Utilization of waste for building materials – a review

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Abstract. Since ancient times naturally available materials are being used for the purpose of construction. Due to overutilization of these resources leads to its unavailability or depletion of these materials. On the other hand, lots of industrial wastes, municipal solid wastes are generated which are sent to landfill. The produced industrial and municipal wastes are not disposed properly. If they are not disposed safely or properly it will pose threats to the human community and also to the environment. These wastes need to be managed properly for safe disposal or alternate ways need to be identified for its utilization. This paper reviews the various types of waste that are used in construction and their usage as building material, its various application and the extent they can be used in building materials are discussed. Sugarcane bagasse ash, municipal solid waste incinerator ash, paper pulp, ground granulated blast furnace slag, copper slag are the wastes reviewed in this study. Many past researches have been identified for utilizing these industrial wastes sustainably in construction sector for manufacturing of bricks, concrete, special concrete etc. The general conclusion from the studies were that GGBS is a good alternative pozzolanic material for cement while the copper slag can be used in many forms as a replacement material in concrete. The MSWI ash is most suitable for use in cement and clay bricks whereas the sugarcane bagasse ash can be ideally used both in cement and clay bricks.

Keywords: waste, management, building material, concrete, brick

1. Introduction
Rapid urban development and the increased industrial activities leads to over utilization of natural resources. On the other hand, lot of wastes are produced from industries causing harm to the human community and the environment. There is an urgent need to consider the following aspects like recyclability, maintainability, energy efficiency etc. in order to reduce the impact on environment. The materials with least environmental impact need to be used as building materials. Also, the renewable and recycling of materials are encouraged in recent years [1].

This paper focusses particularly on the effect of utilization of waste from different industries as building materials. Ground Granulated Blast Furnace Slag (GGBS) is a by – product produced from the iron making industry. The slag is initially in the form of granules and it can be converted in to
powdered form to use it as a substitute for Portland Cement as the environmental impact of GGBS is very much less when compared with Portland Cement [2]. Paper pulp is one of the environmentally friendly material that can be completely recycled and it is used in the building material manufacturing [3]. Past studies are carried out successfully using sludge produced from paper recycling process as a replacement in building materials [4].

Sugarcane Bagasse ash (SBA) is a kind of waste material obtained after the combustion of bagasse which are produced from the Sugar factories. The ash is rich in elements such as silica, alumina etc. so that SBA will be good replacement for building materials. A lot of research works are carried out by using SBA as a replacement material [5]. Copper slag (CS) is a by-product produced during the smelting and pyrometallurgy of copper production from the copper industry. It has been noted that per ton of copper production produces 2.2 tons of copper slag and this slag is considered waste [6]. Copper slag can be suitably used in construction sector as a substitute material for fine aggregate and coarse aggregate and it has been verified experimentally [7].

Over dumping of solid waste will results in limited disposal sites and can cause environmental related problems. Incineration is one of the technologies needs to be adopted for treating the municipal solid waste. By this technology the overall volume of the waste gets reduced by 70 – 90% [8]. The ash produced from incineration (Municipal Solid Waste Incinerator Ash (MSWI Ash)) should be treated to remove the high metal concentrations by leaching tests and can be sustainably used in the manufacturing of building materials as well as minimizing disposal in to landfill [9].

In this paper, the utilization of these wastes in building materials is discussed in detail. The level of replacement done, tests carried out to study the effect of the wastes in building materials are studied from past research works and the optimum utilization of waste in the building materials are also summarized.

2. Review from past research
The wastes reviewed in this paper are Ground Granulated blast Furnace Slag (GGBS), Paper Pulp, Sugarcane Bagasse ash (SBA), Copper slag (CS) & Municipal Solid Waste Incinerator Ash (MSWI Ash). Table 1 summarizes in detail about the percentage replacement of various waste materials in different building materials.

