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THE INFLUENCE OF GRANULATION AND CONTENT OF POLYESTER-GLASS WASTE ON PROPERTIES OF COMPOSITES

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Abstract

Glass fibre reinforced composites are used in many branches of industry. Polyester-glass laminates serve as structural material in shipbuilding (e.g. hulls of units, superstructures), in railways, automotive (e.g. elements of car bodies and interior fittings, roofs of wagons, cisterns) or aviation (e.g. aircraft fuselages, fuel tanks, completion beaks and ballasts). Factors affecting the increase of their use include low specific gravity, optimal strength properties, corrosion resistance. This is associated with a large amount of post-production and post-use waste. The recycling problem of these materials remains unresolved. The article presents the technology of processing polyester-glass waste in order to obtain a recycle with a specific granulation. The selected technology for the production of layered composites with reinforcement in the form of recycle is described. For testing, granulation was selected for 1.2 and 3 mm, as well as content: 0%, 10%, 20% and 30%. Using the water-cutting method, samples were prepared according to the standard static tensile test for plastics. The tests were carried out using a universal testing machine as well as an extensometer for samples with granulation of 1.2 mm and 3 mm, as well as the selected recycled percentage. Obtained results of the research indicated that granulation as well as content affects the strength properties of composites. As the granulation increases, at the same content, the material gains less deformation. The increase in the amount of the recycle reduces the strength properties of the material, and also due to the decrease in the deformation value - the material becomes brittle.

Keywords: *recycling of composites, polyester-glass waste, tensile test, strength properties*

1. Introduction

Composites, and more specifically polyester-glass laminates, are materials used in various industries. They are characterized by good chemical resistance, low specific gravity and high strength properties [4]. They are produced from them, among others hulls of vessels, superstructures (shipbuilding), cisterns, car bodies, interior fittings and roofs of cars (car industry), fuselages and fuel tanks of aircraft (aviation). Composites are also commonly used in civil engineering for bridge elements and as reinforcing bars. The dimensions of composite products can be from very small, millimetre as elements of encapsulation of integrated circuits, to large ones, like wind farm wings or minesweepers from the Polish Navy [7]. Electrotechnical elements, telephone booths, furniture, bathtubs, sinks, and medical device housings are produced from the mouldings. The wide use of these materials in the economy forces us to address the problem of their utilization. Only in Poland, 80,000 tons of polyester-glass laminates are manufactured annually (approximately 845 production plants), which generates approximately 2,000 tons of post-production waste generated next to finished products in the production process. In 2011, only one company, producing floating units made of laminates, produced over 10 tons of waste. In a natural way after the period of use, products from the above Plastics are sent to landfills. The amount of such waste is estimated at over 20,000 tons per year [5]. The widespread use of these materials in the economy and the amount of waste resulting from production as well as from decommissioning resulted in the need to develop methods for their disposal [3]. Ways to process these materials, and use as a full-value product, replacing part of the reinforcement are many [6, 10, 11]. Continued progress in material recycling has made it possible to re-use materials such as composites that have been classified as unreachable in the past [8]. The problem of their recycling caused the search for new and better methods of managing this waste [1]. More sustainable modelling and better waste management – particularly higher recycling rates – can contribute to savings in resource costs. This would help reduce the need for raw material transport and greenhouse gas emissions. Plastics are almost exclusively produced from crude oil; and currently represent 8% of world oil production. 4% is used as raw material, and 3-4% as energy for production [2]. According to research, recycling plastics and materials can have an impact on reducing the impact of climate change, reducing the need for abiotic resources and reducing the toxicity of waters and oceans. Increasing material efficiency for composites could reduce their detrimental environmental impact [12].

The aim of this study was to determine the possibility of using polyester and glass recycle as a post-use material for the production of new composite materials. The article presents the technology of processing of used composite structural elements and then the use of processed recycle for the production of new composites. The use of polyester-glass waste for the production of composites can be one of the ways to utilize composite waste.

