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# Experimental Investigation on Recycled Aggregate Concrete Incorporating Copper Slag, Micro Silica and Nano Silica

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**ABSTRACT**

In this study, an experimental investigation on the strength properties of recycled aggregate concrete M40 incorporating copper slag as partial replacement of fine aggregate and micro silica and nano silica as partial replacement of cement has been carried out. For this purpose, eleven concrete mixes were prepared with different replacement ratios of copper slag, micro silica, and nano-silica. Each set of concrete mix comprised of 12 cubes, tested at the age of 3, 7,14 and 28 days of curing period. The physical properties such as grading, specific gravity, and water absorption were determined. According to the results of the experimental study, it is concluded that with complete replacement of natural aggregates with recycled aggregates there was a decrease in the 28 days compressive strength by 23%. However, the best compressive strength was achieved by mix M7 with an increase of 52.93% in 28 days compressive strength compared to the control R.A.C concrete mix C2. Also with the increasing silica content in the concrete, there was a reduction in both the workability and weight density. Therefore, promising results were obtained showing that recycled aggregate concrete can be very well used in place of natural aggregate concrete with the addition of some strength enhancing materials like micro silica and nano-silica.



## Introduction

Recent developments in the material and construction technology aided with nanotechnology have to lead to significant changes resulting in improved performance, wider and more economical use. Concrete which is of utmost importance to the construction industry has undergone rapid and phenomenal development in the past few years. Also, the use of nanomaterials has received particular interests in various fields of applications to improve the existing technologies and also produce materials with new functionalities. The shortage of space for construction and demolition waste disposal and high renting cost of landfills is becoming a common problem in urban areas and there will be an enormous increase from 55 million tons in 1980 to 302 million tons by the year 2020in the available quantities of construction and demolition concrete waste in the European Environmental Commission (EEC) member countries. . In India, 50% of the C&D waste is reused and recycled while the remainder is mostly landfilled. Recycled aggregates are made up of crushed, graded inorganic particles processed from the materials that have been previously used in construction. This recycling of aggregates was a necessity because the World War II made it a dire need for the structures to be constructed again or be repaired and there was a scarcity of natural aggregates (Kheder and Al-Windawi, 2005). As a result, researchers are developing strategies to utilize waste products as a replacement of aggregates in concrete. Another step towards this approach is the utilization of copper slag in place of natural fine aggregate in concrete. Copper slag is the waste product generated in the production of copper. It is produced during the matte smelting and refining of copper. To produce every ton of copper about 2.2-3 tonnes of copper slag is produced(Chockalingamet al.,2013).Utilization of copper slag in applications such as Portland cement substitution and/or as aggregates have threefold advantages of eliminating the costs of dumping, reducing the cost of concrete, air pollution problems (Kharadeet al., 2013).Silica fume or micro silica is a by-product of the smelting process in the silicon and ferrosilicon industry. The most important function of silica fume addition is as a pozzolanic material in the production of high-performance concrete.

Nano-silica is typically a highly effective pozzolanic material used to improve the properties of concrete. Literature, As a result, numerous experimental investigation have been carried out in recent years to study the performance of recycled concrete.Although the earlier study carried out by researchers on a higher grade of concrete is not well understood. Many of the previous researcher work indicates that the Density of the recycled aggregate is lower than that of natural aggregate. This is by virtue of the porous and less dense residual mortar adhered to the surface of the recycled aggregate. The density of fine recycled aggregate and coarse aggregate have been reported by many researchers between 2180 $Kg/m^3$ to 2430 $Kg/m^3$. The density of recycled aggregate is 7 to 9% lower than the natural aggregate (Bodin et al, Alexandridou et al, Limbachiya et al.).Water absorption of recycled aggregates is much higher than that of the original aggregate. This is because for the higher water absorption of old mortar attached to original aggregate particles. It ranges from 3 to 12 percent for the coarse aggregate and the fine aggregates respectively depending on the type of original

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demolished concrete. This value is much higher compared to the natural aggregate whose absorption is about 0.5 to 1 percent this is due to mortar adhering to the original aggregate. (Malesev et al, Dhir et al, Waghih et al). More water quantity is required to achieve the same workability as that of concrete made with natural aggregates. Waghih et al. observed that replacement up to 25% of natural aggregate had no significant effect on compressive strength of concrete and up to 50%, the reduction in compressive strength was reported in the range of 6-13%. Further, if both recycled coarse and fine aggregate are replaced the compressive strength of recycled aggregate concrete was found to be 85% of the strength of conventional concrete. (Gerardu and Hendrinks). Dhir and Pain, reported that the reduction in compressive strength of concrete made with recycled aggregates was up to 15 percent for the same water-cement ratio. Limbachiya et al. indicated that up to 30% replacement of natural coarse aggregates by recycled coarse aggregates had no effect on the compressive strength of concrete. The recycled aggregate up to 60% replacement may be utilized in making concrete pavements and blocks and concluded that the compressive strength of recycled aggregate concrete is better during the early stage but exhibits lower strength during a later stage. (Yong and Teo).