| S. No | ref. | Type of waste | Building Material | Waste Replaced with | % of Replacement done |
|-------|------|---------------|-------------------|---------------------|-----------------------|
| 1     | [10] | GGBS          | Concrete          | Cement              | 0, 50, 70, 90%        |
| 2     | [11] | GGBS          | Concrete          | Cement              | 0, 33.3, 50, 66.7%    |
| 3     | [12] | GGBS & Metakaolin | Concrete        | Cement              | GGBS – 0 to 80% @ 10% increment  
   Metakaolin – 0, 10, 20% |
| 4     | [13] | GGBS & Silica Fume | Preplaced Aggregate Concrete (PAC) | Cement | GGBS – 30, 35, 40 Silica Fume – 10% |
| 5     | [14] | GGBS          | Concrete          | Cement              | 0 to 80% @ 10% increment |
| 6     | [15] | GGBS          | Geopolymer Recycled Aggregate Concrete (GRAC) | Fly Ash | 0, 25, 50, 75% |
| 7     | [16] | GGBS & Micro Silica | Concrete        | Cement              | GGBS – 20, 30, 40, 50% Micro Silica – 5, 10, 15% |
| 8     | [17] | GGBS & High Magnesium Nickel Slag (HMNS) | Geopolymer Concrete | Fly Ash | GGBS – 5, 10, 20, 30, 40% HMNS – 5, 10, 15,20% |
| 9     | [18] | GGBS          | Ultra High-Performance Concrete | Cement | 20, 40, 60, 80% |
| 10    | [19] | GGBS SO₃, Calcium Carbonate, Anhydrite | Concrete        | Cement              | GGBS – 60 & 70% Other three materials – 1 to 3 % of weight of GGBS |
| 11    | [20] | Ultra fine GGBS & Silica fume | Self Compacting Concrete | Cement | 5, 10, 15% |
| 12    | [21] | GGBS          | Roller Compacted Concrete | Cement | 10, 20, 30, 40, 50, 60% |
| 13    | [22] | Paper Sludge  | Clay Bricks       | Clay                | 0 to 10%              |
| 14    | [23] | Paper sludge & Waste water | Clay Bricks     | Clay                |                      |
| 15 | 24 | Recycle Paper Mill Residue (RPMR), Rice Husk Ash (RHA) & Cement | Bricks | Complete replacement | RPMR – 70, 75, 80% RHA – 10, 15, 20% |
| 16 | 25 | Paper Mill sludge | Clay Bricks | Clay | 0, 5, 10, 15, 20% |
| 17 | 26 | Paper Mill waste | Light weight Cement Bricks | Cement | 0, 5, 10, 15, 20% |
| 18 | 27 | SBA | Cement Mortar | Cement | 0 to 30% |
| 19 | 28 | SBA | Concrete | Cement | 10, 20, 30% |
| 20 | 29 | SBA | Concrete | Cement | 10, 15, 20, 30, 50, 100% |
| 21 | 30 | SBA | High strength Concrete (HSC) | Cement | 10, 20, 30% |
| 22 | 31 | SBA, Fly Ash, Silica Fume | Clay Bricks | Clay | Sugarcane Bagasse Ash – 20, 40% Fly Ash – 10% Silica Fume – 10% |
| 23 | 32 | SBA, Quarry Dust, Lime | Brick | Complete replacement | SBA – 50 to 80% @ 5% increment Quarry Dust – 0 to 30% @ 5% increment Lime – 20% |
| 24 | 33 | SBA | Clay Brick | Clay | 0, 5, 10, 15, 20% |
| 25 | 34 | SBA & Rice Husk Ash (RHA) | Clay Brick | Clay | 5, 10, 15% |
| 26 | 35 | SBA & Lime | Soil Compacted blocks | Soil | SBA - 10, 20% Lime 10% |
| 27 | 36 | SBA & Fly Ash | Concrete | Cement | SBA – 0, 10, 20% Fly Ash – 20% |
| 28 | 37 | SBA | Concrete | Cement | 5 to 25% |
| 29 | 38 | SBA | Concrete | Cement | 5 to 50% @ 5% increment |
| 30 | 39 | SBA | High strength concrete | Cement | 5 to 20% |
| 31 | 40 | SBA | SCC & Light Weight Concrete | Cement | 5, 10, 15, 20, 25% |
| 32 | 41 | CS & Fly Ash (FA) | Concrete | CS for Fine aggregate FA for cement | CS – 0 to 100% @ 20% increment FA – 10, 20, 30% |
| 33 | 42 | CS | Concrete | Cement | 20, 40, 60% |
| 34 | 43 | CS, Fly Ash (FA) & Silica Fume (SF) | High performance concrete | Cement | CS – 5, 10, 15, 20% FA – 5, 10, 15, 20% SF – 2.5, 5, 7.5, 10% |
| 35 | 44 | CS | High performance concrete | Sand | 0 to 100% @ 10% increment |
| 36 | 45 | CS | High strength concrete | Sand | 0 to 100% @ 10% increment |
| 37 | 46 | CS | Binders | Cement | 15, 30, 45% |
| 38 | 47 | CS | Bricks Plaster, concrete | River sand | 25, 50, 75% |
| 39 | 48 | CS | Concrete | Fine Aggregate | 20, 40% |
| 40 | 49 | CS | Concrete | Cement | 5, 13.5% |
| 41 | 50 | CS | Ultra High-performance concrete | Fine Aggregate | 30 to 100% |
| 42 | 51 | CS | Self Compacting Concrete (SCC) | Fine Aggregate | 0 to 60% @ 10% increment |
| 43 | 52 | CS & Silica Fume | High strength concrete | Coarse aggregate | CS - 100% SF – 0, 6, 10% |
| 44 | 53 | CS | Pervious concrete | Coarse aggregate | 0, 20, 40, 50, 60, 80, 100% |
| 45 | 54 | CS | Concrete | Cement | 0, 5, 10, 15% |
| 46 | 55 | CS | High strength concrete | Sand | 0 to 100% @ 20% increment |
| 47 | 56 | MSWI Ash | Bricks | Partial replacement for Brick material | 4% weight |
| 48 | 57 | MSWI Ash | Clay Bricks | Clay | 10, 20, 30, 40, 50% |
| 49 | 58 | MSWI Ash | Bricks | Clay | 0 to 40% by weight |
| 50 | 59 | MSWI Ash | Cement Bricks | Fine Aggregate | Complete replacement for Fine aggregates |
| 51 | 60 | MSWI Ash | Cement Bricks | Cement | Made with different w/c ratio as 0.4, 0.45, 0.5, 0.55 |
| 52 | 61 | MSWI Ash | Bricks | Brick material | The specimens are fired at 1120°C & 1140°C |
| 53 | 62 | MSWI Ash | Bricks | None | MSWI ash utilized |
| 54 | 63 | MSWI Ash | Clay bricks | Clay | 0, 2.5, 5, 7% |
| 55 | 64 | MSWI Ash | Bricks | Brick | 0, 5, 10, 15, 20% |
| 56 | 65 | MSWI Ash | Hot – mix asphalt concrete | Aggregate | 0, 5, 10, 15, 20, 30, 40% |
| 57 | 66 | MSWI Ash | Blended cement | Cement | 0, 10, 20, 40% |
2.1. Production of building materials from waste materials

