Utilization of FRP recyclate in the production of chipboards for construction industry

M. Drdlová[1], P. Böhm[2], M. Šperl[2]

[1,2]Research institute for building materials, Brno, 61700, Czech Republic
[3]The Institute of theoretical and Applied Mechanics, Prague, 19000, Czech Republic

Keywords: FRP recycling, chipboard, glass fibre laminate, mechanical disintegration of FRP
Presenting author email: drdlova@vustah.cz

Abstract

The article deals with the possibilities of using recyclate, prepared by shredding waste fibre reinforced polymer (FRP), in building materials. As the first step, the influence of disintegration parameters on the properties of the output product of FRP recycling was investigated. The outputs in the form of chips of suitable granulometry and shape parameters were further verified for use in chipboard for structural purposes. The effect of chip size and binder content on the physico-mechanical parameters of the chipboard was evaluated. Higher flexural tensile strength was achieved when lower chip lengths were used; the opposite trend was observed regarding the impact toughness. Functionally graded specimens with variable chip lengths were also prepared and the effect of gradation on the mechanical parameters of the chipboard was assessed. The results were compared with commercial particleboard and wood chip-based materials, and the competitiveness of the developed new FRP recyclate-based materials was confirmed.

Introduction

FRP composites are widely used in many industrial sectors, such as automotive, aircraft and renewable energy industries, mainly due to their excellent strength/weight ratio and good corrosion resistance [1]. Being so spread, these materials generate significant amounts of waste at the end of their life cycle. Today, there are solutions for recycling composite materials available, covering mechanical recycling, thermal processes (pyrolysis, fluidised bed pyrolysis, micro-waves pyrolysis), solvolysis, chemical recycling or degradation of the matrix by microorganisms; some of the methods more commercially advanced than others, but mainly their economic viability is limited. Additionally, industrial applications using recycled fibres or resins are still rare, although there are already various studies on the practical applications of FRP recyclate. E.g., the influence of partial replacement of sand aggregates by GFRP recyclate on the properties of polyester-based mortars was investigated by Castro et al [2]. Results showed the positive effect on mechanical properties of the polymer mortars modified with the GFRP recyclate – the authors concluded, that the partial replacement of sand aggregate with GFRP waste materials, up to 8% of the total weight content, has an incremental effect on the flexural and compressive strength of the polymer mortars, regardless of the size class of the GFRP waste [2]. The possibility of using FRP recycling products in cement-based composites has also been studied; some studies concluded an increase in flexural tensile strength when fine aggregates are partially replaced by GFRP recyclate [3,4], while others report a decrease in mechanical parameters, including flexural tensile strength [5,6]. Applying the GFRP recyclate into a cementitious matrix seems to be promising; however, the shape parameters of the recyclate must be carefully selected, and only alkali-resistant fibres should be used to ensure to ensure stable properties over the long period.

The utilization of GFRP recyclate in the production of artificial timber and construction panels has been successfully tested at laboratory scale by [7]. 50% FRP recyclate and 50% wood flakes were used to produce the panels for the construction industry. The panels showed good physico-mechanical properties similar to conventional wood-based particleboard [7]. However, the combination of wood and FRP recyclate can complicate the subsequent recycling of boards at the end of their life cycle. The presented study thus aims to verify the possibility of using the FRP recyclate in (multilayer) composite panels for the construction industry with 100% of wood replaced by waste FRP. Such a material formulation has the potential for high waste material consumption and better recyclability prospects. Almost 358 million m^3 of particle- and chipboard panels are manufactured per annum worldwide [8]; demand for structural panels with mechanical parameters similar to wood-based boards and higher durability can therefore be expected.

The research presented here is therefore focused on:
1) Monitoring the influence of mechanical recycling process parameters on the nature of FRP recyclate.
2) Evaluating the effect of chip size and binder content on the chipboard physico-mechanical parameters

Experimental

Materials and methods

The source material for the preparation of FRP recyclate was discarded fibreglass pressure vessels for gas storage, i.e., vessels at the end of the life cycle and those that did not pass the output inspection in production. The container composition was 82% glass fibre and 18% thermoset resin (epoxy). The vessels were cut into four pieces and further disintegrated using different variants of shredders:

1) single-shaft knife crusher DRJ44 (with sieve 6 mm and 12 mm)
2) double-shaft shredder DRK500 (width of crushing disc 18.36 mm, without sieve)
3) double-shaft shredder DR120 (width of crushing disc 5.5 mm, without sieve)
4) hammer shredder RTZ (width of hammer segment 10 mm, grate 10 mm)
5) shear mill CM 2500 (sieve 10 mm)

All crushers and mills were able to process the waste FRP material. The disintegration output was highly influenced by the crushing equipment used, parameters of its milling unit, and the sieve opening size.

