Mechanical Performance of Textile Reinforced Concretes using Steel Welded Mesh and AR Glass Mesh Reinforcements: Comparative Study in M30 and M40 Grades

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Abstract

Objective: To study the effect of reinforcement type, reinforcement dosage and grade of concrete on the mechanical performance of TRC reinforced with steel welded mesh and AR glass mesh, which are two commercially different reinforcing meshes, and compare their performance with that of an ordinary concrete mix.

Method: Eight sets of mixes (four types of steel mesh – SM1, SM2, SM3, SM4; four types of glass mesh – GM1-GM4) along with two types of plain concrete mixes (one for each grade of concrete, A1: M30, A2: M40) were prepared into concrete cubes (150 mm), cylinders (150 x 300 mm), beams (700 x 150 x 150 mm), and thin cement mortar panels (304.8 x 304.8 x 25 mm) at M30 and M40 grades of concrete with mesh placed in moulds in two doses (1% & 1.5%) (equivalent to two & three layers of mesh).

Key Finding: A dosage increase from 1% to 1.5% of steel mesh consistently provided strength benefits in all specimens, improving strength from ~1% in bulk cubes/cylinders/beams to ~12% in thin panels, where series SM4 (M40 grade, 1.5% steel mesh dosage) achieved the highest recorded strength among all tested configurations. The equivalent dosage increase for the AR-glass mesh resulted in a minor but consistent decrease in strength. The steel mesh outperformed the AR-glass mesh in terms of strength efficiency at all matched grades and dosages, showing a margin varying from 1-3% in bulk specimens to up to 31% in thin panels, and surpassing their grade-matched unreinforced controls by an additional 1-6%.

Conclusion: The configuration with steel mesh at 1.5% dosage in M40 grade concrete proved to be the strongest found in this study, especially for flexure-loaded thin panels, while AR-glass mesh can still serve as a good alternative with reduced strength where corrosion resistance dictates the design. The higher sensitivity of thin sections to mesh type and dosage is consistent with the bond-controlled failure mechanism of flexure-loaded TRC widely reported in literature.

Keywords: textile reinforced concrete; steel welded mesh; AR-glass mesh; compressive strength; flexural strength; mesh dosage

1. Introduction

Textile reinforced concrete (TRC) has become an interesting alternative to traditional steel-reinforced concrete for thin lightweight structures because of the non-corrosive nature of the textile reinforcement and hence, reduced concrete cover requirements. Many studies have been carried out to characterize the flexural properties of TRC with continuous carbon or AR-glass textile fabrics incorporated in fine-grained cementitious matrices, showing that the flexural behaviour of thin TRC elements is significantly controlled by the bond quality of the textile reinforcement and the matrix rather than matrix strength itself (Williams Portal et al. 2016).

The current work expands this research direction by conducting a comparative evaluation of two mesh reinforcement systems - steel welded and AR-glass mesh - at two concrete grades (M30 and M40) and two dosages (1% and 1.5%). Unlike continuous unidirectional textile fabrics considered extensively in most flexural bond studies, this research involves two-dimensional welded/woven meshes embedded in both structural concrete specimens (cubes, cylinders, beams) and thin cement-mortar panels.

1.1 Research Gap

In existing research on the topic, TRC literature has focused on unidirectional continuous AR glass or carbon fibre cloth in slab form, usually coupled with specific pull-out tests or bond-slip characterisation to explain the flexural properties (Williams Portal et al. 2016). Relatively less published literature compares the behaviour of steel and AR glass welded mesh (two different commercial two-dimensional reinforcements) with respect to various specimen geometries (bulk cubes/cylinders/beam and thin panels) and various concrete matrix grades in one controlled experimental programme. In addition, the influence of dosage on strength gain is rarely reported in case of thin panels and the interaction of dosage and panel thickness - whether a certain percentage change in reinforcement dosage will show consistency in effect across bulk cubes and thin panels or not - has not been studied in literature for the aforementioned commercial two-dimensional reinforcement meshes. This paper addresses these knowledge gaps by investigating both types of meshes, at two doses and two grades, across four specimen geometries within one experimental programme and by comparing every mesh-reinforced series with an equivalent unmeshed control mix, in order to isolate the reinforcement effect from the matrix grade effect.

The objectives of this paper are the following: (i) Quantification of the compressive, split tensile, and flexural strengths of the eight concrete mixes at 7 and 28 days, benchmarked against an unmeshed control mix; (ii) Comparison of relative performance of the steel welded mesh against the AR-glass mesh at equivalent grade and dosage; and (iii) Observation of the effect of increasing dosage from 1% to 1.5% on strength gain for the two different reinforcements, especially in thin section specimens where the reinforcing effect should dominate.

2. Materials and Methods

2.1 Materials

For the M30 and M40 grades of concrete series, Ordinary Portland cement OPC 53 grade (IS 12269:2013), Zone II river sand (IS 383) and 10 mm crushed coarse aggregate (IS 383) were used. Class F fly ash (IS 3812 Part 1:2003) was utilised as the 25% replacement of the cement in all mixes. Proportions of the mixes were kept according to the guidelines of IS 10262:2019. Thin flexural panels (304.8 x 304.8 x 25 mm) were manufactured from a cement mortar having a binder to sand ratio of 1:3 without any coarse aggregate, as opposed to the structural concrete mixes, since the former are used as thin non-structural cladding-type elements.

Two types of reinforcements were employed in the experiment, each of which had two dosage levels (1% and 1.5%) and were placed inside the mould prior to casting: steel welded mesh, and AR glass mesh. The steel welded mesh used in this programme is a welded orthogonal wire grid which is normally used as plaster reinforcement. The AR glass mesh used in this programme is a commercial plaster grade alkali-resistant coated fibreglass mesh (as stated in manufacturer packaging) rather than a laboratory grade AR glass mesh conforming to ASTM C1666 standard. The latter is a deviation from the original research proposal as per supervisor approval and is mentioned here because it is a plausible factor - along with the bond and matrix compaction issues as mentioned in Section 4 - responsible for comparatively weak and dosage sensitive performance of the AR glass mesh series in comparison to the steel mesh series in this study. None of the meshes was added to the mix. Both the meshes were mould placed as pre-cut sheets before casting. Detailed process is described in Section 2.7.

The steel welded mesh has a wire diameter of 1.5 mm and square aperture (opening) size of 14 mm, meeting the general product class specifications of IS 1566:2012. The AR glass mesh has a square aperture of 4 mm and areal density of 150 gsm.

2.2 Calculation of Reinforcement Dosage

The reinforcement dosage of this programme is given as a volumetric/areal ratio of reinforcement target, similar to the typical reinforcement ratio for steel bar reinforcement in RC construction, i.e. rho = (volume/cross-sectional area of reinforcement in the specimen / gross volume/cross-sectional area of the specimen) x 100. Where the mesh is batched directly into the mix (in other programmes of this overall research, but not in this particular mesh series), the ratio is simply reduced to a weight/volume calculation, taking into account the density of the reinforcement - e.g., a batched reinforcement of W kg/m3, where the specific gravity of the reinforcement is SG, gives a volume fraction of Vf(%) = [W / (SG x 1000)] x 100.

For this particular mesh series in this paper, however, the mesh is not batched by weight into the mix; instead, the target reinforcement ratio is achieved through variable placement of the number of mesh layers through the specimen depth, setting the positions of the layers to achieve even distribution of the mesh through the section (Section 2.7). In this programme, two layers of mesh have been used for the 1% dosage level, and three layers for the 1.5% dosage level, in the beam, cylinder and panel specimens consistently. The complete numerical derivation, using the known geometry of the steel mesh (wire diameter 1.5 mm, aperture 14 mm square; Section 2.1), is shown below for the 150 x 150 mm beam cross-section: the wire pitch (aperture + wire diameter) is 15.5 mm, yielding a cross-sectional area of wire of pi/4 x 1.52 = 1.77 mm2 and approximately 150 / 15.5 = 9.7 transverse wires passing across the 150 mm width of section per mesh layer, or steel area of 17.1 mm2 per layer. Thus, two layers (the nominal 1% dosage) give a geometric reinforcement ratio of (2 x 17.1) / 22,500 x 100 = 0.15%, and three layers (the nominal 1.5% dosage) give (3 x 17.1) / 22,500 x 100 = 0.23%. As may be seen from the calculations, these computed ratios are less than the nominal 1%/1.5% dosage labelling, which is used in this programme as series designations through the layer numbers, rather than the exact area ratio of reinforcement; the two layer and three layer configurations retain a constant 1:1.5 proportion between themselves, which is the reason why they are being compared by the term 'dosage' in this paper.

2.3 Mix Series and Specimen Types

Eight mesh-reinforced series were cast for this study, along with a plain control mix without reinforcement at each grade (A1: M30, A2: M40; Section 3.7). Series SM1, SM2, SM3, and SM4 represent steel welded mesh reinforcement, while GM1 through GM4 represent AR-glass mesh reinforcement. Two series were cast for each type of reinforcement at each of M30 and M40 grades, each at the 1% and 1.5% dosage levels.

Series ID	Reinforcement	Grade	Dosage
SM1	Steel Welded Mesh	M30	1%
SM2	Steel Welded Mesh	M30	1.5%
SM3	Steel Welded Mesh	M40	1%
SM4	Steel Welded Mesh	M40	1.5%
GM1	AR-Glass Mesh	M30	1%
GM2	AR-Glass Mesh	M30	1.5%
GM3	AR-Glass Mesh	M40	1%
GM4	AR-Glass Mesh	M40	1.5%

Table 1. Mix series and reinforcement configuration.

Four types of specimens were prepared for each series: compressive strength cubes (150 x 150 x 150 mm), split tensile cylinders (150 mm diameter x 300 mm), flexural strength beams (700 x 150 x 150 mm), and flexural thin panels (304.8 x 304.8 x 25 mm, cement mortar). All specimens were water-cured up to 7 and 28 days of age.

