Critical review on the Solid-wastes issue: Generation, Composition, Disposal and their recycling potential for various applications

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Abstract. In sixty-five years, merely nine percent of plastic waste was recycled and reused, twelve percent was incinerated, and the remaining seventy-nine percent has built up in landfills or ended up elsewhere in the environment. Statistically, the remaining seventy-nine percent of plastic wastes can be recycled in more than five-hundred years. Building and construction material is expensive due to the demand of the growing population with a low supply of the materials. To address this, the usage of solid-wastes for the manufacture of bricks and other building materials is an ideal-optimal approach towards tackling the challenges of handling waste-products as well as optimizing the production-cost of construction materials. Subsequently, plastic bottles, plastic containers, and plastic bags are flexible and possesses several characteristics includes good versatility, hardness, lightness, and resistance to chemicals and water and impact which can be heated and reshape to form a building material. Thus, this review briefly focusses on the possibility of utilizing non-hazardous wastes such as plastic wastes, glass bottles, and other solid-industrial wastes in making effective and quality sand brick as substitute for expensive building material. This study is also aimed at educating the engineering public and professionals on the importance and necessity of waste management, reuse and recycling and also awareness on the benefits of conserving our environment through the reuse and utilization of waste within it. The review helps to identify the different types of wastes with potential of utilization towards construction and several key research factors and criteria which can provide focus and direction towards the choice of wastes-type to be used and ensuring that they have utilization potentials in the various value-addition applications. The piling of such wastes poses an environmental problem often on account of chemicals which the ecosystem has never been used to. These affect its proper functioning and in turn at the global level, are likely to affect even the stability of biosphere. The pool of information on Solid Wastes generation, disposal and management is increasing each year. A comprehensive review of available literature regarding Solid Wastes generation, disposal and management has been presented in this article.
1. Introduction
Today, many favorable circumstances exist for the useful and beneficial reduction of waste that might have been disposed in our environment but thanks to those recycling, reuses and construction base recovery of waste and the systems that allows such to be feasible. Professionals and management of the Construction industries instructs and train craftsmen to learn how to reuse waste produce in the construction sites so that they never even leave the site as waste. There are many economically feasible means of reusing of waste as construction material which can promote environmental well-being and health in general with the employment of the most appropriate means of waste reduction methods for total waste disposal after reuse is complete.

By the early twentieth century, it was clear that the Dilute and Disperse strategy had reached its practical limits and a new concept was introduced- “Concentrate and Contain” strategy. The relatively modern concept of Concentration and Containment is to collect Solid Waste and then permanently isolate it from the rest of the environment. Sanitary landfills and Hazardous and Radioactive Waste disposal sites are tangible expressions of the Concentration and Containment strategy of Solid Waste Management. Often the Dilute and Disperse and Concentrate and Contain strategies are used in tandem, as in some incinerator operations [1].

Rubbish may be burned in an incinerator, dispersing into the atmosphere a good percentage of its original volume (60% or more), but the remaining bottom ash and collected fly ash constitute a highly concentrated, and often toxic Solid Waste product that must be isolated from the environment, usually by being permanently contained in a specially designed landfill. There are numerous problems associated with the Concentrate and Contain strategy, especially as it is applied to modern Industrial Wastes. Many Modern Solid Wastes are synthetic or artificial in nature are extremely hazardous, especially in concentrated form. Yet we have learned from experience that perfect Containment is very difficult to achieve. Besides these practical problems, Containment is also subject to deeper criticisms. Is it fair and right for one generation to use resources for its own advantage and then remove them forever from use at the expense of all future generations? It can be strongly argued that ethically we should not be depriving future generations of valuable material resources by converting those materials into hazardous or toxic Waste that must be taken out of circulation permanently [1]. As a result of such considerations, a third strategy toward Solid Waste Management has been promoted, variously referred to as “Resource Recovery”, “Industrial Ecosystems”, “Sustainable Solid Waste Management” and most optimistically “Resource Management”. The basic philosophy underlying this strategy is that there should be no such thing as material waste, although the energy powering the system may product waste heat under Sustainable Solid Waste Management, unnecessary waste is first reduced at source. Once materials (goods) are used for the designated purpose, all remains are reused or recycled. At the moment, however, we are a long way from achieving this goal. Even if the best reuse and recycling programmes currently available were put into place globally, human-produced Solid Waste would still exist. But in the future, there may be no such things as waste- Only Potential Resources. Even our Twentieth century dumps and landfills may be viewed as Raw Resources (antique “Urban Ore”) by the planners of the Twenty first century. Until that day comes, however, we will have to continue to address the question of Solid Waste Management [1].

Solid Wastes, which arise from virtually all man’s activities, can be classified conveniently with respect to their source. Major categories include Household and Consumer Wastes (i.e., Municipal Solid Wastes); Industrial Wastes, Agricultural Wastes, Extraction Wastes, Energy Production Wastes and Sewage Sludges. Solid Wastes can be classified by hazard and by composition. Information on Solid Waste arising, particularly on Industrial and Hazardous Wastes, is often difficult to assemble. Inefficient data collection methods, infrequency of surveys, reluctance of industry to supply information and confusion over definitions of Hazardous Wastes-are all contributory factors. Generally speaking, Municipal Solid Wastes (in terms of mass) are a relatively small part of total Solid Waste arising when
compared with other kind of Solid Wastes but its study is must because it is closer to the public and affect them at large than others. However, the relative importance of the source categories for Solid Wastes largely depends on the economic base [2-3].

Not all the components of Solid Waste are valuable. Some are useful and others are toxic e.g. Selenium, a poisonous element that occurs naturally in the soil is taken up by plants that are used for making paper and is present in newspaper in the amount of about 8.6 ppm, this element is found in incinerator stock gas, raw Solid Wastes, incinerator residue and in water that has been used for removing fly ash. Many other toxic chemicals of various kinds and amounts are present in Municipal and Industrial waste [4].

Today, the disposal of garbage and other Solid Wastes appears to be much simpler. Urban dwellers merely place them in bags or other containers, put these in garbage cans and have then picked up by a public or private collection agency. Only when one passes an open dump or sees a landfill outside a big city at outer ring road, real magnitude of the Solid Waste problem becomes apparent [5].

Waste materials are a major environmental problem, which is a threat to the environment. It is important to reuse these materials and dispose of them. Waste can be used in the construction industry in two ways: by reusing (reuse components) and recycling (processing waste into raw materials used in the production of building materials). Overtime, the cost of our day to day construction materials has increasing rapidly and it is still continually increasing day by day due to the high demand and raw material scarcity, the factor that influence these changes in price is mostly the high cost of energy today. From the point of view of energy conservation and natural resources conservation, there is a rapidly growing concern on the use of alternative components for materials used in construction. For this reason, the scientific and technological professionals now are involved in many different extensive researches to develop alternative materials for construction especially using waste as raw materials towards the development of environmentally friendly materials for the construction industries and the production of sustainable non-polluting materials for construction [6].

Hilary et. al (1992) Industrial growth has increased the volume of wastes generated from energy production, mining, industrial processes and civil works. For economic and related reasons, the use of waste materials in construction as partial or full replacements for conventional geo-materials has increased. This proceedings, Utilization of Waste Materials in Civil Engineering Construction, consists of papers that discuss policy issues, current practices, performance requirements, engineering characteristics and the potential uses of a wide variety of waste materials in geotechnical systems, highway pavements and construction products [7].

Around the world, waste generation rates are rising. In 2016, the world’s cities generated 2.01 billion tons of solid waste, amounting to a footprint of 0.74kg per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 70% from 2016 levels to 3.40 billion tons in 2050. Managing waste properly is essential for building sustainable and livable cities, but it remains a challenge for many developing countries and cities. Effective waste management is expensive, often comprising 20-50% of municipal budgets [8]. The United States Environmental Protection Agency (2015) reports that the total generation of municipal solid waste in 2015 was 262.4 million of which some were recycled. The recycled waste was 67.8 million tons, with paper and paperboard accounting for approximately 67% of that amount [9]. Metals comprised about 12%, while glass, plastic and wood made up between 4 and 5%. Waste generation in sub-Sahara Africa is approximately 62 million tons per year. Per capita waste generation is generally low in this region, but spans a wide range, from 0.09 to 3.0kg per person per day, with an average of 0.065kg per capita per day. The countries with the highest per capita rates are islands, likely due to waste generated by the tourism industry, and a more complete accounting of waste generated [10]. The primarily objective of this review is the necessity of utilizing the solid-wastes in Construction as there is an expression for long that says “killing two birds with one stone”. Well here is where it applies in our research today, here investigators are focusing on using waste as a primary or secondary material in our construction, because our environment is full of waste today considering the new innovative ways of production is increasing day by day and its waste after use is posing danger to our health and the environment. But by utilizing
waste in construction we can be able to achieve two things at the same time, one is, to reduce the concentration of waste in our various environments and the second is, to produce or construct a structure of high performance with waste-base materials as long as they are thoroughly tested and sometimes stabilized to produce an excellent material that can withstand the test of time.