2. Production technology of composite material

The material from which recycle was obtained was made of 10 mm polyester-glass composite panels. The boards came from the hull part of the vessel and were waste. The boards were pre-crushed using a heavy mechanical hammer and then processed using a professional laboratory crusher to obtain the appropriate granulate. The whole was sieved through a set of sieves with a mesh diameter of 1.2 mm and 3 mm, thus obtaining two sets of granules. The preparation of a recycle with a grain size of 1.2 mm or 3 mm is a labour-intensive process and additionally strongly affects the environment – a large amount of irritating dust (particles of torn glass fibres) is created. Preparation of "composite scrap" therefore requires appropriate equipment. In the laboratory in the Gdynia Maritime University, a station for processing waste of layered composites was developed (Fig. 1) [9]. The use of this station enables processing of waste and obtaining granules of various sizes.

Fig. 1. Crusher – a processing station for composite materials [7]

Recyclate of different granulation was a component of the newly produced composite. The next step was to produce a composite based on recycle and other ingredients. Due to the existing possibilities of composite production in the laboratory, it was decided to use manual lamination using the contact method using the mat as a reinforcement. The base was made of POLIMAL 1094 AWTP polyester and construction resin produced by "Organika-Sarzyna" S.A. with a hardener and an accelerator, while the reinforcement was a mat with a random fibre direction, with a weight of 300 g/m^2.

As the base composite against which the properties were compared, a non-recycled composite was produced in an appropriate amount of resin and glass mat. Next, composite materials with polyester-glass recycled content were prepared with a content of 10, 20 and 30% by weight, granulation of 3 mm and 1.2 mm with the appropriate addition of resin and glass matting. The process of making composites consisted in supersaturating with resin (alone or with recycle) subsequent layers of reinforcement. In this process, mats, brushes and laminating rolls were used to more thoroughly supersaturate the mats. The base material (without recycle) consisted of 12 layers of glass mat and polyester resin with hardener and accelerator. The glass and polyester recycle in percentage of 10%, replaced 2 layers of glass mat. In the case of 20% material, the number of mat layers was reduced to 3, while at 30% – to 2. The reduction of mat layers was mainly caused by difficulty in filtration, at 20% and 30% recycled.

3. Research methodology

In order to determine the effect of the content and size of recycled granulate on the properties of composite materials prepared, samples for static tensile test were prepared in accordance with the requirements of the applicable PN-EN ISO 527-4_2000P standard. "Plastics – Determination of mechanical properties at static tension – Test conditions for isotropic and plastic composites orthotropic fibre reinforced". Samples from composite materials were made by water jet cutting. This method ensured very accurate preservation of the samples made, as well as avoiding the influence of temperature on changes in the material structure (in the case of mechanical processing). The shape and dimensions of the samples are shown in Fig. 2.

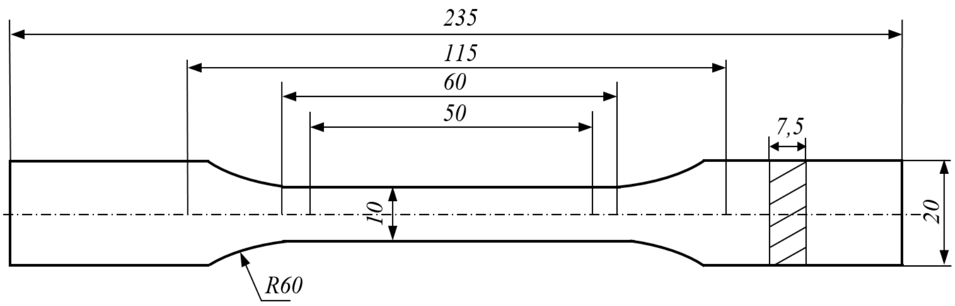

Fig. 2. The shape and dimensions of samples for static tensile tests

A static tensile test of samples was carried out on a universal testing machine with hydraulic drive type MPMD P10B with TestXpert II software version 3.61. Zwick & Roell together with the use of Epsilon 3542 extensometer, to measure elongation. Fig. 3 shows the scrap samples after the tensile test.

Destruction of samples in the middle part proves that the samples were correctly made. None of the tested samples was damaged in the holder or near the handle.

4. Test results and analysis

Figure 4 presents graphs of static tensile test of samples without recycle. The process of stretching all five samples had a similar character. Both the values of elastic modulus, strain and tensile strength of individual samples are closely related.

