captured every 60 seconds until 300 seconds, right after the cube was taken out from the oven. Afterwards, the step was to convert the thermal images into contour plot images using MATLAB software, as shown in Fig. 1 below. Finally, the contour plot will be analysed using AutoCAD by selecting the 3-point circle function to determine each thermal colour's diameter on the infrared images.

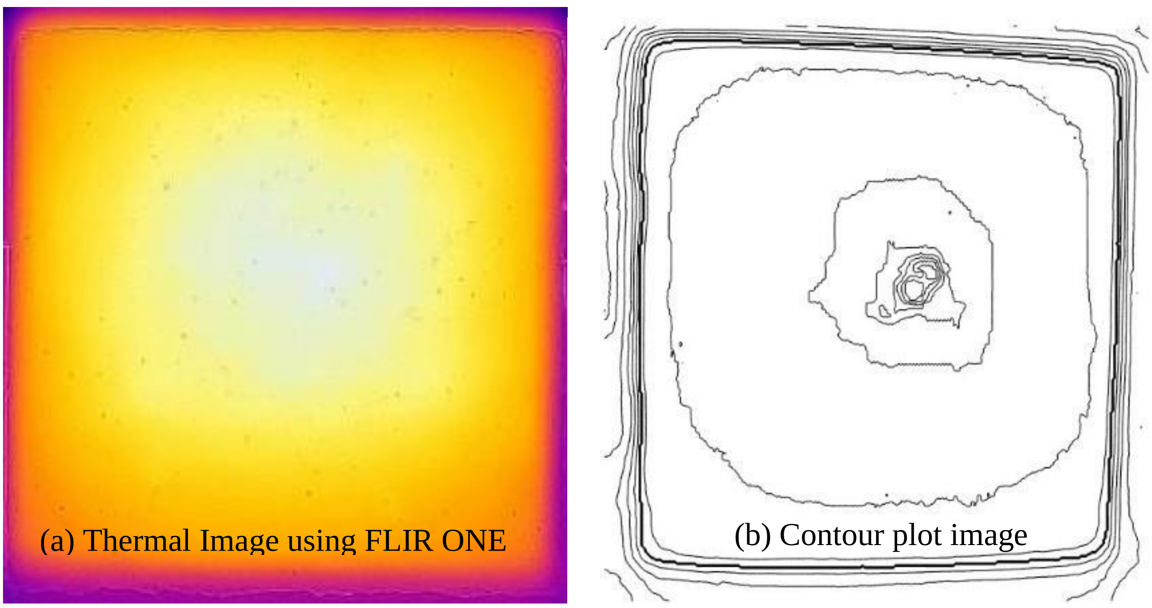

Fig.1 - Infrared images

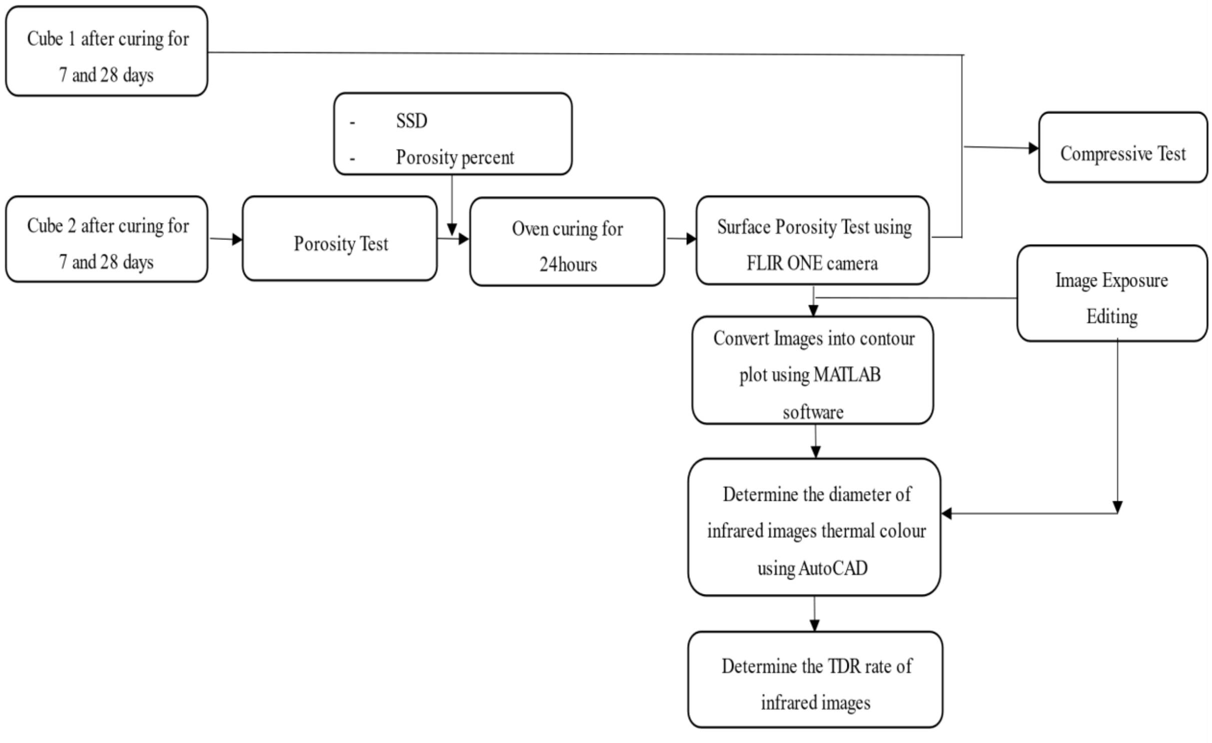

Fig. 2 - The diagram of Infrared (IR) images analysis

3. Results and Discussion

This section contains TWO (2) results from data obtained in different picture editing methods. The first method is to analyse images using MATLAB image processing tools with AutoCAD software. However, to determine the accuracy of the image processing method, additional image editing is performed by utilising image exposure editing in conjunction with AutoCAD. Fig.3 displays the infrared images of concrete right after take out from oven curing for 24 hours.

