EFFECT OF PARTICLE SIZE AND REPLACEMENT RATIO ON MECHANICAL PERFORMANCE OF CONCRETE CONTAINING GROUND-RECYCLED ABS WASTE PLASTICS

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Introduction

The increasing demand for concrete and recycling plastic in various industries raises concerns about the sustainability of these materials, particularly due to environmental challenges associated with the limited availability of natural resources and the challenges in recycling end-of-life plastics. However, substituting recycled waste plastics for natural sand in concrete provides a viable solution from both environmental and economic perspectives.

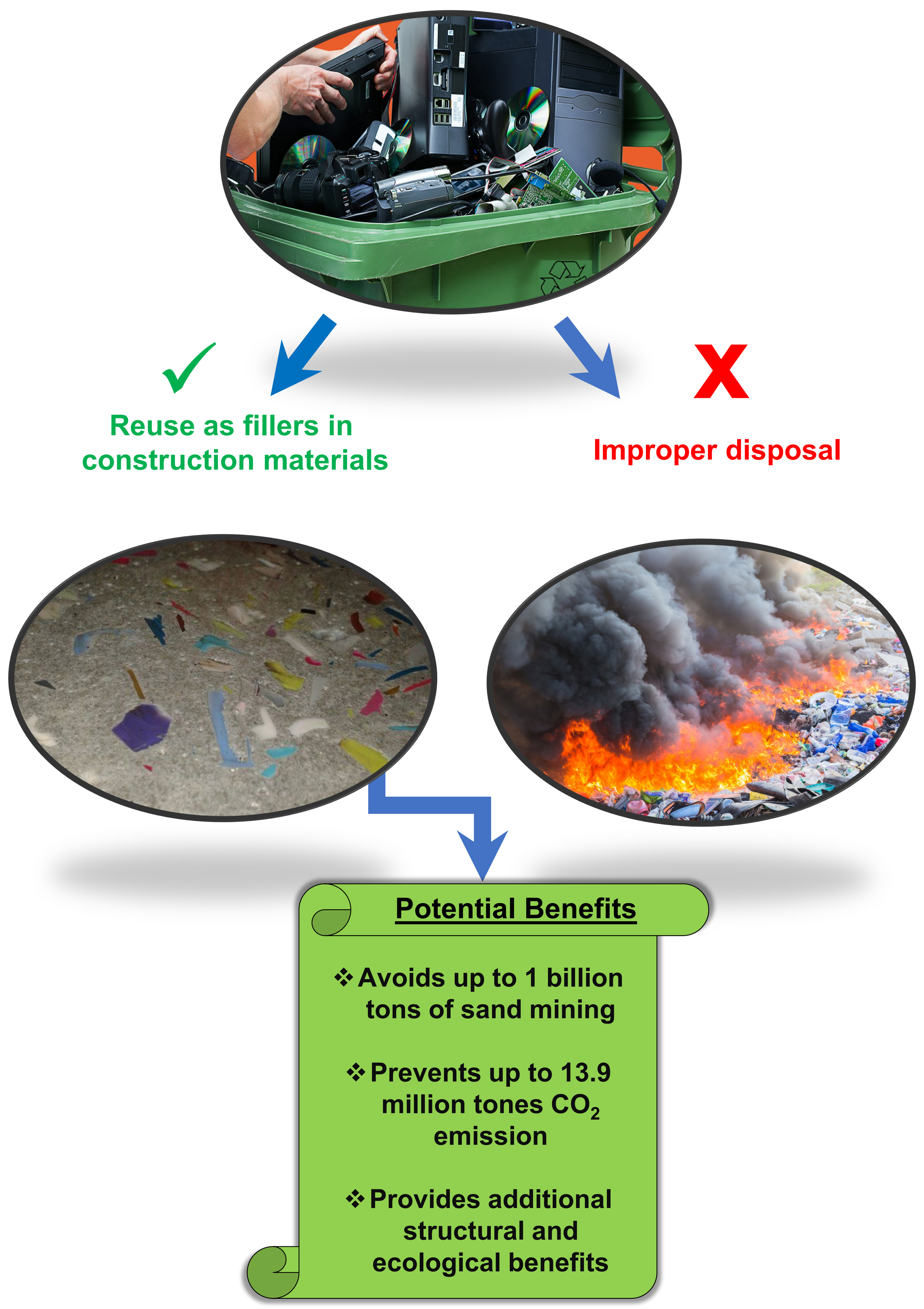

Figure 1. Potential benefits of using plastics as natural sand aggregate replacement in concrete structures

Background

While numerous studies have examined the impact of waste plastic replacement ratios on the structural performance in concrete, there has been a notable neglect of the effects of graded particle size. Here, this study addresses a critical gap in the existing literature, focusing on the limited exploration of the effects of waste plastic particle size and the replacement ratio when substituting sand with waste plastics in concrete. Through this approach, the study aims to bridge the existing knowledge gap and enhance the understanding of the intricate relationship between waste plastic characteristics and the mechanical behavior of concrete as a building construction material.

