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Compressive and Splitting Tensile Strength of Zigzag Steel Fibre Reinforced Concrete

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Abstract

The influence of nominal zigzag steel-fibre content on compressive and splitting tensile strength is examined using the experimental summary results of an M25-targeted concrete programme. Plain concrete and mixtures labelled 1%, 2% and 3% fibre were evaluated at 7, 14 and 28 days. The reported fibre length and diameter were 13 mm and 0.25 mm, giving an aspect ratio of 52. Twelve compressive-strength values and twelve splitting-strength values were transcribed and visually checked against the source tables. Same-age strength gains and adjacent-dose increments were recalculated. At 28 days, compressive strength increased from 33.27 MPa for plain concrete to 42.80, 45.05 and 47.65 MPa, corresponding to gains of 28.64%, 35.41% and 43.22%. Splitting tensile strength increased from 2.98 MPa to 4.91, 5.68 and 5.75 MPa, giving gains of 64.77%, 90.60% and 92.95%. The nominal 2% treatment retained 98.78% of the splitting strength of the 3% treatment, although equivalence cannot be tested. Compressive and splitting strengths increased with age in every reported series. The largest tested dosage produced the highest tabulated strength, but an optimum or a decline beyond 3% cannot be established. Fibre-percentage denominators, specimen counts and individual failure loads are absent from the accessible records, so findings remain descriptive. The analysis identifies a pronounced tensile response and a small additional 28-day splitting gain from 2% to 3%, while defining the evidence needed for mixture validation.

Keywords: zigzag steel fibres; concrete; compressive strength; splitting tensile strength; nominal fibre content; curing age; marginal strength gain.

1 Introduction

Discontinuous steel fibres are used to modify the response of concrete to cracking and loading. Their performance depends on the fibre product as well as its content. Soroushian and Bayasi [1] investigated fibre-type effects, while Yazıcı et al. [2] varied aspect ratio and volume fraction. These experiments show why geometry and dosage should be identified separately. A study with one fixed fibre geometry can evaluate its dosage series but cannot determine which aspect ratio is best.

Compressive and tensile responses should also be assessed separately. Song and Hwang [3] and Thomas and Ramaswamy [4] examined multiple mechanical properties of steel fibre concrete. Their studies provide context for comparing the relative sensitivity of different tests. Splitting tensile strength is an indirect tensile measure and does not by itself establish direct tensile behaviour or residual capacity. Post-cracking performance requires additional measurement, as illustrated by the toughness investigation of Banthia and Trottier [5].

The present work develops a research manuscript from a recorded zigzag-fibre programme rather than claiming a new laboratory campaign. The available results cover plain concrete and three nominal fibre treatments at three ages. Their value lies in the internally comparable property and age grid. The objectives are to preserve those results, calculate same-age relative changes, examine the incremental response between tested dosage labels, and identify the boundary between a promising treatment and a verified mixture recommendation.

The study does not claim novelty in adding steel fibres to concrete. Its specific contribution is an auditable account of the reported short zigzag-fibre

results, including corrections to derived percentages and removal of conclusions that would require untested dosages or geometries. No specimen-level uncertainty is invented when only summary values are available.

2 Experimental programme and data treatment

2.1 Source and evidence level

The experimental source is the thesis reproduced within the supplied similarity-report PDF [6]. Methods appear in Chapter 3, and Tables 4.1 and 4.2 appear on PDF page 49 of the 59-page report. These tables supply four dosage conditions × three ages × two strength properties, giving 24 reported strength values. They are not 24 verified individual specimens. The source does not state whether each entry is a single test result or an average, and it provides no individual specimen count, load series or standard deviation.

Page images were used to verify the numerical transcription because the PDF embeds the thesis principally as images. Only the thesis content is used as experimental evidence. The similarity-report percentage or matching annotations are not treated as evidence of mechanical quality, data validation or publication readiness. The present calculations do not alter a strength entry; they derive comparisons from the tabulated values.

2.2 Materials and fixed fibre geometry

The methods identify ordinary Portland cement of 43 grade, fine aggregate, coarse aggregate and zigzag steel fibres. The selected fibre is described as 13 mm long and 0.25 mm in diameter. These dimensions give L/d = 52. Table 3.6 of the source lists other fibre types and aspect ratios, but the strength results identify only the zigzag series. Consequently, fibre shape and aspect ratio are not independent experimental factors in the analysed dataset.

