Compressive, Flexural, and Tensile Strengths of Various Mortar Mixes Containing Synthetic Lightweight Aggregate

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ABSTRACT

This paper presents strength results of concrete mortars, some of which contained synthetic lightweight aggregates (SLAs) – a construction material created from waste plastic and coal fly ash. Five mortar mixes were created using a sand-size aggregate that satisfied ASTM's standard C33 gradation for fine aggregate; i.e., aggregate particles ≤ 4.75mm in size. Moderate-strength mortars (f'_c < 42 MPa) consisted of a control mix (Mix A) containing natural, normal weight sand; a Mix B that substituted SLA for 50% of the sand with a size ≥ 2.38mm (3.3% SLA content); and a Mix C that substituted SLA for 100% of the sand with a size ≥ 2.38 mm (6.7% SLA content). High-strength mortars (f'_c > 42 MPa) consisted of a Mix D containing sand-only and a Mix E in which SLA was substituted for all sand ≥ 2.38mm in size.

Uniaxial compressive strengths (f'_c), flexural strengths (f_r) and split tensile strengths (f_{sp}) were determined on all mixes after 28-days of curing. In summary, for the moderate-strength mixes, the f'_c and f_r reduced as the SLA content increased. A similar trend in strength reductions were noted for the high-strength mortars. It is concluded that these results are due to the lower rigidity SLA possesses compare to traditional natural aggregates. However, no significant change in f_{sp} strengths occurred for all tests. The inconsequential presence of SLA in flexure test results may be indicative that the f_{sp} strength of mortar is more dependent on the cement than the type of aggregate present.

Introduction

Most every industrial process has a byproduct; often considered waste. However, efficient waste management, including recycling and reuse, allows the “byproduct” to be converted to a “resource” thus leading to a more sustainable system. Sustainability has many definitions, the Brundtland Commission’s[13] being the most notable, and is applicable to numerous subject areas – e.g., agriculture, construction, economics, engineering, environmental issues, manufacturing, psychology, process design, and society, to name a few[7]. When sustainability is applied to an industrial system - the set of processes which directly or indirectly utilize material resources to create final products – it is clear that the most efficient and sustainable industrial systems minimize both the input of resources and the output of wastes. This is done by optimizing the interaction of the system’s various internal components such as changes in the material, manufacturing, and/or waste management processes (Figure 1).

However, many current waste management strategies are often highly inefficient and

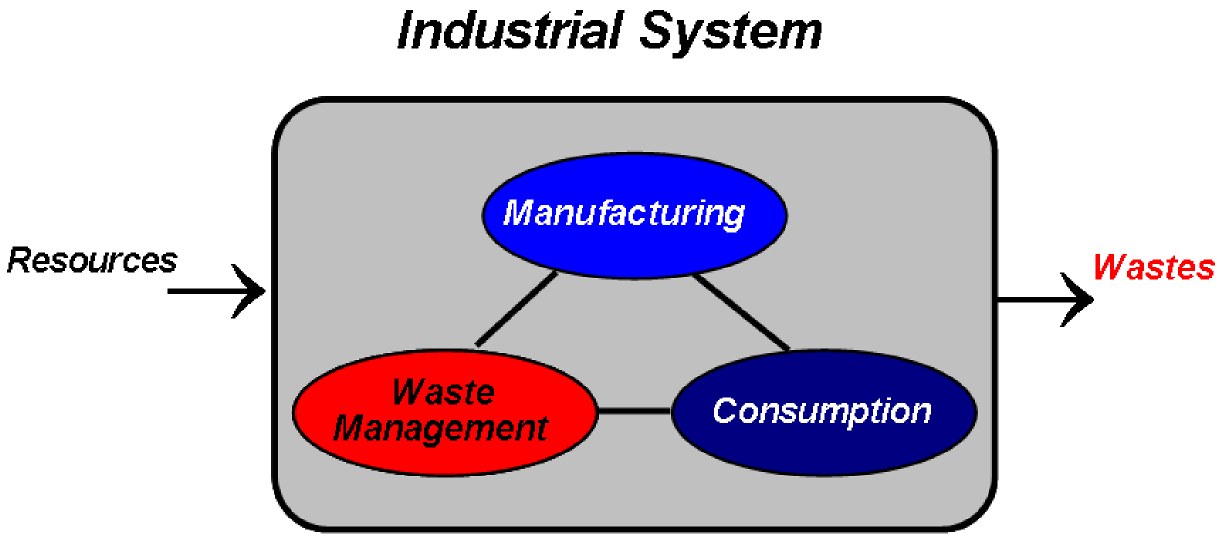


Figure 1 Schematic of Industrial System

un-sustainable; e.g., though the use of plastics in electronics (computers, televisions, etc.) is significant, current processes to reclaim and recycle plastics from electronics are lacking; due in part to initial production processes that do not allow easy recovery; i.e., a low “design for recyclability”.[5]