Fig. 3. Samples after static tensile testing

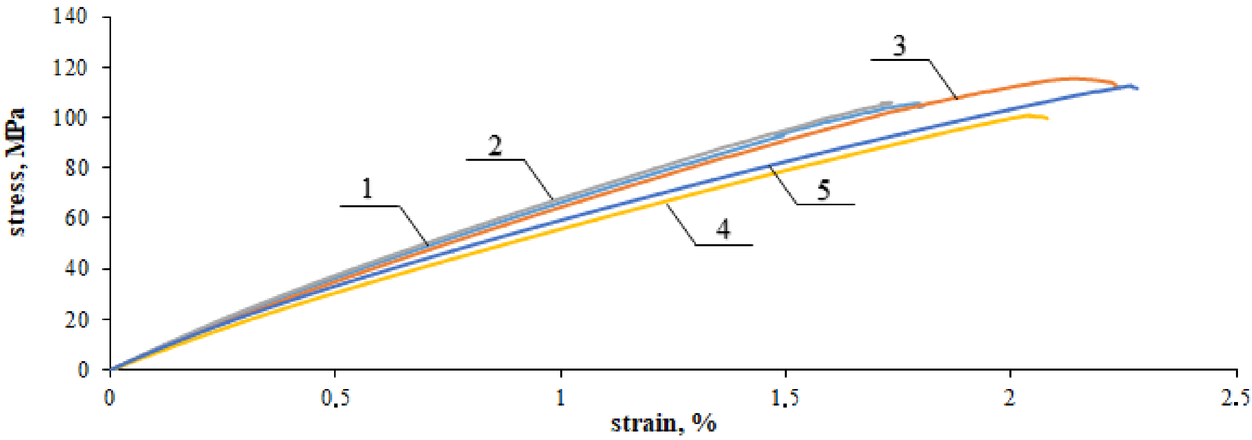

Fig. 4. Graphs of static tensile test for non-recycled samples

Figure 5 presents graphs of static tensile test for samples with 10% recycle content of granulation 1.2 mm and 3 mm. The obtained results showed that the size of the granulate in the range of 1.2 and 3 mm, only slightly affects the strength of the composite, however, it can be observed that for smaller particles of recycle, (more homogeneous material), the strength properties increase.

The conducted analysis of the tests showed that for samples made of composite materials with a content of 10% recycled and granular size of 1.2 mm, tensile strength decreased by 24% while maintaining the Young's modulus and strain in relation to the composite without recycle. However, for the same percentage of recycle and pellet size of 3 mm, a similar reduction in tensile strength of 24% occurred, while maintaining the same strain and decreasing the Young's modulus by 10%.

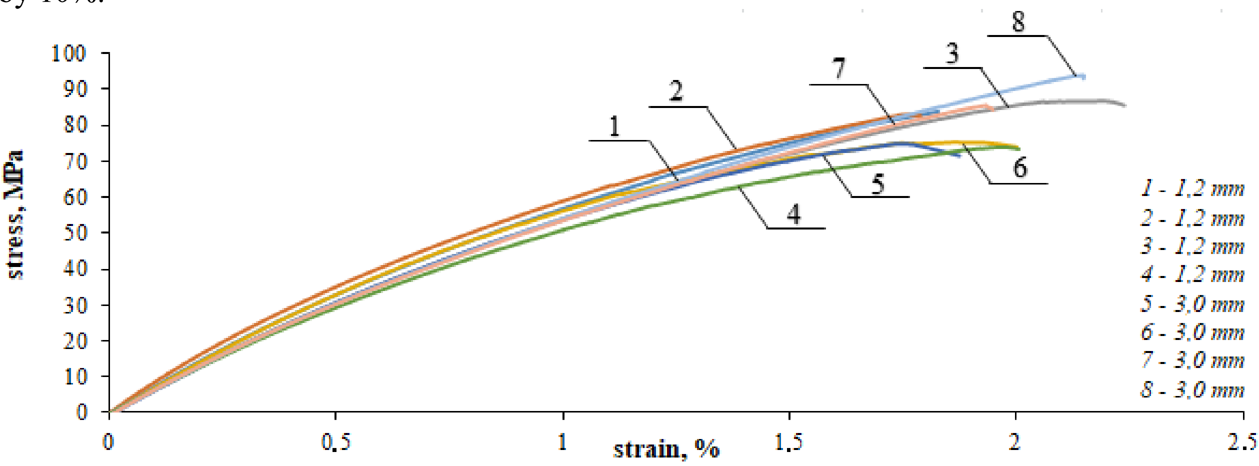

Fig. 5. Graphs of static tensile test for samples with 10% recycle content and 1.2 mm granulation and 3.0 mm

