Load-Displacement Response of Oil Palm Shell Concrete Compressive Test Using Digital Image Correlation

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Abstract. Study of compressive strength of oil palm shell (OPS) concrete has been conducted by varying the content of admixture of silica fume and fly ash to increase concrete strength. Digital Image Correlation (DIC) was used as a tool to capture the physical change of concrete cube during the test which can be converted to load-displacement response by using open source software, Ncorr. It is evident that DIC can be carried out with ordinary camera DSLR which reveal from test result. Poison’s ratio as a ratio between lateral and vertical displacement is successfully obtained. The value are between 0.2096 to 0.2264. Concrete strength improved by 30% to 43% by adding the admixture, silica fume and fly ash.

1. Introduction

Digital image processing named as Digital Image Correlation (DIC) in civil engineering is one of tools to capture displacement and strain of an object during test. Those are measured by tracking the difference between two digital images, prior and after testing. The correlation between the two images was analyzed in order to find the position of a point in the region of interest (ROI). Hence, analysis of displacement and strain can be conducted. Traditional experiment usually employs a set of LVDT located on particular position to obtain deformation that points and install strain gauge to capture strain development and that equipment are connected to data logger. The more data needed the greater number of equipment required.

With the development of digital camera, DIC is now vastly applicable in experimental study. It helps researcher to capture crack propagation and displacement along structural element with the change of loading applied. Research conducted by Sneed, et al [1] employed DIC to capture displacement and crack mouth opening displacement of column found that the results obtained from DIC was close with results measured by LVDT. Similar results confirmed by Beizaee, et al [2] and Huang [3] that DIC results was accurate. All those researches used high resolution of digital camera accompanied by licensed software to analyses the data. However, research conducted by Aghlara [4] proved that DIC can be conducted by employing ordinary camera. Moreover, open source MatLab software, Ncorr [5], is currently available as data processing.

DIC is seldom used in structural testing in Indonesia perhaps due to lack of experience. As a part of research conducted on Oil Palm Shell (OPS) concrete, bearing in mind to employ DIC to capture load displacement response of concrete cube under compressive test by using ordinary camera, DSLR Canon
EOS 1300D with an 18-megapixel resolution. Open source software, Ncorr – matlab, was used as data processing to obtain displacement.

Indonesia and Malaysia are two which produce accounts for 85 to 90% of total global palm oil production [6]. In 2017, there were around 37.8 million tons of palm oil produced derived from around 14 million ha of plantation areas across different regions in the country [7]. The solid waste as a result of palm oil production is in shell form, the so-called Oil Palm Shell (OPS). It is one of the wastes produced during palm oil processing and produced massively in Indonesia.

As a part of environmental conscious, civil engineer is challenged to invent building material by utilizing waste material, and OPS is one of the alternatives that can be utilized as substitute aggregate in concrete mixture. Several studies have been conducted of OPS concrete in Malaysia and Indonesia [8 – 14]. The research found that OPS concrete is categorized as lightweight concrete since the density is in range of 1120-1920 kg/m3 according to ACI 213R-03 [14]. Yew et al [8] investigated effect of different species (OPS) coarse aggregates on the properties of high strength lightweight concrete in Malaysia. It was found that is possible to produce OPS high strength light weight concrete until 55 MPa by selecting OPS aggregates aged between 10 and 15 years old. In this case, OPS concrete also can be use potentially in construction application that require low to moderate strength concrete for lightweight concrete mixture [9].

In Indonesia, study of OPS concrete result the OPS concrete strength still in range of 20-23 MPa [10]. Research conducted by Lee, et.al [11] found that pretreatment of OPS was required to eliminate oily surfaces inside the shell and hot water treatment slightly increase concrete strength than normal water treatment. Study of OPS concrete have been carried out to structural element such as slab and beam [11-13]. In order to improve OPS concrete strength, study was conducted by varying content of two different admixtures, silica fume and flying ash. Pretreatment suggested by former research was adopted. The OPS species is *Elaeis guineensis fo. tenera* which comes from the island of Sumatra, specifically from Bengkulu Province. DIC was used to capture load - displacement curve during compression test. At the end of study, poison’s ratio as one of important material properties of OPS concrete was obtained.

