CHEMICAL ENGINEERING TRANSACTIONS
VOL. 101, 2023
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Paolo Ciambelli, Luca Di Palma

ISBN 979-12-81206-00-7; **ISSN** 2283-9216
DOI: 10.3303/CET23101034

Recycling of Rubber and Polyethylene Terephthalate (PET) to Produce Ecological Bricks in Peru

Danny Lizarzaburu-Aguinaga*, Jaqueline D. Farfan Gomez, Elmer Benittes-Alfaro, Eusterio Acosta Suasnabar, Manuel G. Lizarzaburu Aguinaga, Rosalina Orrego Cumpa

César Vallejo University, Av. Alfredo Mendiola 6232 Los Olivos Lima Peru
dlizarzaburu@ucv.edu.pe

According to the World Economic Forum, (2016) 95 % of the material value of plastic packaging is lost (80 to 120 billion dollars), with the global recycling rate being 14 %, then there is a problem of exorbitant dimensions, To such an extent that for the, by the year 2050, it is estimated that 99 % of seabirds will ingest this material, also in the ocean there will be more plastic than fish. One type of plastic waste is discarded tires after their useful life. The present investigation had the objective of manufacturing ecological bricks incorporating in its structure rubber (R) and Polyethylene terephthalate (PET) which are plastic components of used tires, to partially replace conventional aggregates in the manufacture of bricks. In the process, the specifications of these bricks are compared with the physical and mechanical characteristics indicated in standard E. 0.70 of the Ministry of Housing, Construction, and Sanitation (MVCS). Manufacturing was tested with doses of 12 %, 24 %, and 36 % of R and PET together with cement and silica in the mixture, obtaining average compressive strength mechanical values of 174.71 kg/cm^2, 134.02 kg/cm^2, and 71 kg/cm^2 for the indicated compositions, which classifies it as type V, type IV, and type III bricks respectively (NTP 399.604 and NTP 399.613). The most optimal dose was 12 % R and PET, 50 % cement, and 25 % silica, which corresponds to type V brick. This use of waste is done within the concept of circular economy in the life cycle of the materials.

1. Introduction

In 2015, 47 % of plastic waste worldwide (300 million tons) was represented by single-use containers, in addition, this situation is worsening since in the last 60 years the growth of waste plastics has been sustained in the world, it has been Asia and North America that generated the most (Geyer et al., 2017). R and PET are two types of plastics that are produced in excess worldwide, which is why an adequate practice would be to reuse them when disposing of them (buried in landfills, incinerated, or discarded) since they produce environmental impacts by producing toxic elements (dioxins and furans), contribute to the generation of greenhouse gases (GG), contamination of bodies of water, affectation of wildlife, etc. (United Nations Environment Programme, 2019).In 2019, the world consumption of rubber was 28.9 million tons (Malaysian Rubber Board, 2020), generating around 1,200 million tires that are discarded annually, this residue has a high persistence in the environment, so recycle them and give them life useful in the construction industry making bricks, it is an alternative with a certain advantage, such as lightening the weight of the brick. There is research such as the one that seeks to incorporate these products with far-reaching impact into the circular economy, recycling tire rubber and polyethylene terephthalate in the production of construction elements (Van Fan et al., 2022).The consumption of PET in the USA in 2013 was 21.3 million beverage container units, making it the second type of container preferred by consumers (Kang et al., 2017), this type of container ends up, to a large extent, being discarded, thus sharing the problem of persistence over time, so recycling them for use in construction materials is an attractive alternative.In this concern, the research was raised to incorporate tire rubber and PET instead of concrete or clay in the production of ecological bricks, and evaluate the standard mechanical behavior to allow the recycling of this waste to be viable (Liang et al. al., 2017). Research related to the use of rubber tires (Ajay Kumar et al., 2019) or the use of PET (Alighiri et al., 2019) to partially replace the

Paper Received: 21 March 2023; Revised: 02 May 2023; Accepted: 09 June 2023
Please cite this article as: Lizarzaburu Aguinaga D., Farfan Gomez J.D., Benites-Alfaro E., Acosta Suasnabar E., Lizarzaburu Aguinaga M.G., Orrego Cumpa R., 2023, Recycling of Rubber and Polyethylene Terephthalate (PET) to Produce Ecological Bricks in Perù, Chemical Engineering Transactions, 101, 199-204 DOI:10.3303/CET23101034

fine aggregates in bricks, has given favorable results, substantiating the research idea to use both residues to make building blocks. The positive impact of this research lies in the opportunity to prove that the waste that is commonly discarded outdoors can be included in a new process, responding to a circular economy model to reduce the GG that is produced during the burning in the manufacture of conventional brick.