The split tensile strength results of Waghih et al. at the age of 28 days indicate towards a decreasing trend when the quantity of recycled aggregate is increased. The strength ranged from 9-24% lower when compared to the conventional concrete. Ravindrarajah and Tam reported the tensile strength reduced up to 20% when both recycled coarse and fine aggregates were used. Gerardu and Hendrikes, reported a maximum of 10% lower indirect tensile strength to concrete made with recycled coarse aggregate and natural sand as compared to conventional concrete. Dhir and Pain reported a loss of nearly 15% in flexural strength when recycled coarse aggregate was used as a replacement to the natural aggregates. Higher 28-days flexural strength can be achieved with up to 50% replacement and the flexural strength of concrete of recycled aggregate were from 1/5 and 1/8 of its compressive strength. Gumede and Franklin reported that replacement up to 20% the reduction in flexural strength was 8.2%. The maximum reduction in flexural strength for 100% replacement was reported as 48.8%. The workability of recycled aggregate concrete is lower for the same water-cement ratio especially when the replacement level exceeds 50% (Waghih et al.). It is also reported that 9 to 13% more water is required to achieve the same workability while using recycled coarse aggregates. Modulus of elasticity decreases with an increase in the percentage of recycled aggregates, due to the presence of pores in the recycled aggregate. According to Mullick et al. a clear enhancement in the values of modulus of elasticity was observed in all types of processed recycled aggregates. A number of studies have been carried by different researcher to determine the effects of addition of silica fume(micro silica) on the split tensile strength, compressive strength and modulus of elasticity of low-quality coarse aggregate concrete and concluded that the type of coarse aggregate used affected the split tensile strength, compressive strength and modulus of elasticity in both the mixes of plain cement concrete as well as silica fume concrete with the distinction that the concrete mixes produced with silica fume increased resulted in the concrete mixes achieving higher early strengths when compared to the control mixes (Abdullah et al., (2004) ,Li et al., (2004) Saloma et al., (2012) M. Nili et al., (2010) Dr. D. V. Prasad Rao et al.,(2014) and JitendraPatil et al., (2016) )

Further some researcher study on properties of concrete containing copper slag as fine aggregate made use of concrete, Their observations show that workability increases by replacement of copper slag as a fine aggregate and that the maximum compressive strength of concrete increase by using the copper slag as partial replacement of sand (Al-Jabri et al., (2009) Srinivas and Muranal (2015)[Mavroulidou M. et al.,(2015)[R.R. Chavan et al.,(2013) Based on the existing literature it is evident that there are no standard guidelines for the use of recycled aggregates in place of natural aggregates along with some additives. The main objectives of the present study to examine the properties of recycled aggregates, copper slag, nano silica, and micro silica and propose a suitable replacement ratio depending on the compressive strength of concert. From the above literature, its found that recycle concrete can be used for making normal grade concrete and more efforts are needed in the direction of developing a relevant specification and guidelines for making the different grades of concrete from the recycled aggregate.

## 2. Experimental Procedure

**2.1 Materials:** In this study, the Portland Cement 43 grade, the coarse and fine aggregates with nominal well-graded sizes of 20 mm and 4.5 mm, were used respectively. A super plasticizer was also used for specimens, to achieve the required workability of concrete.

**2.2 Mix Proportions:** A total of 132 cubes were cast for this study with varying the percentages of the aggregates with copper by replacing cement with micro silica and nano silica and their different percentage combinations. All the specimens were cast and de-mold 24 hours later after casting and placed in a water tank at room temperature for 28 days. After the curing periods finished, the cube specimens were then tested for mechanical properties after a period of 3 days, 7 days, 14 days and 28 days respectively. For measuring the mechanical properties of all specimens a CTM of loading capacity is 2000 kN was used as shown in figure 1. For each test, the result represents the average of three specimens of concrete. All were conducted according to relevant Indian codes. The materials properties and mix proportions and Nomenclature of concrete mixes are surmised in Table 1 and Table 2 respectively.

