Engineering assessment of waste aggregate concrete modified with non-slip sand and micro steel fibers

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Abstract. Recycling and re-use building and demolishing wastes has represented an important challenge for civil and environmental engineers. They have worked hard to find new solutions to recycle and re-use these inorganic and incombustible wastes. This research concerns on studying the mechanical properties of waste aggregate concrete before and after modifying it with different rates of non-slip sand and constant rate of micro steel fibers for the sake of discovering environmentally friendly, strongly enough, and safely appropriate concrete to use it in different structures and buildings. The results clarified that the compressive, tensile, and flexural strengths of waste aggregate concrete were less than these values on normal concrete. These properties began to improve increasingly when adding different rates of non-slip sand until getting to the final increment rates (compressive 44%, tensile 85%, and flexural 113%). After micro steel fibers had been added to the mixture, the properties of this concrete amended more to make the final increments of compressive, tensile, and flexural strengths equal (48, 128, and 192)% respectively. The analysis of the final outcomes of this research have suggested use the waste aggregate concrete, which contains 20% of non-slip sand and 1% of micro steel fibers.

Keywords. Waste aggregate; non-slip sand; micro steel fiber; compressive; tensile; flexural

1. Introduction
Aggregate is an important part of concrete composition, which presents 80 % of its volume, therefore; the global consumption of aggregate for concrete production equals 3000 kg/capia/year [1]. Recycled aggregate concrete was used greatly to re-build and develop the recycling industry in B&H and Serbia after natural disasters and wars for the sake of reduce the high quantity of demolition wastes and because of reducing construction cost [2]. The mechanical properties of concrete with recycled aggregates from precast debris and waste glass permits an increased amount of recycled coarse aggregates, reducing the loss of mechanical performance of the concrete, and enhances the environmental value of the final material [3]. It was found that inclusion of up to 1.0% steel fibres gave enhanced tensile and bond strength as well as toughness to the oil palm shell light weight concrete [4]. Anti-slip aggregates could double the compressive strength comparison with white aggregate concrete, it could increase it from 25.5 MPa to 52.9 MPa [5].

Waste concrete can be used as aggregate in concrete to produce new concrete but this new concrete mostly has less strength than ordinary concrete [6], but it can be used to product concrete that improving the environment by reducing demolition wastes and also reducing cost of concrete, the waste concrete can be obtained from old structures and also from damaged buildings after accidents or wars.
can be ground in order to get coarse aggregates and even fine aggregate. The mechanical properties of waste concrete aggregates are less than ordinary concrete but can be used in structural concrete. Concrete with waste concrete aggregate can be improved by using admixtures and also can be improved by using steel fibers, steel fibers can improve mechanical properties such as compressive, tensile and flexural strength and also increasing the toughness and ductility of concrete [7].

This research aims to study mechanical properties of waste aggregate concrete, and improving this type of concrete by using non-slip sand, which is an artificial sand, made from fine quartz and gives additional bond between concrete ingredients. Also adding steel fibers to the mixture increases mechanical properties of new concrete such as compressive, tensile, and flexural strengths.

2. Mix proportions, materials, and specifications
Reference mixes proportion is shown in Table (1), with fresh concrete density of 2400 kg/cubic meter, and containing 500 kg cement. The waste aggregate mixes contain the same mix proportions and grading. Fine and coarse aggregates sieve analysis is shown in tables (2) and (3) and confirming British standards 882 [8]. Ordinary Portland cement is used in all mixes, non-slip sand aggregate is added as percentage of sand weight (10, 20, …, 100%) and tested for each case. Figure (1) shows the non-slip sand that is used in this study, while tables (4) and (5) show the properties of these type of sand (non-slip sand) and micro steel fibers respectively. Micro steel fibers are used as percentage of total volume of concrete with one ratio (1%), the steel fibers are shown in Figure (2).