Experimental Methods

Before the grinding process, ABS waste plastics were subjected to a liquid nitrogen environment to enhance their brittleness and facilitate shredding. The structural morphology of the resulting recycled waste plastics after sieve analysis is illustrated in Figure 2.

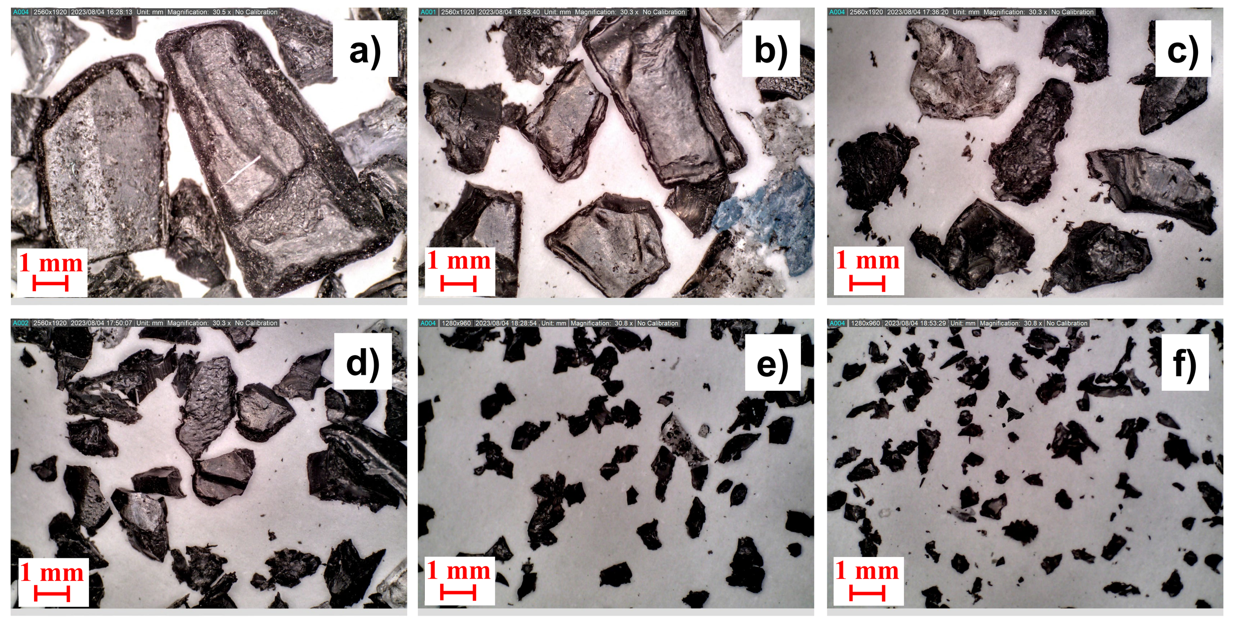

Figure 2. Optical micrographs showing the recycled waste plastics: (a) Ungraded, (b-g) remaining on #4, #16, #30, #50 and #100 mesh size sieves, respectively.

For the preparation of ungraded samples investigating replacement ratios, sand was entirely replaced with plastic up to 100%. In graded samples exploring the effect of particle size, 25% sand and 25% plastic were utilized as aggregates. The water-to-cement (w/c) ratio was 0.36 for all samples. After casting test samples, they underwent a 7-day curing process in the fog room (Figure 3). The mixtures formulated to examine the impact of plastic loading rate and particle size are outlined in Table 1.

Table 1. Mix proportions for mortar cement structures.

Mix ratios			Mix ID
Cement (%)	Sand (%)	Plastic (%)	
50	50	0	5C:5S:0P †
50	40	10	5C:4S:1P
50	30	20	5C:3S:2P
50	20	30	5C:2S:3P
50	10	40	5C:1S:4P
50	0	50	5C:0S:5P
50	25	25	5C:2.5S:2.5P/G-X*

* X denotes sieve numbers from mesh size #4 (4.75 mm) to #100 (0.15 mm).

