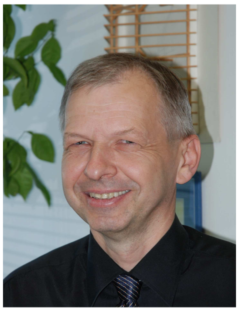
SAVINGS OF NATURAL RESOURCES BY THE USE OF ELEMENTS FROM RECYCLED MUNICIPAL WASTE IN BUILDING CONSTRUCTION

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Summary

Recycling is an essential phase of the life cycle which determines the feasibility of further material use. As the possibilities of primary recycling are limited, at the moment the relevance of secondary recycling is growing. The use of separated municipal waste (plastic, glass, paper, laminated carton) in building construction can be a good example.

The article presents and discusses the use of recycled mixed plastic in the form of optimized lightening fillers for reinforced concrete (RC) floor slabs and the use of recycled laminated cartons processed as structural boards. Environmental aspects, technical and technological aspects as well as mechanical properties of the recycled boards are investigated.

Keywords: Recycled materials, recycled municipal waste, recycled plastics, recycled laminated cartons, environmental impacts, integrated design

1 Introduction

The required balance in the consumption of natural materials can be achieved in the form of closed material cycles, based on recycling of wastes which originate from previous use. Using recycled municipal waste in construction it is possible to keep once used primary material in a many times longer life cycle, and therefore considerably support saving of natural resources. The possibility of the use of structural components from recycled municipal waste in building constructions has been proved by theoretical, as well as experimental and in situ results of the long term research project performed at CTU in Prague.

2 Recycled municipal waste as an environmental friendly material

The main environmental advantages of the use of recycled materials from municipal waste are as follows: (i) reduction of primary raw materials use, (ii) reduction of environmental load by land filling, (iii) reduction of combusting of plastic or other waste with consequent environmental impacts, (iv) use of materials originally produced for a relatively short life span (several weeks or months) in construction with life span counting many years. The main concern should be paid to those waste materials which are produced in large amounts and are not recycled or just a small amount is recycled. Such waste materials are e.g. non-sorted plastics and laminated carton drink boxes both from municipal waste.

Separated salvage of municipal waste (plastic, glass, paper, laminated carton) is the common practise in developed countries but not all its types are utilized at the same level as salvaged glass or paper. In case of salvaged plastic usually only PET is further utilized the rest of plastic waste and laminated cartons are being incinerated to the great extent with all the negative environmental impacts.

Further in this article the use of recycled mixed plastic in the form of lightening fillers for reinforced concrete floor slab and the potential use of recycled laminated cartons in the form of structural boards are discussed. To illustrate the environmental load of these recycled materials the embodied energy and emissions of CO_2 and SO_2 are listed in **Tab. 1**. Concerning the embodied energy the recycled plastic consumes less then 1/10 comparing to plastics that the recycled material is made of. Boards from recycled laminated cartons consume approx. the same amount of energy comparing to wood based boards and gypsum plasterboard.

Tab. 1 Embodied energy and embodied emissions of CO_2 and SO_2 of different materials; source: author's calculation and [6].

Embodied values of materials					
material	product	embod. $CO_{2\ ekv}$	embod. $SO_{2\ ekv}$	embodied energy	
		kg/kg	g/kg	kWh/kg	MJ/kg
Recycled materials					
recycled non-sorted plastic	lightening fillers	0,492	1,05	2,04	7,36
recycled laminated cartons	building board	0,550	0,94	2,38	8,55
Plastics					
polyethylene PE	water proofing	2,500	18,00	24,17	87,00
polypropylene PP	fleece	2,100	16,00	23,61	85,00
polystyrene EPS	thermal insulation	2,300	20,00	26,39	95,00
Building boards					
gypsum plasterboard	building board	0,300	0,80	1,42	5,10
wood-fibre board	building board	0,000	3,40	4,17	15,00
oriented strand board OSB	building board	0,000	3,20	1,81	6,50

Further recycleability of recycled materials and structures should be of a great interest. Especially this kind of structures should be designed with concern to available recycling techniques so that feasible, effective, and environmentally-sound recycling can pass off.

3 Recycled plastic from municipal waste

3.1 Mixed plastic waste

The pre-sorted plastic waste is processed by crushing and grinding and resulting fractions then serve for preparation of mixtures in proportions ensuring good workability guaranteeing high quality of products. The mixture is subsequently homogenized, melted and squeezed into iron moulds where products receive their final shape. Elaborateness and energetic demands are not high, see **Tab. 1**. There are no hazardous environmental outputs from production – no hazardous waste material, waste water or harmful emissions of such a kind to endanger the surrounding environment. The recycled plastic material is used in production of several types of products – e.g. grassing paving elements, fence laths, plastic profiles, shipping pallets, etc.

