УДК 624.016

SELF-STRESSING OF EXPANSIVE CONCRETE FILLED STEEL AND FRP TUBES

Liu Min
Brest State Technical University, Brest, Republic of Belarus
e-mail: liumin930406@163.com

This study investigates expansive recycled aggregate concrete (RAC) confined by steel tubes and fiber-reinforced polymer (FRP) shells and places both systems on a common lateral-pressure scale using thin-cylinder relations. A compact dataset is compiled from tests that either report core self-stress in concrete-filled steel tubes (CFST) or provide initial hoop pre-strain in prefabricated FRP shells filled with expansive grout/concrete. Directly reported CFST self-stress clusters near 5 MPa and coincides with measurable gains in axial capacity, particularly in slender members. For FRP shells, converting the measured hoop pre-strain with laminate stiffness and thickness yields active confinement of roughly 0.9–3.4 MPa for typical GFRP/CFRP stacks, consistent with observed improvements in strength and ductility over ordinary infill. A thin-walled RAC baseline without expansive action shows a capacity shortfall relative to natural-aggregate mixes, framing the performance gap that controlled expansion can recover under confinement. The resulting pressure-scale mapping offers a transparent, data-lean way to compare steel and FRP encasements and to plan targeted experiments and laminate selections.

Keywords: recycled aggregate concrete, expansive concrete, self-stress, confinement, steel tube, FRP tube.

САМОНАПРЯЖЕНИЕ ТРУБОБЕТОННЫХ ЭЛЕМЕНТОВ В СТАЛЬНЫХ И КОМПОЗИТНЫХ (FRP) ОБОЛОЧКАХ ПРИ ИСПОЛЬЗОВАНИИ РАСШИРЯЮЩЕГОСЯ БЕТОНА

Лю Минь
Брестский государственный технический университет, г. Брест, Республика Беларусь
e-mail: liumin930406@163.com

В данном исследовании рассматривается расширяющийся бетон на вторичных заполнителях (RAC), заключенный в стальные трубы и оболочки из фиброармированного полимера (FRP). Обе системы сопоставляются по единой шкале бокового давления с использованием зависимостей для тонкостенных цилиндров. Сформирован компактный набор данных на основе испытаний, в которых либо фиксировалось самонапряжение ядра в сталетрубобетонных элементах (CFST), либо измерялась начальная кольцевая предварительная деформация в готовых FRP-оболочках, заполненных расширяющимся составом или бетоном. Напряжения самонапряжения в CFST группируются в районе 5 МПа, что совпадает с ощутимым приростом осевой несущей способности, особенно у гибких элементов. Для FRP-оболочек расчет активного обжатия на основе измеренной кольцевой деформации, жесткости ламината и его толщины дает значения примерно 0,9–3,4 МПа для типичных слоев GFRP/CFRP, что согласуется с наблюдаемым повышением прочности и пластичности по сравнению с обычным заполнителем. Базовые показатели тонкостенных элементов из RAC без расширяющих добавок демонстрируют дефицит несущей способности относительно смесей на природных заполнителях; этот разрыв в характеристиках может

быть восполнен за счет контролируемого расширения в условиях обойменного сжатия. Предложенное сопоставление по шкале давления представляет собой прозрачный и малозатратный с точки зрения данных способ сравнения стальных и композитных оболочек, а также планирования целевых экспериментов и выбора структуры ламината.

Ключевые слова: бетон на вторичных заполнителях, расширяющийся бетон, самонапряжение, обойменное сжатие (конфайнмент), стальная труба, FRP-труба.

Introduction

Recycled aggregate concrete offers environmental benefits but can show greater variability in strength and stiffness than mixes with natural aggregates, which motivates structural solutions that stabilize performance without sacrificing sustainability. Concrete filled tubes and shells provide radial restraint to the core. When the core uses expansive concrete, the restrained chemical expansion develops beneficial self-stress in compression within the concrete and a corresponding hoop tension in the encasing member. In steel tubes, tests on thin-walled columns filled with self-compacting recycled aggregate concrete indicate both the promise and the limits of confinement when expansive action is absent, including measurable reductions in peak load relative to natural aggregate mixes, which motivates the use of controlled expansion to recover capacity and deformability [1]. In fiber reinforced polymer systems, expansive cement has been used to convert passive confinement into active confinement by inducing an initial hoop strain in prefabricated shells, providing a direct and quantifiable route to self-stress that can be tuned through shell geometry and laminate design [2].

Building on these developments, this paper assembles verifiable evidence on expansive recycled aggregate concrete in steel and FRP tubes, extracts the essential geometric and material variables for quick self-stress estimation from published relations, and provides a concise model to data check.

Materials and Methods

1.1 Literature scope and data fields

This study targets experimental reports where expansive concrete or expansive binders are used in tube-confined systems and, when available, incorporate recycled aggregate concrete. Eligible sources report at least one measurable indicator of self-stress such as early-age internal pressure, hoop strain in the encasing member, or pre-compression inferred from tube strain. For each study we extracted tube material and geometry, laminate or hoop modulus when applicable, recycled aggregate replacement ratio, expansive system and nominal dosage, curing age at reading, and the reported indicator used for model-to-data checks.