The output from the single-shaft knife crusher showed a high degree of uniformity when using both 6 and 12 mm sieves. The output can be characterized as flakes to chips, see Fig. 1.

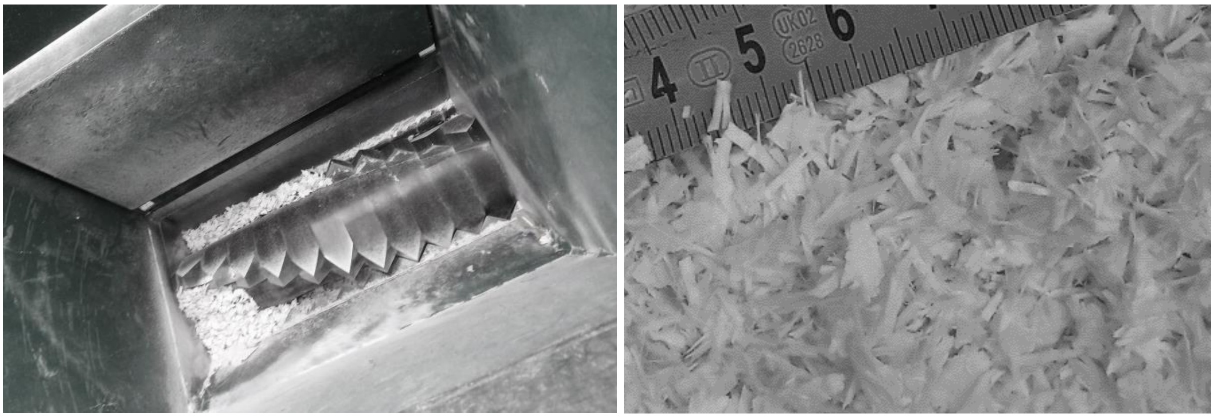

Fig. 1 Single-shaft knife crusher DRJ44 (left), crushing output with sieve 6 mm (right)


Fig. 2 Hammer shredder RTZ: hammer part (left), grate (middle), crushing output (right)


Fig. 3 Double-shaft shredder DR120, (left), crushing output (right)

Hammer shredder combined with 10 mm grate provided output in the form of needle-type chips, see Fig. 2 right. The output also showed a high level of homogeneity. The recyclate prepared using double-shaft shredder DR120 is depicted in Fig. 3 right. The output is very inhomogeneous, containing needle-like and plate-like particles of variable size. The coarse part of this recyclate is not usable for the preparation of chipboard due to its large length and width. Additional treatment of the material in the form of separation and subsequent regrinding of the coarse component would be necessary for any further use.

Fig. 4 Double-shaft shredder DRK500 (left), crushing output (right)

The DRK500 double shaft shredder with wide blades can shred material efficiently. However, the recyclate is in the form of irregular flat plates up to 7x4 cm (see Fig. 4 right), which are unsuitable for chipboards. The recyclate prepared by the shear mill had a high percentage of fine particles. Particles up to 3 mm represent 62% of the total weight of the mixture, while the remaining part consists of a heterogeneous mixture of chips and fibres of different sizes (see Fig. 5 right). A high proportion of fine particles is not desirable in the preparation of particleboard due to the increase in binder consumption; this output is therefore also not very suitable for the intended use.

Fig. 5 Shear mill CM 2500 (left), crushing output (right)

The crushing outputs of the single-shaft knife crusher DRJ44 (designation ST, Fig. 1) and the hammer shredder RTZ (designation V, Fig. 2) were selected as suitable for preparing chipboard test samples. Two types of chipboards were prepared – dense and cavern (open structure).

The chips ST were used to prepare the dense chipboard samples. To evaluate the effect of the chip size and resin content on the flexural strength, 10 formulations were prepared. From each recipe, 3 test pieces of 250×50×10 mm were prepared. The two-component epoxy resin EPO R (producer: Recetex company) was used as a binder; the content ranged from 16% to 24% in increments of 2%. The recyclate was mixed with the resin for 5 min. in a laboratory mixer, after which the mixture was manually layered into a mould. The covered mould was subsequently pressed at an elevated temperature (150°C) for 15 min.