2. Methodology

In the production of the ecological bricks, four stages were followed (see Figure 1) taking into account the methods and instruments necessary for the recycling of waste (rubber from tires and PET) as a substitution of conventional aggregates, verifying compliance with the physical-mechanical tests. established in national regulations (González-Montijo et al., 2019).

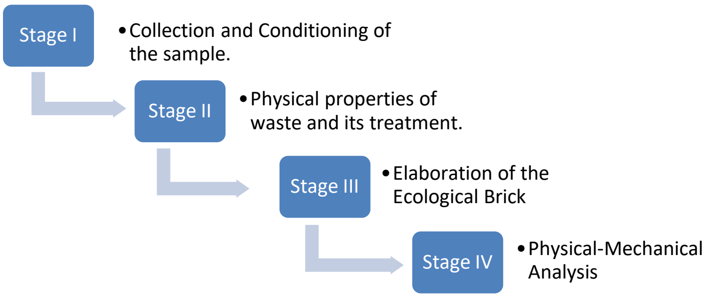

Figure 1: Procedure for the elaboration and analysis of handmade bricks.

Stage I: Collection and conditioning of the sample, here the sample of the recycled material (Rubber tires and PET) is extracted, cleaned, and washed under pressure.
Stage II: Determine the physical properties of rubber tires and PET, the volume is weighed and calculated (Eq1), and the textile fiber and steel were extracted from the waste directly and measured with a tape measure, odor, color, and elasticity. were evaluated by direct observation, the insolubility was determined through a 10% organic solution of benzene, and the temperature and the abrasion resistance were determined by exposing the tire to a metallic roller, this resistance to abrasion increases according to the amount and type of carbon black (Color Index International PBL-7) and with the help of a digital stopwatch the exposure time was measured. The temperature was measured with an infrared thermometer. The rubber and PET were crushed and scraped in a small-size grinding machine that can be mixed and homogenized with the other compounds (30 kg of rubber and 16 kg of polyethylene terephthalate), 500 g of sample was sieved according to the ASTM D-422 standard in 5 different mesh sieves (N°45, N°30, N°18, N°10, N°06). Density was determined by the beveled cylinder method with the use of Eq2. With the thermogravimetric method according to the ASTM D-3172 standard, the moisture percentage was found with Eq3. The volatile matter (%) is the carbon released when heating the material to 900 °C and discounting the hygroscopic humidity, Eq4 was used. The percentage of Ash considers the remaining residue after burning the coal, destroying the organic matter, and leaving the minerals, Eq5 was used. The percentage of fixed Carbon that represents the portion that must be burned in the solid state was used in Eq6 (Małek et al., 2021).

$$V = \pi \, x \, r^2 x h \qquad Eq(1)$$

$$\rho = \frac{Dry\ material\ weight\ (g)}{V\ (m^3)} \qquad Eq(2)$$

$$\%\ Humidity = \frac{(crucible\ weight\ +\ sample) - (crucible\ weight\ +\ sample\ at\ 105\ °C)}{(crucible\ weight\ +\ sample) - (crucible\ weight)} x\ 100 \qquad Eq(3)$$

$$\%\ Volatile\ Matter = \frac{(crucible\ weight\ +\ sample) - (crucible\ weight\ +\ sample\ at\ 900\ °C)}{(crucible\ weight\ +\ sample) - (crucible\ weight)}\ x\ 100 \qquad Eq(4)$$

$$\%\ Ash = \frac{(crucible\ weight\ +\ sample\ at\ 900\ °C) - (crucible\ weight)}{(crucible\ weight\ +\ sample) - (crucible\ weight)} x\ 100 \qquad Eq(5)$$