† The control group of ungraded concrete is referenced throughout the article.

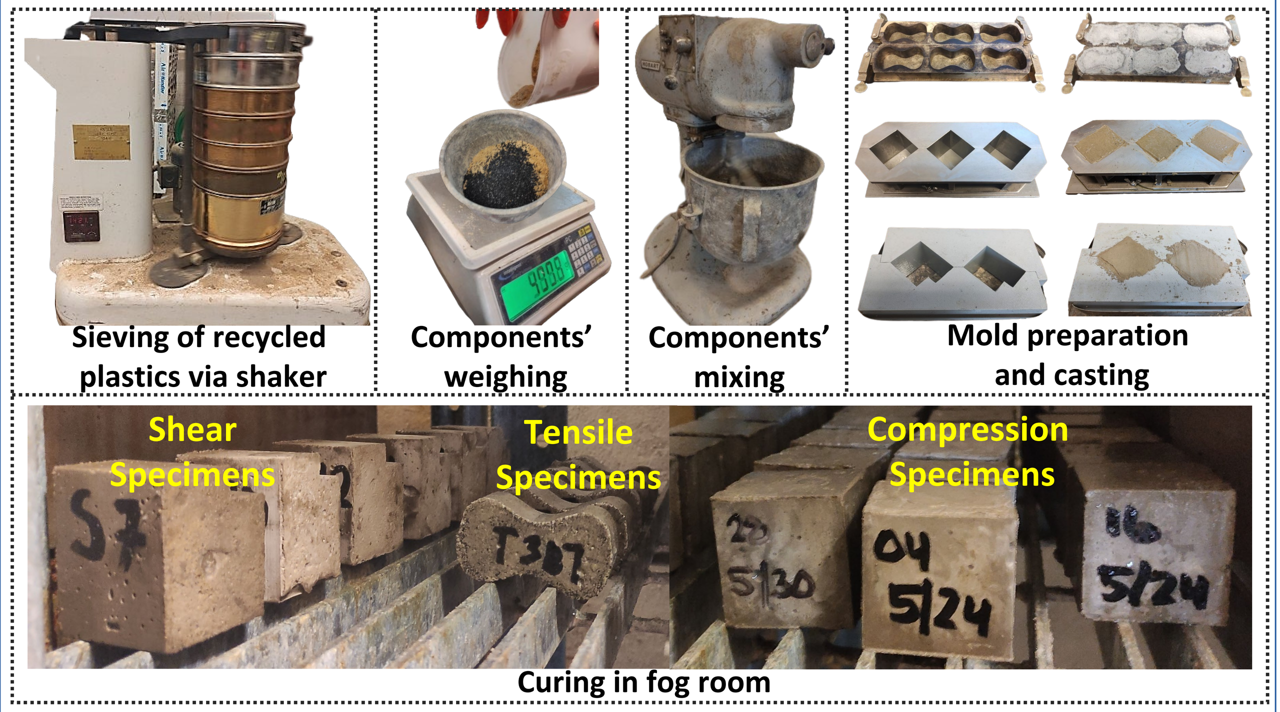

Figure 3. Sample preparation steps

The test machines and fixtures are shown in Figure 4. The cubic compressive test specimens were tested at 300 lbf/s [1335 N/s] according to ASTM C109 standards. Briquet specimens were prepared according to ASTM C307 to evaluate the tensile properties and tested at a speed of 0.20 in/min [5.08 mm/min]. The shear strengths of the specimens were measured with guillotine shear tests, conducted per ASTM D905 by Tinius Olsen Super-L 400 testing machine at a displacement rate of 0.015 in/min [0.381 mm/min].