2.4 Casting Procedure

For each series, the constituents of the concrete or mortar were mixed by weight as per the proportions specified in the mix design in Section 2.6. The cement, fly ash, fine (and for the structural specimens, also the coarse) aggregate were dry-blended and water added to achieve the design water-cement ratio followed by further mixing until a consistent mix was obtained. The moulds for the cube, cylinder, beam and panel specimens were cleaned and slightly oiled before casting. For the mesh-reinforced series, the pre-cut steel welded mesh or AR-glass mesh layers were arranged inside the moulds at the desired depth (see Table 5); for the control (i.e., unreinforced) specimens, no mesh was inserted. The fresh concrete/mortar was poured into the moulds in layers and consolidated to avoid entrapping of air pockets, and subsequently the top surface was screeded off. The specimens were left in the moulds without disturbance at room temperature for about 24 hours before demoulding.

2.5 Curing Procedure

Right after the demoulding (that is, after 24 hours since casting), all the specimens were transferred to the curing water tank kept at room temperature and were fully immersed in water until the testing age (7 or 28 days) according to the standard procedure for curing of concrete and mortar specimens under IS

456:2000. The specimens were taken out from the curing tank just before testing, dried on the surface briefly and tested in the saturated surface-dry state.

2.6 Mix Design

The quantities of batching per unit m3 were calculated according to IS 10262:2019 for each grade and are presented per m3 and per specimen in Tables 2 and 3 respectively. As both the steel welded mesh and the AR-glass mesh are placed inside the moulds prior to pouring and are not batched in the concrete or mortar, the mix of the concrete/binder batch is the same for the control (i.e., unreinforced) series and for all other single-mesh series of a particular grade – that is, the batch of the M30 concrete mix used for the control series (A1) is the same batch for SM1, SM2, GM1 and GM2, and the batch of the M40 concrete mix used for the control series (A2) is the same batch for SM3, SM4, GM3 and GM4. This is an important methodological issue: thus, any strength differences between the control series and the mesh-reinforced series, and/or between the steel and AR-glass mesh series at a certain grade, are due to the presence of the mesh and its interaction with the specimen but not to any difference in the batching of the matrix.

Constituent	Specification	M30 (per m3, kg)	M40 (per m3, kg)
OPC 53 Grade	IS 12269:2013	300	345
Fly Ash (Class F, 25%)	IS 3812 (Pt 1):2003	100	115
Water	Potable, IS 456:2000	166 (w/b = 0.415)	166 (w/b = 0.361)
Fine Aggregate	Zone II Sand, IS 383	823	797
Coarse Aggregate	10 mm Crushed, IS 383	1040	1007

Table 2. Batch mix design of the concrete per m3 – common for the control mix and all single-mesh series (SM1, SM2, GM1, GM2 at M30; SM3, SM4, GM3, GM4 at M40).

Constituent	1 Cube, M30 (kg)	1 Cylinder, M30 (kg)	1 Beam, M30 (kg)	1 Cube, M40 (kg)	1 Cylinder, M40 (kg)	1 Beam, M40 (kg)
OPC 53	1.0125	1.5903	4.725	1.1644	1.8288	5.4337
Fly Ash	0.3375	0.5301	1.575	0.3881	0.6096	1.8113
Water	0.5603	0.88	2.6145	0.5603	0.88	2.6145
Fine Aggregate	2.7776	4.3627	12.9623	2.6899	4.2249	12.5527
Coarse Aggregate	3.51	5.513	16.38	3.3986	5.3381	15.8603

Table 3. Batch mix design of the concrete per specimen (150 mm cube; 150 x 300 mm cylinder; 700 x 150 x 150 mm beam), M30 and M40 grades.

The thin panels were made of cement mortar of a separate mixture with a 1:3 (cement: sand) ratio without any coarse aggregates, according to grade-specific proportions presented in Table 4. As was done with the concrete for the structural beams, this mortar composition is common both to the control panels and single-mesh panels series of each grade because the mesh is mould-placed rather than batched in the mortar.

Constituent	M30 Mortar (per m3, kg)	1 Panel, M30 (kg)	M40 Mortar (per m3, kg)	1 Panel, M40 (kg)
OPC 53 Grade	368	0.8549	424	0.985
Fly Ash (Class F, 25%)	122	0.2834	141	0.3275
Water	245 (w/c = 0.5)	0.5691	246 (w/c = 0.44)	0.5715
Fine Aggregate (sand only)	1470	3.4148	1695	3.9375

Table 4. Cement-mortar mix design for thin panels (304.8 x 304.8 x 25 mm), M30 and M40 grades.

2.7 Reinforcement Placement

Reinforcement was mould-placed before casting with the help of spacer supports, which ensured the required layer positioning with the nominal 25 mm cover for the beams. The number of mesh layers was based on the reinforcement dosage (see Section 2.2): thus, 1% dosage series (SM1, SM3 for the steel reinforcement system; GM1, GM3 for the AR-glass system) was made of two layers, and 1.5% dosage series (SM2, SM4; GM2, GM4) had three mesh layers in accordance with Table 5 and Figure 1.

Specimen	1% Dosage - 2 Layers	1.5% Dosage - 3 Layers
Beam (150 mm depth, 25 mm cover)	Layer 1: 25 mm above bottom; Layer 2: 25 mm below top	Layer 1: 25 mm above bottom; Layer 2: mid-level (75 mm); Layer 3: 25 mm below top
Cylinder (300 mm height)	75 mm and 225 mm above bottom	50 mm, 150 mm, and 250 mm from base
Panel (25 mm depth)	4 mm and 11 mm above bottom	3 mm, 9 mm, and 15 mm above bottom

Table 5. Mesh layer positioning for specimens depending on the dosage.

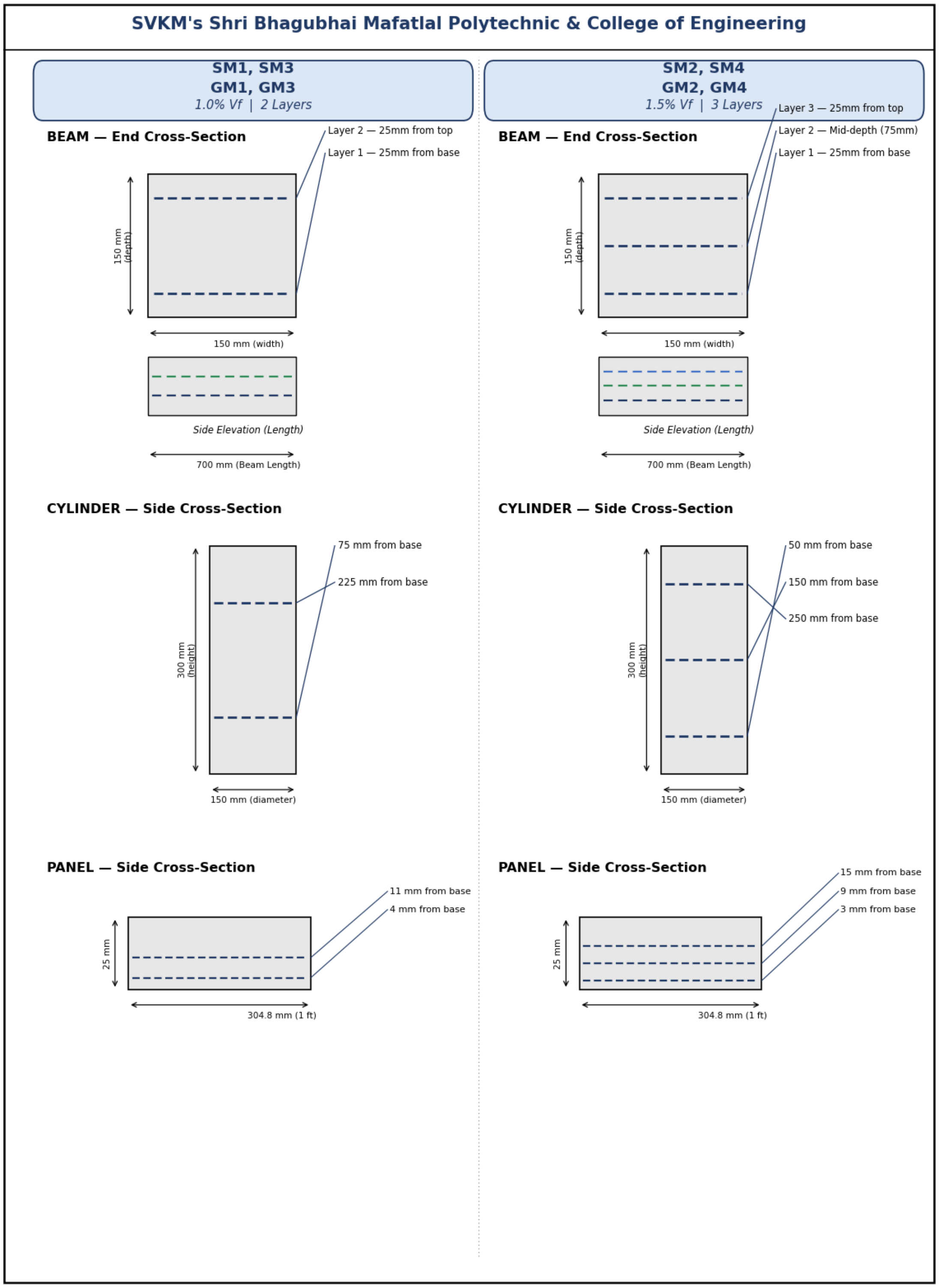

Figure 1. Layout of reinforcement arrangement – beam, cylinder and panel cross-sections for 1% (2 layers) and 1.5% (3 layers) dosages (Steel welded mesh and AR-glass mesh have the same layer positioning for a given dosage: 1% corresponds to series SM1, SM3, GM1, and GM3; 1.5% corresponds to series SM2, SM4, GM2, and GM4).