Since the industries cannot stop or reduce their production, there is always something has to be done in order to minimize the waste concentration in environment and today the most professional way to do that is by utilizing those waste and putting them to use [11-12]. Today management of waste has become very essential aspect of our sustainable development and building. In this circumstance, waste management means eliminating waste where possible and ensuring that it is minimize where feasible. The following categories of waste are the most suitable types of waste to be used in the construction industries as mentioned-follows,

Agricultural Waste: The organic agricultural waste products have high utilization potential. Organic Agricultural waste like wheat straw, cotton stack, vegetable waste, groundnut shells, orange peels, wheat husk are some good examples.

Mineral Waste: The products of mining also produce waste that a suitable and having the potential of utilization in construction, waste like washeries of coal, iron mining waste etc.

Ceramic-like Waste: These are non-hazardous waste and they make good construction material. Ceramic-like waste can be found in form of lime sludge, broken glass, broken ceramic materials, kiln dust etc.

Industrial Waste: These are the inorganic waste from industries only and they include steel slag, bauxite, residues of coal combustion etc.

Other Hazardous Waste: Other Industrial or Workshop base waste that are hazardous in nature like metal working residues, blasting waste, tannery waste, waste water sludge etc. also has a high potential of utilization in construction.

2. Literature review:

2.1. Generation, Composition and Disposal of Solid-wastes:
Waste treatment, such as incineration and permanent disposal in landfills are on the bottom of many people’s Waste Management Hierarchy. Due to the air pollution and other dangers inherent in some forms of incineration, some environmentalists contend that land filling and other forms of permanent storage should be placed before incineration in the hierarchy. In contrast, many proponents of the “Waste-to-Energy” industry argue that incineration should be much higher on the hierarchy than it already is Waste-to-Energy incineration plants are touted as a form of “recycling”-heat from burning trash is converted to usable energy. Other people suggest that the whole nation of a “Waste Management Hierarchy” is counter productive. They argue that individual communities should be allowed to pursue an “integrated approach” to Waste Management, choosing the technologies that best suit local need. A strong argument against this line of thinking is that Waste Management is no longer simply a local problem. The world must soon begin addressing this issue in concert if we are not to be overwhelmed by trash and pollution on the land, in our waters and in the world’s atmosphere.

Beside the Municipal Solid Waste that is organic and inert in composition, the hospital waste, which contains germs of contagious diseases, is not disposed off properly. Very few hospitals have incinerators, which either remain out of order or are not used. As a result, the hospital waste is thrown outside the hospitals and finally this waste finds its way into Municipal Solid Waste system and gets disposed off with the other wastes causing serious environmental problems [13].

Air samples taken from Municipal incinerators and Municipal compost plants show that the potential health hazard from pathogens associated with dust has been somewhat significant. The dust was found to carry a large number of microorganisms including pathogens of intestinal and respiratory infections. The degree of hazard is dependent on the concentration of dust and on the type of organism carried [14].

As the hospital wastes are categorized under the hazardous waste, therefore the toxic hospital wastes are disposed off according to regulations for handling of the hazardous waste given under Environment
Protection Act (1987). The toxic hospital wastes must be collected by worker, which is trained to handle hazardous waste. The hazardous and infectious waste material must be segregated from the non-hazardous and non-infectious wastes and the treatment of the waste must be undertaken. Various treatment methods like use of incinerators, autoclaving, microwaving, chemical treatment and disposal in secured landfills are commonly practiced by some hospitals. The use of incinerators has said to reduce the volume of waste by 60-80% thereby reducing the public health hazards.

In 1995, incinerators were considered to be an easy solution for solving the medical waste problem. But in 1998, anti-incinerator campaign had taken shape in the wake of knowledge about disadvantages in incinerators. Installing of incinerators is not an easy way-out in countries like India. A single incinerator cost in Rs. Lakhs. Beside this, the P.V.C. (Polyvinyl chloride) and thermocoal waste in the hospital waste produces various carcinogenic dioxins and fumes into the atmosphere [15].

The piling of such wastes poses an environmental problem often on account of chemicals which the ecosystem has never been used to. These affect its proper functioning and in turn at the global level, are likely to affect even the stability of biosphere.

The pool of information on Solid Waste generation, disposal and management is increasing each year. A review of available literature regarding Solid Waste generation, disposal and management has been presented.

Hoffman (1968) suggested the use of pyrolysis for the disposal of Solid Municipal Wastes [17].

Klee (1969) while discussing tactics and strategies to tackle Solid Waste Management in Ohio-reported that workers in the field of the Management of Solid Wastes were frequently overwhelmed by a plethora of Management terms, systems, analysis, operation, research, cost-benefit analysis etc [18].

Hershaft (1972) reported that advances in research of Commercial Solid Waste handling offer many processing choices and has an era of sophistication in Solid Waste Management [19].

Schaefer (1975) suggested the disposing of Solid Waste by pyrolysis in which waste is subjected to heat that dries the organic materials and converts them to gases and carbon [20].

Wilson (1976) reviewed the history of Solid Waste Management in Western hemisphere [21]. De Renzo (1977) developed an equation to theoretically predict the quantity of methane produced from the chemical combustion of waste and also suggested that anaerobic decomposition of Solid Waste is a method of waste disposal, which leads to almost total environmental pollution control [22].

Wilson (1977) reported that methane produced during anaerobic decomposition of Solid Waste in landfill, defused readily and was explosive at atmospheric- pressure in concentration 5-15% by volume. Therefore, its movement must be controlled particularly if settlements are located nearby [23].

Barnhart (1978) highlighted the problems and solution of the disposal of hazardous wastes in U.S. [24]. Wilson (1981) reported that all human activities give rise to residual materials which are not of immediate use where they arise and suggested that these residuals may by recycled, reclaimed or reused; otherwise they constitute waste which will ultimately be released to the environment [25].

Cointreau (1982) reported that per capita generation of Municipal Waste varies between 2.75- 4.0 kg/day in developing countries and it is about 500 gm/day in developed countries [26].

Cook and Kalbermatten (1982) observed that decomposable organic matter was the highest component (60-85%) of the Municipal Solid Waste and this waste besides, emitting bad odour act as ground for breeding and proliferation of undesirable and disease-causing life forms [27].

Bhide (1984) observed that difference in collection and disposal practices, geographical situation, seasonal variation in waste production and characteristics including standard of living and economic conditions affect the waste characteristics [28].

Nath (1984) reported that in the urban areas of India, about 1600-1800 tonnes of refuse were collected per day and 90% of this was disposed off in sanitary landfills. The average cost of disposal of Solid Waste by this method was found to be Rs.10 per tonne [29].

Krishan Murti (1988) suggested that it is important to evaluate ecological risks associated with hazardous waste disposal sites. Ecotoxic effect on terrestrial and aquatic flora and fauna should be evaluated with special emphases on endangered species and sensitive ecosystem [30].
Shen and Sewell (1988) reviewed the problem of volatile organic emissions (VOC) from Waste Management facilities like treatment, storage and disposal [31].

Ultrich (1989) reported that the reuse of salvageable waste material was commonly regarded as an appropriate way to protect environment and conserve resources. He highlighted that about 2% of the gainfully employed population make their living by collecting, sorting and using or selling salvageable material from reuse [32].

Freeman (1990) stressed that Waste Management should be seen as one aspect of integrated strategy to conserve natural resource and energy, and to produce pollution [33].

Olaniya et al. (1991) studied the effects of Solid Waste disposal on land and observed that most of the metals are retained on top soil and the concentration decreases with increase in depth. Fulvic acid and Lumic acid played a major role in the migration of metals. They concluded that the application of compost and sewage sludge increase the organic matter in the soil which helped to maintain the soil productivity, but the waste percolating from such soils added inorganic ingredients as chloride, sulphates and nitrates and metals to ground and sub-soil water [34].