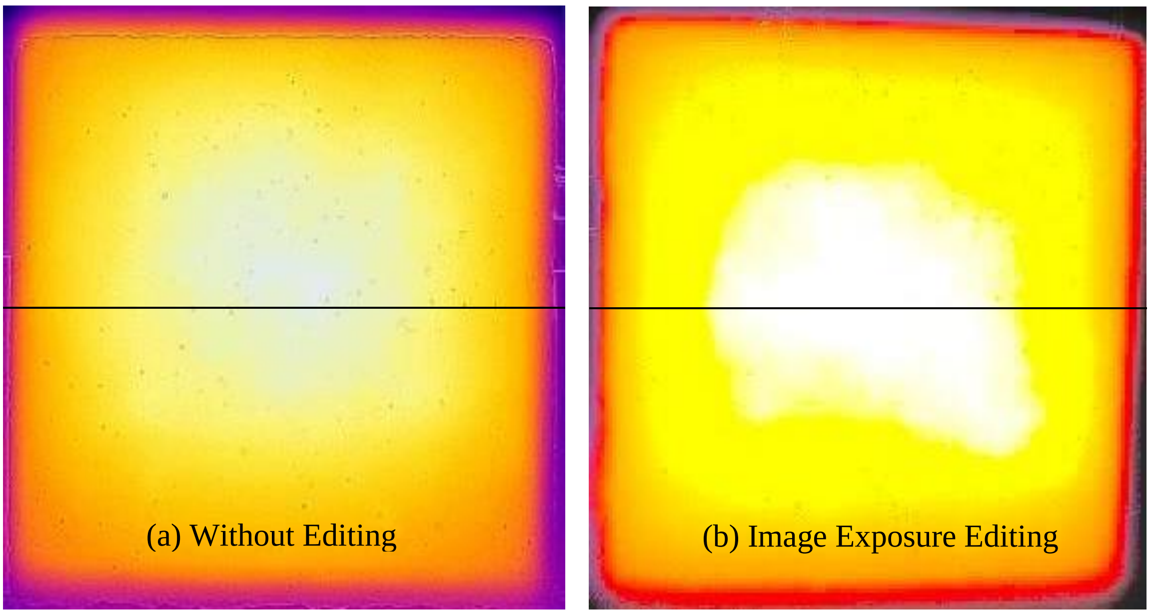

Fig. 3 - Infrared images

3.1 Correlation between Thermal Diameter Reduction (TDR) rate of concrete with porosity

3.1.1 Analyse using MATLAB image processing and AutoCAD

Fig.4 displays the influence of porosity on concrete's thermal diameter reduction rate. For example, from Fig.4 (a), it can be seen that with the increase of porosity value (14.20 %), the TDR rate value also increased (0.029 mm/s). In contrast, the TDR rate is 0.0041 mm/s when the porosity value is 8.18 %. On the other hand, the correlation between TDR rate inner and porosity is shown in Fig.4 (b) below. It was found that as the porosity value decreased (8.18 %), the TDR rate increased (0.096 mm/s).

However, this study has three outliers since the data did not fit the rest: 9.52 %, 11.66 %, and 12.23 %. It may be due to specimen error, even though the analytical error was eliminated. The best correlation between porosity and TDR rate was found in TDR rate outer