2.8 Test Methods

In determining the compressive strength, split tensile (cylinder splitting) strength, and flexural strength, the test methods adopted followed IS 516 (Part 1/Sec 1):2021, Method of Test for Strength of Concrete - Part 1: Testing of Hardened Concrete, Section 1: Compressive, Flexural, and Split Tensile Strength, which supercedes the earlier IS 516:1959 and IS 5816:1999. Flexural strength of the 700 x 150 x 150 mm beams was determined using two-point loading applied symmetrically about the mid-span (third-point loading), rather than single centre-point loading. Flexural strength of the thin cement mortar panels was determined using the same two-point, mid-span-symmetric loading configuration, scaled to the panel dimensions. All samples within a series and test age were tested in one batch, and the reported values correspond to those obtained at 7 days and 28 days for each series.

3. Results

3.1 Testing Programme and Specimen Count

Eight series of mesh reinforced were tested at two ages (7 and 28 days) using four specimen types (cube, cylinder, beam, and panel), and each series, specimen type and age had three replicate specimens, as can be directly seen from the results of replicate readings given in Section 3.8. Thus, 3 specimens x 4 specimen types x 2 ages x 8 series = 192 confirmed specimens for the mesh reinforced programme.

Control (unreinforced) concrete, on the other hand, were tested at 7 days and 28 days using cubes, cylinders and beams. For the cube compressive strength, tests were conducted on three replicate specimens of each grade at 7 days and 28 days (A1: M30; A2: M40). Specimens of cylinder and beams were also cast and tested at the two grades at 28 days only. Hence, the split tensile and beam flexural strength results reported in Section 3.7 are direct results of testing, giving 3 (cube, 7 day) + 3 (cube, 28 days) + 3 (cylinder, 28 days) + 3 (beam, 28 days) = 12 confirmed control specimens tested per grade, 24 in total across the two grades.

Based on the above, the total confirmed specimen number for the programme reported in this paper is 216 (192 mesh reinforced + 24 control).

3.2 Compressive Strength

Table 6 shows the 7 days and 28 days cube compressive strength of all eight series. As would have been expected, the M40 series (SM3, SM4, GM3, GM4) had significantly higher 28-day strength (approximately 48-51 MPa) compared to the M30 series (approximately 35-37 MPa), as would be expected from the grade mixing. For each of the grade, the steel-mesh series showed marginally higher compressive strength than the corresponding AR-glass series: at M30, SM1/SM2 (36.75/37.10 MPa) were higher than GM1/GM2 (36.05/35.35 MPa), and at M40, SM3/SM4 (50.40/50.88 MPa) were higher than GM3/GM4 (49.44/48.48 MPa).

Series	Reinforcement	Grade	Dosage	7-Day (MPa)	28-Day (MPa)
SM1	Steel Welded Mesh	M30	1%	17.08	36.75
SM2	Steel Welded Mesh	M30	1.5%	17.25	37.10
SM3	Steel Welded Mesh	M40	1%	21.82	50.40

Series	Reinforcement	Grade	Dosage	7-Day (MPa)	28-Day (MPa)
SM4	Steel Welded Mesh	M40	1.5%	22.03	50.88
GM1	AR-Glass Mesh	M30	1%	16.76	36.05
GM2	AR-Glass Mesh	M30	1.5%	16.43	35.35
GM3	AR-Glass Mesh	M40	1%	21.40	49.44
GM4	AR-Glass Mesh	M40	1.5%	20.99	48.48

Table 6. Cube compressive strength (150 x 150 x 150 mm)

Another clear trend emerges as mesh dosage is increased: an increase from 1% to 1.5% in the steel mesh dosage increased 28-day compressive strength at both grades by 0.95%, while an increase from 1% to 1.5% in the AR-glass mesh dosage decreased the 28-day compressive strength at both grades by 1.9%. The series SM4 (with M40 concrete and 1.5% steel mesh dosage) yielded the highest compressive strength across all tested grades at 50.88 MPa (refer to Figure 2).

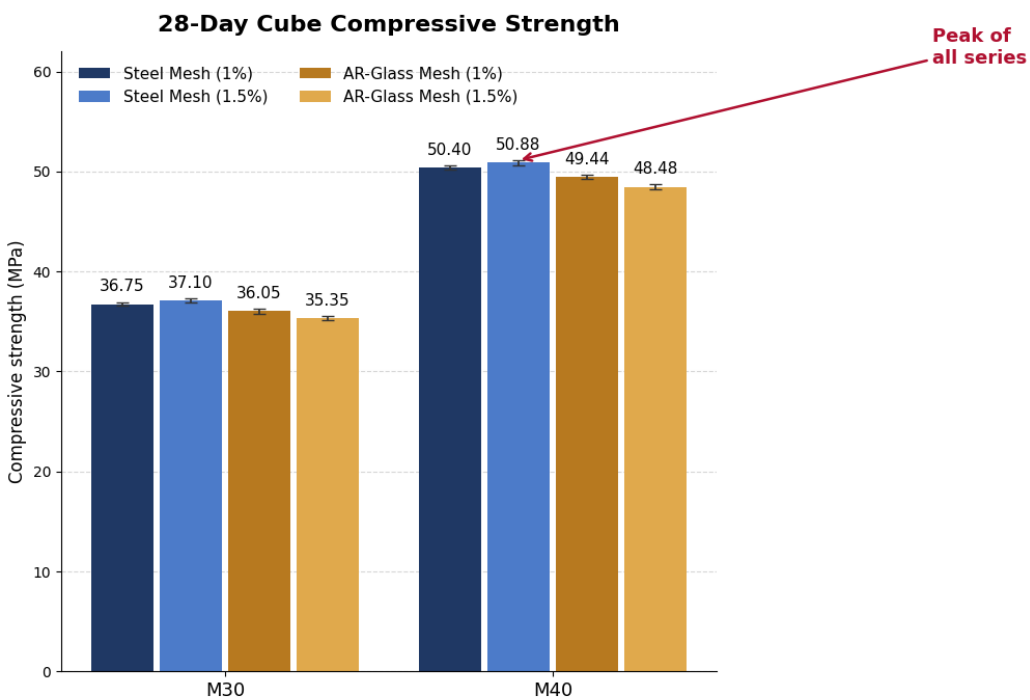

Figure 2. 28-day cube compressive strength by grade, mesh type and dosage. Error bars represent ±1 standard deviation (n=3).

3.3 Split Tensile Strength

The results obtained for split tensile strength, provided in Table 7, exhibit the same qualitative pattern as the results for compressive strength. For M30 grade, the steel-mesh series (values of 3.94-3.96 MPa at 28 days) were slightly higher than the AR-glass series (values of 3.86-3.90 MPa), and for M40 grade, the steel-mesh series (values of 4.61-4.64 MPa) were higher than the AR-glass series (values of 4.53-4.57 MPa). An increase in dosage from 1% to 1.5% marginally increased split tensile strength in steel mesh (+0.5% at M30, +0.7% at M40) and marginally reduced it in AR-glass mesh (-1.0% at M30, -0.9% at M40).

Series	Reinforcement	Grade	Dosage	7-Day (MPa)	28-Day (MPa)
SM1	Steel Welded Mesh	M30	1%	2.69	3.94
SM2	Steel Welded Mesh	M30	1.5%	2.70	3.96
SM3	Steel Welded Mesh	M40	1%	3.04	4.61
SM4	Steel Welded Mesh	M40	1.5%	3.05	4.64
GM1	AR-Glass Mesh	M30	1%	2.66	3.90
GM2	AR-Glass Mesh	M30	1.5%	2.63	3.86
GM3	AR-Glass Mesh	M40	1%	3.01	4.57
GM4	AR-Glass Mesh	M40	1.5%	2.98	4.53

Table 7. Split tensile strength, cylinder (150 mm dia. x 300 mm).

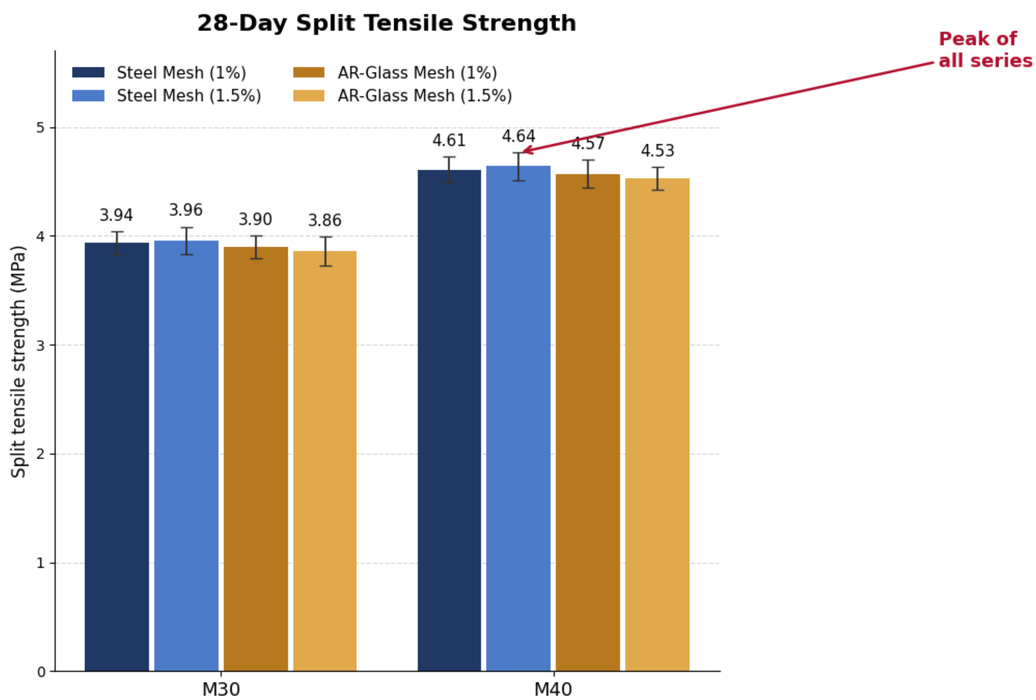

Figure 3. 28-day split tensile strength by grade, mesh type, and dosage. Error bars represent ±1 standard deviation (n=3).

