UTILIZATION OF GLASS WASTE IN VEHICLE RESTRAINT SYSTEMS

László Gáspár[1], Zsolt Bencze[2]
[1] *KTI Institute for Transport Sciences Non-Profit Ltd, Hungary;*
[2] *FERROBETON Ltd., Budapest*

Abstract

The growing demand of society requires that engineers should concentrate more and more on recycling of broken road materials and various by-products in order to ensure environmental sustainability for future generations. Concrete technology has evolved to such an extent that it has become an important role in waste/secondary material management by now. There are several benefits of using glass waste in concrete mixtures. The experi-ments carried out at the Hungarian firm Ferrobeton Ltd. concentrated on exploring the possibility of using glass waste in the cement concrete recipe of vehicle restraint systems in order to release reflection in its material and thereby to increase road safety. In the concrete recipe, the maximization of both usability and reflectivity were aimed to. However, it was also necessary to make sure that the resistance to mechanical and environmental loads could not be worse than in the case of reference (basic) mixture recipe. The quality and type of concrete surface finishing is a financial and also lifetime design issue. The surface treatment method actually applied basically influence the light properties (gleam, reflectivity) of concrete surface as a significant traffic safety parameter.

Keywords: glass waste, vehicle restraint system, road restraint system, traffic safety, compressive strength, reflectivity

1 Introduction

One of the main challenges of our days is the providing environmental sustainability for future generations. It is well-known that there are many advantages of applying glass waste in concrete mixtures. A Hungarian test series was aimed at scutinizing the possibility of partially replacing natural concrete aggregate by broken glass in vehicle restraint systems in order to improve glitter and reflectivity of the material, and thereby to increase road safety. At the same time, it was also compared the compressive strength values of the mixture of new recipe with those of the reference mixture.
First a short international review is presented on the experiences obtained with the use of glass waste in cement concrete surface, then the main features of vehicle (road) restraint systems are shown briefly. Finally, the research aim, the methodology followed, the laboratory test results and the conclusions drawn are introduced.

2 Glass in concrete

Glass aggregate can replace part or all of the sand and gravel in concrete, for effects that range from colourful terrazzo, to granite- or marble-like finishes, to concrete that reflects light like a mirror. Glass aggregate can even be used to produce concrete that literally glows [1]. Glass aggregate almost always comes from recycled glass, saving landfill space and requiring no mining. Glass aggregate is typically graded by colour and size. Sizes can range from six-inch (some 190mm) rocks to gravel-sized pieces to a fine talc-like powder. Polishing, grinding or other exposed aggregate techniques are employed to reveal the glass. Also glass can be seeded on the surface and then exposed.
Coloured glass can be coordinated with the matrix of integrally coloured concrete. In general, lighter colours of glass are used in darker matrixes, and vice versa. A dark brown glass in a dark brown matrix can have an appeal all its own. Mixing light and dark colours of glass will give you a terrazzo effect. If you use clear glass aggregate, it will take on the colour of the matrix, and it will add the most depth. Since glass is acid resistant, acid staining will colour the surrounding matrix without affecting the colour of the aggregate.
Finely ground glass can add background colours to the matrix. Using finely ground clear glass in place of sand can make for purer colours of concrete. Finely ground glass also lends itself to highly polished finishes. A marble or granite look can be attained by putting a high polish on concrete made with finely ground, earth-toned glass aggregates.
As for strength, glass aggregate can match, exceed or fall short of traditional aggregates, depending on size. Studies have found that very finely ground glass aggregate used in place of sand actually increases the strength of the concrete, whereas gravel-sized glass aggregate decreases strength. Mixing fine and coarse glass aggregates can have a net effect of zero, rendering concrete no stronger or weaker than that mixed with traditional sand and gravel.
Glass aggregate can be obtained from a variety of sources. Locally, recycling centers may have cullet — crushed bottles and other glass — cleaned and sorted by size and colour. Nationally, specialty glass manufacturers melt down bottles and window glass to produce glass aggregate for terrazzo floor contractors, landscapers and decorative concrete artisans. Specialty glass aggregates made from recycled glass that is melted down and re-formed give you a different look than plain old crushed glass. Crushed bottles and window glass tend to be flat, with parallel sides, whereas specialty glass aggregates can have fuller, more irregular shapes, like crushed gravel.
When using glass aggregate outdoors, or anywhere else that the concrete will be exposed to moisture, beware of the dreaded alkali-silica reaction, an unhappy phenomenon. The reaction may happen right away or it may take 20 years, but in either case it can cause cracking. Any source of moisture can set it off, including mopping, using excess water in the concrete mix, and so forth.
But the alkali-silica reaction can be prevented since the reaction can be avoided if the glass is ground finely enough to pass through 50-mesh or smaller screen. They also found that the mineral admixture metakaolin will suppress the reaction — an effective but expensive solution. It was also found that green glass does not cause the alkali-silica reaction, due to the chromium oxide used to get the green color.
As part of a comprehensive scientific research project, HERING [2], together with the University of Siegen, over a period of several months attempted to discover a method of manufacturing permanent and stable concrete mixtures that included real glass. The optimum mixture ratio was discovered, with eight of the tested glass types being suitable for use and meeting the requirements of the DAfStb Alkali Guideline. HERING's specially-developed „concrete-glass recipe“ also fulfils the defined criteria of DIN 1045 for structural concrete components. The tested glass types are naturally also suitable for various types of surface treatment, including acidification, washing, blasting and grinding.