concrete. Therefore, the power regression based on this study is R^2 (0.82) and R^2 (0.013), correspondingly outer and inner of TDR rate concrete. Although this analysis causes unusual data, it has proven that porosity affected the concrete's TDR rate.

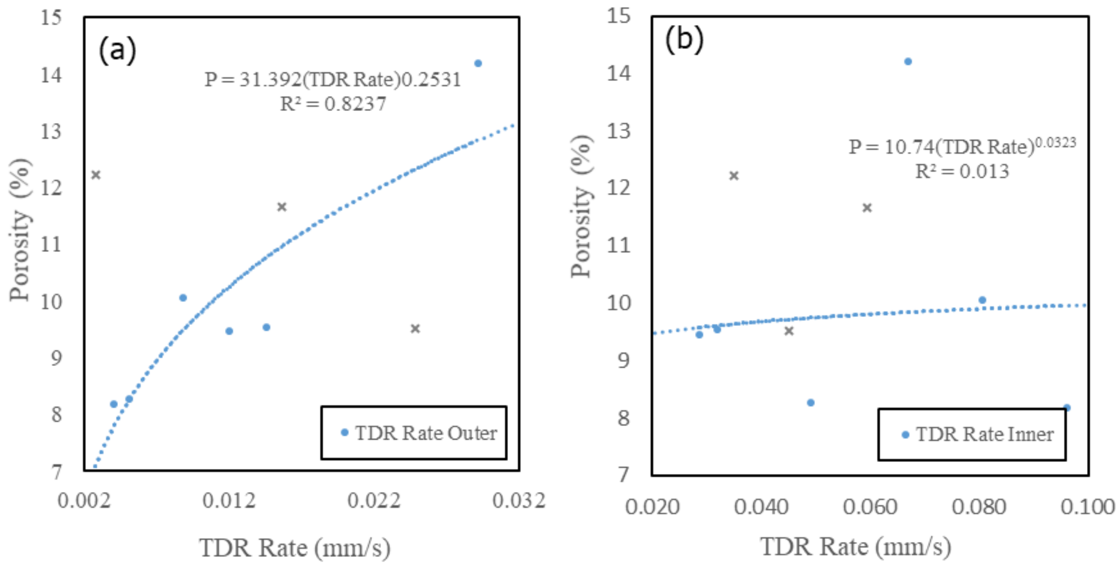

Fig. 4 - The correlation between TDR rate and porosity of concrete (a) TDR Rate Outer; (b) TDR Rate Inner

3.1.2 Analyse using Image Exposure Editing and AutoCAD

The influence of porosity on the thermal diameter reduction rate of concrete with image exposure editing is illustrated in Fig.5 below. From the graph, it can be seen that the result is in contrast with the MATLAB image processing data graph. Both graphs below show the same pattern trendline. However, the TDR rate outer concrete showed a decreased porosity value (8.18 %) and increased (0.03 mm/s). Meanwhile, the inner TDR rate concrete shows the porosity value decreased (8.18 %), and the TDR rate value decreased (0.074 mm/s).

