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Effect of Copper Slag and Granite Powder on the Mechanical Properties of Reclaimed Asphalt Pavement Aggregate Concrete

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Abstract

The replacement of natural gravel aggregate with reclaimed asphalt as coarse aggregate would help in reduction of environmental and ecological effects. Researches were rarely performed by replacing fine aggregate in reclaimed asphalt pavement aggregate concrete. This project aims to investigate the feasibility of improving the strength of recycled asphalt aggregate concrete in which recycled asphalt aggregate is used as a partial replacement of coarse aggregate at 30%. Abrasion and attrition technique is used to modify or roughen the surface of RAP aggregates. Granite powder and copper slag are used as a partial replacement of sand at 5, 10, 15, 20 and 25% in Abrasion and attrition Treated Reclaimed Asphalt Pavement Aggregate Concrete (ABTRAPC). Thirty cubes, twenty cylinders and twenty beams of concrete with granite powder and thirty cubes, twenty cylinders and ten beams of concrete with copper slag were made and tested. The 7th and 28th day strengths were found out at these replacements. It was observed that the compressive strength, split tensile strength and flexural strength was found to be maximum at 15% replacement of sand by copper slag. The compressive strength was increased about 29.8% compared to ABTRAPC. Flexural strength similar to normal concrete and about 12.8% greater compared to ABTRAP concrete. The compressive strength and flexural strength was also increased to a maximum at 15% replacement of sand by granite powder and split tensile strength at 20% replacement of granite powder. The results showed that the potential of reclaimed asphalt aggregates as a partial replacement of coarse aggregates in concrete could be effectively enhanced with its a combination with granite powder or copper slag. The increase in compressive strength values and the increase in flexural strength values similar to normal concrete proved that this concrete has its potential to be used in pavement applications.

Keywords: *Reclaimed asphalt pavement aggregate, Abrasion, and attrition, Copper slag, Granite powder, Compressive strength, Flexural strength, Split tensile strength, Sustainability*

1.0 Introduction

The current concrete construction practice is thought unsustainable due to the consumption of enormous quantities of stone, sand, drinking water and cement. To move towards ecological sustainability, we must move on to low cost and highly durable concrete mixtures containing largest possible amounts of industrial and urban byproducts that could be suitable as a partial replacement of Portland cement, aggregate and drinking water. Natural aggregate accounts for more than 70% of the volume of concrete. The increasing demand for quality natural aggregates and the subsequent effects on the environment led to the need to consider locally and cheaply available materials in concrete.

India has the second largest road network in the world. Reclaimed Asphalt Pavement (RAP) is the removed pavement materials composed of asphalt and aggregates. These materials are produced when asphalt pavements are removed during reconstruction and resurfacing. The replacement of gravel aggregate with reclaimed asphalt would also help in reducing the quantity of reclaimed asphalt which would otherwise be disposed of in landfill sites. The applications of concrete containing recycled asphalt have been very limited due to its low strength. Thus there is a need to find methods to improve the properties of concrete containing RAP as partial replacement of coarse aggregate. Partial replacement of fine aggregate of this concrete containing RAP with a suitable cheap and recyclable material is an interesting area of study. Granite powder is obtained as a by-product from granite cutting or polishing industries. Granite powder is also generated from recycling marble tops, granite pavers and stone scraps. This powder is deposited in large amounts causing a threat to the environment. Inhalation of fine dust of granite powder causes lung diseases. The use of granite powder in concrete would minimize its effect on the environment. Copper slag is an industrial by-product material produced from the process of manufacturing copper. Approximately 24.6 million tons of slags are estimated to be generated from the copper industries in the world. Some amount of copper slag is mainly used in the sand blasting industry and in the manufacturing of abrasive tools and the remaining is disposed of in the ecosystem without any reuse.

2.0 Literature Review

Reference [1] studied on fine fraction of Reclaimed Asphalt Pavement (RAP) aggregates as an alternative to natural fine aggregates. Cement mortar samples were prepared with 25%, 50%, 75% and 100% replacement of natural aggregates. The decrease in strength of cement mortar may be due to the increase in the porosity of Interfacial Transition Zone (ITZ) and the predominance of asphalt-cohesion failure in comparison to asphalt adhesion failure. It also opens up the scope to incorporate mineral admixtures in mortar mixes to improve the strength of the same with a higher percentage of RAP content. Reference [2] investigated the effect of using copper slag replacement by preparing eight concrete mixes with different proportions of copper slag (0-100%). The compressive, tensile and flexural strength of concrete was comparable to the control mix using up to 50% copper slag. Copper slag, in the range of 40–50%, could potentially replace sand in concrete mixtures. Al-Mufti et al. [3] investigated improving the strength properties of recycled asphalt aggregate concrete. Replacement of 20 mm gravel with recycled asphalt aggregate at 25%, 50%, 75% were compared with 100% recycled asphalt aggregate concrete and control concrete. A replacement of 25% reduces 28 days strength by 27%. Further increase in replacement results in further reduction in strength but at a more reduced rate. Roughening of aggregate prior to mixing for 3 hour increases the strength reaching similar strength to normal concrete. Roughening of recycled asphalt aggregate alone for 3 hours made a limited improvement in concrete strength. The treatment of recycled asphalt aggregate with solvent turpentine has no effect on strength development of concrete.