**Table 1. Materials Properties**

| Materials | Properties | Values | |
|---|---|---|---|
| Cement | Standard consistency | 30% | |
| | Blaine's fineness | 2436 cm$^2$/g | |
| | Soundness | 7 mm | |
| | Specific gravity | 3.15 | |
| | Initial setting time | 45 minutes | |
| | Final setting time | 385 minutes | |
| | Air permeability | 71 second | |
| | Cube compressive strength | 27 MPa | |
| | 3 days | | |
| | 7days | 34 MPa | |
| | 28days | 52.8 MPa | |
| | Grade | 43 | |
| Fine Aggregate | Fineness modulus | 2.75 | |
| | Grading | II | |
| | Water absorption | 0.8% | |
| | Specific gravity | 2.61 | |
| | Moisture content | 0.6% | |
| | Silt content | 10.3% | |
| Coarse | | NA | RA |

| | | | |
|---|---|---|---|
| Aggregate | Type of aggregate | crushed | Mechanically Crushed |
| | Specific gravity | 2.65 | 2.33 |
| | Water absorption | 1.4% | 5.32% |
| | Moisture content | 0.82% | 0.40% |
| | Fineness modulus | 5.98 | 5.78 |
| Copper Slag | Particle shape | Irregular | |
| | Appearance | Black & glassy | |
| | Type | Air cooled | |
| | Specific gravity | 3.68 | |
| | Percentage of voids | 43.20% | |
| | Bulk density | 1.70 to 1.90 g/cc | |
| | Fineness modulus | 3.47 | |
| | The angle of internal friction | 51° 20' | |
| | Particle size | 0.075 mm to 4.75 mm | |
| | Hardness | Between 6and 7 | |
| Micro silica | Color | Grey | |
| | Texture | Powder | |
| | Specific Gravity | 2.20-2.23 | |
| | Bulk Density | 375- 420 kg/m3 | |
| | SiO2 | 85% minimum | |
| | LOI | 2.30% minimum | |
| | Moisture | 1.0% maximum | |
| Nano silica | Color | White | |
| | Texture | Fluffy Powder | |
| | Specific Surface Area (m2/g) | 202 | |
| | pH value | 4.12 | |
| | Loss on Drying @105 deg. C | 0.47% | |
| | Loss on Ignition @ 1000 deg. C | 0.66% | |
| | Tamped Density g/L | 44 | |
| | SiO2 content | 99.88% | |
| | Carbon content | 0.06% | |
| | Chloride content | 0.009% | |
| | Al2O3 | 0.005% | |
| | Fe2O3 | 0.001% | |
| | TiO2 | 0.004% | |
| Water | PH | 6.8 | |
| Admixtures | Name | HYPERPLAST PC 710 | |
| | Physical state | Light yellow liquid | |
| | pH value | 6.12 | |
| | Specific gravity | 1.101 | |
| | Solid content (% by weight) | 46.32 | |
| | Chloride Content (% by weight) | 0.0007 | |

NA =Natural aggregate , RA= Recycled aggregate

## 3. Results and Discussions

As per present lab facilities, experimental investigations were carried out to study the properties of recycled aggregates as a complete replacement of natural aggregate along with the properties of micro silica(silica fume) and nano silica as a partial replacement of cement. In the present study slump test were measured for each mix and its ranges were 60 mm to 95 mm. The lower and higher values of the slump were recorded in mix M3 and mixM9 respectively as shown in figure 1. The densities of the different concrete mixes are shown figure 2, from the figure the density of concrete mix was in mix M 9 is equal to 22.08kN/m$^3$ and 24.66kN/m$^3$ in Mix 3.

