Properties of concrete containing industrial waste as a fine aggregate: A review

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Abstract- This paper presents a discussion of work reported on properties of concrete prepared using industrial wastes as partial replacement of fine aggregate. Industrial wastes such as waste generated during mining and dressing of marble and granite; refining of zinc and lead waste i.e. jarosite, WFS (Waste Foundry Sand), broken glass waste, ISF (Imperial Smelting Furnace) slag, and Waelz slag as fine aggregate have been studied. The effect of these materials on compressive strength, flexural strength, water absorption, carbonation, sulphate resistance, chloride resistance and freeze thaw resistance were studied. The review of reported results indicated that the particle size distribution of industrial waste significantly influences the properties of fresh and hardened concrete. It was observed that replacement of natural fine aggregate with an industrial waste possessing particle size proximal to that of natural sand does not significantly alter the properties of concrete. Moreover, it was observed that waste materials that are finer than natural sand may have a negative effect on the properties of concrete. Majority of the waste materials indicated comparable to control compressive/flexural strength, resistance to water absorption, carbonation, sulphate attack, chloride ion permeability, and freeze-thaw properties of concrete containing waste materials as replacement of fine aggregate.

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1. Introduction

Economic and the demographic changes across the world have resulted in extensive infrastructural development raising the production of concrete to 12 billion tonnes per year [1]. This has led to exploitation of constituent materials namely, cement, sand, and aggregates. In 2015, the United Nation General Assembly had set 17 sustainable development goals and stated, responsible consumption and production as one of the goals to be achieved by 2030. Therefore, exploring alternative concrete materials ingredients is the need of the hour.

Researchers have explored the possibility of utilizing industrial wastes as constituent material in concrete. It is estimated that 27 billion tonnes of solid waste would be generated annually
worldwide by 2025 [2]. This estimate includes residential, commercial, institutional, industrial and construction and demolition waste. In India, the total municipal solid waste has been estimated at 85 million tonnes per year [3]. This paper presents a review of reported work on concrete containing different types of industrial wastes as fine aggregate in concrete.

2. Industrial waste generation and the related environmental issues

The industrial wastes such as marble and granite processing waste, WFS (Waste Foundry Sand), waste glass, jarosite, ISF (Imperial Smelting Furnace) slag, and Waelz slag have been used as partial replacement of fine aggregate in concrete [4-24].

The problem of marble waste is evident in China, India, Italy, Iran and Turkey. It is reported that the quantity of marble waste in Italy and Turkey is 6 million tonnes and 1 million tonnes per year, respectively [25-27]. In India, 5-6 million tonnes of marble waste is produced per year in the form of slurry [28]. Similarly, the granite production which is estimated at 90000 tonnes produces mining and processing waste in the form of granite sludge [29]. Approximately 65% of the total production of granite is wasted as granite sludge [14].

Jarosite is a powdered waste material generated during mining of lead and zinc from the sulphite ore using hydrometallurgical process. In India, state of Rajasthan is endowed with largest resources of Lead and Zinc amounting to 607.53 million tonnes [30]. HZL (Hindustan Zinc Limited) is the leading Lead and Zinc producer in the country operating at Udaipur and Rajsamand district of Rajasthan. ISF slag is generated during extraction of Zinc from sulphite ore by pyro-metallurgical process. The annual production of ISF slag is approximately one million tonnes [31], globally and 720000 tonnes in India [32]. Around 65000 tonnes of ISF slag has been reported to be stockpiled in Rajasthan [11].
The waste produced during recovery of zinc from Electric Arc Furnace is called Waelz slag. The annual global production of Waelz slag has been estimated around 800000 tons [33]. Disposal of jarosite, ISF slag, and Waelz slag is difficult due to the presence of lead, sulphur, cadmium, copper, and chromium.

WFS is a by-product from the production of ferrous and non-ferrous metal castings. The United States and India produces approximately 10 million tonnes and 2 million tonnes of WFS every year [8,34]. Foundry industry effectively recycles and reuses the foundry sand in the casting process until it is usable. The constituents of foundry sand vary depending on type of binder used. Further, the known contaminants in WFS are metals and organic compounds such as phenols and acetone [35].

Various researchers have reported effective utilization of glass in concrete [6, 21]. In 2015, 11.47 million tons of glass waste was generated in the United States [36]. In India more than 1.3 million tons of glass waste is generated every year [37]. Glass being rich in silica can be effectively used in concrete as a replacement of either cement or fine aggregate, eliminating the burden on the existing landfills.

