Research Journal of Applied Sciences, Engineering and Technology 14(5): 196-202, 2017
DOI:10.19026/rjaset.14.4289
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: December 12, 2016 Accepted: March 19,2017 Published: May 15, 2017

Research Article

On the Review of Glass Reinforced Concrete

As'ad Munawir
Department of Civil Engineering, Malang 65141 Brawijaya University, Indonesia

Abstract: This review aimed to explore different use of glass wastes in the form of sand or cullet as an alternative fine or coarse aggregates or others for projects that will fulfill the government regulation to assist the industry rescuing the environment. Although glassy wastes satisfy recycling goals, but in the concrete structures application, although easy sustain good product performance, but in the long term glass waste suffer a serious problem due to Alkali-Silica Reaction (ASR) phenomena. This study basically explore several extensive studies were carried out to counter this. Using recent advances this matter was mainly overcomed. The effective of waste glass application in spreading novelty markets as well as paving stones, concrete masonry blocks, terrazzo tiles and precast concrete panels. Beside its problem, glass waste seems a great material to civil engineering application.

Keywords: ASR, glass concrete, glass waste, sand replacement

INTRODUCTION

The construction material around the world, half are used for building, bridges, dams, tunnel, flyover *etc* and half became the waste. These materials have strong effect on the environment in its every construction step such as raw material extraction, processing, fabrication, delivery and finally become construction and demolition waste and these cycles chain can be depicted in Fig. 1.

Economic Co-operation and Development report that construction responsible for 30% natural material, 42% energy, 25% water, 12% land, 40% atmosphere emission, 25% waste and 13% others from all used. McCoole *et al*. (2012) in the National Waste Report data 2010 show that 22,707,000 ton or 52% from Australian was having been recycled. Grocon's Pixel, was the one of recycled-made building was depicted in Fig. 2.

Although glassy wastes satisfy recycling goals, but in the concrete structures application, industry need to know different use of glass wastes well. Hence, this review describe the state of the art of glass wastes in the form of sand or cullet as an alternative fine or coarse aggregates or others for projects that will fulfill the government regulation to assist the industry rescuing the environment.

LITERATURE REVIEW

Glass material: Virgin glass, in general, is a molten mixture of sand (silicon dioxide-*a.k.a.* silica), soda ash (sodium carbonate) and/or limestone super-cooled to form a rigid solid. Glass beads, in particular, are a product of recycled soda-lime glass. This material's primary source is from manufacturing and postconsumer waste. At recycling centers, recovered glass is hand sorted by color (clear, amber and green) and then crushed to customized sizes (Illinois Department of Transportation, 2002).

In 1674 George Ravenscroft was granted a patent for glass manufacture and the Glass Sellers entered into an agreement with him to buy all of the glass that he produced (Dungworth and Brain, 2005). Glasses, in the current sense of the term, are essentially non-crystalline materials obtained by using together silica (sand) with *Na* and *Ca* oxides (in the form of carbonates), which act as fluxes and lower the processing temperature. The resulting melt is cooled at a sufficient rate to avoid crystallization and then shaped into different forms: flat sheets, containers, fibers. Non-crystalline solids, glasses and amorphous materials alike now play an increasingly important role in modern technology. Besides common glass, which is an indispensable material in today's economy in architecture, transport, lighting, conditioning, etc., there is a whole set of glasses and amorphous materials which enter into more and more sophisticated applications in optics, electronics, optoelectronics, biotechnologies, etc. (Zarzycki, 1991). Figure 3 shows the percentage of glass product in year 2007.

Glasses have an amorphous structure and a wide range of compositions. Oxide-based glasses can be classified as silicates, borates, phosphates, or germanates, depending on which of the glass-forming

Fig. 1: Construction-demolition cycle chain

Fig. 2: Grocon's Pixel, made from recycled waste

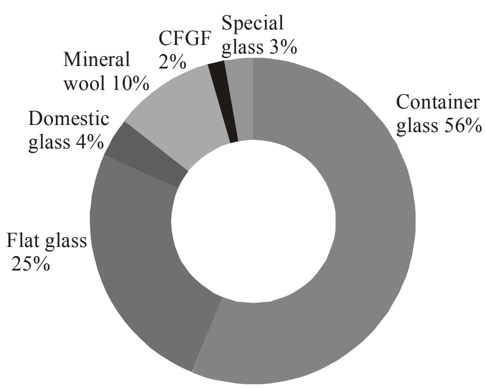

Fig. 3: Sectors of the glass manufacturing industry and their percentage contributions to the total production volume; Source: Vieitez *et al*. (2011)

oxides (SiO_2, B_2O_3, P_2O_5, or GeO_2) make up the structure (Harper, 2001).