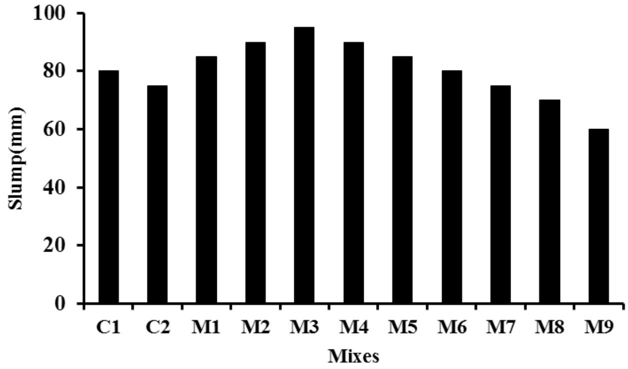


**Figure 1. Slump Verse Difference Mixes of Recycled Aggregate**

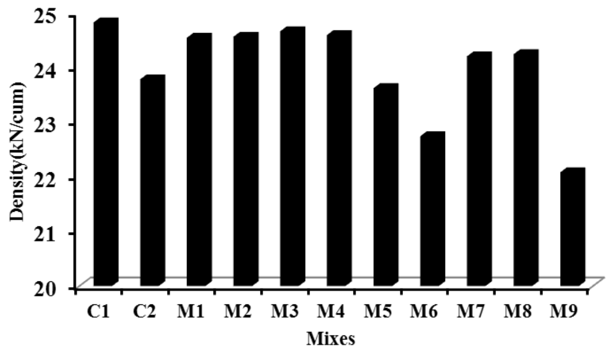


**Figure 2. Density Verse Difference Mixes of Recycled Aggregate**

### 3.1Compressive Strength Test:

The compression testing machine along with the test specimen is shown in figure 3.

The compressive strength test results are shown in the tables 2 and the compressive strength values for 28 days curing were ranges from 31.54 to 57.11 MPa. The test results for the comparison between conventional concrete, control mix and R.A.C with copper slag are shown in figure 4.From the figure the replacement of natural aggregates with recycled aggregates show a reduction in its strength by 23% due to a decrease in its density and higher water absorption on account of the adhered mortar. On the other hand, the replacement of fine aggregates with copper slag increases the compressive strength by 28% on account of higher density (of copper slag) and lower water absorption. The experimental results for the comparison between control mix and R.A.C with copper slag and micro silica (MS) are shown in figure 5.The compressive strength of recycled concrete increases with the addition of micro silica. The addition of micro silica (M.S) increases the compressive strength of concrete on two grounds. Firstly on account of its pozzolanic property micro silica provides a more uniform distribution and a greater volume of hydration products. Secondly, as a filler, micro silica decreases the average size of pores in the cement paste and in turn increases the compressive strength of the concrete mix. The tests on mixes with micro silica with different percentages of nano silica are shown in figure 6 and 7. From the figure, its shown the maximum compressive strength was exhibited by the mix having 10% micro silica along with 2% nano-silica. This is a direct result of the dual strength increasing property of the micro silica (pozzolana and filler) and the pozzolanic property of nano silica combined with its pore-filling effect. Nano silica acts as a nanofiller to fill up the spaces between particles of the gel of calcium-silicate-hydrate (C-S-H). Also, nano silica has a high rate of pozzolanic reaction because of its high surface area to volume ratio. The pozzolanic reaction of both micro silica and nano silica with calcium hydroxide increases the amount of C-S-H which in turn increases the strength and durability. Also, it was seen that if nano silica was added in large percentages there was a subsequent reduction in the compressive strength, this was contributed to the presence of an excess binder in the concrete mix thereby hindering the hydration process and in turn decreasing the compressive strength.