3. Properties of industrial wastes

The gradation analysis of industrial wastes used in different studies revealed that either the particle size of the material was very fine or somewhat similar to that of fine aggregate. Waste marble used by Aliabdo et al. [13] consisted of 100% of material finer than 90 µm. Vijaylakshmi et al. [10] and Singh et al. [14] used granite waste finer than 300 µm. Mehra et al. [16] used jarosite having particle size in the range of 1 µm-100 µm. Singh and Siddique [8] used very fine WFS having $d_{50}$ value of 33 µm.

Vardhan et al. [23] used marble waste conforming to zone-III of fine aggregate, having fineness modulus value of 2.23. The particle size of granite waste used by Ghannam et al.
[15] conformed to zone IV of fine aggregate. Basar and Aksoy [9] used WFS having particle size distribution conforming to zone III of fine aggregate respectively. Tripathi and Chaudhary [18] and Morrison et al. [4] used ISF slag conforming to zone-I and zone-II of fine aggregate, respectively. Quijorna et al. [38] reported gap graded Waelz slag having coarser particle size.

For the glass to be used as fine aggregate in concrete it needs grinding therefore the particle size depends on the grinding technique and desirable particle size. Kim et al. [21] used waste glass having particle size in the range of 250 µm–4 mm and fineness modulus of 3.34 whereas Chen et al. [6] used glass waste having particle size in the range of 38 µm–300 µm and fineness modulus of 0.94. Although the risk of alkali-silica reaction has been reported with use of glass waste in concrete, however, Chen et al. [6] reported that expansion due to alkali-silica reaction was less than 0.10% which is within the acceptable limits.

The physical properties (specific gravity and density) and chemical composition of different industrial wastes are given in Table 1 and 2, respectively. Gupta and Vyas [39] and Basar and Aksoy [9] have reported bulk density of granite waste and WFS, attributing to large difference in density as compared to materials used in other studies.

### Table 1. Specific gravity and density values of different industrial wastes

| Replacement Material | Specific Gravity | Density (kg/m³) | References |
|----------------------|------------------|-----------------|------------|
| Marble waste         | 2.50             | 2690            | [14]       |
| Marble waste         | 2.88             | -               | [23]       |
| Granite waste        | 2.46             | 1368            | [39]       |
| Granite waste        | 2.53             | -               | [15]       |
| WFS                  | 2.18             | -               | [8]        |
| WFS                  | -                | 1160            | [9]        |
| Glass waste          | -                | 3000            | [21]       |
| Glass waste          | 2.56             | -               | [6]        |
| ISF slag             | 3.88             | -               | [4]        |
| ISF slag             | 3.69             | -               | [11]       |
### Table 2: Chemical properties of different industrial wastes

| Replacer material | Constituents (%) | References |
|-------------------|------------------|------------|
| Marble waste      | CaO 28.6, SiO2 4.6, Al2O3 0.2, Fe2O3 0.49 | [23] |
| Granite waste     | CaO 4.8, SiO2 64.5, Al2O3 12.01 | [15] |
| Glass waste       | CaO 10.8, SiO2 67.8, Al2O3 2.1 | [40] |
| WFS               | CaO 1.21, SiO2 81.8, Al2O3 10.4 | [9] |
| Jarosite          | CaO 2.80, SiO2 13.0, Al2O3 3.206 | [22] |
| ISF slag          | CaO 13.1, SiO2 17.0, Al2O3 6.84 | [18] |
| Waelz slag        | CaO 20.0, SiO2 8.97, Al2O3 2.91 | [41] |

4. **Compressive Strength**

The compressive strength of concrete was observed to be comparable to or better than that of the control on replacing fine aggregate with different types of industrial wastes. It was observed that the use of marble waste, granite waste, jarosite, WFS, ISF slag, Waelz slag, and glass waste had no negative impact on compressive strength.

The compressive strength improved up to 30% on replacement of fine aggregate with marble waste in the range of 15-100% [7,14,20,23]. Vijaylakshmi et al. [10] and Singh et al. [14] reported comparable values of compressive strength on adding 25% and 50% of granite waste, respectively. Ghannam et al. [15] reported significant improvement in compressive strength as compared to the control on 20% replacement of fine aggregate with granite waste.