Meanwhile, the inner and outer TDR rate coefficient is R^2 (0.0004), too far from 1.0. Therefore, it can be concluded that this analysis is likely inaccurate than the MATLAB image processing method. Plus, considering the influence of porosity on the TDR rate of concrete, this analysis technique cannot prove the objective. The apps used in this editing cannot detect the target area.

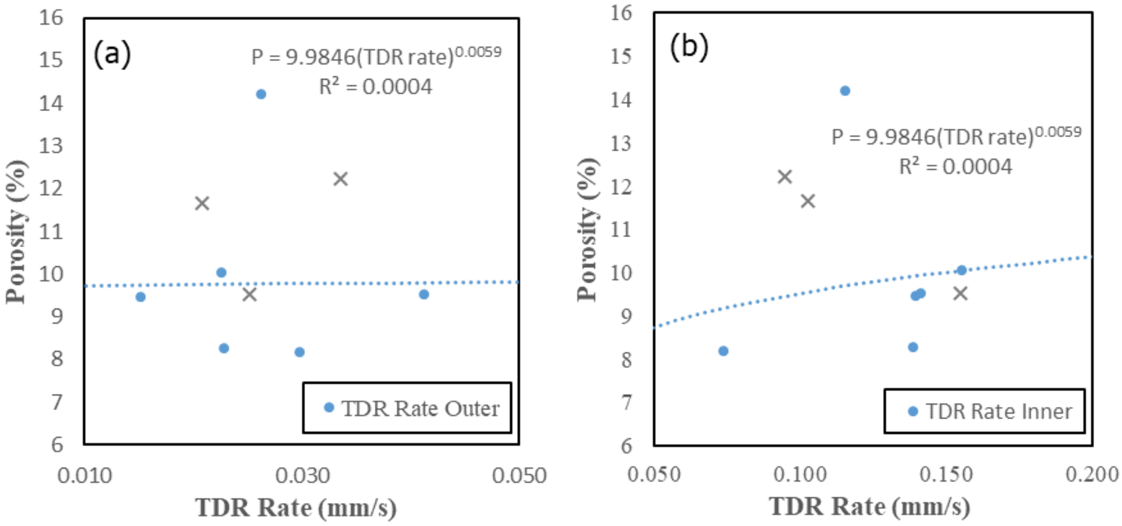

Fig. 5 - The correlation between TDR rate and porosity of concrete (a) TDR Rate Outer; (b) TDR Rate Inner

3.2 Correlation between Thermal Diameter Reduction (TDR) Rate of Concrete with Compressive Strength

3.2.1 Analyses using MATLAB image processing and AutoCAD

The influence of compressive strength on the TDR rate is shown in Fig.6 below. In Fig. 6(a), the TDR rate increased with increased compressive strength. As a result, the mixture has a maximum compressive strength of 46.38 MPa with a 0.004 mm/s TDR rate and a minimum compressive strength of 19.56 MPa with a 0.029 mm/s TDR rate. However, there is an inverse relationship between TDR rate inner with compressive strength, as shown in Fig.6 (b). The mixture has a maximum compressive strength of 46.38 MPa with a 0.029 mm/s TDR rate and a minimum compressive strength of 19.56 MPa with a 0.067 mm/s TDR rate. Therefore, the value of the coefficient of determination (R^2) for TDR rate outer is 0.91. At the same time, the correlation coefficient for TDR inner rate is 0.2. Therefore, it can be concluded that the correlation between compressive strength TDR rate outer which is more accurate than the correlation between inner. However, more samples are needed to get a perfect analysis result. Therefore, a better correlation between TDR rate and compressive strength is expected if more experiments are conducted.