Table 1. Ingredients for reference mix concrete for each 1 cubic meter.

| Cement  | Sand   | Coarse aggregate | Water | Fresh density |
|---------|--------|------------------|-------|---------------|
| 500 kg  | 800 kg | 950 kg           | 150 kg| 2400 kg/cubic meter |

Table 2. Fine aggregates grading used in the study.

| Sieve size ,mm | % Pass by weight | % Pass type M FINE Aggregate (BS Standards) |
|----------------|------------------|--------------------------------------------|
| 10             | 100              | 100                                        |
| 5              | 100              | 100                                        |
| 2.36           | 69.7             | 65 -100                                    |
| 1.18           | 50.5             | 45-100                                     |
| 600 micron     | 43.7             | 25-80                                      |
| 300 micron     | 8.3              | 5-48                                       |
| 150 micron     | -                | -                                          |

Table 3. Coarse aggregates grading used in the study.

| Sieve size ,mm | % Pass by weight | % Pass , (BS Specification) 14 mm max size |
|----------------|------------------|------------------------------------------|
| 20             | 100              | 100                                      |
| 14             | 96.9             | 90-100                                   |
| 10             | 74.1             | 50 - 85                                  |
| 5              | 1.3              | 0-10                                     |
| 2.36           | -                | -                                         |
### Table 4. Non-slip sand (NO.II Type) properties used in study.

| Non-slip sand chemical composition | Color appearance | dimensions of particles | absorption | Specific gravity | Production |
|-----------------------------------|------------------|-------------------------|------------|------------------|-----------|
| quartz Powder =99%, and Alumina   | White – slightly brownish | 0.3 mm – 0.4 mm | Less than 0.1% | 2.8- 2.9         | Kuwait    |

### Table 5. Properties of micro steel fiber used in the study.

| Type and manufacture               | length | Diameter | Aspect ratio | Density       | Tensile strength |
|------------------------------------|--------|----------|--------------|---------------|-----------------|
| Micro steel fiber coated with brass | 13 mm  | 0.2 mm   | 65           | 7800 kg/m3    | 2850 MPa        |

### 3. Specimens and testing procedure

Compressive strength was done by using iron moulds with 10*10*10 cm dimensions, concrete then cast in molds with mechanical compacting, then left for 24 hours until it hardened. Specimens were put in water for 27 days and tested for 28 age test. Taking 3 specimens for all mixes and taking the average. The same steps were carried out for tensile and flexural tests. The tensile strength test was done by using splitting test for 10*20cm cylinders, while the flexural test was done by using beams with 10*10*40 cm and loaded according to BS-1881 [9]. Figures (3, 4, and 5) show specimens under testing for compressive, tensile and flexural strengths respectively.

![Figure 1. Non-slip sand used in study.](image)

![Figure 2. Micro steel fibers used in study.](image)
4. Results and discussion

Table (6) shows the mechanical properties (compressive, tensile, and flexural strengths) of reference normal concrete and waste aggregate concrete with different rates of non-slip sand (0, 10, 20, ..., 100%). The increments of these mechanical properties have calculated between the normal concrete as a reference sample and the other types of concrete. It is seen from this table that the mechanical properties of the waste aggregate concrete are least than their values in the reference normal concrete, their increments are
(-15%) for compressive strength, (-21%) for tensile strength, and (-20%) for flexural strength, these properties begin to increase gradually when adding determined rates of non-slip sand instead of normal sand, the increments of mechanical properties get positive after adding 20% of non-slip sand to the waste aggregate concrete to be (3%) for compressive, and (11%) for tensile and flexural strengths respectively. The increments continue to be (44, 85, and 114) % when adding 100% of non-slip sand to the waste aggregate concrete. The reason of this improvement in mechanical properties is attributed to the nature of non-slip sand, it has 99% of micro silica, which reacts with calcium hydroxide \( \text{Ca(OH)}_2 \) evolving from cement hydration process to form extra cement gel, this gel enters voids and cavities inside concrete and gives additional strength [10] & [11].