**Figure 3. Compression Testing Machine (CTM)**

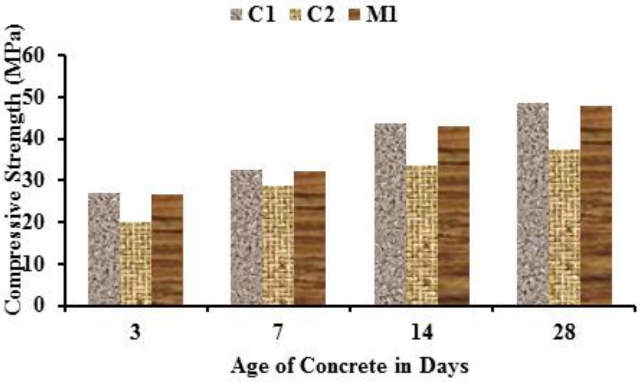


**Figure 4. Compressive Strength Verse Difference Mixes of Recycled Aggregate**

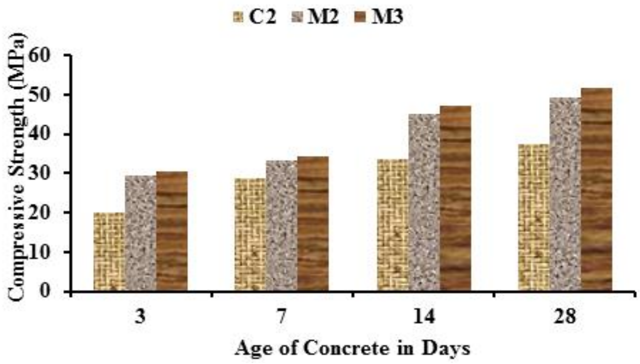


**Figure 5. Compressive Strength Verse Difference Mixes of Recycled Aggregate**

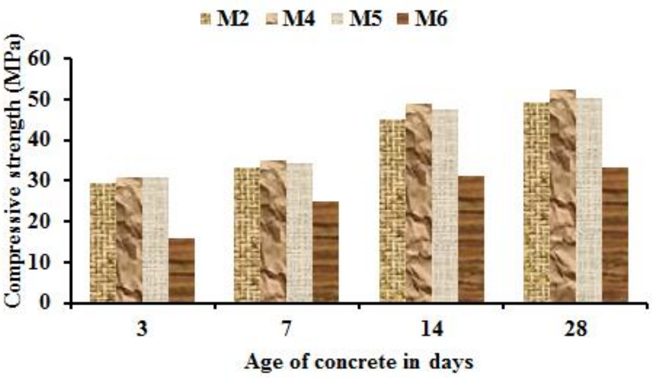


**Figure 6. Compressive Strength Verse Difference Mixes of Recycled Aggregate**

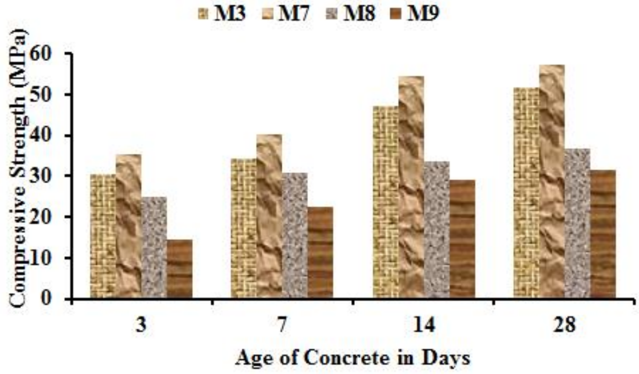


**Figure 7. Compressive Strength Verse Difference Mixes of Recycled Aggregate**

**Table 2. Comparison of 28 Days Compressive Strengths of All Mixes**

| S.no | Mix | Description | 28 days Compressive strength(mpa) | Percentage Increase or decrease |
|---|---|---|---|---|
| 1. | C1 | CONVENTIONAL | 48.41 | ------- |
| 2. | C2 | CONTROL MIX | 37.35 | Nil |
| 3. | M1 | RAC + 25%C.S | 47.88 | + 28 |
| 4. | M2 | RAC + 25%C.S +5%M.S | 49.31 | +32 |
| 5. | M3 | RAC + 25%C.S +10%M.S | 51.68 | +38.36 |
| 6. | M4 | RAC + 25%C.S +5%M.S+2% N.S | 52.24 | +39.86 |
| 7. | M5 | RAC + 25%C.S +5%M.S+5%N.S | 50.36 | +34.83 |
| 8. | M6 | RAC + 25%C.S +5%M.S+10%N.S | 33.32 | -10.78 |
| 9. | M7 | RAC + 25%C.S +10%M.S+2%N.S | 57.12 | +52.93 |
| 10. | M8 | RAC + 25%C.S +10%M.S+5%N.S | 36.86 | -1.31 |
| 11. | M9 | RAC + 25%C.S +10%M.S+10%N.S | 31.54 | - 15.56 |

Plus(+) means increase

Negative(-) means decrease

**4. Conclusions**

1. The workability of the concrete mix M3 (with 10% M.S) was the highest and that of concrete mix M9 (with 10% M.S + 10% N.S) was the lowest.

The weight density of the all the mixes was smaller than the conventional control concrete mix and it was the lowest for mix M9 by 11.04% when compared to that of the conventional concrete mix and by 7.15% when compared to the control RAC mix.

2. The replacement of natural aggregates completely by recycled aggregates resulted in a decrease in 28 days compressive strength of 22.84%.

the addition of increased the 28 days compressive strength of concrete by 32% for 5% M.S addition (mix M2) and38.36 % for 10% M.S addition (mixM3).

3. The compressive strength of the concrete mixes is found to decrease with an increase in the total silica content of the mix. The concrete mixes M6, M8 and M9 exhibited a reduction in compressive strength by 10.78%, 1.31% and 15.56% respectively.

4. The compressive strength of concrete mixes M4, M5 and M7 are found to have increased by 39.86%, 34.83%, and

52.93% respectively when compared with the control RAC mix.

5. The compressive strength of the concrete mix M7 was the highest with 28 days compressive strength of 57.12 MPa which was 52.93% more than the control RAC mix. Hence it was concluded that the best strength was achieved with a cement replacement with 10% of micro silica (M.S) and 2% of nano silica (N.S).

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