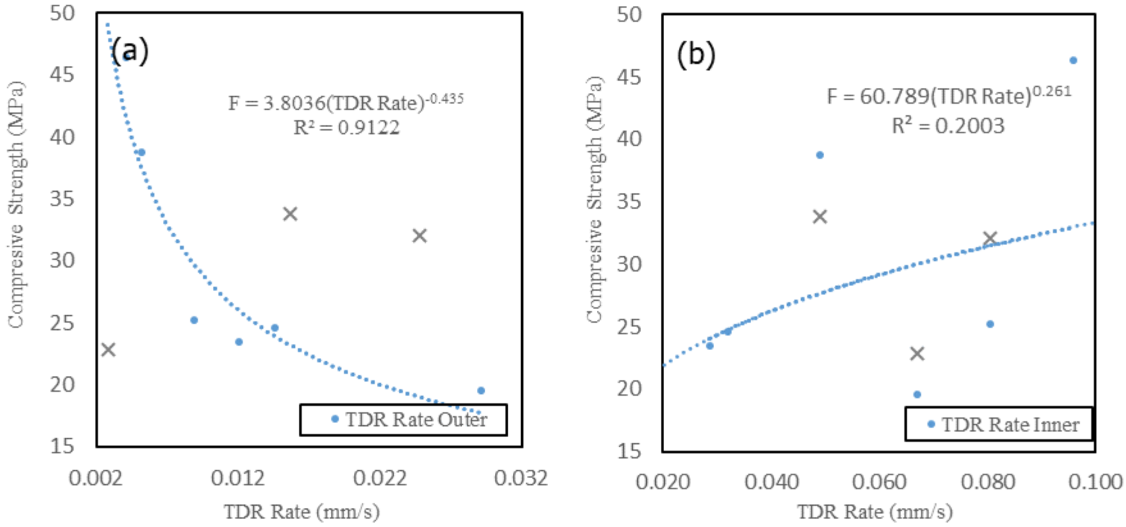

Fig. 6 - The correlation between TDR rate and compressive strength of concrete (a) TDR Rate Outer (b) TDR Rate Inner

3.2.2 Analyses using Image Exposure Editing and AutoCAD

The impact of compressive strength on the TDR rate is seen in Fig.7 below. In Fig.7 (a), the TDR rate increased with increased compressive strength. The combination has a maximum compressive strength of 46.38 MPa with a TDR rate of 0.004 mm/s and a minimum compressive strength of 19.56 MPa with a TDR rate of 0.029 mm/s. However, as seen in Fig.7 (b), there is an inverse correlation between TDR rate inner and compressive strength. The mixture has a maximum compressive strength of 46.38 MPa with a TDR rate of 0.029 mm/s and a lowest compressive strength of 19.56 MPa with a TDR rate of 0.067 mm/s. However, there is an inverse result between the MATLAB image processing method with image exposure editing. The coefficient of determination (R^2) values for the TDR rate are 0.02 and 0.4, respectively. Therefore, using other image processing technology and analysing it will provide a better result. Therefore, a better correlation between TDR rate and compressive strength is expected if more experiments are conducted.

