Effect of Different Geometrical Patterns on Mechanical Properties of GRC Modules with Varying Thickness Having Same Area

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Abstract— GRC is a family of closely related materials, the design stresses to be used is depend on the choice of formulation and manufacturing process. Furthermore, it is influenced by the environment to which it is subjected. Also, each individual material has several design stresses levels because the material characteristics result in different strengths, dependent upon the type of loading and the section being loaded. In this paper, mechanical properties of different geometric GRC modules (Rectangle, Square, Triangle, and Trapezoidal) are evaluated considering same area and varying skin thickness. The aim of this paper is to evaluate the variation in the physical properties of GRC like MOR, LOP and deflection with respect to the shape and the size of the module. This paper concludes that considering the primary criteria of design either MOR, LOP or deflection for GRC modules, desirable shape of the module also changes.

Keywords: GRC, MOR, LOP, skin thickness, module

I. INTRODUCTION

Glassfibre reinforced concrete (GRC) elements have become a sought-after cladding material since their first introduction as cladding material for buildings. Cladding system is designed with geometrically simple GRC elements based on a flat building pattern and requirement of the client. The design of any product has to satisfy many requirements. Adequate strength against the specified loads is an obvious requirement, and therefore mechanical design is commonly be performed to ensure satisfactory performance of any GRC element. MOR (Modulus of Rupture) and LOP (Limit of Proportionality) plays an important role in the design of GRC modules. This paper presents an innovative approach to the manufacture of GRC as façade cladding for buildings with a range of different geometries considering skin thickness varying from 10 mm to 20 mm. Area for all the geometries is kept same.

II. LITERATURE REVIEW

In this paper various complexity of thin-walled GFRC element such as 1-Dimentional, 2-Dimentional and 3-Dimentional are studied based on current architectural and aesthetic requirements to obtain the boundaries for most appropriate production method. This study can produce the various guidelines for future design of GFRC and it can allow an innovative attitude to additional development the available moulding techniques for thin-walled GFRC elements for a variety of complex geometry building envelopes. From the result and output it is concluded that additional steps need to be taken to advance thin-walled glass fibre reinforced concrete for future architectural buildings envelopes with complex geometries [1].

In this paper properties of cement composites prepared from alkali-resistant Cem-FIL glass fibres and Portland cement and then modified by styrene-butadiene rubber (SBR) latex which is kept in three different environments for a period of 15 years are studied. From the result it is seen that by adding SBR the long-term weather ability of GRC composites is upgraded. In air storage SBR-modified GRC has remained strong and tough up to the period of study but the polymer did not reduce the extent of long-term strength loss in GRC in wet environments. A proportion of the cement in GRC modified by SBR can be replaced by pulverized fuel ash without sacrificing the improvements in the long-term weathered strength of the composite brought about by polymer addition [2].

In this paper, function reinforcement level and binder consumption are studied. Physical and mechanical properties along with the flexural and compression strength of GFRC is examined. The correlation between long-term strain (creep and shrinkage) and the reinforcement level has been identified as well. From the result it is concluded that adding glass fibre would cause significant growth of flexural strength however there is minor decrease in compressive strength. Experiment proved that adding high reactivity metakaolin as modifier will increase the flexural and compressive strength than usage of micro-silica or fulleroid nano--modifier. They also concluded that the obtained results may be used to evaluate the effect of various modifiers on the properties of GFRC [3].

III. METHODOLOGY

In this paper, different geometrical patterns of GRC modules such as Rectangle, Square, Triangle and Trapezoidal are considered. Each geometrical pattern of GRC modules having same area of 4 m^2 with varying thickness of 10 mm to 20 mm with increment of 2 mm. To establish this analytical study some of the parameters are assumed as per standard guide and the material available for the same. All the assumed parameters are same for all the geometrical patterns. With the standard design, MOR, LOP and deflection values are obtained and plotted on a graph with average value to conclude the results.

IV. ANALYTICAL DETAILS

Following are the four types of geometrical details for GRC modules i.e. rectangle, square, triangle and trapezoidal. These patterns are used for design and analysis to obtain MOR, LOP and Deflection values.