Table 6. Mechanical properties and increments of waste aggregate concrete with different rates of non-slip sand.

| Concrete type                        | Compressive strength | Tensile strength | Flexural strength |
|--------------------------------------|----------------------|------------------|-------------------|
|                                       | MPa                  | %                | MPa               | %                | MPa               | %                |
| Reference normal concrete.            | 41.32                | 0                | 3.16              | 0                | 4.67              | 0                |
| Waste aggregate concrete with 0% non-slip sand. | 35.30                | -15              | 2.51              | -21              | 3.74              | -20              |
| 10% non-slip sand.                    | 38.91                | -6               | 3.31              | 5                | 4.63              | -1               |
| 20% non-slip sand.                    | 42.47                | 3                | 3.5               | 11               | 5.16              | 11               |
| 30% non-slip sand.                    | 44.63                | 8                | 3.77              | 19               | 5.94              | 27               |
| 40% non-slip sand.                    | 46.61                | 13               | 3.98              | 26               | 6.43              | 38               |
| 50% non-slip sand.                    | 47.9                 | 16               | 4.20              | 33               | 7.34              | 57               |
| 60% non-slip sand.                    | 49.27                | 19               | 4.43              | 40               | 8.21              | 76               |
| 70% non-slip sand.                    | 51.02                | 23               | 4.88              | 54               | 8.96              | 92               |
| 80% non-slip sand.                    | 53.81                | 30               | 5.12              | 62               | 9.24              | 98               |
| 90% non-slip sand.                    | 55.60                | 35               | 5.66              | 79               | 9.58              | 105              |
| 100% non-slip sand.                   | 59.41                | 44               | 5.86              | 85               | 9.97              | 114              |

Table (7) shows the mechanical properties and their increments of the waste aggregate concrete with different rates of non-slip sand and 1% of micro steel fibers. It is seen that the results of mechanical properties have been increased comparison with the results in table (6). The increments of tensile and flexural strengths get positive without need to add non-slip sand, but it becomes positive for compressive strength after adding 20% of non-slip sand to the mixture, therefore, it is preferable to add 20% only of costly non-slip sand to the waste aggregate concrete supporting with 1% of micro steel fibers, where these fibers work to reduce the cracks in concrete during loading [12] & [13], and bear more additional stresses.

Figures (6, 7, and 8) show the effect of using non-slip sand in concrete and show the increments in strengths of compressive, tensile and flexural. Figures (9, 10, and 11) show comparison the compressive, tensile, and flexural strengths by using only nonslip sand and using both (steel fibers and nonslip sand), and showing also slight increment in compressive strength by using steel fibers but very high increment in tensile and flexural strength and that attributed by high tensile strength of steel fibers (2850 MPa), and the
effect of steel fibers in concrete that reduce the propagations of cracks in concrete under loading [14] & [15].

Table 7. Mechanical properties and increments of waste aggregate concrete with different rates of non-slip sand and 1% micro steel fibers.

| Concrete type                          | Compressive strength | Tensile strength | Flexural strength |
|----------------------------------------|----------------------|------------------|------------------|
|                                        | MPa      | %    | MPa    | %    | MPa     | %    |
| Reference normal concrete              | 41.32    | 0    | 3.16   | 0    | 4.67    | 0    |
| Waste aggregate concrete with 0% non-slip sand | 37.41    | -9   | 5.14   | 63   | 6.96    | 49   |
| 10% non-slip sand                     | 40.18    | -3   | 5.46   | 73   | 7.49    | 60   |
| 20% non-slip sand                     | 44.17    | 7    | 5.61   | 78   | 7.70    | 65   |
| 30% non-slip sand                     | 45.90    | 11   | 5.76   | 82   | 8.38    | 79   |
| 40% non-slip sand                     | 47.54    | 15   | 5.9    | 87   | 9.72    | 108  |
| 50% non-slip sand                     | 49.28    | 19   | 6.1    | 93   | 10.29   | 120  |
| 60% non-slip sand                     | 50.23    | 22   | 6.39   | 102  | 11.20   | 140  |
| 70% non-slip sand                     | 52.33    | 27   | 6.52   | 106  | 11.92   | 155  |
| 80% non-slip sand                     | 54.71    | 32   | 6.81   | 116  | 12.54   | 169  |
| 90% non-slip sand                     | 57.23    | 39   | 7.11   | 125  | 13.22   | 183  |
| 100% non-slip sand                    | 61.28    | 48   | 7.2    | 128  | 13.64   | 192  |

5. Conclusions and recommendations
It can be concluded that It is possible to re-use inorganic building and demolition wastes as a course aggregate in concrete after adding determined rates of non-slip sand and steel fibers as modifiers to the mixture for the sake of increasing the mechanical properties of this waste aggregate concrete. The mechanical properties of concrete increase gradually whenever adding constant rates of non-slip sand instead of normal sand till arrive the highest values at rate 100% of non-slip sand.