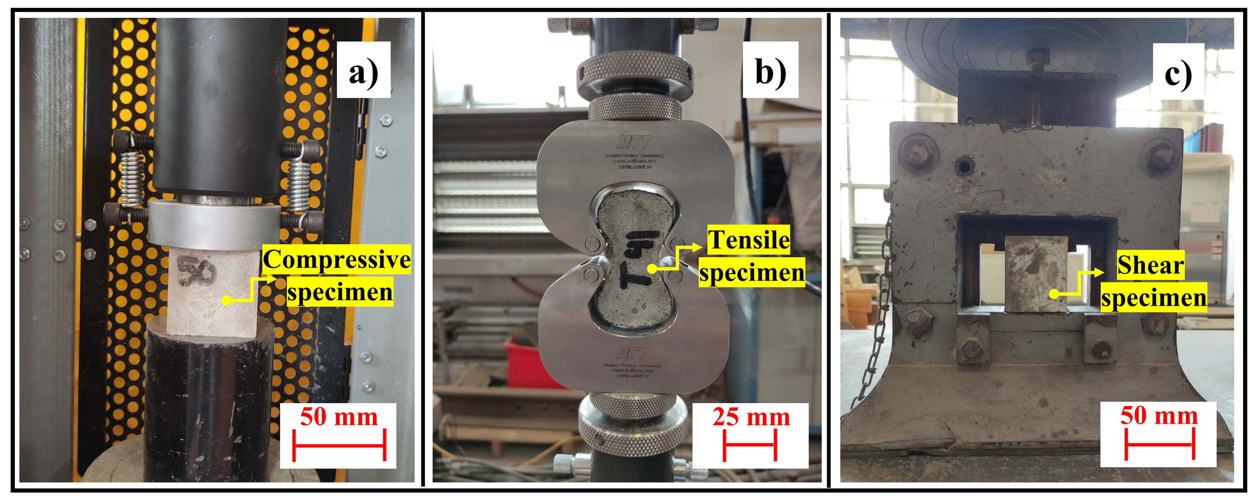

Figure 4. Mechanical testing fixtures for (a) compressive, (b) tensile, and (c) shear tests

Results

✓In compressive loading, the strength of the samples decreases as the plastic ratio increases due to poor plastic-cement interfacial bonding. In the case of graded-ABS usage, the compressive strength values are improved by replacing sand with decreasing particle size, thanks to smaller plastics' tight package stacking and dispersion ability (Figure 5).

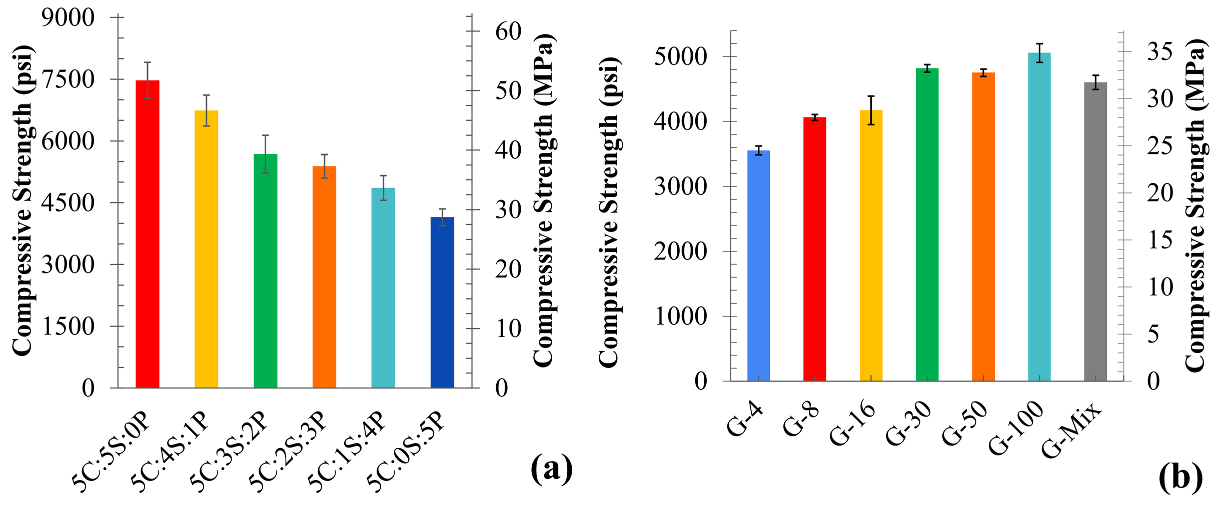

Figure 5. Compressive strength values for (a) ungraded and (b) graded ABS

✓Gradually reducing the plastic particle size enhances the tensile properties. In the case of mesh size 50 plastics, the average tensile strength increases compared to G-Mix (un-graded) specimens. Gradually reducing the particle size enhances the tensile properties. In the case of mesh size 50 plastics, the average tensile strength increases compared to G-Mix (un-graded) specimens (Figure 6).

