

Experimental Investigation on the Sustainable Utilization of Municipal Solid Waste Landfill Materials and Recycled Face Mask Fibres in High-Performance Concrete

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Abstract - Municipal solid waste landfill (MSWL) material and discarded polypropylene face masks represent persistent waste streams that can be diverted into useful construction constituents. This study experimentally evaluates processed MSWL material as a partial replacement for manufactured sand and recycled face-mask fabric as dispersed reinforcement in M30 concrete. MSWL was incorporated at 0%, 4%, 5%, 7% and 10% of manufactured sand, while recycled face-mask fabric was used at 0%, 0.3%, 0.5%, 0.7% and 1.0% of cement mass. Workability, compressive strength, split tensile strength and flexural strength were evaluated at multiple curing ages. The 5% MSWL mixture achieved 41.0 N/mm² compressive strength, 3.60 N/mm² split tensile strength and 6.28 N/mm² flexural strength at 28 days, compared with 38.0, 3.34 and 5.93 N/mm² for the control. The 0.5% recycled face-mask fabric mixture achieved the highest overall response, with 44.0 N/mm² compressive strength, 3.66 N/mm² split tensile strength and 6.36 N/mm² flexural strength at 28 days. Higher replacement levels reduced workability and strength, indicating that controlled dosage is essential. The results demonstrate that suitably processed landfill-derived fines and recycled face-mask fabric can contribute to resource conservation and improved mechanical performance in sustainable concrete.

Key Words: municipal solid waste landfill, recycled face-mask fibres, sustainable concrete, polypropylene fibre, M30 concrete, waste-derived aggregate.

1. INTRODUCTION

Concrete is a major infrastructure material, but its production depends heavily on natural mineral resources and generates substantial environmental burdens. At the same time, municipal waste accumulation and the widespread disposal of single-use polypropylene face masks create persistent waste-management challenges. Sustainable concrete development therefore requires strategies that recover waste materials while preserving the engineering performance expected from structural concrete.

Municipal solid waste landfill material is heterogeneous and may contain soil-like fines, glass, stones, plastics, cloth and other residual constituents. The investigated material

was obtained from an aged landfill deposit. Four age groups were considered, and the 12-year-old material showed the most suitable physical characteristics for further concrete utilization. Proper removal of visible contaminants, grading and quality control are essential before incorporation into cementitious mixtures.

Discarded face masks are predominantly composed of polypropylene-containing nonwoven layers. When cleaned, processed and cut into controlled reinforcement pieces, the material can function as distributed polymeric reinforcement. Its principal contribution is crack bridging and stress transfer, while excessive fibre content can increase internal friction, reduce workability and create non-uniform zones.

The study therefore examines the combined sustainability potential of two distinct waste streams through controlled replacement and reinforcement. The principal response variables are fresh-state workability, compressive strength, split tensile strength and flexural strength. The central engineering objective is to identify practical replacement levels that provide material conservation without unacceptable loss of mechanical performance.

2. LITERATURE REVIEW

Previous investigations have demonstrated the feasibility of incorporating recycled masks, waste plastics, municipal waste-derived materials and polypropylene fibres into cementitious composites. Miah et al. reported that recycled mask fibres can improve selected mechanical properties of mortar when fibre dosage and dispersion are controlled. Koniarczyk et al. and Ajam et al. similarly demonstrated the potential for mask waste valorization in cement-based materials.

Ahmed and Lim investigated disposable medical-mask fibres in sustainable green concrete and reported beneficial mechanical behaviour from controlled fibre hybridization. Idrees et al. examined waste facial masks as construction material and highlighted the need for controlled processing and durability assessment. Kilmartin-Lynch et al. showed that polypropylene fibres recovered from single-use masks

can improve concrete performance, supporting the use of mask-derived reinforcement in a circular construction approach.

Research on municipal solid waste incineration ash and landfill-derived materials indicates that processing, chemical composition, particle morphology and replacement level strongly influence concrete performance. Yang et al. and Kong et al. emphasized washing, weathering and treatment as important approaches for reducing soluble contaminants and improving engineering properties. Pavlik et al. demonstrated that low replacement of selected municipal waste-derived fractions can improve performance, whereas unsuitable fractions or excessive dosages can reduce strength.

