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TESTING OF RECYCLED BUILDING ELEMENTS FOR ROAD CONSTRUCTION USE

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Abstract

The use of recycled materials in both their material and processed has become permitted in the majority of relevant European technical standards. Our institute was commissioned by manufacturers and resellers to carry out background tests for the authorizations required to place their recycled products on the market. Our research project focused on how products with plastic aggregate and extruded products recycled in 100 % perform in the case of traditional test methods. Besides, it was also examined which innovative test methods would be the ones that could reliably characterize the important performance properties of non-conventional materials. Based on our test results, there was no need to modify traditional test methods, but there are certain non-standard technological steps that must be followed to determine adequately the major properties of the products. KTI's research results have also proved that, compared to the transport building elements used so far, recycled products also have properties that could surpass those of concurrent conventional elements offering serviceability advantages to the obvious environmental benefits.

Keywords: recycling, plastic aggregate, extruded products, non-traditional laboratory tests

1 Introduction

The production and the use of plastic products is a consequence of the rapid technological development of our civilization. After the first plastic was introduced in London in 1862, the first polymer was made in 1869, and in 1907, the first fully artificial plastic, bakelite, was introduced. In the 1950s, 2.5 million tons of plastic were produced worldwide each year. It has now become nearly 500 million tons a year. In the 1980s, plastics manufacturers began to introduce recycling, not only to increase their economic efficiency, but also to reduce their environmental impact, "carbon footprint". Mass collection of plastic materials has begun not only on land but also at sea.

For the 21st century, humanity has had several solutions to the problem of plastics. This article concentrates on two possible solutions: plastics recycling by hot pressing (extrusion) and by additive bond. When these materials are used as agg-regate of transport construction elements, a question arises if this kind of elements can be tested by conventional laboratory methods with appropriate results or these test types should be modified, supplemented or, eventually, to combine them with other tests [1-5].

The types of solutions mentioned represent different product manufacturing technologies and, consequently, the use of the finished products is not the same, either. This is due to the differences in their strength properties coming from the manufacturing technology. Extrusion achieves a higher strength category, but the geometrical options of the products are significantly limited.

2 Application possibilities

Requirements for transport construction elements are generally a national com-petence, however, there are already technical regulations that apply throughout Europe. The most important cornerstone of these regulations is road safety, as each element of transport construction serves the purpose of enabling road users to drive more safely. Therefore, each transport construction element must have different properties in accordance with their use. The diversity of the use of extruded products can be found on the website of Lüft GmbH [8]. They are primarily applicable in places where the element is not subject to direct load.
A high number of publications have been already published on the utilization of waste plastics in civil engineering – starting from soil reinforcement through improving the properties of thermoplastic-bound flexible pavement structures to the production of lightweight sidewalks [7].
Our research has therefore focused on the necessary properties of a “novel” structure exposed to changing climatic conditions, which allow them to compete with the performance of transport construction elements manufactured by “traditional” technological solutions.

3 Pavement structure options

India is a pioneer in the utilization of plastics in road pavement construction, where more than 33,000 km of roads have already been built using waste plastics [9].
Waste plastics can be applied in both surfacing layers and base courses, as confirmed by previous research works. However, when using it in a stabilized base course, an important property of the new generation of plastics must be taken into account, according to which they can be easily degraded, so exclusively a solution could come into view that can bind the used plastics and does not release them into nature.
In Hungary, the plastic waste (PET) as a modifier in asphalt wearing courses was first used in the road construction industry, in the early 2000s. Then, some 20 years later, in 2020, experimental works took place, several test road sections were carried out, where the hydraulically bound base layer was produced with 3 different types of plastic waste.
So far, there has been no reference in Hungary for its use in concrete pavements or road concrete elements. Extruded transport construction products can be made from hydraulically bound options in the same way, but their strength, taking into account also financial considerations, has been lower.