Reference [4] studied bonding properties in cementitious materials with asphalt-coated particles. Interfacial Transition Zone (ITZ) properties and phase distribution with age of reclaimed asphalt showed high porosity, larger ITZ size, low CH and CSH contents near the interface. This caused a reduction in concrete strength and bulk modulus. Hydrophobic nature of asphalt prevented hydration products from growing around aggregate in larger and porous ITZ. Mortars with RAP showed a decreasing trend in the CH content near the aggregate interface suggesting that somehow asphalt is preventing CH growth. Even though the silica fume decreased the porosity to some extent, the CH content is found to reduce with age due to the pozzolanical reaction of silica fume. Reference [5] studied the nature of the cement-asphalt bond. The interfacial cement-asphalt bond energy was found to improve by several chemical oxidative treatments of the asphalt without affecting the porosity and size factors in the ITZ. Asphalt cohesion is found out to be as the preferential failure mode than the cement-asphalt adhesion or ITZ cohesion. A lower bulk modulus is produced due to the higher porosity in ITZ which allows for easier crack initiation, and the preferential asphalt cohesion failure. An improvement in the concrete the mechanical properties in concrete with RAP aggregates would be improved by increasing the cohesive strength of the asphalt coating thus driving the failure mode to an asphalt-cement adhesive and decreasing the ITZ porosity. Reference [6] studied the use of fractionated reclaimed asphalt pavement (FRAP) as a partial replacement (0%,20%, 35%, and 50%) of coarse aggregate in a ternary blend concrete containing cement, slag, and fly ash. The increase in the percentage of FRAP in concrete resulted in a decrease in the compressive, split tensile, and flexural strength. The elastic and dynamic moduli also decreased with increasing FRAP content. The results of the study indicated that up to 35% FRAP can be replaced as coarse aggregates while still meeting the sufficient fresh, strength, and durability specifications of conventional concrete. Dirty FRAP without washing was found to meet the IDOT compressive strength requirements up to 50% replacement. Reference [7] studied on the potential of blasted copper slag as fine aggregate in Portland cement concrete. The greatest reductions of compressive strength were found when the replacement was over 40%.

Reference [8] conducted studies on soft and hard bitumen from unaged, aged recycled asphalt concrete mixtures for rheological, thermal, microstructural aspects. Bitumen with 50% weight of virgin bitumen and 50% from recycled asphalt pavements were studied. Aging and recycling changed rheological properties of soft bitumen by increasing complex modulus and decreasing phase angle. Recycled asphalt pavement bitumen has an adverse effect on adhesion properties. Reference [9] conducted an experimental study of concrete made with granite and iron powders as partial replacement of sand. The test resulted showed that for 10% ratio of granite powder in concrete, the increase in compressive strength was about 30% compared to normal concrete. Similar results were obtained for flexure. For replacement, up to 20% of sand by weight with iron powder in concrete resulted in an increase in compressive and flexural strength.

Reference [10] conducted studies on experiments with control concrete with natural sand and gravel, concrete with reclaimed coarse and reclaimed fine aggregate, concrete with reclaimed coarse and natural sand, and concrete mix with reclaimed coarse and natural sand where 30% OPC replaced with flash. Concrete made with reclaimed coarse asphalt aggregates and sand showed less reduction in strength compared to others. Reference [11] studied on RAP aggregate materials treated with different dosages of portland type I/II cement and with alkali-resistant glass fibers. Reference [12] investigated on portland cement concrete containing recycled asphalt aggregate. Soft asphalt binder induces stress concentration and microcracking in concrete matrix causing a reduction in strength. Concrete made with only coarse RAP showed the least reduction in strength and a significant increase in toughness. Compared with rubber, RAP had a better chance of replacement in concrete. Reference [13] studied the durability of copper slag contained concrete exposed to sulfate attack. Replacement of cement with copper slag up to 15% led to more than 50% decrease in sulfate expansion. Reference [14] experimentally investigated the feasibility of granite powder waste as a possible replacement in manufacturing concrete. At 0.5 water to cement ratio, experiments were done for 10, 25, 40, 55 and 70% sand replacement by granite powder. Compressive strength results for 7, 28, and 56 days were highest at 25% replacement and lowest at 70% replacement.

Reference [15] studied the effect of incorporating Dirty RAP (DRAP) Washed RAP (WRAP), and Abrasion and Attrition (AB&AT) treated RAP on the fresh, mechanical and durability properties of concrete and compared with each other as well as normal aggregate concrete. Beneficiation of RAP by AB&AT method increased the compressive strength of concrete by 9.74% and 12.21% and flexural strength by 6.05% and 8.55% as compared to WRAP and DRAP inclusive concrete. ABTRAP aggregates were found to possess both the desirable properties of RAP as well as natural aggregates. Aggregates processed with both washing and AB&AT method resulted in better workability than natural aggregate concrete. Reference [16] studied on improving the properties of ABTRAP (Beneficiated RAP aggregates by Abrasion & Attrition technique) inclusive concrete by incorporating mineral admixtures such as Silica Fume (SF), Fly ash (FA) and Sugarcane Bagasse Ash (SCBA).). 6 mixes were prepared by partially replacing Ordinary Portland Cement (OPC) by SF (5% &10%), FA (10% & 20%) and SCBA (5% & 10%). Maximum improvement in compressive, flexural and split tensile strength of ABTRAPC mix was found when 10% OPC was partially replaced by SF followed by 20% replacement by FA and 5% replacement by SCBA.

Reference [17] found out that replacement of 10% cement by BGA was found to increase the compressive strength by 15%, modulus of rupture by 12%, and splitting strength by 13% compared to concrete containing 100% RAP aggregates. Shi et al. [18] investigated the viability of partial replacement of virgin coarse aggregate by coarse RAP to formulate PCC paving mixtures. Replacing virgin coarse aggregate by RAP in a typical PCC pavement mix has caused a reduction in strength and modulus of elasticity. The coarse RAP with sufficient intermediate size particles can help to make dense graded RAP-PCC mixtures which can show better workability and mechanical properties compared to other gap-graded RAP-PCC mixtures. Reference [19] studied the strength and durability properties of concrete made with granite industry waste. The obtained test results were indicated that the replacement of natural sand by GP waste up to 15% of any formulation is favorable for the concrete making without adversely affecting the strength and durability criteria.