From Table 1 the usage of various wastes and their percentage utilization in building materials from past research can be observed. Many studies are carried out by utilizing waste materials in to building materials. GGBS is mostly replaced for cement at various percentages of 30-70% and studies are carried out experimentally [10,11,14,16,18,21]. The pozzolanic nature of GGBS is the main reason for replacing with cement. In some studies, in addition to GGBS other materials like Metakaolin, Silica Fume are also added to enhance the property in the cement mortar or in the concrete in which they are utilized. The GGBS application can be seen in wide variety of concretes such as High-performance concrete, Geo Polymer concrete, Self Compacting concrete, Roller compacted concrete etc.

With utilizing the paper pulp in building materials very limited studies are carried out and they are effectively used in bricks up to replacement of 10% [22-26]. The addition of paper pulp residue in clay bricks contributed in energy savings up to 3% [22]. SBA finds its use in different types of concretes as well as in bricks too. In concretes it is replaced for cement due to the nature of ash is similar to cement [27,28,29,30,36,37,38,39,40]. The SBA is replaced for cement at 0-100% in various studies including special concretes such as High strength Concrete, Self Compacting concrete and light weight concrete [30,39,40]. In bricks, the SBA is replaced for clay up to a maximal of 40% and along with this other siliceous material such as Fly ash and silica fume are also added to enhance the property of the bricks [31].