The synthetic lightweight aggregates technology (SLAs) represents ‘green engineering’ as it creates viable construction products created exclusively from two large volume waste streams – coal fly ash and mixed thermoplastics. Over the past decade, research on SLAs has focused on its potential uses in construction; most noticeably as a replacement for traditional normal-weight aggregates in concretes. It is now realized that the SLA technology is a waste management strategy; one where a range of particulates can be commingled with single or multiple thermoplastic polymers.

When characterized as an industrial system (Figure 2), this waste reuse strategy involves three different industrial sectors – coal-burning industries, the plastics recycling from municipal and industrial waste streams, and the construction materials industry – each having their own set of technical and non-technical (social, economic, regulatory/political) factors that must be considered.

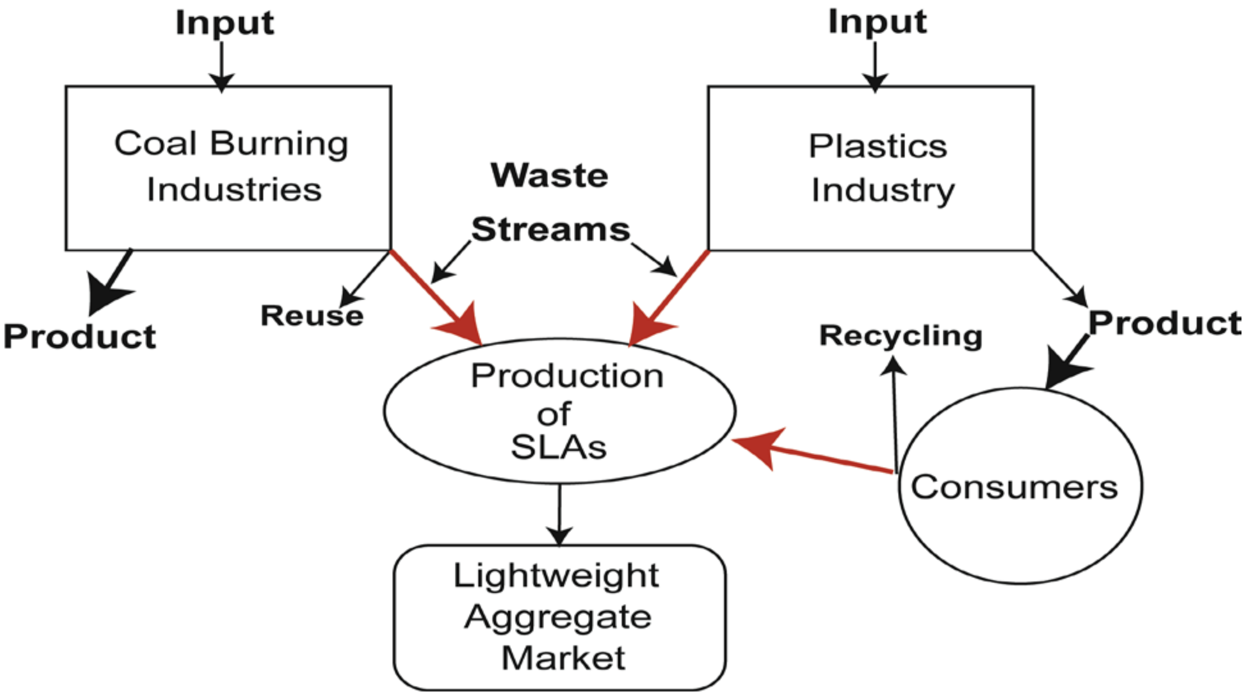


Figure 2 Production of SLAs

Background on SLAs

Synthetic lightweight aggregates (SLAs) represent a potential waste reuse strategy for two, high-volume, negative value wastes – coal fly ash and waste plastics. The patented SLA production process (U.S. Patent No. 6,669,773) was first developed in the late 1990s and consisted of a fly ash "particulate" co-extruded with a multi-thermoplastic "matrix". Co-extrusion is performed via a co-rotating, intermeshing, twin-screw extruder (Figure 3). As illustrated, SLA manufacturing involves initial passing of plastics into the extruder, introducing fly ash downstream in the extrusion process, cooling the resulting composite extrudent, and granulating the monolithic 'bars' to create a granular aggregate.