Glass waste and its values in applications: The U.S. glass industry includes establishments engaged in manufacturing flat glass, container glass, specialty glass and fiberglass. These four primary industry segments produce over 20 million tons of glass per year, with a value of over $16 billion (Worrell *et al*., 2008). The process of glass wastes recycling from glass cullet into

Fig. 4: Recycling process from post-consumer glass waste into glass cullet's and glass sand grain; Source: Bangil recycling

glass cullets and then formed into glass sand shown in Fig. 4.

Mixed, colored, broken glass can be used in flowable concrete. This flowable concrete exhibits decreased permeability, which could prevent future leaching of heavy metals or other undesirable compounds. Due to the strong potential for Alkali-Silica Reaction (ASR) between cement alkalis and reactive silica in glass, using glass as a coarse or fine aggregate also requires the use of Class F fly ash to control ASR (Naik, 2002). Concrete Materials Research at Columbia University underlined for concrete

Fig. 5: Current and potential application of developed glass-concrete products in construction industries, Ling *et al*. (2013)

masonry blocks that by initially limiting the goal of aggregate replacement by glass to 10%, the solution of the ASR problem seemed to be manageable. In addition, it was found that very finely ground glass (of size 38 μm or less) has pozzolanic properties and therefore may serve as an effective partial cement replacement (Concrete Materials Research, 2000).

Glass aggregate has been investigated by many state DOTs including New York, Washington and Pennsylvania. Since the 1960s, Washington DOT has used a portion of glass aggregate in bituminous concrete pavements. This aggregate material is also used in backfill for foundations, pipe bedding and other applications not subject to heavy repeated loading. When glass is properly crushed, this material exhibits coefficient of permeability similar to coarse sand. Also, the high angularity of this material, compared to rounded sand, may enhance the stability of asphalt mixes. In general, glass is known for its heat retention properties, which can help decrease the depth of frost penetration (Illinois Department of Transportation, 2002). Figure 5 explores the potential market of glass waste as civil engineering application.

For many years, the recycling and waste management industry has struggled with the problem of identifying or developing reliable markets for mixed-color broken glass. To date, only low-value applications are available, which do not utilize the physical and other inherent properties of the glass. Recent research has made it possible to use such glass as aggregate in concrete, either in commodity products, with the only objective being to utilize as much glass as possible, or in value-added products that make full use of the physical and esthetic properties of color-sorted crushed glass. The potential applications are basically limitless and it is expected that commercial production of specialty glass concrete products will have a major impact on the economics of glass recycling (Meyer *et al*., 2001).

A review on the use of waste glasses in the production of cement and concrete was studied by Shi and Zheng (2007). The economic benefits from the reuse of recycled waste glasses in cement and concrete production can also be very significant. In US, the tipping fee for landfill usually ranges from $40 to 100/ton of waste, while the concrete aggregates cost about $5-15/ton and supplementary cementing materials cost about $30-80/ton. The grinding cost may range from $15 to 30/ton depending on the production scale (Shi and Zheng, 2007).

Although a number of initiatives have been made both by the government and the private sector to promote waste glass recycling, for example in big city, but there is still hundred tons of waste glass require landfill disposal every day. There is a need to find alternative ways to recycle and develop a reliable market for this waste type (Ling *et al*., 2013).

DISCUSSION

State of the art of glass waste research in concrete and others: Some mechanical properties of glass fibre reinforced concrete at elevated temperatures were discussed by Purkiss (1985) but he explained that the residual compressive strength is independent of the volume fraction of fibres and there appears to be no benefit in the flexural tensile strength by the addition of glass fibres.

Municipal waste glass has been investigated by Polley *et al*. (1998) for use as an aggregate for Portland cement concrete to provide an additional option for communities targeting glass for recycling and to potentially reduce the costs of glass disposal and concrete production. Results of their study indicate glass aggregate to be a satisfactory substitute for natural fine aggregate at replacement levels up to 20% of the total aggregate and at a glass gradation between 75 μm and approximate 1.5 mm, with strength comparable to control concrete at comparable w/(c+f) ratios.

Shao *et al*. (2000) study on concrete containing ground waste glass. Compared to fly ash concrete, glass concrete had a higher early strength as well as a higher late strength. The high early strength could be attributed to the high alkali content in soda-lime lamp glass. Nevertheless, the high alkali content in mixture did not deteriorate the strength of the concrete at a late age.

