RESEARCH ARTICLE

RSP Science Hub

International Research Journal on Advanced Science Hub
2582-4376
Vol. 05, Issue 05 May
www.rspsciencehub.com

Check for updates

http://dx.doi.org/10.47392/IRJASH.2023.034

Reuse of Hazardous Wastes in Construction Materials

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Article History

Received: 2 May 2023
Accepted: 24 May 2023

***Keywords**:*

Hazardous waste;
Reuse;
Construction Material

Abstract

Production and consumption of goods and services has been leading to the generation of various kinds of wastes and these wastes are usually dumped in landfills. It is damaging to human and environment as the dumped wastes can contain harmful chemicals. Hence, we have to switch to other ways for the management of these wastes. It is possible for some waste to reduce their toxicity levels to a safer level after undergoing some treatments and are dumped later. Scientists are also working on some wastes to reuse in various applications. In this work of study, we tried to give an overview on what kind of wastes can be reused in construction industry. If experiments are successful, construction industry can provide a large scope for the reuse of hazardous wastes. It also helps to reduce the consumption of natural resources such as aggregates, sand, rocks, coal etc. In this review work, we also discussed about the products manufactured from hazardous wastes and their potential in reuse as construction material.

1. Introduction

Wastes are generated from various kinds of activities, most commonly industrial, commercial and household. Due to human activity, everyday wastes are piling up all over the world, consuming a lot of space and creating impact on environment. Even though some liquid wastes can undergo wastewater treatment or sewage treatment, for solid wastes, recycling is not that direct and cost effective. Liquid and solid form of wastes can be divided as hazardous and non-hazardous wastes.

Non-hazardous wastes (e.g., wastes from communities, non-reactive e-wastes) are dumped in areas isolated from the rest of environment. These wastes cause no harm to human and environment. Unlike non-hazardous wastes, hazardous wastes are reactive, toxic, corrosive, ignitable, infectious or radioactive. According to the nature of the material, these wastes require special handling, storage and disposal methods. People have been experimenting on new ways for proper hazardous waste management. In this work, we have shown some methods found that researchers and scientists. According to the statistics, we produce 400 million tonnes of hazardous wastes each year. There is a 400-fold increase in hazardous waste generation. These wastes can cause acute effects like causing death and violent illness when consumed, chronic effects like causing cancer and biological changes in the offspring of human and animals after some period of exposure, cause explosions or toxic vapours when exposed to air and water, cause infections and can emit ionizing energy that harms living organisms. Hence many governmental agencies formulated their own set of laws and policies to remedy existing problems and to prevent future harm from hazardous wastes.

Hazardous waste treatment can be done by chemical, thermal, biological and physical methods. Molecular form of wastes is changed in the treatment by chemical, thermal and biological methods whereas the wastes are solidified and their volume is reduced by physical methods. Incineration of thermal method releases gases that cause air pollution. Solidification process of physical method concentrates on enclosing the waste in concrete, asphalt or plastic etc. The idea of reusing hazardous wastes in manufacturing construction materials do not only helps to immobilize hazardous wastes but also helps to preserve natural resources. After water, concrete is the largest consumed product in the world. Construction industry consumes huge amount of natural resources like aggregates, clay, rocks, lime etc. In many places, these resources have been depleting significantly and their costs are increasing highly. Through this work, we attempted to explain how wastes are encapsulated into construction materials.

Encapsulating these hazardous wastes in construction materials at a safer amount is a necessary step to be followed. Because the resulted product should not cause any harm later. Some research results indicate that reusing wastes as construction materials are economically cheaper. Even less amount of incorporation of wastes contribute in a large scale as the industry is spread widely. In this review work, we have shown the various products manufactured from various kinds of hazardous wastes and their performance as construction materials is discussed.

2. Reuse of hazardous wastes in construction industry

Among the many hazardous wastes, most of them can be recycled into various useful products for construction industry, using different recycling methods. Some of the recycled products that we've reviewed include concrete, cement, aggregates, composites, bricks and others. In their work, S. Bayar and I. Talinli (Bayar and Talinli) manufactured a product from treatment sludge obtained from chemical-metal finishing industry that contains high concentrations of total organic carbon, Cr, Cu, Hg, Ni, Pb and Zn. To observe its hazard characteristics, several tests like extraction procedure toxicity test, DIN 38414-S4 test etc. were conducted. Portland cement was used for solidification of the sludge. They conducted compressive tests on concrete specimens made by solidified sludge and found that compressive strength of the specimen increase as curing time increases and is shown in Fig-1. Better results were observed after 90 days of curing. Due to the high compression strengths, they concluded that the solidified sludge can be reused as construction material and it was also found that the sludge no longer contains toxic metals after stabilization/solidification process. Smita Badur and Rubina Chaudhary (Badur and Chaudhary) , in their review literature, explained how industrial by-products and hazardous solid wastes such as expanded fly ash, slag, sludge, etc. can be reused in manufacturing of green concrete using stabilization/solidification treatment process. They n some experimental results conducted on the concrete partially replaced by waste or by-products in Fig-2.