The compressive strength of concrete was found to be comparable to control on replacement of fine aggregate with WFS up to 20% [8, 9]. Mehra et al. [16] reported 40% increase in compressive strength of jarosite added concrete with 25% replacement of fine aggregate. All these studies reported that this may be attributed to the pore filling effect of waste materials used in the study and improvement of the interstitial transition zone (ITZ). In addition to this, Vardhan et al. [23] stated that the calcite present in marble waste reacts with C3A present in
cement resulting in the formation of Calcium Carbo-Aluminates which improves the binding capacity of mix and thereby forms a compact structure.

The Compressive strength of waste glass added concrete was observed to depend upon the fineness of glass waste used. Kim et al. [21] reported comparable to control values of compressive strength at 50% replacement and 26% decrease as compared to the control at 100% replacement. In contrast to this, Chen et al. [6] reported 17% increase in compressive strength on adding 40% glass waste as replacement of fine aggregate. It can be concluded that the particle size used by Chen et al. [6] being finer than that used by Kim et al. [21], both pozzolanic and hydration reactions might have occurred and resulted in increased compressive strength. Further, Kim et al. [21] reported that the reduction in strength may be due to poor adhesion of the glass particles to the cement paste owing to a smooth surface of glass particles.

Tripathi et al. [11] reported that compressive strength of concrete was comparable to control at w/c ratio of 0.55, 0.50, 0.45 and it improved by up to 16% as compared to the control at w/c of 0.40 on replacing fine aggregate by ISF slag in the range of 10-70%. Sorlini et al. [5] reported comparable to control values of compressive strength on replacing fine aggregate with Waelz slag up to 30%.

5. Flexural Strength

The results of flexural strength for all types of industrial wastes added concrete are in line with those of compressive strength. Ghanam et al. [15], Singh et al. [14] and Vijayakshmi et al. [10] reported comparable to control values of flexural strength in granite waste added concrete at 15-30% replacement. Kim et al. [21] reported comparable to control values of Flexural strength up to 100% replacement of fine aggregate with glass waste. Mehra et al. [16] reported 20% increase in flexural strength of jarosite added concrete on 25% replacement of fine aggregate. Tripathi et al. [11] reported comparable to control values of
flexural strength on 60% replacement of fine aggregate with ISF slag at w/c ratios of 0.55, 0.50 and 0.45, however, this improved slightly as compared to the control at w/c ratio of 0.40. Sorlini et al. [5] reported that flexural strength of Waelz slag added concrete remained comparable to control at all levels of replacement up to 30%.

6. Resistance To Water Absorption

Vardhan et al. [23] reported that the resistance to water absorption increased by 21% as compared to the control at 40% replacement of fine aggregate with marble waste. Vijaylakshmi et al. [10] and Singh et al. [14] reported comparable to control or slightly higher values of water permeability at all levels of replacement of fine aggregate with granite waste. Gurumoorthy and Arunchalam [19] reported that resistance to water absorption was comparable to control at 40% replacement of fine aggregate by WFS. In fact water absorption was less than 5% for all concrete mixes. In these studies neither plasticizer dosage nor the quantity of water was altered therefore it can be concluded that addition of marble waste, granite waste and WFS increases resistance to water absorption. Further, Singh et al. [14] did not observe any significant change in water absorption on adding 3% of water to obtain workable mix for concrete mixes containing granite waste as fine aggregate replacement.

Gameiro et al. [12] observed that resistance to water absorption by capillary action and immersion decreased up to 20% as compared to the control at 100% replacement of fine aggregate by marble waste. Basar and Aksoy [9] reported resistance to water absorption decreased by 32% on 40% replacement of fine aggregate by WFS. However, up to 20% replacement level it remained comparable to control. Therefore, it can be concluded that for mixes in which water quantity had been altered the water absorption resistance of concrete decreased. In contrast to this, the Mehra et al. [22] observed a significant increase of 58% and 25% in resistance to water permeability and water absorption, respectively, on replacement of
fine aggregate with 25% jarosite in combination with 20% replacement of cement with Fly ash as admixture. This may be attributed to increased hydration and dense particle packing due to the presence of jarosite and fly ash in the matrix.

Tripathi and Chaudhary [18] reported that water permeability remained comparable to control up to 60% replacement of fine aggregate with ISF slag at w/c of 0.55, 0.50 and 0.45, however it decreased with increasing ISF slag percentage up to 50% at w/c 0.40. Kim et al. [21] reported that the resistance to water absorption increased by 15% on 100% replacement of fine aggregate by glass waste.