Studies on polypropylene and waste-fabric reinforcement consistently identify an optimum dosage. Mohod reported an optimum polypropylene fibre content near 0.5% for the investigated concrete systems, while Akça et al. found that polypropylene fibres can compensate for some strength losses associated with recycled aggregate. Qin et al. demonstrated that polypropylene fibre-fabric systems can improve stress transfer and crack resistance. These findings establish the research basis for investigating recycled face-mask fabric at controlled contents.

3. RESEARCH GAP AND OBJECTIVES

Although waste-derived aggregate and recycled polymer reinforcement have each been studied independently, fewer investigations directly compare landfill-derived fine material and recycled face-mask fabric using a common M30 concrete matrix and the same set of mechanical indicators. The present work addresses this gap through parallel experimental series and multi-age strength evaluation.

1. Characterize the principal concrete constituents and waste-derived materials.
2. Develop an M30 concrete mixture suitable for controlled MSWL incorporation and face-mask fabric reinforcement.
3. Evaluate fresh-state workability using the slump test.
4. Determine compressive strength using 150 mm cube specimens.
5. Determine split tensile strength using 150 mm diameter $\times$ 300 mm cylinder specimens.
6. Determine flexural strength using 150 $\times$ 150 $\times$ 700 mm beam specimens.
7. Compare strength development over curing ages and identify optimum waste-material contents.
8. Interpret the results from structural-material and sustainability perspectives.

4. MATERIALS AND EXPERIMENTAL PROGRAMME

4.1 Materials

The concrete matrix consists of Portland Pozzolana Cement (PPC), manufactured sand, graded coarse aggregate, potable water and a high-range water-reducing admixture. The two waste-derived constituents are

processed MSWL fine material and recycled face-mask fabric.

Table 1: Properties of cement

Property	Value
Fineness	322 m ² /kg
Normal consistency	33%
Initial setting time	170 min
Final setting time	4 h 40 min
Specific gravity	2.81
3-day compressive strength	30 N/mm ²
7-day compressive strength	42 N/mm ²
28-day compressive strength	56 N/mm ²
56-day compressive strength	58 N/mm ²
Soundness	1 mm



Fig. 1: View of landfill sites

Table 2: Physical properties of manufactured sand and landfill samples

Property	M-sand	MSWL1 2	MSWL1 0	MSWL 8	MSWL 6
Water absorption (%)	2.28	9.50	11.35	13.85	14.15
Specific gravity	2.69	2.29	2.12	1.94	1.91
Bulk density	1.687	1.42	1.185	0.815	0.74

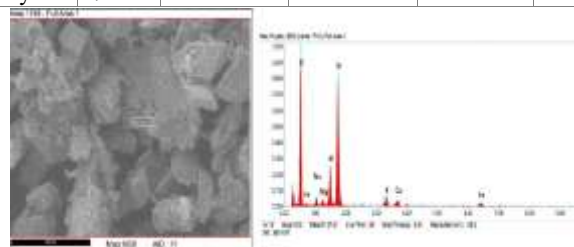


Fig. 2: Particle-size distribution of M-sand and MSWL samples

Table 3: Properties of coarse aggregates

Property	20 mm aggregate	12.5 mm aggregate
Water absorption	0.81%	0.63%
Specific gravity	2.72	2.37
Bulk density	1.64	1.522
Aggregate impact value	—	27.13%

Property	20 mm aggregate	12.5 mm aggregate
Aggregate crushing value	23.30%	24.27%
Los Angeles abrasion	27.60%	—
Flakiness index	11.65%	0.65%
Elongation index	14.65%	6.05%

Table 4: Properties of superplasticizer

Parameter	Reported property
Physical state	Free-flowing liquid
Colour tone	Dark brown
Specific gravity	1.30 ± 1.0
pH	7.0 ± 1.0
Chloride content	<0.2%
Chemical description	Sulphonated Naphthalene Formaldehyde



Fig. 3: MSWL samples with different ages

Table 5: Oxide composition of manufactured sand and MSWL

Oxide	M-sand (%)	MSWL (%)
SiO ₂	72.34	48.88
CaO	5.14	7.65
Al ₂ O ₃	12.55	7.35
Fe ₂ O ₃	4.43	4.18
Na ₂ O	1.67	2.02
K ₂ O	1.32	1.99
MgO	1.25	1.50
P ₂ O ₅	0.24	1.14
TiO ₂	0.75	0.49
SO ₃	<0.05	0.12
Loss on ignition	1.28	24.26



