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Structural Health Monitoring: GGBS – Foam concrete evaluation for Stress-Strain Characterization

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Abstract

Digital Image Processing (DIP) uses photogrammetry principles to monitor elements in space and attribute respective coordinates to a pre-set reference frame. The comparison makes the measure of a graphic collection taken above fixed intervals. The technique may be performed in many experiments, including compressive, longitudinal, torque, bending, and different combined loading for static and dynamic applications. As the world's engineering structures (such as towers and highways) mature, there seems to be a critical necessity to maintain and analyse the integrity of the system of large buildings. As per the American Society of Civil Engineers (ASCE), there were 161,892 obsolete or technically deficient bridges in the U. S. as of 2008, with the mean lifespan of a bridge being 43 years old. The primary method used to assess deck integrity today is subjectively direct observation, which is unreliable since specific damage can be hard to spot, difficult to quantify visibly, or subject to individual perception. Bridges have lately been monitored using classic detectors like strain gauges and deflection indicators.

Keywords: *Digital Image Processing, graphic collection, classic detectors, strain gauges, deflection indicators.*

1. Introduction

This paper's improvements in living conditions worldwide must focus on environmental subjects through all their forms, particularly buildings. By applying technical and architectural solutions to decrease the energy consumption of the construction products business, decrease ecological footprint, and optimize price and ecological effects, the construction sector hopes to contribute to developing environmentally friendly structures [1]. Finding environmentally friendly building materials is essential since indoor air quality substantially impacts health. The environmental impact of polyethylene garbage disposal is seen as severe due to its abundance and poor biodegradability [2]. When writing, industrial and urban wastes made of GGBS were considered partial replacements for conventional concrete aggregates. Discovering environmentally friendly alternatives to current garbage disposal techniques is thus turning into a big research challenge. On the other hand, it might both immediately and later enhance concrete qualities like tensile properties, chemical stability, dimensional stability, and creep. To limit the utilization of energy and materials, researchers have devised new engineering kinds, such as efficient and environmentally friendly engineering. By minimizing adverse conditions while increasing the positive impact on economic growth, community, and ecosystem, sustainable technology attempts to improve all three. Ecological materials production aims to improve material management, reduce waste, and obtain good physical and mechanical properties. Because of their economic and environmental benefits, plastic trash can be used in various civil engineering applications, including recycling plastic waste and replacing aggregate with concrete. Furthermore, plastic can improve road and pavement construction's strength and durability as a precursor for the synthesis of textiles, as an isolator or conductor in the construction of buildings, and as a fastener for bulk items. Intelligent materials and technologies design structural health monitoring systems' sensor networks and diagnostic and inference procedures. Based on the previously presented broad definition of sustainable design, such an intelligent health monitoring system would result in a sustainable engineering system integrated with any given structural system. For the production of cementitious materials or alkali-activated compounds, the combined application of FA and GGBS predecessors has gained popularity increasingly. This is due to the fact that their joint use can balance out the restrictions placed on every substance used alone. In contrast, Class-F FA (low Ca) requires prolonged curing at increased temperature (usually 60 °C to 80 °C) and sealing while curing to achieve exceptionally high resilience [3,4]. GGBS, which often contains a high amount of calcium, is renowned for having a quick setting time at room temperature and significant dry shrinkage that encourages the growth of micro cracks that may compromise strength. If FA and