The recycling of waste glass poses a major problem for municipalities nationwide. New York City alone collects more than 100,000 tons annually and pays Material Recycling Facilities (MRF's) up to $45 per ton for the disposal of the glass, commingled with metals and plastics. While the MRF's have little difficulty with profitably disposing of the metals and plastics, markets for recycled glass are limited to nonexistent. The use of crushed waste glass as aggregate in concrete is problematic because of the chemical reaction between the alkali in the cement and the silica in the glass. This alkali-silica reaction (ASR) creates a gel, which swells in the presence of moisture, causing cracks and unacceptable damage of the concrete. It can also occur in regular concrete, if the natural aggregate contains certain reactive (typically amorphous) silica. ASR in uranyl acetate treated concrete, visualized under UV-light This phenomenon is particularly vexing, because it is a long-term problem, and the detrimental consequences may not show for years. Predictions of the susceptibility of naturally occurring aggregates are uncertain, as they require accelerated laboratory tests, which are of limited reliability.
There is not much uncertainty with regard to ASR if waste glass is used as aggregate in concrete. Research at Columbia University [3] has focussed on a basic understanding of the ASR phenomenon and on searching for ways to avoid it or to mitigate its detrimental consequences. Some of the techniques developed so far or under investigation are: grinding the glass fine enough; replacing part of the cement by metakaolin; applying protective coatings to the glass particles; modifying the chemical formulas for the glass; use of lithium in glass powder. Old glass may find use in new, better concrete although glass is thought of as being relatively eco-friendly because it‘s recyclable, the fact is that a lot of it doesn‘t get recycled – this is particularly true of small fragments, that are too fiddly to sort. Australian researchers started with various pieces of non-recyclable glass, then ground them up into a coarse powder [4]. They then utilized that powder as an aggregate in polymer concrete, in place of the sand that‘s normally used. Polymer concrete itself substitutes polymer resin for cement as a binding agent, and is typically used in applications such as waterproof flooring. It was found to be significantly stronger than its traditional sand-based counterpart. Additionally, because sand has to be mined, washed and graded, it was determined that use of the ground glass resulted in lower concrete production costs. While a shortage of appropriate sand has been predicted, there are stockpiles of old glass that are just sitting around unprocessed.

3 Road (Vehicle) Restraint Systems

Road Restraint Systems are an essential component of a modern road infrastructure and constitute one of the most important life-saving devices available to public authorities and road operators [5]. They represent an immediately available solution that can, in addition to saving lives, significantly reduce the accident related health care cost.
Road restraint systems can be also considered as the most "flexible safety device" possible: they are designed to withstand a crash from different kind of vehicles in different conditions. According to their containment level, they are tested both for a small city car or a large family car; small to heavy truck or coach, with the possibility to equip it with a motorcyclist protection system (MPS) to further extend this protection to a particularly affected class of vulnerable road users.
An example of the effectiveness of those solutions is the analysis carried out by the German Land of Hessen. The erection of a median and a road side barrier in two identified 'black spots' in the German road network resulted in a decrease in accidents with injuries by 65 % and 91 % respectively, while, at the same time, reducing the annual accident costs by 70 % and 88 %, thus leading to a global yearly saving of € 1.214.000.