Raw materials used in the creation of SLAs have consisted of various blends of the following thermoplastics – polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (PVC), low density polyethylene (LDPE), polypropylene (PP), and/or polystyrene (PS). SLAs have also been created from various coal fly ashes including fly ashes of low carbon (approximately 2% carbon by weight), high carbon (up to 30% carbon by weight) and ammonia (up to 400 pm) contents. After extrusion, the material is granulated producing a material resembling dark gray sand or fine gravel, having particle sizes up to 12mm in diameter.

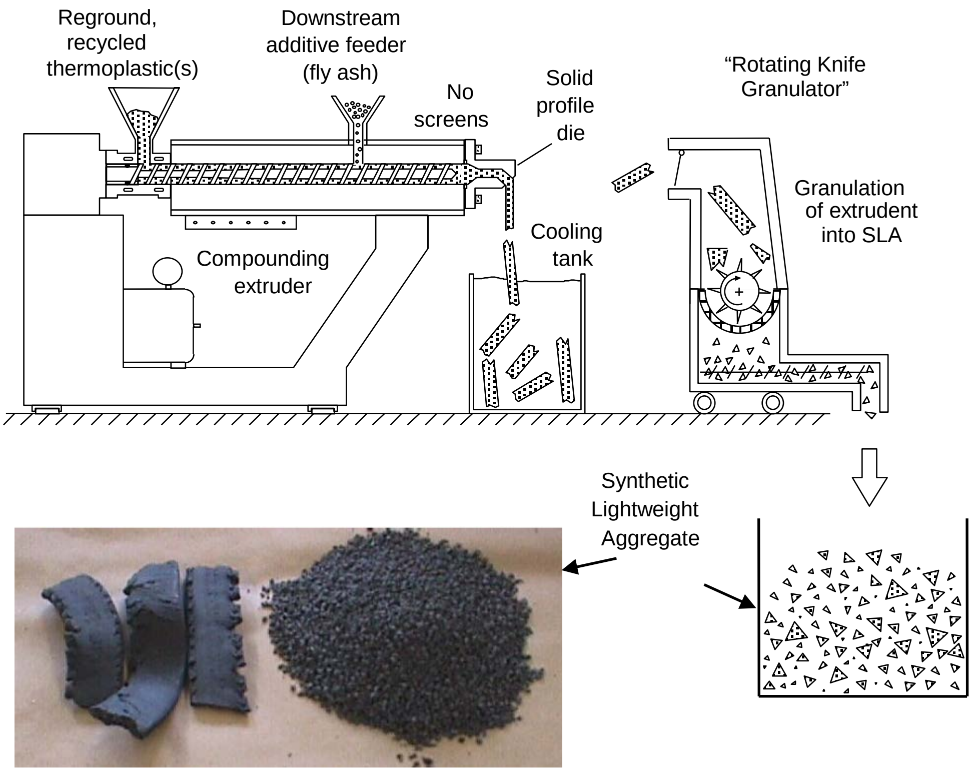


Figure 3 Schematic of SLA Production with Images of Extrudent (left) and Final Granulated Product (right)