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GGBS are blended in the right ratios, these drawbacks can be eliminated [5]. To reduce the fossil fuel consumption, the construction industry has been encouraged to use agro - based residual wastes [6]. In order to build several types of architecture, including roads, structures, and coastal operations, Portland cement is being used [7]. Alkali-activated substances are divided into a subset known as geopolymers. The substantial amount of CO2 that is generated during the production of OPC is minimized by something like cementitious materials. According to reports, Geocretes is an extremely robust substance, which should help typical concretes' problems with durability [8]. All of that is accomplished by utilizing minimally processed organic or inorganic besides [9]. Silica and alumina are often obtained by processors of thermally induced substances or commercial lignocellulosic. The primary elements of geocrete, also known as polyacrylate or alkali-activated concrete, are then converted into molecules networks and supply chains using hydroxide ions [10]. Industrial waste, red mud (RM), Metakaolin (MK), rice husk ash (RHA), Blast furnace slag (BFS), and silica fume ash (SFA) are a few adhesive substances [11-16]. All of these elements were utilized as an additional bonding component. The change between solid wastes to byproduct conditions seems to have a major impact due to ecological imprint involving resource exploitation [17-22]. SCMs are used in chemical composites, which are thought to be more durable than Pozzolanic materials concrete [23-29]. It indicates how geocrete is a great material for speedy building since it can rapidly boost resilience while decreasing waste products [2, 30-32]. A byproduct of the steel and iron industries is known as GGBS [33]. Adding GGBS to a concrete matrix has several benefits, including increased strength, decreased permeability, high resistance to sulfate and chloride attack, and reduced rate of hydration [34]. The inclusion of GGBS in the LDFC matrix demonstrates several benefits, including reduced consumption of natural resources and reduced CO2 emissions due to energy savings. According to [35, 36], rice husk ash (RHA) is a sustainable and environmentally friendly cementitious material that can be used in place of cement in some applications. Because of its amorphous form, fineness, surface area, and compatibility with concrete matrix, the RHA has a silica concentration of 82–89%, which reflects exceptional pozzolanic qualities [37-40].

2. Methodology

It is less optically demanding since ordinary incoherent light is adequate, and no optical components are required. This experiment needs a high-resolution camera for 2D and 3D displacement, a computer, and a frame-grabbing circuit card to digitize the output, as illustrated in Fig. 1. Fig. 1(a) indicates Initial and final pixels before and after applying the loads and Fig. 1(b) shows Initial and final pixels before and after using the loads comparing reference image to deformed image.

The premise is pretty straightforward. A photograph of the specimen's surface is taken with a digital camera. A-frame grabber circuit card is used to download the image from the camera. The CCD array's analog signal is subsequently digitized. The information is saved from being processed later. The target pattern is sprayed on the specimen's surface.

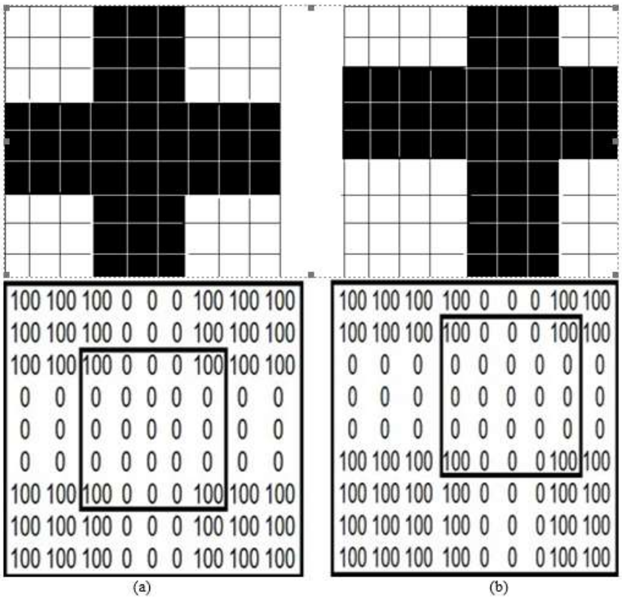

Fig. 1: SHM pattern Initial and final pixels before and after (a) applying and (b) using the loads.

