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High performance concrete using recycled aggregate, Microsilica and synthetic macro fibre

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Abstract—**The conventional ballasted rail track system incorporating steel tendon in prestressed concrete sleepers is predominantly used throughout the railway network in the UK. Despite its benefits, the associated demerits and the need to revolutionise rail transportation in the UK necessitated this investigation. The objective was to determine physical and mechanical characteristics of recycled aggregate concrete incorporating synthetic macro fibre and mineral admixtures to develop a low maintenance and corrosion-free prestressed concrete sleepers which is a high strength structural application. These materials were incorporated with varying percentage replacement (i.e. 0%, 25%, 50%, 75% & 100% respectively) of natural coarse aggregate by recycled aggregate, 54mm forta-ferro synthetic macro fibre dosage (0.11% and 0.5%), 5% dosage of Microsilica and 0.4% High Range Superplasticiser by weight of cement. A total of 621 concrete samples (cubes, cylinders & prisms) were subjected to workability test, density measurement, modulus of elasticity, compressive strength, flexural strength, and tensile splitting strength test in four different phases. Results obtained from phases 1, 2, and 3 indicate reduction in workability, density, modulus of elasticity, compressive strength, tensile splitting strength, and flexural strength of recycled aggregate concrete without mineral and chemical admixtures as the percentage content of recycled coarse aggregate increased compared with the control concrete samples and no significant effect was observed from dosage of synthetic macro fibre. The addition of microsilica and superplasticiser to the concrete mix in phase 4 brought about great improvement in workability, density, compressive strength, flexural strength, and tensile splitting strength and this was evident from 1, 7, and 28 curing days' strengths respectively. This enhanced strength could be associated with the densifying quality and pozzolanic action of microsilica. Recycled aggregate concrete without fibre dosage (phase 2) performed satisfactorily up to 25% replacement, while 50% replacement produced 97% of the target compressive strength, which indicates the possibility of raising the current recommended optimum use of recycled aggregate in concrete production from 25% to 50%.**

Keywords—**Ballasted rail track system; Synthetic macro fibre; Prestressed concrete sleepers; Compressive strength.**

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I. Introduction

High Performance Concrete is characterised with high strength, workability and durability derived from cement replacement materials like microsilica, fly ash, and ground granulated blast furnace slag (ggbs) incorporated in the concrete mix with chemical admixture (superplasticiser). High Performance Concrete (HPC) consists of essential concrete materials selected to produce properties of concrete such as low permeability and high strength for the intended function of the structure. The long term cost benefits of high performance concrete outweighed the greater economy of initial procurement. Microsilica enhances durability of concrete with high resistance to critical environment, thus effectively protecting embedded steel bars in the concrete. In order to ensure that rail transportation remain more eco-friendly, the paradigm in construction of railways infrastructure like pre-stressed concrete sleepers would have to shift from the existing conventional method using natural aggregates and cement which is a significant source of global CO_2 emissions, to the use of recycled coarse aggregates, cementitious materials like fly ash, and mineral admixture such as microsilica which in the long term would mitigate the problems of depletion of natural resources, waste disposal, other environmental issue related to rail transportation and achievement of low maintenance and corrosion-free ballasted rail track system. Synthetic macro fibre was envisaged to enhance the mechanical properties of recycled aggregate concrete and this would be assessed. Attempt would be made to increase the optimum use of recycled coarse aggregate currently between 25% and 30% as specified by BS8500-1 [1] and BS8500-2 [2] respectively to 50% without any cause for concern.

II. Mix Design and Experimental Materials

A. *Materials*

The design target compressive strength and water-cement ratio (w/c), obtained from Building Research Establishment's (BRE) design of normal concrete mixes were 50MPa and 0.37 respectively.

Table 1 illustrates the types of materials used for the production of concrete in the laboratory for all the phases.

TABLE 1. CONCRETE MATERIALS

Materials	Type
Cement	CEM II/B-V 32,5N (Portland - fly ash cement)
Synthetic macro fibre	54mm Forta- Ferro. Virgin copolymer / polypropylene, Specific gravity of 0.91, and tensile strength from 570 -660MPa
Microsilica	Elkem Microsilica Grade 940-U
Recycled coarse aggregate	Maximum size of 10mm, sourced from demolition debris by Coleman and company, Birmingham, UK

B. *Mix Design*

Tables 2 – 5 shows details of concrete mixes used in the laboratory work. Fibre contents added were 0%, 0.11% (1kg/m³) and 0.5% (4.5kg/m³) by weight of concrete respectively.