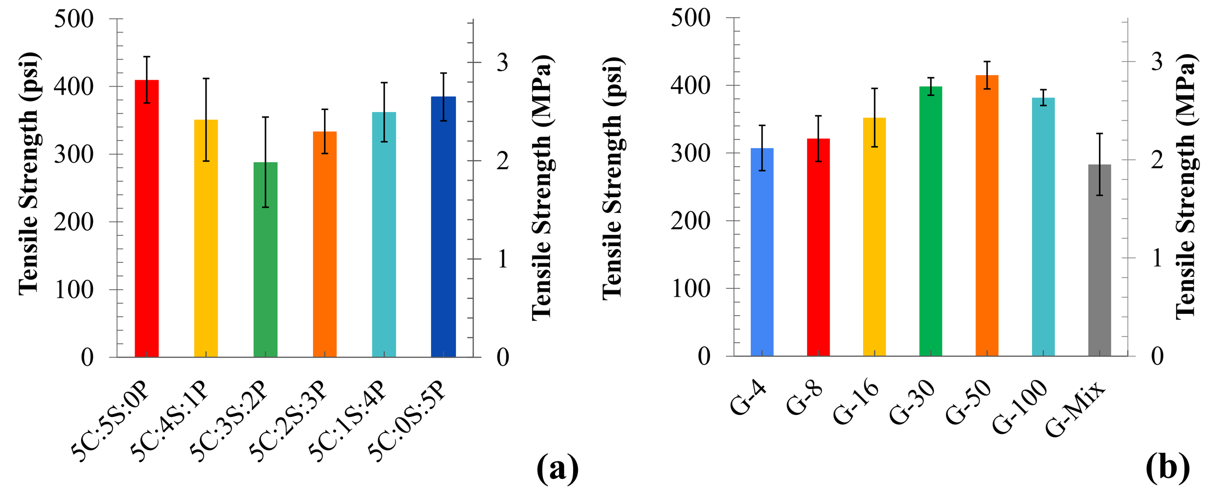

Figure 6. Tensile strength values for (a) ungraded and (b) graded ABS

✓Substituting sand aggregates with recycled plastic up to 20% reduces load-bearing capacity. However, substitution rates exceeding 30% lead to a significant reduction. When recycled plastics are made finer, shear strength is enhanced due to the increase in their specific surface area, which leads to enhanced plastic-cement interfacial interaction (Figure 7).

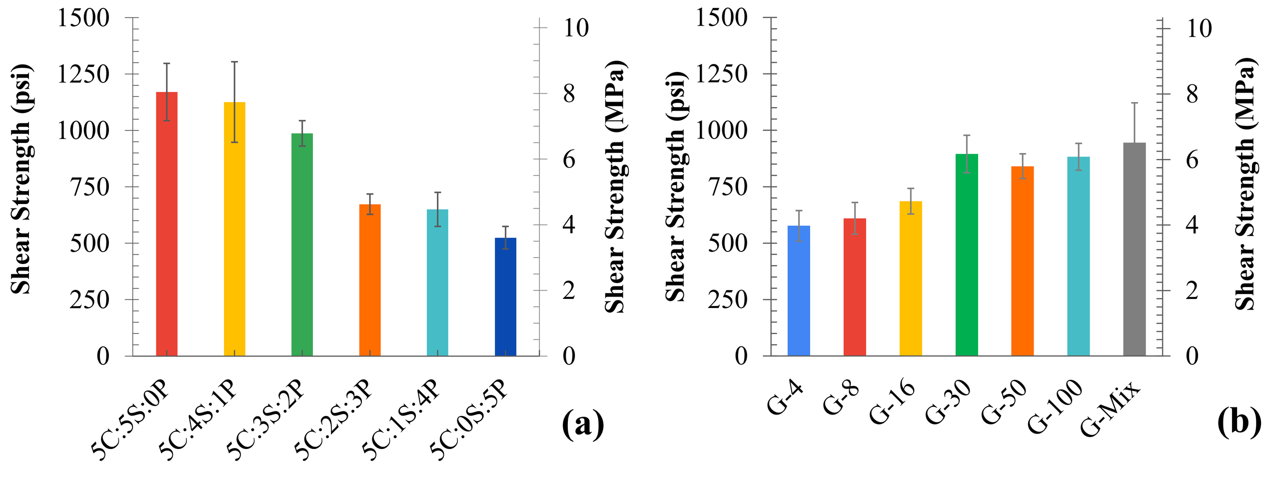

Figure 7. Bar graphs of shear strength values for (a) ungraded and (b) graded ABS-containing concretes.