Fig. 4: Cutting of discarded face masks into reinforcement pieces



Fig. 5: Prepared recycled face-mask pieces

Table 6: Tensile characteristics of recycled face-mask fabric

Property	Outer layer	Middle layer	Inner layer
Peak load (kg)	0.90	0.60	0.90
Break load (kg)	0.90	0.10	0.90
Yield load (kg)	0.60	0.60	0.80
Elongation at yield (mm)	13.75	21.48	27.82
Thickness (mm)	0.16	0.08	0.22
Tensile strength at peak (N/mm ²)	7.36	4.91	7.36
Tensile strength at break (N/mm ²)	7.36	0.82	7.36
% elongation at peak	83.30	65.70	83.32
Yield strength (N/mm ²)	4.91	4.91	6.54

4.2 Mix Proportioning

The M30 concrete was proportioned using the reported control ratio of approximately 1 : 1.683 : 1.795 : 1.197 with a water-to-cement ratio of 0.45. Superplasticizer dosage was adjusted within each series to maintain practical fresh-state behaviour. MSWL replaced manufactured sand at 0%, 4%, 5%, 7% and 10%, while face-mask fabric was incorporated at 0%, 0.3%, 0.5%, 0.7% and 1.0% of cement mass.

Table 7: Mix proportions for MSWL-incorporated concrete

Mix	Cement	M-sand	MSWL	20 mm CA	12.5 mm CA	Water	SP (%)
M0	1	1.683	0	1.795	1.197	0.45	0.5
M4	1	1.616	0.067	1.795	1.197	0.45	0.5
M5	1	1.599	0.084	1.795	1.197	0.45	0.5
M7	1	1.565	0.118	1.795	1.197	0.45	0.4
M10	1	1.515	0.168	1.795	1.197	0.45	0.3

Table 8: Mix proportions for recycled face-mask fabric concrete

Mix	Cement	M-sand	Face-mask fabric (% of cement)	20 mm CA	12.5 mm CA	Water	SP (%)
M0	1	1.683	0	1.795	1.197	0.45	0.5
A1	1	1.683	0.3	1.795	1.197	0.45	0.6
A2	1	1.683	0.5	1.795	1.197	0.45	0.6
A3	1	1.683	0.7	1.795	1.197	0.45	0.7
A4	1	1.683	1.0	1.795	1.197	0.45	0.7



Fig. 6: Slump measurement procedure

Table 9: Specimen programme and curing ages

Test	Specimen	Dimension	Curing ages
Workability	Fresh concrete	Slump cone	Immediately after mixing
Compressive strength	Cube	150 × 150 × 150 mm	3, 7, 28, 56, 90, 180 days
Split tensile strength	Cylinder	150 mm dia × 300 mm	3, 7, 28, 56, 90, 180 days
Flexural strength	Beam	150 × 150 × 700 mm	7, 28, 56, 90, 180 days



Fig. 7: Compression testing method



Fig. 8: Split tensile strength test and broken specimens



Fig. 9: Flexural strength test apparatus and specimens



Fig. 10: Prepared ingredients and mask pieces used during concrete mixing

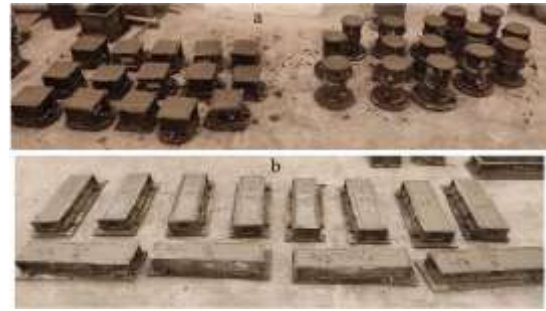


Fig. 11: Cast specimens for compressive, split tensile and flexural strength tests

4.3 Test Methods

Workability was measured immediately after mixing using the slump cone. Compressive strength was evaluated on 150 × 150 × 150 mm cubes at 3, 7, 28, 56, 90 and 180 days. Split tensile strength was evaluated on 150 mm diameter × 300 mm cylinders at the same ages. Flexural strength was determined using 150 × 150 × 700 mm beams at 7, 28, 56, 90 and 180 days. For each test, average values were used for comparative interpretation.