2. Experimental Study

2.1. Mix Design of OPS Concrete

Table 1 present mechanical properties of OPS and sand whereas Table 2 shows mix design composition of OPS concrete. In general, weight comparison between cement, sand and OPS are 1: 1.72: 0.35 with water cement ratio is 0.35. Admixture of silica fume, fly ash, and superplasticizer were added with different portion as shown in Table 2. There are four specimens with admixture named as FFI, FF2, FS1 and FS2 and one without admixture (N). Silica fume (SF) and fly ash (FA) meant to increase concrete strength, meanwhile superplasticizer (SP) was to improve workability or slump. Based on prior research [14], treatment of OPS should be done to eliminate oil from the shell. Hot water of 50oC was recommended to be used as washing water since it results higher compressive strength than treatment with common room water (+28oC). The same treatment was adopted in this study.

Range of slump of specimens with admixture were 9.5 to 12.8cm and specimen without admixture was 3cm. To obtain concrete strength, a compressive test were conducted on 15 x 30cm cylinder which were tested on 7, 14, and 28 days. Table 3 presents density, slump and compressive test results. Similar with former research, the OPS concrete have density in the range of 1866 – 1875 kg/m3 which can be categorized as lightweight concrete [15].
Table 1. Properties of OPS and sand

| Property materials          | OPS  | Sand |
|----------------------------|------|------|
| Spesific Gravity (SG)      | 1.123| 2.44 |
| Absorption                 | 19.19%| 3.31%|
| Bulk Density (Compacted)    | 681 kg/m³ | 1625 kg/m³ |
| Size Max. Aggregate        | 10 mm | -    |
| Fm (smoothness modulus)     | 1.413| 2.78 |
| Abration value              | 3.14%| -    |
| Organic content test        | No. 5| No. 1|

Table 2. Mix design composition of OPS concrete

| Specimen                  | Weight (kg/m³) |
|---------------------------|----------------|
|                           | Cement | Sand | OPS | Air | SF | Fly Ash | SP |
| FS1 (6.5% SF; 1.2% SP)    | 500    | 860  | 273 | 175 | 32.5| -       | 6  |
| FS2 (5.0% SF; 1.0%SP)     | 500    | 860  | 273 | 175 | 25  | -       | 5  |
| FF1 (6.5% FA; 1.2% SP)    | 500    | 860  | 273 | 175 | -   | 32.5    | 6  |
| FF2 (5.0% FA; 1.1% SP)    | 500    | 860  | 273 | 175 | -   | 25      | 5.5|
| N (control concrete)      | 500    | 860  | 273 | 175 | -   | -       | -  |

Table 3. Density, slump, and compressive test results

| Specimen                  | Compressive strength (MPa) | Percentage of increasing relative to N | Density (kg/m³) | Slump (cm) |
|----------------------------|----------------------------|----------------------------------------|-----------------|------------|
|                            | 7 days | 14 days | 28 Days |                                      |             |             |
| FS1 (6.5% SF; 1.2% SP)    | 28.33  | 31.25   | 31.72    | 43.60%                             | 1871        | 9.7         |
| FS2 (5.0% SF; 1.0%SP)     | 26.26  | 28.72   | 30.3     | 37.20%                             | 1867        | 10.2        |
| FF1 (6.5% FA; 1.2% SP)    | 26.74  | 29.03   | 29.5     | 33.50%                             | 1876        | 9.5         |
| FF2 (5.0% FA; 1.1% SP)    | 24.02  | 26.18   | 28.79    | 30.30%                             | 1875        | 12.8        |
| N (control concrete)      | 19.38  | 21.85   | 22.09    | -                                   | 1866        | 3.5         |

2.2. DIC setup for Compressive Test Monitoring

Figure 1 shows setup of compressive test and apparatus prepared for DIC. Compressive strength test of concrete was carried out according to ASTM C39/C39M-18 Standard [16]. Test for compressive strength in this research is done by using a compression test machine with small cylinders at ages 7, 21 and 28 days. Ordinary digital camera, DSLR Canon EOS 1300D with an 18-megapixel resolution, were used as camera 1. It was connected to the shutter with speed of 1/50 second which was controlled by remote to take pictures during the test. Camera 1 was intended to capture speckle from concrete cube. Camera 2 is a camcorder with 9-megapixel resolution meant to record dial indicated concrete strength during test shown by compression machine. Record from two cameras will be synchronized by using the digital watch attached to compressive test machine. The recording process were conducted from the beginning until concrete reach its maximum strength and fail.

