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lastic Properties of High-Performance Recycled Concrete: Materials–Structure

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KEYWORDS

High performance;
Recycled concrete;
Elastic properties

ABSTRACT

This review synthesises recent evidence on elastic properties of high performance recycled concrete from a materials to structure perspective. At comparable strength, static elastic modulus decreases with increasing recycled coarse aggregate. Typical penalties are about 0 to 10% at 0 to 30% replacement, about 5 to 20% at 30 to 60% replacement, and about 15 to 30% at 60 to 100% replacement. Low water to binder ratio with silica fume or slag improves the interfacial transition zone and reduces the loss. Dynamic modulus from resonance or ultrasonic methods exceeds static values by about 5 to 15% at 28 days under similar moisture. Poisson ratio is usually about 0.16 to 0.23. Fibres do not raise modulus at equal strength but can moderate losses at high replacement. The review compares empirical, micromechanics, numerical representative volume element and data driven models, and proposes a concise reporting and validation protocol to support serviceability focused design.

INTRODUCTION

Elastic properties, especially elastic modulus and Poisson's ratio, govern member stiffness, crack development and deflection control in structural design, so they are central to the engineering use of high performance concrete and its recycled variant. From a materials viewpoint, a low water to binder ratio combined with mineral admixtures and high range water reducers produces a dense paste and an improved interfacial transition zone, which together raise stiffness at a given strength level. When recycled aggregates are introduced, lower aggregate modulus, adhered mortar and higher water absorption increase porosity and weaken the interfacial transition zone, so at comparable compressive strength a reduction of static elastic modulus is frequently observed. The magnitude of this reduction depends on replacement level, recycled aggregate quality indices such as density, absorption and adhered mortar fraction, paste composition, curing regime, age and moisture state, and on the test method used to report static or dynamic values [1]. For structural applications, these material changes affect serviceability checks for deflection and crack width, and they motivate clear reporting of mixture features and recycled aggregate quality so that results can be compared across studies and used in practice [2]. This review follows a materials to structure logic, compiles compact numeric windows for elastic properties by replacement band and quality class, and organises prediction approaches into empirical relations, micromechanics models, numerical representative volume element simulations and data driven learners, with an emphasis on transferability to high performance recycled concrete [1,2].

Materials and Methods

This study is a structured literature review. Scopus, Web of Science Core Collection and Google Scholar were searched for the years 2000 to 2025 using combinations of the terms high performance concrete, recycled concrete, elastic modulus, Poisson ratio, recycled aggregate and interfacial transition zone. Titles and abstracts were screened first, followed by full texts. Eligible sources were peer reviewed journal articles and standards that reported numerical elastic modulus or Poisson ratio together with mixture details and

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test procedures. Exclusions were non structural materials, theses, abstracts or posters, and items without numerical results. To enable comparison, we recorded for each source the concrete strength class and whether elastic modulus was static or dynamic.

Data extraction followed a predefined template. Mixture variables captured were water to binder ratio, binder system and mineral additions, replacement ratios for coarse and fine recycled aggregates, and recycled aggregate quality indices including density, water absorption, adhered mortar fraction and flakiness. Test and conditioning variables captured were curing regime and age, moisture state at test, specimen geometry, strain range and the named test method. All values were converted to SI units. Static and dynamic elastic moduli were reported separately without conversion unless an explicit relation was provided by the source. Poisson ratio values were retained only when the age, moisture state and method were stated. To summarise trends for practice, records were grouped by replacement bands of 0 to 30%, 30 to 60% and 60 to 100% and by recycled aggregate quality class. Where three or more records were available in a group, we reported the range with a central tendency. For engineering context, measured values were also compared with code type relations based on strength and density, and deviations were expressed as simple percentage errors. The grouped results support the numeric ranges in Table 1 and the workflow in Figure 1.