Compressive strength was obtained from the maximum failure load divided by the loaded cross-sectional area. Split tensile strength was evaluated from the standard diametral-loading relation, $f_t = 2P/(\pi LD)$. Flexural strength was evaluated in accordance with the applicable flexural-testing provisions for the adopted beam configuration.

5. RESULTS AND DISCUSSION

5.1 Workability of MSWL Concrete

Table 10: Slump values of MSWL-incorporated concrete

Mix	Slump (mm)	Workability
M0	75	Medium
M4	75	Medium
M5	70	Medium
M7	70	Medium
M10	70	Medium

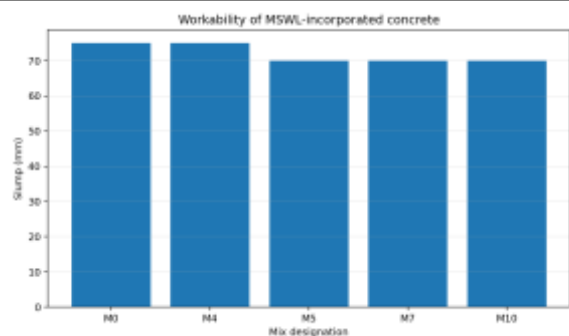


Fig. 12: Workability variation with MSWL replacement

The control mixture and the 4% MSWL mixture recorded 75 mm slump, while the 5%, 7% and 10% mixtures recorded approximately 70 mm. All mixtures were classified as medium workability. The relatively small reduction indicates that moderate MSWL replacement can be accommodated without severe loss of fresh-state mobility, although the higher absorption of MSWL requires moisture control.

5.2 Compressive Strength of MSWL Concrete

Table 11: Compressive strength of MSWL-incorporated concrete

Mix	3 d	7 d	28 d	56 d	90 d	180 d
M0	15.7	26.5	38	44	48.5	54
M4	17	27	40	46.5	50	55
M5	18	28	41	48	51.5	57
M7	15	24	37	40.5	46.8	49
M10	7.8	14.5	30	36	39	42

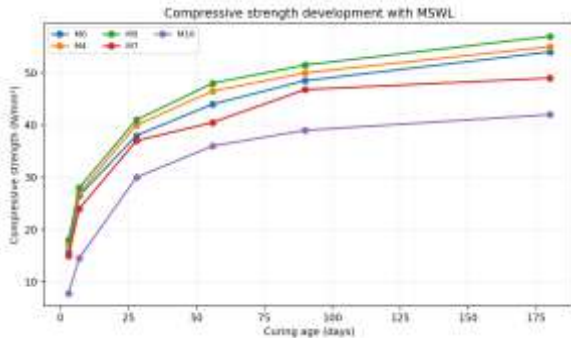


Fig. 13: Compressive strength development with curing age

Table 12: Twenty-eight-day compressive strength comparison for MSWL mixes

Mix	28-day compressive strength (N/mm²)	Change from M0 (%)
M0	38	0.0
M4	40	5.26
M5	41	7.89
M7	37	-2.63
M10	30	-21.05

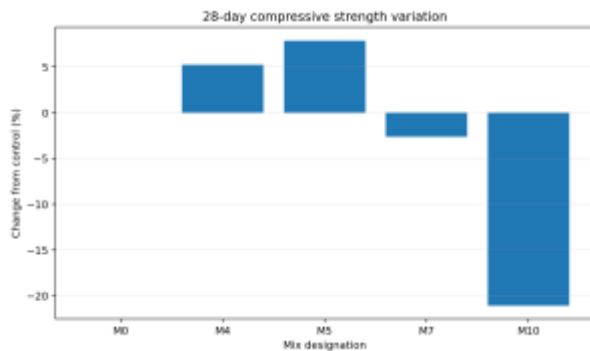


Fig. 14: Percentage change in 28-day compressive strength

Compressive strength increased continuously with curing age for all mixtures. At 28 days, M4 and M5 reached 40 and 41 N/mm² compared with 38 N/mm² for M0, representing increases of 5.26% and 7.89%, respectively. At higher replacement, strength declined: M7 reached 37 N/mm² and M10 reached 30 N/mm². The response indicates an optimum MSWL level near 5%, beyond which higher absorption, weaker particle-matrix interaction and increased void content become increasingly influential.