1.2 Harmonization and computation workflow

All quantities were converted to SI units. When the diameter to thickness ratio was sufficiently large, the tube or shell was treated under thin wall assumptions. If hoop strain of the tube or shell was reported, an equivalent lateral pressure was estimated using the thin cylinder hoop relation combined with linear elasticity in the circumferential direction; if internal pressure was reported directly, that value was adopted as the self-stress at the measurement age. For steel tubes that reported a concrete self-stress level and compressive strength, a nondimensional self-stress ratio was formed to enable comparison across mixes and to reference published capacity multipliers without re-calibration.

1.3 Minimal formulas and source

For a thin circular cylinder under uniform internal pressure p, the circumferential stress satisfies $\sigma_\theta = p\, r/t$, where r is the mean radius and t is the wall thickness, and the hoop strain is $\varepsilon_\theta = \sigma_\theta / E_\theta$

when evaluated with the appropriate circumferential modulus Eθ. Eliminating σθ yields the working estimator p=(Eθ t/r) εθ used here to convert reported hoop strain into an equivalent lateral pressure. For prefabricated fiber-reinforced polymer shells filled with expansive grout, the measured initial hoop pre-strain after curing is converted to an active confinement pressure through p0=2 Efrp tfrp εθ,ini/D, noting that D=2r. These relations are standard results from thin cylinder theory and elementary elasticity [3].

Results

2.1 Dataset snapshot with compact table and per-row citations

Table 1 keeps only the fields needed for later calculations and removes the previous first column. The reference index for each study appears in the Encasing cell in square brackets so that the table remains compact in a word processor while staying fully traceable.

Table 1. – Minimal dataset summary for tube-confined expansive or baseline RAC systems

Encasing	D×t (mm)	RAC (%)	Expansive system	Indicator reported	Headline outcome
Steel tube, CFST [4]	about 159×3 to 5	n a	Self stressing concrete	Self-stress level, geometry, axial tests	Fifty-one short columns with documented self-stress and capacity trends
Steel tube, thin-walled baseline [1]	140×1.2 and 140×3.0	up to 100	None	Peak load versus natural aggregate concrete	Maximum load lower by 18.4 % at t equals 1.2 mm and 5.8 % at t equals 3.0 mm relative to natural aggregate
GFRP tube with expansive concrete [5]	FRP tube walls	no	Expansive concrete mix	Axial compression response	Active confinement discussed under axial loading with expansive mix
CFRP or GFRP shells with expansive grout [2]	circular and rectangular shells	no	Type K expansive grout	Initial hoop pre strain	Measured initial hoop pre strain suitable for active confinement quantification

The steel tube self-stressing program provides the clearest quantitative anchor because it reports explicit self-stress magnitudes together with diameter and thickness and the associated axial capacities. The thin-walled recycled aggregate baseline without expansive action sets a reference envelope for what can be achieved by confinement alone when recycled aggregate is used, and it shows the performance gap that controlled expansion is intended to recover. The two fiber reinforced polymer entries capture the active confinement route that arises from expansive grout or expansive concrete. The shell study reports initial hoop pre strain that can be turned into an equivalent lateral pressure using the thin cylinder relation in Section 1, while the GFRP tube study documents axial response differences when the infill is expansive. This combination supplies geometry, encasing stiffness cues and at least one measurable indicator per row, which is sufficient for the quick conversions performed in Section 2.2.

2.2 Model to data checks with explicit use of the Section 1 formulas

Here the Section 1 thin cylinder relations are applied in a minimal way to demonstrate how reported quantities map to an equivalent lateral pressure. For steel tubes that already report a concrete self-stress, the reported value is used directly as the chemical pre stress. For fiber reinforced polymer shells the measured initial hoop pre strain is converted to an initial active confinement using the thin cylinder relation, and when laminate properties are not given the result is shown in normalized form.

Table 2. – Compact model to experiment touchpoints for self-stress or active confinement

Encasing	Indicator basis from study	Formula used	Derived quantity used for checks
Steel tube, CFST [4]	Reported concrete self-stress for a representative short column case near the upper bound	Direct use of reported value as chemical pre stress	Self-stress about 5 MPa which the authors associate with an increase in axial capacity of about twelve percent for short columns
CFRP shell, circular, two layers [2]	Initial hoop pre strain at aspect ratio B over D equal to 1 from the empirical fit	$\varepsilon_{\theta,ini} = 0.0020 - 0.00041(B/D)$ and $p_0 = 2E_{frp}t_{frp}\varepsilon_{\theta,ini}/D$	$\varepsilon_{\theta,ini} = 0..00159.$ Normalized pressure $p_0/(Et/D) = 2\varepsilon_{\theta,ini} = 0.00318$. A numerical p_0 follows once E, t, and D are specified
GFRP shell, circular, six layers [2]	Initial hoop pre strain at aspect ratio B over D equal to 1 from the empirical fit	$\varepsilon_{\theta,ini} = 0.0020 - 0.00041(B/D)$ and $p_0 = 2E_{frp}t_{frp}\varepsilon_{\theta,ini}/D$	$\varepsilon_{\theta,ini} = 0..00209$). Normalized pressure $p_0/(Et/D) = 2\varepsilon_{\theta,ini} = 0.00418$. A numerical p_0 follows once E, t, and D are specified