Reference [21] investigated the effect of using alternatives for both fine and coarse aggregates with copper slag (30%, 40% and 50%), iron slag (30%, 40% and 50%)and recycled concrete aggregate (20%, 25% and 30%) with various proportions of mix by the partial replacement of sand and gravel respectively. From the study, it has been concluded that 40% of copper slag, 40% iron slag and 25% of recycled concrete aggregate possess more strength than a conventional concrete mix. Reference [22-23] studied the interactions between granites and asphalts based on theology. Different granite powders and asphalt showed significant differences in their interactions and this compatibility problem between asphalt and granite should be considered during the choice of materials.

3.0 Research Significance

Granite powder and copper slag are industrial by-products obtained from the granite cutting and copper manufacturing industries. These can be used as partial replacement of sand in concrete. RAP aggregates are obtained during the reconstruction or resurfacing of pavements. These aggregates, when used as coarse aggregate in concrete, have shown to decrease the mechanical properties of concrete. The modification of RAP coarse aggregates by abrasion and attrition and the partial replacement of sand in the concrete by granite powder or copper slag is an interesting area of research. The use of RAP aggregates, granite powder and copper slag in concrete will reduce the consumption of natural resources in the construction process. The health hazards and the effects on the ecosystem will also be reduced by the recycling of these byproducts.

4.0 Experimental Investigation

The experimental investigation comprised of preparing specimens of normal concrete, concrete with RAP aggregate replaced as coarse aggregate at 100%, concrete with RAP aggregate replaced as coarse aggregate at 30%, concrete with RAP aggregate replaced as coarse aggregate at 30% after abrasion, and abrasion treated RAP concrete with granite powder or copper slag replacement. The specimens comprised of concrete cubes, beams, and cylinders for testing the compressive strength, flexural strength and split tensile strength respectively. The concrete mix consists of Portland Pozzolana Cement, coarse aggregates, RAP aggregates, m-sand, granite powder or copper slag, superplasticizer and water.

4.1. Materials

The materials used for the study included Portland Pozzolana Cement coarse aggregates (gravel) RAP aggregates, fine aggregates (m-sand), granite powder, copper slag, superplasticizer, and water. Portland Pozzolana Cement (PPC) conforming to (IS 1489 part1) fly ash based is used for the experimental work. The specific gravity of cement is 2.89 found using le chatelier flask method as per IS 2720 part3. Reclaimed Asphalt Pavement aggregates and natural aggregates are used as coarse aggregates in this experiment. Reclaimed Asphalt Pavement Aggregates were collected from the highway works in Calicut. Dirty Reclaimed Asphalt Pavement Aggregates were used for the work without washing. Natural coarse aggregates of size passing through 20 mm sieve and retained on 12.5 mm sieve are taken. Reclaimed Asphalt Pavement aggregates of size passing through 20 mm sieve and retained on 12.5 mm sieve are taken. The specific gravity of coarse aggregates and RAP aggregates are 2.66 and 2.35 respectively. M-Sand, granite powder and copper slag are used as fine aggregates. Granite powder is collected from Cemal Gems & Minerals, Bangalore. Copper slag is collected from Blastine private Limited, Koratty, Kerala. Chemical composition analysis results for granite powder and copper slag were obtained from their suppliers i.e. Cemal Gems & Minerals and Blastine private limited respectively. The chemical composition of granite powder and copper slag are given in Table 1 and Table 2 respectively. Specific gravities of m-sand, granite powder, and copper slag are 2.6, 2.5 and 3.2 respectively found out using a pycnometer test as per IS-2386 part-3. Fineness modulus of m-sand, granite powder, and copper slag are 3.44, 2.64 and 3.43 respectively. Sieve analysis test was conducted according to IS 2386 part-1. Gradation curves for fine aggregates are shown in Fig.1. High range water reducing super plasticizer Glenium B233 of specific gravity 1.09 is used for the experiment.

Table 1: Chemical composition of granite powder

Particulars	**Values**
SiO_2	72.04%
Al_2O_3	14.42%
K_2O	4.12%
Na_2O	3.69%
CaO	1.82%
FeO	1.68%
Fe_2O_3	1.22%
MgO	0.71%
TiO_2	0.3%
P_2O_5	0.12%
MnO	0.05%

Source: Batch Inspection Certificate, Cemal Gems, and Minerals, Bangalore

Table 2: Chemical composition of copper slag

Constituent	**Percentage weight**
Silica, SiO_2	26- 30 %
Free Silica	< 5%
Alumina, Al_2O_3	2%
Iron Oxide, FeO	42-47%
Calcium Oxide, CaO	1-2 %
Magnesium Oxide, MgO	1.04 %
Copper Oxide, CuO	6.1 % max
Sulfates	0.13 %