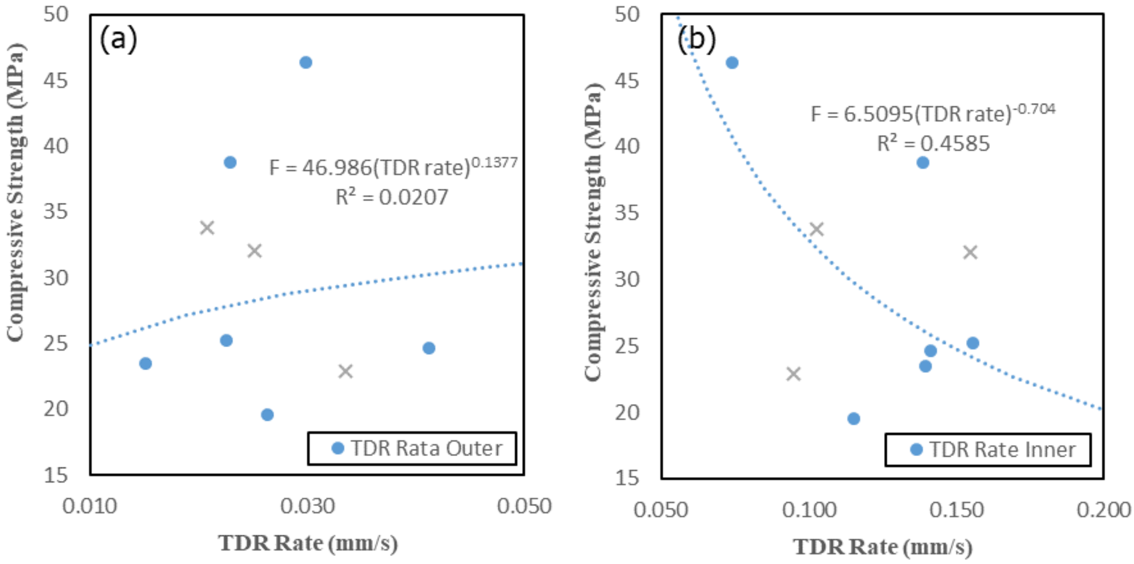

Fig.7 - The correlation between TDR rate and compressive strength of concrete (a) TDR Rate Outer (b) TDR Rate Inner

3.3 Correlation between Porosity and the Compressive Strength of Concrete

The strength and porosity relationship apply to an extensive range of materials. Fig.8 depicts the relationship between the porosity and the compressive strength of the accelerator's concrete. As shown in Fig.8, as compressive strength was increased, concrete porosity decreased. For example, the concrete with a strength of 19.56 MPa has a maximum porosity value of 14.20 %. Concrete with a strength of 46.38 MPa, on the other hand, has a porosity value of 8.18 %. It demonstrates that high-strength concrete has less porosity than low-strength concrete. Since three samples were identified as outliers because the data did not fit the rest, the correlation coefficient between density and porosity is 0.6484. Finally, it has long been recognised that reducing porosity in a solid material enhances its strength in general and the strength of cement-based materials in particular. Porosity has also been revealed to play a substantial impact on the frost resistance of concrete.

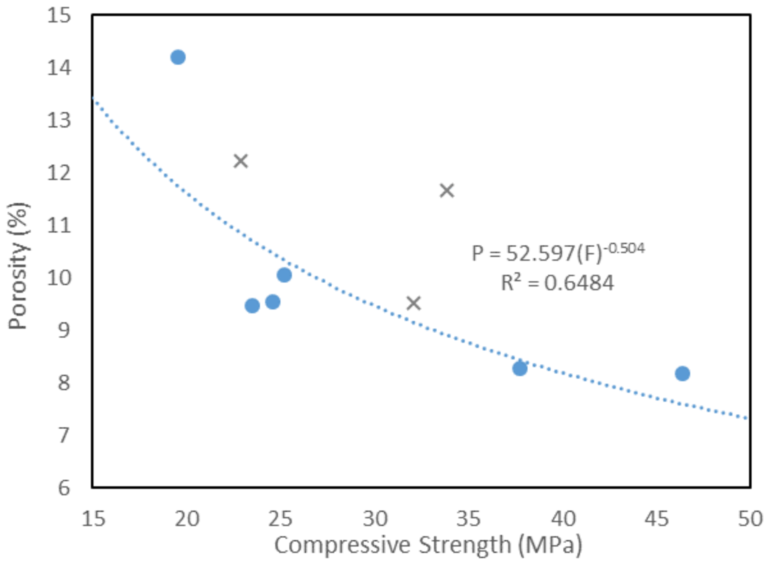

Fig.8 - The correlation between porosity and compressive strength of concrete

3.4 Correlation between Density with Porosity of Concrete

The correlation between density and porosity of all specimens is shown in Fig.9. From the figure below, density decreases by 2160 kg/m^3 as the corresponding porosity increases by 14.20 %. In addition, the porosity is 8.18 % when the density value is 2256.7 kg/m^3. Therefore, it can conclude that concrete density becomes lighter due to porosity. At the same time, the linear function can be used to describe the relationship. However, the correlation coefficient between density and porosity is 0.5. After all, the concrete density varies depending on the amount and density of aggregate, how much air is entrapped or purposely entrained, the cement concentration and the maximum size of aggregate used. Nonetheless, all precautions were taken to remove any analytical mistakes during specimen preparation, including using the DOE form's aggregate. Finally, denser concrete has been demonstrated to have better strength and fewer voids and porosity.