$$\%\ Fixed\ Carbon = 100 - (\%\ Ash + \%\ Volatile\ Matter) \qquad Eq(6)$$

Step III: Elaboration of ecological bricks, instead of conventional clay, bricks were made taking doses of 12 %, 24 %, and 36 % of the recycled rubber-PET mixture (See figure 2a) in the total composition of the brick (the percentage was in equal parts of rubber and PET). For rubber, it was taken from the fractions retained in meshes No. 30 (0.6 mm), No. 18 (1 mm), No. 45 (0.355 mm), and for PET from meshes No. 06 (3.5 mm). No. 10 (2 mm) and No. 18 (1 mm). For each dose, 3 prototypes with 3 repetitions were made (See figure 2b). The components are mixed and characterized (pH, electrical conductivity, temperature, and redox potential). Then the mixtures are loaded into a steel mold (See figure 2c) and hydraulically pressed exerting a pressure of 5 t to achieve adequate compaction (Rojas and Vidal, 2014) obtaining the "ecological brick" as a product, then they are dried. Step IV: Physical-mechanical analysis of the brick, Dimensions (mm), Weight (kg), Volume (cm^3), Density (g/cm^3), Warping (mm), Absorption (%), Compressive strength (kg) is determined /cm^2).

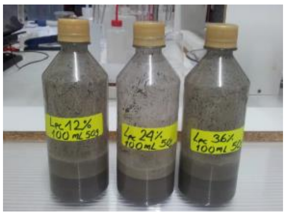

Figure 2a: Craft brick mixes (12 %, 24 % and 36 %)

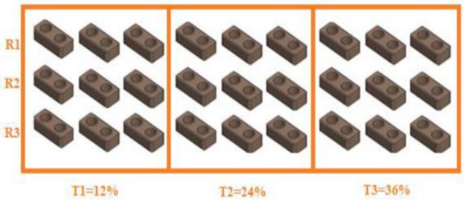

Figure 2b: Doses and repetitions of the handmade bricks

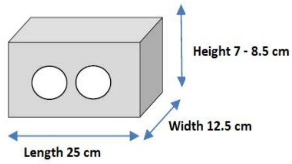

Figure 2c: Craft brick unit

3. Results and discussion

3.1 Physicochemical parameters of Rubber and PET.

Table 1 shows the results obtained from the initial sample of each residue, considering the physicochemical parameters of rubber (R) and PET.

Table 1: Physicochemical parameters of plastic waste

Property / Material	Volume (m^3)	Average weight (kg)	Textile fiber (m)	Steel (m)	Color/Smell
Rubber	2.26289448	10,913	1.25	0.80	Carbon black / Pneumatic
PET	0.0012	8.20	-	-	Transparent / Odorless
Property / Material	**Elasticity**	**Softening with heat**	**Abrasion resistance**	**Stickiness**	**Insolubility in solution with benzene.**
Rubber	Yes	No	Slow	No	Yes
PET	-	-	-	-	-
Property / Material	**Density (g/cm^3)**	**Humidity (%)**	**Volatile Matter (%)**	**Ash (%)**	**Fixed Coal (%)**
Rubber	0.55	1.35	44.54	3.16	52.30
PET	0.006	0.88	83.36	1.16	15.48

From the values shown in the table, it can be indicated that the abrasion resistance is slow, due to the loss of volume and the increase in temperature in the rubber of the tire, making the tire's lifespan long, the higher density of rubber on PET shows that rubber would occupy more space than PET, intervening in the porosity and compaction of the brick unit (ISO, 2010). The volatile matter of PET (83.36 %) is greater than that of rubber (44.54 %), this prevents the risk of spontaneous combustion from being greater, and the ashes improve the pozzolanic properties of the mortar (Farfan Gomez, 2019).

3.2 Physicochemical parameters of ecological bricks.

The physicochemical characterization of the mortar mixture (12 %, 24 %, and 36 %) of the ecological brick resulted in the values of Table 2.

Table 2: Physicochemical parameters of the ecological brick mixtures.

Repetition	Property							
	Temp. (°C)	pH (1-14)	EC (µS/cm)	redox (∑h)	Humidity (%)	Volatile Matter (%)	Ash (%)	Fixed Coal (%)
R1 - 12 %	25.4	12.45	10,350	-289	18.46	8.03	89.4	2.57
R2 - 12 %	24	12.49	10,310	-292	18.48	8.04	89.46	2.5
R3 - 12 %	23.6	12.43	10,316	-288	18.45	8.02	89.44	2.54
R1 - 24 %	24.2	12.47	7,990	-288	20.33	17.86	65.37	16.77
R2 - 24 %	24	12.45	7,989	-285	20.36	17.85	65.35	16.8
R3 - 24 %	23.6	12.46	7,992	-286	20.34	17.88	65.36	16.68
R1 - 36 %	24.2	12.6	10,018	-295	23.51	27.02	58.07	14.91
R2 - 36 %	24	12.63	10,025	-296	23.56	27.04	58.09	14.87
R3 - 36 %	23.6	12.59	10,020	-297	23.54	27.06	58.08	14.86