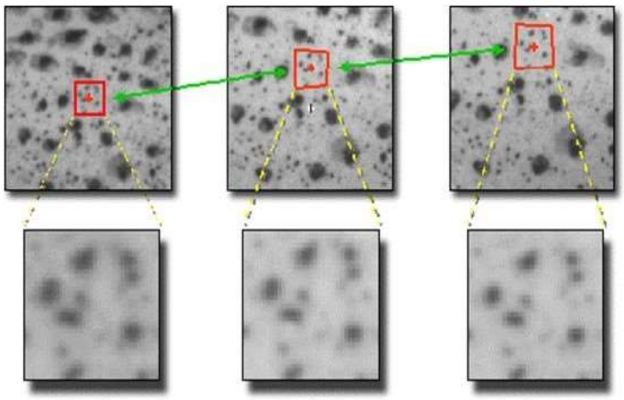

Fig. 2: Images of changing the material on the surface of concrete structures

This is a picture of the model before and after it has been distorted. The intensity measurements at each pixel position on the CCD (charge coupling device-sensor) array before and after are included in the digital picture of the item. A displacement field is created using target characteristics and their locations. Up to 0.02 pixel accuracy has been obtained. It estimates the displacement and cracks of all subsets by tracking the grey value pattern of subgroups.

$$\boldsymbol{C(5,5,-2,-2)} = \sum_{\boldsymbol{i,j=-2}}^{\boldsymbol{2}} \boldsymbol{(I(5+i,5+j) - I^{*}(5-2+i,5-2+j))^2}$$

At the center pixel,

$= (100-0)^2 + (0-0)^2 + (0-0)^2 + (0-0)^2 + (100-0)^2 +$
$(0-100)^2 + (0-100)^2 + (0-100)^2 + (0-100)^2 + (0-0)^2 +$
$= (0-100)^2 + (0-100)^2 + (0-100)^2 + (0-100)^2 + (0-0)^2 +$
$= (0-100)^2 + (0-100)^2 + (0-100)^2 + (0-100)^2 + (0-0)^2 +$
$= (100-100)^2 + (0-100)^2 + (0-100)^2 + (0-100)^2 + (100-0)^2 = 18{,}000$

100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	**0**	**0**	**0**	0	0	0	0
100	100	**100**	100	0	0	0	100	100
100	100	**100**	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100

(a)

100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	**0**	0	0	0	0
0	0	0	0	0	0	0	0	0
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100

(b)

Fig. 3: Displacement (a) Initial C (0, 0, 0, 0) (b) at C (5, 5, -2, -2)

I (x, y) =A + Bfx + Cfy +Dfxfy
Where fx & fy are the fractional part of x & y
A = I (ix, iy)
B = I (ix + 1, iy) + A C + I (ix, iy + 1) + A
D = I (ix + 1, iy + 1) + (A, B, C)
Where ix & iy are the integer part of x & y

2.1 Principles:

- Testing of materials (Young's Modulus, Poisson's Ratio, and Elasto-Plastic Behavior)
- Mechanics of Fracture
- Applications with a Fast Response Time (Dynamic measurements)
- High-tech materials (CFRP, wood, fibre-injected PE, metal foam, rubber, etc.)
- Testing of individual components (Displacements, Strains, etc.)
- The measurement area is variable, ranging from mm^2 to m^2.
- The measurement results include surface contour, 3D displacement, and stresses.
- Sensitivity measurements: down to 1/100,000 of a field of view
- Method of analysis

DIC_GUI (A new tab will open as shown in Fig. 4)
Now we have to insert the undeformed image that is without a crack cube image, as shown in Fig. 5.
Next, we have to insert the deformed image that is with a crack cube image, as shown in Fig. 6.