The existence of protective barriers on road can reduce fatalities up to a factor of 4 when compared to collisions against other road obstacles. Actually, the presence of a road restraint system appears to offer the highest level of protection compared to accidents against obstacles in non-urban environments [6].
The European Norm 1317 for Road Restraint Systems was created in 1998 and lays down common requirements for the testing and certification of road restraint systems in all countries of the CEN. The introduction of EN 1317 represents a significant change in terms of safety and quality for European drivers insofar that it establishes an EU market based on performance, replacing previous 'prescriptive based systems based on empirical experience'. In practical terms, this means first, that new barriers placed on European roads can offer guaranteed levels of safety and secondly, that the level of guarantee is the same across the whole of the EU, i.e. a single market for safety barriers.
While the EN 1317 for Road Restraint Systems guarantees common testing methods for road restraint systems across EU Member States, it is up to national governments to decide the level of protection on their road network. As a result, European drivers are confronted with varying levels of road restraint systems protection on the European motorway network despite the fact that speed limits and driving conditions are very similar.
As for cars, roadside obstacles represent a high danger for motorcycles as well: an impact against a tree, or a fall from a cliff, is dangerous for the 4-wheel vehicle as well as for the 2-wheel ones. Additionally, standard road restraint systems are designed to redirect cars and trucks and thus, are not designed to prevent the impact of motorcyclists against obstacles. On the contrary, they represent an obstacle in themselves.
For more than 20 years, road restraint systems manufacturers have invested and carried out research and development on dedicated products in order to increase the safety also of motorcyclists. Since 2008, CEN (European Committee for Standardization) and its members have been working on the development of a European standard for the testing of those products, which has been approved as a Technical Specification (TS 1317) and published..
While motorcycle riders often advocate the removal of standard safety barriers, the fact is that such a decision would increase the risk of serious collisions for all users, given that their drivers would be unprotected against roadside obstacles. In the view of the ERF, the use of high protection (HIC ‹650) TS 1317 - part 8 [7] tested products would be the best solution to guarantee a higher motorcyclist safety, and to maintain the existing safety level for 4 wheel vehicles.
While placing better performing barriers on Europe's motorways can undoubtedly improve driver safety, the potential safety gains by acting on Europe's rural roads can be said to be substantial given that 56 % of Europe's fatalities occur on rural roads compared to only 6 % on motorways, which can be attributed also to the existence of guard rails.
As the previous examples of 'black spot management' have demonstrated, placing barriers on secondary/rural roads can have impressive results at a relatively low cost. These findings are also supported by the European Road Assessment Programme, which found that a median barrier on a rural road can help reduce the kinetic energy of a run-off crash, thus decreasing the risk factor by approximately a factor of 310.
The ERF believes that, at a time of economic constraint, acting on passive safety solutions that are already available can represent one of the most cost-effective solutions for public authorities and citizens alike. In this respect, it welcomes the European Parliament's Transport Committee's Report on European Road Safety Programme 2011-2020 and the paragraph 26 [8]. It'calls on the Member States to take prompt action (including replacing the existing guard rails) to refit dangerous stretc-hes of road with rails with upper and lower elements as well as with other alternative road barrier systems, in accordance with Standard EN 1317, in order to lessen the repercussions of accidents for all road users.

Some of the road restraint systems can be customised to provide optimum solutions and are designed and tested according to European standards [9]. The main function of crash cushions is to prevent lethal damage to car passengers when crashing into static objects. The modular structure of the parapets contributes to quick installation and low cost.

4 Research aim

The aim of the experiments carried out at Ferrrobeton Ltd. (Hungary) was to identify the amount (share) of glass aggregate in the concrete vehicle restraint systems that ensures favourable visual appearance („lightness”) to the elements, without influencing negatively the mechanical properties of concrete structure.

5 Methodology

The steps of research methodology chosen and carried out were as follows:

- determination of basic concrete recipe,
- identification of the aggregate fractions to be replaced eventually, partly by crushed glass,
- choosing the shares of above aggregate fractions for possible glass waste replacement,
- identification of the recipes creating favourable visual appearance of glass concrete surface,
- producing specimens of concrete mixtures with promising recipes,
- measuring compressive strength of specimens after 10 and 28 days,
- producing and testing various surface treatment methods on various samples,
- identification of time need and surface gleam of various surface treatment methods,

6 Laboratory test results

Table 1 shows the cement concrete mixture recipe that was considered as a basic (reference) one for the research on the optimum use of glass aggregate in vehicle restraint systems.