Value-added utilisation of waste glass in concrete was researched by Shayan and Xu (2004) and they have been concluded that 30% fine glass powder could be incorporated as cement or aggregate replacement in concrete without any long-term detrimental effects. Up to 50% of both fine and coarse aggregates could also be replaced in concrete of 32-MPa strength grade with acceptable strength development properties.

Park *et al*. (2004) study on the mechanical properties of concrete containing waste glass aggregate and they noted this summary. The compressive, tensile and flexural strengths of concretes containing the waste glass aggregates demonstrated a decreasing tendency along with an increase in the mixing ratio of the waste glass aggregates. The concrete containing waste glass aggregates of 30% mixing ratio gave the highest strength properties. Additionally, the mechanical properties of the concretes did not display any notable differences depending on color of the waste glass aggregates.

Topcu and Canbaz (2004) carry out about the properties of concrete containing waste glass. When hardened concrete specimen properties were analyzed, compressive, flexural and indirect tensile strengths as well as Schmidt hardness values were determined to decrease in proportion to an increase in waste glass. In particular, the compressive strength decreased as much as 49% with a 60% of waste glass addition. They conclude that using waste glass in preference to fine aggregate would produce better results assuming that its geometry be more proper and almost spherical.

Lam *et al*. (2007) point that it was not feasible to produce durable concrete paving blocks with the use 100% recycled crush glass without the use of mineral admixtures as ASR suppressant. Good quality and environmentally friendly paving blocks can be produced by 100% recycled material as aggregate which consists of 50% recycled crush glass and 50% recycled fine aggregate with an addition of 10% by weight of total aggregate of pulverized fuel ash.

A detailed investigation into the potential use of expanded porous recycled waste glass was carried out by Petrella *et al*. (2007). They concluded that there is a potential use of these materials for the manufacture of floors roughs and specifically for the installation of lightweight insulating layers.

Properties of concrete contain mixed colour waste recycled glass as sand and cement replacement was examined by Taha and Nounu (2008). They say that due to the inherent smooth surface and negligible water absorption of glass particles, the presence of recycled glass sand in concrete will reduce the consistency of the concrete mix and adhesive bond of the ingredients inside the concrete mix. Therefore, severe bleeding and segregation were observed when natural sand was replaced by waste recycled glass sand and plastic properties of the concrete mix undergo notable changes.

Taha and Nounu (2009) utilizing waste recycled glass as sand/cement replacement in concrete. No major changes were found in the compressive strength of concrete with the presence of recycled glass sand in concrete as 50 or 100% as sand replacement. But, it was confirmed in their study that the use of recycled glass sand in concrete as sand replacement possesses high risk of Alkali Silica Reaction (ASR). Extreme damage due to the ASR cracking was observed when recycled glass sand was represented in concrete.

Ismail and Al-Hashmi (2009) research on the recycling of waste glass as a partial replacement for fine aggregate in concrete. The optimum percentage of waste glass that gives the maximum values of compressive and flexural strengths is 20%. Using finely ground waste glass in preference to fine aggregate could produce promising results, assuming that the geometry will be less heterogeneous.

Limbachiya (2009) shows that test results show that up to 20% waste glass sand has no influence on the compressive strength of concrete, but thereafter there was a gradual reduction in strength with increase in waste glass sand content. Limbachiya *et al*. (2012) also observed the performance of granulated foam glass concrete and emphasize that the effect of coarse granulated foam glass was strongly related to the w/c and the proportion of the foam glass embedded. Generally, the use of coarse granulated foam glass has led to a significant strength loss and modulus of elasticity reduction while a positive effect on the compressive strength was observed when using fine granulated foam glass in concrete mixes. On the other hand, flexural strength of granulated concrete was, generally, slightly improved compared to the control mix.

Nassar and Soroushian (2013) explore the use of milled waste glass in recycled aggregate concrete and they obtain that replacement of about 20 wt.% of cement with milled waste glass results in significant improvement of the structure of hydrated cement paste and interfacial transition zone in recycled aggregate concrete as well as normal concrete. At 90, 156 and 300 days of age, the strengths of recycled glass concrete materials were higher than those of the corresponding control concrete materials at different w/c ratios.