Table 1 Reported materials and specimen characteristics

Item	Recorded description	Interpretive status
Cement	43-grade ordinary Portland cement	Identified in the materials chapter.
Coarse aggregate	Specific gravity 2.70; fineness modulus 6.2; absorption 0.4%	Reported material properties, not independently remeasured.
Fine aggregate	Specific gravity 2.65; fineness modulus 2.47; absorption 0.85%	Free surface moisture reported as 0.90%.
Zigzag fibre	Length 13 mm; diameter 0.25 mm; aspect ratio 52	One selected geometry in the strength tables.
Fibre properties	Specific gravity 7.86; modulus 200 GPa; tensile strength 350 MPa	Source-table values; product certification not available.
Compression specimen	150 × 150 × 150 mm cube	Nominal dimensions stated in the methods.
Splitting specimen	150 mm diameter × 300 mm length cylinder	Nominal dimensions stated in the methods.

2.3 Matrix description and dosage definition

The source calls the programme M25 concrete and describes a cement:fine aggregate:coarse aggregate ratio of 1:1:2 with a water–cement ratio of 0.50 in the compression-test procedure. These are reported nominal descriptions, not a complete reconciled recipe per cubic metre. Actual batch quantities, admixture identity and aggregate-water corrections are not supplied with the strength tables. M25 is

therefore used as the programme's target designation; a characteristic-strength compliance assessment is not attempted.

Fibre conditions are labelled 0%, 1%, 2% and 3%. The percentage denominator is not established in the accessible methods. The labels are retained as nominal treatments S0, S1, S2 and S3, without relabelling them as volume fractions or percentages of cement mass. A reported specific gravity of 7.86 alone cannot convert an unknown percentage into kg/m³. Verified fibre mass and concrete yield are needed for that calculation.

2.4 Mixing casting curing and strength testing

The source describes dry mixing the concrete ingredients, adding water and assessing slump. For the fibre specimens, fibres were measured according to the nominal treatments and introduced manually in three layers. The described cube procedure used three layers, tamping and vibration. Cylinder casting is described using four layers with tamping. These details are retained as the stated procedure; the accessible record does not establish a uniformly dispersed bulk-fibre mixture or measure fibre orientation in each specimen.

Specimens were demoulded after approximately 24 hours and subjected to curing. Some method passages mention only 7 and 28 days, but casting descriptions and the result tables include 7, 14 and 28 days. The analysis follows the three reported result ages. Individual casting and testing dates, curing temperature and independent batch allocation are not available. A general slump range of 50–75 mm appears in the methods, but there is no treatment-specific slump table. Therefore, no numerical slump–dosage relationship is reconstructed.

For nominal cube side a and maximum load P, compressive strength is P/a^2 when force is in newtons and dimensions are in millimetres. Splitting tensile strength is $2P/(\pi LD)$, where L and D are cylinder length and diameter. The equations identify the reported test quantities:

$$\text{Compressive strength } f_c = P / a^2 \quad (1)$$

$$\text{Splitting tensile strength } f_{sp} = 2P / (\pi LD) \quad (2)$$

Failure loads and measured dimensions are absent, so the tabulated strengths cannot be independently recalculated from primary machine records. Equations 1 and 2 are not used to manufacture loads or missing observations. The source loading-rate units require confirmation before a standard-compliant laboratory procedure can be reconstructed.

2.5 Descriptive comparisons

For each property and age, percentage gain is calculated relative to the plain-concrete result at the same age. Adjacent-dose increments compare consecutive nominal labels. The analysis also reports the ratio of splitting strength to cube compressive strength as a descriptive index of two different tests, not a design coefficient.

$$\text{Gain (\%)} = 100 \times (\text{treated strength} / \text{same-age control} - 1) \quad (3)$$

$$\text{Adjacent increment} = \text{strength at next label} - \text{strength at current label} \quad (4)$$

$$\text{Property ratio} = f_{sp} / f_c \quad (5)$$

Calculations use the reported decimal values and are displayed to two decimals. Because individual results and counts are unavailable, no sample standard deviation, error bar, p-value or confidence interval is reported. No hypothesis of equivalence between S2 and S3 is tested. Connecting lines in the figures aid comparison; they are not fitted response functions. No prediction beyond S3 is generated.