Source: Batch Inspection Certificate, Blastline Pvt.Ltd

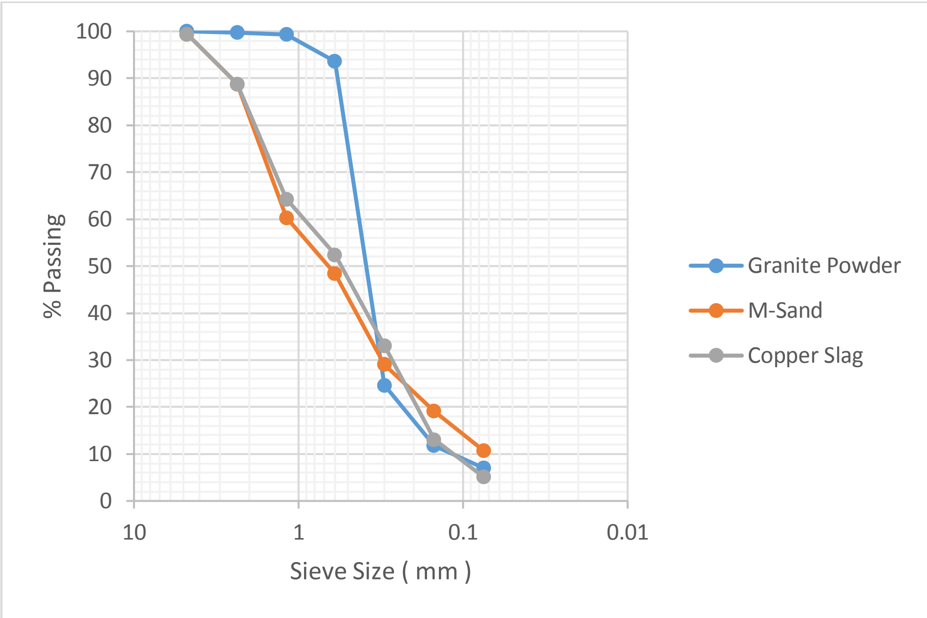

Figure 1: Particle size distribution curves of fine aggregates

4.2 Mix Design of Concrete

Concrete mixtures were prepared with recycled asphalt pavement aggregates as coarse aggregates and granite powder or copper slag as partial replacement of fine aggregate at various percentages i.e. 0% (for the control mix), 5%, 10%, 15%, 20%, and 25 %. The control mixture was designed to have a target 28 day compressive strength of 30 N/mm² (M-30). The mix design obtained is 1:0.43:2.13:2.89 as per IS 10262-2009. Slump test was conducted at admixture dosages of 0.4, 0.45 and 0.5% by mass of cementitious material. As better slump value and mix was obtained at 0.4% dosage, admixture dosage is fixed as 0.4% by mass of cementitious material for all mixes except for the abrasion treated RAP aggregate concrete mix with granite powder replaced as fine aggregate at 20 and 25% in which the dosage is increased to 0.42 and 0.43% by mass of cementitious material.

4.3 Reference Specimens and Abrasion Process

Reference specimens like Normal Aggregate Concrete (NAC), concrete with RAP aggregate replaced as coarse aggregate at 100% (RAPC), concrete with RAP aggregate replaced as coarse aggregate at 30% (R-APC) and concrete with RAP aggregate replaced as coarse aggregate at 30% after abrasion (ABTRAPC) were cast. Los Angeles abrasion test was conducted according to IS 2386 part-4.

The principle of Los Angeles abrasion test is to produce abrasive action by use of standard steel balls which when mixed with aggregates and rotated in a drum for a specific number of revolutions also cause an impact on aggregates. In the modification process, Los Angeles Abrasion Testing Machine is used to do the abrasion process. The machine consists of a hollow cylinder, mounted on a steady frame on ball bearings. It has a detachable shelf which extends throughout the inside length of the drum. The drum is rotated at a speed of 30-33 rpm by an electric motor through a heavy reduction gear. Abrasive charge i.e., cast iron or steel balls, approximately 48mm in diameter and each weighing between 390 to 445 g of twelve numbers are used. Optimum duration time for the abrasion process is fixed at 10 minutes as longer duration resulted in fractured aggregates which might cause a loss in load transfer efficiency. As a number of abrasive charge increases, reduction in asphalt content also increases. Therefore 10 steel balls were selected for the abrasion process. Input quantity of Reclaimed Asphalt Pavement (RAP) Aggregates in the machine was selected based on the materials passing 4.75 mm sieve after the abrasion process as per Table 3. When the number of aggregates was 30 kg, maximum attrition took place and hence the input quantities of aggregates were fixed as 30 kg. Bitumen content was found to reduce about 40.4% by centrifugal extraction method.

Table 3: Percentage passing through 4.75 mm sieve

RAP (kg)	15	20	25	30	35
Passing 4.75 mm Sieve (%)	4.02	5.15	6.2	6.63	6.38

4.4. Preparation of Test Specimens with Granite Powder and copper slag

Granite powder and m-sand were mixed thoroughly. Natural coarse aggregate and RAP aggregates modified by abrasion were mixed thoroughly and added to the mix. Once all materials were mixed thoroughly, superplasticizer was added to water and this water is added to the concrete mix. Hand mixing was done thoroughly. Specimens like 150X150X150 mm cubes, 100X100X500 mm beams, 150 mm X 300 mm cylinders were prepared using the concrete mix. After pouring into molds compaction of 25 blows was done using compaction rod in three layers. After finishing the surface, molds are dried for 24 hrs. After the removal from molds, the specimens are cured in an open water tank for a period of 28 days. The percentages of granite powder used were 5%, 10%, 15%, 20% and 25 of sand by weight designated by GP05, GP10, GP15, GP20, and GP25 respectively. Preparation of concrete specimens with copper slag was similar to those of granite powder specimens. The percentages of copper slag used were 5%, 10%, 15%, 20% and 25 of sand by weight designated by CS05, CS10, CS15, CS20 and CS25 respectively.

5.0 Testing of Fresh and Hardened Properties in Concrete

Slump test is done to check the workability of freshly made concrete. Concrete cubes, beams, and cylinders were used for testing the compression tests, flexural tests and split tensile strength tests into cubes, beams, and cylinders respectively. Compressive strength test, Flexural strength test and split tensile strength test were done according to IS 516-1959 at the 7th and 28th day. 24 cubes, 16 beams, and 16 cylinders were prepared as the reference specimens. Thirty cubes, twenty cylinders, and twenty beams were prepared each for granite powder and copper slag concrete mix in total. Slump variations for concrete mixes are given in Fig.2.

6.0 Slump Test Results

Reclaimed Asphalt Pavement Aggregate Concrete mixes were more workable compared to normal concrete mixes and are high due to its small particle size and larger fineness. These mixes were less workable at higher percentage replacements, especially above 15%. Concrete mixes with copper slag were highly workable and the problem of bleeding occurred at replacements above 15%.