5.3 Split Tensile Strength of MSWL Concrete

Table 13: Split tensile strength of MSWL-incorporated concrete

Mix	3 d	7 d	28 d	56 d	90 d	180 d
M0	2.23	3.03	3.34	4.2	4.62	4.75
M4	2.42	3.12	3.47	4.25	4.68	4.84
M5	2.58	3.18	3.6	4.27	4.75	5.06
M7	1.83	2.15	2.55	2.95	4.14	4.49
M10	1.11	1.75	1.99	2.87	3.66	4.11

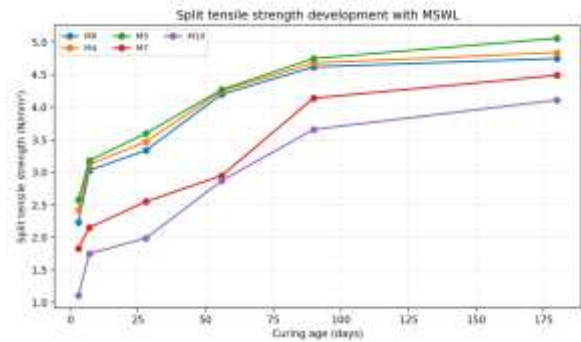


Fig. 15: Split tensile strength development with curing age

The split tensile response follows the general compressive-strength trend. M5 reached 3.60 N/mm² at 28 days compared with 3.34 N/mm² for the control. The improvement is consistent with improved particle packing and a stronger interfacial zone at the optimum replacement. At 10% MSWL, the 28-day value decreased to 1.99 N/mm², demonstrating that excessive replacement can reduce tensile integrity.

5.4 Flexural Strength of MSWL Concrete

Table 14: Flexural strength of MSWL-incorporated concrete

Mix	7 d	28 d	56 d	90 d	180 d
M0	3.81	5.93	6.75	7.61	7.77
M4	4.34	6.22	6.81	7.75	7.97
M5	4.43	6.28	6.98	7.91	8
M7	4.28	5.98	6.12	6.26	6.38
M10	3.18	4	5.34	5.47	5.57

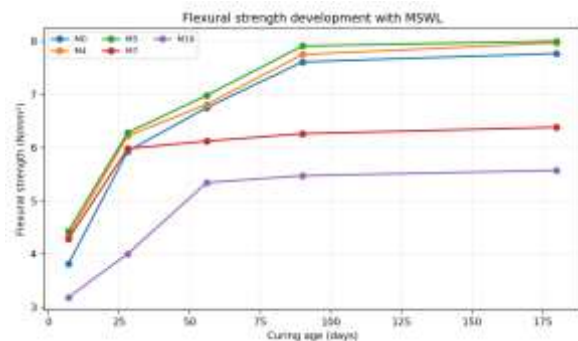


Fig. 16: Flexural strength development with curing age

Moderate MSWL replacement improved flexural performance. M5 recorded 6.28 N/mm² at 28 days and 8.00 N/mm² at 180 days, compared with 5.93 and 7.77 N/mm² for M0. M10 showed the lowest response, confirming that excessive replacement reduces matrix continuity and bending resistance.

5.5 Workability of Face-Mask Fibre Concrete

Table 15: Slump values of recycled face-mask fibre concrete

Mix	Slump (mm)	Workability
M0	75	Medium
A1	70	Medium
A2	65	Medium
A3	60	Medium
A4	60	Medium

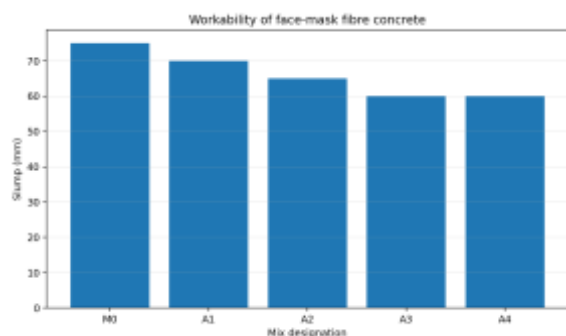


Fig. 17: Workability variation with face-mask fibre content

Slump decreased from 75 mm for M0 to 70, 65, 60 and 60 mm for A1, A2, A3 and A4, respectively. The sharper reduction than in the MSWL series indicates that fibre geometry and internal friction have a stronger immediate influence on fresh-state movement.