3.2 Shell and ribbed fillers from recycled plastic waste

Two types of lightening fillers from recycled waste plastic were developed [1]. The shapes of fillers were determined as a result of integrated environmental design and optimization considering environmental criteria, as well as structural parameters of the resulting composite RC structure. The initial optimization steps, covering the use of the ribbed or waffle shape and use of recycled materials, resulted in the reduction of embodied values.

The shape of waffle shell fillers was optimized for the use as a formwork of two way waffle RC floor slabs with ribs in axial distances 300×300 mm. There are two basic alternatives, a removable formwork and a permanent formwork that remains in the floor structure. The second alternative requires application of fire protection of plastic filler elements by suspended lower ceiling. This alternative was experimentally verified and applied in construction practice. One forming element contains 4 cassettes and covers 1,2×0,3 m area (**Fig. 1**). The height of the cassettes is 160 mm + 20 mm high ribs to support mesh in a top RC covering slab.

Fig. 1 Waffle shell fillers from recycled waste plastic

Fig. 2 Installation shell fillers from recycled waste plastic

The shape of light shell elements from plastic makes it possible to create installation space inside a RC floor slab which can be used for wiring and other building services (**Fig. 2**). The installation space can be accessed through installation holes in an axial distance

600 mm. The height of the element is 100 mm + 50 mm the access installation hole. The length of one element is 1,2 m.

The production of both types of shell plastic filler elements has been proved by experimental production in the recycling company Transform Lázně Bohdaneč in 1999-2000. These fillers are nowadays a part of common production assortment.

3.3 Application in construction of buildings

The alternatives of optimized RC composite slabs lightened by the above described types of fillers from recycled waste plastics were experimentally tested and applied in construction practice. The first practical application was construction of Senior Centre in Morovany in 2000 where RC floor slabs with installation shell elements were used. The second in site application was reconstruction of the floor structure in a two storey factory hall in 2004. The third application is the current development of prefab panels with installation fillers. For more details see [7].

4 RECYCLED BOARDS FROM LAMINATED CARTONS

4.1 History

The idea of production of boards from recycled laminated cartons with intended use in building industry is neither new nor original. Since 1994 Kuruc company Slovakia has been dealing with problems of recycling of laminated beverage cartons when subsequently new simple and effective technology of carton processing was developed (Tetra K boards). This technology was adopted and further modified by Novapak company in Nová Paka in the frame of pilot project with the support of Eko-kom company between years 1998 and 2001. In 2003 R.P.O. company in Hrušovany u Brna was established. This company was processing different types of composite packages inclusive laminated cartons, the processing technology remained very similar to the Kuruc one.

At the beginning of the year 2006, production of Flexibuild boards from recycled laminated cartons was restarted in Hrušovany. At the same time cooperation between the producer and the Faculty of Civil Engineering was initiated. This cooperation resulted in requirements for verification of selected boards properties, specifying the potential of properties improvement and finally setting of new perspective ways of use.

Besides these producers EVD company in Diez, Germany has been processing laminated drink cartons in its own technology for several years. Their processing technology is not much different from the above mentioned one but the final boards, as they are intended for furniture manufacturing, are significantly of a better quality.

4.2 Laminated cartons

Concerning the raw material both laminated cartons from sorted municipal waste and process scrap from the production of drink cartons are used. The cartons are shredded (cartons from municipal waste are subsequently washed and dried), spread into sheets and compressed at a temperature of about 170 °C. The polyethylene (PE) content in the material melts and acts as a binder. Besides PE content in the raw material additional waste PE is being added to the raw material to reach the proper cohesion. Usual composition of the beverage cartons is as follows: cartoon ~73 %, PE ~21 %, aluminium ~21 %, pigments ~0.5%.

The boards are intended for interior and exterior panelling where final thin external rendering, tilling, etc. must be applied. Boards can be also used as underflooring or as a temporary surface protection. Furthermore, partition wall panels and cladding panels are produced from these panels.

4.3 Tested material characteristics

In the first phase several property groups were estimated that were arranged to be important for both sides the manufacturer and authors, and concurrently were feasible to test in the faculty laboratories.

Mechanical properties were chosen as essential utility properties for further use. Some mechanical properties were already known from previous research [1], where especially the orthotropy (considerably different properties in longitudinal and transverse direction) of the Tetra K boards comparing to new Flexibuild boards were verified. Another issue was the choice of technical standards according to that the material should be tested. Finally the standards for testing of wood based materials were chosen [2, 3]. According to these standards were tested basic mechanical properties: modulus of elasticity in bending and bending strength according to EN 310 [2], tensile and compression strength according to EN 789 [3]. Bending properties will be also tested according to EN 789.

The boards for test samples were manufactured in the end of 2006. There were prepared two types of the boards the first one was of standard composition (mixture of approx. 1/2 of used cartons from municipal waste and 1/2 of technological waste) and the second one was a special type from pure technological waste. Originally, it was arranged to prepare special boards for testing from finer scrap (fraction less than approx. 8 mm) but at that time it wasn't technologically feasible. This treatment should improve the structure of material (avoid presence of local cavities) and therefore improve all mechanical properties. Such a special boards will be prepared and tested later on.