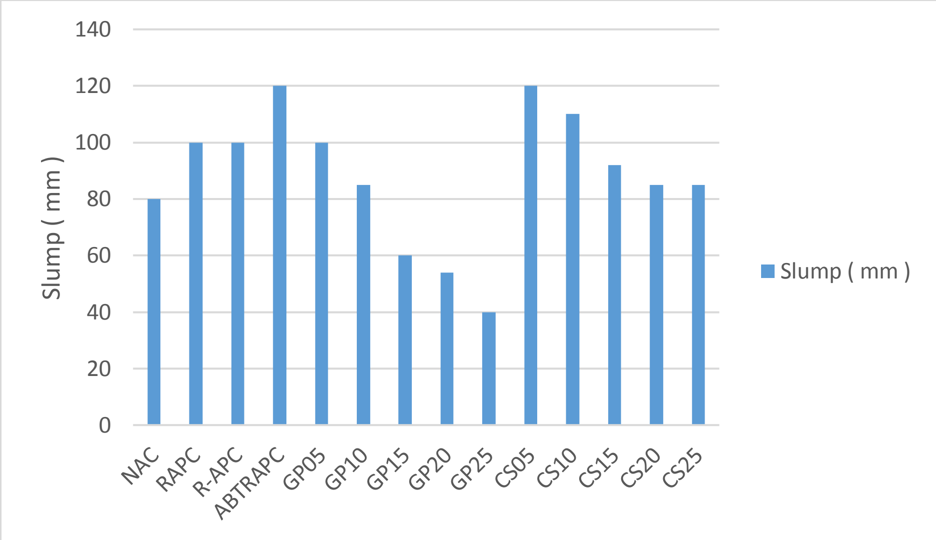

Figure 2: Slump variations for concrete mixes

7.0 Hardened Concrete Test Results

Strength tests were performed at the 7th and 28th day. Hardened concrete test results were obtained as an average of three specimens for each mix. A Compressive strength of 37.55 N/mm^2 is obtained for the NAC at 28 days. RAPC showed a reduction in strength of 62.13% (14.22 N/mm^2) compared to NAC. R-APC showed a reduction in strength of 34.32% (24.66 N/mm^2) compared to NAC. ABTRAPC showed a reduction in strength of 33.44% (24.99 N/mm^2) compared to NAC and it exhibits the least reduction in strength. Fig.3 and Fig.4 show the compressive strength of cubes with different proportions of (GP) and (CS) respectively. A Flexural strength of 7.62 N/mm^2 is obtained for the NAC at 28 days. RAPC showed a reduction in strength of 40.94% (4.5 N/mm^2) compared to NAC. R-APC showed a reduction in strength of 32.15% (5.17 N/mm^2) compared to NAC. ABTRAPC showed a reduction in strength of 11.41% (6.75 N/mm^2) compared to NAC and it exhibits the least reduction in strength. A split tensile strength of 2.63 N/mm^2 is obtained for the NAC at 28 days. RAPC showed a reduction in strength of 61.21% (1.02 N/mm^2) compared to NAC. R-APC showed a reduction in strength of 28.89% (1.87 N/mm^2) compared to NAC. ABTRAPC showed a reduction in strength of 24.33% (1.99 N/mm^2) compared to NAC and it exhibits the least reduction in strength. Split tensile strength of ABTRAPC mixes (1.99 MPa) were 6.41% greater than R-APC mixes. Strength values of reference specimens are given in Table 4. Strength values of specimens with granite powder and copper slag are given in Table 5 and Table 6 respectively.

Table 4: Strength values of reference specimens

MIX	Average Compressive Strength (N/mm^2)		Average Flexural Strength (N/mm^2)		Average Tensile Strength (N/mm^2)	
	7 days	28 days	7 days	28 days	7 days	28 days
NAC	24.22	37.55	5	7.62	2.13	2.63
RAPC	6.505	14.22	0.17	4.5	0.78	1.02
R-APC	18.75	24.66	5.12	5.17	1.52	1.87
ABTRAPC	20.10	24.99	6	6.75	1.71	1.99

Table 5: Strength values of specimens with granite powder

MIX	**Average Compressive Strength (N/mm²)**		**Average Flexural Strength (N/mm²)**		**Average Tensile Strength (N/mm²)**	
	7 days	28 days	7 days	28 days	7 days	28 days
GP05	14.99	18.55	3.87	4.75	1.83	1.96
GP10	17.22	19.66	4.55	4.92	1.93	1.98
GP15	23.12	30.99	5.87	6.12	1.96	1.99
GP20	19.56	25.37	4.55	6	1.8	2.08
GP25	14.48	17.82	3.77	4.25	1.2	1.37

Table 6: Strength values of specimens with copper slag

MIX	Average Compressive Strength (N/mm²)		Average Flexural Strength (N/mm²)		Average Tensile Strength (N/mm²)	
	7 days	28 days	7 days	28 days	7 days	28 days
CS05	16.37	30.77	4.62	6.37	1.95	2.41
CS10	22.21	31.84	5.00	6.67	1.94	2.46
CS15	23.19	32.46	5.05	7.62	1.99	2.67
CS20	20.26	24.31	5.00	6.87	1.95	2.59
CS25	17.45	22.71	4.87	6.8	1.92	2.38

A maximum strength of 30.99 MPa is achieved by granite powder mixes at 15 % replacements at 28th day and it is equal to an increase of 24% compared to ABTRAPC mix. At 20% replacement it showed an increase of 1.52 % compared to ABTRAPC and at 25% replacement, strength decreased to 17.82 MPa.