Copper slag was found to be replaced for cement, fine aggregate, coarse aggregate in concrete [41-55] and experiments are carried out by replacing it at various percentages. The CS finds its application in special concretes such as High Strength Concrete, High Performance Concrete, Ultra High-Performance concrete, Self Compacting Concrete and Pervious concrete [43,44,45,50,51,52,53,55]. CS has been completely replaced in concrete and many experiments are carried out based on this [41,44,45,50,52,55]. MSWI ash was utilized in both clay bricks and cement bricks at varying proportion [56-70]. Studies are also carried out by utilizing MSWI ash in Autoclaved aerated Concrete, Hot-mix asphalt concrete, Geopolymer matrix [65,68,70]. With MSWI ash in cement bricks different water-cement ratios are adopted [60] whereas the clay bricks with MSWI ash are fired at different temperatures to evaluate the various properties [61].

3. Results and Discussions

Table 2 discusses the specimen details, experimental studies carried out to determine the strength and other parameters, conditions adopted to proceed the study and the conclusions brought from the study is presented.

| ref. | Type of Waste            | Specimen Details         | Tests Conducted          | Condition Adopted                  | Remarks                                      |
|------|--------------------------|--------------------------|--------------------------|------------------------------------|----------------------------------------------|
| [10] | GGBS                     | Cubes, Cylinders, Prisms | Compressive strength, Flexural and tensile strength | 28 days curing at room temperature | 70% replacement improved the mechanical properties |
| [11] | GGBS                     | Cube                     | Compressive strength, Permeability, Chloride diffusion | Tested after 28 & 90 days of age. | 33.3% replacement accounted for durability |
| [12] | GGBS & Metakaolin        | Cubes, Prisms            | Compressive strength, Flexural strength | Specimens are tested for 1, 7, 14, 28 & 90 days | GGBS @ 60% & Metakaolin @ 20% was found optimum |
| [13] GGBS & Silica Fume | Cubes, Prisms | Compressive strength, RCPT, Drying shrinkage | 7 & 28 days | GGBS @ 30% & Silica Fume @ 10% |
| [14] GGBS | Cube | Compressive Strength, Efficiency by analytical concept | 28 days | 50% replacement was efficient |
| [15] GGBS | Cube | Compressive strength, Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) | Tested at 7 & 28 days of age under curing temperatures of 20°C, 40°C, 60°C, 80°C, 100°C | GGBS @ 80°C curing temperature showed good results |
| [16] GGBS & Micro Silica | Cubes, Cylinders, Prisms | Compressive strength, Flexural and tensile strength | Tested at 7, 28, 90, 180 & 356 days | GBS – 30% Micro Silica – 10% showed good results |
| [17] GGBS & HMNS | Cubes, Cylinders | Compressive strength, Split tensile strength, SEM, XRD, Fourier Transform Infrared Spectroscopy (FTIR) | Specimens are tested at 7, 14, 28 days | GBS – 20% HMNS – 10% improved the microstructural property |
| [18] GGBS | Cubes, Cylinders, Prisms | Compressive strength, Flexural and tensile strength, RCPT, Water Sorptivity, SEM, XRD | All the specimens are tested for 7, 28, 56, 90 days | 60% replacement was found optimal |
| [19] GGBS | Cubes, Prisms | Compressive Strength, Flat prism test | Tested @ 3, 7, 28 days | Sulphate resistance was increased at both replacement percentages. |
| [20] Ultra fine GGBS & Silica Fume | Cubes | Compressive strength, Water absorption, RCPT, Water Sorptivity, Sulphate attack, acid attack | Tested @ 7, 28, 56 & 90 days | 10% addition was optimal and improved the durability |
| [21] GGBS | Cubes, Cylinders, Prisms | Compressive strength, Flexural and tensile strength, RCPT, Water Sorptivity, SEM, XRD | Specimens are tested at 3, 7, 28, & 90 days | 50% replacement had more resistance |
| [22] Paper Sludge | Bricks | Compressive strength, Water absorption, linear shrinkage | Specimens are fired at 750°C | 10% replacement was optimal and it also reduced the energy up to 3% |
| [23] Paper sludge & Waste water residue | Bricks | Compressive strength, Linear shrinkage, Loss on ignition, Bulk density, Water absorption | Specimens are fired at 950°C for 6 hours | 6% replacement was optimal and it also had energy savings |
| [24] Recycle Paper Mill Residue (RPMR), Rice Husk Ash (RHA) & Cement | Bricks | Compressive strength, water absorption, efflorescence | Tests are carried as per IS standards | RPMR – 80%, RHA – 10% Cement – 10% was optimal |
| [25] Paper Mill sludge | Clay Bricks | Compressive strength, Linear shrinkage, Loss on ignition, Bulk density, Water absorption, efflorescence, Apparent porosity | Specimens are fired at 850°C & 900°C | 10% replacement was optimal at 900°C firing temperature |
| [26] Paper Mill waste | Bricks | Compressive strength, water absorption, Specific weight, dimension change | Specimens are tested as per standards | 10% replacement was optimal |
| [27] SBA | Mortar cubes | Compressive strength, Flexural strength, Water permeability, soundness, SEM, XRD, XRF, FTIR | Specimens are tested at 3, 7, 28 days | 10% replacement possessed good properties |
| [28] SBA | Cylinder | Compressive strength, Water permeability, Heat evolution | Specimens are tested at 28 & 90 days of age | Up to 20% replacement was optimal beyond that the mechanical properties decreases. |
| [29] SBA | Cubes, Cylinder | Compressive & tensile strength, water absorption, SEM, XRD | Specimens are tested at 7, 14, 28 days age | 20% & 30% was optimal |
| [30] SBA | Cylinder | Compressive strength, porosity, Water absorption, RCPT, Chloride diffusion | The specimens are tested at 7, 28 & 90 days | HSC was able to produce up to 30% bagasse ash |
| [31] SBA, Fly Ash, Silica Fume | Bricks | Compressive strength, Linear shrinkage, porosity, density | All the specimens are fired at 900°C, 1000°C, 1100°C | Bricks made with 7% clay, 20% SBA & 10% silica fume is considered optimal |
| [32] SBA, Quarry Dust, Lime | Bricks | Compressive strength, Flexural strength, Shear bond test, Bond wrench test | All the tests are carried out as per standards | Bricks produced with 50% SBA, 30% Quarry Dust, 20% Lime is the most optimal.