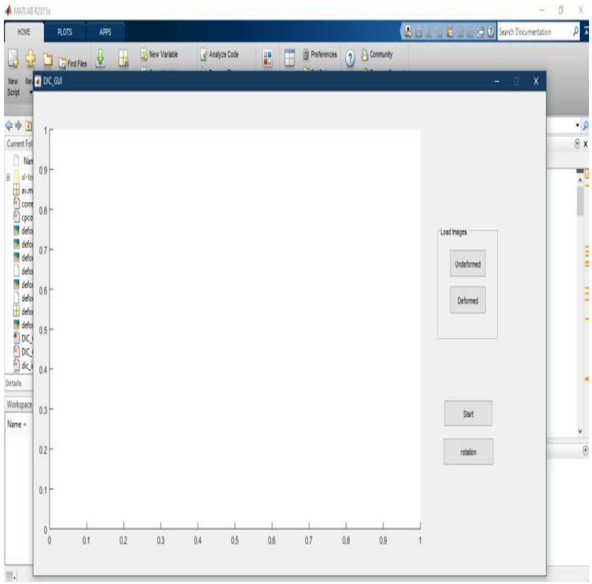

Fig. 4: MATLAB®-DIC_GUI

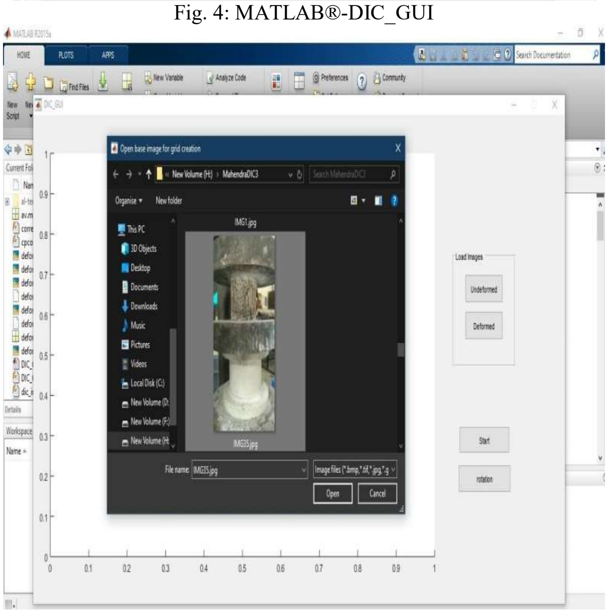

Fig. 5: MATLAB®-select undeformed image

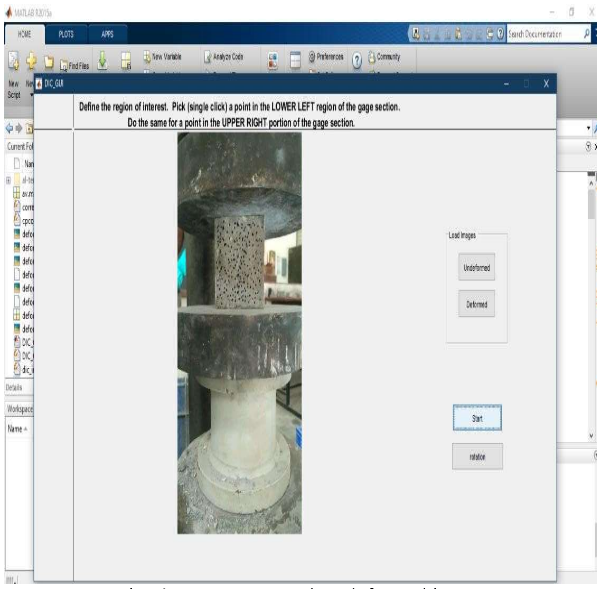

Fig. 6: MATLAB®-select deformed image

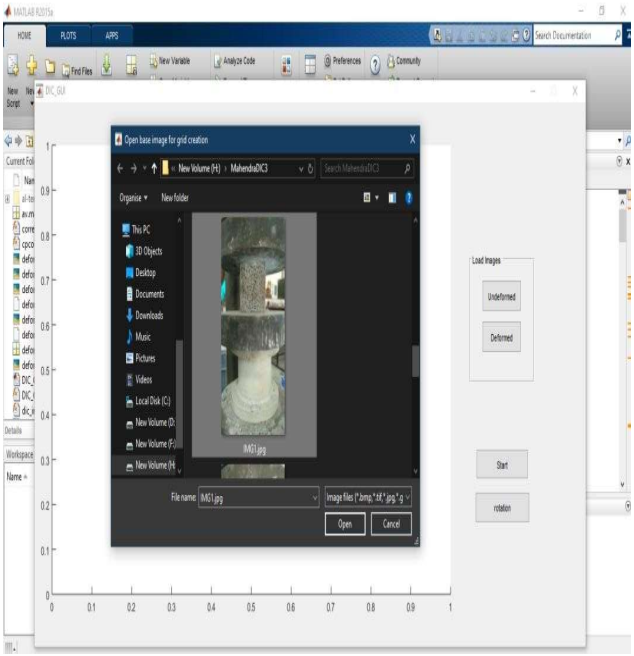

Fig. 7: MATLAB®- Define the region of interest

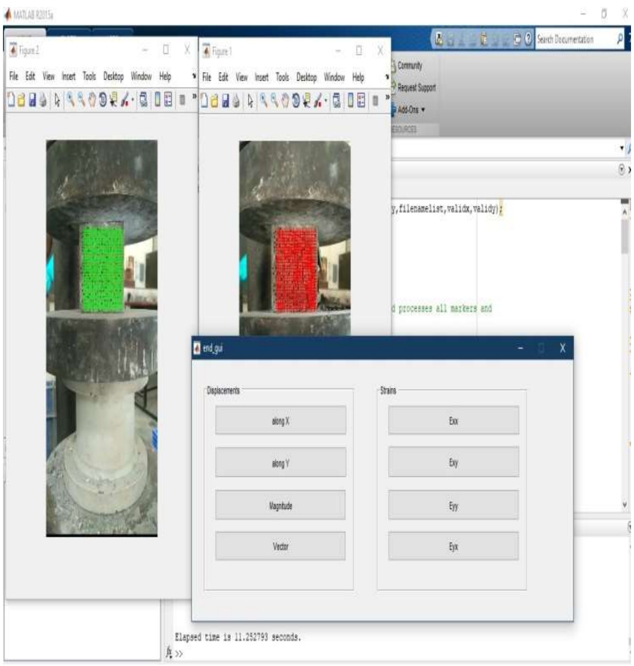

Fig. 8: MATLAB®- for displacement and strains

And then, click on start and define the region of interest (as shown in Fig. 7), i.e., part of interest; one has to select the area where the cracks develop and, by default, give the grid size 10 x 10. Then a new tab will open (as shown in Fig. 8) and go for the result one wants here displacement in x and y direction and magnitude of the respective movement and strains in the different approach, which is ε_{xx}, ε_{xy}, ε_{yy}, and ε_{yx}.

3. Result and Discussions

The various concrete cube specimens were subjected to DIC testing. This progressive equilibration with gradually rising relative stress assisted in the formation of cracks in the different types of cubes. The 3D and 2D surface displacements and strains in concrete were measured using an optical approach (DIC technique) and the accessible mathematical application MATLAB®. The speckle pattern was correctly created on the specimen surface for digital image correlation. MATLAB® was used to process some chosen pictures captured throughout the test. The photographs collected during loading and unloading selected a few suitable images for examination. For correlation, a 20-pixel square grid pattern in the x-direction and 20- a pixel square grid pattern in the y-direction were used.

Fig. 9 depicts 3D surface displacement graphs at various loading levels. The fracture propagation with increasing loading can be observed in all images in Fig. 9.

Finally, the x-direction strain in concrete against the picture number corresponding to the load has been displayed to demonstrate how strain in concrete varies during cyclic loading. With increasing stress, the variance of strain in concrete measured by the DIC method rises. The DIC method analyses the damage in concrete cubes by measuring the pressures in the concrete.

