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# MECHANICAL PROPERTIES OF POLYMER CONCRETES BASED ON UNSATURATED POLYESTER RESIN REINFORCED WITH MILLED CAR WINDSCREEN WASTE GLASS AND QUARTZ SAND

**This article presents an attempt to evaluate the mechanical properties such as the flexural strength and impact strength of polymer concretes based on unsaturated polyester resin reinforced with milled car windscreen waste glass and quartz sand. A set of five samples was prepared with a stable volume content of resin at 30% and varying proportions of milled glass from recycled car windscreens and quartz sand. The materials were tested in static and dynamic (Charpy) bending conditions. Based on the collected data, it was found that the most favorable properties were obtain by the polymer concrete with milled glass, and milled glass and sand (volume ratio 1:1). It is predicted that the developed materials can be successfully used in the production of paving slabs as well as prefabricated garden and road accessories. This would enable the disposal of troublesome waste, which is car windscreens, to produce high-quality products with a long service life.**

**Keywords:** **polymer concrete, car windscreen, glass powder, unsaturated polyester resin, mechanical properties**

## INTRODUCTION

The main reasons cement-based concrete has been used as a building material for centuries are the easily available raw material supply, low cost, good strength, good durability and good formability. Due to some problems arising in traditional concrete over time, especially in some specific applications, research has been conducted to develop new types of building materials that can be applied instead. The typical disadvantages of traditional concrete are its high water absorption leading to a reduction in frost resistance, low chemical resistance, low modulus of elasticity, low impact strength and long hardening time to achieve the maximum properties [1-3]. As a result of the research carried out in the years 1950-1960, a construction material called polymer concrete (PC) was developed that can be employed as an alternative to traditional concrete [4, 5]. It is a material from the group of polymer matrix composites (PMCs). Materials of this type are known as excellent construction materials owing to their very good mechanical properties and low weight. Due to the elasto-plastic character of the polymer matrix, PCMs also have good vibration-damping properties [5, 6], which is important for building materials, and in turn, has an advantageous effect on other mechanical properties. Particle-reinforced polymer matrix composites may also be produced as high-tech functional materials [7-9]. Different from conventional concrete, research on PCs is performed by using different types of mineral-based aggregates and polymer resins [3, 10, 11]. In PCs, various types of polymer resins are used with curing agents instead of using cement as the binder in conventional concrete. Both in the production of traditional concretes and polymer concretes, waste materials may be applied, e.g. fly ash from power plants, ground blast furnace slag, ash from sewage sludge or ground ceramic materials [12]. One of the types of waste, which is one that is difficult to reuse because of its multi-material composition, is car windshield glass. A car windshield is composed of layers of glass and polyvinyl butyral (PVB) foil, which are difficult to separate completely; therefore, such waste material must be milled as a whole and then can be added to concrete [13]. The PVB layer between the layers of glass is added to prevent the windshield from smashing in the case of any impact, and at the same time to provide visibility as it has a transparent structure.

Basically, polymer concretes are divided in four different classes. They are called polymer concrete (PC), polymer cement concrete (PCC), polymer Portland cement concrete (PPCC) and polymer impregnated concrete (PIC). A synthetic polymer with a binder is present in PCC or PPCC type concretes, which are produced by spraying monomer on cement. In PIC type concretes, the polymerization process is carried out with a low viscosity monomer [14, 15]. Only PC is a "classic" polymer-matrix composite in which the whole matrix is cured polymer resin and the whole reinforcement is (usually varying in diameter) a mineral filler. The polymer resin acts as binder, while the filler adds volume and hardness to PC [16, 17]. Concrete is composed mostly of aggregates of different grain size. The production of polymer concrete using sand as a coarse-grained aggregate and fine-ground car windows is justified. The role of fine-grained glass filler is to change the mechanical properties. Appropriate selection of the milling parameters allows a fine fraction of grains to be obtained, which fill the voids in the structure of polymer concrete, leading to material compaction and enhanced mechanical properties. Furthermore, the use of waste windshields in PC production reduces the cost by eliminating the supply of a new raw material and also allows a waste material to be recycled [18-20].