| [33] SBA | Bricks | Tensile strength, water absorption, Linear shrinkage, Apparent density, SEM | All the specimens were fired at 1000°C | 10% replacement can be adopted in practice.

| [34] SBA & RHA | Bricks | Compressive strength, water absorption, porosity, Sulphate attack | All the specimens were fired at 1000°C for 36 hours | 5% replacement is optimal.

| [35] SBA & Lime | Blocks | Compressive & Flexural strength | The specimens are fired @ 700°C to 900°C and the tests are carried at 3, 7, 14, 28, 90 days | 10% SBA & 10% Lime improved the mechanical properties.

| [36] SBA & Fly Ash | Cubes | Compressive strength | Specimens are tested at 7, 28, 56, 90 & 120 days | 20% replacement improved the mechanical properties.

| [37] SBA | Cubes | Compressive strength, Oxygen permeability, RCPT, Chloride conductivity, Water sorptivity, Water permeability | Tested at 3, 28, 56 days | 25% replacement is considered optimum.

| [38] SBA | Cylinder, Prism | Compressive strength, Modulus of Rupture & elasticity | Tests are done at 7 & 28 days | 20% replacement improved the properties.

| [39] SBA | Cubes | Compressive strength, Chloride resistance, Sorptivity | Tests are carried out as per standards | Replacement of 15% is optimum.

| [40] SBA | Cubes, Cylinder | Compressive & Tensile strength, Impact resistance, SEM, XRD | Tests are carried out as per standards | 5% replacement gave good results.

| [41] CS & Fly Ash (FA) | Cubes, Cylinder, Prism | Compressive strength, Flexural & tensile strength, NDT | Tests are carried out at 7, 28, 56 & 90 days | CS @ 100% & FA @ 30% did not affect any properties.

| [42] CS | Cubes, Cylinder | Compressive & Tensile strength, SEM, XRD, Carbonation | Tests are carried out as per standards | CS addition was suitable in concrete.