Sandwar (1991) discussed in detail the hazardous Waste Management practices which were followed to regulate the handling and disposal of hazardous wastes in India. They also discussed the categorization and sources of hazardous wastes and harmful effect of such wastes on human health in India [35].

Trehan (1992) pointed out that with the increasing economic activities and technological development to fulfill the need and greed of poor and riches respectively, production of Municipal Solid Waste was increasing much faster than the previous decades in a similar stage of economic development [36].

Varadarajan and Viraraghavan (1992) reviewed sampling, analysis and management procedure for Municipal Solid Waste [37]. Alagappan (1993) stressed on the recycling of waste and source separation and also reviewed recyclable potential of paper, plastic, aluminum, glass and role of ragpickers in recycling waste [38].

Foley et al. (1993) while discussing the recycling and management of Solid Waste in urban areas reported that the largest portion of Municipal Solid Waste was collected in regular trash pickups from residences, business and institutions. The recycling of household and other Municipal Waste has become a common activity in many communities, resulting in rapidly growing segment of the Waste Management industry [39].

Rao and Shantaram (1993) while studying the physical characteristics of urban Solid Waste generated in Hyderabad city, observed that paper, metals, plastics and glass were low in wastes at landfill sites and the weight volume relationship of refuse varied from 265.0 to 480.0 Kgm$^3$ [40].

Bhiday (1994) reported that Indian cities and rural areas produced nearly 7000 million metric of organic waste which was either burnt or landfilled [41].

Jain and Kuniyal (1994) reported that the Solid Waste Management problem in the Himalayan regions was centered on the tourist spots and observed that both religious and recreational tourists’ resorts were becoming polluted by Solid Wastes due to inadequate infrastructural carrying capacity [42].

Khan (1994) highlighted the problem of Municipal Solid Waste generation in India in the context of population growth in urban areas and emphasized on the sound Waste Management strategy which should include waste minimization, recovery, recycling and reuse. The examiners also mentioned the legal framework existing in India for collection, treatment and disposal of urban Solid Wastes [43].

Moghissi (1994) highlighted the need of recycling of waste as need of hour and for recycling, the cost of disposal of all goods must be calculated and accounted for. Furthermore, the impact of production, use and disposal of the article must be assessed [44]. Shah (1994) observed that 90% of total waste generated was disposal off by landfill method and remaining by incineration. Landfill method was not favorable due to contamination of ground water and explosion because of landfill gas. He suggested that by recycling, waste can be used to produce similar product or by combustion waste energy can be generated [45].
Singh et al. (1994) reviewed the present status and development in disposal of plastic waste along with its prospects in building and construction industry [46].

Chakrabarty et al. (1995) discussed Solid Waste disposal methods like sanitary landfill, incineration, composting on the basis of environmental costs. They laid down emphasis on the method of anaerobic decomposition which proved to be environment friendly and lead to energy recovery [47].

Kuniyal et al. (1995) reported the problem of Solid Waste Management in the pocket patches of tourist or trekking/expedition areas of Himalayan region. Due to inadequate infrastructures carrying capacity, the religious and recreational tourist resorts of area were going to be extensively polluted by Solid Wastes [48].

Saini and Dadhwal (1995) reported the production of Solid Waste from a number of health care units in Chandigarh and observed generation of 3.5 kg/day/bed from hospitals, 1.0 kg/day/bed from nursing homes and laboratory or dispensary [49].

Bhoyar et al. (1996) while discussing the Municipal and Industrial Solid Waste Management in India, reported that Municipal agencies used to carry out Solid Waste Management by spending about 5.25% of their total budget. They described and identified shortcomings in the various aspects of Solid Waste Management, viz. collection, transportation and disposal in India cities based on extensive study carried out by NEERI during 1970-94. They suggested that the knowledge of the characteristics and quantity of Solid Waste must be known prior to designing and monitoring the performance of various sub-systems of Solid Waste Management [50].

Jain et al. (1996) while studying Solid waste Management in Mohali, observed that on an average 427 gm/day/household and 5 tonnes per day of Solid Waste was generated and there were no Municipal mechanisms for waste collection, transportation and disposal [51].

Karthikeyan (1996) highlighted some problems and perspectives of Solid Wastes Management in urban area [52].

Khandelwal (1996) presented the overview of the National projects’ taken by the Ministry of Non-Conventional Energy Sources (MNES) and the Indian Renewable Energy Development Authority (IREDA) to promote harnessing of wealth from wastes. They conclude that these initiatives taken by MNES and IREDA for promotion of bio-methanation technology to generate energy from human waste, sewage, garbage, slaughter-house waste, vegetable market waste etc. were expected to attract private participation in its direction [53].

Menon et al. (1996) reported that large number of medical items like disposable syringes, used bandages, surgical gloves, blood bags, catheters and intravenous tubes which were ideally meant to be used once were hitting market again after being washed and repacked [54].

Agrawal and Chaturvedi (1997) carried out a study of Solid Waste disposal and recycling in Delhi and observed that significant amount of Delhi’s waste stream (12 to 15%) finds its way in to an unorganized recycling activity. The collection of these recyclable materials was carried out by ragpickers who were at the base of recycling activity. They act as first level collectors by rummaging in Municipal bins for materials with any economic value, since segregation at source is not practiced in households. From the bins these materials are channelled in to a distribution network of small traders, “Kabaris” and small innumerable recycling operations. The city of Delhi alone estimated to have more than 1,00,000 peoples engaged in such activities. They also discussed about structure of informal sector, social factor in the recycling trade, nature of the demand for material, economics of recycling, recycling: unaccounted costs, health of environmental risks and social aspects of Waste Management [55].

Bhattacharyya (1997) suggested that urban Solid Waste low in calorific value, high moisture content was generally unsuitable for thermal technologies [56].

Kuniyal et al. (1997) while assessing Solid Waste Management in and around valley of flowers observed that 96.32% Solid Waste belong to non-biodegradable waste, of which 68.48%, 25.48% and 2.06% of reusable and recyclable Solid Waste were cold drink bottles, plastic and metal respectively, whereas 3.65% of Solid Waste constituted the biodegradable waste [57].

Ravindra and Tripathi (1997) reported that recent world review placed Canada first in Municipal Solid Waste (MSW) generation (2.7 kg/person/day) followed by Switzerland (2.6 kg), France (0.9-2.5
kg), the United States (1.6 kg), the Netherlands (1.6 kg), Germany (1.1 kg), Japan (0.9-1.1 kg) and India (0.5 kg) /person/ day [58].

Sikka et al. (1997) highlighted the strategies used to achieve Municipal Solid Waste Management including recycling, landfill, incineration, pelletization, anaerobic digestion, vermin-culture and the production of low-cost construction material [59].

Agarwal (1998) reported that Solid Waste generated from domestic agricultural and industrial sources was small and got naturally recycled being mostly biodegradable in earlier times. But after that industrial revolution, the resources had been recklessly used, there-by, generating diverse types of wastes which were both non-biodegradable and hazardous posing a serious threat being remained in place for a relatively longer period of time unless removed, burned, washed away or otherwise destroyed [60].

Das et al. (1998) carried out anaerobic digestion of artificially prepared Municipal Solid Waste by coupling a solid phase acidogenic system with an up flow fixed film reactor, there-by converting Municipal Solid Waste to mainly volatile fatty acids and CO₂. Moreover, 88.3% of BOD removal was observed at a loading rate of 1.48 kg BOD/ cu.m/day [61].

Haq et al. (1998) made study on the hazardous waste generation and Management in Punjab and Jammu province and identified 209 and 26 hazardous waste generating industries respectively during study period (1993-94). The total quantity estimated was about 17,301 tonnes per annum (TPA) in Punjab and 1,200 TPA in Jammu province. They analyzed that the major contribution to waste generation was from fertilizer units (6,528 TPA), followed by pulp and paper (4,762 TPA). They also highlighted the classification of wastes, its toxicity characteristics, waste generation factors and hazardous Waste Management [62].

Jain et al. (1998) while carrying out the study on the effect of Municipal and Industrial waste disposals on water quality of river Kali in western U. P., observed that the addition of Municipal Waste to the river resulted in heavy depletion of O₂ over a small stretch of river, besides, the severe deterioration of quality of river water. They recommended the treatments of waste effluents necessary before discharging into river [63].