7. Carbonation

Gameiro et al. [12] reported that resistance to carbonation decreased by 47% as compared to the control at 100% replacement of fine aggregate with marble waste after 91 days of exposure to CO₂. Vijaylakshmi et al. [10] reported that resistance to carbonation decreased considerably at 25% replacement of fine aggregate by granite waste after 180 days of exposure to CO₂. It may be concluded that resistance to carbonation for marble waste and granite waste added concrete decreased for the mixes in which no alteration in water and plasticizer quantity was made to achieve uniform workability. In contrast to this, Ashish [20] found that the resistance to carbonation increased by 53% at 10% replacement of fine aggregate with marble waste after 56 days of exposure to CO₂ having 4% concentration.

Tripathi and Chaudhary [18] reported that resistance to carbonation increased with decrease in w/c ratio up to 70% replacement of fine aggregate with ISF slag on 84 days of exposure to CO₂ having 5% concentration. Also, it remained comparable to control at 70% replacement. It was also observed that resistance to carbonation improved considerably up to 50% replacement with ISF slag. The resistance to carbonation increased by 44% on replacement
of fine aggregate by 25% jarosite after 100 days of exposure to CO₂ having 5% concentration [17].

8. **Resistance to Sulphate Attack**

Vijaylakshmi et al. [10] reported resistance to sulphate attack decreased considerably on 25% replacement of fine aggregate by granite waste after 180 days of exposure to sulphate solution. The study reported that the presence of impurities such as diesel, kerosene, and wax in granite waste might have increased sulphate activity in concrete. Gurumoorthy and Arunachalam [24] reported comparable to control resistance to sulphate attack at 40% replacement of fine aggregate with WFS. The resistance to sulphate attack was found to be comparable or slightly better than control at all levels of replacement of fine aggregate with waste glass [21]. It can be concluded that for the concrete mixes with no plasticizer and water quantity adjustment the resistance to sulphate attack was found to decrease or was similar to control.

9. **Resistance to chloride ion penetration**

Vardhan et al. [23] reported that resistance to chloride ion penetration increased by 30% on 60% replacement of fine aggregate by marble waste. Vijaylakshmi et al. [10] reported that resistance to chloride penetration remained comparable to control up to 15% replacement of fine aggregate with granite waste, however, it decreased considerably on further replacement of fine aggregate by granite waste. Singh and Siddique [8] reported that the resistance to chloride ion penetration increased by 20% on 20% replacement of fine aggregate by WFS. Kim et al. [21] reported 28% increase in resistance to chloride ion penetration at 100% replacement of fine aggregate by glass waste.

Tripathi and Chaudhary [18] observed that resistance to chloride ion penetration was comparable to that of control for all levels of replacement of fine aggregate with ISF slag up
to 70% at w/c of 0.5, 0.45 and 0.4. However, it decreased on replacing fine aggregate with ISF slag beyond 30% at w/c of 0.55.

Gameiro et al. [12] reported that resistance to chloride ion penetration remained comparable to control at all levels of replacement of fine aggregate by marble waste. The resistance to chloride ion penetration increased by 25% at 25% replacement of fine aggregate by jarosite [22].

10. Resistance to freeze-thaw

The average compressive strength of concrete samples made from marble waste replacement was found to be 60% more than that of control mix after 60 cycles of freeze-thaw [42]. The freeze-thaw resistance was comparable to that of control on all replacement levels of fine aggregate with glass waste [21].

11. Concluding remarks

This paper presented a comparison of properties of concrete consisting different types of industrial wastes such as marble and granite waste, jarosite, WFS, ISF slag, Waelz slag, and waste glass. The following conclusions can be drawn-

1. Compressive strength and flexural strength remained comparable or better than control for ISF slag and Waelz slag added concrete. In studies where no adjustment to workability was made by adding water on using marble waste, granite waste, WFS there was improvement in compressive and flexural strength. Similar results were obtained in the cases where change in superplasticizer dosage was made as in the case of jarosite.

2. The resistance to water absorption for industrial waste added was found to be comparable or better than control concrete, except for the cases where water content was increased to obtain a workable mix.
3. The resistance to carbonation for concrete containing most of the industrial wastes was found to be better than control concrete, except for granite waste added concrete.

4. The resistance to chloride ion penetration for industrial waste added concrete was found to be comparable or better than control concrete, except for granite waste added concrete.

5. There was no negative effect on freeze-thaw resistance of concrete on adding marble and glass waste as a replacement of fine aggregate.

Overall, it can be concluded that the particle size of industrial waste used as fine aggregate in concrete affects the workability of concrete which in turn affects the mechanical and durability properties of the concrete. The industrial wastes having particle gradations in close proximity to the natural fine aggregate exhibited comparable mechanical and durability properties in comparison to control concrete. The waste materials that possessed gradation finer than that of natural fine aggregate showed difference in results of the properties examined due to addition of on water for adjusting the workability of concrete mixes.