The influence of waste glass on the physical properties of Portland cement concrete was studied by Miranda Jr *et al*. (2014). They found that void content of the concrete decreased with increasing waste glass content at the w/c ratios of 0.55 and 0.58. However, at the w/c ratio of 0.50, the void content decreased with the waste glass content of 0% to 5% and then increased up to a glass content of 20%.

The review study by Jani and Hogland (2014) showed that waste glass can be used in cement and concrete but the particle size of the glass waste plays a vital role in the ASR destructive reaction and the performance of concrete. Their results point that the pozzolanic properties of glass increased with decreasing its particle sizes under 100 μm. While, all the experimental results showed that increasing the percentage of waste glass aggregate reduces the maintenance of concrete.

While Almesfer and Ingham (2014) investigated the use of domestic waste glass as a partial replacement for natural coarse and fine aggregates in concrete. They found that the waste glass tested in their investigation was found to slightly increase the air content of concrete and significantly decrease the compressive strength and flexural strength of concrete in the absence and presence of supplementary cementitious materials such as fly ash and micro-silica.

But, contrary with Almester and Ingham results, Wang *et al*. (2015) research on waste glass concrete basic mechanical property note that cube compressive strength and axial compressive strength of glass aggregate concrete are 1.23 times higher than ordinary concrete.

Walczak *et al*. (2015) study the feasibility of using glass additives for the production of autoclaved aerated concrete, they summarized that the pozzolanic characteristics of glass powder may be the main cause of the compressive strength enhancement. They also found that the use of glass in the AAC (autoclaved aerated concrete) production can be great way of the waste utilization.

Rahim *et al*. (2015) research the utilization of recycled glass waste as partial replacement of fine aggregate in concrete production and they found that the optimum percentage of glass waste that gives the maximum values of compressive strengths is 10%.

Beside glass utilisation in concrete, Xiang *et al*. (2014) also examined the making of insulation wall materials based on waste foam glasses. They point out that a recycling use of glass is realized-glass-foam glass-self heat preservation block can reduces the consumption of resources and energy and the material can be used as long as the building structure. Reutilization and stabilization of wastes by the production of glass foams also proposed by Bernardo *et al*. (2007) and summarized that the porosity and the mechanical strength of the achieved foams are close to that of commercial samples; the proposed approach, as a consequence, may have the potential for producing useful materials from a mixture of wastes. They also deduce that the mechanical strength is strongly influenced by the homogeneity of the foaming, which in turn depends on the additions of SiC and oxidizer.

Bai *et al*. (2014) proposed preparation of foam glass from waste glass and fly ash as starting materials, as well as *SiC* as high temperature foaming agent successfully. Glass foam from window panes and bottle glass wastes was presented by Vancea and Lazău (2014) and their results confirm the viability of the proposed solution for obtaining medium-high density foam glasses, that utilize common glass wastes and plaster from used ceramic casting molds as a foaming agent, where the final product has a good chemical stability and insulating properties.

Glass cullet processing methods: This section was adopted from HDR Engineering (1997) and presents an overview of the processing methods used to produce marketable glass cullet for use in civil engineering applications. Processing methods can vary, depending on the anticipated end use. The following discussion is limited to the typical process necessary to produce glass cullet for reuse as a construction aggregate. This category of use includes: general backfill, roadways, utilities and drainage applications and miscellaneous applications such as landfill leachate collection or gas venting layers.

Glass crushing equipment has been derived from the rock crushing industry. Several types of equipment can produce cullet which may be used as construction aggregate. Typically, glass crushers will be smaller than rock crushers (glass production capacities of 1 to 20 tons per hour) and designed to handle the abrasive nature of glass cullet.

The basic glass crushing system consists of a crusher (crushing mechanism), a feed hopper and a discharge chute. The types of crushing mechanisms commonly available are: hammermill, rotating disk and breaker bar, rotating drum and breaker plate, rotating breaker bar, impactor and helical fluted roller. Optional components to aide in production of glass cullet include infeed and outlet conveyors and a screening mechanism. With this system, glass bottles are loaded into the feed hopper either manually or by a front-end loader, conveyed to the crusher, processed and screened and conveyed to a bin or the floor. The screening mechanism will likely be necessary to produce aggregate-quality cullet by removing the oversize particles and most of the debris.

Glass crushing may be possible in mills designed for crushing rock; however, several factors need to be considered for crushing glass based on Dames and Moore's observations of glass crushers (HDR Engineering, 1997). Cullet is more abrasive than natural aggregate which will result in greater wearing of surfaces and subsequently more frequent maintenance.