Jha (1998) reported that in Pune, a programme for Waste Management was initiated involving the Mayor, Municipal staff, citizens, volunteers and others to manage 900 tonnes of daily garbage produced. But the programme petered out for many reasons [64].

Kuniyal et al. (1998a) while carrying out Solid Waste study in selected region of Himalayas, observed that the major source of waste generation in the tourist spots were residences and hotels. A large proportion i.e. 64% & 72% of wastes was observed to be Readily Biodegradable Wastes (RBW) and Biodegradable Wastes (BW) respectively in Kullu and Manali. In valley of flowers, the extremely high amount of wastes generation (0.288 kg/capita/day ) was recorded which was comparable to 0.273 kg/capita/day collected at Nagpur city [65].

Manohar et al. (1998) investigated the quantitative and qualitative aspects of Solid Waste generated in a typical 300 bed super specialty hospital. The rate of generation of infectious and non-infections wastes were 1.20 and 0.19 kg per day per bed and the average combustible and non-combustible fraction of the combined waste were 91.67 and 8.33% respectively [66].

Patel and Tripathi (1998) while discussing the utilization and disposal of Municipal Solid Waste in European countries, reported that most developed countries had landfill as major system for waste disposal while Belgium, Netherland, Japan, Switzerland Sweden preferred to adopt incineration system instead of landfill [67].

Prabhakarachary et al. (1998) while studying physico-chemical characteristics of Solid Waste from Warangal and Hyderabad Municipal Corporation areas, concluded that domestic Solid Wastes possessed less calorific value and greater ash content than those from market yards [68].

Ahmad (1999) reported that family of 3 to 4 members in a developed country throws away 50kg of organic refuse every week which includes cloth, vegetables, paper etc. In India, about 225 million tones of cattle and more than 1000 tonnes of straw and crop waste are produced every year. Kitchen and Lawn trimmings comprise 25% of our nations Solid Waste material. By implementing massive technological
skills, these organic wastes can be converted into bio-fertilizers to increase the productivity of agriculture and arable soil. Paper wastes dumped in Environment from different sources such as offices, markets, surface transport can be collected from the garbage stacks and reused in the new forms. Rubber, plastics, polythene wastes can also be converted to new forms to be used as baskets, carry bags container, file trays etc [69].

Ahsan (1999) discussed an integrated Solid Waste Management Plan including waste minimization, material recovery, waste processing and transformation and its disposal on land to solve the Solid Waste problem of majorities [70].

Alappat and Dikshit (1999) stressed on the role of recycling of plastic for the Management of plastic and reported Karadamuri case of Nov. 1994 in which four people were killed due to cloud of cyanide laden gas which was generated due to burning of heaps of polyethylene bags by local junk dealers [71].

Carpenter et al. (1999) while discussing technology and health effects of Hazardous Waste Management in the countries of eastern and central Europe, suggested the incineration as a means of disposal of hazardous wastes [72].

Chaturvedi (1999) reported plastic bags in the sea cause immeasurable harm to marine life. In mountainous regions, the problem intensifies as ragpickers do not scavenge for waste on the steep slopes. As a result, the polybags along with other waste find a permanent resting place. It gets buried in the ground, destroys the local eco-system and retards the soil’s carrying capacity. Being non-porous, the plastic seals off air, affecting plant life. In the mountainous regions, this can reduce the vegetation and hence soil binding, increases the risk of landslides [73].

Jalan (1999) analyzed various specific sectors involved in Solid Waste Management like biodegradable recycling, non-biodegradable recycling, composting, incineration, pyrolysis and sanitary land filling [74].

Kantharia (1999) while discussing the bio-waste recycling reported the introduction of Municipal Waste disposal rigidity in Germany [75]. Kishore et al. (1999) while viewing the Hospital Waste Management in India, reported that medical care especially in hospitals has contributed significantly to environmental pollution. They stressed for reduction of hospital waste by strict segregation and handling, avoiding unnecessary disinfection procedure and disposal and implementing energy and water saving technologies [76].

Kuniyal and Jain (1999) while studying the Waste Management practices in UP Himalayan tourist’s treks observed that 78% of stall keepers throw wastes in and around the stall without installing dustbins. The principal waste such as cold drinks bottles (68.48%), plastics (25.48%) and metals (2.06%) were found to be worth transporting from their point of origin to the road ahead and ultimately to recycling centres for reuse and recycling [77].

Patel (1999) while studying the physico-chemical characteristics of Municipal Solid Waste (MSW) in Rourkela, observed that these characteristics depends on the topography, climatic conditions, economy conditions, social customs, food habits, availability of different materials locally. He suggested exploring the possibility of utilization of Municipal Solid Waste for processing, recovering and recycling on the basis of calculated data [78].

Rao and Shantaram (1999) observed the presence of potentially toxic elements (heavy metals) in soils treated with the urban Solid Wastes [79].

Agarwal (2000) reported the improper disposal of medical waste in India as there is illegal sale of used syringes, bandages and cotton for reuse, especially-in rural locations. Infected bandages and used cotton wool were being sold to mattress and quilt manufacturers. Those engaged in waste picking and recycling (estimated to be more than one million nationally) handle and collect dangerous medical wastes and in the process suffer injuries and infections. He also observed ragpickers sorting through medical waste at a dump behind a Delhi hospital. Often unaware of the risks and inadequately projected such workers are vulnerable to disease. They sometime sell used syringes which are repacked by unscrupulous dealers and put back on the market [80].

Aggarwal et al. (2000) studied the change of physico-chemical characteristics of soil at the Varuna river corridor due to mixing of domestic wastes [81].
Kathuria (2000) reported that plastic waste though non-biodegradable yet is recyclable. About 80,000 tonnes of Solid Waste is generated every day in our country (India), of which 3-4% on an average by weight was plastic waste. The plastic recycling trade is based on a network of ragpickers, waste collectors, waste-dealers and in India over 20,000 recycling unit are present producing about 0.8 million tons of recycled plastic products annually [82].

Sonesson et al. (2000) advocated the resource use; biological waste treatment and alternative solutions to decrease the environmental impact of solid and liquid organic waste on environmental [83].

Upreti and Kandpal (2000) reported the use of domestic fuel from mixture of forest and Municipal Waste in many rural areas of Kumaon and Garhwal hills [84].

Borthakur (2001) debated the eco-friendly aspects of the biodegradable plastic [85]. Farrell (2001) reported that Bright Star Environmental Australia has developed a technology- Solid Waste Energy and Recycling facility (SWERF) for Municipal Solid Waste Management and described three main components i.e. processing of Municipal Solid Waste, gasification and electricity generation. They further reported that this technology has a tremendous potential to eliminate waste and reduce greenhouse gas emission, besides, generating electricity at the same time [86].

Katakam (2001) revealed that though the informal sector-comprising waste pickers, itinerant buyers, retail traders, whole-sale traders, play a big role in reprocessing of scrap and employment generation, yet they are unprotected by the law and largely ignored by society and lead life full of misery. He also discussed the need of hour [87].

Kumar and Patel (2001) reported that glass/bottle-manufacturing factory generated large amount of Solid Waste, which were not properly managed and suggested the requirement of Management practices to reduce, reuse and recycle, besides, land disposal delineation for a typical glass factory [88].

Ray et al. (2001) observed that large number of medical articles that are meant to be used just once come back to the market after being washed and repacked at much cheaper rates than the original articles. These articles are collected by ragpickers who sell these to Kabadiwalas or Junk dealers. The dealers used to sell the medical products to traders or brokers who in turn take them to small medical product manufactures and obtain good returns. The manufactures clean, wash and repack the waste and sell them in the market at a handsome profit [89].

Sharma (2001) highlighted the latest technology status of obtaining energy from waste and critically reviewed the progress made in India in generating energy from waste [90].

Singh et al. (2001) while studying the effects of Hazardous Solid Waste disposal on land, observed that heavy metals were retained on the top and middle soil and decrease with increase in depth and the percolating water, adds hazardous waste metals to ground and sub-soil waters [91].

Singhal and Pandey (2001) while presenting the statics and future directions of Solid Waste Management in India reported various future projections for estimating the growth of Municipal Solid Waste and the impacts of such waste on environment [92].

Bhargava and Gupta (2002) while discussing expert for Solid Waste Management, highlighted Soldmang expert system which stressed short-range and long-range transfer, separation of useful matter [93].