The steel tube case establishes a practical magnitude for chemical pre stress that has already been linked to strength gain in a large set of short columns, which makes it a useful benchmark for expansive recycled aggregate concrete in steel encasements. The two shell cases [8] show how an experimentally measured initial hoop pre strain translates into an initial active confinement at zero external load. The normalized form p0/(Et/D)=2ε,ini, avoids assumptions about laminate moduli and thickness and allows a direct comparison of different shells once their materials are specified. The values of the normalized pressure coefficients for the two shell configurations are of the same order and indicate a realistic path to generate a measurable lateral pressure that can be compared with the steel tube self-stress magnitude. Together the conversions demonstrate that the formulas introduced in Section 1 are not only theoretical relations but also practical tools for screening studies and designing future tests with recycled aggregate and expansive action.

2.3 Experimental benchmarking and consistency check

This subsection harmonizes measurable indicators from published tube-confined tests onto a common lateral-pressure scale by applying the thin-cylinder relations introduced earlier, namely the pretrain-to-pressure map $p_0 = \frac{2Et}{D}\varepsilon_\theta$ and the reverse check $\varepsilon_\theta = \frac{pr}{Et}$. Two representative systems are considered: concrete-filled steel tubes (CFST), where the core self-stress is reported directly, and prefabricated FRP shells filled with expansive grout/concrete, where the initial hoop pre-strain is measured and converted to an equivalent active lateral pressure; the resulting pressure magnitudes are then read against the observed strength/ductility changes for consistency of order of magnitude [1–5].

Table 3. – Indicator-to-pressure mapping and performance check for expansive RAC in steel tubes and FRP shells

System	D(mm)	t(mm)	E(GPa)	Measured input	Conversion	(MPa)	Experimental outcome
CFST (self-stress) [1]	159	4	200	Core self-stress p_0 ≈ MPa	p0= p and $\varepsilon_\theta \approx \frac{pr}{Et}$ (for a check)	5.00	Axial capacity increases, more pronounced for long columns
FRP shell, 2-ply CFRP [2]	150	tf = 0.68	234.5	Initial hoop pre-strain $\varepsilon_{\theta,ini}$≈0.00159) (circular)		3.38	Strength/ductility improved vs. ordinary infill
FRP shell, 6-ply GFRP [2]	150	tf = 1.08	29	Initial hoop pre-strain $\varepsilon_{\theta,ini}$≈0.00209) (circular)		0.87	Same trend; magnitude lower than CFRP
CFST, RAC baseline (no expansive agent) [5]	—	thin-wall	—	Capacity deficit vs. NA: −18.4% (t=1.2 mm), −5.8% (t=3.0 mm)	baseline only	—	Defines the gap to be recovered

Conclusion

Mapping encasing measurements to a common pressure scale demonstrates that expansive RAC can develop practical levels of core self-stress in both steel and FRP confinement, and that these levels can be estimated from routine geometric and material inputs via thin-cylinder relations. CFST programs indicate a robust self-stress anchor near 5 MPa with commensurate increases in load capacity, while FRP shells with expansive binders provide active confinement on the order of 0.9–3.4 MPa, aligning with the recorded gains in strength and deformability. The thin-walled RAC baseline without expansion clarifies the underlying deficit relative to natural aggregate and situates the benefit of chemical pre-compression within a consistent comparative frame. Overall, the framework enables like-for-like assessment across steel and FRP encasements, supports early-stage design and specimen planning, and highlights priorities for future refinement, including time-dependent expansion and relaxation, laminate orthotropy, and uncertainty quantification.

REFERENCES

1. Wang Y., Sun S., Zhang L., Jia Y. Compressive behaviors of thin-walled steel tube stub columns filled with self-compacting concrete containing recycled aggregate // Materials. 2023. Vol. 16, No. 18. Article 6088.
2. Yan Z., Pantelides C. P., Reaveley L. D. Shape modification with expansive cement concrete for confinement with FRP composites // In: SP-230: 7th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures. Farmington Hills: American Concrete Institute, 2005. P. 1047–1058.
3. Young W. C., Budynas R. G., Sadegh A. M. Roark's formulas for stress and strain. 8th ed. New York: McGraw-Hill Education, 2011. ISBN 978-0-07-174247-4.
4. Xu L., Zhou P., Yu M. Performance of the high-strength self-stressing and self-compacting concrete-filled steel tube columns subjected to the uniaxial compression // International Journal of Civil Engineering. 2018. Vol. 16, No. 9. P. 1069–1083.
5. Cao Q., Li H., Lin Z. Study on the active confinement of GFRP-confined expansive concrete under axial compression // Construction and Building Materials. 2019. Vol. 227. Article 116683.