5.6 Compressive Strength of Face-Mask Fibre Concrete

Table 16: Compressive strength of recycled face-mask fibre concrete

Mix	3 d	7 d	28 d	56 d	90 d	180 d
M0	15.7	26.5	38	44	48.5	54
A1	18	30	41.5	48	53	59
A2	20	33.5	44	51	57	61
A3	17	28	39	46	51	57
A4	11	20	26.5	33	39	45

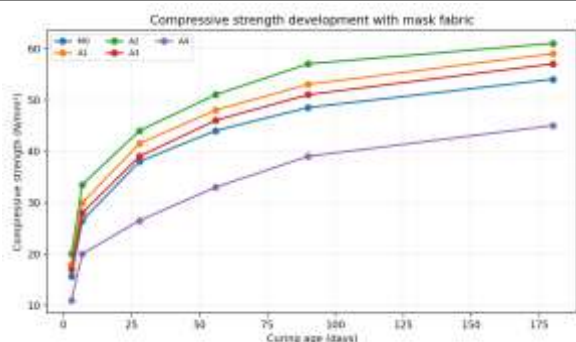


Fig. 18: Compressive strength development with face-mask fabric

Table 17: Twenty-eight-day compressive strength comparison for mask-fibre mixes

Mix	28-day compressive strength (N/mm²)	Change from M0 (%)
M0	38	0.0
A1	41.5	9.21
A2	44	15.79
A3	39	2.63
A4	26.5	-30.26

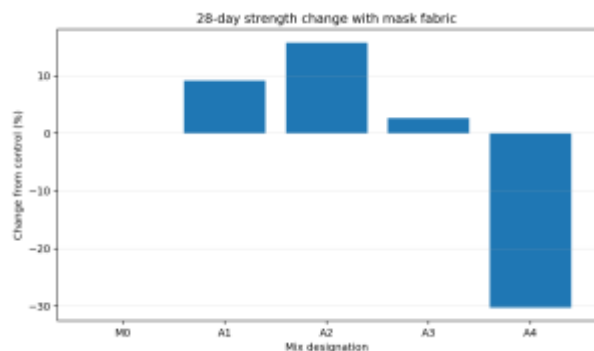


Fig. 19: Percentage change in 28-day compressive strength for mask-fibre mixes

The A2 mixture containing 0.5% recycled face-mask fabric produced the highest compressive strength at all major curing ages considered. At 28 days, A2 reached 44.0 N/mm², 15.79% above the 38.0 N/mm² control. A1 reached 41.5 N/mm² and A3 reached 39.0 N/mm², whereas A4 decreased sharply to 26.5 N/mm². The results indicate a clear optimum fibre dosage and demonstrate the adverse effect of excessive fabric content.

5.7 Split Tensile Strength of Face-Mask Fibre Concrete

Table 18: Split tensile strength of recycled face-mask fibre concrete

Mix	3 d	7 d	28 d	56 d	90 d	180 d
M0	2.23	3.03	3.34	4.2	4.62	4.75
A1	2.32	3.06	3.54	4.39	4.71	4.97
A2	2.55	3.11	3.66	4.62	4.87	5.06
A3	2.45	3.06	3.54	4.49	4.68	4.9
A4	1.59	2.87	3.28	3.82	4.46	4.59

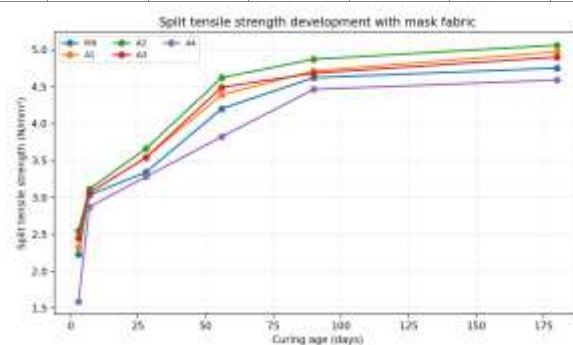


Fig. 20: Split tensile strength development with face-mask fabric

At 28 days, A2 reached 3.66 N/mm² compared with 3.34 N/mm² for M0. A1 and A3 both reached 3.54 N/mm², while A4 decreased to 3.28 N/mm². The improved tensile response at moderate dosage is consistent with crack bridging and stress-transfer mechanisms provided by dispersed polypropylene fabric.