In the next step, the 3-layered functionally graded samples have been prepared from ST chips to achieve higher flexural strength and to evaluate the influence of the fine/coarse chip ratio on the physico-mechanical properties of the panel. The mix proportions of the samples are summarized in Table 1; 2-12 mm chips were used for the core in all cases, whereas the surface layers were formed by chips with length of 2-6 mm. All samples contained the same amount of resin – 20% by weight.

Table 1. Mix proportions of the functionally graded chipboard samples

Designation	Fine (2-6 mm)/coarse (2-12 mm) chip ratio
ST3-0.4	0.4
ST3-0.75	0.75
ST3-1	1

Chips designated as "V" obtained from processing the laminate waste by the hammer shredder RTZ were used to prepare the cavern chipboard samples with low bulk density, similar to the product of Velox, Durisol, etc. As a binder, the same epoxy resin EPO R was used. The test slabs were manufactured as follows: The recyclate was mixed with the resin for 5 min. in a laboratory mixer, after which the mixture was manually layered into a mould. Subsequently, the covered mould was pressed at an elevated temperature (100°C) for 15 min. The mix proportions are given in Table 2.

Table 2. Mix proportions and physico-mechanical properties of the V chipboard samples

Designation	Amount of epoxy % wt	Chip size (mm)
REF (Velox WSW 85)	-	-
V-1	20	2-30
V-2	16	2-30
V-3	14	2-30

The mechanical parameters (flexural strength) were obtained using the universal strength testing machine TIRAtest 2710, R58/02. The flexural load (three-point flexural test) was applied at quasi-static conditions (speed of 5 mm/min). Izod impact strength test was used to determine the impact toughness of the materials.

Results and discussion

Examples of the prepared test specimens are shown in Fig. 6. All the prepared test bodies were solid and coherent. The physico-mechanical properties of the specimens with chips designated ST (length of 0-6 and 0-12 mm) are summarized in Table 3. The flexural strength and impact toughness increase with increasing resin proportions for both sets of test bodies. The highest value of flexural strength (34.88 MPa) was achieved in the case of the specimen with 24% of binder. In the study [7], similar values of flexural strength and bulk density of particleboard samples prepared with partial replacement of wood flakes with GFRP recyclate were reported (35 MPa and 1035 kg/m^3, respectively). In this case, however, only 50% of the wood flakes were replaced, whereas in the case of the presented study, the wood mass was fully replaced by recyclate. Higher flexural strength of the specimens can also be noted compared to the wood chip-based reference specimen, with better results in the case of samples based on the chips with a size of 2-6 mm. But it must be mentioned that the Ref sample's bulk density is lower compared to the recyclate-based test bodies. In the case of impact toughness, better results were obtained for specimens with longer particles.