Figure 6 shows a graph of static tensile test for samples with 20% recycle content of polyester-glass and granulation of 1.2 mm and 3 mm. An increase in recycled content up to 20% for granules of 1.2 mm resulted in a drop in strength by over 60%, a reduction in Young's modulus by over 50% and a decrease in deformation by almost 30% in relation to a composite without recycle. For the same content of 3 mm recycle and granulate, there was a 70% reduction in strength, a reduction in Young's modulus by over 50% and a decrease in deformation by almost 40% in relation to the composite without recycle. It can be noticed that the increase in the same content of the recycle, the increase of the granulate size causes a decrease in the strength properties of the composite.

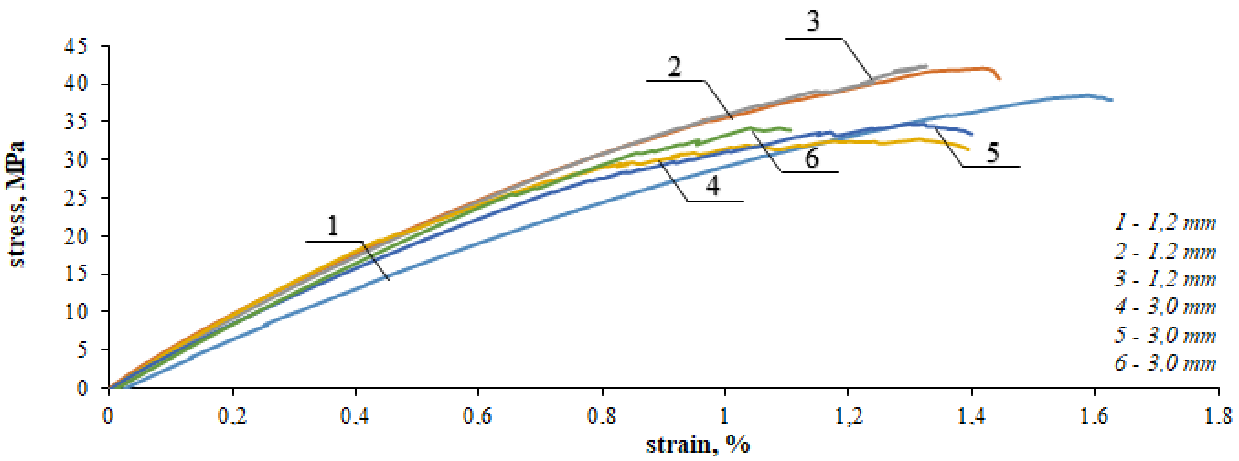

Fig. 6. Graphs of static tensile test for samples with 20% recycle content and 1.2 mm and 3 mm granulation

Figure 7 shows a graph of static tensile test for samples with 30% recycle content of polyester-glass and granulation of 1.2 mm and 3 mm. Tab. 1 shows the average values of Young's modulus, tensile strength, strains for samples with 0%, 10%, 20% and 30% of recycled content, granulation of 1.2 mm and 3 mm.

Recycled quantity 30% with a granulate size of 1.2 mm, reduced the composite strength by nearly 80%, reduction of Young's modulus by 45%, as well as reduction of deformation by nearly 60% in relation to the composite without recycle. The size of the 3 mm granulate with the same recycled content resulted in a reduction in strength by more than 80%, Young's modulus by nearly 60% and deformations by nearly 60% in relation to the composite without recycle. In this case, the mechanical properties of the composite are very pronounced, both with the increase of the recycled content and the granulate size.