| [43] CS, Fly Ash (FA) & Silica Fume (SF) | Cubes, Prism | Compressive & Flexural strength, Sorptivity, RCPT | Tests are carried out as per standards | Copper slag improved the properties and it will be a useful material.

| [44] CS | Cubes, Cylinder, Prism | Compressive strength, Tensile strength, Flexural strength and durability | Specimens are tested at 7 & 28 days | 40% CS can be used to produce HPC with good properties.

| [45] CS | Cubes, Cylinder, Prism | Compressive strength, Tensile strength, Flexural strength and durability | Specimens are tested at 7, 28, 56 days | CS can be replaced by 100% for sand to produce HSC.

| [46] CS | Cubes | Compressive strength, XRD, TG/DTG | Specimens are tested at 3, 7, 28 & 60 days | With increase in CS the properties of the mortar also improved.

| [47] CS | Bricks | Compressive strength, Water absorption | Tests are carried out as per standards | It can be replaced up to 50% effectively.

| [48] CS | Cubes, Cylinder, Prism | Compressive strength, Flexural strength, Water absorption, Carbonation, Alkali silica | Specimens are tested at 7 & 28 days | Copper Slag is suitable for replacement natural sand.

| [49] CS | Cubes, Cylinder, Prism | Compressive strength, Tensile strength, Flexural strength | Specimens are tested at 7 & 28 days. The w/b ratio adopted are 0.5, 0.6, 0.7 | The addition of copper slag has no significant effect on concrete.

| [50] CS | Cubes, Beams | Compressive and Flexural strength | The specimens are tested at 3, 7, 14 & 28 days | Copper slag is a promising material in construction.

| [51] CS | Cubes, Cylinder | Compressive and Tensile strength, Statistical analysis | Tested at 7, 28, 90 days | The 28 & 90 days results showed improvements.

| [52] CS & Silica Fume | Cubes, Cylinder | Compressive and Tensile strength, NDT | w/b ratio adopted is 0.4, 0.35, 0.3 | CS as coarse aggregate replacement is more effective.

| [53] CS | Cubes, Cylinder, Prism | Compressive strength, Tensile strength, Flexural strength, porosity, permeability | Tests are carried out as per standards | 60% replacement was found to be optimal.

| [54] CS | Cubes, Prisms | Compressive strength, | Tests are carried out as | 15% replacement was
3.1. Mechanical properties

From Table 1 it is understood that GGBS replacement varies from 0-90% for cement. An optimum of 60% replacement for cement contributes to long term strength of concrete and along with that 20% of metakaolin for cement imparts early strength to concrete [12]. In plain concrete GGBS addition with 70% replaced for cement improves the mechanical properties at 28 days [10]. It has been experimentally verified that the compressive strength increases with increase in the GGBS content [14]. The microstructure of geopolymer concrete cured at 80°C possessed good results with the addition of GGBS [15]. The addition of paper pulp did not affect the mechanical properties of the bricks but it reduced the energy requirement to produce the brick by 3% [22]. The homogeneous mixture of paper mill sludge with rice husk ash had mechanical strength more than that of control one [24]. In the case of SBA, high strength concrete can be produced with 30% replacement of SBA for cement and it also lowered the chloride penetration at this level [30]. SBA along with silica fume replaced at 20 & 10% for clay improved the properties of the bricks when compared with the control specimen [31]. In clay bricks, the strength was higher up to 10% replacement of SBA for clay [33]. With 5% replacement of SBA it is able to produce Self compacting concrete and light weight concretes possessing good concretes [40].

The mechanical properties of the concrete were not affected when copper slag was replaced at 100% for fine aggregate and fly ash added at 30% for cement [41]. In this study, it was noted that the strength and durability of concrete increased with addition of copper slag [42]. High performance concrete can be manufactured with 40% CS for fine aggregate and it also possess good mechanical properties.
and durability properties [44]. The CS replacement for fine aggregate in Self compacting concrete improved the properties of the concrete after 28 and 90 days [51]. In the case of pervious concrete, the CS is replaced for coarse aggregate at various percentage and among that 60% replacement was found to be optimal [53]. As per Chinese standards, bricks made with MSWI ash replaced at 40% by maintaining the firing temperature at 800°C met the brick quality standards [58]. With increase in the sintering temperature the strength of the bricks also increased thus reducing the pore volume and absorption rate [61]. MSWI ash was used in Hot-mix asphalt concrete and the replacement at 15 & 20% satisfied all the requirements [65]. The geopolymer mortar containing MSWI ash at 20% replacement gave good compressive strength and the microstructure of the mortar also improved with MSWI addition [68]. The mechanical properties of Autoclaved aerated concrete improved with 60% addition of MSWI ash for sand [70].