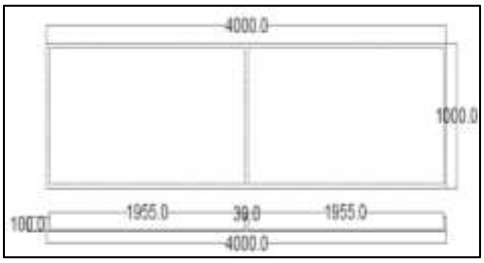

Fig. 1. Rectangular panel geometry

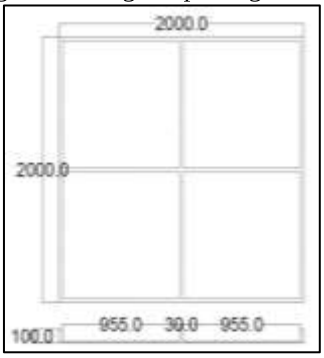

Fig. 2. Square panel geometry

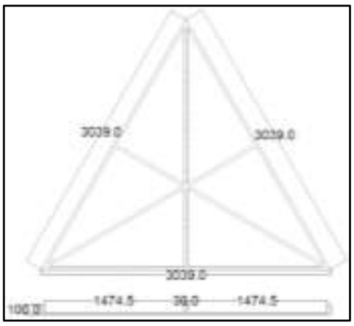

Fig. 3. Triangular panel geometry

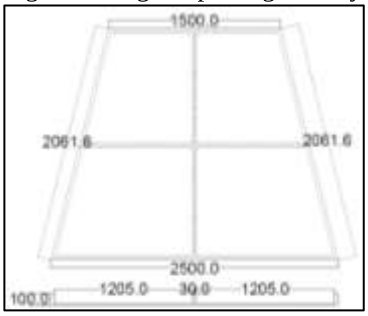

Fig. 4. Trapezoidal panel geometry

Sr no.	Geometrical pattern	Width	Height	Area	Thickness	Least Moment of Inertia	Least Section Modulus
1	Rectangle	4 m	1 m	4 m^2	10 mm	1.673 x 10^7	2.304 x 10^5
2	Rectangle	4 m	1 m	4 m^2	12 mm	1.718 x 10^7	2.318 x 10^5
3	Rectangle	4 m	1 m	4 m^2	14 mm	1.745 x 10^7	2.321 x 10^5
4	Rectangle	4 m	1 m	4 m^2	16 mm	1.762 x 10^7	2.320 x 10^5
5	Rectangle	4 m	1 m	4 m^2	18 mm	1.770 x 10^7	2.315 x 10^5
6	Rectangle	4 m	1 m	4 m^2	20 mm	1.774 x 10^7	2.311 x 10^5
1	Square	2 m	2 m	4 m^2	10 mm	2.004 x 10^7	2.487 x 10^5
2	Square	2 m	2 m	4 m^2	12 mm	2.028 x 10^7	2.486 x 10^5
3	Square	2 m	2 m	4 m^2	14 mm	2.038 x 10^7	2.481 x 10^5
4	Square	2 m	2 m	4 m^2	16 mm	2.041 x 10^7	2.476 x 10^5
5	Square	2 m	2 m	4 m^2	18 mm	2.041 x 10^7	2.475 x 10^5
6	Square	2 m	2 m	4 m^2	20 mm	2.042 x 10^7	2.479 x 10^5
1	Triangle	3.039 m	2.631 m	4 m^2	10 mm	2.170 x 10^7	2.569 x 10^5
2	Triangle	3.039 m	2.631 m	4 m^2	12 mm	2.181x 10^7	2.564 x 10^5
3	Triangle	3.039 m	2.631 m	4 m^2	14 mm	2.183x 10^7	2.559 x 10^5
4	Triangle	3.039 m	2.631 m	4 m^2	16 mm	2.183 x 10^7	2.561 x 10^5
5	Triangle	3.039 m	2.631 m	4 m^2	18 mm	2.186 x 10^7	2.571 x 10^5
6	Triangle	3.039 m	2.631 m	4 m^2	20 mm	2.195 x 10^7	2.592 x 10^5
1	Trapezoid	a =1.5 m, b = 2.5 m	2 m	4 m^2	10 mm	1.874 x 10^7	2.419 x 10^5
2	Trapezoid	a =1.5 m, b = 2.5 m	2 m	4 m^2	12 mm	1.907 x 10^7	2.423 x 10^5
3	Trapezoid	a =1.5 m, b = 2.5 m	2 m	4 m^2	14 mm	1.925 x 10^7	2.420 x 10^5
4	Trapezoid	a =1.5 m, b = 2.5 m	2 m	4 m^2	16 mm	1.932 x 10^7	2.415 x 10^5
5	Trapezoid	a =1.5 m, b = 2.5 m	2 m	4 m^2	18 mm	1.935 x 10^7	2.411 x 10^5
6	Trapezoid	a =1.5 m, b = 2.5 m	2 m	4 m^2	20 mm	1.935 x 10^7	10^5

Table I: Geometrical Details of GRC Modules

V. DESIGN GUIDELINES

Following are the design guidelines given by the Practical design Guide for Glassfibre Reinforced Concrete (GRC). (Using Limit State Theory):

A. Calculate Characteristic load

Characteristic load is that value of load which has a 95 % probability of not being exceeded during the life time of the structure. Wind load plays an important role in the design of GRC module. In this paper, wind load is calculated assuming some of the parameters from IS 875 (Part 3): Design Load (Other than Earthquake) for Building and Structures – Code of practice