3 Results

3.1 Compressive strength

Table 2 Reported compressive strengths in MPa

Treatment	7 days	14 days	28 days
S0 (0% nominal)	26.02	31.06	33.27
S1 (1% nominal)	29.37	35.15	42.80
S2 (2% nominal)	31.11	37.08	45.05
S3 (3% nominal)	33.56	38.88	47.65

The reported compressive strength increased with nominal fibre content at each age. At 7 days, values rose from 26.02 MPa for S0 to 29.37, 31.11 and 33.56 MPa for S1–S3. At 14 days, the corresponding values were 31.06, 35.15, 37.08 and 38.88 MPa. At 28 days, they were 33.27, 42.80, 45.05 and 47.65 MPa. S3 therefore had the largest reported compressive strength among the tested conditions at every age.

At 28 days, the recalculated gains relative to S0 were 28.64%, 35.41% and 43.22%. The last value differs from the 41.2% stated in the source conclusion. The table entry of 47.65 MPa is retained; the percentage is recalculated against 33.27 MPa. This is an arithmetic reconciliation, not a replacement of an experimental observation.

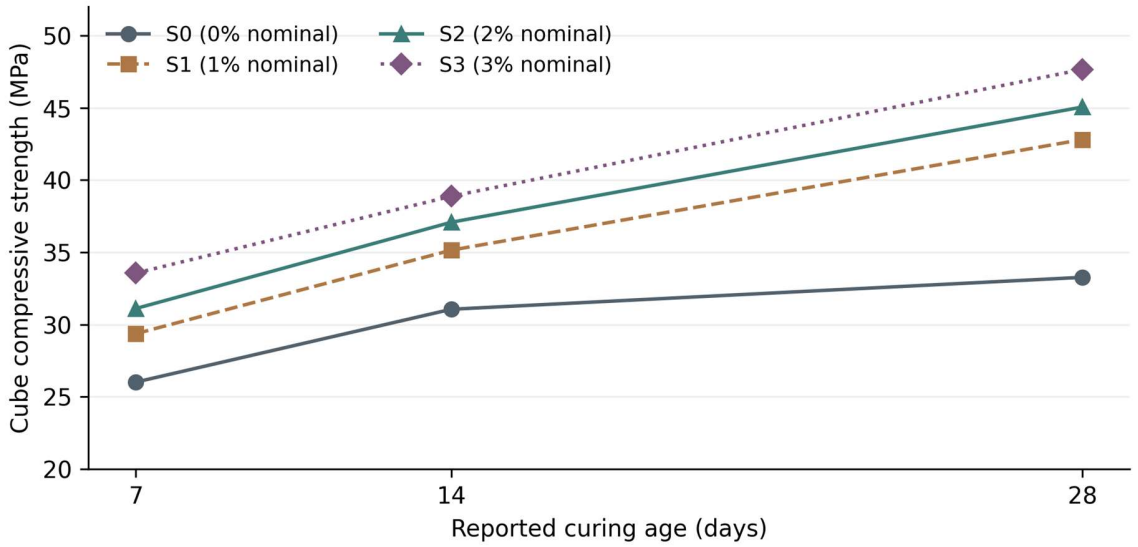


Figure 1 Reported cube compressive strengths at the three ages. Values are source-table entries with unknown replicate counts; no error bars or fitted curves are implied.

3.2 Splitting tensile strength

Table 3 Reported splitting tensile strengths in MPa

Treatment	7 days	14 days	28 days
S0 (0% nominal)	2.47	2.71	2.98
S1 (1% nominal)	3.90	4.44	4.91
S2 (2% nominal)	4.50	5.54	5.68
S3 (3% nominal)	5.30	5.66	5.75

Splitting strength also increased with nominal fibre content at each age. At 28 days, S0 had a reported value of 2.98 MPa, increasing to 4.91, 5.68 and 5.75 MPa for S1–S3. The corresponding gains were 64.77%, 90.60% and 92.95%. These calculations do not reproduce the source conclusion's approximate 62%, 87% and 89% increases. The differences arise from calculation against the displayed same-age control rather than from any adjustment to the strength entries.

At 7 days, S3 exceeded S0 by 114.57%; at 14 days the corresponding increase was 108.86%. Therefore, a single range such as 60–90% does not describe every property–age cell. Percentage statements should identify both dosage and age. In the full table, fibre-associated relative gains were greater for splitting than for compression at every matched dose and age.