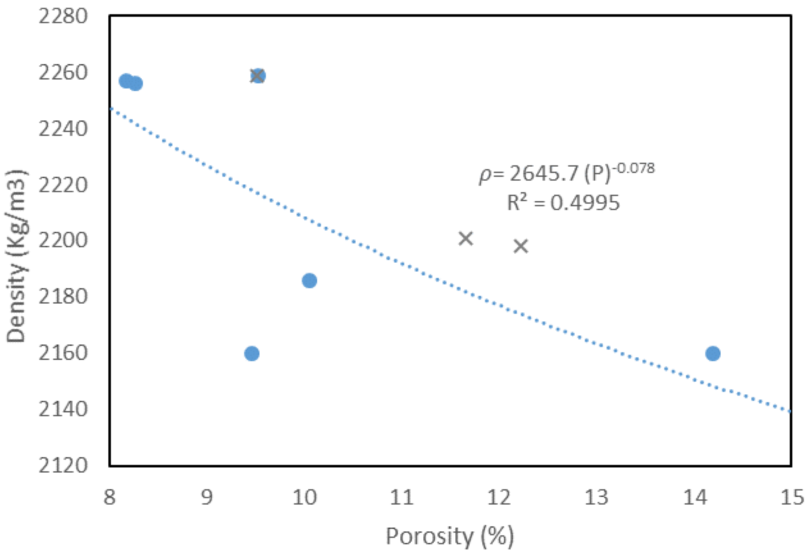

Fig. 9 - The correlation between porosity with the density of concrete

3.5 Correlation between Density with Compressive Strength of Concrete

Concrete must have to ensure sufficient compressive strength and durability. Therefore, its density highly influences the mechanical properties of concrete. The effect of density on the compressive strength of accelerator concrete is shown in Fig.10 below. The figure below shows that the density increased as compressive strength increased. For example, when the compressive strength is 46.36 MPa, the density value is 2256.7 kg/m^3. Fig.10 also demonstrates the best fit lines for the density obtained from samples show different compressive strengths with R^2 (0.56). Since the outlier's data have been recognised in this analysis, it has impacted the R^2 of the graph. However, it has been proven that denser concrete generally provides higher strength and fewer voids and porosity.