Thermal and moisture properties, specifically the sensitivity to increased moisture content, have to be observed due to a high content of carton in the material. From this group only bulk density and water vapour diffusion coefficient were specified. Further properties like coefficient of thermal and moisture expansion, swelling capacity, etc should be specified subsequently.

Finally, embodied energy and emission of CO_2 and SO_2 were quantified to estimate the environmental impact, see **Tab. 1**. These values were counted based on energy bills and the year production amount, using also data from the Czech database of Gemis software.

4.4 Results

In the first phase water vapour diffusion coefficient was verified. Due to relatively high content of polyethylene in the raw material and considering thermic processes during the manufacturing phase, assumption of high water vapour diffusion coefficient arise, furthermore, supported also by expert's survey [2]. The measurement was carried out on delivered test samples – Tetra K panels made by Slovakian manufacturer Kuruc because at that time the production of Flexibuild panels in Hrušovany wasn't started yet. The measurement was done on circular test samples using wet cup method. The measurement results corroborated with the initial assumption, nevertheless, there arose a problem with high variance of the values, so typical for majority of recycled materials. Average value of the coefficient was $\mu = 183$, measured values lay in interval (110, 326). The outcomes resulted in the need for further testing with higher amount of test samples. The new tests are planed already on Flexibuild boards which are visibly of a better quality, especially concerning homogeneity.

Tab. 2 Mechanical properties of Flexibuild boards – standard and special test samples

Mechanical properties of Flexibuild boards					
material characteristic	standard	average values		mean deviation	
		stand. samples	special samples	stand. samples	special samples
		N/mm^2	N/mm^2	N/mm^2	N/mm^2
bending strength rh 30%	ČSN EN 310	**7,70**	**5,98**	1,38	0,77
bending strength rh 65%	ČSN EN 310	**6,82**	**7,06**	1,01	0,87
modulus of elasticity rh 30%	ČSN EN 310	**596**	**499**	112	82
modulus of elasticity rh 65%	ČSN EN 310	**463**	**499**	104	89
tensile strength	ČSN EN 789	**3,21**	**2,94**	0,65	0,44
compression strength	ČSN EN 790	**2,31**	**2,22**	0,36	0,51

Bending properties were tested according to EN 310 [2] where the first set was climatized to relative humidity of 30 % and the second set to 65 % as the standard prescribes. There was observed the dependence of the strength on humidity rise. The measured values are arranged in **Tab. 2**. The most apparent property mutual to all the values is great deviance which subsequently obscures readability of the results. The dependence on humidity is evident but concerning the special samples the influence is unclear. Another partly expected property is the lower deviance of special samples which is linked with worse average values. **Fig. 3** shows the relation between bulk density and bending strength, the essential dependence which shows the potential for material improvement.

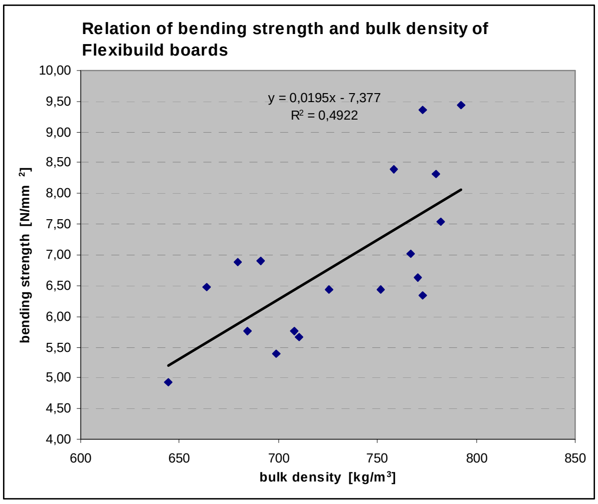

Fig. 3 Relation of bending strength and bulk density of Flexibuild boards

5 Conclusions

Building construction typically uses large amounts of materials in relatively less demanding techniques. Therefore, there is a high potential for the use of secondary materials obtained from its own material cycles but also from recycling of waste generated by other industrial processes and from municipal waste. This results in reduction of consumption of primary material sources and reduction of waste and emissions generation.

Structural advantages resulting from lightening of solid RC floor slabs are significant material savings and related transportation cost savings. Together with using fillers from recycled waste plastic these structures contribute to reduction of embodied values (CO_2,

SO_2, energy) and decrease the environmental load by land filling or combusting. The fillers can be further recycled in the same way without noticeable down-cycling.

The structural boards from recycled laminated cartons represent interesting material where the described processing technology has to be optimized to improve the materials characteristics, especially the deviation of values. Anyway, the verified characteristics show that the boards, concerning a certain potential for improvement, can be compared with other structural boards like gypsum plasterboard or various wood-fibre boards and in addition can add specific characteristics like high water vapour diffusion coefficient.

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