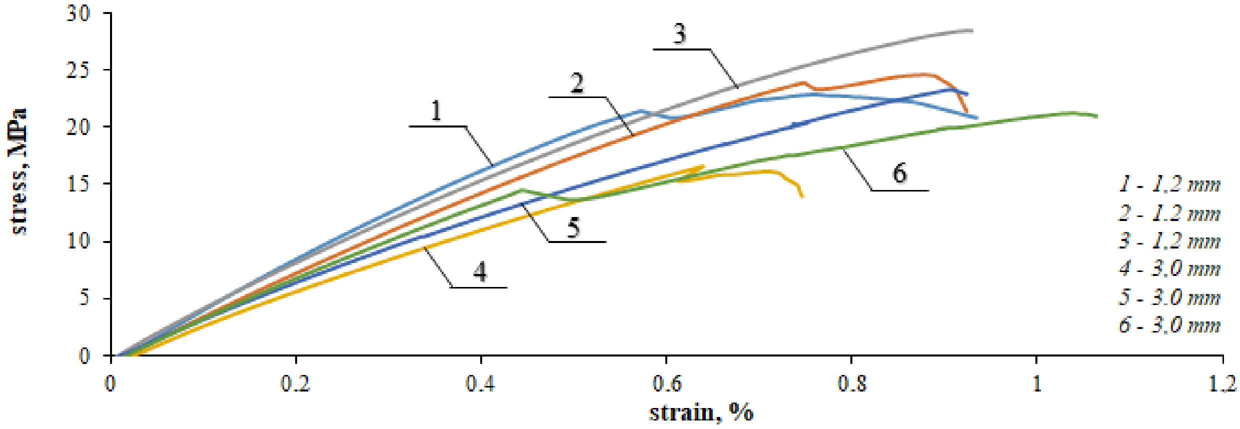

Fig. 7. Graphs of static tensile test for samples with 30% recycle content and 1.2 mm and 3 mm granulation

Tab. 1. Average results of Young's modulus, tensile strength and deformation of samples from composites with different recycled content and granulation

recycle	E	R_m	ε
	MPa	MPa	%
0%	7356	108	2.00
10% – 1.2 mm	7123	82	1.91
10% – 3.0 mm	6568	82	1.95
20% – 1.2 mm	4225	40	1.44
20% – 3.0 mm	4365	33	1.23
30% – 1.2 mm	4097	25	0.85
30% – 3.0 mm	3285	20	0.86

The results of the static tensile test of samples from composite materials with different recycle content and granulates showed that the increase of the recycled content causes a significant reduction of the mechanical properties of the composite. In particular, this applies to a composite with a recycled content above 20%. It was observed that the increase of recycled granulate from 1.2 mm to 3 mm resulted in additional reduction of mechanical properties. Replacing the reinforcement (mats) with polyester-glass recycle cannot improve the strength properties of the material. The glass mat is the component part of the composite material whose task is to transfer the load, replacing it with the dispersed material resulted in lowering the strength properties.

Studies have shown that the addition of up to 30% of the recycle with a granular size of 3 mm allows the formation of material having a compact structure from which it is possible to produce various components of structural elements.

Sipping the glass mat with a mixture of resin and recycle is connected with the possibility of "damaging" the bonds between the reinforcement and the warp. Using the technology of manual lamination using the contact method one should take into account the formation of air spaces (pores). The recycled powder fraction can have a significant impact on increasing the amount of imperfections, which further weakens the material and affects its elasticity. 30% recycle addition to the composite significantly reduces the technological possibility of seeping the mat. The resin becomes dense and the fabrication of materials by lamination, and above all, the exact filtration of the glass mat layers are difficult. It is also worth mentioning the unpredictable time of crosslinking, in the case of composites without the addition of recycle it is possible to estimate the time of material curing. However, with the next increase in the percentage of recycle, the crosslinking time is extended.

Positive results lead the authors to continue searching for the most effective way of managing the ever-increasing amount of composite waste.

4. Conclusions

The results of the research and the analysis made on their basis allow elaborating the right conclusions. It should be clearly stated that the increase in the content of polyester-glass recycle in the produced composite causes its mechanical properties to be lowered. In addition, an analysis of the size of the 1.2 mm and 3 mm granules contained in the composite showed an additional reduction in the mechanical properties of the composite, with an increase in the size of the granulate.

In the case of load-bearing elements, composites with a recycled content of up to 15% and granulate size of 1 mm can be produced, in the case of manufacturing non-load-bearing common items, the recycled content may exceed 15% and the size of the granulate may be above 1 mm.

However, the mechanical properties of the recycled composite produced are not necessarily the most important. The glass-and-glass recycle is waste in nature, polluting and poisoning the natural environment. The processing of this “scrap” and its full use may be more important than obtaining a material with high mechanical properties.

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