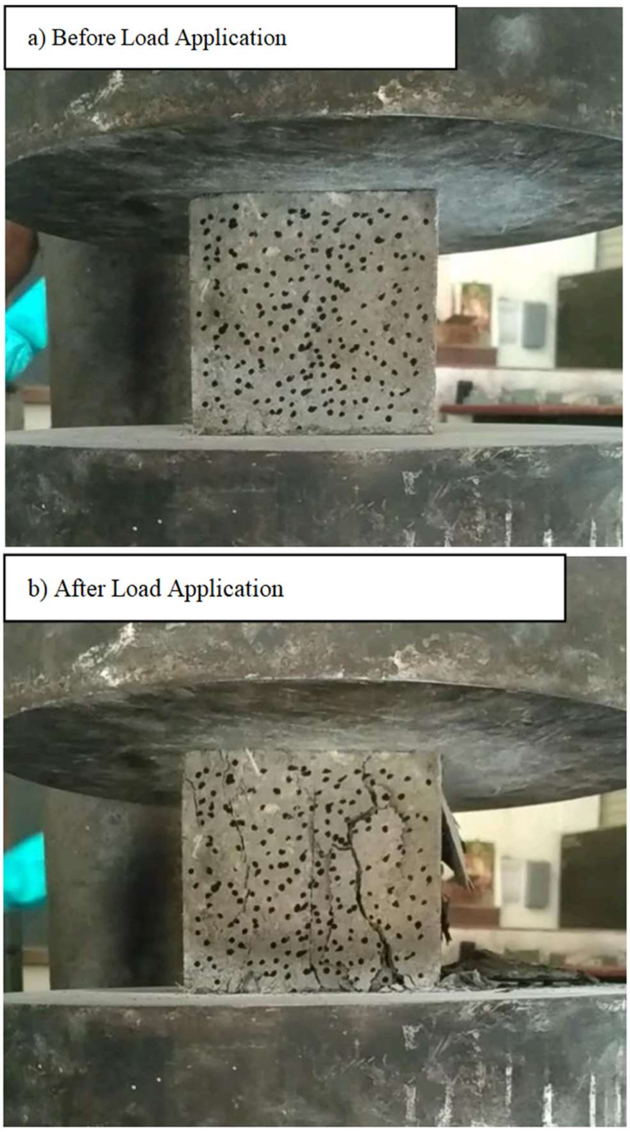

Fig. 9: Speckled pattern marked cube (a) before and (b) after applying load for control mix.

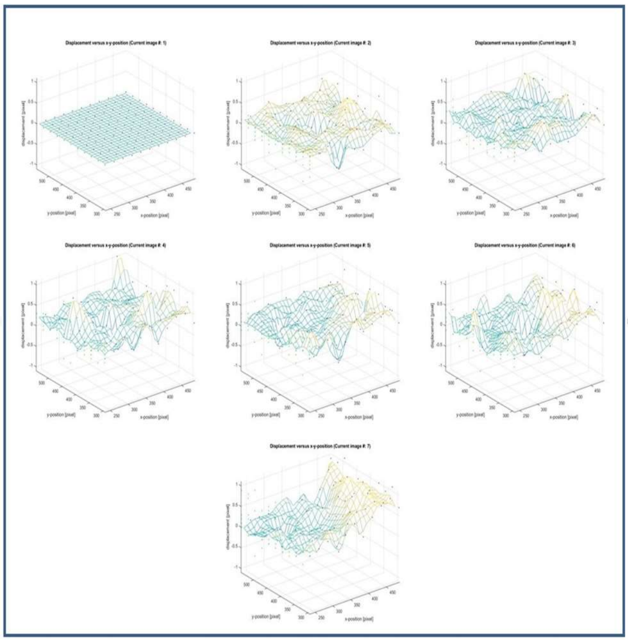

Fig. 10: Deflections graph for different loading conditions for control mix

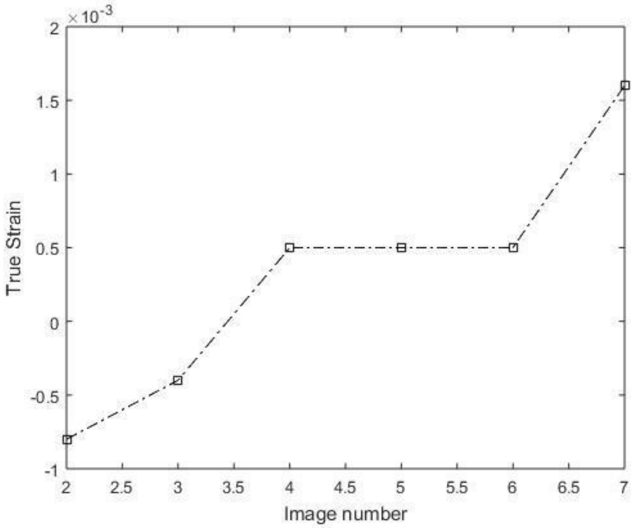

Fig. 11: Strain graph for control mix

3.1 *Displacement graphs:*

3.2 strain graph:

3.3 2-d displacement diagram:

The displacement diagrams are as follows Fig. 13(a) shows the displacement in the x-direction, Fig. 13 (b) shows the removal in the y-direction, and Fig. 13(c) shows the displacement in the resultant direction. Fig. 13(d) shows the vector.

3.4 2-d strain diagram:

The strain diagram shows the strains in Ɛxx, Ɛxy, Ɛyy, and Ɛyx

As shown in Table 1 here shows the strain (in pixels) and then converted into strain(in mm); then, to find out the stress, one has to consider the young's modulus of the concrete, which can be found by using this formula (E = 5000 √(fck) MPa). G0 mix is 0% GGBS replacement, is the control mix, G1 is 10% GGBS replacement, G2 is 20% GGBS replacement, G3 is 30% GGBS replacement, G4 is 40% GGBS replacement, and the last G5 is 50% replacement of GGBS waste. The statistical method computed all the mixes in MATLAB® software by the DIC technique. Now compare the stress for G0, G1, G2, G3, G4, and G5; one can see that up to the G3 mix, the pressures are increasing, then it started decreasing the stress so by these results, we can conclude that the up to G3 mix strength is higher compared to other mixes, therefore up to 30% GGBS waste replacement can be done in construction.

As shown in Table 2 here shows the strain (in the x-direction), strain (in the x-direction), magnitude, and vector are given, and then found out the maximum strain from that results in strain (in mm); then again, to find out the stress we have to consider the young's modulus of the concrete which can be found out by using this formula (E = 5000 √ (fck) MPa). The finite element method computed all the mixes in MATLAB® software by the DIC technique. Now compare the stress for G0, G1, G2, G3, G4, and G5; one can see that up to the G3 mix, the stresses are increasing, then it started decreasing the stress so by these results, we can conclude that the up to G3 mix strength is higher compared to other mixes, therefore up to 30% GGBS waste replacement can be done in construction.

Table 1: DIC results for different mix proportions (E = 5000 √ (fck) MPa)

Mix	Strain (ε) pixel/ pixel	Strain (ε) mm/mm	Stress (σ = Eε) MPa
G0	1.3 x 10-3	0.158 x 10-3	3.94
G1	1.55 x 10-3	0.196 x 10-3	4.91
G2	1.6 x 10-3	0.208 x 10-3	5.19
G3	2.2 x 10-3	0.222 x 10-3	5.54
G4	1.8 x 10-3	0.216 x 10-3	5.39
G5	0.8 x 10-3	0.168 x 10-4	4.20

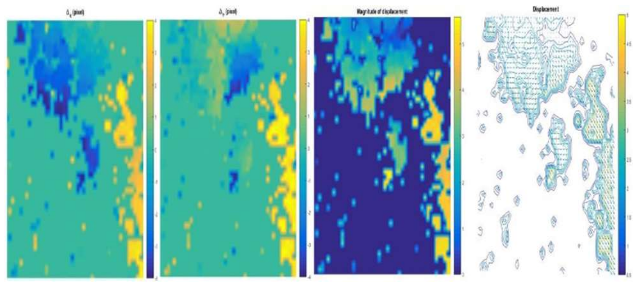

Fig. 12: Displacement (pixel) (a) x-direction (b) y-direction (c) Magnitude (d) Vector

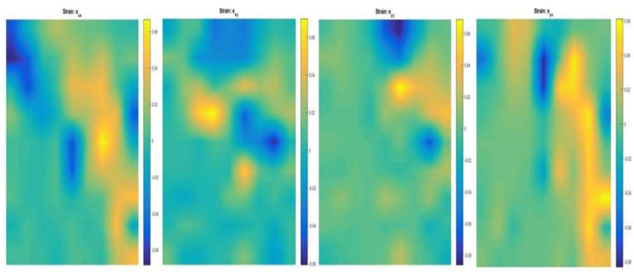

Fig. 13: Strain (pixel/ pixel) (a) Ɛxx (b) Ɛxy (c) Ɛyy (d) Ɛyx
And so on for G0 to G5.