In the study done by D. Xuan et al. (Xuan et al.) , they prepared a concrete partition wall block using fresh concrete slurry waste (CSW) as cementitious binder from ready mix plant, a fine recycled aggregate (FRCA) from recycling plant and small amount of cement. With the use accelerated carbonation technique, it was found that compressive strength achieved good value, lower shrinkage values can be achieved. The fabrication of block using CSW is represented in fig-3 and 4, accelerated carbonation is represented in fig-5. The accelerated carbonation technique consumes CO2 that can reduce CO2 emissions. In their review work, Ahmad Assi et al. (Assi et al.) mentioned that rice husk ash had been used in concrete as partial replacement of cement and it was revealed that, with 10% replacement, compressive strength of concrete attained more than that of control concrete mixture. The Fig-5 demonstrates the possible applications for various MWSI. A-M O. Mohammed et al. (O Mohamed and Gamal) used chemically modified pure sulphur to produce a sulphur polymer concrete (SPC), they observed that SPC is more durable than Portland cement concrete (PPC). In experimental results, it is indicated that the product is excellent for its use in s/s process of hazardous waste and increase of compressive strength of concrete up to certain amount of sulphur addition, also pore size increases as temperature increases which is a stress release mechanism due to thermal expansion and as per mineralogical point of view, sulphur stopped formation of ettringite in PCC which is not feasible. In Fig-6 and 7, stress-strain relationship of SPC and PPC is graphically represented 7 and XRD pattern of SPC at 7 days of aging is also shown 6.

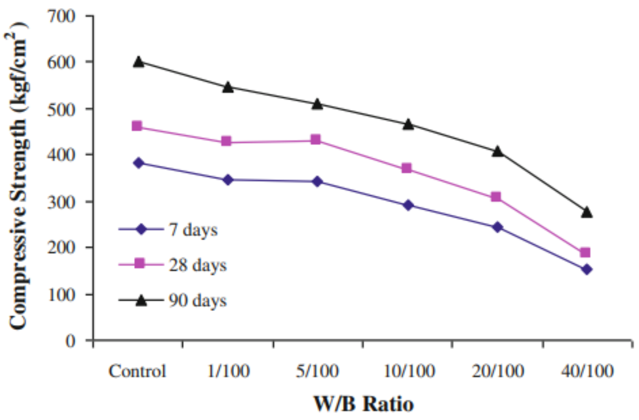

FIGURE 1. Compressive strength of the specimen for different waste/binder ratios

There were other research groups that worked in production of cement after recycling of HW. Iwona Ryłko-Polak et al. (Ryłko-Polak, Komala, and Białowiec) mentioned about replacement of cement by waste from bitumen coal mining and processing and they mentioned that it didn't change any mechanical properties. They also mentioned that flotation wastes, fly ash and sulfur waste can be partially replaced as raw material in cement production giving strong and durable compounds. D. Wang et al. (D. Wang, Q. Wang, and Xue) manufactured a material from electrolyte magnetic residue (EMR) generated after sulphuric acid leaching during electrolytic metal manganese production. The product has been made by mixing EMR, ground granulated blast furnace slag, Ca (OH) 2 and water. NH3-N and Mn are the most hazardous components present in EMR. This product can be used as a cementitious material. In their work, some leaching tests and geochemical modelling were performed in order to characterize the EMR. The results of compression tests revealed that the product can achieve compressive strength of 30 MPa at 28 days and can be applied to general constructions like rural roads, embankment, even buildings etc. Its EMR utilization ratio can reach up to 45%. Vedant Pinarli and Gülgün Kaymal (Pinarli and Kaymal) attempted to substitute cement by pulverized sludge ash in mortar samples. With 5, 10, 15 and 20 percent by weight replacement by sludge ash, they prepared samples with cement to sand ratio of 1:3 and water-cement ratio of 0.5 and were examined. The results revealed that the compressive strength and tensile strength values were attained very close to control reference samples, with 10% replacement. The specific area of the cement is also increased with 20% percent replacement, Z.-h. He et al. (He et al.) examined cement samples with 0, 10, 20, and 30% replacement of modified water treatment sludge. The results indicated that samples with 10% replacement attained higher compressive strength than that of control sample and significant decrease in drying shrinkage values.