Note. R1-X%: repetition 1 to x%

The average values of the determined physicochemical parameters were 24.33 °C, 12.46 pH, 10,325 µS/cm of electrical conductivity (C.E.), -289.67 ∑h of Redox potential, 18.46 % humidity, 8.03 % volatile matter, 89.43 % ash and 2.54 % of fixed carbon for the three repetitions with a dose of 12 % (RX-12 %); In the case of the three repetitions with the second dose (RX-24 %), the averages were 23.9 °C, 12.46 pH, 7,990 µS/cm E.C., -286.3 ∑h Redox, 20.34 % humidity, 17.86 % volatile matter, 65.36 % ash, and 16.75 % fixed carbon; finally 23.90 °C, 12.61 pH, 10,021 µS/cm C.E., -296 ∑h Redox, 23.54 % humidity, 27.04 % volatile matter, 58.08 % ash and 14.88 % fixed carbon for the three repetitions with the third dose (RX-36 %).

3.3 Analysis of ecological bricks according to the E.070 Masonry standard.

In the first analysis carried out, the dimensions, weight, volume, and density of the 27 brick units with rubber and PET were determined (See Table 3 and Figure 4), to classify it as a brick according to NTP 399.604 and NTP 399.613. From the results obtained, the class of masonry unit is defined for its use and application for structural purposes. The environmental conditions during the analysis were 20.3 °C ambient temperature and 72 % relative humidity.

Table 3: Average of the dimensional analysis, weight, volume, density, warping, brick absorption

Sample Average	Dimensions (mm)			Weight (kg)	Volume (cm^3)	Density (g/cm^3)	Warp (mm)	Absorption (%)	Compressive strength (kg/cm^2)
	Length	Width	Height						
LCP12%-±X	248.6±0.73	123.7±1.06	79.1±2.05	3.82	2431.89	1.59	2.13	1.55	174.71
LCP24%-±X	249.8±0.09	121.8±2.06	81.3±4.90	3.93	2474.15	1.59	2.08	1.55	134.02
LCP36%-±X	245.3±1.40	122.2±0.02	90.0±0.15	3.79	2711.78	1.40	2.13	1.64	97.93

Note: LCP12% ± x: Brick with R residues and 12% PET ± variation

The dimensional variation of the 27 units, for the brick sample with 12 % recycled material in the dimensional test showed ± 0.73 mm in length, ± 1.06 mm in width, and ± 2.05 mm in height. The brick with 24 % recycled material gave ± 0.09 mm length, ± 2.06 mm width, and ± 4.9 mm, and the brick with 36 % recycled material gave ± 1.40 mm length, ± 0.02 mm width, and ± 0.15 mm; this affects the compressive strength and shear strength of the wall due to the thickness of the joints.The average weight of the structural unit was 3.82 kg (12 %), 3.93 (24 %), and 3.79 (36 %), comparing a 3-hole concrete brick that weighs approximately 4.5 kg, it can be inferred that the recycled rubber and plastic reduced the weight of the structural unit (Lamba et al., 2022, p.13).The average density for the brick of 12% recycled material was 1.59 g/cm^3 the same as the 24 % unit and the density is reduced to 1.40 g/cm^3 for the 36 % unit (Małek et al., 2021).The warping, the averages are 2.13 mm, 2.08 mm, and 2.13 mm for bricks with 12 %, 24 %, and 36% recycled plastic respectively, this concavity or convexity generates a decrease in adherence with the mortar by forming spaces in the area of greater warpage (INDECOPI, 1978).The average absorption (internal moisture content) was 1.55% for 12% and 24% bricks, for 36% bricks the absorption was 1.64%; the 24-hour test determined that as absorption increases, the brick surface is more porous and therefore less resistant to weathering (INDECOPI, 2002), as demonstrated in the research by Tayeh et al., (2023) who made an ecological brick with sugarcane pulp sand and paper. The resistance to compression (see Figure 3) has to do with the fractions water/cement, cement/aggregate, the granulometry used, the hardness, angular profile and texture of the aggregate; To determine their values, manual uniaxial equipment was used, where it was identified that there is an inversely proportional behavior to the % of recycled plastics, it was found for bricks with 12% the average was 174.71 kg/cm2, for bricks with 24% the average was 134.02 kg/cm2 and for bricks, with 36% it was 97.93 kg/cm2; With these results, the structural units with each type of brick were classified.