4 Laboratory tests

Using a solution comparable to concrete production, products with lower strength characteristics can be produced, but without any geometric constraints. The pro-ducts chosen for the research work were:

a) Hot pressed or extruded products
Two market products were used for the study: GERAB elements [6] and Lüft Leichtsysteme [8].

b) Additive products
Concrete manufactured with the use of admixtures patented by Masuko Ltd. [10].

4.1 Laboratory tests of samples with extruded plastics

As part of the road applicability tests of these „novel” products done at KTI Institute for Transport Sciences Non-Profit Ltd., Budapest, a series of laboratory tests were also carried out in which the answer to the question sought if the tests described in European standards are appropriate or not to the quality control of concretes with plastic admixture.
Before starting the investigation, the plastic frame structure and the traditional concrete structure were scrutinised in order to attempt the quantification of our “trivial” hypothesis: “the quality and the quantity of the plastic influences the compliance with the exposure class of the product”. Figure 1 presents the samples tested in the research work and Figure 2 shows the “theoretical” structure of the three samples that can be compared to the virtual structure of normal concrete surface shown in Figure 3.

Figure 1 The three samples tested (from left. samples with gravel, crushed stones and plastic aggregate)

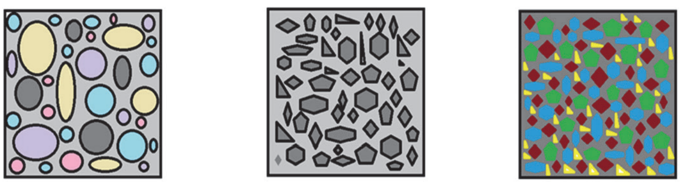
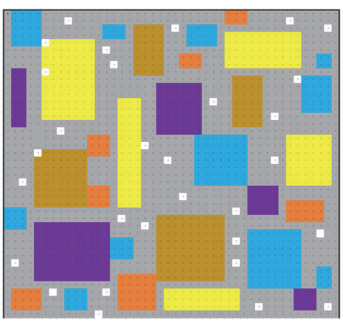


Figure 2 Theoretical” structures of the three samples



Components	Ratio [%]	Colour code
Concrete matrix	39	
Aggregate 1	15	
Aggregate 2	7	
Aggregate 3	12	
Aggregate 4	16	
Aggregate 5	9	
Air	2	
Sum	100	

Figure 3 Virtual structure of a „traditional” concrete sample

The initial „theoretical” characteristics in the samples were supposed to be as follows:
- The characteristics of sand and cement paste are the same in all three cases,
- The properties of the aggregate skeleton (gravel, crushed stone, plastic) within each sample are homogeneous,
- The density of the samples amounts to 98 %, i.e. 2 % air content can be found in each sample.

It is supposed that the aggregate has the same properties as concrete paste in normal concrete has, while it has better properties than the mix with crushed stone. (Of course, we are aware of the fact that our finding for crushed stone is only valid for basalt or andesite that are widely used in Hungary.) In the case of plastic agg-regate, the test result may vary depending on the type of plastic used. The simplest selection of plastics can be made based on their densities, thus the following three "fractions" of waste plastics were distinguished:
- Density of 0 kg/m^3 – 100 kg/m^3,
- Density of 100 kg/m^3 – 200 kg/m^3,
- Density above 200 kg/m^3.

Typical density of extruded plastics available as finished products: 700-900 kg/m^3. In addition to the classical strength tests (compressive strength, splitting tensile strength), the compliance with the exposure classes (wear, erosion under freezing) was tested in the laboratory. Based on the test results, the following conclusions can be made:
- In addition to the strength characteristics of the extruded products, another effect can be identified, the so-called „secondary creep”, when the sample is deformed further by the load even if the load rate is not increased any more (Figure 4), and when the load is released, the cracks close (Figure 5).
- In extruded products, a technological feature observed is the formation of „honey-combs”, which makes the product inhomogeneous and causes its weight loss (Figure 6),
- The extruded plastics tested are frost-resistant,
- Their abrasion resistance is ten times higher than that of „normal” concrete.