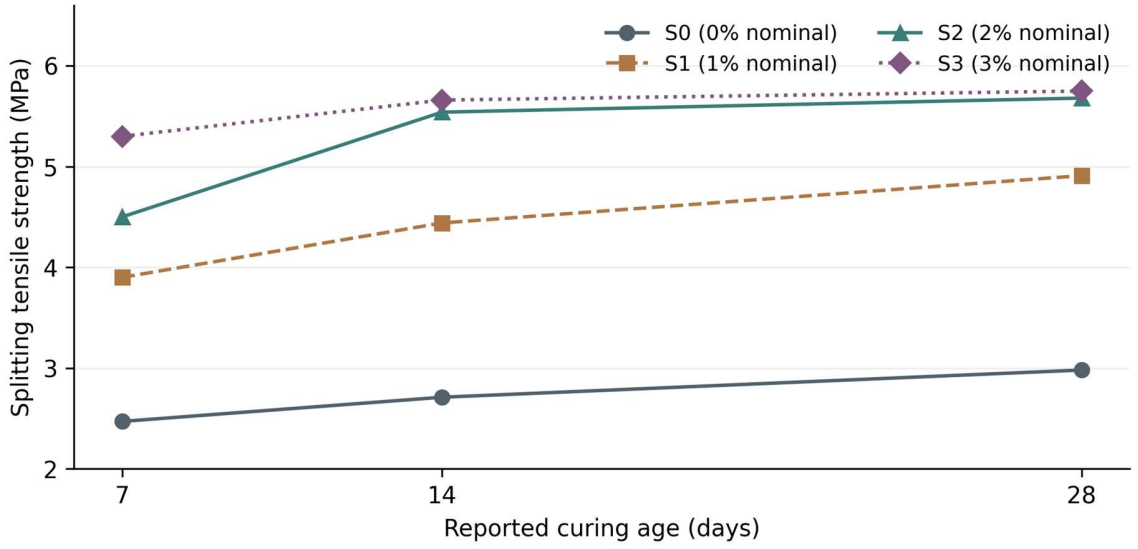


Figure 2 Reported splitting tensile strengths. The small S2–S3 separation at 14 and 28 days is shown without implying statistical equivalence.

3.3 Same-age normalisation and property ratios

Table 4 Recalculated same-age gains and strength ratios

Dose label (%)	Age (days)	Compression gain (%)	Splitting gain (%)	f_sp / f_c

Dose label (%)	Age (days)	Compression gain (%)	Splitting gain (%)	f_sp / f_c
1	7	12.87	57.89	0.133
1	14	13.17	63.84	0.126
1	28	28.64	64.77	0.115
2	7	19.56	82.19	0.145
2	14	19.38	104.43	0.149
2	28	35.41	90.60	0.126
3	7	28.98	114.57	0.158
3	14	25.18	108.86	0.146
3	28	43.22	92.95	0.121

For S0, the splitting-to-compressive ratio was approximately 0.095, 0.087 and 0.090 at 7, 14 and 28 days. At 28 days, it increased to 0.115, 0.126 and 0.121 for S1–S3. Although S3 had the largest absolute strengths, S2 had the largest 28-day property ratio. This does not make S2 a universally preferred mix: it shows that a ratio and an absolute-strength objective select different features of the same dataset.

These ratios combine cylinder splitting and cube compression and should not be treated as constitutive tensile-to-compressive ratios for structural design. No specimen pairing or covariance information is available. The result is a descriptive comparison of the tabulated property values.