Cullet is also less dense than natural aggregate which may cause difficulties in existing crushed rock gravity feed systems. The rock crushing equipment is designed to crush rock to a desired gradation (grain size distribution). The gradation of cullet from this same piece of equipment may be significantly different.

Glass cullet may be handled, spread and compacted with conventional construction equipment. Civil engineering applications of glass cullet include the substitution of cullet or cullet-aggregate mixtures for conventional aggregate materials in backfills, roadway base course, subbase or embankments, utility trench bedding and backfill, drainage fills and landfills.

Further processing to pulverize or ground glass will require additional equipment and cost. Pulverizing makes glass into particles the size of sand. Civil engineering applications and products of pulverized glass can include glasphalt, concrete additive, building materials, filter media, drainage and erosion control and reclamation of beaches (HDR Engineering, 1997).

CONCLUSION

This review explores the state of the art of glass waste in concrete material and others. It can be summarized the different use of glass wastes in the form of sand or cullet as an alternative fine or coarse aggregates or others for projects that will fulfill the government regulation to assist the industry saving the environment. This study basically explore several extensive studies were carried out to counter this Alkali-Silica Reaction (ASR) phenomena. Using recent advances this matter was mainly overcomed. The effective of waste glass application in spreading novelty markets as well as paving stones, concrete masonry blocks, terrazzo tiles and precast concrete panels. Beyond its problem, glass wastes have a great chance to become alternative of civil engineering materials.

CONFLICT OF INTEREST

Herewith I certify and declare that there is no conflict of interest at all with the authors in relation to the above-mentioned article and also I have no conflict of financial or relevant interest with any manufacturer of a product discussed in this study. And I have disclosed all conflicts of interest to the Editors.

REFERENCES

Almesfer, N. and J. Ingham, 2014. Effect of waste glass on the properties of concrete. J. Mater. Civil Eng., 26(11): 06014022.

Bai, J., X. Yang, S. Xu, W. Jing and J. Yang, 2014. Preparation of foam glass from waste glass and fly ash. Mater. Lett., 136: 52-54.

Bernardo, E., R. Cedro, M. Florean and S. Hreglich, 2007. Reutilization and stabilization of wastes by the production of glass foams. Ceram. Int., 33(6): 963-968.

Concrete Materials Research, 2000. Concrete Masonry Block. Columbia University, pp: 1-2. Retrieved from: www.columbia.edu/cu/civileng/meyer/download/masonry.pdf.

Dungworth, D. and C. Brain, 2005. Investigation of late 17th century crystal glass. English Heritage, Centre for Archaeology Report 21/2005, pp: 5.

Harper, C.A., 2001. Handbook of Ceramics, Glasses, and Diamonds. McGraw Hill, Toronto, New York, pp: 1-36.

HDR Engineering, 1997. Glass cullet utilization in civil engineering applications. Nebraska State Recycling Association, HDR Engineering Inc., pp: 1-26.

Illinois Department of Transportation, 2002. Utilization of recycled materials in illinois highway construction. Physical Research Report No. 142, May 2002.

Ismail, Z.Z. and E.A. Al-Hashmi, 2009. Recycling of waste glass as a partial replacement for fine aggregate in concrete. Waste Manage., 29(2): 655-659.

Jani, Y. and W. Hogland, 2014. Waste glass in the production of cement and concrete – a review. J. Environ. Chem. Eng., 2(3): 1767-1775.

Lam, C.S., C.S. Poon and D. Chan, 2007. Enhancing the performance of pre-cast concrete blocks by incorporating waste glass – ASR consideration. Cement Concrete Compos., 29(8): 616-625.

Limbachiya, M.C., 2009. Bulk engineering and durability properties of washed glass sand concrete. Constr. Build. Mater., 23(2): 1078-1083.

Limbachiya, M., M.S. Meddah and S. Fotiadou, 2012. Performance of granulated foam glass concrete. Constr. Build. Mater., 28(1): 759-768.

Ling, T.C., C.S. Poon and H.W. Wong, 2013. Management and recycling of waste glass in concrete products: Current situations in Hong Kong. Resour. Conserv. Recy., 70: 25-31.

McCoole, F., I. Kurz, J. Reilly, H. Searson, E. Cotter and D. O'Neill, 2012. National Waste Report for 2012. Environmental Protection Agency, Ireland, ISBN: 978-1-84095-550-7 08/14/250.