Figure 4 Cracking of recycled plastic beam in splitting test

Figure 5 The resealed crack in the beam made of recycled plastic after the load is released

Figure 6 Cross-section of the beam where the inhomogeneous core is clearly visible

4.2 Laboratory testing of products containing Masuko additive

For the experimental mixtures required for the tests, a special mixing technology had to be developed in order to homogenize the plastic waste with different characteristics in the aggregate skeleton with sufficient efficiency; so, for example, the floating or the sorting of plastics lighter than water should be avoided during production. Based on the test results, the following statements can be made:

- The compressive strength of the concrete mixture with 1 % Masuko additive de-creases nearly in proportion to the volume of the plastic used, as if only air were in place,
- The degree of erosion under freezing is not affected by the plastic used, but by water cement ratio and cement dosage,
- “Traditional” plastics act as air inclusions in concrete, i.e. they do not participate in the load-bearing role in the classical sense,
- In addition to cement and sand, the wear rate is also affected by the quality of plastic, so, for example, wear-resistant mosaic pavement with similar surface to the “exposed aggregate surface” of cement concrete pavement can be attained by using PE-UHMW (ultra-high-molecular-weight polyethylene).

5 Trial sections

Compared to the scale of India mentioned before, it seems to be an almost in-significant solution, but an important step forward in Hungary was that cement-bound road bases were made using 1 % Masuko additive and plastics. The sections (300 m each in a low-volume road) were built using three types of plastic waste, and 0/4 sand and crushed stone was added to the fine part of aggregate. Plastic wastes were classified into the following simplified waste management classes:

1. Mixed plastic packaging waste,
2. Mixed plastic industrial waste,
3. Polyethylene terephthalate (PET) recycled plastic [11].

Some basic features and the strength characteristics of the mixtures used in mixed-in-plant, cement-bound trial sections are summarized in Table 1.

Table 1 Some basic features and the strength characteristics of trial mixtures

Sections of M30 motorway	**Proctor dry density** [kg/m³]	**Proctor optimum moisture content** [%]	**Cube strength in 7 days** [N/mm²]	**Cube strength in 28 days** [N/mm²]
I/1	1,53	7,3	3,4	4,8
I/2	1,61	5,7	6,5	9,5
I/3	1,68	6,0	6,5	9,5
II/1	1,67	6,5	4,9	6,5
II/2	1,47	6,8	2,9	3,6
II/3	1,96	5,6	7,5	12,5

In order to increase the implementation and dissemination of the novel technology, another trial project was carried out on a sidewalk section, the main aim of which was to clarify the extent to which hot bituminous mastic asphalt (Gussasphalt) reacts with concrete containing plastic. Figure 7 shows samples drilled from a mastic asphalt sidewalk pavement. It can be clearly seen that the plastic additive layer does not separate from the top asphalt layer (the sample on the right side of the photo is shown upside down). The results of a similar research work are summarized in [12].

Figure 7 Core samples of trial sidewalk with bonded layers

6 Conclusion

The use of plastic waste as a kind of aggregate in road construction has already been investigated for more than 30 years. In 2020, Hungary joined the countries where experimental projects have already been completed using also hydraulically bound plastic aggregate. Based on the results, it can be stated that the test sections met the hopes for the technology (e.g. Masuko additive). The next step in the dissemination of the technology is to apply it in an in-service road pavement structure utilizing fully the test results obtained so far. Preparations for this extended trial have already begun. Hopefully, in some 5 years there will be an opportunity to prove with a complete data time series that this novel road construction technology can be used without any problem. It is evident that the technique is economically viable, by reducing considerably the quantity of available plastic waste, and in addition to it, enabling the optimum use of scarce primary mineral resources (high quality stone, gravel, sand) of the country.

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