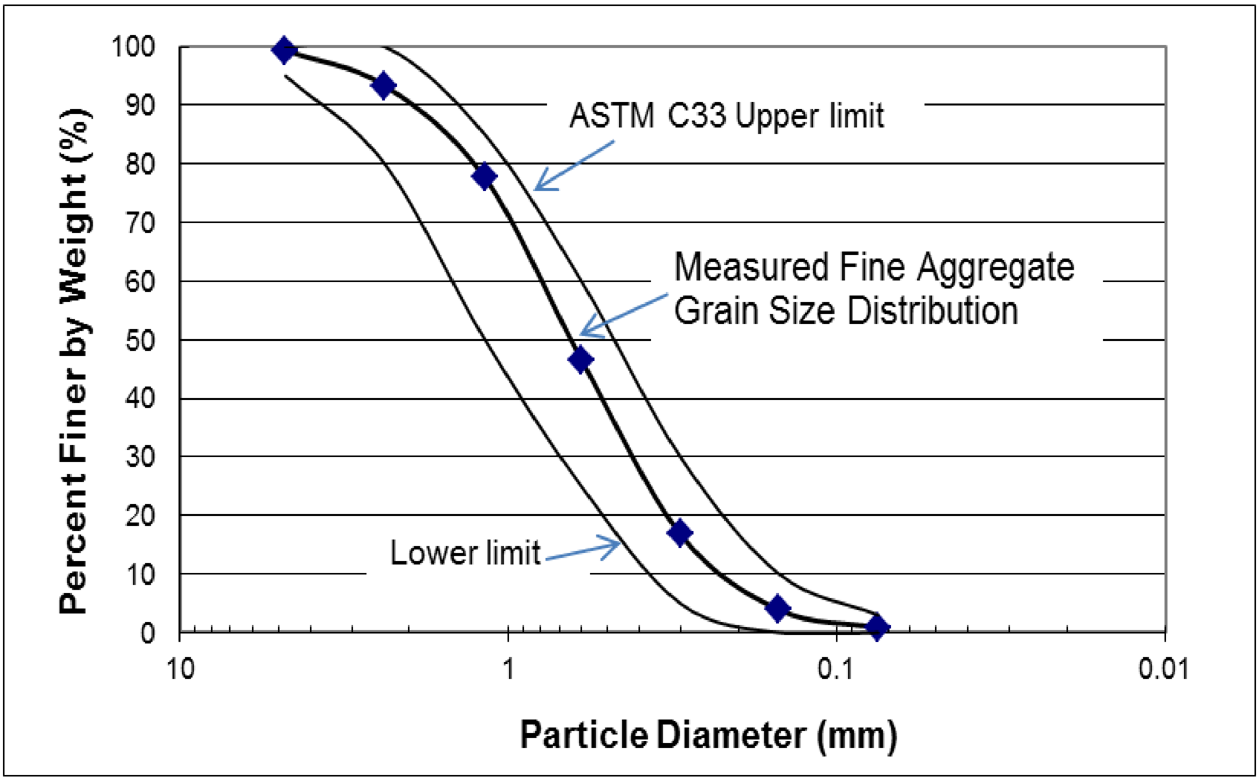
Research to-date has evaluated SLA development and manufacturing [4,6,10]; its use in geotechnical [1,11], concrete[3], asphalt [2], and other sustainable engineering applications.[12] These research efforts show the potential of SLAs as alternative, 'green' construction materials. Previous research has also shown the potential of SLAs to mitigate contaminate migration[9], expanding the use of SLAs as a viable waste management strategy.

Current Research Effort

The current research effort consisted of creating and testing five mortar mixes containing cement, water and various sand-size aggregate mixtures. The aggregate mixtures satisfied ASTM's standard C33 gradation for fine aggregate; i.e., aggregate particles ≤ 4.75mm in size. Table 1 presents the composition of the various moderate-strength mortars (f'_c < 42 MPa) consisted of a control mix (Mix A) containing natural, normal weight sand; and a Mix B that substituted SLA for sand with a size ≥ 2.38mm (a 3.3% SLA content); and a Mix C that substituted SLA for 100% of the sand with a size ≥ 2.38 mm (a 6.7% SLA content). High-strength mortars (f'_c > 42 MPa) consisted of a Mix D containing sand-only and a Mix E in which SLA was substituted for all sand ≥ 2.38mm in size (a 3.3% SLA content).

Table 1 Summary Mix Designs for Various Mortar Concretes						
	Mix Proportions by weights (%)				Design ratios	
Mix Number	Cement	Water	Aggregate		Water/Cement	Cement/Agg
			Normal Weight	SLA (by % aggregate)		
A	24.4	14.6	61.0	0	0.55	0.4
B	24.4	14.6	60.9	3.3	0.55	0.4
C	24.4	14.7	60.8	6.7	0.55	0.4
D	24.7	13.6	61.7	0	0.5	0.4
E	25.6	14.5	59.9	6.7	0.5	0.4

All mixes were created using Type I/II cement and portable tap water. The normal weight sand, or fine aggregate, was obtained from Boston Sand and Gravel in Boston, MA. As shown in the grain-size distribution in Figure 4, the sand meets ASTM C33 standard as fine aggregate.