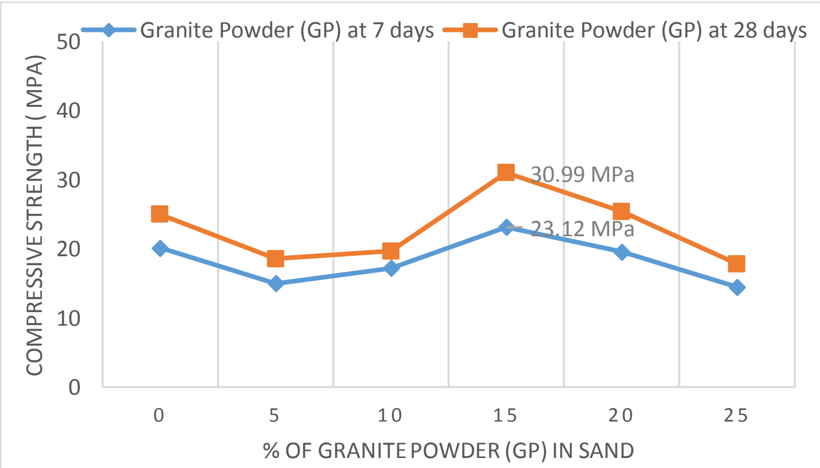

Figure 3: Compressive strength of cubes with different proportions of (GP)

Copper slag at 5% replacement itself shows an increase of 23.12% (30.77 MPa) compared to ABTRAPC mix. A maximum strength of 32.46 MPa is achieved by copper slag mixes at 15 % replacements at 28th day and it is equal to an increase of 29.89% compared to ABTRAPC mix. At 20% strength decreases to 24.31 MPa and decreases further.

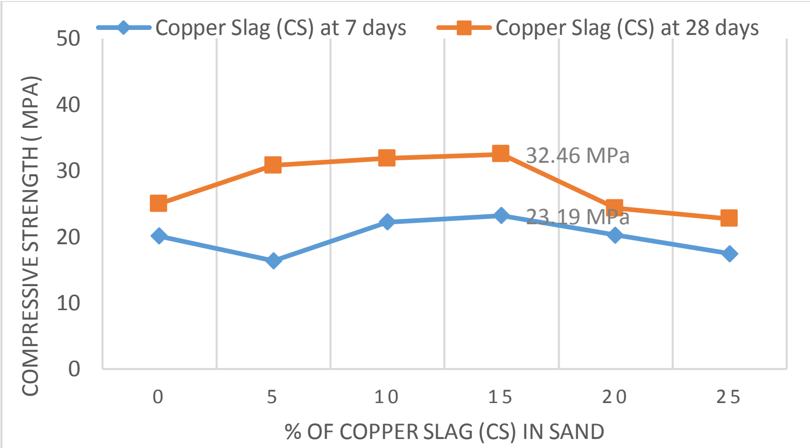

Figure 4: Compressive strength of cubes with different proportions of (CS)

Fig.5 and Fig.6 shows the flexural strength of beams with different proportions of (GP) and (CS) respectively.

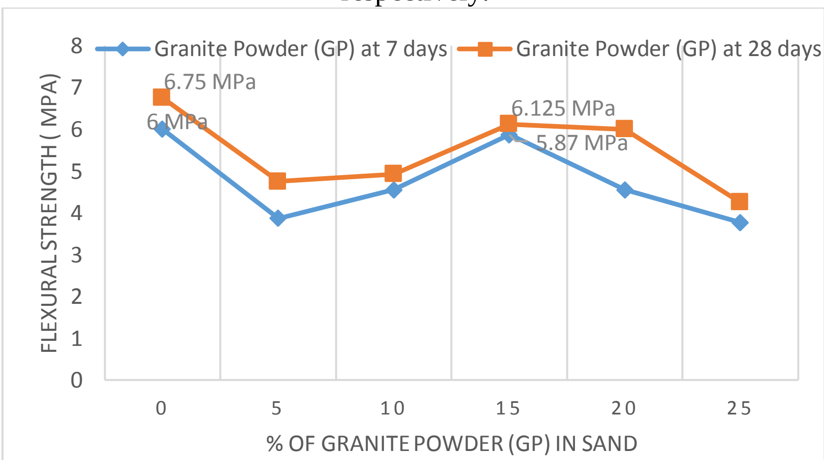

Figure 5: Flexural strength of a beam with different proportions of (GP)

Abrasion process increased the bending strength (5.17MPa) by 30.5% comparing to non-abrasion treated aggregates (6.75 MPa) at 28 days. At 15% replacement of fine aggregate with granite powder, a flexural strength of 6.12 MPa is obtained which shows a reduction of 9.3% compared to abrasion treated RAP aggregates (6.75 MPa) at 28 days. At 15% replacement of fine aggregate with copper slag, a flexural strength of 7.62 MPa is obtained which is similar to that of normal concrete and about 12.8% greater compared to ABTRAP concrete mix at 28 days. All mixes with copper slag exhibited greater flexural strength than granite powder mixes and all other reference mixes.

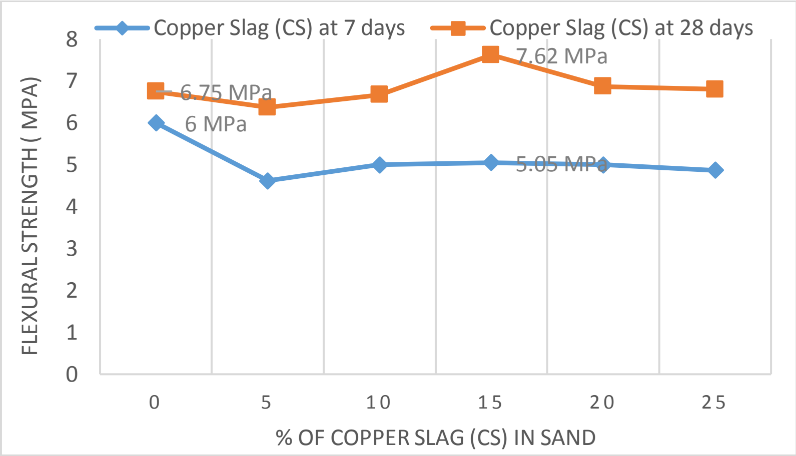

Figure 6: Flexural strength of a beam with different proportions of (CS)

Split tensile strength increased with an increase in the percentage of granite powder replacements up to 20% with a maximum of 2.08 MPa at 20% replacement and decrease further. A maximum split tensile strength of 2.67 MPa is obtained at 15% replacement of fine aggregate with copper slag which shows an increase of 1.52% compared to normal concrete and 34.17% compared to ABTRAP mixes. Fig.7 and Fig.8 shows the split tensile strength of cylinders with different proportions of (GP) and (CS) respectively.