Some research studies were also done to produce some alternatives to natural aggregate after recycling hazardous waste. A. Pappu et al. (Pappu, Saxena, and Asolekar) mentioned in their review work, non-ferrous metal wastes can be used as aggregates in lightweight concrete and high strength concrete. R. Argane et al. (Argane et al.) collected metal based tailings from Zeida and Mibladen mining sites and examined their behaviour as fine aggregates in mortars. It was found that good compressive strength and porosity results were attained and water demand is increased due to high finer content. They demonstrate that these metal-based tailings can be a good alternate to fine aggregates.

Some research work such as done by M.R. Ahmad et al. [12] (Ahmad et al.) were done to produce various composites by recycling hazardous wastes. In their study of work, they had prepared four bio-composites with different mix IDs (CM, 50FA, 50RM, GP), using industrial and hazardous waste materials (e.g. red mud, fly ash and ground granulated blast furnace slag). Through their study, they revealed that bio-composites attained good thermal insulation, hygroscopic and energy-efficient properties. Table-1 shows the classification of materials based on compressive strength and thermal conductivity results. Jarosite is a waste from zinc industry, on which Asokan et al. did Experiments using different ratio of jarosite waste and

FIGURE 3. Sample preparation process of concrete mixture

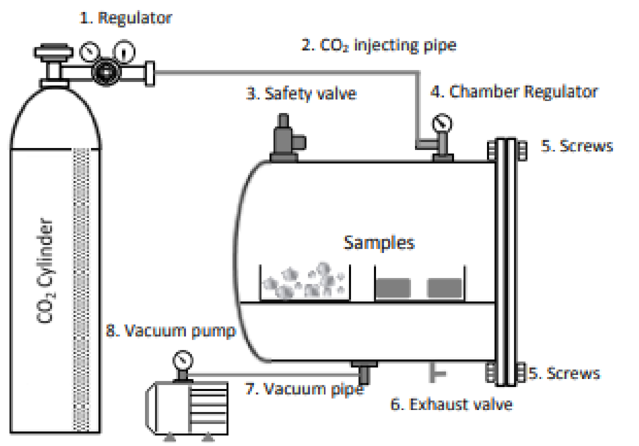

FIGURE 4. Schematic diagram of accelerated carbonation

clay soil in combination with varying concentration of CCRs. The optimized experimental results (with 15% CCR) showed that it is possible to make

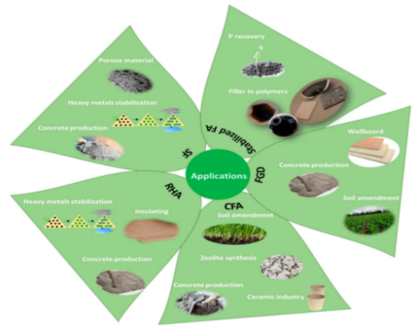

FIGURE 5. Possible applications of MSWI ash

a composite having desirable mechanical properties such as compressive strength (50–81 kg/ cm); water absorption (13–17%); shrinkage (11–32%); and density (1.6–1.8 gm cm−3) that we can use as a construction material. In their review literature, Iwona Ryłko-Polak et al.mentioned that sulphur waste and biomass ash can be used to prepare good concrete and cement composites respectively. Products other than cement and concrete have been made by recycling hazardous waste, such as hydrocalumite-type materials were examined by R.Segni et. al.They introduced Cr, v and Si into hydrocalumite by co-precipitation and anion exchange method and examined XRD patterns of the samples. Jakub Hodul et al.had examined solidifica-