For Mixes A and D, 100% normal weight aggregate was used. For Mixes B, C, and E, part of the normal weight aggregate was replaced by an equal volume of SLA with a similar grain-size.

Various specimens were then molded and cured under conditions of near 100% humidity at room temperature.

Testing Results

<u>Compression Testing</u>
Uniaxial compressive strengths (f'_c) were then performed on three, 5x10cm cylinders after 28 days of curing. Test results are plotted in Figure 2. A summary of results are presented in Table 2, which shows that the compressive strengths decreased significantly as SLA content increased.

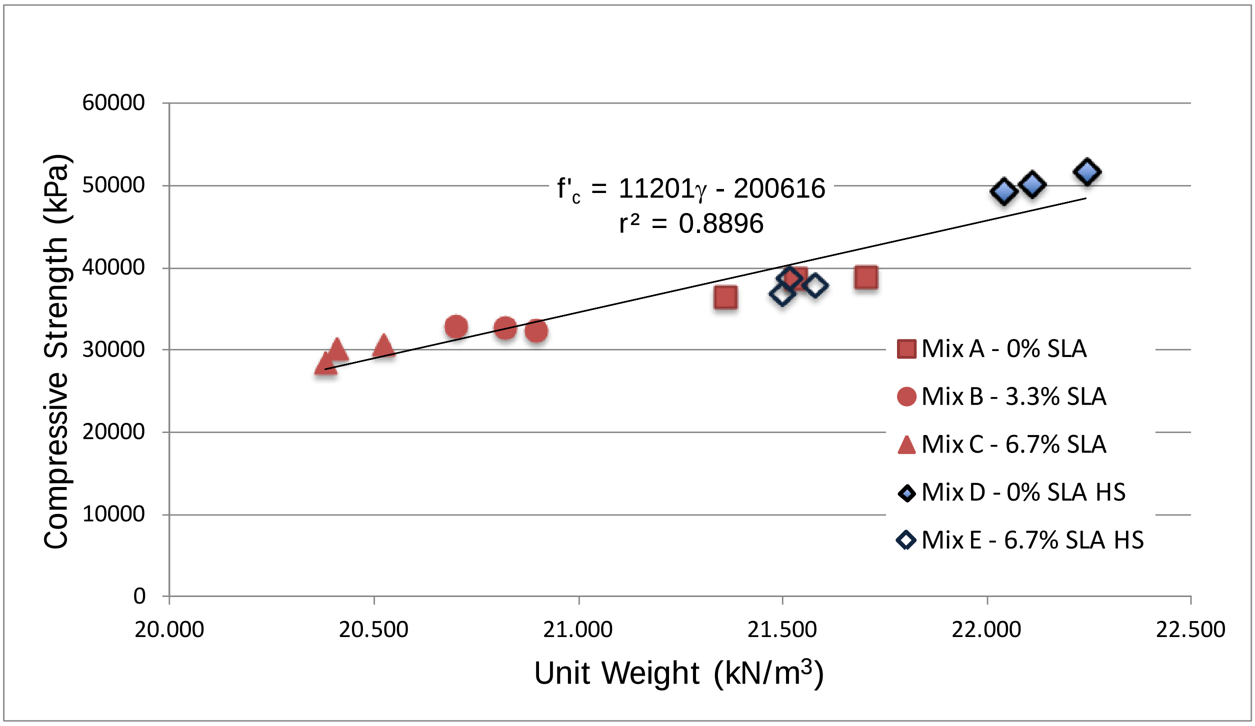


Figure 2 Compressive Strength Results for Various Mortar Concrete Tests Containing SLA

Table 2 – Compressive Strength Test Results for Various Mortar Concrete Mixtures		
Mix	**% SLA**	**f'_c (kPa) Mean ± STD**
Moderate-Strength Mortars		
A	0	38046 ± 1357
B	3.37	32710 ± 180
C	6.65	29775 ± 1142
High-Strength (HS) Mortars		
D	0	50555 ± 1267
E	6.65	38023 ± 917

Flexural Strengths

Four-point flexural strengths (f_r) tests were performed on five mini-bar beams, 2x5x22cm in dimension, after 28 days of curing. Figure 3 shows a plot of these results. A summary of test results are presented in Table 3 and indicate that while flexural strengths are influenced by SLA content, the influence is not as significant or consistent as it was for compressive strength results.