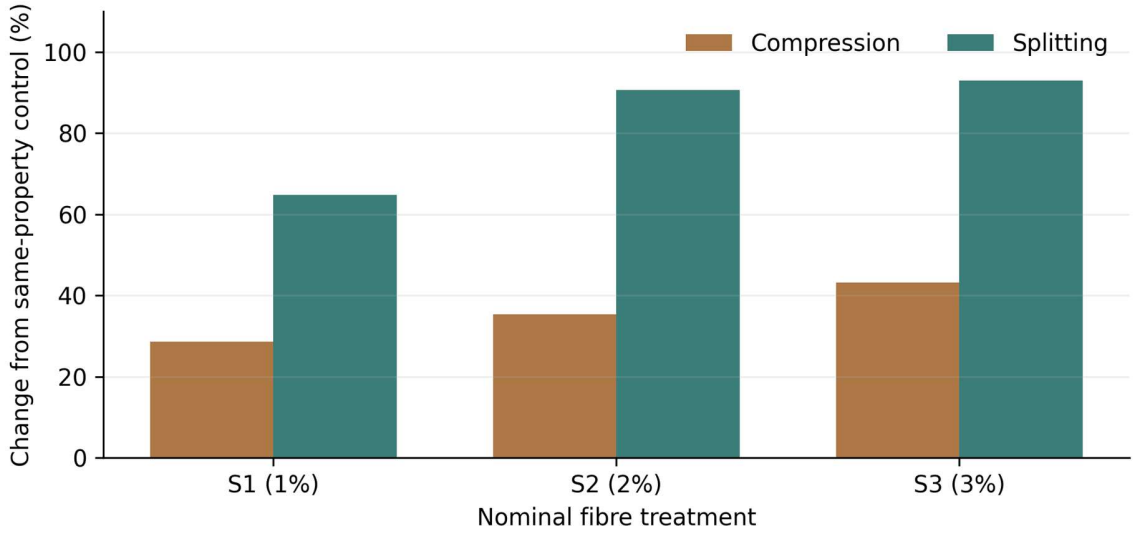


Figure 3 Recalculated 28-day gains relative to plain concrete. Each bar uses the control for its own property; the two percentage scales share a definition but represent different tests.

3.4 Marginal changes between dosage labels

Table 5 Adjacent-dose changes at 28 days

Nominal transition	Compression increase (MPa)	Compression increase (%)	Splitting increase (MPa)	Splitting increase (%)
S0 to S1	9.53	28.64	1.93	64.77
S1 to S2	2.25	5.26	0.77	15.68
S2 to S3	2.60	5.77	0.07	1.23

The 28-day splitting increment decreased across successive dosage transitions, from 1.93 MPa to 0.77 MPa and then 0.07 MPa. S2 reached 98.78% of the S3 splitting value. In compression, S2 reached 94.54% of the S3 value. The additional nominal dosage therefore had different marginal responses for the two tests. These calculations do not establish a material-efficiency advantage because actual steel quantities and production costs are not known.

The small final splitting increment could reflect a diminishing response, measurement variation or the rounding of summary data. The accessible record cannot distinguish these possibilities. It would be incorrect to claim either significant improvement or equivalence without the underlying test variability. A more precise optimum cannot be obtained by fitting a curve through four nominal conditions with an unknown dosage basis.

3.5 Age-related development

Every reported treatment increased in both properties from 7 to 14 days and from 14 to 28 days. From 7 to 28 days, compression increased by 27.86%, 45.73%, 44.81% and 41.98% for S0–S3, respectively. Splitting increased by 20.65%, 25.90%, 26.22% and 8.49%. The lower relative splitting growth for S3 reflects its already high 7-day entry and does not establish a different hydration mechanism.

No direct comparison of growth rates is made between the 7–14 and 14–28 intervals because their durations differ. Measurements at different ages are not repeated loading of the same specimen. With no allocation record, they cannot be treated as paired specimen trajectories or independent production-batch replications.

4 Discussion

4.1 Meaning of the larger tensile response

The observed relative response is stronger in splitting than in compression. This is compatible with the role of discontinuous reinforcement in crack-related behaviour, but the present programme does not directly measure crack bridging or pull-out. Banthia and Trottier [7] investigated bond–slip behaviour, while Dupont and Vandewalle [8] examined fibre distribution across sections. Those studies identify mechanisms and spatial variables that could be examined in a follow-up test; they cannot validate an unmeasured mechanism in this dataset.

Published volume-fraction experiments [2], [3] support interpreting dosage and test type together. Their numerical gains should not be used as validation bounds for the present nominal labels, because the denominator, fibre geometry and matrix differ. The contribution here is the within-programme descriptive pattern rather than proof that a published fibre-efficiency model has been reproduced.

4.2 Choice between the nominal 2% and 3% conditions

If the sole criterion is the largest tabulated peak strength, S3 leads the tested set. If the question is

whether the final dosage increment produces a practically meaningful increase in splitting strength, the 0.07 MPa difference requires confirmation. A production decision would also consider placement, actual steel content, repeatability and the relevant residual-performance requirement. None of those additional acceptance criteria can be inferred from the two peak-strength tables.