a: Measurement *b: Heavy* *c: Concavity* *d: Absorption test* *e: Compressive strength.*

Figure 3: Characterization of the ecological brick

3.4 Classification of structural units made of recycled material.

Ecological brick is the name given to the structural unit of masonry whose size and weight allow it to be manipulated with one hand, it is solid and was manufactured by hand with cement, silica, rubber and PET whose granulometry less than 3.5 mm influences the pozzolanic activity of the mixture. and the properties of the mixed cement (Zhao et al., 2020), this unit has been cured with water (24 hours) and has a term of 28 days, where they reach their specific resistance and volumetric stability to be released (MVCS, 2006).

Table 4: Brick-type classification based on the results.

Brick-type	Classification according to E.070			Final Classification
	Dimension variation	Warp	Compressive strength	
LCP12%	Brick V	Brick V	Brick IV	Brick V
LCP24%	Brick V	Brick V	Brick IV	Brick V
LCP36%	Brick V	Brick V	Brick III	Brick IV

Note: LCPX: Brick with residues R and PET at X%

According to the properties found, the ecological bricks can be manufactured with the use of recycled rubber and PET, with a dimensional variation that allowed classifying the LCP12% unit as a type V brick, the LCP24% unit as type IV and the LCP36% unit. unit as type V due to its millimeter variations, the warpage had values of 2.13 and 2.08, placing it in the classification of type V brick, the absorption indicates that it is type V with values well below the norm (12%), in terms of compressive strength LCP12% units are classified as type V, LCP24% type V and LCP36% type III; all the specimens made comply with the physical and mechanical characteristics required in the masonry standard E 0.70. As indicated by Nasr et al. (2020), these ecological bricks have unique properties, and this is also because the preparation of the mortar was developed by mixing the recycled material until it was homogenized with cement and silica and curing with water; As an environmental benefit, this type of brick is distinguished from the commercial ones because it does not generate CO2 emissions when burned, the substitution of plastics prevents its final disposal and reduces the consumption of virgin materials (Gounden et al., 2022). As an economic benefit, it would reduce the cost of the construction unit, so access to housing would be more accessible for low-income populations, as Rizwan et al., (2019) has stated and without modifying the construction techniques, hoping that by increasing the scale This brick has a behavior like the commercial one according to the brick classification of the Peruvian standard (MVCS, 2006). It is important to highlight that the LCP36% has lower quality characteristics within the final classification of masonry units, also the LCP12% unit has the same final classification as the LCP24% unit, however, a lower percentage of waste can be recycled Therefore, the LCP24% unit would be the most optimal because it is the best alternative to recycle rubber and PET waste that is harmful to the environment, within the objectives of sustainable development.

4. Conclusion

With the results obtained, it is verified that the handmade manufacture of an ecological brick using recycled rubber and polyethylene terephthalate, has exceeded the values required by the Peruvian standard, therefore the optimal dose of 24% PET and recycled rubber together with 50% cement and 26% silica allows the reuse of solid waste without losing the physical-mechanical characteristics of the construction unit. About these physical-mechanical characteristics, the results position the unit of 24% (optimal) in the type V classification with 1 mm width, 3 mm length, 5 mm height, a warpage of 2.08 mm, and 1.55% absorption. characteristics provide a positive effect on the compressive strength in a mechanically tested wall with a value of 134.02 kg/cm2.

References

Ajay Kumar D., Venkat Rao N., and Papolu R. M. R, 2019, Affect of waste tyre rubber recycle properties of concrete by partial replacement of coarse aggregate with rubber. International Journal of Innovative Technology and Exploring Engineering, 8(12), 1984–1988. doi.org/10.35940/ijitee.L2910.1081219

Alighiri D., Yasin M. N., Rohmawati B., and Drastisianti A., 2019, Processing of recycled waste PET (polyethylene terephthalate) plastics bottle into for the lightweight and reinforcement bricks. Journal of Physics: Conference Series, 1321(2). doi.org/10.1088/1742-6596/1321/2/022023

Farfan Gomez J, 2019, Uso de caucho reciclado y tereftalato de polietileno (PET), para la elaboración de ladrillos ecológicos a nivel artesanal en el distrito de Chorrillos. In Universidad César Vallejo.