For DIC study, a cube of 15 x 15 x 15 cm were prepared to be tested on 28-days age. Prior testing, the concrete cube was imposed by speckle pattern. It was manually conducted to control spacing and size pattern. The pattern is the most integral part of DIC analysis as it determines how the images will be interpreted by the software. It should be uniform, not biased to one side, and adequately spaced.
Camera need to be set up on a tripod so that the images taken could all be uniformly still and steady. It is also important to ensure that the camera stay in focus during the test. Hence, optimum distance of the camera to the object should be investigated prior testing. To provide sufficient lighting, a spotlight was also employed. It is important to note that vibrations of any kind; for example, from movement of camera or wind from fan, should be minimized. Since DIC analysis is based on movement of speckle pattern due to compressive testing, any movement resulted from other sources could disturb the accuracy of the experiment.

![DIC setup](image)

**Figure 1. DIC setup**

3. **Results and Discussion**

3.1. **Compressive Strength Test**

Figure 2 shows compressive strength of OPS concrete in different concrete age. It is noted that OPS concrete with admixture have higher compressive strength than those without admixture. The range of strength are 31.72 to 28.79 MPa which are 30% to 43% higher than specimen without admixture which is only 22.09 MPa. Specimen FS1 which contain of 6.5% silica fume and 1.2% of superplasticizer has the highest strength as 31.25 MPa. It is evident that addition of admixture, silica fume and fly ash, improve strength of OPS concrete. In addition, silica fume increase concrete strength slightly better than fly ash, as the difference is about 7%.

![Compressive Strength of OPS Concrete](image)

**Figure 2. Compressive Strength of OPS Concrete**
3.2. Load - Vertical Displacement Response

Figure 3 shows one example of comparison between real test and DIC record that have been analysed by Ncorr software which is displayed in displacement countour. As shown, crack that appear on real test is detected as different vertical displacement at adjacent distance which shown as different colour. The change of contour with additional load during test until maximum load of all specimens are shown in Figure 4. Based on DIC results, load versus vertical displacement of each specimen are plotted on Figure 5. The initial gradient of this graph is defines as elastic stiffness and presented on Table 4. Similar with concrete strength results, elastic stiffness of specimens with admixture are higher in the range of 925.16 – 1083.37 kN/mm, whereas specimen without admixture has only 726.96 kN/mm of stiffness. It seems that, the magnitude of stiffness is determined by concrete strength.

![Development of displacement contour of OPS concrete](image1)

**Figure 3.** Development of displacement contour of OPS concrete

![Diagram V-Displacement of FS2](image2)

**Figure 4.** Diagram V-Displacement of FS2
Figure 5. Load – vertical displacement of OPS Concrete

Table 4. Stiffness of OPS Concrete

| Specimen                          | Stiffness (kN/mm) |
|-----------------------------------|-------------------|
| FS1 (6.5% SF; 1.2% SP)            | 1050.71           |
| FS2 (5.0 % SF; 1.0% SP)           | 1076.31           |
| FF1 (6.5% FA; 1.2% SP)            | 925.16            |
| FF2 (5.0% FA; 1.1% SP)            | 1083.37           |
| N (no admixture)                  | 726.96            |

3.3. Poisson’s Ratio

Poisson’s ratio is one of important material properties which is determined by ratio from lateral displacement and vertical displacement. NCORR software can also provide lateral displacement based on recording image. Figure 6 presents correlation between vertical and lateral displacement of all specimens. By using curve fitting, hence approximate ratio between the two displacements can be determined which is poison’s ratio. The results are presented on Table 5. As can be seen, the values are between 0.2096 to 0.2264.

Figure 6. Lateral vs vertical displacement of OPS concrete

Table 5. Poisson’s ratio of OPS Concrete
4. Conclusion
Study of load-displacement response and poison’s ratio of OPS concrete as one of material properties has been performed by utilizing DIC. Five different concrete compositions have been evaluated incorporating admixture of silica fume, fly ash, and superplasticizer. The concrete strength with addition of two admixtures are 28 to 31 Mpa, which are higher than former research, 20 – 23MPa. OPS concrete with admixture has higher compressive strength by 30% compare to specimen without admixture (22Mpa). Silica fume increase concrete strength better than fly ash which is about 7% higher.

DIC method by utilizing ordinary camera succeed in capturing load-displacement response of concrete cube under compressive test. Open source software, Ncorr, is appropriate to analyse DIC record. Based on analysis, poison’s ratio as one of important material properties of OPS concrete has been successly be obtained. The value are between 0.2096 to 0.2264.

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