5.8 Flexural Strength of Face-Mask Fibre Concrete

Table 19: Flexural strength of recycled face-mask fibre concrete

Mix	7 d	28 d	56 d	90 d	180 d
M0	3.81	5.93	6.75	7.61	7.77
A1	4.87	6.16	6.87	7.81	8.12
A2	5.49	6.36	7.14	8.16	8.48
A3	4.75	6	7.02	7.77	7.89
A4	3.88	5.81	6.71	7.53	7.65

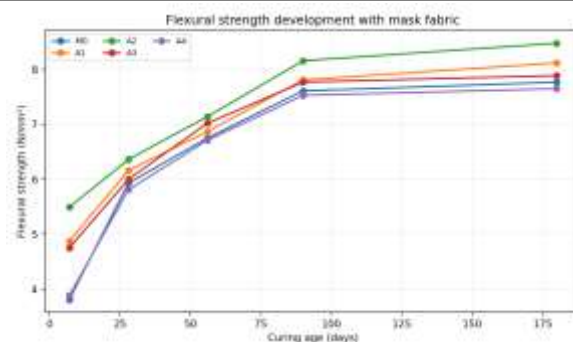


Fig. 21: Flexural strength development with face-mask fabric

A2 achieved the highest flexural performance, reaching 6.36 N/mm² at 28 days and 8.48 N/mm² at 180 days. The control values were 5.93 and 7.77 N/mm², respectively. The response confirms that moderate recycled fabric content can improve bending resistance, whereas excessive content

reduces homogeneity and limits the benefit of reinforcement.

5.9 Comparative Assessment of Optimum Mixtures

Table 20: Comparison of control and optimum waste-material mixtures

Mix	MSWL	Mask fabric	Slump (mm)	28-d CS (N/mm ²)	28-d STS (N/mm ²)	28-d FS (N/mm ²)
M0	0	0	75	38.00	3.34	5.93
M5	5% MSWL	0	70	41.00	3.60	6.28
A2	0	0.5% mask fabric	65	44.00	3.66	6.36

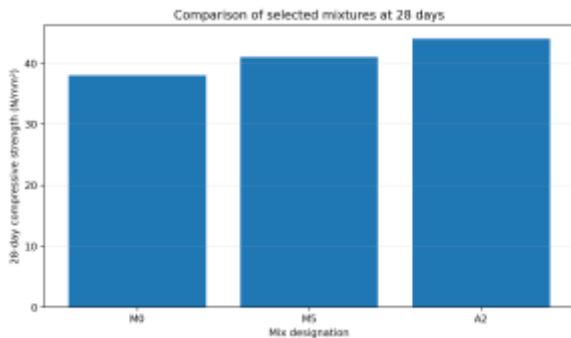


Fig. 22: Comparison of 28-day compressive strength

M5 is the preferred mixture where the primary objective is conservation of manufactured sand through controlled MSWL replacement. A2 is the preferred mixture where distributed polymeric reinforcement and higher overall mechanical performance are prioritized. At 28 days, A2 provides the highest compressive, split tensile and flexural strengths among the investigated mixtures.

5.10 Integrated Strength Comparison

Table 21: Normalized 28-day strength comparison

Mix	28-day CS	Change (%)	28-day STS	28-day FS
M0	38.00	0.00	3.34	5.93
M4	40.00	5.26	3.47	6.22
M5	41.00	7.89	3.60	6.28
M7	37.00	-2.63	2.55	5.98
M10	30.00	-21.05	1.99	4.00
A1	41.50	9.21	3.54	6.16
A2	44.00	15.79	3.66	6.36
A3	39.00	2.63	3.54	6.00
A4	26.50	-30.26	3.28	5.81