3.4 Flexural Strength - Beam

Flexural strength of the 700 x 150 x 150 mm beams (Table 8) confirms the relative hierarchy established above: steel-mesh series achieved 28-day flexural strengths of 4.24-4.99 MPa, while AR-glass-mesh series showed 4.16-4.92 MPa at the two grades under consideration. As far as the dosage influence is concerned, it stays consistent with the results obtained earlier in relation to the compressive and split tensile strengths, with slight advantage in favor of steel mesh at the higher dosage and slight deterioration at the higher dosage for AR-glass mesh.

Series	Reinforcement	Grade	Dosage	7-Day (MPa)	28-Day (MPa)
SM1	Steel Welded Mesh	M30	1%	2.89	4.24
SM2	Steel Welded Mesh	M30	1.5%	2.91	4.26
SM3	Steel Welded Mesh	M40	1%	3.27	4.97
SM4	Steel Welded Mesh	M40	1.5%	3.29	4.99
GM1	AR-Glass Mesh	M30	1%	2.87	4.20
GM2	AR-Glass Mesh	M30	1.5%	2.84	4.16
GM3	AR-Glass Mesh	M40	1%	3.24	4.92
GM4	AR-Glass Mesh	M40	1.5%	3.21	4.87

Table 8. Flexural strength, beam (700 x 150 x 150 mm).

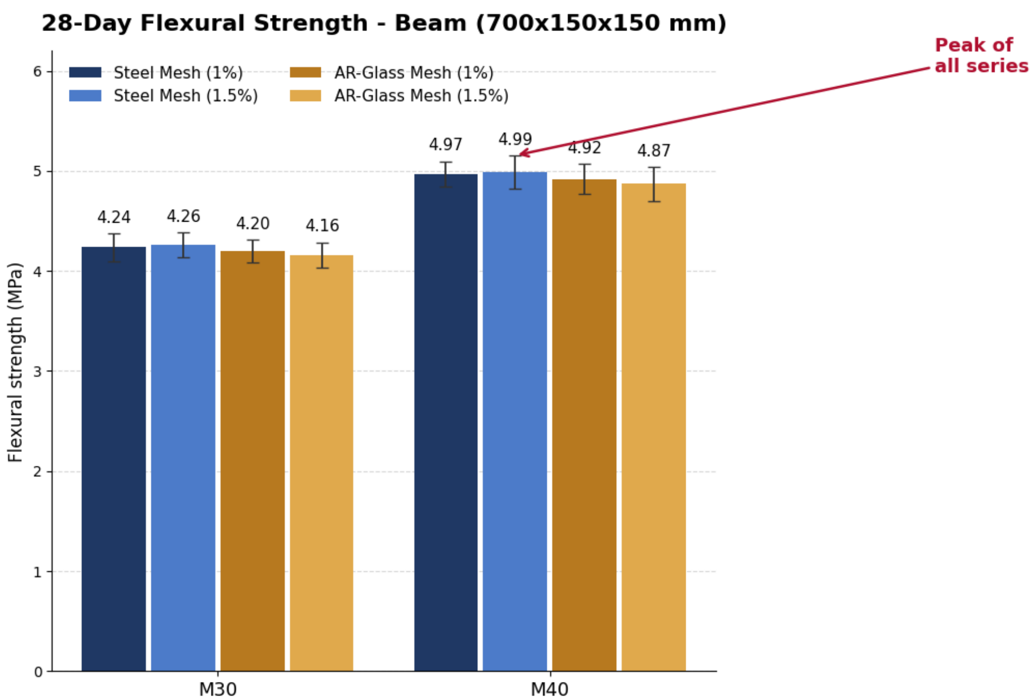

Figure 4. 28-day beam flexural strength by grade, mesh type, and dosage. Error bars represent ±1 standard deviation (n=3).

3.5 Flexural Strength - Thin Panel

Thin cement-mortar panels (304.8 x 304.8 x 25 mm) display the strongest response to both the mesh type and dosage among all specimen types examined (Table 9), and it is exactly here when the most remarkable feature of the current investigation is revealed. In case of grade M30, 28-day panel flexural strength increases from 5.95 MPa (SM1, 1% steel mesh) to 6.65 MPa (SM2, 1.5% steel mesh), i.e. about 12%. In case of M40 grade, the same dosage increase raises panel flexural strength from 8.16 MPa (SM3) to 9.12 MPa (SM4). This corresponds to about 12% in relative terms as well, however in absolute terms, it means the highest increase in strength observed throughout the entire programme.

Series	Reinforcement	Grade	Dosage	7-Day (MPa)	28-Day (MPa)
SM1	Steel Welded Mesh	M30	1%	2.77	5.95
SM2	Steel Welded Mesh	M30	1.5%	3.10	6.65
SM3	Steel Welded Mesh	M40	1%	3.54	8.16
SM4	Steel Welded Mesh	M40	1.5%	3.95	9.12
GM1	AR-Glass Mesh	M30	1%	2.53	5.42
GM2	AR-Glass Mesh	M30	1.5%	2.36	5.08
GM3	AR-Glass Mesh	M40	1%	3.22	7.44
GM4	AR-Glass Mesh	M40	1.5%	3.02	6.96

Table 9. Flexural Strength of Thin Panel (304.8 x 304.8 x 25 mm, cement mortar).

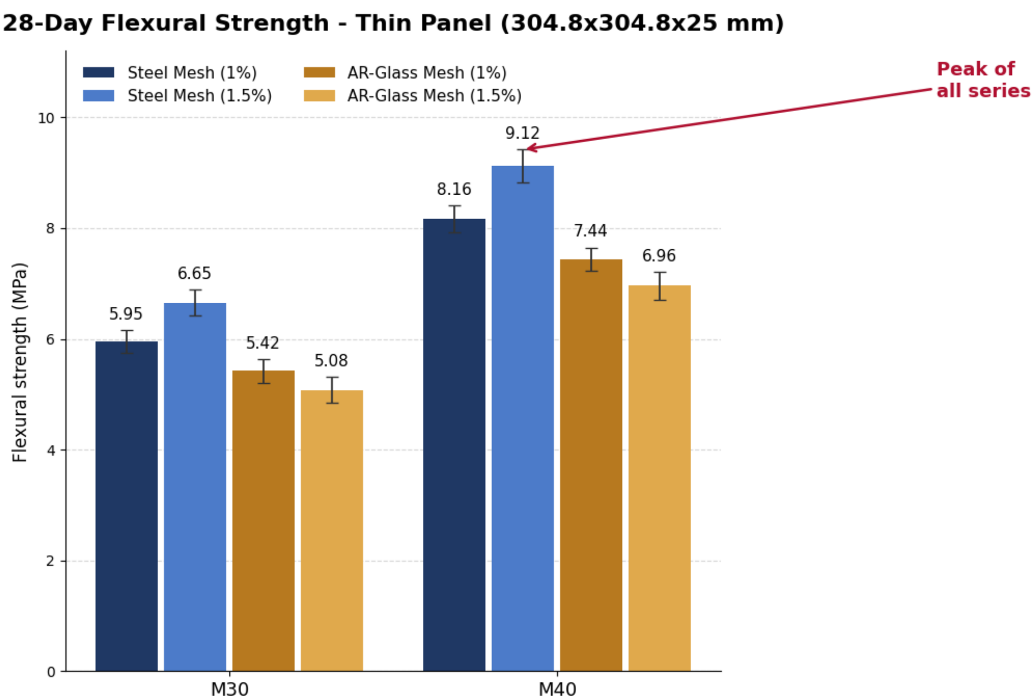

Figure 5. 28-day Panel Flexural Strength by Grade, Mesh Type, and Dosage – highlighting SM4 (M40, 1.5% Steel Mesh) Peak. Error bars represent ±1 standard deviation (n=3).

With a strength of 9.12 MPa, SM4 is the strongest of all the panels tested in this project, being 53% stronger than the weakest set of panels tested, GM2 (M30, 1.5% AR-glass mesh, 5.08 MPa), as well as 31% stronger than its closest equivalent in the series, GM4 (M40, 1.5% AR-glass mesh, 6.96 MPa). This represents a considerably larger gap than the 1-3% found in the bulk cube, cylinder, and beam tests between steel mesh and glass mesh, and is discussed further below. The effect of increasing steel mesh dosage from 1% to 1.5% in the panels is consistent in relative terms across both grades: at M30 the strength rises from 5.95 to 6.65 MPa (+11.8%), and at M40 from 8.16 to 9.12 MPa (+11.8%). In absolute terms, however, the dosage gain is modestly larger at M40 (0.96 MPa) than at M30 (0.70 MPa); this is the real, though limited, positive interaction between concrete grade and steel mesh dosage in this specimen type, and it is presented here explicitly rather than as a categorical ‘step change’. A full 2×2 factorial analysis, or a wider range of grades and dosages, would be needed to confirm whether this interaction persists outside the values tested here. The large 31% SM4-versus-GM4 gap at M40, 1.5% dosage should not itself be read as evidence of a grade×dosage synergy, since it is driven mainly by GM4 declining relative to GM3 (M40, 1% AR-glass mesh, 7.44 MPa) rather than by any disproportionate gain in SM4: the same dosage increase that benefits the steel mesh series in panels is mildly detrimental to the AR-glass series in this specimen type, in contrast to the consistent 1.5%-dosage advantage seen for the steel mesh series in panels at both grades.