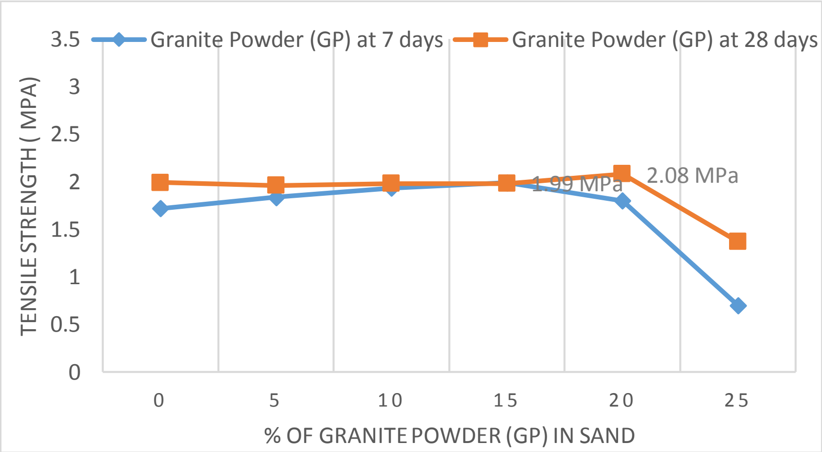

Figure 7: Split tensile strength of cylinders with different proportions of (GP)

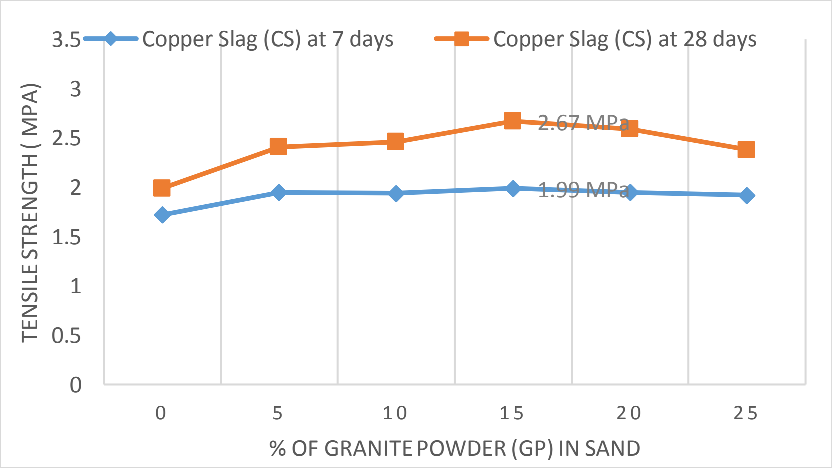

Figure 8: Split tensile strength of cylinders with different proportions of (CS)

8.0 Comparison of Test Results

Compressive strength increased with an increase in the percentage of replacement of granite powder up to 15% compared to ABTRAPC and increase in this case was 24%. Maximum flexural strength was obtained at 15% replacement even though it exhibited a reduction of 9.3% compared to ABTRAPC. Maximum split tensile strength is obtained at 20% and the increase was 4.52% compared to ABTRAPC. Compressive strength increased with an increase in the percentage of replacement of copper slag up to 15% and there was an increase of 29.89% compared to ABTRAPC. Maximum flexural strength was obtained at 15% replacement similar to normal concrete and 12.8% compared to ABTRAPC. Maximum split tensile strength is obtained at 15% and the increase was 1.52% compared to normal aggregate concrete and 34.17% compared to ABTRAPC. Replacements at 25% showed the least water absorption and more resistance to acid attack.

Fig.9 shows a comparison of compressive strength of concrete with granite powder and copper slag. Comparing the results of GP and CS, it is observed that up to 15% replacements, CS exhibited a higher compressive strength. At 20%, the compressive strength of GP increases and at 25% maximum strength was exhibited by CS.

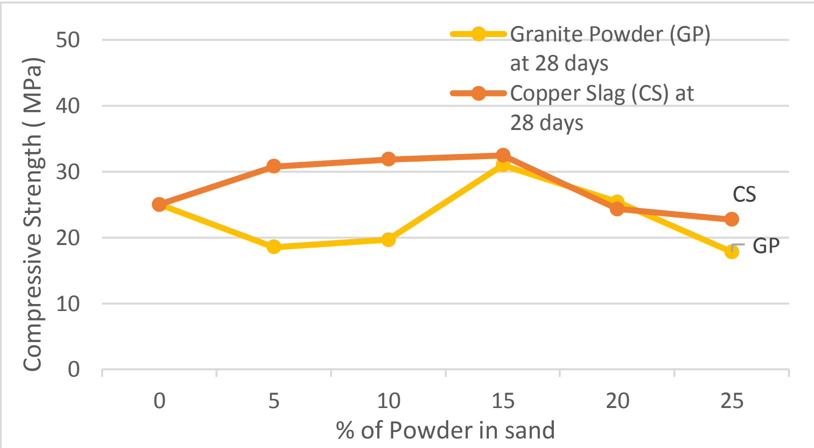

Figure 9: Effect of % of (GP) and (CS) on the Compressive Strength of Concrete

Fig.10 shows a comparison of flexural strength of concrete with granite powder and copper slag. Comparing the results of GP and CS, it is observed that at all replacements, CS exhibited a higher flexural strength comparing to GP.