TABLE 2. CONCRETE MIX DETAILS –PHASE 1

Recycle Coarse Aggregate (%)	0	25	50	75	100
Cement	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Synthetic Macro Fibre (kg/m³)	0	4.5	4.5	4.5	4.5
Water (kg/m³)	230	230	230	230	230

TABLE 3. CONCRETE MIX DETAILS –PHASE 2

Recycle Coarse Aggregate (%)	0	25	50	75	100
Cement	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Synthetic Macro Fibre (kg/m³)	0	0	0	0	0
Water (kg/m³)	230	230	230	230	230

TABLE 4. CONCRETE MIX DETAILS –PHASE 3

Recycle Coarse Aggregate (%)	0	25	50	75	100
Cement	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Synthetic Macro Fibre (kg/m³)	1	1	1	1	1
Water (kg/m³)	230	230	230	230	230

TABLE 5. CONCRETE MIX DETAILS –PHASE 4

Recycle Coarse Aggregate (%)	0	25	50	75	100
Cement	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Synthetic Macro Fibre (kg/m³)	1	1	1	1	1
Water (kg/m³)	230	230	230	230	230
Microsilica (kg/m³)	29.2	29.2	29.2	29.2	29.2
Superplasticiser (kg/m³)	2.33	2.33	2.33	2.33	2.33

III. Tests

A. *Compressive Strength Test*

Concrete samples were subjected to uniaxial compression in order to determine the failure stress of the test samples using Avery-Denison compression testing machine at a constant loading rate of 2.4kN/s. The test was conducted in accordance to BS EN 12390-4:2000 [3] using three concrete cube samples of dimension 100 mm per concrete mix at 1, 7, and 28 days curing age respectively.

B. *Tensile Splitting Strength Test*

This test was carried out using Denison testing machine in order to determine the indirect tensile strength of the concrete samples. Three concrete cylinder samples of 100mm diameter and 200mm high were tested for each concrete mix at 1, 7, and 28 days curing age respectively. Tensile splitting strength test was conducted in accordance to BS EN 12390-6. [4]

C. *Flexural Strength Test*

Flexural strength test was carried out in compliance with BS EN 12390-57 [5] to determine the flexural strength of hardened concrete at 1, 7, and 28 days curing age respectively. The test was conducted using three concrete prism samples of dimension 100 x 100 x 500mm for each concrete mix.

IV. Results and Discussion

A. *Compressive Strength Test*

Figure 1 illustrates the results of compressive strength at 28 days for all the phases of concrete mixes shown in tables 2 – 5 respectively.