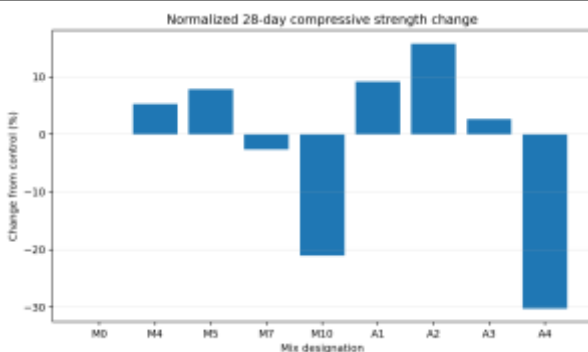


Fig. 23: Normalized 28-day compressive strength change

The normalized comparison confirms that M5 provides a 7.89% increase in 28-day compressive strength, while A2 provides a 15.79% increase. Conversely, M10 and A4 show reductions of 21.05% and 30.26%, respectively. The results

establish a consistent optimum-type response in which controlled waste addition improves performance, while excessive addition causes strength deterioration.

5.11 Engineering Interpretation

MSWL has substantially higher water absorption than manufactured sand. This characteristic can reduce effective mixing water and alter the interfacial transition zone if moisture conditioning is not controlled. The moderate strength increase at 4–5% replacement is therefore attributed to a favourable balance between filler/packing effects and the adverse influence of absorption and heterogeneity.

The recycled mask fabric acts differently from MSWL because it does not primarily function as a granular filler. The polymeric pieces provide distributed crack-bridging paths, improving tensile and flexural response at moderate dosage. However, increasing fabric content increases internal friction, reduces slump and can produce clustering or weak zones, explaining the sharp performance reduction at 1.0%.

From a structural-material perspective, the optimum mixtures demonstrate that waste utilization should be based on performance-controlled dosage rather than maximum substitution. The results support the use of M5 and A2 for further durability, bond, member-level and field-scale investigation, subject to environmental and quality-control verification.

6. CONCLUSIONS

- The investigated MSWL material can be incorporated as a partial replacement for manufactured sand when grading, absorption and heterogeneity are controlled.
- MSWL mixtures maintained medium workability, with slump reducing from 75 mm for the control to approximately 70 mm at the higher replacement levels.
- MSWL replacement improved compressive strength up to an optimum level. M5 reached 41.0 N/mm² at 28 days compared with 38.0 N/mm² for M0.
- M5 reached 3.60 N/mm² split tensile strength and 6.28 N/mm² flexural strength at 28 days, compared with 3.34 and 5.93 N/mm² for the control.
- Replacement beyond the optimum reduced performance; M10 recorded 30.0 N/mm² compressive strength, 1.99 N/mm² split tensile strength and 4.00 N/mm² flexural strength at 28 days.
- Recycled face-mask fabric progressively reduced slump, with A2 at 0.5% giving 65 mm and A3/A4 giving 60 mm.
- A2 containing 0.5% face-mask fabric produced the most favourable overall mechanical response, reaching 44.0 N/mm² compressive, 3.66 N/mm² split tensile and 6.36 N/mm² flexural strength at 28 days.
- The improvement in tensile and flexural performance at moderate fabric dosage is consistent with distributed crack bridging, while excessive fabric reduces homogeneity and mechanical performance.
- The two waste streams provide complementary sustainability routes: MSWL can reduce demand for virgin fine aggregate,

while recycled mask fabric can recover polypropylene waste as dispersed reinforcement.

- The most suitable contents are controlled rather than maximum replacement levels, with M5 and A2 identified as the most promising mixtures for further investigation.

7. FUTURE SCOPE

- Investigate reinforced concrete beams, slabs and columns containing optimum MSWL and recycled face-mask fabric mixtures to determine member-level strength, ductility and serviceability.
- Study long-term durability under carbonation, chloride, sulphate, freeze-thaw and wet-dry exposure.
- Evaluate bond strength between reinforcement and the sustainable concrete matrix.
- Determine modulus of elasticity, shrinkage, creep and fracture energy for structural modelling.
- Develop standardized processing and quality-control protocols for heterogeneous landfill-derived fine material.
- Investigate automated processing systems for high-volume preparation of uniform face-mask reinforcement pieces.
- Examine alternative mask-piece geometries and aspect ratios and their effects on workability, crack bridging and flexural toughness.
- Conduct life-cycle and cost assessments including collection, processing, transportation, washing, energy consumption and avoided disposal impacts.
- Evaluate field-scale production, batch-to-batch variability and quality assurance.
- Investigate optimized hybrid combinations of MSWL, recycled mask fibres and other supplementary cementitious or recycled constituents.

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