Meyer, C., N. Egosi and C. Andela, 2001. Concrete with waste glass as aggregate. In: Dhir, Dyer and Limbachiya (Eds.), Recycling and Re-Use of Glass Cullet. Proceeding of the International Symposium Concrete Technology Unit of ASCE and University of Dundee, March 19-20, pp: 179-187.

Miranda Jr., E.J.P., A.E.M. Paiva and E.N.L. Rodrigues, 2014. Influence of waste glass on the physical properties of Portland cement concrete. Mater. Sci. Forum, 798-799: 576-581.

Naik, T.R., 2002. Greener concrete using recycled materials. Concrete Int., 24(7): 45-49.
Nassar, R.U.D. and P. Soroushian, 2013. Use of milled waste glass in recycled aggregate concrete. P. I. Civil Eng-Constr. Mater., 166(5): 304-315.
Park, S.B., B.C. Lee and J.H. Kim, 2004. Studies on mechanical properties of concrete containing waste glass aggregate. Cement Concrete Res., 34(12): 2181-2189.
Petrella, A., M. Petrella, G. Boghetich, D. Petruzzelli, D. Calabrese, P. Stefanizzi, D. De Napoli and M. Guastamacchia, 2007. Recycled waste glass as aggregate for lightweight concrete. P. I. Civil Eng-Constr. Mater., 160(4): 165-170.
Polley, C., S.M. Cramer and R.V.D.L. Cruz, 1998. Potential for using waste glass in Portland cement concrete. J. Mater. Civil Eng., 10(4): 210-219.
Purkiss, J.A., 1985. Some Mechanical Properties of Glass Reinforced Concrete at Elevated Temperatures. In: Marshall, I.H. (Ed.), Composite Structures 3. Springer, Netherlands, pp: 230-241.
Rahim, N.L., R. Che Amat, N.M. Ibrahim, S. Salehuddin, S.A. Mohammed and M. Abdul Rahim, 2015. Utilization of recycled glass waste as partial replacement of fine aggregate in concrete production. Mater. Sci. Forum, 803: 16-20.
Shao, Y., T. Lefort, S. Moras and D. Rodriguez, 2000. Studies on concrete containing ground waste glass. Cement Concrete Res., 30(1): 91-100.
Shayan, A. and A. Xu, 2004. Value-added utilisation of waste glass in concrete. Cement Concrete Res., 34(1): 81-89.
Shi, C. and K. Zheng, 2007. A review on the use of waste glasses in the production of cement and concrete. Resour. Conserv. Recy., 52(2): 234-247.
Taha, B. and G. Nounu, 2008. Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. Constr. Build. Mater., 22(5): 713-720.
Taha, B. and G. Nounu, 2009. Utilizing waste recycled glass as sand/cement replacement in concrete. J. Mater. Civil Eng., 21(12): 709-721.
Topcu, I.B. and M. Canbaz, 2004. Properties of concrete containing waste glass. Cement Concrete Res., 34(2): 267-274.
Vancea, C. and I. Lazău, 2014. Glass foam from window panes and bottle glass wastes. Central Eur. J. Chem., 12(7): 804-811.
Vieitez, E.R., P. Eder, A. Villanueva and H. Saveyn, 2011. End-of-Waste Criteria for Glass Cullet: Technical Proposals. JRC Scientific and Technical Reports, EUR 25220 EN – 2011, European Union-Spain.
Walczak, P., J. Małolepszy, M. Reben, P. Szymański and K. Rzepa, 2015. Utilization of waste glass in autoclaved aerated concrete. Proc. Eng., 122: 302-309.
Wang, F.C., H. Gong, S.L. Jia, B.C. Zhang and C.F. Zhang, 2015. Research on Waste Glass Concrete Basic Mechanical Property. Appl. Mech. Mater., 711: 406-409.
Worrell, E., C. Galitsky, E. Masanet and W. Graus, 2008. Energy Efficiency Improvement and Cost Saving Opportunities for the Glass Industry. An ENERGY STAR Guide for Energy and Plant Managers. Environmental Energy Technologies Division, US Environmental Protection Agency, Lawrence Berkeley National Laboratory.
Xiang, Y., Y.Y. Luo and H.B. Jiang, 2014. The Optimization of Performance the New Type of Insulation Wall Materials Based on Waste Foam Glasses. Adv. Mater. Res., 873: 298-303.
Zarzycki, J., 1991. Glasses and Amorphous Materials. In: Cahn, R.W., P. Haasen, E.J. Kramer (Eds.), Vol. 9 of Materials Science and Technology: A Comprehensive Treatment. VCH, Weinheim, pp: 797.