It is recommended add only 20% of non-slip sand with 1% of steel fibers to the waste aggregate concrete so as to have the optimal mechanical properties of concrete with less cost. Also it is recommended study the fluidity of these different mixtures, beside study the mechanical properties of waste aggregate concrete after adding different rates of micro steel fibers so as to find the optimal mixture.
Figure 6. Relation between compressive and non-slip sand percentage.

Figure 7. Relation between tensile and non-slip sand percentage.

Figure 8. Relation between flexural and non-slip sand percentage.

Figure 9. Relation between compressive and non-slip sand percentages with and without steel fibers.
Figure 10. Relation between tensile and non-slip sand percentages with and without steel fibers.

Figure 11. Relation between flexural and non-slip sand percentages with and without steel fibers.

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References
[1] Katzer, J and Domski, J, 2016 Specific properties of waste ceramic aggregate concrete reinforced by steel fibre, Annual Set The Environmental Protection, 18, 112 – 23
[2] Malsev, M, Radonjain, V and Broceta, G, 2014, Properties of recycled aggregate concrete, Jour. Contemporary Materials, 2, 239 – 49
[3] Letelier V, Tarela, E, Osses, R, Cardenas, J P and Moriconi, G, 2017, Mechanical properties of concrete with recycled aggregates and waste glass, Int. Fed. Structural Concrete, 18, 40 – 53
[4] Mo, K H, Goh, S H, Alengaram, U J, Visintin, P and Jumaat, M Z, 2017, Mechanical, toughness, bond and durability-related properties of lightweight concrete reinforced with steel fibers, Material and Structures, 50:46, 1 – 14
[5] Altalqany, F J, 2017, Effect of anti-slip aggregate percentages on structural behaviour of polymer modified concrete, IJCJET, 8:12, 662 – 8
[6] Frondistou, S, 1977, Waste Concrete as Aggregate for New Concrete, ACI Jour., 74:37, 373 – 6
[7] Beshara, F, 2012, Nominal flexural strength of high strength fiber reinforced concrete beams, Arab J. Scientific Engineering, 291 – 01
[8] B-S 882, 1992, Specifications for aggregates from natural sources for concrete, (Incorporating Amendment No.1), BSI, (Chiswick High Road, London)
[9] B.S, 1881 Testing concrete – method for determination of flexural strength, (British Standards part 118), (British Standards Institution, London, UK)
[10] King, D, 2012, The effect of silica fume on the properties of concrete as defined in concrete society report 74, cementitious materials’, 37th Conf. on our World in Concrete and Structures, (Singapore), 29 – 1
[11] Malhotra, V and Curette, G, 1983, Silica fume concrete properties, applications and limitations, *Concrete Int. J.*, 40 – 6

[12] Ganesan, N and Abraham, R, 2007, Steel fiber reinforced high performance concrete beam – column joints subjected to cyclic loading, *Iset J. Earthquake Tech.*, 144, 445 – 56

[13] Rai, A, 2014, Applications and properties of fiber reinforced concrete, *Int. J. Eng. Res. and App.*, 4:5, 123 – 31

[14] Holschemacher, K, 2006, Effect of fiber type on properties of steel fiber reinforced concrete, *Proc. 10th East Asia – Pacific Conf. on Structural Engineering and Construction*, (Bangkok, Thailand), 383 – 8

[15] Adeyanju, A, 2011, Effect of steel fibers and iron fillings on thermal and mechanical properties of concrete for energy storage application, *J. of Minerals and Materials Characterization and Engineering*, 10:15, 1429 – 48