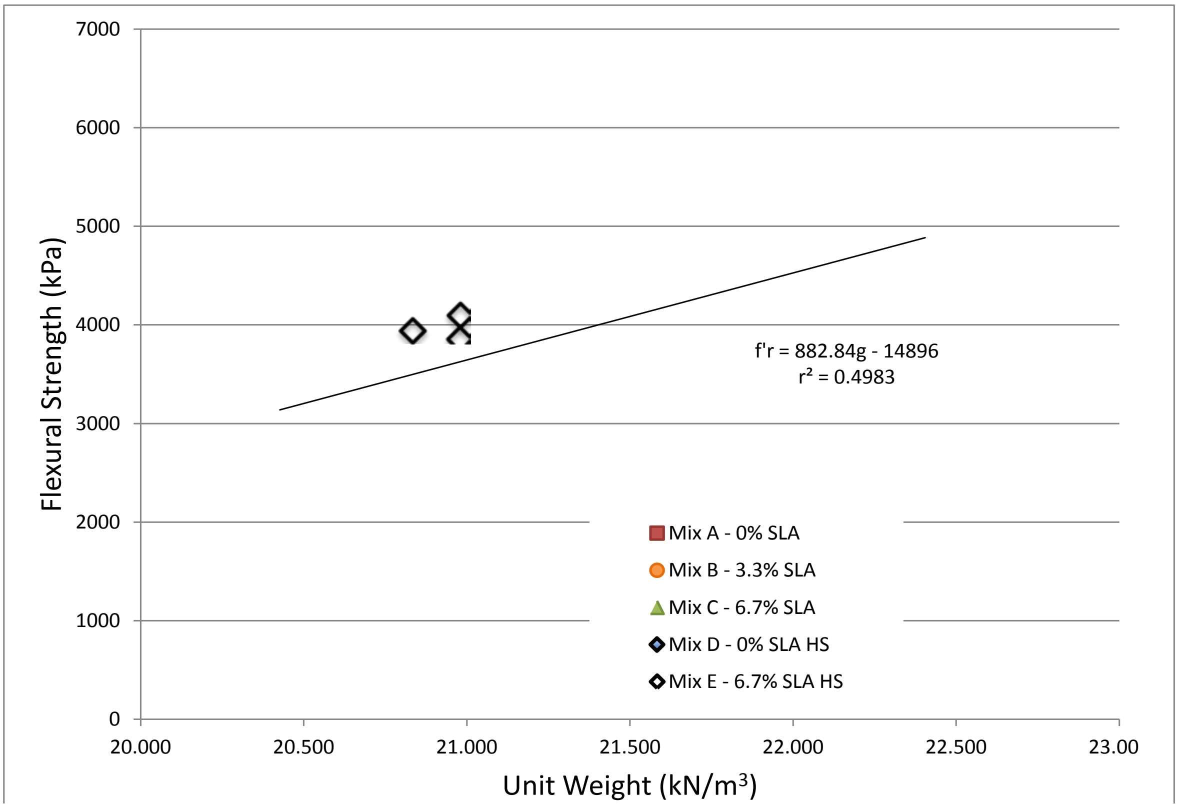


Figure 3 Flexural Strength Results for Various Mortar Concrete Tests Containing SLA

Table 3 – Flexural Strength Test Results for Various Mortar Concrete Mixtures		
Mix	**% SLA**	**f_r (kPa) Mean ± STD**
Moderate-Strength Mortars		
A	0	3579 ± 364
B	3.37	3592 ± 444
C	6.65	3348 ± 235
High-Strength (HS) Mortars		
D	0	4287 ± 928
E	6.65	4011 ± 173

Split Tensile Strengths

Split tensile strengths (f_{sp}) were determined on small concrete 'discs' 7.5cm-diameter by 4cm-thick. Test results are plotted as Figure 4. Tests results, summarized in Table 4, indicate that the split tensile strength are approximately constant regardless of SLA content.