3.2. Durability properties

GGBS replacement at 33.3% for cement paste had more resistance to chloride penetration than the control specimen and it was found to be durable [11]. The durability of the concrete increases with the combined effect of addition of GGBS with silica fume at 30% and 10% respectively [13]. The durability of ultra high-performance concrete with GGBS content at 60% for cement was found to be higher [18]. The sulphate resistance was less at 60 & 70% replacement of GGBS for cement in concrete [19]. 10% addition of ultra fine GGBS in Self compacting concrete improved the durability of the concrete [20]. The cement bricks made with paper mill residue at 80% and cement at 10% possessed good durability properties [24]. The durability properties of clay bricks were more when paper mill sludge is added at 10% for clay fired at 900°C when compared with standard bricks [25]. High strength concrete can be manufactured with 30% of SBA for cement and thus improving the durability properties of the concrete [30]. The combined effect of SBA and Rice husk ash for clay in clay bricks had good sulphate resistance when the replacement was done at 5% and the specimens are burnt at 1000°C [34]. With SBA at 25% replacement the durability properties such as chloride penetration, water sorptivity was less in plain concrete [37] whereas in another study for high strength concrete with 15% replacement accounted for the durability properties [39].

In addition to CS, fly ash and silica fume are added to cement in the production of High-performance concrete and it improved the durability properties of the concrete [43]. High strength concrete was able to produce with full replacement of CS for sand thus without compromising the durability property of concrete [45]. In pervious concrete the durability is assessed by porosity and permeability. Both the factors showed less values when copper slag was replaced at 60% for aggregates [53]. In plain concrete, the copper slag replacement at 15% for cement had more sulphate resistance than the control mix [54]. It was verified experimentally that the increase in sintering temperature of the bricks increased the durability of the bricks [61]. The clay bricks fired at 1000°C with 2.5% MSWI ash for clay possessed good durability properties [63]. MSWI ash was mostly used in the manufacture of clay and cement bricks and it is replaced for clay and cement. Generally, the durability of the bricks improved with MSWI ash addition [60, 66].

4. Conclusions

In this paper, the utilization of various industrial waste as construction materials has been discussed in detail. A lot of studies are carried out by using various wastes so that to prove that they can be sustainably utilized as construction material. Most commonly the industrial wastes are used in the construction of various types of concretes, brick, pavement material, etc.

- GGBS was found to be a good pozzolanic material and its replacement for cement up to 30% improves the durability properties of concrete.
- The GGBS addition gives good strength, better resistance to concrete and also it provides stiffness to concrete beam when replaced up to 70%.
• The paper sludge finds its application in manufacturing of bricks and when replaced at 10% & fired at controlled temperature it meets the brick quality standard.

• The SBA is a powdered waste that finds its application in both concrete and also in bricks. The mechanical property of concrete gets improved when SBA is replaced at 20-25% whereas in bricks the optimal replacement of 10-20% imparts additional strength.

• Copper slag was found to be used in various percentage replacement in concrete and it has been proven effective to be used as fine & coarse aggregate in concrete.

• The copper slag addition of 40-60% improves the mechanical and durability properties of normal concrete and it also finds its application in special concretes too.

• The MSWI ash is used as replacement material both in clay and cement bricks and when utilized in manufacturing the bricks it meets the brick quality standard. The mechanical property of bricks with MSWI ash up to 40% was found optimal in an average.

• The MSWI ash should be treated by TCLP test in order to remove the toxic contaminants and then it is suitable to use in bricks at various percentage replacement.

From the above discussion it is evident that industrial wastes whichever is suitable can be used in construction material so that over use of natural resource can be prevented and also the waste disposal cost can be saved thus reducing the cost of the construction materials.

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