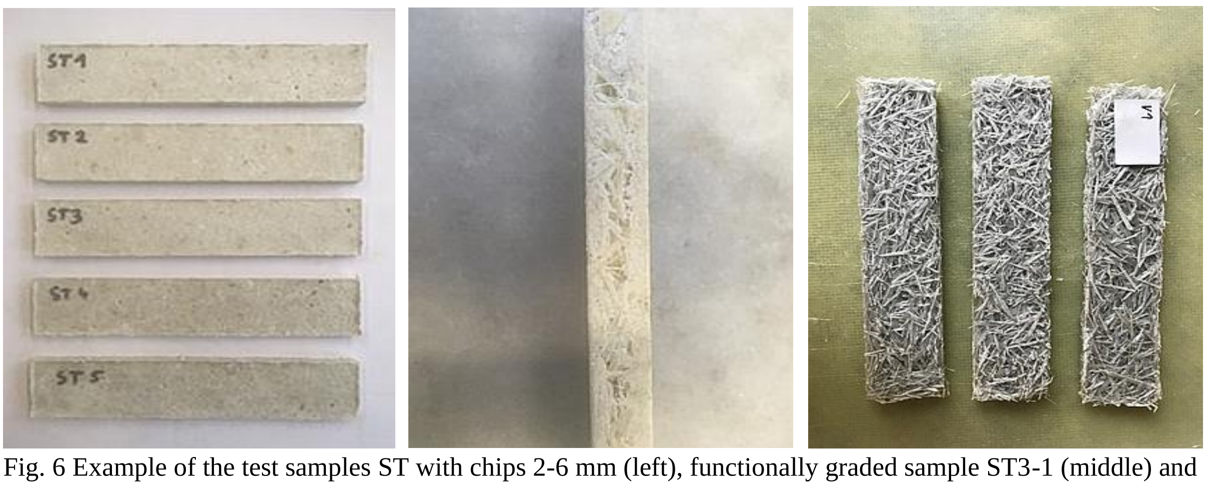

Fig. 6 Example of the test samples ST with chips 2-6 mm (left), functionally graded sample ST3-1 (middle) and example of the test sample V-1 with chips up to 30 mm (right)

Table 3. Physico-mechanical properties of the ST chipboard samples

Designation	Amount of epoxy % wt.	Chip size (mm)	Bulk density (kg/m^3)	Flexural strength (MPa)	Impact toughness (kJ/m^2)
Ref - wood	NA	NA	741.8	17.86	6.2
ST 1	16 %	2-6	1047.5	17.02	7.9
ST 2	18 %	2-6	1074.3	17.96	8.6
ST 3	20 %	2-6	1105.3	24.32	9.4
ST 4	22 %	2-6	1138.9	29.41	13.1
ST 5	24 %	2-6	1159.4	34.88	12.6
ST 6	16 %	2-12	1002.4	11.59	6.2
ST 7	18 %	2-12	1046.5	14.63	10.3
ST 8	20 %	2-12	1073.6	22.24	11.2
ST 9	22 %	2-12	1120.8	27.15	15.4
ST 10	24 %	2-12	1157.0	25.66	17.5

The results of physico-mechanical properties of functionally graded specimens are summarized in Table 4. Functionally graded material may be characterized by the variation in composition and/or structure gradually over volume, resulting in corresponding changes in the material's properties. Regarding the designed particleboard, the aim of the gradation was to optimize the composition to achieve a better flexural strength/weight ratio. The measured values of flexural strength and impact toughness (see Table 4) show that changing the fine/coarse chip ratio in the composition of the three-layer boards does not have a significant effect on the mechanical properties. Additionally, the functionally graded samples showed similar values of both impact toughness and flexural strength compared to the samples without gradation (at same binder content); only a very limited reduction in bulk density was observed.

Table 4. Mix proportions and physico-mechanical properties of the functionally graded chipboard samples

Designation	Bulk density (kg/m^3)	Flexural strength (MPa)	Impact toughness (kJ/m^2)
ST3-0.4	1077.7	23.81	10.8
ST3-0.75	1116.7	24.42	11.1
ST3-1	1093.3	23.67	11.3

The last tested material group was the cavern chipboard samples with low bulk density. The recyclate designated as “V” with particle length up to 30 mm was used to prepare these samples. This group aimed at achieving the parameters of wood-chip cement-bonded slabs with open structure, which are currently utilised e.g in noise barriers, as lost formwork and in monolithic building technology. The physico-mechanical properties of prepared test specimens are summarized and compared with the reference sample (commercial Velox slab) in Table 5.

Table 5.Mix proportions and physico-mechanical properties of the “V” based chipboard samples

Designation	Amount of epoxy % wt	Chip size (mm)	Bulk density (kg/m^3)	Flexural strength (MPa)	Impact toughness (kJ/m^2)
REF (Velox)	-	-	502	0.28	3.2
V-1	20	2-30	497	5.29	8.4
V-2	16	2-30	471	3.81	6.1
V-3	14	2-30	430	2.72	4.2

Both flexural tensile strength and impact resistance increase with increasing binder content. The recyclate-based chipboards achieved significantly higher flexural strength compared to the reference sample based on wood chips by maintaining low bulk density (same or lower compared to the reference sample, depending on the content of the resin). Even the specimen with the lowest binder content shows higher flexural tensile strength values (2.72 MPa) than the reference specimen (0.28 MPa) of the same dimensions. Further addition of binder increases the strength characteristics significantly. This allows reducing the amount of material used in the production of the elements while maintaining the same mechanical parameters. [9] and [10] reported similar mechanical properties of waste-based particleboards. In addition, the chipboard prepared from waste FRP shows other advantages compared to the commercial wood boards – notably lower water absorption and rot resistance. The material appears promising as an alternative to lightweight woodchip panels.