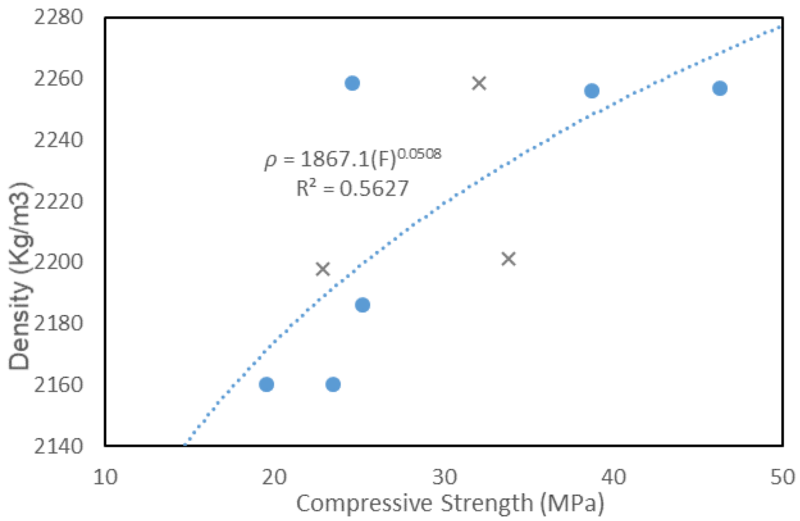

Fig. 10 - Effect of compressive strength on the density of concrete

4. Conclusion

Overall, few conclusions can be concluded in this study. Firstly, concrete with high characteristic strength had the most negligible porosity value based on the saturation technique. For example, concrete grade 20 has a porosity value of 9.76 %. Likewise, concrete grade 30 has a porosity value of 9.53 %, and concrete grade 40 has a porosity value of 8.23 %. In this study, the infrared images are based on the Thermal Diameter Reduction (TDR) rate of concrete. The result shows that porosity affected the TDR with reliable accuracy of 80%. Secondly, the correlation between compressive strength shows coefficient (R^2) is 0.9. The TDR rate trend shows that the concrete with high characteristic strength is in a less porous state, which means it is denser and transfers heat slowly to the surface, thus making the concrete a minimum TDR value. However, the inner TDR rate shows that it is not suitable to determine the correlation of porosity with the characteristic strength of concrete. Therefore, further research can be recommended by using other software to analyse the porosity of concrete and using point heat to the concrete surface instead of surrounding heat to get the infrared images data.

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References

[1] Z. Li, "Introduction to Concrete," *Adv. Concr. Technol.*, no. April, pp. 1–22, 2011, doi: 10.1002/9780470950067.ch1.

[2] S. Y. Chung, P. Sikora, T. Rucinska, D. Stephan, and M. Abd Elrahman, "Comparison of the pore size distributions of concretes with different air-entraining admixture dosages using 2D and 3D imaging approaches," *Mater. Charact.*, vol. 162, no. August 2019, p. 110182, 2020, doi: 10.1016/j.matchar.2020.110182.

[3] C. Lian, Y. Zhuge, and S. Beecham, "The relationship between porosity and strength for porous concrete," *Constr. Build. Mater.*, vol. 25, no. 11, pp. 4294–4298, 2011, doi: 10.1016/j.conbuildmat.2011.05.005.

[4] X. Chen, S. Wu, and J. Zhou, "Influence of porosity on compressive and tensile strength of cement mortar," *Constr. Build. Mater.*, vol. 40, pp. 869–874, 2013, doi: 10.1016/j.conbuildmat.2012.11.072.

[5] P. A. Claisse, Ã. J. G. Cabrera, and D. N. Ã. Hunt, "Measurement of porosity as a predictor of the durability performance of concrete with and without condensed silica fume," no. July, 2014, doi: 10.1680/adcr.13.4.165.39285.

[6] R. Shabbar, P. Nedwell, and Z. Wu, "Porosity and Water Absorption of Aerated Concrete with Varying Aluminium Powder Content," *Int. J. Eng. Technol.*, vol. 10, no. 3, pp. 234–238, 2018, doi: 10.7763/ijet.2018.v10.1065.

[7] M. Safiuddin, H. B. Mahmud, and M. Z. Jumaat, "Efficacy of ASTM Saturation Techniques for Measuring the Water Absorption of Concrete," *Arab. J. Sci. Eng.*, vol. 36, no. 5, pp. 761–768, 2011, doi: 10.1007/s13369-011-0080-6.

[8] B. Wei Chong *et al.*, "Image analysis of surface porosity mortar containing processed spent bleaching earth," *Materials (Basel).*, vol. 14, no. 7, 2021, doi: 10.3390/ma14071658.

[9] G. F. Sirca and H. Adeli, "Infrared thermography for detecting defects in concrete structures," *J. Civ. Eng. Manag.*, vol. 24, no. 7, pp. 508–515, 2018, doi: 10.3846/jcem.2018.6186.

[10] A. Zaki, Y. Jusman, M. A. M. Johari, and W. M. A. W. Hussin, "Image Processing for Corrosion Quantification in Concrete Slabs using GPR data," *J. Phys. Conf. Ser.*, vol. 1471, no. 1, 2020, doi: 10.1088/1742-6596/1471/1/012049.