S. No.	Type of waste or by-products	Waste or by-products %	Curing days	Admixture	Admixture %	Water/Cement Ratio	Waste/Binder Ratio	Compressive Strength (MPa)
1.	Fly ash	20	7,28	Silica fume, Metakaolin	10, 30	0.33	0.2	108-127
2.	Fly ash	20	7,28	Metakaolin	20	0.40	0.2	58.4
3.	-	-	7,28	$CaCl_2 2H_2O$ $Ca(OH)_2$	10-30	0.36-0.40	-	1100 (kPa)
4.	Fly ash	16.5 g	7,28	Silica fume, Metakaolin	16.5 g	0.4,0.45	0.6,1.6	72-90
5.	RHA, PA	10 - 30	1,3,7,28, 51,90,180	$Cr(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$	>25	0.45-0.70	0.1-0.3	89.37
6.	SA, SMW	20	3,5,7,21,28, 28,51,90	$Ca(OH)_2$ lime stone	80	0.38	0.2-1	70-100
7.	PFyA	70	1,3,5,7,21, 28,51,91	Lime, Na_2SiO_3, Na_2CO_3	30, 4, 8	0.5	0.1-0.5	67–200
8.	Fly ash	40 - 60	7,28	Superplasticizer	4.5-5.1 liters/cu.yd	0.32-0.42	0.68,1,1.5	41
9.	Fly ash, Slag	57, 8 - 35	13,5,7,21,28, 51,91,151, 265-3650	Silica fume	7, 8, 12	0.30±0.01	1.3,0.4,0.5, 0.08	87.5-112.3
10.	GBFS, Fly ash	15 - 60	7,14,28	-	-	0.3-0.4	0.42	15.91-51.48
11.	GBFS, BA	20 - 50	28	Silica fume, waste glass	2.08,2.04	0.5,0.32,0.47	4.1-4.8	42.5
12.	Electroplating sludge	25	7, 28	Lime	10	1	0.5	35
13.	-	-	3 - 28	NaCl, Al_2O_3	3, 10	0.6	-	36.67
14.	Hazardous Wastes, Fly ash	10, 25	28	Clay	25, 40, 50, 90	.45 - .65	0.1, 0.25	250 Kg/m^2
15.	Sludge	15	3, 7, 28	-	-	0.4,0.5	0.15	Equal to contro
16.	Sludge & PFuA	0, 10, 20, 30	1-28-91	-	-	0.5	0.1, 0.2, 0.3	450, 80, 75 Kg/m^2
17.	-	-	3, 7, 28, 90	Silica fume, $Ca(OH)_2$	0 - 30	0.40	0.35, 0.4, 0.45, 0.50	55, 62
18.	POFA	10, 20, 30, 40	28, 90, 364	Lime stone	-	0.7, 0.72, 0.77, 0.87, 0.95	0.1, 0.25, 0.42, 1.5	30 – 37.6
19.	Sludge	2.5, 5, 10	7 - 90	Melcret PF - 75	1.68	0.55	0.1	18 - 32
20.	Fly ash, San fiber	35,45,55 0.25,0.50,0.75	28	Centriplast FF90 (melamine formaldehyde)	0.015	0.47 ± 0.02	0.35, 0.45, 0.55	26.7, 23.1

FIGURE 2. Factors affecting on concrete made of various industrial wastes and by-products by Smita Badur and Rubina Chaudhary

tion of neutralization sludge (NS) using three different formulas (3A, 3B, 7B). The results of compressive strength of solidification products marked that their strength is decreasing with time, while 3B and 7B formulae noted slight (SPs) increase in strength after 90 days. They explained the reason for the decrease of strength might be due to chemical reaction between non-reacted components of the NS and the matrix causing gradual degradation of the SPs. However, the work done by Jakub Hodul et al. succeeded in reducing the toxicity of waste by solidification but their potential of utilizing in building materials still has to be examined. They suggested optimal future applications of the solidification product that are shown in Fig-9. In the review literature of Richa singh et al., it was reported that waste such as fly ash, ground granulated blast furnace slag, rice husk ash, kaolin and metakaolin can be used as green binders by combining with sodium silicate and alkalis through geopolymerization. These binders can be replaced with cement in the solidification/stabilization process of hazardous waste. Fig-8 shows the production of the geopolymers. S.Srivastava et al. had experimented on sludge generated from Common Effluent Treatment Plant that has high concentrations of metals like Pb, Fe, Ni, Zn and Mn and Low calcium fly ash, and commercially available 53 grade Portland cement was used as a binder in solidification/stabilization process. In Table-2, samples with different compositions of fly ash and cement are given. They had conducted UCS tests, leaching tests and environmental tests for reference sample and alkali activated samples. It was found that UCS is decreasing for all waste/binder ratios except for reference sample with the increase of sludge percentage and Table-3 gives UCS results of all the samples. In order to achieve environmentally friendly s/s process for sustainable remediation, two hazardous wastes – contaminated marine sediment and municipal solid waste incineration (m.s.w.i) fly ashes were studied using Life cycle assessment (LCA) by various mixtures of different proportions, by M.U.Hossain et al.They evaluated samples for 17 scenarios under two technologies for reutilization of these hazardous wastes using LCA. Results of each strategy are observed and scenarios 1,6,10,15 and 17 were preferred over others in their respective strategies based on their impacts. They concluded that using calcium aluminates cement and supplementary cementitious materials as binders is a good idea for reducing environmental impacts. Karamazov had manufactured four sintered glass-ceramics from three industrial wastes (municipal solid waste incinerator (MSWA), jarosite (JAR) and flotation waste (FW)). These glass-ceramics exhibits mechanical properties that are alike natural stones and traditional tiling ceramics. The four glass-ceramics were labelled as G1 and G2 (MSWA composition), G3 (JAR composition) and G4 (FW composition). He had conducted TCLP, XRD and DTA test on the glass-ceramics and obtained materials that have very high chemical durability.