Nagori (2002) while carrying out study on Municipal Solid Waste generation and its disposal in Morena, observed that a Solid Waste generation varies from 0.27 to 0.33 Kg per capita per day in Morena City. The researchers further observed that Municipal Solid Waste Corporation of city did not have appropriate technology for Management of Municipal Solid Waste which was the prime necessity of the city. The investigators suggested that the Chambal ravines which were very close to this city could provide a vast dumping area in due course of time till it reclaims the ravine [94].

Temburkar and Landge (2002) while discussing the Medical Waste Plan, stressed the minimization, management and treatment of waste [95].

Panda et al. (2003) made study on the generation and disposal practices of Municipal Solid Waste of Bhubaneswar city and observed average per capita generation of Solid Waste 0.19±0.23 kg and 0.17±0.03 kg in 2001 and 2002 respectively amounting to total refuse generation of 162,000 mt and 180,000 mt respectively. They further observed that separated vehicles were used to carry Solid Waste
from hospitals and other places, but both the categories of wastes were dumped at common disposal sites, thereby, violating the standing guidelines of Solid Waste disposal. Their observation further revealed that majority of the disposal sites were located near water bodies (used for drinking purpose), parks (used for recreations), educational institutions and slums. During the rainy season, the dumping sites were observed to provide breeding grounds for flies, mosquitoes, cockroaches, fleas and worms, which are the vectors of various diseases. The health survey revealed the frequent occurrence of malaria, hepatitis, dysentery, diarrhoea, skin infections, worms infections in people inhabiting the areas near the dumping sites [96].

Rampal and Sharma (2003) while studying Solid Waste generation and disposal at Bagh-e- Bahu Complex, observed that on an average 114.668 kg/day of the Solid Waste with 70.09% biodegradable and 29.91% non-biodegradable was dumped in open and no storage bin had been observed in study area. The bulk of waste was observed to be biodegradable and organic in origin, providing breeding grounds for germs and flies. They observed that Solid Waste collection facility by Municipal Committee of Jammu was available at an interval of one week [97].

Rao et al. (2003) analyzed the physical constituents and micronutrients and heavy metal contents of urban Solid Waste of Hyderabad and observed that the average physical constituents of urban Solid Waste in Hyderabad (with a population of more than six million) was gravel 17, glass 1.13, rags and textiles 0.86, papers 1, metals 1.05, leather 1.05, rubber 1.93, plastics 2.06, earth and ash 47.21, compostable matter 17, miscellaneous 9.56 percent. The micronutrient and heavy metal contents of components of urban Solid Waste varied widely. Among the metals studied, iron was found to be the highest that ranged from 213 to 6300 ppm and cobalt found to be least, which ranged from 2.1 to 6.3 ppm [98].

Pande et al. (2004) while studying the organic matter in Industrial and Municipal Solid Waste observed that the concentration of organic matter is very high in comparison to soil samples. They further observed that the amount of organic matter was less in Municipal Solid Waste in comparison to Industrial Solid Waste due to the use of organic compounds (dye etc.) in dyeing and printing processes and its final discharge with Solid Waste [99].

Sharma et al. (2004) conducted experiments to evaluate the suitability of Municipal Solid Waste (MSW) for cultivation of Lentinus sajar-caju (formerly known as Pleurotus sajor-caju) and Agaricus bisporus. They used MSW, Vermicomposted MSW separately as well as in combination with the conventional substrate wheat straw in different ratios. They obtained good results and concluded that MSW/Vermicomposting MSW could be exploited to yield protein rich fruit bodies of mushrooms, besides, producing quality compost [100].

Shivakumar et al. (2004) reported that to manage increased Solid Waste generation in urban areas, many Municipality and Corporation were disposing off waste by filling depressions, thereby, resulting in ground water pollution due to percolation of leachate from sanitary land-filling through physical, chemical and microbial process [101].

Agrawal et al. (2004) develop a multiple regression model to estimate energy content of Municipal Solid Waste [102].

Bhide (2004) stressed the role of Ragpickers in recycling of Solid Waste and observed that the total Solid Waste generated per day in Delhi was about 6000 metric tonnes. The ragpickers lift 720 to 900 tones, thus saving Rs. 6,20,000 to 7,75, 000 of Municipal Corporation of Delhi [103].

Kirubakaren et al. (2005) worked on energy recovery from organic fraction of Solid Waste by adopting the process of thermo chemical conversion (Incineration/Pyrolysis/Gasification) and biochemical conversion (Anaerobic digestion/Biomethanization/Alcoholic fermentation). They found that energy recovery from waste could reduce greenhouse gases and other liquid and solid pollutants, thus contribute to sustainable development [104].

Pandey and Chaplot (2005) while investigating environmental status evolution of bio-medical waste at Udaipur, reported that per capita waste generated by these hospitals, ranged from 0.67 to 2.40kg/bed/day with respect to the total waste load, the general hospital with bed capacity of 1000 release 2200kg of waste per day. Hospital with low bed capacity (number of beds=10) generated about
15 kg waste/day. The study further indicated that in Udaipur the common method of disposal of hospital waste is land burial. But due to lack of adequate segregation and transportation methods, large amount of infectious and other kind of medical wastes are dumped into the Municipal garbage [105].

Foolmaun and Ramjeawon (2008) conducted a study on disposal of PET bottles, using the life cycle assessment tools in Mauritius and reported 100% incineration as the most preferred option [106].

Hazra and Goel (2008) worked on the Solid Waste Management practices in Kolkata and observed more than 2920 tonnes per day generation of waste. They also found deficiencies in all elements of Solid Waste Management like lack of suitable facilities (equipments and infrastructure), inadequate management and technical skills, improper bin-collection and road planning [107].

Seema and Joshi (2011) observed that Solid Waste generation and its disposal to safer sites is a potential threat to human health and causes environmental degradation and also found that MSW dumped in landfill site in Doon valley along-with the plant species including two tree species, four shrub species, remaining herb species and invasive species like Lantana camara, Eupatorium adenophorum and Parthenium hysterophorus are best source to remediate Solid Waste by the technique of phyto-remediation [108].

2.2. Research needs and comprehensive applications to solid-wastes utilization:
The following will guide one to come up with a good waste utilization focus and help ensure it’s intended use is achieved;

i. Check the availability of a particular waste, it must be in abundant and recorded in tonnage.
ii. Consider the location where the type of waste is predominantly produced.
iii. Consider the cost of processing before it is ready for use as a construction material.
iv. Test the performance or workability of the particular waste and consider any engineering or scientific approach in making workable material.
v. Always put in mind that the waste-base material can be used as a primary, secondary or tertiary construction material, such that it will be use as a means of reducing weight or as a stabilizing material etc.
vi. Make sure that the waste in question has undergo full laboratory testing and has satisfy all the geotechnical, structural and strength aspect of it propose use.

2.3. Utilization potential of Solid-wastes in Construction and other applications:
The employment of solid wastes in construction has come of age, since engineers and scientist started looking for a way to channel waste from within the environment. Solid waste can be used as aggregates or as special cementing material in concrete production. Many studies have focused on the effects of solid wastes on the physical and mechanical properties of construction products. Many of such studies attempted to investigate the durability and performance of solid waste as construction materials. These are some utilization potential of waste in construction;

i. Production of high-performance concrete.
ii. Production of construction base fibers.
iii. Production of polymeric composites.
v. Use in Erosion control and Soil stabilization.
vi. Use in Acoustic control etc.

Nadeem et al. (2020), investigated the feasibility of Autoclaved aerated concrete (AAC) production using 40% waste will be utilized, Construction waste (5%, 10%, 15% upto 40%) and Fly ash (35%, 30%, 25% upto 0%) respectively, keeping the aerating agent constant at 0.06% that is aluminum powder (waste of construction and fly-ash as a substitute for siliceous material, e.g. quartz sand) [109]. The compressive strength of the material has been checked after autoclaving at 200°C temperature and 1 MPa Pressure for 6 hours for designing a light-weight porous, autoclave aerated concrete material as showed below in the fig.1. The feasibility of utilizing construction and demolition waste, fly ash waste for the production of lightweight autoclaved aerated concrete has been illustrated. Results revealed that
the sample AC-4, containing 20% fly ash and 20% C&D waste, showed the highest compressive strength along with satisfactory density and low water absorption. The first two samples, AC-1 and AC-2 gave approximately similar results. Sample AC-4 containing 20% C&D waste and 20% fly ash showed the highest strength of 2.2 MPa. On the other hand, sample AC-8 containing 40% C&D waste and zero additive of fly ash gave the lowest strength (1.43 MPa) and lowest density (655.49 Kg/m³) (Table 1, Fig.2(a)). The value of water absorption (WA) of the samples is given in fig.2(b), and results demonstrated that the samples AC-7 and AC-8 had relatively high WA value, 23.0-25.6%. This is due the fact that these samples were too porous as compared to other samples. An increase in the content of C&D waste and a corresponding decrease in the content of fly ash leads to a deterioration of all studied features of AAC, especially for sample AC-8 with zero content of fly ash. Based on the obtained results, the AC-4 concrete with the highest compressive strength can be used for simple applications such as partitions, roofing, floor filling, and possibly for masonry. However, even this material does not meet the strength standard required for load-bearing structures. Finally, it can be concluded that the use of construction waste along with waste of other industries in concrete production can be a positive step forward in saving resources and improving the environment. Moreover, reducing the consumption of valuable siliceous raw material, sand, through the processing and disposal of waste, allows to save energy and improve the ecological state of the environment [109].