Results

At comparable compressive strength, the static elastic modulus of high performance recycled concrete decreases with increasing recycled coarse aggregate. The magnitude depends on replacement level and recycled aggregate quality. In mixes with low water to binder ratio and silica fume or slag, the loss is smaller because the interfacial transition zone is improved. The compact ranges that follow from the screened studies are summarised in Table 1 [3 – 5]. Dynamic modulus obtained from resonance or ultrasonic methods is higher than static modulus measured from stress strain tests. The difference is typically 5 to 15% at 28 days when moisture state is similar. Poisson's ratio remains comparatively stable in the range 0.16 to 0.23 with modest sensitivity to replacement and quality. The combined picture for modulus and Poisson's ratio by replacement band and quality class is given in Table 1 [5]

Replacement band, coarse RA (%)	RA quality class	Binder and curing note	Static elastic modulus change at matched strength (%)	Dynamic vs static at 28 d (%)	Poisson's ratio at 28 d
0 to 30	high quality, low absorption and low adhered mortar	silica fume or slag; standard curing	0 to −10	dynamic greater by 5 to 10	0.18 to 0.22
30 to 60	moderate quality	fly ash or slag; standard curing	−5 to −20	dynamic greater by 5 to 15	0.18 to 0.22
60 to 100	mixed or low quality	silica fume and extended curing	−15 to −30	dynamic greater by 10 to 20	0.19 to 0.23

Table.1. Elastic modulus and Poisson's ratio of high performance recycled concrete by replacement band and recycled aggregate quality [3 – 5,8]

Notes. Static values come from compressive stress – strain tests. Dynamic values come from resonance or ultrasonic methods. Ranges depend on density, absorption and adhered mortar fraction, on water to binder ratio, and on moisture state and strain range at test.

Model behaviour follows a consistent pattern. Empirical equations based on strength and density reproduce the central tendency for low to moderate replacement but lose accuracy at high replacement unless density or a quality proxy is added. Micromechanics three phase schemes capture changes caused by modulus contrast and adhered mortar but require inputs that are not always reported.

Numerical representative volume element studies support mechanism insight and can generate synthetic data for calibration. Data driven learners such as gradient boosting reduce bias across heterogeneous datasets when features include absorption, adhered mortar fraction, binder descriptors and age. The evidence synthesis and model comparison steps used in this review are shown in Figure 1 [3,4,6,7].

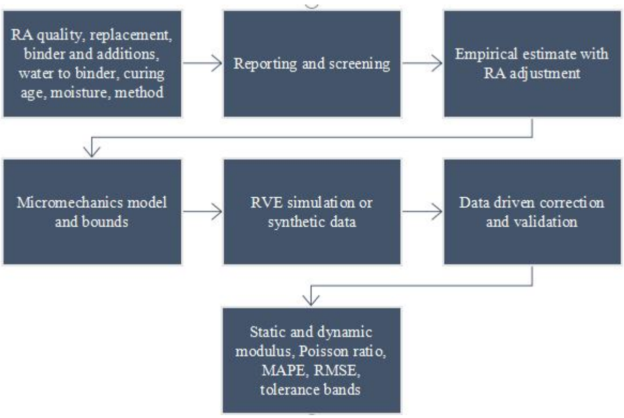

Fig.1. Evidence synthesis and model comparison workflow for elastic property prediction in high performance recycled concrete

Studies that include steel or recycled steel fibers indicate that fibers do not systematically raise elastic modulus at constant strength. They can moderate the loss at high replacement by improving matrix continuity and crack stability, especially with medium quality recycled aggregate and silica fume in the binder. When models are evaluated on independent sets, unified or machine learning equations tailored to recycled aggregate features achieve mean absolute percentage errors near 6 to 10%, which is an improvement over code type relations calibrated for natural aggregate concrete.

Conclusion

This review links materials choices to elastic response in high performance recycled concrete. At similar strength, static elastic modulus decreases as recycled aggregate content rises, with the loss governed by replacement band and aggregate quality. Dynamic modulus exceeds static by about 5 to 15% at comparable age and moisture, while Poisson's ratio remains about 0.16 to 0.23. Table 1 summarises compact ranges and Figure 1 shows the workflow used to organise evidence and models. For prediction, empirical relations suit low to moderate replacement, micromechanics and representative volume elements add interpretability when phase data exist, and data driven learners benefit from quality descriptors. A hybrid scheme with micromechanics priors and data driven correction, supported by standardised reporting and stratified validation, improves comparability and supports serviceability focused design.

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