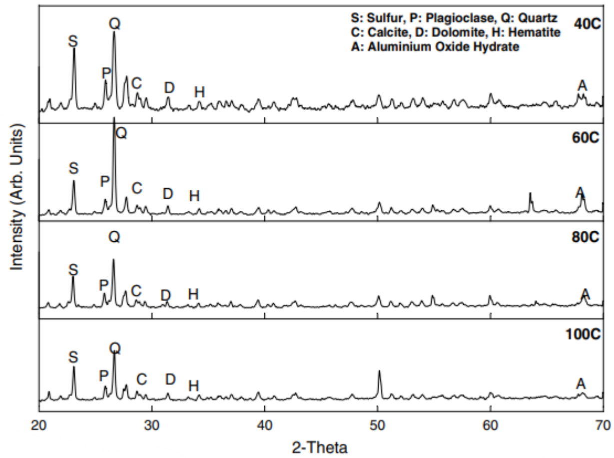

FIGURE 6. XRD of SPC sample cured for 7 days at different temperatures

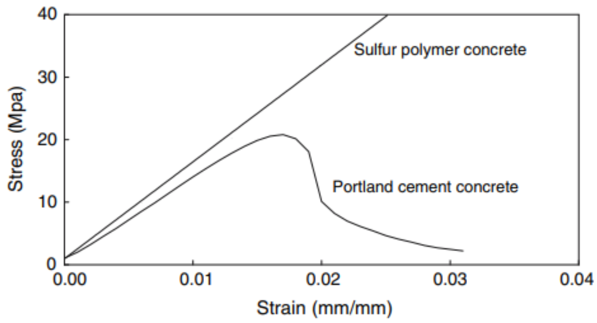

FIGURE 7. Stress-strain relationship of SPC and PPC

He demonstrated that granite like appearance of resulted glass-ceramics has good potential in modern architecture. In fig-10, sintered glass ceramics made from MSWI compositions are shown. Ettringites with selenate, chromate, borate, sulfite and carbonate replacing sulfate had been synthesized and

TABLE 1. Classification of materials based on strength and thermal characteristics RILEM standard(Rilem, 1978) by M.R. Ahmad et al

Mix ID	Compressive strength(MPa)	Thermal Conductivity ($Wm^{-1}K^{-1}$)				Classification
		20^0C	30^0C	40^0C	50^0C	
CM	3.49	0.177	0.221	0.238	0.241	Class-II
50FA	2.92	0.164	0.201	0.219	0.241	Class-III
50RM	4.26	0.139	0.174	0.177	0.192	Class-II
GP	3.81	0.127	0.147	0.15	0.18	Class-II

TABLE 2. Percentages of binders and sludge content used in preparation of samples

Sample no.	Sludge(%)	Cement(%)	Fly ash(%)
1	0	30	70
2	10	27	63
3	14.2	25.7	60
4	20	24	56
5	25	22.5	52.5
6	33	20	46.6
7	50	15	35

TABLE 3. UCS test results of the samples

Sample no.	Sludge(%)	UCS	
		7 Days	28 Days
1	0	20	21.4
2	10	18.5	18.6
3	14.2	16.5	17.4
4	20	17	17.8
5	25	13.5	15.4
6	33	11	13.4
7	50	10.5	12.2

checked for its use in hazardous waste immobilization (Mccarthy, Hassett, and Bender). Inert asbestos made from Industrial wastes can be used as a raw material in construction sector (Sergio et al.). The drilling solid waste is made up of drilling mud and rock cuttings and is collected from central field and piled up in a massive field and gradually calcined to bricks (Zhang et al.). Waste tyre products can be reused in the construction of highway/railway embankments and other field embankments (Mohit et al.).