**Table 1. Characteristics of the tested samples [109]**

| Sample identification | Cross-section area (mm²) | Density (Kg/m³) | Compressive Strength (MPa) |
|----------------------|--------------------------|-----------------|---------------------------|
| AC-1                 | 3600                     | 753.83          | 1.83                      |
| AC-2                 | 3600                     | 746.54          | 1.80                      |
| AC-3                 | 3600                     | 739.26          | 2.00                      |
| AC-4                 | 3600                     | 728.33          | 2.22                      |
| AC-5                 | 3600                     | 721.04          | 1.74                      |
| AC-6                 | 3600                     | 710.12          | 1.47                      |
| AC-7                 | 3600                     | 680.99          | 1.53                      |
| AC-8                 | 3600                     | 655.49          | 1.43                      |
Ursua (2020) investigated the compression test, water-absorption test, efflorescence test and hardness test by utilizing the non-hazardous wastes such as plastics-wastes, crushed glass-bottles, and shredded-paper in making an effective and quality sand-bricks as a substitute based, eco-building and construction material instead of concrete hollow-blocks as illustrated in the fig.3 and 4 respectively [110]. The key-goal is to reduce the plastic-wastes, glass-bottles, and paper produced from households, schools, commercial, industrial and other establishments. Furthermore, the other reason is to lessen the impact of pollution on the environment is to reduce, reuse or recycle the plastics. The possibility of utilizing these materials in making effective and quality sand-bricks as non-load-bearing masonry material was the primarily objective. Results demonstrated that for net area compressive strength, all the sand brick specimens surpassed the minimum requirements of 500 psi (3.45 MPa) for individual brick and 600 psi (4.14 MPa) average for three units according to ASTM C129 for Non-Load-Bearing Masonry units. Also, the results showed that, as the amount of plastic increases, the compressive strength of brick also increases. However, due to the massive amount of plastic for brick A with 39% of plastic by weight gained a compressive strength of 628.82 psi (4.34 MPa). With this, as the plastic reaches its molten state and liquefies the sand and crushed glass settle quickly which the molten plastic with shredded paper floated on the surface of the mixture [110].

Moreover, results also reported that the Brick A with 39% of plastic wastes gained a water absorption percentage of 1.285%. While Brick B with 34% of plastic wastes got a water absorption percentage of 1.443%. Also, in this study, findings indicated an excellent performance since specimens gained less than 20% of water absorption on the different sand brick specimens after the water absorption test. Thus, the existence of plastic wastes helps in the performance of sand bricks. Moreover, the result showed that, as the percentage of plastic wastes increases, the percentage of water absorption decreases. Also, all the sand brick specimens were classified as “Slight” (≤10%) after the efflorescence test was performed. Whitish layers were slightly visible on the surface of the sand bricks which simply showed a deposit of soluble salts or alkalis. However, the whitish thin layer was visible nearly 10% of the brick surface, thus the presence of alkalis was in an acceptable range. Finally, there was a very light impression left on the sand brick surfaces with the aid of common nail on the bricks after the hardness test were performed. The hardness of the brick was due to the plastic wastes which acted as a binder as well as the sand and crushed glass bottles as fillers. Thus, all the sand brick specimens were considered “Hard” based on the impression made. Hence, the examiners created the sand-bricks from non-hazardous wastes has a great possibility in employing as an alternative building and construction material for a non-load-bearing wall as well as an effective solution in fighting the problem on reducing the effect of solid-wastes [110].
The melted waste plastic-bags are seen as a good-substitute for cement in the manufacture of concrete paving-blocks and building-bricks/tiles was reported by Abdel et al. (2020) [111]. The key-goal was to produce construction bricks using sand and waste plastics and to produce concrete blocks using sand, gravels and waste plastics. Results indicated that increasing the amount of plastic in the mixture decreased the final density of the molded bricks and concrete blocks. Results also revealed that the thermal conductivity was depended upon the plastic content of the molded materials. Decreases in the thermal conductivity were observed with increases in the plastic content of both the bricks and concrete blocks. Increasing the plastic content from 33.33% to 66.67% (100%) in the bricks decreased the thermal conductivity from $1.7 \times 10^{-3}$ W/m.K to $1.43 \times 10^{-3}$ W/m.K (16%) while increasing the plastic content from 20% to 50% (150%) in the concrete blocks decreased the thermal conductivity from $1.61 \times 10^{-3}$ W/m.K to $1.5 \times 10^{-3}$ W/m.K (7%). It was also noticed that bricks and concrete blocks with similar plastic contents (50%) have similar thermal conductivity values. The thermal conductivity measured in this study was slightly affected by the temperature difference $\Delta T$. Increasing the time from 5 min to 15 min increased the temperature difference $\Delta T$ from 286 K to 294 K (2.7%), from 284K to 292K (2.7%) and from 282K to 288K (2.1%) for bricks having plastic: sand ratios of 2:1, 1:1 and 1:2, respectively as revealed from the fig.5. Also, the temperature difference $\Delta T$ increased from 289K to 294K (1.7%), from 287K to 292K (1.7%) and from 285K to 289K (1.4%) for the concrete blocks having plastic: sand: gravel ratios of 2:1:1, 1:1:1 and 1:2:2, respectively. However, the variation in $\Delta T$ is with the reported range in the literature of 1-3% for the thermal conductivity transient measurement technique. The thermal conductivity apparatus and the transient measurement methods used in this study provided consistence results with high degree of accuracy. The variations in $\Delta T$ were within the rage (1-3%) reported in the literature for the thermal conductivity transient measurement technique and resulted in very small
variations in the thermal conductivity measurements (0.59-0.70% for bricks and 0.62-0.69% for concrete blocks) [111].

Figure 5. Effect of plastic content on the thermal-conductivity of the molded materials [111]

The results obtained from the flexure test showed that the bending moment and thus the bending stress increased with increasing the plastic content in both the bricks and concrete blocks. Increasing the plastic content of the brick from 33.33% to 66.67% (100%) increased the bending moment from 540.00 N.m to 1711.25 N.m (216%) and the bending stress from 3.24 N.m\(^{-2}\) to 10.26 N.m\(^{-2}\) (216%) and increasing the plastic content of the concrete blocks from 20 % to 50 % (150%) increased the bending moment from 901.40 N.m to 1442.55 N.m (60%) and the bending stress from 5.40 N.m\(^{-2}\) to 8.65 N.m\(^{-2}\) (60%). It was also noticed that for similar plastic contents (50%), the concrete blocks had a lower bending moment (1442.55 N.m) than that of the bricks (1711.25 N.m) and thus a lower bending stress (8.65 N.m\(^{-2}\)) than that of the bricks (10.26N.m\(^{-2}\)) as indicated from the fig.6(a-b). Using waste plastic in making construction materials such as bricks and concrete blocks is advantageous due to its light weight, significant durability and potential to be customized to accommodate certain engineering-requirements. Also replacing cement with waste plastic will reduce environmental problems associated with the disposal of waste plastic as well as those associated with the cement industry [111].

Figure 6. Effect of plastic content on the, (a). Maximum bending moment of molded materials and (b). Maximum bending stress of molded materials [111]

Jassim (2017) mixed high-density polyethylene waste with Portland cement with percentages varying from 15% to 85% to investigate the possibility of producing plastic cement and reported a
decrease in density with increases in the percentage of plastic [112]. The author considered this process to be environmentally friendly method for manufacturing.