Table 1 “Basic” cement concrete mixture recipe

Constituent	Unit weight [kg/m³]
Aggregate	1950
Cement I 42.5 R	400
Water	195
Additive (Glenium 51)	4

Based on the analysis of relevant international literature, two – 0/4 mm and 4/8 mm – glass fractions were tested for the eventual replacement of natural aggregate ones. The first version of „mixing plan” consisted of the replacement of 5 % - 10 % - 25 % - 50 % of the fractions mentioned by broken glass. However, based on the results of first concrete mixture variant, it became apparent that the use of 0/4 mm glass aggregate cannot meet the expected, favourable visual appearance of cement concrete surface. That is why susequently the experiment concentrated on the replacement options of 4/8 mm fraction by glass aggregate.
Further laboratory tests proved that the entire (100 %) replacement of 4/8 mm fraction by broken glass could ensure the expected positive changing in the surface reflective appearance. From that pont on, the experiment carried out was driven towards the grain size distribution of the cement concrete mixture. Thus concrete specimens with poorly graded grain

(particle size) distribution of concrete aggregate were produced in which various fractions and shares were replaced by glass. Table 2 presents the 10-day and 28-day laboratory compressive strength test results of the samples with various glass aggregate contents compared to that of reference value (basic recipe).

Table 2 Compressive strength values of concrete samples with various broken glass aggregate shares

Replaced fraction share(s) by glass	**Compressive strength [N/mm²]**	
	10 days	**28 days**
(reference)		69.0
5% 0/5 mm	55.1	64.8
10% 0/5 mm	59.0	66.5
25% 0/5 mm	62.1	65.5
50% 0/5 mm	57.2	65.1
5% 4/8 mm	63.2	69.5
10% 4/8 mm	61.3	70.0
25% 4/8 mm	61.1	65.5
50% 4/8 mm	62.7	67.8
100% 4/8 mm	62.1	66.8
100% 4/8 mm + 50% 8/16	60.8	66.1

The laboratory test values shown in Table 2 have proved that the increasing addition of broken glass as cement concrete aggregate does not have a negative effect on the compressive strength of the mixture.
After the positive results of water tightness (6 mm) and freeze-thaw scaling tests (XF4) of concrete specimens, trial factory production had started not showing any technological difficulties in casting, application and formworks.
In such a way, it was clearly demonstrated that the partial replacement of the cement concrete mixture aggregate of vehicle restraint systems does not worsen the mechanical properties while offering an environmental-friendly solution by the use of a waste material instead of natural material. The next issue to be tested was the analysis of the abilities of various surface treatment procedures on the reflectivity of cement concrete surface as an importont traffic safety feature. The following surface treatment methods were covered: grinding, sandblasting and pressurewashing. Table 3 introduces not only the measure of reflectivity (gleam) in each case but also the time need of various surface treatment methodologies. (The reflectivity of concrete surface was characterized by the number of gleaming aggregate grains per unit area).

Table 3 Time needs (working hours) and reflectivity (gleam) of the unit area of sample surfaces treatad by various procedures

Surface treatment method	**Working [hours/m²]**	**Reflectivity [gleaming grains/m²]**
Grinding	1.5	4
Sandblasting	1.0	6
Pressurewashing	1.0	4

Of course the reflectivity attained is not comparable to glass beaded or prismatic solutions, but it had never targeted. However, it has been clearly demonstrated that utilization of glass aggregate in the recipe of restraint systems can achieve a glitter level that makes it detectable for the drivers even without light effect coriginated by road vehicles.

7 Conclusion

Laboratory and early site experiments on the partial replacement of aggregate of cement concrete vehicle restraint system by broken glass were performed by Ferrrobeton Ltd. (Hungary). The results proved that the mechanical properties (actually compressive strength) of concrete structure were not negatively influenced by the addition of glass as aggregate. The use of this kind of waste material is obviously an environmental friendly solution by reducing deposited by-product, and decreasing the need of the use of primary aggregates with less greenhouse gas emiss-ion. As an additional advatage, it was also shown that the glass aggregate grains on the concrete surface of vehicle restraint elements ensure a favourable visual appearance, a kind of glitter after appropriate surface treatment increasing the traffic safety effect of vehicle restraint systems. .

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