3.6 Consolidated Summary

Table 10 summarizes the 28-day strength results for all the test configurations for the eight series.

Series	Reinforcement (Dosage)	Grade	Cube (MPa)	Cylinder (MPa)	Beam (MPa)	Panel (MPa)
SM1	Steel Welded Mesh (1%)	M30	36.75	3.94	4.24	5.95
SM2	Steel Welded Mesh (1.5%)	M30	37.10	3.96	4.26	6.65
SM3	Steel Welded Mesh (1%)	M40	50.40	4.61	4.97	8.16
SM4	Steel Welded Mesh (1.5%)	M40	50.88	4.64	4.99	9.12
GM1	AR-Glass Mesh (1%)	M30	36.05	3.90	4.20	5.42
GM2	AR-Glass Mesh (1.5%)	M30	35.35	3.86	4.16	5.08
GM3	AR-Glass Mesh (1%)	M40	49.44	4.57	4.92	7.44
GM4	AR-Glass Mesh (1.5%)	M40	48.48	4.53	4.87	6.96

Table 10. Summary of 28-Day Strength Results.

3.7 Comparison with Control (Unreinforced) Mix

In order to have a basis of comparison, an unreinforced control mix was also prepared and tested for both series - A1 (M30) and A2 (M40) - in terms of cube compressive strength, split tensile strength and beam flexural strength. Unreinforced cube compressive strength was directly tested at 7 and 28 days, and unreinforced split tensile and beam flexural strength was directly tested at 28 days, using 3 replicate specimens per test. Unreinforced panels were not included in this study, and thus no baseline is established for panel flexural test; hence, the results in Sections 3.5 and 3.6 should be interpreted as a comparative study of the mesh series only, and not against an unreinforced control.

Series	Grade	Cube 7-Day (MPa)	Cube 28-Day (MPa)	Split Tensile 28-Day (MPa)	Beam Flexural 28-Da (MPa)
A1 (Control)	M30	16.27	35.02	3.78	4.07
A2 (Control)	M40	20.78	47.98	4.42	4.76

Table 11. Unreinforced control mix strength, M30 and M40.

All mesh-reinforced series outperformed their grade matched controls in all three tests, although with a much smaller difference compared to that between the mesh series in the thin panels. For the M30 series, the control cube strength of 35.02 MPa was surpassed by SM1 (36.75 MPa, +4.9%), SM2 (37.10 MPa, +5.9%), GM1 (36.05 MPa, +2.9%) and GM2 (35.35 MPa, +0.9%). Similarly, the split tensile and beam flexural strength improved by about 2-5% for the same 4 series. For the M40 series, the control cube strength of 47.98 MPa was surpassed by SM3 (50.40 MPa, +5.0%), SM4 (50.88 MPa, +6.0%), GM3 (49.44 MPa, +3.0%) and GM4 (48.48 MPa, +1.0%), with the split tensile and beam flexural strength showing similar improvement of about 2-5%. Fig. 6 and Fig. 7 show the comparison for M30 and M40 series respectively.

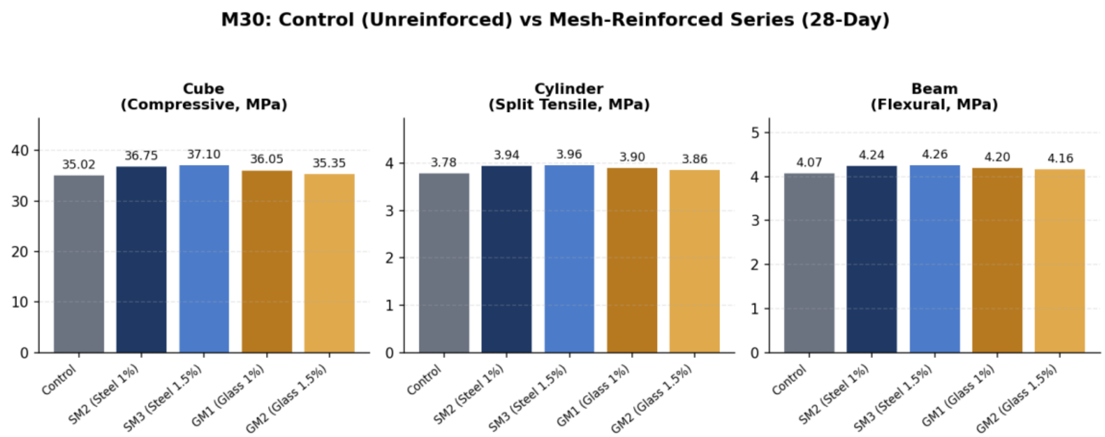

Figure 6. Comparison of M30 unreinforced control mix vs steel and AR-glass mesh series in terms of 28-day cube, split tensile, and beam flexural strength

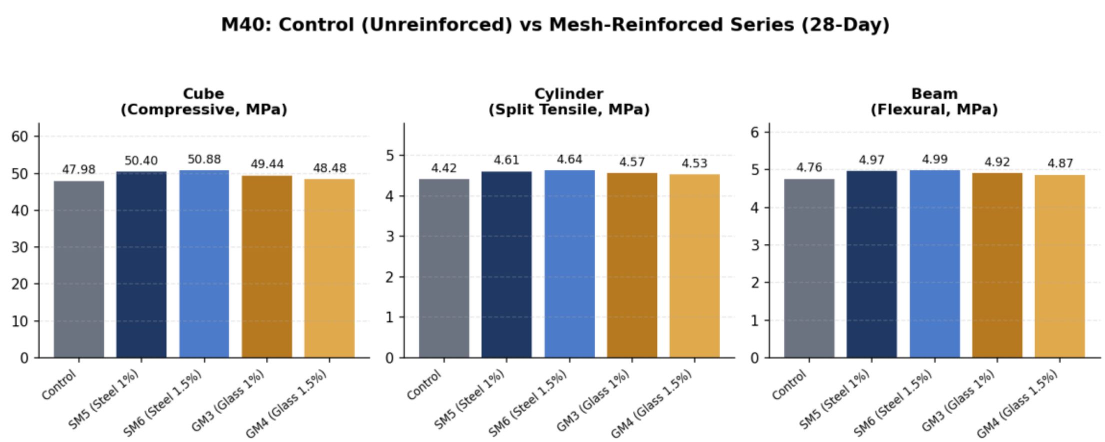

Figure 7. Comparison of M40 unreinforced control mix vs steel and AR-glass mesh series in terms of 28-day cube, split tensile, and beam flexural strength

Series SM4 (M40, 1.5% steel mesh), however, continues to provide the best performance among all test subjects both compared to the control, and in absolute terms. As seen in Table 11, its 6.0% increase in compressive strength, 5.0% improvement in split tensile strength, and 4.8% gain in beam flexural strength compared to the M40 control show the largest margin over any unreinforced control in the study. The fact that an unconfined, two-dimensional mesh reinforcement added at low volume fraction does provide a certain level of internal confinement or crack arrest even in the bulk strength test, where this type of reinforcement is usually expected to have minimal effect, is another indicator that benefits of steel mesh reinforcement cannot be restricted only to thin sections.

3.8 Statistical Analysis: Mean, Standard Deviation, and Coefficient of Variation

Replicate readings are available for both the control (unreinforced) mix, and all eight mesh-reinforced series, thus allowing us to demonstrate full statistical analysis throughout the entire test program.

For a series of n readings x1...xn, sample mean, sample standard deviation and coefficient of variation are calculated as follows: mean (x-bar) = (x1+x2+...+xn) / n; sample standard deviation (s) = sqrt[sum(xi-x-bar)^2 / (n-1)]; and coefficient of variation (CoV, %) = (s/x-bar)x100. Using this formula for three individual 7-day cube compressive readings for each control series, as given in Table 12 below, we obtain the result presented in Table 13.

Control Series	Grade	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)
A2 (M40)	M40	21.06	20.35	20.92
A1 (M30)	M30	15.66	16.61	16.55

Table 12. Individual 7-day cube compressive readings for the control series, converted from recorded load (kN) to strength (MPa) on a 150 mm cube (22,500 mm2).

Control Series	Grade	Mean (MPa)	Std. Dev. (MPa)	Coefficient of Variation (%)
A2	M40	20.78	0.379	1.82
A1	M30	16.27	0.534	3.28

Table 13. Mean, standard deviation, and coefficient of variation for control 7-day cube compressive strength, calculated per the formulae above.

For both control series the coefficient of variation is relatively low (below 3.5%). The eight mesh-reinforced series (Table 14) exhibit coefficients of variation of 0.42-6.70%, with a large majority below 5%. This suggests very good repeatability of the casting and testing procedure throughout the whole experiment, as evidenced by the fact that panel specimens (the thinnest and most reinforcement-sensitve type) exhibit more variability than cube, cylinder and beam specimens, which was to be expected due to higher sensitiveness to precise mesh positioning at small cover depths.