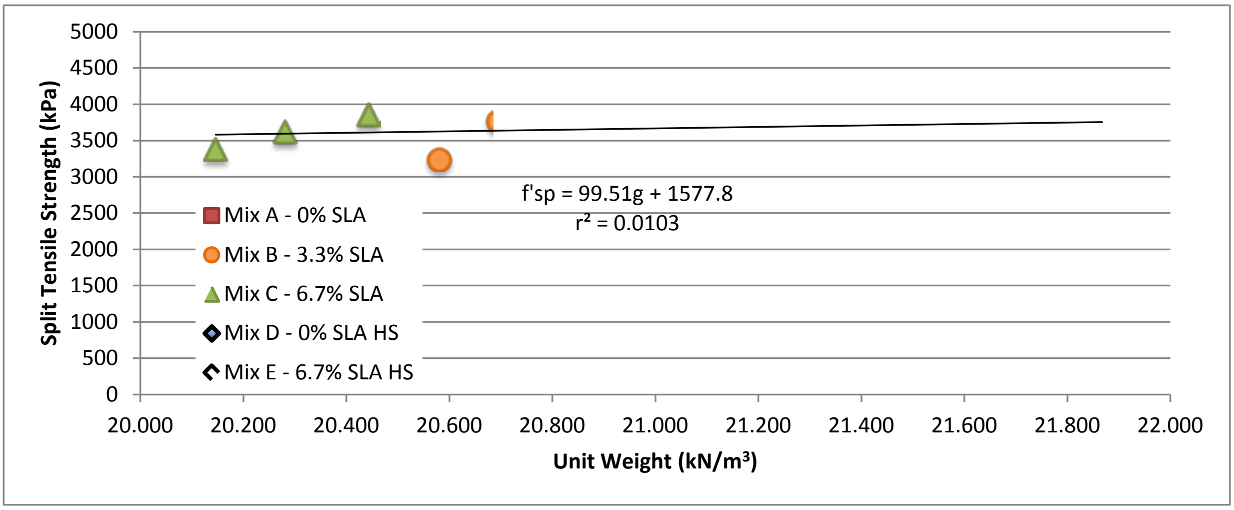


Figure 4 Split Tensile Strength Test Results for Various Mortar Concrete Tests Containing SLA

Table 4 – Split Tensile Strength Test Results for Various Mortar Concrete Mixtures		
Mix	**% SLA**	**f_{sp} (kPa) Mean ± STD**
Moderate-Strength Mortars		
A	0	4285 ± 262
B	3.37	3684 ± 407
C	6.65	3624 ± 239
High-Strength (HS) Mortars		
D	0	3911 ± 394
E	6.65	2885 ± 129

Discussion

As indicated in test results, the addition of SLA causes the average compressive and flexural strengths of the mortar concretes to decrease when compared to the control strength from mortar concrete made with 100% normal weight sand. Previous research on SLAs has indicated that a reduction in compressive strength could be anticipated.[3] In addition, it is well-known that the strength of concretes reduce as their densities decrease and that the strength of concrete depend significantly on the type, shape, and density of its aggregates.[8] However, given the limited data set of test results, it would be pre-mature to try to quantify this strength-to-unit weight relationship for SLA concretes.

It is also interesting to note that the split tensile strength of the concretes is not as significantly impacted by the inclusion of SLA in the concrete mixture as were the compressive or flexural strengths. The mechanism for this may lie in the inability of the plastic content of the SLA to help resist this form of tensile loading. However, this unique phenomenon requires additional study.

Summary

Based on the data presented above, for the moderate-strength mixes, the f'_c and f_r reduced as the SLA content increased. A similar trend in strength reductions were noted for the high-strength mortars. It is concluded that these results are due to the lower rigidity SLA possesses compare to traditional natural aggregates. However, no significant change in f_{sp} strengths occurred. This inconsequential presence of SLA in split tensile test results may be indicative that the f_{sp} strength of mortar is more dependent on the cement than the type of aggregate present.

In summary, SLAs can be represented as an innovation with the potential to strongly impact infrastructure development and rehabilitation, waste management options, and environmental sustainability efforts. However, it should be recognized that inclusion of SLA in concretes could significantly impacts compressive strength and the testing of potential concrete mix designs should be seen as necessary in their use.

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