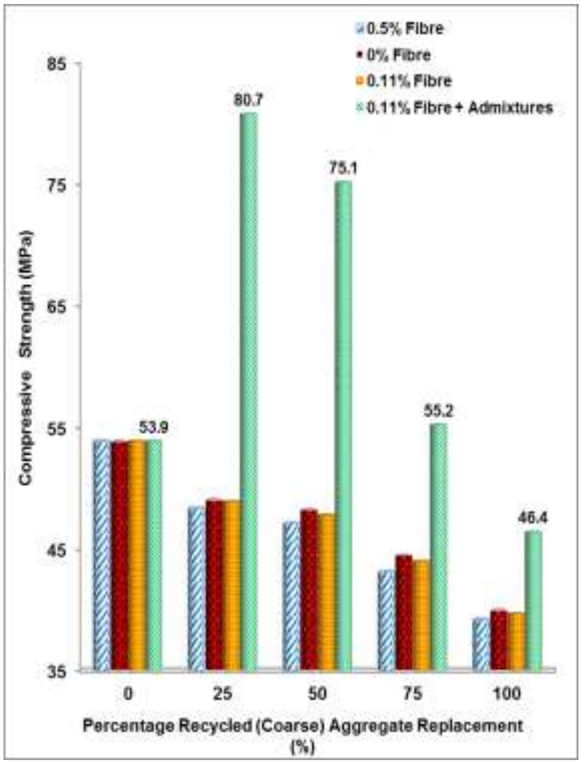

Figure 1. 28 days compressive strength

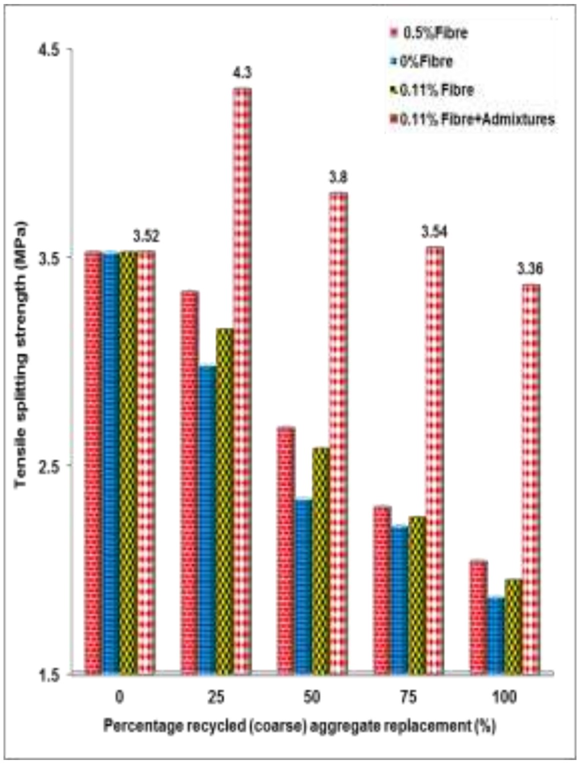

Figure 2. 28 days tensile splitting strength

Results revealed that the mix with microsilica addition produced the highest compressive strength due to the densifying property and pozzolanic action of microsilica. The control concrete achieved strength of about 54MPa while the mix with microsilica produced approximately 71MPa at 28 days. It was also observed that the strength of recycled aggregate concrete made with 50% and 75% recycled coarse aggregates respectively exceeds the target compressive strength of 50MPa at 28 days while 100% replacement produced 92% of the target strength. Concrete mix with no fibre addition produced better results than other mix with fibre inclusion and implies that synthetic macro fibre does not have significant effect on compressive strength of concrete.

B. *Tensile Strength Test*

Tensile splitting strength at 28 days for all the concrete mixes is presented in figure 2. It could be observed that tensile splitting strength decreased with an increase in percentage content of the RCA in the mixture. Concrete samples with no dosage of fibre produced the least tensile strength while concrete mix with higher dosage shows increased tensile strength. The increase was due to the bridging ability of fibre to absorb energy in the concrete to prevent cracking. These findings agreed with reported findings by Bagherzadeh et.al [6]. The reduction in tensile strength with an increasing content of RCA was due to porous nature of recycled coarse aggregate and this correlates with the strength reduction pattern reported by Evangelista and Brito [7].

C. *Flexural Strength Test*

Figure 3 illustrates the 28 days flexural strength of all the concrete mixes from phase 1 – phase 4.

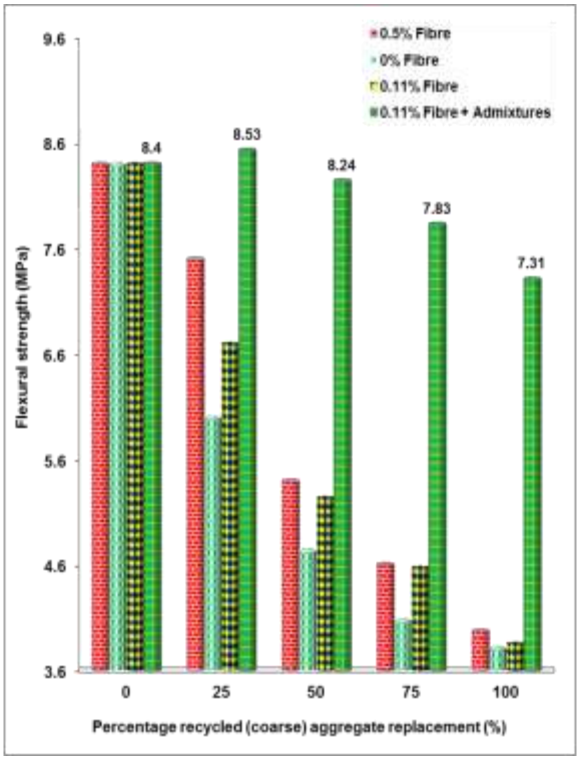

Figure 3. 28 days flexural strength

It was observed that concrete mix without any dosage of fibre reduced considerably while samples with addition of fibre indicate a better increase in strength although flexural strength decreased with increase in percentage replacement of natural coarse aggregate by recycled coarse aggregate. This finding was similar to findings by Kumutha, R. & Vijai, [8].

V. Conclusion

The following were observed;

1) Physical and mechanical characteristics of recycled aggregate concrete decreased significantly with increase in percentage content of recycled coarse aggregate in phases 1 – 3 of the concrete design mix;

2) Addition of synthetic macro fibre has no significant effect on compressive strength of the concrete mix in all phases;

3) Significant satisfactory performance was observed up to 25% recycled coarse aggregate contents without fibre dosage in phase 2 of the laboratory work, while 50% contents produced about 97% of the target compressive strength;

4) Addition of mineral admixture (Microsilica) and chemical admixture (superplasticiser) greatly improved physical and mechanical properties of all the concrete mix in phase 4, and even better than natural aggregate made concrete irrespective of the percentage content in the mix;

5) Optimum use of recycled coarse aggregate from 25 – 30% (BS 8500-1&2) to 50% is very feasible. This would lead to a landmark for conservation of quarry, reduction in cost of construction materials, & reduced pressure on landfills which are among the priority of the benefits of this research to the railway industry.

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