Zhao et al. (2016) reported that thermal conductivity is affected by the temperature, surface roughness, surface hardness, impurities, cleanliness and contact pressure [113]. The thermal conductivity measured in this study was slightly affected by the temperature difference $\Delta T$. Increasing the time from 5 min to 15 min increased the temperature difference $\Delta T$ from 286 K to 294 K (2.7%), from 284 K to 292 K (2.7%) and from 282 K to 288 K (2.1%) for bricks having plastic: sand ratios of 2:1, 1:1 and 1:2, respectively. Also, the temperature difference $\Delta T$ increased from 289 K to 294 K (1.7%), from 287 K to 292 K (1.7%) and from 285 K to 289 K (1.4%) for the blocks having plastic: sand: gravel ratios of 2:1:1 and 1:2:2, respectively. However, the variation in $\Delta T$ was with the reported range in the literature of 1-3% for the thermal conductivity transient measurement technique [114-116].

Agyeman et al. (2019) produced concrete paving blocks with a cement: quarry dust: sand ratio of 1:1:2 by weight to serve as control. They replaced cement with plastic and produced paving blocks with high-plastics (H.P.) and low-plastics (L.P.) contents with plastic: quarry dust: sand ratios of 1:1:2 and 1:0.5:1 by weight, respectively. All paving blocks were tested for compression-strength at seven, fourteen and twenty-one days cured through water-spraying. Water-absorbing testing was performed after 72 hr of drenching. Results disclosed that after 21 days, the control, HP and LP paving blocks had compressive strengths of 6.07 N/mm², 8.53 N/mm² and 7.31 N/mm² and water absorptions of 4.9%, 0.5% and 2.7%, respectively [117].

Other researchers used granular waste plastic as aggregates in concrete an reported their effects on weight loss, impact load, sulphate attack [118], porosity [119], abrasion resistance [120], oxygen permeability [118-119], splitting strength [121-122], density [123-124], modulus of elasticity [120, 125], water absorption [122, 125-126], compression [118, 120-127], flexural strength [120-121, 125-126], workability [123-124, 128-129] and strength [120, 123, 125-126]. Silva et al. (2013) and Kumar and Baskar (2015) reported reductions in both the fresh and dry density of concrete made with waste plastic aggregates [130-131]. Coppola et al. (2018) stated that increasing the percentage of plastic in concrete reduced the dry weight after 28 days [132]. Akram et al. (2015) and Hama and Halil (2017) reported 50% reduction in dry weight of a concrete containing 50% plastic aggregates and referred that to the lower specific gravity of plastic [122, 133].

Shrimali S. et al. (2011), determined from this the type A, 5 kg of plastics used in 22×10×5.5 mould and the compressive strength 90.86 kg/cm.sq. In type B, 10 kg of plastics used in 22×10×5.6 mould and the compressive strength is 128.91 kg/cm.sq. In type C, 15 kg of 22.5×9.5×5.8 mould and the compressive strength is 198.45 kg/cm.sq [134]. Due to some physical and chemical properties of plastics, this can be disadvantageous to the brick, created from it. Ronak Shah et al. (2017), shows that the Compressive strength test was performed on the plastic dust bricks in areas of strength was found to be 6.66 N/mm² which is higher than the red clay bricks. The water absorption is higher in comparison to conventional block. To manufacture these bricks, they are burnt in alkaline which creates large amount of pollution and toxic gases [135]. Gopu Mohan et al. (2016), observed that the plastic bricks in the ratio of 70:25:5 (70% M sand, 25% plastics and 5% thermocol gets the compressive strength is 11 N/mm². Thermocol acts as the binder and so it has very high strength [136]. Neha Mumtaz et al. (2017), shows that the softening temperature of PET, PE was 170°C at that point it not produces any noxious gas. The compressive strength of clay bricks is found to be 7.6 N/mm² and fly ash & plastic bricks are found to be 9.7 N/mm². The average absorbed moisture content of clay bricks is found to be 11.9% and for fly ash & plastic bricks is found to be 2.75% [137].

Adela et al. (2020) evaluated the technical feasibility of plastic wastes (Polyethylene) and plastic bottles (polyethylene terephthalate) as a partial replacement of coarse aggregate in a concrete mix using volcanic pumice as an admixture and also identifies curve based operational cut-off value for practical application [138]. Concrete test specimens prepared with standard M20 mix design were measured for a compressive and split tensile strength. Results delineated that the density of the concrete decreases with increasing the percent replacement of plastic aggregate made from both plastic bottles and bags aggregate as shown in Fig.7(a-b). The density of the concrete without pumice ranged from 2222 kg/m³
to 1780 kg/m³ whereas concrete consisting of pumice had a density that ranges from 2190 kg/m³ to 1644 kg/m³ for zero and 35 percent plastic bag aggregate replacement respectively for both groups. The density of concrete with and without pumice has shown no observed difference at a percent replacement of less than 25% of plastic bag aggregate as revealed from the Fig.7(a) [138].

![Figure 7. Dry Density of specimens made from (a). Plastic bag aggregate and (b). Plastic bottle aggregate [138]](image)

However, the density at 35% replacement of plastic bag aggregate with (1644 kg/m³) and without (1780 kg/m³) has indicated a difference between the two categories [138]. Similarly, the density of the concrete decreased upon the increment of the plastic bottle aggregate in the mix as indicated in Fig.8(a). In the case of concrete comprising plastic bottle aggregate with no pumice, the density ranged from 2222 kg/m³ (0% replacement) to 1556 kg/m³ (75% replacement) as shown in Fig.8(a). In the presence of pumice, the density was found to be 2195 kg/m³ at 0% replacement and 1630 kg/m³ at 75% replacement (Fig.7(b)). Unlike the concrete mixed with plastic bag aggregate, the density of the concrete mixed with plastic bottle aggregate and pumice showed a slight increase than that of concrete with no pumice. In both types of plastic aggregates used in this study, the density of the concrete was observed to decrease in comparison with the control specimens that do not contain plastic aggregate. The density of the concrete specimens (plastic bag aggregate with no pumice) had shown a 20% decrease in the specified replacement range whereas the density decreased by 25% upon addition of pumice as an admixture. The density of the specimen that comprises plastic bottle aggregate without pumice decreased by 30% and 25% decrease in the presence of pumice in the replacement range. Comparing the two plastic aggregate categories, a relative decrease of density is observed for the plastic aggregate made from bottles. These would be probably due to the texture of the plastic, which increases the volume. In general, the reduction of the density of the concrete containing plastic aggregate is mainly associated with the difference in the specific gravity of gravel and the plastic aggregates. The observed density showed that the concrete density of those specimens that contain plastic aggregate (bags and bottles) and pumice admixture is in the range of 2093 kg/m³ to 1630 kg/m³. Plastic aggregate made from plastic bags and bottles has shown a different degree of workability to replace the concrete mix. The compressive and split tensile strength tends to decrease with increasing the ratio of plastic aggregates for both types of plastics. However, the curve based operational cut-off value shows that the plastic bag and bottle aggregates can replace coarse aggregate from 11-14% and 35-37.5% respectively. Findings also reported from the Fig.8(b) and Table 2, that the compressive strength of the cast specimens replaced with plastic aggregates decreases significantly (p-value=0.000) in comparison with the control standard M20 grade concrete cast. The replacement of coarse (gravel) aggregate made from plastic bags without pumice shows the lower compressive strength upon increasing the percent replacement of the plastic aggregates. In the second test group of the same percent replacement of plastic bag aggregates but containing pumice, a relative increment of the strength is observed as clearly indicated in Fig.8(a). This could be related to the synergetic effect of the pumice and plastic bag aggregate where the high iron oxides, aluminum oxides
and silicon oxides in pumice, and the thin thickness of the plastic play a role. In general, in both groups, the compressive strength decreases by more than 50% with increasing the plastic bag aggregate content than the nominal concrete mix so that the operational cut-off value is required to use plastic bags in lightweight construction activity. Accordingly, the operational cut-off plastic bag aggregate replacement is determined using the 10MPa and 15MPa load (Fig.8(a-b)) [138].

\[8. \text{Operational cut-off value for, (a). plastic bag aggregate replacement with pumice and (b). plastic bag aggregate replacement without pumice [138]}\]

| Percent-replacement | Split-Tensile Strength (MPa) |
|---------------------|-----------------------------|
|                     | Day 7 | Day 14 | Day 28 |
| 0                   | 2.4   | 2.53   | 3.1    |
| 25                  | 1.6   | 1.78   | 2.83   |
| 35                  | 1.6   | 1.76   | 2.17   |
| 50                  | 1.6   | 1.76   | 2.19   |