The resin chosen as the binder in PC production transfers its properties to the concrete. Therefore, there are particular parameters to be considered in resin selection. Examples of these parameters are adhesion, curing time, strength and chemical properties [21]. In addition to all these, since it is known that the production of polymer concrete is more costly than conventional concrete, the cost should also be considered in the selection of the resin [22, 23]. Compared to other resins, polyester resin is less expensive, and thus it is often preferred in PCs. Polyester resin-based PCs exhibit good chemical resistance and physical properties such as high strength and low shrinkage [24, 25]. Polyester resin-based PC composites are generally used as filling materials, pipes, stairs, and in prefabricated applications. Since high compressive strength can be obtained in a short time, they are employed in mining, tunnels and highways where rapid-set concrete is required. They are applied in industrial works, coatings and repairs owing to their high mechanical and chemical resistance [26, 27]. However, their cured state is weaker than epoxy resin, and are therefore is not suitable for bonding with many substrates. Finally, as a consequence of its toxic nature, appropriate protection must be used; otherwise, it poses a safety risk [27, 28].

The aim of this paper is to evaluate the mechanical properties (flexural and impact strength) of PCs containing milled car windshields.

## MATERIALS AND METHODS

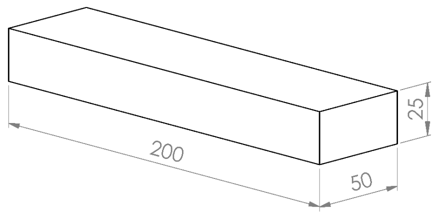
Havelpol-1 unsaturated polyester resin catalyzed with Butanox-M50 (100:2 by mass, produced by Havel Composites, Czech Republic) was selected as the matrix material. Broken car windshields were milled in a Retsch SK300 cross beater mill using sieves with trapezoid holes (in order) 2.0 mm, 1.0 mm, 0.5 mm. Before the casting process the aggregates, sand and windshield powders were dried for 24 hours at 60°C. Firstly, five different proportions (Table 1) of sand grains and windshield powders were mixed with the polyester resin.

Secondly, mold release wax was applied to the molds before casting to enable easy removal of the samples from the molds after curing. Aluminum molds 200 x 50 x 25 mm (Fig. 1a) and silicone molds 70 x 10 x 7 mm (Fig. 1b) were used to cast the PC samples. The aluminum mold cast samples were subjected to the three-point bending test and the silicone mold cast samples were subjected to Charpy impact tests. Finally, the PC samples were cast and the molds were left to cure. After 72 hours, the samples were removed from the mold and subjected to mechanical tests. The produced samples are shown in Figure 2.

TABLE 1. **Composition of polymer concrete samples containing car windshield waste (glass + PVB)**

| | Glass waste with PVB foil [vol.%] | Sand [vol.%] | Polyester resin [vol.%] |
|---|---|---|---|
| G70S0 | 70 | 0 | 30 |
| G50S20 | 50 | 20 | 30 |
| G35S35 | 35 | 35 | 30 |
| G20S50 | 20 | 50 | 30 |
| G0S70 | 0 | 70 | 30 |

a)




b)

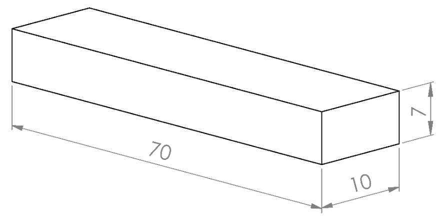



Fig. 1. Sample dimensions: a) for three-point bending tests, b) for Charpy impact tests

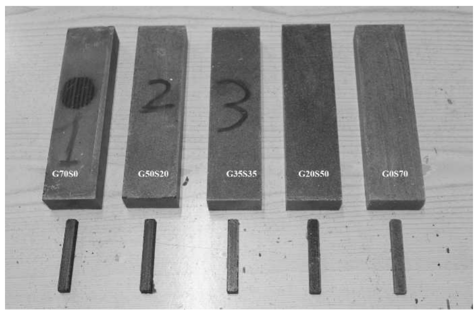



Fig. 2. Polymer concrete samples

Single samples of each type for the three-point bending test and three samples of each type for the Charpy impact tests were produced. The three-point bending tests were performed at room temperature on an Instron

4469 machine (Fig. 3). The support spacing was 190 mm and the deformation speed was 10 mm/min. Impact testing was conducted with a Charpy hammer at room temperature. The spacing of the supports was 39 mm. In both tests, the force was applied to the upper surface of the sample. The three-point bending tests were carried out according to the PN-EN ISO 14125 standard and the Charpy impact tests were performed in accordance with the PN-EN ISO 179-1 standard.