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References-
[1] Savadkoohi, M.S., and Reisi, M. (2020). “Environmental protection based sustainable development by utilization of granite waste in Reactive Powder Concrete.” Journal of Cleaner Production, 266, 121973.

[2] Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M.Z., and Christensen, T.H. (2014). “Review of LCA studies of solid waste management systems- part I: lessons learned and perspectives.” Waste Management, 34 (3), 573–588.

[3] Mir, I.S., Cheema, P.P.S., and Singh, S.P. (2021). “Implementation analysis of solid waste management in Ludhiana city of Punjab.” Environmental Challenges, 2, 100023.

[4] Morrison, C., Hooper, R., and Lardnera, K. (2003). “The use of ferro-silicate slag from ISF zinc production as a sand replacement in concrete.” Cement and Concrete Research, 33(12), 2085–2089.

[5] Sorilini, S., Collivignarelli, C., Plizzari, G., and Foglie, M.D. (2004). “Reuse of Waelz slag as recycled aggregate for structural concrete.” Conference proceedings on Use of Recycled Materials in Buildings and Structures, RILEM, Barcelona, Spain, 1086-1094.

[6] Chen, C.H., Huang, R., Wu, J.K., and Yang, C.C. (2006). “Waste E- particles used in cementitious mixtures.” Cement and Concrete Research, 36, 449-456.

[7] Heboub, H., Aoun, H., Belachia, M., Houari, H., and Ghorbel, E. (2011). “Use of waste marble aggregates in concrete.” Construction and Building Materials, 25, 1167-1171.
[8] Singh, G., and Siddique, R. (2012). “Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete.” Construction and Building Materials, 26, 416-422.

[9] Basar, H.M., and Aksoy, N.D. (2012). “The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete.” Construction and Building Materials, 35, 508-515.

[10] Vijaylakshmi, M., Sekar, A.S.S., and Prabhu, G.G. (2013). “Strength and durability properties of concrete made with granite industry waste.” Construction and Building Materials, 46, 1-7.

[11] Tripathi, B., Misra, A., and Chaudhary, S. (2013). “Strength and abrasion characteristics of ISF slag concrete.” Journal of Materials in Civil Engineering, 25, 1611–1618.

[12] Gameiro, F., Brito, D.J., and Silva D.C. (2014). “Durability performance of structural concrete containing fine aggregates from waste generated by marble quarrying industry.” Engineering Structures, 59, 654-662.

[13] Aliabdo, A.A., Elmoaty M.A., and Auda, E.M. (2014). “Re-use of waste marble dust in the production of cement and concrete.” Construction and Building Materials, 50, 28-41.

[14] Singh, S., Khan, S., Khandelwal, R., Chugh, A., and Nagar, R. (2016). “Performance of sustainable concrete containing granite cutting waste.” Journal of Cleaner Production, DOI- 10.1016/j.jclepro.2016.02.008.
[15] Ghannam, S., Najm, H., and Vasconez, R. (2016). “Experimental study of concrete made with granite and iron powders as partial replacement of sand.” Sustainable Materials and Technologies, 9, 1-9.

[16] Mehra, P., Gupta, R.C., and Thomas, B.S. (2016). “Properties of concrete containing jarosite as a partial substitute for fine aggregate.” Journal of Cleaner Production, DOI: 10.1016/j.jclepro.2016.01.015.

[17] Mehra, P., Gupta, R.C., and Thomas, B.S. (2016). “Assessment of durability characteristics of cement concrete containing jarosite.” Journal of Cleaner Production, DOI: 10.1016/j.jclepro.2016.01.055.

[18] Tripathi, B., and Chaudhary, S. (2016). “Performance based evaluation of ISF slag as a substitute of natural sand in concrete.” Journal of Cleaner Production, 112(1): 672-683.

[19] Gurumoorthy, N., and Arunachalam, K. (2016). “Micro and mechanical behaviour of Treated Used Foundry Sand concrete.” Construction and Building Materials, 123, 184-190.

[20] Ashish, D.K. (2018). “Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth.” Journal of Building Engineering, 15, 236-242.

[21] Kim, S., Choi, S.Y. and Yang, E.I. (2018). “Evaluation of durability of concrete substituted heavyweight waste glass as fine aggregate.” Construction and Building Materials, 184, 269-277.