Design wind speed,

$$V_Z = V_b \times K_1 \times K_2 \times K_3$$

Design wind pressure,

$$P_Z = 0.6 \times (V_Z)^2$$

where,
V_z = Design wind speed
V_b = basic wind speed = 44 m/s
K_1 = Probability factor = 1
K_2 = terrain roughness and height factor = 0.927
K_3 = topography factor = 1
P_z = Design wind pressure = 1 KPa

B. Calculate load factor

Load factor is combination of partial safety factors
Load factor for MOR

$$\gamma_f = \gamma_f' \times \gamma_{tv} \times \gamma_b \times \gamma_c$$

For LOP no partial safety factors are considered.
where,
MOR = Modulus of Rupture
LOP = Limit of Proportionality
γ_f' = load factor = 1.4
γ_{tv} = factor for variations in thickness of GRC, hand spread moulded = 1.1
γ_b = factor for differences in bending between test coupons and full-size sections = 1
γ_c = factor for mode of collapse and consequences of failure = 1

C. Calculate design load

For MOR,

$$F_d = F_k \times \gamma_f$$

For LOP,

$$F_s = F_k$$

where,
F_d = ultimate design load
F_s = serviceability design load
F_k = Characteristic load

D. Calculate section properties of GRC

Obtain GRC module properties such as area, moment of inertia, and section modulus

E. Calculate bending stress

For MOR,

$$\sigma_{ub} = \frac{M}{Z}$$

For LOP,

$$\sigma_{sb} = \frac{M}{Z}$$

where,
σ_{ub} = ultimate bending stress
σ_{sb} = serviceability bending stress
M = Moment
Z = Section modulus

F. Estimate shrinkage and thermal stresses for design

σ_{ss} = 0.6 (full term external)
σ_{ts} = 1 (for dry summer)
where,
σ_{ss} = Shrinkage stress
σ_{ts} = Thermal stress

G. Determine global factor of safety

γ_m = global safety factor for ultimate limit state = 3
γ_g = global safety factor for serviceability limit state = 1.8

H. Calculate MOR and LOP required

$$MOR = \gamma_m \times (\sigma_{ub} + \sigma_{ss} + \sigma_{ts})$$
$$LOP = \gamma_g \times (\sigma_{sb} + \sigma_{ss} + \sigma_{ts})$$

I. Calculate ultimate shear force

$$V_u = \frac{(F_d \times A)}{2}$$

where,
V_u = Ultimate shear force
A = Area

J. Calculate required shear stress

$$v_u = \frac{(1.5 \times V_u)}{A_f}$$
$$v_{uk} = \gamma_m \times v_u$$

where,
v_u = Required Shear stress
A_f = Flange area
v_{uk} = Characteristic inter-laminar sear strength

K. Check for allowable shear stress

$$v = 0.4 \times LOP$$

where,
V = Allowable shear stress

L. Check for deflection (δ)

Deflection check is done for serviceability limit state only

$$\delta = \frac{5}{384}\left(\frac{WL^3}{384EI}\right)$$

Allowable deflection = L / 360 for long term loading
where,
δ = Deflection obtained
W = load
L = length
E = modulus of elasticity = 18000 MPa
I = moment of inertia

VI. DESIGN AND ANALYSIS

Table II gives summary of stress, and other mechanical values obtained by following standard guidelines as stated above.

Geometry	Skin thickness	σ_{ub}	MOR	σ_{sb}	LOP	δ	V_u	v_u	v_{uk}
Rectangle	10 mm	3.340	13.62	2.169	6.06	2.76	3.08	0.513	0.872
Rectangle	12 mm	3.487	14.06	2.156	6.04	2.69	3.234	0.539	0.916
Rectangle	14 mm	3.482	14.04	2.153	6.03	2.65	3.234	0.539	0.916
Rectangle	16 mm	3.484	14.05	2.155	6.03	2.62	3.234	0.539	0.916
Rectangle	18 mm	3.541	14.22	2.159	6.04	2.61	3.280	0.546	0.929
Rectangle	20 mm	3.598	14.39	2.163	6.05	2.6	3.326	0.554	0.942
Square	10 mm	6.190	22.17	4.019	9.39	0.57	3.08	0.513	0.872
Square	12 mm	6.503	23.11	4.022	9.39	0.57	3.234	0.539	0.916
Square	14 mm	6.517	23.15	4.030	9.41	0.56	3.234	0.539	0.916
Square	16 mm	6.276	22.42	4.038	9.42	0.56	3.234	0.539	0.916
Square	18 mm	6.626	23.47	4.040	9.43	0.56	3.280	0.54	0.929
Square	20 mm	6.706	23.72	4.032	9.41	0.56	3.326	0.554	0.942
Triangle	10 mm	7.883	27.24	3.891	9.16	2.46	3.08	0.513	0.872
Triangle	12 mm	8.295	28.48	3.899	9.17	2.44	3.234	0.539	0.916
Triangle	14 mm	8.309	28.52	3.906	9.19	2.44	3.234	0.539	0.916
Triangle	16 mm	8.305	28.51	3.904	9.18	2.44	3.234	0.539	0.916
Triangle	18 mm	8.391	28.77	3.889	9.16	2.44	3.280	0.546	0.929
Triangle	20 mm	8.439	28.91	3.857	9.1	2.43	3.326	0.554	0.942
Trapezoid	10 mm	6.365	22.69	4.133	9.60	1.2	3.08	0.513	0.872
Trapezoid	12 mm	6.672	23.61	4.126	9.58	1.18	3.234	0.539	0.916
Trapezoid	14 mm	6.680	23.64	4.131	9.59	1.17	3.234	0.539	0.916
Trapezoid	16 mm	6.694	23.68	4.139	9.61	1.16	3.234	0.539	0.916
Trapezoid	18 mm	6.802	24.00	4.147	9.62	1.16	3.280	0.546	0.929
Trapezoid	20 mm	6.901	24.30	4.149	9.62	1.16	3.326	0.554	0.942