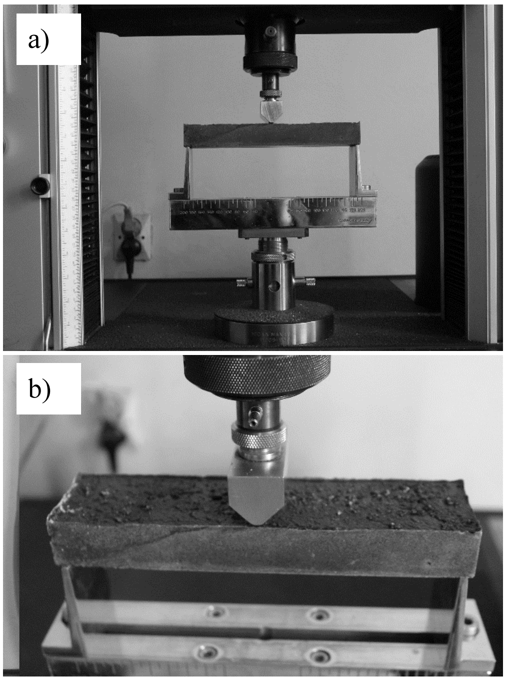



Fig. 3. Three-point bending test: a) view of entire measuring system, b) close-up view of sample

## RESULTS AND DISCUSSION

Tables 2 and 3 summarize the results of the three-point bending and impact tests. Figure 4 shows the flexural stress, deflection at maximum load $f_{Rg}$", and the load-displacement curves of the three-point bending results. Figure 5 presents the results and standard deviations of the impact tests.

The results of the three-point bending tests (Fig. 4 and Table 2) reveal that the sample with milled glass (G70S0) and the sample with milled glass and sand of the volume ratio 1:1 (G35S35) have the highest bending strength ($R_g$). A further increase in the volume of sand relative to the volume of milled glass leads to a decrease in the bending strength, which is seen successively in samples G20S50 and G0S70. The G50S20 sample has reduced bending strength and deformation at $R_g$, which may indicate an unfavorable volume ratio of milled glass and sand. The effect of the favorable increase in the $R_g$ of the material as a result of the favorable size ratio of the powders is observed in the G35S35 sample. In this sample, there probably is a strengthening effect caused by the fine glass powder filling the voids between the larger grains of sand, making the material denser and filling micronotches. Glass powder in the same volume as sand has a significantly larger specific surface, which strengthens the material as a consequence of the increased interface area. Deformation at $R_g$ does not seems to be affected by the addition of milled windscreen glass as the values are in fact comparable and do not show any specific trend. The obtained values are much higher than for high-quality cement concrete, for which the flexural strength reaches a value of less than 8 MPa [29].

TABLE 2. **Results of three-point bending tests**

| Material | G70S0 | G50S20 | G35S35 | G20S50 | G0S70 |
|---|---|---|---|---|---|
| Max load $F_{max}$ [N] | 3801 | 3317 | 3497 | 3229 | 2544 |
| Displacement at $F_{max}$ [mm] | 1.67 | 0.90 | 1.49 | 1.45 | 1.39 |
| Flexural strength $R_g$ [MPa] | 34.67 | 29.77 | 32.67 | 29.21 | 22.30 |
| Deformation at $R_g$ [%] | 0.69 | 0.38 | 0.61 | 0.60 | 0.59 |

TABLE 3. **Results of Charpy impact tests**

| Material | G70S0 | G50S20 | G35S35 | G20S50 | G0S70 |
|---|---|---|---|---|---|
| Impact strenght [kJ/m$^2$] | 7.48(0.67) | 8.37(0.89) | 7.57(1.6) | 6.12(0.61) | 4.8(0.68) |