Series	Specimen Type	Age	Mean (MPa)	Std. Dev. (MPa)	CoV (%)
SM1	Cube	7-Day	17.08	0.135	0.79
SM1	Cube	28-Day	36.75	0.204	0.56
SM1	Cylinder	7-Day	2.69	0.069	2.58
SM1	Cylinder	28-Day	3.94	0.104	2.65
SM1	Beam	7-Day	2.89	0.096	3.34
SM1	Beam	28-Day	4.24	0.139	3.28
SM1	Panel	7-Day	2.77	0.142	5.12
SM1	Panel	28-Day	5.95	0.208	3.50
SM2	Cube	7-Day	17.25	0.185	1.07

SM2	Cube	28-Day	37.10	0.229	0.62
SM2	Cylinder	7-Day	2.70	0.095	3.53
SM2	Cylinder	28-Day	3.96	0.125	3.16
SM2	Beam	7-Day	2.91	0.131	4.49
SM2	Beam	28-Day	4.26	0.122	2.86
SM2	Panel	7-Day	3.10	0.165	5.31
SM2	Panel	28-Day	6.65	0.234	3.52
SM3	Cube	7-Day	21.82	0.131	0.60
SM3	Cube	28-Day	50.40	0.221	0.44
SM3	Cylinder	7-Day	3.04	0.085	2.81
SM3	Cylinder	28-Day	4.61	0.118	2.56
SM3	Beam	7-Day	3.27	0.120	3.67
SM3	Beam	28-Day	4.97	0.128	2.57
SM3	Panel	7-Day	3.54	0.148	4.18
SM3	Panel	28-Day	8.16	0.243	2.97
SM4	Cube	7-Day	22.03	0.157	0.71
SM4	Cube	28-Day	50.88	0.255	0.50
SM4	Cylinder	7-Day	3.05	0.079	2.60
SM4	Cylinder	28-Day	4.64	0.125	2.70
SM4	Beam	7-Day	3.29	0.137	4.18
SM4	Beam	28-Day	4.99	0.165	3.31
SM4	Panel	7-Day	3.95	0.217	5.48
SM4	Panel	28-Day	9.12	0.297	3.26
GM1	Cube	7-Day	16.76	0.157	0.94
GM1	Cube	28-Day	36.05	0.235	0.65
GM1	Cylinder	7-Day	2.66	0.079	2.98
GM1	Cylinder	28-Day	3.90	0.104	2.66
GM1	Beam	7-Day	2.87	0.113	3.93
GM1	Beam	28-Day	4.20	0.115	2.75
GM1	Panel	7-Day	2.53	0.106	4.18
GM1	Panel	28-Day	5.42	0.208	3.84
GM2	Cube	7-Day	16.43	0.122	0.74
GM2	Cube	28-Day	35.35	0.235	0.67
GM2	Cylinder	7-Day	2.63	0.072	2.74
GM2	Cylinder	28-Day	3.86	0.137	3.56
GM2	Beam	7-Day	2.84	0.113	3.97
GM2	Beam	28-Day	4.16	0.128	3.07
GM2	Panel	7-Day	2.36	0.114	4.81
GM2	Panel	28-Day	5.08	0.227	4.47
GM3	Cube	7-Day	21.40	0.139	0.65
GM3	Cube	28-Day	49.44	0.210	0.42
GM3	Cylinder	7-Day	3.01	0.111	3.70
GM3	Cylinder	28-Day	4.57	0.128	2.79
GM3	Beam	7-Day	3.24	0.104	3.22
GM3	Beam	28-Day	4.92	0.151	3.07
GM3	Panel	7-Day	3.22	0.174	5.41
GM3	Panel	28-Day	7.44	0.210	2.82
GM4	Cube	7-Day	20.99	0.139	0.66

GM4	Cube	28-Day	48.48	0.279	0.57
GM4	Cylinder	7-Day	2.98	0.092	3.08
GM4	Cylinder	28-Day	4.53	0.104	2.29
GM4	Beam	7-Day	3.21	0.135	4.21
GM4	Beam	28-Day	4.87	0.170	3.49
GM4	Panel	7-Day	3.02	0.202	6.70
GM4	Panel	28-Day	6.96	0.248	3.56

Table 14. Average values, standard deviation and coefficient of variation for all eight mesh-reinforced series (SM1-SM4, GM1-GM4), cube/cylinder/beam/panel, 7-day and 28-day, according to the formulas above.

To confirm that the differences reported above reflect real effects rather than experimental scatter, Welch's two-sample t-test (which does not assume equal variance between the two groups being compared) was applied to the 28-day results for every steel-versus-glass comparison and every 1%-versus-1.5% dosage comparison at matched grade, across all four specimen types. For each comparison the test statistic (t), the corresponding p-value, and whether the difference is significant at the α = 0.05 level are reported in Table 15. Error bars representing ±1 standard deviation have been added to Figures 2-5 accordingly.

Specimen Type	Comparison	Mean A (MPa)	Mean B (MPa)	t (Welch)	p-value	Significar (α=0.05)
Cube	Steel vs Glass, M30, 1%	SM1=36.75	GM1=36.05	3.90	0.018	Yes
Cube	Steel vs Glass, M30, 1.5%	SM2=37.10	GM2=35.35	9.24	0.001	Yes
Cube	Steel vs Glass, M40, 1%	SM3=50.40	GM3=49.44	5.45	0.006	Yes
Cube	Steel vs Glass, M40, 1.5%	SM4=50.88	GM4=48.48	11.00	0.000	Yes
Cube	Steel dosage 1% to 1.5%, M30	SM1=36.75	SM2=37.10	-1.98	0.120	No
Cube	Steel dosage 1% to 1.5%, M40	SM3=50.40	SM4=50.88	-2.46	0.071	No
Cube	Glass dosage 1% to 1.5%, M30	GM1=36.05	GM2=35.35	3.65	0.022	Yes
Cube	Glass dosage 1% to 1.5%, M40	GM3=49.44	GM4=48.48	4.76	0.011	Yes
Cylinder	Steel vs Glass, M30, 1%	SM1=3.94	GM1=3.90	0.47	0.662	No
Cylinder	Steel vs Glass, M30, 1.5%	SM2=3.96	GM2=3.86	0.93	0.404	No
Cylinder	Steel vs Glass, M40, 1%	SM3=4.61	GM3=4.57	0.40	0.711	No
Cylinder	Steel vs Glass, M40, 1.5%	SM4=4.64	GM4=4.53	1.17	0.308	No
Cylinder	Steel dosage 1% to 1.5%, M30	SM1=3.94	SM2=3.96	-0.21	0.842	No
Cylinder	Steel dosage 1% to 1.5%, M40	SM3=4.61	SM4=4.64	-0.30	0.778	No
Cylinder	Glass dosage 1% to 1.5%, M30	GM1=3.90	GM2=3.86	0.40	0.709	No
Cylinder	Glass dosage 1% to 1.5%, M40	GM3=4.57	GM4=4.53	0.42	0.697	No
Beam	Steel vs Glass, M30, 1%	SM1=4.24	GM1=4.20	0.38	0.721	No
Beam	Steel vs Glass, M30, 1.5%	SM2=4.26	GM2=4.16	0.98	0.383	No
Beam	Steel vs Glass, M40, 1%	SM3=4.97	GM3=4.92	0.44	0.685	No
Beam	Steel vs Glass, M40, 1.5%	SM4=4.99	GM4=4.87	0.88	0.430	No
Beam	Steel dosage 1% to 1.5%, M30	SM1=4.24	SM2=4.26	-0.19	0.861	No
Beam	Steel dosage 1% to 1.5%, M40	SM3=4.97	SM4=4.99	-0.17	0.877	No
Beam	Glass dosage 1% to 1.5%, M30	GM1=4.20	GM2=4.16	0.40	0.708	No

Specimen Type	Comparison	Mean A (MPa)	Mean B (MPa)	t (Welch)	p-value	Significar (α=0.05)
Beam	Glass dosage 1% to 1.5%, M40	GM3=4.92	GM4=4.87	0.38	0.723	No
Panel	Steel vs Glass, M30, 1%	SM1=5.95	GM1=5.42	3.12	0.036	Yes
Panel	Steel vs Glass, M30, 1.5%	SM2=6.65	GM2=5.08	8.34	0.001	Yes
Panel	Steel vs Glass, M40, 1%	SM3=8.16	GM3=7.44	3.88	0.019	Yes
Panel	Steel vs Glass, M40, 1.5%	SM4=9.12	GM4=6.96	9.67	0.001	Yes
Panel	Steel dosage 1% to 1.5%, M30	SM1=5.95	SM2=6.65	-3.87	0.018	Yes
Panel	Steel dosage 1% to 1.5%, M40	SM3=8.16	SM4=9.12	-4.33	0.013	Yes
Panel	Glass dosage 1% to 1.5%, M30	GM1=5.42	GM2=5.08	1.91	0.129	No
Panel	Glass dosage 1% to 1.5%, M40	GM3=7.44	GM4=6.96	2.56	0.064	No

Table 15. Welch's two-sample t-test results (n=3 per series) for steel-versus-glass and dosage comparisons at matched grade, 28-day results, all four specimen types.

The steel-versus-glass comparisons are statistically significant specifically in the cube and panel specimens (all 8 comparisons, $p \leq 0.036$) but not in the cylinder or beam specimens (all 8 comparisons, $p \geq 0.31$): the small absolute differences reported for split tensile and beam flexural strength in Sections 3.3 and 3.4 fall within experimental scatter at the present replicate count (n=3), whereas the cube compressive and panel flexural differences are real. The dosage effect follows a similar pattern: for the panel specimens the 1%-to-1.5% increase is statistically significant for the steel mesh series at both grades ($p = 0.018$ and $p = 0.013$), consistent with the interaction discussed in Section 4.3, and significant for the glass mesh series in the cube specimens ($p = 0.022$ and $p = 0.011$), but not significant for the steel mesh series in the cube specimens ($p = 0.120$ and $p = 0.070$) or for either mesh type in the cylinder or beam specimens. The apparent decline in AR-glass panel strength with increased dosage is likewise not statistically significant at either grade ($p = 0.129$ at M30; $p = 0.064$ at M40, borderline), and should not be over-interpreted as strong evidence of a detrimental dosage effect on its own. Overall, the specimen-type pattern – real differences in the bulk compressive and thin-panel flexural results, but not in split tensile or beam flexure – reinforces the bond-and-geometry-sensitivity argument made throughout Section 4.