Table 2. Split tensile strength [138]

For the concrete specimens without pumice under M20 grade mix design, the operational cut-off value for percent plastic replacement is found to be 5% and 11% for 15MPa and 10MPa compressive strength respectively (Fig.9(a)). For those test specimens containing pumice, 6% and 14% replacement can be made for the 15MPa and 10MPa compressive strength (Fig.9(b)). In other words, 11% and 14% plastic bag aggregate replacement can be operational for 10MPa load requiring construction. This implied that plastic bags can be consumed in concrete to the specific lightweight construction that requires the particular strength in the operational cut-off value range so that the cost associated with gravel can be reduced. Since the behavior of the cast against fire was not studied, the use of such concrete is highly recommended for the construction of pedestrian pavement, compound floor tiles, room partitioning, and others. Despite the operational cut-off value is viewed from the meaningful load (10MPa and 15MPa) experienced in the construction sector, under special cases where the concrete load lowers to 5MPa the use of plastic bag aggregate increases up to 27% that indicates that such amount of dumped plastic can be removed. Plastic bottles differ from plastic bags in chemical, physical and mechanical properties that in turn affect their properties in the same application for similar activity. Studies also concluded in terms of physical property (density) and mechanical property (compressive strength). The compressive strength of the test specimens containing the plastic aggregate made from plastic bottles has showed that its compressive strength decreases by 35% when the plastic replacement increases. As can be seen from Fig.9(a-b), there is a difference between the control specimens and the experimental specimens (p-value= 0.065). The effect of pumice is not yet significant to affect
compressive strength. Unlike the effect observed in specimens containing plastic bags, its presence in the specimens containing plastic bottles caused a slight decrease in the compressive strength. Similarly, the operational cut-off value for plastic bag aggregate replacement in the absence of pumice to maintain 15MPa and 10MPa compressive strength is 16% and 35% respectively (Fig.9(a)). For the test specimen with pumice the percent replacement of 16% and 37.5% is operational to maintain 15MPa and 10 MPa compressive strength respectively (Fig.9(b)). Therefore, the operational cut-off value ranges from 16% to 37.5% for the desired compressive strength. In the economic term, 37% of the gravel cost can be reduced if the plastic bottles are used as coarse aggregate in concrete that requires a 10MPa load. However, an increase in percent replacement (~58-75%) can be maintained for compressive strength of 5MPa though this type of concrete is commonly used. In general, using plastic bottles as an aggregate could be an alternative means to manage plastic wastes and economically viable. For standard M20 mix design, the tensile strength is estimated to be 3.1MPa based on equation 1 as followed, [138].

\[ T = \frac{2P}{\pi LD} \]  

Where, \( T \) = Splitting Tensile Strength (MPa); \( P \) = Maximum applied load indicated by test-machine, N; \( D \) = Diameter of specimen (mm) and \( L \) = Length of specimen

![Figure 9](image.png)

Figure 9. Operational cut-off value for, (a). Plastic bottle aggregate replacement without pumice and (b). Plastic bag aggregate replacement with pumice [138]

Findings also cleared that the tensile strength has also decreased with increasing the percent replacement of the plastic bottle aggregate. However, the measured tensile strengths are found in the operational workability range (3.10-2.19). Hypothetically, the incorporation of elastic materials such as plastics in the concrete mix could increase the tensile strength. However, the tensile strength tends to decrease with increasing the plastic content. This indicated that another specific mix design could better improve and manage the issue of plastic waste. Conclusively, utilizing the plastic aggregates as a partial replacement of coarse aggregate is technically feasible. However, applying the nominal concrete standard mix proportion is seemingly inappropriate while plastic aggregates used as an aggregate which in turn require a specific mix design. Despite the percent replacement is low, utilizing waste plastics in the concrete mix would help countries with the weak waste management system [138].

3. Conclusions:
The utilization of waste is turning out to be the savior of tomorrows industrialized and the never-ending waste producing world in today. Waste production is now a focus by all the professionals involved with the environment and in engineering, the investigators have now become active parties in researches involving the environment in a very large scale and it has so far yield good results in the field of Environmental and water resources engineering and also Geotechnical engineering. A Solid Waste Management plan was proposed and the fate of waste after adopting proposed Solid Waste Management
plan was discussed. Awareness of public regarding the utility of waste can further reduce Net Solid Waste generation, thereby, generating resources and minimizing the menace of Solid Waste generation. Both plastic bottles and bags showed some potential to be used as a partial replacement of coarse aggregate in the concrete mix. Due to the major physical properties difference between bags and bottles, workability property and the amount of coarse aggregate replacement capacity is also different. Provided all the above findings and limitations to be filled by research, consuming plastic wastes in the construction sector would help to manage plastic wastes in countries which have poor waste management system and facilities. The review aims to designed a building material and also to recycle the waste generated by various industries mainly from the construction sectors. Production of building materials using waste-utilization is the best technical route. As revealed from the in-depth literature, that the production of good quality construction materials is achievable. Due to the ever-booming construction industries, especially in India, waste of construction and demolition is a widely available. Thus, this review delineates the feasibility of construction building materials production using different solid-wastes as a substitute for siliceous material, e.g. quartz sand [109]. Reducing the consumption of valuable siliceous raw material, sand, through the processing and disposal of waste, allows to save energy and improve the ecological state of the environment [109].

4. Recommendations:
It has been observed that there has been lack of civic sense among the people of India and also lack of determination on the part of Municipality and Government in respect of Solid Waste Management. Therefore, there is an urgent need to organize mass awareness campaign in this regard.

- Municipality should pay due attention towards Solid Waste Management in the area, otherwise problem is likely to become acute with the present rate of increase in Solid Waste generation.
- The number of storage bins should be increased to avoid over-spilling and dumping in open areas.
- The Solid Waste from hospitals should be disposed off separately, preferably by incineration and specialized land-filling.
- Municipality should identify more collection sites at Study Area.
- People should not be allowed to burn the Solid Waste because of health hazards arising from burning.
- Municipality workers should collect waste properly from a collection site.
- Municipality should provide covered vehicles for transport of waste.
- Municipality should start sanitary land-filling system and install compost treatment plant for the Management of Solid Waste.
- Ragpickers should not be allowed to throw any leftovers on the roads rather they should be directed to put left over in dustbins.
- Services of ragpickers should be utilized by Municipality for collection of waste from door to door and segregation of waste into recyclable and non-recyclable waste.
- Municipal employees should keep a check on the public for proper disposal of waste into the dustbins or collection site and one who offends the laws should be given penalty.
- Interactive participation of NGO’s and local residents with the waste management body should be encouraged to create mass awareness.
- Manpower development should be in proportion to the waste generation in respective wards.
- Composting and vermi-composting is the most beneficial and eco-friendly method for Solid Waste disposal.
- Segregation of waste at Household’s level should be encouraged. Source segregation into two separate bins for biodegradable and non-biodegradable Solid Waste should be promoted through mass awareness programmes.
- Solid Waste from Vegetable Market should be segregated and processed separately.
- Technology must be needed where ecology meet with economy.
- Street food vendors should be directed to have their own storage bins to store the waste generated during their activities.
- Waste generated during cleaning such as sludge etc. should be stored and disposed separately.
- Collection and transportation system may be privatized phase wise.
- Special attention should be paid to Solid Waste worker by providing them adequate protective measures.
- The triple ‘R’ policy i.e. Reuse, Recycle and Reduce policy must be effectively followed.
- The Dilute and Dispersion Policy must be properly shunned.
- Waste Management Hierarchy must strictly follow. This approach involves the options ordered from the most desirable to least desirable.
- Government should enact the “Polluter Pays Principle”.
- Government should promote the “Industrial Ecosystem” or “Resource recovery” or “Sustainable Waste Management” or “Resource Management” and must consider the Solid Waste as “URBAN ORE”.

5. Future-outlook:
The following recommendations will help in further studies on waste utilization if considered;
   i. Researchers should at least consider exploring the use of other waste-materials that have been then considered not to be a construction material, because it will be very fortunate that today it might be a useful material indeed.
   ii. Research should also perform a continual and advance test on leather waste, because leather waste is abundant in so many parts of the world and they do not decompose easily.
   iii. Educational institutions should consider the utilization of waste in construction.

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