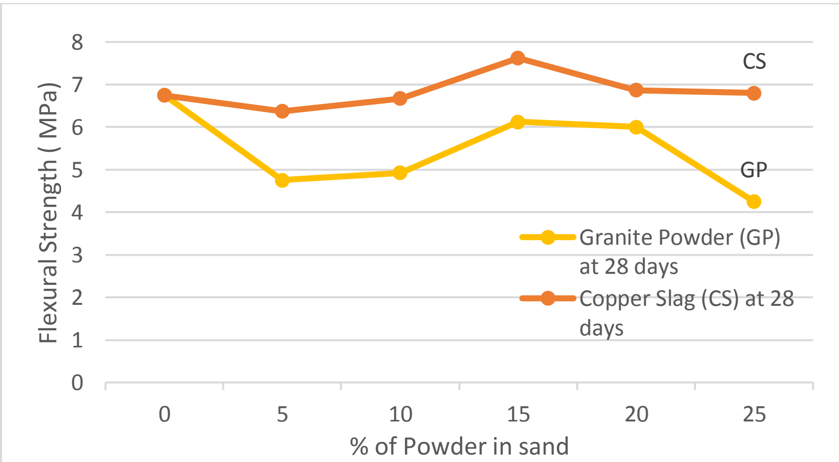

Figure 10: Effect of % of (GP) and (CS) on the Flexural Strength of Concrete

Fig.11 shows a comparison of the split tensile strength of concrete with granite powder and copper slag. Comparing the results of GP and CS, it is observed that at all replacements, CS exhibited a higher split tensile strength comparing to GP.

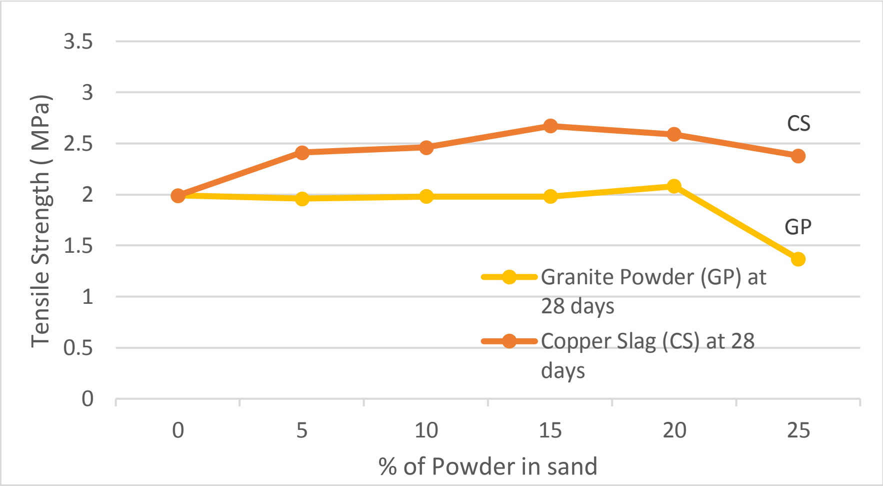

Figure 11: Effect of % of (GP) and (CS) on the Tensile Strength of Concrete

9.0 Conclusions

Based on the test results, the following conclusions can be made.

1. Abrasion and attrition improved the workability, mechanical and durability properties in concrete than the concrete with reclaimed pavement aggregates without abrasion since now the aggregate surface is more available to bonding with mortar and aggregates.
2. Workability of concrete mixes with granite powder and copper slag were good up to 15% of replacement. High water absorption of granite powder caused poor compactness and porosity and low water absorption property of copper slag caused bleeding above the replacement rates.
3. M30 grade concrete mix was developed by using reclaimed asphalt pavement aggregates as a partial replacement of coarse aggregate and granite powder as a fine aggregate at 15% and copper slag as a fine aggregate at 5, 10 and 15%.
4. Granite powder replaced at 15% showed a compressive strength of 23.12 MPa at 7th day and a maximum strength of 30.99 MPa at 28th day. Compressive strength gain of 34.03% was attained in the 28th day. Strength at 15% replacement is about 24% greater than the ABTRAPC specimens and strength at 20% replacement is 1.52% greater than the ABTRAPC specimens. Granite powder specimens developed strength ranging from 18.55MPa, 19.66 MPa, 30.99 MPa, 25.37 MPa, and 17.82 MPa at 5, 10, 15, 20 and 25 % replacements respectively.
5. Copper slag replaced at 5% itself showed a compressive strength similar to that attained by granite powder at 15% and it is 23.12% greater than ABTRAPC. Copper slag replaced at 15% showed a maximum strength 29.89% greater than ABTRAPC of 23.12 MPa at 7th day and a maximum strength of 30.99 MPa at 28th day. Compressive strength gain of 34.03% was attained in the 28th day. Strength at 15% replacement is about 24% greater than the ABTRAPC specimens and strength at 20% replacement is 1.52% greater than the ABTRAPC specimens. Copper slag specimens developed strength ranging from 30.77MPa, 31.84 MPa, 32.46 MPa, 24.3 MPa, and 22.7 MPa at 5, 10, 15, 20 and 25 % replacements respectively.
6. At 15% replacement of fine aggregate with granite powder, a flexural strength of 6.12 MPa is obtained which shows a reduction of 9.3% compared to abrasion treated RAP aggregates (6.75 MPa) at 28 days.
7. At 15% replacement of fine aggregate with copper slag, a flexural strength of 7.62 MPa is obtained which is similar to that of normal concrete and about 12.8% greater compared to

ABTRAP concrete mix at 28 days. All mixes with copper slag exhibited greater flexural strength than granite powder mixes and all other reference mixes.

8. Split tensile strength increased with an increase in the percentage of granite powder replacements up to 20% with a maximum of 2.08 MPa at 20% replacement which is 4.52% greater than ABTRAPC and decrease further. A maximum split tensile strength of 2.67 MPa is obtained at 15% replacement of fine aggregate with copper slag which shows an increase of 1.52% compared to normal concrete and 34.17% compared to ABTRAP mixes.

Conflict of Interest Statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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