Conclusions

FRPs are increasingly being used in construction due to their low weight, durability and tailor-made properties. FRP is widely considered to be un-recyclable, and at present, the most common disposal method for such material is landfill and incineration. The main objective of the presented research was to evaluate the effect of waste FRP chip dimensions and binder content on the physico-mechanical parameters of the chipboard samples in order to verify the possibility of the utilization of the shredded FRP in chipboard production. The following conclusions can be drawn:

-By mixing and subsequent hot pressing of recycled FRP chips with appropriately dosed organic binder (14-20% by weight) it is possible to prepare boards with good mechanical parameters, potentially suitable for using in the construction or furniture industry (partitions, lost formwork, building cladding, floor boards, anti-noise wall panels). The mechanical properties are comparable with commercial particleboard available on the market. In the case of cavern chipboards, the achieved physico-mechanical parameters outperform the values of commercial reference specimens.

-The overall character, shape and size parameters of FRP recyclate can be highly influenced by the device used for shredding, parameters of milling unit, used sieve and the parameters of the shredding process itself. Therefore, it is possible to design the processing line so that the output material corresponds with the planned application.

-Flexural tensile strength and impact toughness of FRP based chipboards increase with increasing binder content.

-Regarding the dense particleboards, test specimens consisting of shorter chips (2-6 mm) show higher flexural strength values compared to those produced from longer chips (2-12 mm). Gradation and changing the fine/coarse chip ratio does not significantly affect the mechanical parameters of the chipboards.

A significant advantage of the GFRP based chipboard is that they do not require drying before use (unlike woodchip) which reduces the overall energy input of production. Based on the results of the presented first phase of research work, the described direction of using FRP recyclate can be evaluated as promising; however, additional tests need to be performed to fully verify the suitability of the proposed boards for structural purposes. Further work will thus be focused on the preparation of large-scale (1200x700 mm) test bodies and the evaluation of dimensional stability, impact resistance, long-term durability and acoustic parameters.

Acknowledgement

The authors wish to express their gratitude and sincere appreciation to the authority of The Technology Agency of the Czech Republic, project No. FW01010355, for financial support.

References

[1] Gay, D and Hoa, S.V Composite Materials: Design and Applications, CRC Press, 2003

[2] Castro, M.C.S et al, Sustainable waste recycling solution for the glass fibre reinforced polymer composite materials industry, Construction and Building materials, Vol. 45, 2013, p. 87-94

[3] Mastali, M., Dalvand, A and Sattarifard, A.R., The impact resistance and mechanical properties of reinforced self-compacting concrete with recycled glass fibre reinforced polymers, Journal of Clean Production, Vol. 124, 2016, p. 312-324

[4] Ribeiro, M.C.S et al, Re-use assessment of thermoset composite wastes as aggregate and filler replacement for concrete polymer composite materials: a case study regarding GFRP pultrusion wastes, Resources, Conservation and Recycling, Vol. 104, Part B, 2015, P. 417-426

[5] Fox, T.R., Recycling wind turbine blade composite material as aggregate in concrete, Master Thesis, Iowa State University 2016

[6] Correia, J.R., Almeida, N.M. and Fiqueira, J.R., Recycling of FRP composites: reusing fine GFRP waste in concrete mixtures, Journal of Clean Production, Vol. 19, 2011, p. 1745-1753

[7] Conroy, A., Halliwell, S., Reynolds, T. Composite recycling in the construction industry, Composites Part A: Applied Science and Manufacturing, Vol. 37, Is. 8, 2006, p. 1216-1222

[8] Pedzik, M., Janiszewska, D and Rogozinski, T. Alternative lignocellulosic raw materials particleboard production: A review, Industrial Crops and Products, Vol. 174, 2021

[9] Binici, H. et al. Investigating sound insulation, thermal conductivity and radioactivity of chipboards produced with cotton waste, fly ash and barite, Construction and Building materials, Vol. 30, 2012, p. 826-832

[10] Monteirode, R. and Filho, B. Hybrid chipboard panels based on sugarcane bagasse, urea formaldehyde and melamine formaldehyde resin, Industrial Crops and Products, Vol. 33, Is. 2, 2011, p. 369-373