The fixed aspect ratio of 52 is internally consistent with the stated dimensions. It is not an experimentally established optimum aspect ratio. The source lists other fibre products, but supplies no corresponding strength matrix with which to isolate shape or length effects. Similarly, the statement that strength decreases after 3% is unsupported because no result above the 3% label is provided. The present paper restricts its conclusion to the tested range.

4.3 Production and structural interpretation

Bayasi and Soroushian [9] demonstrate that fresh properties depend on fibre conditions and testing method. In the present source, the general 50–75 mm slump range cannot establish the workability of a particular treatment. Manual fibre introduction, layer placement and vibration may also affect distribution. A repeat programme should record actual fibre mass, mixing sequence, placement direction and treatment-specific consistency before evaluating a production recommendation.

A higher splitting or cube strength does not establish ductility, toughness, fatigue resistance or member capacity. The toughness work of Banthia and Trottier [5] requires deformation-sensitive testing, which was not part of the available results. No claim is made that fibres can replace conventional reinforcement in an intended structure. Such a design decision would require additional material characterisation and application-specific verification.

5 Limitations and required confirmation

The experimental evidence consists of summary strength values from a thesis record, not raw machine observations. Replicate counts, individual loads, standard deviations and independent batches are unavailable. The percentage basis and full mix quantities require confirmation. The source test-rate units and exact ages should be checked against laboratory logs. These gaps prevent inference about population variability, causal dosage effects under a fully controlled matrix, or compliance with a material specification.

The arithmetic analysis is reproducible from Tables 2 and 3, but it cannot validate a transcription in the original thesis. Recovering specimen records would allow verification of the reported entries and determination of whether they are averages. Appendix A lists the documentation needed before converting this analysis into a stronger submission claim. Missing evidence is not replaced with fabricated observations or statistical estimates.

6 Conclusions

Within the four nominal treatments and three reported ages, both compressive and splitting tensile strength increased with the dosage label. At 28 days, the largest tabulated values occurred at S3: 47.65 MPa in compression and 5.75 MPa in splitting.

Recalculated 28-day compression gains were 28.64%, 35.41% and 43.22%, while splitting gains were 64.77%, 90.60% and 92.95%. These values correct the derived percentages while preserving all experimental table entries. Splitting response was proportionally greater than compression response in every matched comparison.

The final nominal dosage transition increased 28-day splitting strength by only 0.07 MPa, or 1.23%, while increasing compression by 2.60 MPa, or 5.77%. This difference identifies a useful confirmation question but does not demonstrate equivalence or a cost-optimal dosage.

The reported dimensions establish an aspect ratio of 52 for the selected fibre, but the programme does not test alternative ratios or dosages above 3%. Neither a universal geometric optimum nor a post-3% decline is supported. Verified fibre quantities, individual specimen results, treatment-specific fresh testing and post-cracking measurements are needed before a validated structural mixture recommendation can be made.

Data availability

All 24 source strength values are reproduced in Tables 2 and 3. Relative gains and ratios are derived using Equations 3–5. Individual specimen records were not available in the experimental source [6].

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Appendix A Documentation needed for submission

Table A1 Evidence required to resolve remaining experimental questions

Question	Required record	Reason
What do 1%, 2% and 3% mean?	Fibre masses, percentage denominator and concrete yield.	Makes the dosage reproducible and comparable.
How many tests produced each entry?	Specimen register and batch allocation.	Establishes sample size and independent replication.
Are the tabulated values correct?	Machine failure loads and measured specimen dimensions.	Enables primary strength recalculation.
Was consistency comparable?	Slump results for every treatment and measurement times.	Tests the proposed workability trade-off.
What exact mixture was cast?	Complete batch sheet, water correction and admixture details.	Distinguishes a fibre response from matrix changes.
Are ages and loading conditions verified?	Casting/testing dates, curing logs and loading-rate units.	Supports accurate methods and test interpretation.
Is the final dosage benefit reproducible?	Independent repeat batches for S2 and S3.	Quantifies variation relative to the 0.07 MPa splitting gap.
Is structural post-cracking performance adequate?	Instrumented tensile or flexural response for the intended use.	Prevents peak-strength results from substituting for residual capacity.