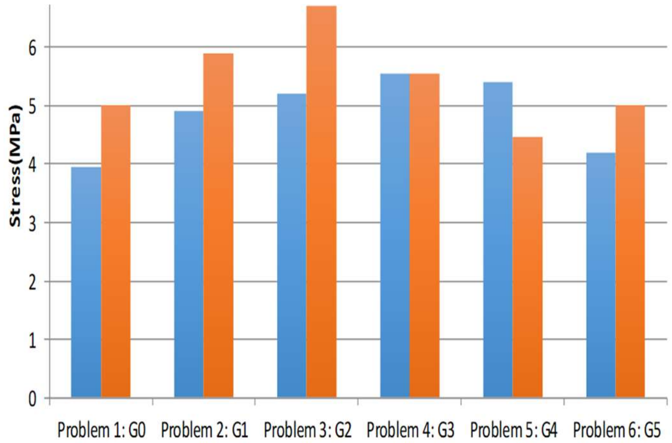

Fig. 14: Comparision of statistical and finite element method results

Table 2: FEM DIC results for different mix proportions

Mix	G0	G1	G2	G3	G4	G5
Δx (pixel)	-4 _ 4	-4 _ 4	-4 _ 4	-4 _ 4	-4 _ 4	-4 _ 4
Δy (pixel)	-4 _ 4	-4 _ 4	-4 _ 4	-4 _ 4	-4 _ 4	-4 _ 4
Magnitude (pixel)	0 _ 5.5	0 _ 5.5	0 _ 5.5	0 _ 5	0 _ 5.5	0 _ 5
Vector (pixel) (10^{-2})	8(50x8)	9(90x9)	2.5(19x2.5)	10(45x10)	8(45x8)	4.5(56x4.5)
Ɛxx (pixel/pixel) (10^{-2})	-7 _ 7	-8 _ 7	-1.5 _ 2	-10 _ 10	-5 _ 2.5	-2 _ 1.5
Ɛxy (pixel/pixel) (10^{-2})	-6 _ 7	-4.5 _7	-1.5 _ 2	-8 _ 8	-3.5 _ 3	-1 _ 2
Ɛyy (pixel/pixel) (10^{-2})	-8 _ 7	-4.5 _ 6	-1.5 _ 2.5	-6.5 _ 8	-8 _ 8	-2.5 _ 4.5
Ɛyx (pixel/pixel) (10^{-2})	-8 _ 6	-9 _ 5	-1.5 _ 5	-2 _ 6	-7 _6	-4 _ 1.5
Max (Ɛ) (pixel/pixel) (10^{-2})	8	9	2.5	10	8	4.5
Stress (MPa)	5	5.9	6.7	5.55	4.46	5

4. Conclusions

Since various SHM methods can detect damage to composite structures, no single approach has proven helpful in all situations. It should also be noted that there are too many methods available today to be considered in one article. Therefore, the focus is on strategies that can be used as a starting point for studying the detection, location, evaluation, and prediction of damage in specific structures to search for ideologically oriented goals behind the system. However, outside the scope of the work, it is believed that once the above is understood, an updated abstract like this might be helpful to other researchers in the same field.
As shown in Fig. 14, it is suitable to replace coarse aggregate with recycled GGBS waste for up to 30%; after that, strength decreases. DIC is suitable for displacement & strain measurements. Simple, economical, and flexible. Recycled GGBS mix can be used for temporary and minor road construction. DIC results show good stress values up to 30% GGBS replacement.

Disclosures

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