Geyer R., Jambeck J. R., and Law K. L, 2017, Production, use, and fate of all plastics ever made. Science Advances, 3(7), 3–8. doi.org/10.1126/sciadv.1700782

González-Montijo M. A., Soto-Toro H., Rivera-Pérez C., Esteves-Klomsingh S., and Suárez O. M, 2019, Design and characterization of concrete masonry parts and structural concrete using repurposed plastics as aggregate. Journal of the Mechanical Behavior of Materials, 28(1), 81–88. doi.org/10.1515/jmbm-2019-0010

Gounden K., Mwangi F. M., and Mohan T. P, 2022, A Perspective on Four Emerging Threats to Sustainability and Sustainable Development. Earth, 3(4), 1207–1236. doi.org/10.3390/earth3040069

INDECOPI, 1978, NORMA TECNICA PERUANA PERU NORMA TECNICA NACIONAL ELEMENTOS DE ARCILLA COCIDA Ladrillos de Arcilla usados en Albañilería. <ladrillositalperu.com> accessed 11.05.2023.

INDECOPI, 2002, Unidades de albañilería. Métodos de muestreo y ensayo de unidades de albañilería de concreto. In Norma Técnica Peruana 399.604: Vol. 1era edici. <kupdf.net/download/norma-tecnica-peruana-ntp-399604-2002_59efca8908bbc537369d180e_pdf> accessed 06.05.2023.

International Standarization Organization, 2010, Rubber, vulcanized or thermoplstic - Determination of abrasion resistance using a rotating cylindrical drum device.

Kang D. H., Auras R., and Singh J, 2017, Life cycle assessment of non-alcoholic single-serve polyethylene terephthalate beverage bottles in the state of California. Resources, Conservation and Recycling, 116, 45–52. doi.org/10.1016/j.resconrec.2016.09.011

Lamba P., Kaur D. P., Raj S., and Sorout, J, 2022, Recycling/reuse of plastic waste as construction material for sustainable development: a review. Environmental Science and Pollution Research, 29(57), 86156–86179. doi.org/10.1007/s11356-021-16980-y

Liang J., Du X., Liu P., and Shi J, 2017, The effect of different admixtures on the basic properties of recycled pervious concrete. Chemical Engineering Transactions, 59, 355–360. doi.org/10.3303/CET1759060

Malaysian Rubber Board, 2020, Natural Rubber Statistics 2020.

Małek M., Łasica W., Kadela M., Kluczyński J., and Dudek D, 2021, Physical and mechanical properties of polypropylene fibre-reinforced cement–glass composite. Materials, 14(3), 1–19. doi.org/10.3390/ma14030637

MVCS, 2006, Norma E.070 Albañilería. El Peruano, 295–309. <busquedas.elperuano.pe/normaslegales/decreto-legislativo-que-aprueba-el-codigo-de-responsabilidad-decreto-legislativo-n-1348-1471548-8/> accessed 15.02.2023.

Nasr M. S., Shubbar A. A., Abed Z. A. A. R., and Ibrahim M. S, 2020, Properties of eco-friendly cement mortar contained recycled materials from different sources. Journal of Building Engineering, 31(March), 101444. doi.org/10.1016/j.jobe.2020.101444

Programa de las Naciones Unidas para el Medio Ambiente, 2019, Plásticos De Un Solo Uso. In Tecnology for Enviroment (Vol. 227, Issue 5).

Rizwan M., Khan W., Bhargava R., and Salim M, 2019, Sustainable development of eco-friendly economical construction material by using of waste plastic bottles & fly ash. AIP Conference Proceedings, 2158(September). doi.org/10.1063/1.5127144

Tayeh B. A., Ahmed S. M., and Hafez R. D. A, 2023, Sugarcane pulp sand and paper grain sand as partial fine aggregate replacement in environment-friendly concrete bricks. Case Studies in Construction Materials, 18, e01612. doi.org/10.1016/j.cscm.2022.e01612

World Economic Forum, 2016, The new plastics economy: Rethinking the future of plastics. Ellen MacArthur Foundation, January, 120. <www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf> accessed 15.02.2023.

Zhao Y., Gao J., Liu C., Chen X., and Xu Z, 2020, The particle-size effect of waste clay brick powder on its pozzolanic activity and properties of blended cement. Journal of Cleaner Production, 242, 118521. doi.org/10.1016/j.jclepro.2019.118521