3.9 Percentage Improvement Summary

Table 16 summarizes the percentage strength improvement of each mesh-reinforced series in comparison with its grade-matched control mix (Section 3.7), for the three test types with a control baseline measured directly.

Series	Reinforcement (Dosage)	Grade	Cube (%)	Split Tensile (%)	Beam Flexural (%)
SM1	Steel Welded Mesh (1%)	M30	+4.94	+4.23	+4.18
SM2	Steel Welded Mesh (1.5%)	M30	+5.94	+4.76	+4.67
SM3	Steel Welded Mesh (1%)	M40	+5.04	+4.30	+4.41
SM4	Steel Welded Mesh (1.5%)	M40	+6.05	+4.98	+4.83
GM1	AR-Glass Mesh (1%)	M30	+2.94	+3.17	+3.19
GM2	AR-Glass Mesh (1.5%)	M30	+0.94	+2.12	+2.21

Series	Reinforcement (Dosage)	Grade	Cube (%)	Split Tensile (%)	Beam Flexural (%)
GM3	AR-Glass Mesh (1%)	M40	+3.04	+3.39	+3.36
GM4	AR-Glass Mesh (1.5%)	M40	+1.04	+2.49	+2.31

Table 16. Percentage strength improvement of each mesh-reinforced series over its grade-matched control mix, 28-day results.

Table 17 is an individual summary of the percentage difference in strength between the steel welded mesh series and the AR-glass mesh series at equal grade and dosage of reinforcement for all four test types, based on the data presented in Sections 3.2-3.5.

Grade / Dosage	Cube (%)	Split Tensile (%)	Beam Flexural (%)	Panel Flexural (%)
M30, 1% (SM1 vs GM1)	+1.94	+1.03	+0.95	+9.78
M30, 1.5% (SM2 vs GM2)	+4.95	+2.59	+2.40	+30.91
M40, 1% (SM3 vs GM3)	+1.94	+0.88	+1.02	+9.68
M40, 1.5% (SM4 vs GM4)	+4.95	+2.43	+2.46	+31.03

Table 17. Percentage strength advantage of steel welded mesh over AR-glass mesh at matched grade and dosage, 28-day results.

4. Discussion

4.1 Effect of Reinforcement Type

For every test combination and at both grades, the strength of the steel welded mesh series did not fall below and was equal or superior to the strength of the matched AR-glass mesh series. The gap between the two reinforcement systems is narrow in the bulk specimens (cube, cylinder, beam - usually 1-3%) but significantly larger in the thin specimens (up to 31% at M40, 1.5% dosage). This is consistent with what could be expected in the light of the TRC literature: in the bulk specimens, where the reinforcement takes up a minor percentage of the section cross-sectional area, the matrix determines the strength properties, while the reinforcement affects the post-crack and bond behaviour. The thin specimens, however, show a much larger reinforcement to thickness ratio and thus have their flexural capacity very sensitive to the stiffness, geometry, and bonding characteristics of the embedded mesh, as evidenced in flexural tests of carbon-textile TRC slabs, where the quality of bonding of the textile reinforcement with the matrix was shown to determine the flexural failure mode of the slabs (Williams Portal, Thrane and Lundgren 2016). It is possible that another factor contributing specifically to the performance difference between the two reinforcement types in this programme could be the difference in the stiffness and geometric characteristics of the meshes - the steel welded mesh is a stiffer and higher-modulus mesh which forms a grid that locks itself firmly into the fine-grained matrix at a relatively small cover thickness, while the AR-glass mesh - softer, with lower modulus, depending on the bonding at the interface and mesh opening interlock as opposed to weld points - is more dependent on achieving a good-quality and compacted bonding surface for load transfer - a feature that is more difficult to ensure in a 25 mm thick slab than in a 150 mm cube or beam. The difference should be considered in the context of the material deviation described in Section 2.1 - the AR-glass mesh used in this programme was a commercial plaster-grade AR-coated fibreglass mesh as opposed to laboratory-grade AR-glass mesh according to ASTM C1666, so a part of the poorer performance compared to steel mesh could be due to the mechanical properties and coating quality of the commercial mesh.

4.2 Effect of Mesh Dosage

One of the key findings of this study is the opposite response of the two mesh types to increasing their dosage, shown in Figure 8. An increase in steel mesh dosage from 1% to 1.5% increased strength in every test specimen type and at both grades, with the gain growing from moderate ~0.5-1% in the bulk cube, cylinder, and beam specimens to ~12% in the thin specimens. Increasing AR-glass mesh dosage over the same dosage range, on the contrary, led to a small but consistent decrease in strength in all test specimens - ~ -1 to -2% in the bulk specimens and approximately ~ -6% in the thin specimens. The difference is not a marginal statistical result specific to one test type only - it consistently occurs in compressive, split tensile, and flexural test types, and grows markedly with decreasing section thickness from 150 mm bulk specimens to the 25 mm thick panels.

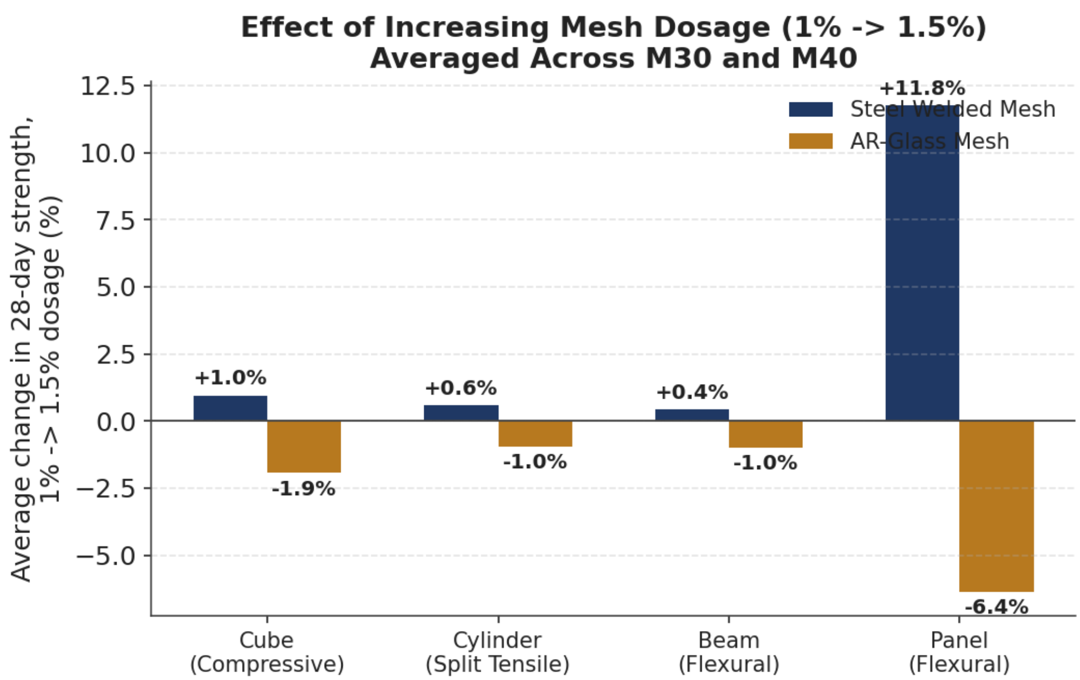

Figure 8. Average change in 28-day strength when mesh dosage is increased from 1% to 1.5%, by test type and mesh type (averaged across M30 and M40).

A plausible reason could be that adding a higher amount of steel mesh leads to better load transfer and bridging without negatively affecting the matrix compaction, thanks to the good workability of the fine-grained matrix with the wire mesh. With the AR-glass mesh, however, a higher dosage of mesh could possibly impede slightly the matrix compaction through the mesh openings during casting - which would affect the bonding achieved with the matrix, an important factor, especially in thin specimens, where the proportion of the matrix around the reinforced zone is relatively small.

4.3 The M40, 1.5% Steel Mesh Result (Series SM4)

Series SM4 – M40 grade concrete with steel welded mesh reinforcement at 1.5% dosage – achieved the highest strength value among all series in each of the four test configurations: 50.88 MPa in compression, 4.64 MPa in split tension, 4.99 MPa in beam flexure, and 9.12 MPa in panel flexure. The panel flexure result is the most notable: at 9.12 MPa, SM4 is 12% ahead of the second-highest steel series (SM3, M40, 1% dosage, 8.16 MPa), 31% ahead of the matching-grade AR-glass series (GM4, 6.96 MPa), and 79% ahead of the weakest series overall (GM2, M30, 1.5% AR-glass mesh, 5.08 MPa).

Isolating the grade and dosage effects individually in the panel specimens: raising the matrix grade from M30 to M40 at 1% steel mesh dosage (SM1 to SM3) increases panel flexural strength by 2.21 MPa (+37.1%), while raising the dosage from 1% to 1.5% at M30 (SM1 to SM2) increases it by 0.70 MPa (+11.8%). If these two effects acted independently and additively from the SM1 baseline (5.95 MPa), the combined M40/1.5% result would be predicted at 8.86 MPa; the measured SM4 value of 9.12 MPa is 0.26 MPa (2.9%) above this additive prediction. This is a real but modest positive interaction between concrete grade and steel mesh dosage in the panel geometry, not a step change: the interaction term is comparable in magnitude to the standard deviation of an individual series (0.20-0.30 MPa, Table 14), so a formal two-way ANOVA or a wider grade/dosage matrix would be needed to establish it beyond the precision of this dataset. By contrast, the same grade×dosage combination for the AR-glass series does not show even this modest positive interaction: GM4 (M40, 1.5% glass) performs worse than GM3 (M40, 1% glass), consistent with the dosage effect for AR-glass mesh discussed in Section 4.2. From a practical perspective, this means that if steel welded mesh is chosen as the reinforcement, the M40/1.5% combination remains the best-performing configuration identified in this study for thin flexure-critical panel elements, though the margin over simply summing the individual grade and dosage benefits is small.