Table II: Summary of Design and Analysis

VII. RESULT AND DISCUSSION

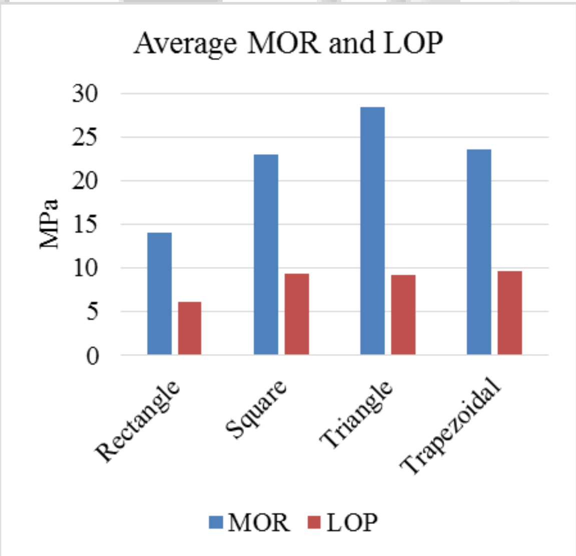

Fig. 5: Average MOR and LOP for different geometric modules

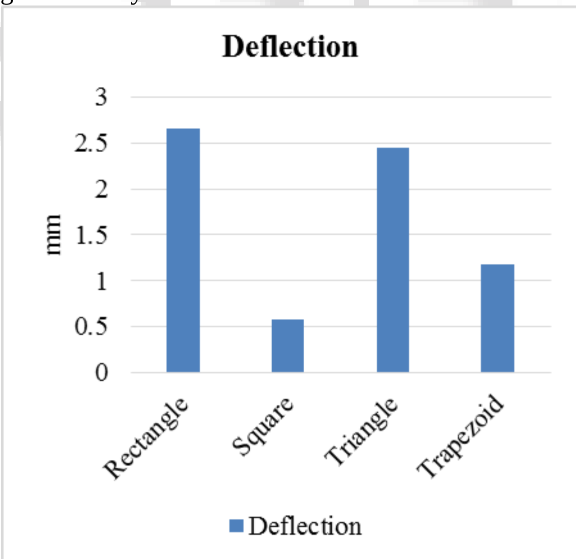

Fig. 6: Average Deflection for different geometric modules

From Fig. 5, it is observed that, for same area with different geometry and varying skin thickness, obtained average MOR is more for triangular shape and lesser for rectangular shape.

From Fig. 5, it is observed that, for same area with different geometry with varying skin thickness, obtained average LOP for Square, Triangle and Trapezoidal is almost same while obtained average LOP for Rectangular geometry is less from all of them.

From Fig. 6, it is observed that, for same area with different geometry with varying skin thickness, obtained average deflection obtained is more for rectangle shape and lesser for square shape.

VIII. CONCLUSION

1) Considering only MOR as primary criteria most desired geometrical shape is Rectangular pattern. As geometrical shape changes, required MOR value increases and it is more for triangular geometry.
2) Considering only LOP as a primary criteria most desired geometrical shape is Rectangular pattern. As geometrical shape changes, required LOP value increases and it is more for trapezoidal geometry.
3) Considering only deflection as primary criteria most desired geometrical shape is Square pattern. As geometrical shape changes, deflection value increases and it is more for rectangular geometry.
4) Considering all of the three criteria of MOR, LOP and Deflection, most desirable geometrical pattern is rectangular shape.

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