3. Conclusion

In this paper, we have shown how wastes are encapsulated into building materials. Depending upon

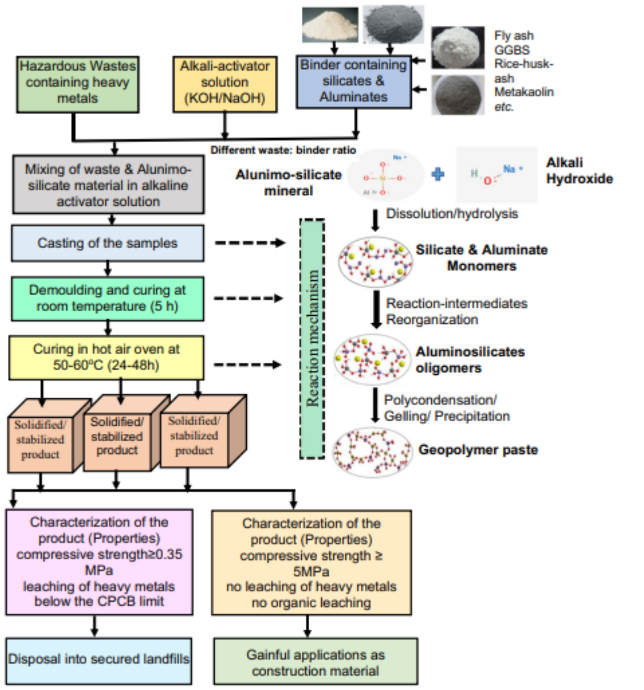

FIGURE 8. The production of geopolymers by solidification/stabilization (s/s) process and the corresponding mechanisms involved.

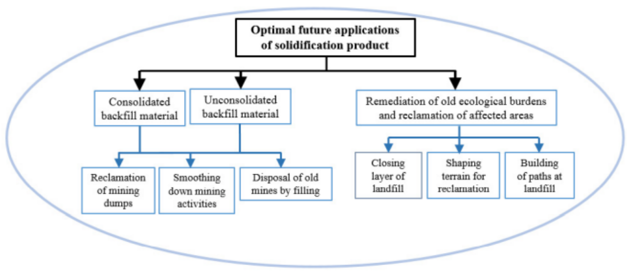

FIGURE 9. Optimal future application of solidification products

the nature and toxicity of wastes, they undergo various kinds of treatments. Later, the wastes are shaped such that they are viable to partially replace the building materials. Further, they are checked for their physical and mechanical characteristics.

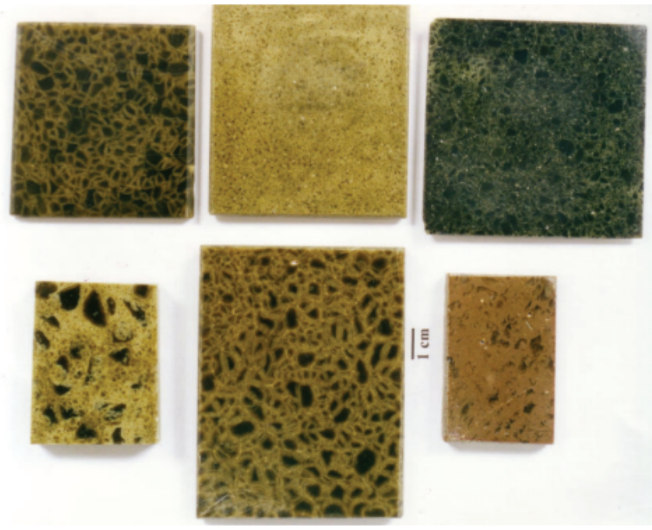

FIGURE 10. Sintered glass-ceramics based on MSWA

Since it has to be ensured that the wastes should not cause harm during its utilization, hence, toxicity tests were also done in many research studies. Life cycle assessment of the products needs to be done to ensure safe reuse of wastes. Government agencies have to perform standard tests for valorisation of reuse in construction materials, design new policies and create public awareness about hazardous waste generation and management as necessary steps to achieve sustainable environment with economical goals

4. Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the pa-per was free of plagiarism.

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Embargo period: The article has no embargo period.

To cite this Article: , Venkatesh G, Lahari K , and Balgovind Tiwari . "**Reuse of Hazardous Wastes in Construction Materials**." International Research Journal on Advanced Science Hub 05.05 May (2023): 181–188. http://dx.doi.org/10.47392/IRJASH.2023.034