✓In the case of the control group (without plastic), specimens exhibit a smooth transverse fracture (Figure 8a-b). However, oblique fractures are seen for plastic-added concretes. Although plastics have relatively low interfacial interactions with the cement matrix, they can contribute to stress transfer through crack branching and crack bridging mechanisms (Figure 8c-e). These toughening mechanisms lead to significant fracture energy absorption, improving mechanical properties under tensile loading.

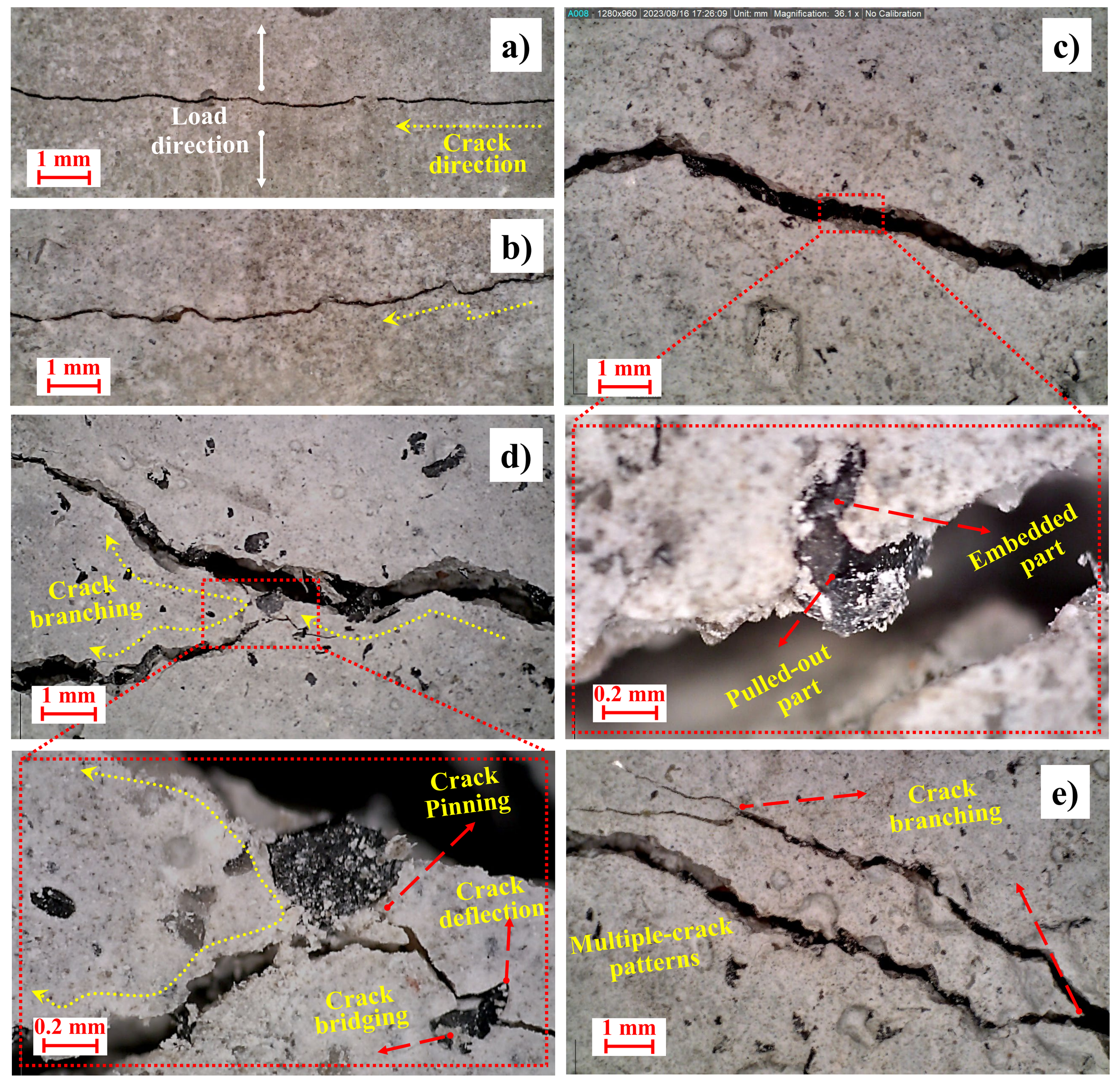

Figure 8. Fracture examination of tensile test specimens: (a-b) concrete specimens without plastic, (c-e) concrete specimens with un-graded plastic

Acknowledgments

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