4.4 Effect of Concrete Grade

It came as no surprise that higher-grade M40 series outperformed the M30 series in every test type and reinforcement configuration, with matrix grade being the major determinant of strength in the bulk specimens. The relative benefit of increasing steel mesh dosage was similar in percentage terms across both grades of matrix in the bulk specimens (Section 4.2), and, as discussed in Section 4.3, produces only a modest additional interaction with grade in the thin panel specimens.

4.5 Comparison with Existing TRC Literature

The sensitivity to bonding found in this test is consistent with experimental and numerical research on carbon-textile-reinforced concrete slabs, where the four-point bending tests in combination with the pull-out characterisation and finite-element modelling showed that flexural failure of thin TRC specimens is governed by the bond-slip behaviour between textile reinforcement and the surrounding matrix rather than matrix strength alone (Williams Portal, Thrane and Lundgren 2016). In that carbon-textile study, the local bond stress-slip relationship calibrated from pull-out tests and implemented in the finite-element model was found to govern both the crack development pattern and the ultimate flexural capacity of a nominally similar 50 mm-thick one-way slab. While this study did not include the pull-out tests or any characterisation of bond in thin specimens, the much larger dosage and reinforcement type dependent variation found in 25 mm thick panels compared to 150 mm bulk specimens is consistent with the increasing importance of bond and reinforcement ratio in thinner sections. This lends credence to the idea of future research on the bond/pull-out characterisation of the steel and AR-glass mesh used in this study, which will help establish the source of the grade×dosage interaction in the SM4 series described in Section 4.3.

4.6 Position Relative to Ferrocement

The steel welded mesh series in this study sit conceptually close to ferrocement, a thin cement-mortar composite reinforced with closely spaced layers of small-diameter steel wire mesh, typically at high specific surface area and low cover (ACI Committee 549 2018). The 1.5 mm wire diameter and 14 mm aperture welded mesh used here, placed at 25 mm cover with a 25 mm total panel thickness, is broadly consistent with the geometry ranges surveyed in the ferrocement literature (Naaman 2000), which has long established that closely spaced, well-distributed mesh reinforcement in thin cementitious sections can achieve flexural and crack-control performance well beyond what the same steel content would achieve as conventional discrete reinforcement, primarily because of the improved bond area and more uniform stress distribution. The steel-mesh panel results reported in Section 3.5, and the grade×dosage interaction discussed in Section 4.3, are consistent with that body of work. Positioning this study relative to ferrocement also clarifies where the AR-glass mesh series depart from that precedent: ferrocement's performance gains are specifically tied to the high stiffness and yield behaviour of steel wire, and the more limited, dosage-sensitive gains observed for the AR-glass series in the thin panels (Section 4.2) suggest that AR-glass mesh should be evaluated on its own terms as a textile-reinforced-concrete (TRC) system rather than assumed to behave as a lower-density substitute for a ferrocement-type steel mesh.

5. Practical Applications and Real-World Relevance

The reinforcement systems and specimen geometries investigated in this study can be applied to a number of practical applications where thin, lightweight and corrosion-resistant construction elements have advantage over conventionally reinforced concrete.

TRC Precast panels for facade and cladding applications: The thin 25 mm cement-mortar panel specimens represent the precast architectural cladding panels, rainscreen facade panels, as well as decorative/sunshade elements, for which weight and section size reduction are key criteria for the design. Based on the strength test results achieved in the panel specimens, particularly those of the steel-mesh reinforced series and especially the SM4 (M40, 1.5%), this composite seems to be suitable for the above-mentioned application of precast architectural panels, if the corrosion protection of the steel mesh is considered in case of its exposure (galvanizing or sufficient cover).

Retrofitting and strengthening of existing structures: Mesh-reinforced overlays, usually thin TRC-based, are used to improve the properties of existing reinforced concrete beams and slabs and/or masonry walls when it comes to seismic retrofitting or structural rehabilitation, due to their ability to increase the flexural and shear capacity of the members without increasing their thickness and dead loads. In this context, the flexural strength test results of the beams conducted in this study could be used to evaluate the potential performance of steel welded mesh or AR-glass mesh reinforced overlays for the purpose of strengthening of existing RC structures.

Corrosion-sensitive and marine environment: Being non-metallic, the AR-glass mesh reinforcement could be used in the structures which are located in corrosive and marine environment where conventional steel reinforcement is not desirable – for instance, coastal boundary walls, water-retaining structures, drainage channels and similar. Despite the fact that in this study steel mesh reinforced panels showed better results in the strength tests compared to the AR-glass mesh ones, the latter could be preferable in the above mentioned applications due to their corrosion resistance.

Secondary non-structural elements: In applications where lightweight construction is required, such as pedestrian walkway covers, boundary and compound walls, water tank panels, false ceiling and partition panels, modular housing components and alike, this technology of reinforcement could be used to produce the above mentioned elements.

Sustainable construction: Being the reinforcement systems which do not require significant concrete cover (as in case of steel mesh reinforcement the corrosion protection of the steel mesh is not necessary, or as AR-glass mesh reinforcement does not corrode at all), TRC/mesh systems allow using thinner sections, which is very important in terms of embodied carbon reduction.

In summary, the test results suggest that the selection of steel welded mesh or AR-glass mesh reinforcement and the dosage level of mesh chosen should be made according to the intended application, with steel welded mesh reinforced at the high dosage level (1.5%) in M40 grade matrix giving the highest strength recorded in this study and suitable for strength-driven thin section applications where corrosion resistance can be dealt with, whereas AR-glass mesh remains a strong option whenever corrosion resistance becomes the driving design consideration.

6. Limitations

There are a number of limitations associated with this study which should be taken into account when considering the implications of the findings. The first limitation is that the AR-glass mesh selected for use in the present programme is a commercial plaster-grade mesh, not a laboratory-grade mesh in line with ASTM C1666 (Section 2.1). This mesh deviation might explain the comparatively lower performance of the AR-glass mesh series and renders the results of the AR-glass series non-comparable with those obtained from AR-glass TRCs in the literature. Another limitation is the lack of the unreinforced control panels to cast and compare the thin-panel flexural performance results obtained, specifically the SM4 grade×dosage interaction (discussed in Section 4.3). In addition, the dosage levels of 1% and 1.5%, and concrete grades of M30 and M40 examined in this study mean that the identified trends, especially the differing dosage response behaviour of steel and AR-glass mesh, hold specifically to these dosage and grade values and need to be confirmed within a broader parameter range. Finally, no bond characterisation studies have been conducted in this study to confirm directly any of the bond-based hypotheses put forward in Section 4, as is done in the case of carbon-textile TRCs in the existing literature (Williams Portal et al. 2016).

7. Future Work

Taking into account the aforementioned limitations, the following suggestions are provided for future work: (i) casting and testing of unreinforced control panels for establishing a thin-section baseline for the panel flexural results; (ii) conducting physical tests up to 56 days (and even later ages) to characterise the continued strength gain beyond 28 days for all eight series; (iii) conducting pull-out and bond-slip characterisation of both steel welded and AR-glass mesh, along the lines of that done in carbon-textile TRC (Williams Portal et al. 2016) to verify whether the bond mechanism proposed in Section 4 for the differences noted here holds true; (iv) conducting the AR-glass mesh series using a laboratory-grade mesh in line with ASTM C1666 to differentiate the effect of the grade of the mesh from the effect of the type of the mesh; (v) extending the dosage and grade ranges beyond 1-1.5% and M30/M40 to see if the diverging dosage response of steel and glass observed in Section 4.2 continues, plateaus, or reverses outside the examined ranges; and (vi) conducting corrosion performance testing of the steel welded mesh system under exposed or simulated marine conditions to quantify the strength vs. corrosion resistance trade-off discussed in Section 5.

8. Conclusions

Conclusions based on the obtained test results of the eight TRC mix series at M30 and M40 grades can be drawn as follows:

- The strength values obtained for steel welded mesh-reinforced specimens are equal to or higher than those obtained for AR-glass mesh-reinforced specimens in every test configuration and concrete grade, with the difference being most evident in the thin cement mortar flexural panels.
- Increased use of steel mesh, from 1% to 1.5%, resulted in higher strength (up to ~12% in thin panels), whereas increased use of AR-glass mesh led to decreased strength (up to ~6% in thin panels).
- The impact of the mesh type and dosage was significantly larger in the thin flexural (25 mm) panels compared to the bulk cube, cylinder, and beam specimens due to bond and reinforcement ratio dominated behaviour of thin section TRC elements described in the literature.
- Concrete grade (M30 versus M40) was the dominant parameter that controlled absolute strength of tested materials in any specimen type, with relative trends related to mesh type and dosage being consistent across both grades.
- Series SM4 (M40 grade concrete and 1.5% steel welded mesh) exhibited the highest strength across all four specimen types in comparison to all other series of the test matrix. In addition, flexural strength of panels made of this series (9.12 MPa) was 31% higher than flexural strength of panels made of the AR-glass series of the same grade and dosage (6.96 MPa). Isolating the grade and dosage effects individually (Section 4.3), the measured SM4 result is only 2.9% above what an additive combination of the individual grade and dosage gains would predict, indicating a real but modest positive interaction between matrix grade and steel mesh dosage in this specimen type, rather than a large synergistic effect.

It may be concluded that steel welded mesh is the stronger reinforcement of the two types investigated in this work at the dosages used, especially when applied in thin panels. At the same time, it is necessary to conduct a direct investigation of bond properties of AR-glass mesh in order to verify whether lower strength of meshes with increased dosage is due to some workability issues or bond limitations per se.

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