[22] Mehra, P., Kumar, S., Thomas, B.S., and Gupta, R.C. (2018). “Analysis on hazardous jarosite added concrete.” Construction and Building Materials, 191, 153-159.
[23] Vardhan, K., Siddique, R., and Goyal S. (2019). “Strength, permeation and micro-structural characteristics of concrete incorporating waste marble.” Construction and Building Materials, 203, 45-55.

[24] Gurumoorthy, N., and Arunachalam, K. (2019). “Durability Studies on Concrete Containing Treated Used Foundry Sand.” Construction and Building Materials, 201, 651- 661.

[25] Singh, M., Chaudhary, K., Srivastava, A., Sangwan, K.S., and Bhunia, D. (2017). “A study on environmental and economic impacts of using waste marble powder in concrete”, Journal of Building Engineering, DOI- http://dx.doi.org/10.1016/j.jobe.2017.07.009

[26] Tunc, E.T. (2019). “Recycling of marble waste: A review based on strength of concrete containing marble waste.” Journal of Environmental Management, 231, 86-97.

[27] Bostanci, S.C. (2020). “Use of waste marble dust and recycled glass for sustainable concrete production.” Journal of Cleaner Production, 15, 236-242.

[28] Indian Bureau of Mines (IBM). (2018). “Indian Minerals Yearbook 2016: Marble.” 55th edition, Ministry of Mines, Nagpur, India.

[29] Indian Bureau of Mines (IBM). (2018). “Indian Minerals Yearbook 2016: Granite.” 55th edition, Ministry of Mines, Nagpur, India.

[30] Indian Bureau of Mines (IBM). (2015). “Indian Minerals Yearbook 2016: Lead and Zinc.” 52nd edition, Ministry of Mines, Nagpur, India.
[31] Alex T.C., Kalinkin, A.M., Nath, S.K., Gurevich, B.I., Kalinkina, E.V., Tyukavakina and Kumar, S. (2013). “Utilization of zinc slag through geopolymerisation: Influence of milling atmosphere.” International Journal of Mineral Processing, 123, 102-107.

[32] Prasad, P.S., and Ramana, G.V. (2016). “Imperial smelting furnace (zinc) slag as a structural fill in reinforced soil structures”, Geotextiles and Geomembranes, 44, 406-428.

[33] Mombelli, D., Mapelli, C., Barella, S., Gruttadauria, A., and Liandro U.D. (2014). “Laboratory investigation of Waelz slag stabilization.” Process Safety and Environmental Protection, DOI: http://dx.doi.org/10.1016/j.psep.2014.06.015.

[34] Siddique, R., Schutter, G. D., and Noumowe, A. (2009). “Effect of used-foundry sand on the mechanical properties of concrete.” Construction and Building Materials, 23, 976–980.

[35] United States Environment Protection Agency (USEPA). (2002). “Beneficial Reuse of Foundry Sand- A Review of State Practices and Regulations.” Washington D.C., USA.

[36] United States Environment Protection Agency. (USEPA). (2018). “Advancing Sustainable Materials Management: 2015 fact sheet.” Washington D.C., USA.

[37] Nandy, B., Sharma, G., Garg, S., Kumari, S., George, T., Sunanda, Y., and Sinha, B. (2015). “Recovery of consumer waste in India – A mass flow analysis for paper, plastic and glass and the contribution of households and the informal sector.” Resources, Conservation and Recycling, 101, 167- 181.
[38] Quijorna, N., Coza, A., Andresa, A., and Cheesemanb, C. (2012). “Recycling of Waelz slag and waste foundry sand in red clay bricks.” Resources, Conservation and Recycling, 65, 1-10.

[39] Gupta, L.K., and Vyas, A.K. (2018). “Impact on mechanical properties of cement sand mortar containing waste granite powder.” Construction and Building Materials, 191, 155-164.

[40] Xuan, D., Tang, P., and Poon, C.S. (2019). “MSWIBA-based cellular alkali-activated concrete incorporating waste glass powder.” Cement and Concrete Composites, 95(1), 128-136.

[41] Munoz, I., Cifrian, E., Andres, A., Miguel, G.S., Ruiz, D., and Viguri, J.R. (2018). “Analysis of environmental benefits associated with the incorporation of Waelz slag into fired bricks using LCA.” Construction and Building Materials, 168, 178-186.

[42] Binici, H., and Aksogan, O. (2018). “Durability of concrete made with natural granular granite, silica sand and powders of waste marble and basalt as fine aggregate.” Journal of Building Engineering, 19, 109-121.