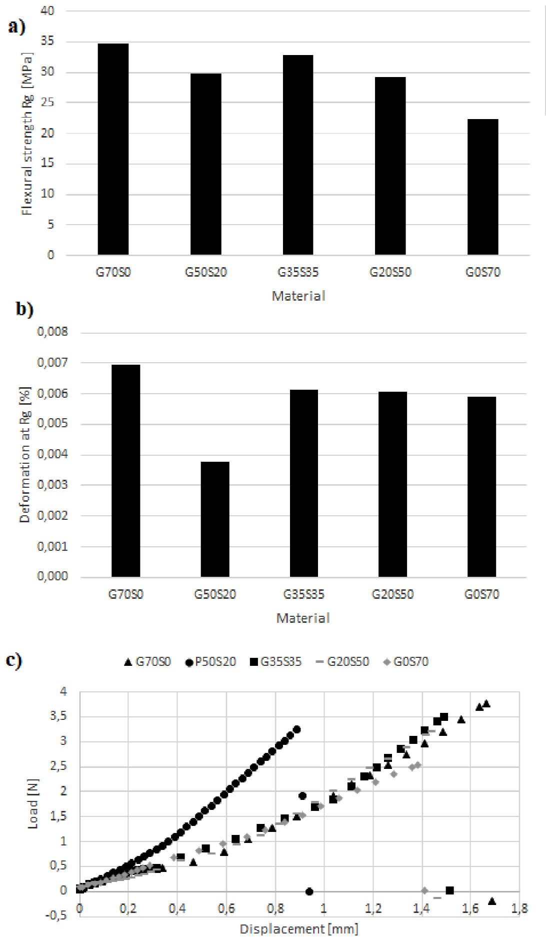



Fig. 4. Results of three-point bending test: a) flexural strength $R_g$, b) deformation at $R_g$, c) load-displacement curves

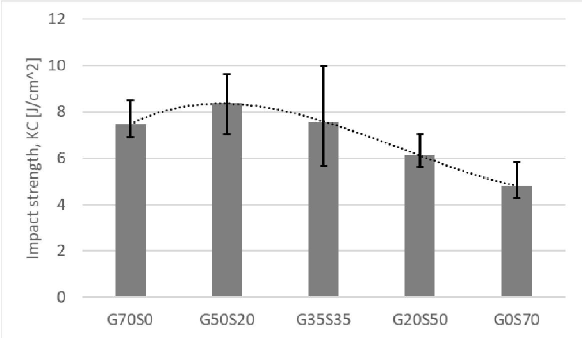



Fig. 5. Results of Charpy impact tests

The Charpy impact testresults (Fig. 5 and Table 3) indicate that adding the milled windscreen glass improves the impact strength.

The G50S20 sample exhibited the highest impact strength. Similar results were obtained by samples G70S0 and G35S35. There was large statistical dispersion in the results for the G35S35 sample, which is probably due to the non-homogeneity of the PC mass. Similar to the bending test results, G35S35, G20S50, G0S70 are characterized by a linear dependence of the impact strength, namely, as the sand content increases, the impact strength decreases. This may be because of the synergistic effects resulting from the different grain sizes of the filler in the composite and the beneficial effect of the PVB film on the glass surface [30]. The obtained values of impact strength are comparable to commonly declared values for traditional cement concrete.

## CONCLUSIONS

Samples of polymer concrete containing 30 vol.% unsaturated polyester resin reinforced with quartz sand and milled car windshield waste were assessed in three-point static bending and Charpy impact tests. The obtained results give the possibility to draw the following conclusions:

- The addition of milled glass improves the flexural strength and impact strength of the polymer concretes; the samples containing 35 to 70 vol.% milled glass exhibited evidently higher flexural strength and impact strength than those containing 20 vol.% and no glass.
- Filling the polymer concrete mass with the finely milled glass does not result in any technological problems as it is easy to mix and can be applied without special conditions.
- Polymer concretes containing milled glass can compete with traditional concretes; although they are more expensive, they exhibit higher flexural strength, which enables, for instance, the number of reinforcing steel elements to be reduced (lightweight constructions).
- The application of milled car windshields in polymer concretes seems to be an attractive, long-term and large-tonnage method for recycling of this group of wastes.

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